II-G-12: Conceptual Models Supplementary Peer Review Report. December 1996

A Peer Review
Conducted By

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for

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EXECUTIVE SUMMARY

This report is a supplement to a July 1996 report that presented the results of an independent technical peer review of the adequacy of 24 conceptual models representing features, events, and processes involved in assessing the long-term performance of the Waste Isolation Pilot Plant (WIPP). WIPP has been developed at a site near Carlsbad, New Mexico, to become the nation's geologic repository for disposal of transuranic waste resulting from nuclear weapons programs. This independent peer review is required by 40 Code of Federal Regulations 194.27 as part of the Compliance Certification Application prepared by the U.S. Department of Energy (DOE). The U.S. Environmental Protection Agency (EPA) will use the peer review to help ensure that an adequate scientific foundation exists for a national decision on whether to dispose of this waste at WIPP.

The peer review was initially conducted from April through June 1996 at the DOE Sandia National Laboratories by a six-member interdisciplinary Review Panel having the requisite broad experience to address the range of issues associated with waste isolation over the 10,000-year regulatory time frame. The Panel selection process and the biographies of the Panel members are included in the July 1996 report.

A conceptual model is a statement of how important features, events, and processes such as fluid flow, chemical processes, or intrusion scenarios, are represented in the performance assessment. The Panel originally reviewed in detail the 24 conceptual models against the criteria of the EPA and NUREG 1297, including the scientific information used to develop the model, the assumptions, alternative models considered, uncertainties, adequacy, accuracy, and validity of conclusions. The Panel then determined whether the conceptual model is adequate for

implementation in the overall performance assessment model.

In its July 1996 report, the Panel concluded that of the 24 conceptual models, 13 were adequate for implementation, and 11 were not adequate for implementation based on the Panel review of the available information and the stated EPA criteria.

In this supplementary report, the Panel provides the results of a review of the DOE responses to the Panel findings in the July 1996 report, additional information available since the earlier report (including the Compliance Certification Application) and changes that were made to eleven of the models. Following is a list of the 24 conceptual models and a statement of the Panel's current conclusions.

Disposal System Geometry	Adequate
Culebra Hydrogeology	Adequate*(1)
Repository Fluid Flow	Adequate*(2)
Salado	Adequate
Impure Halite	Adequate
Salado Interbeds	Adequate
Disturbed Rock Zone	Adequate
Actinide Transport in the Salado	Adequate
Units Above the Salado	Adequate*(3)
Transport of Dissolved Actinides in the Culebra	Adequate
Transport of Colloidal Actinides in the Culebra	Adequate
Exploration Boreholes	Adequate*(4)
Cuttings/Cavings	Adequate
Spallings	Not Adequate
Direct Brine Release	Adequate*(5)
Castile and Brine Reservoir	Adequate*(6)
Multiple Intrusions	Adequate
Climate Change	Adequate

Creep Closure	Adequate
Shafts and Shaft Seals	Adequate
Gas Generation	Adequate
Chemical Conditions	Not Adequate
Dissolved Actinide Source Term	Adequate
Colloidal Actinide Source Term	Adequate

The Panel continues to find two of the models to not be adequate, and six additional models to be adequate on the basis that there appears to be little consequence on performance assessment. For the two models found not adequate, Spallings and Chemical Conditions, the remaining issues could have a significant effect on predictions of the future state of the repository. The details of evaluations and responses to previous issues are contained in Section 3 of this supplementary report. Section 4 assesses the integration of the 24 models, and a summary of the remaining issues is contained in Section 5.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Conceptual Models Peer Review Panel issued its report in July 1996. The peer review was conducted in accordance with the regulatory requirements of 40 Code of Federal Regulations (CFR) 191 and the implementation of those requirements by 40 CFR 194. The Department of Energy (DOE) included the Conceptual Models Peer Review Report as part of its Compliance Certification Application (CCA) for WIPP that was submitted to the Environmental Protection Agency (EPA) in late October 1996.

In the Conceptual Models Peer Review Report of July 1996, 24 conceptual models were evaluated using the evaluation criteria specified by the EPA, including those of NUREG 1297. The Panel report identified thirteen conceptual models as adequate for implementation in WIPP Performance Assessment (PA) and eleven as not adequate for implementation, based on information available to the Panel. The Panel findings on each of the models judged inadequate were provided in the report. Since the Panel report was issued, DOE has developed additional information and made changes to some of the conceptual models. The DOE has also prepared responses to the findings in the Conceptual Models Peer Review Report of July 1996.

The DOE reconvened the Panel in October 1996 to review the changes to the conceptual models, the DOE responses to the findings in the July 1996 Panel report, and information available in the CCA. This report therefore supplements the July 1996 report. It is noted that preliminary DOE responses to the Panel findings were informally provided to some of the Panel members, and DOE may have reached some preliminary conclusions based on this informal process. However, the Panel considers any such DOE conclusions as not dispositive of the Panel findings. This report contains the only definitive Panel review of the DOE responses.

Section 2 of this report describes the process for this supplementary review. For each of the 24 conceptual models, Section 3 describes any identified changes to the models and additional significant results that are important to model evaluation, as well as the DOE responses to the findings and the Panel review of those responses. Section 3 also includes any remaining findings identified, as well as the Panel conclusions on the impact of these findings on the performance assessment. Section 4 of the original report contained a discussion of the integration of the 24 models into an overall conceptual model for the waste disposal system, and Section 4 of this supplementary report provides additional discussion of model integration in the performance assessment based on the additional information now available. Section 5 provides a summary of the supplementary review including any issues remaining to be addressed. Section 5 is followed by administrative information and references. Professional biographies of each of the Panel members are included in the July 1996 report.

2.0 SUPPLEMENTARY REVIEW PROCESS

The supplementary review was conducted in accordance with DOE Quality Assurance requirements at Sandia National Laboratories (SNL) during the period October 1996 to December 1996. The Panel was provided access to written responses to earlier Panel findings, briefings and written material on changes to some of the models, results of sensitivity studies to determine the most important processes and parameters, and the final CCA, including appendices and referenced reports, as well as other information in draft form for work in progress. All this added information supplemented the information available to the Panel at the time of preparation of its July 1996 report.

This supplementary review utilized the same review criteria to judge the acceptability of conceptual models as in the July 1996 report. In the July 1996 report and in this supplementary report, a finding of adequacy was reached if any of the following were valid: (1) the model was judged technically adequate to describe the future states of the disposal system over the 10,000-year regulatory period using the EPA technical criteria; (2) adequately conservative assumptions were made for key input parameters for which a firm technical basis could not be established; or (3) the conceptual model was determined to be inconsequential to the results of performance assessment.

3.0 MODEL EVALUATIONS

3.1. Disposal System Geometry

The manner in which the dimensionality of engineered systems and surrounding geologic/hydrogeologic formations is presented in relevant chapters of the October 1996 CCA remains substantively unchanged from previous information. Minor changes observed in the October 1996 CCA include discussions of additional intrusion scenarios and editorial inclusions that do not change the conceptual model or its adequacy. The issue raised in Section 3.1.2.2 of the July 1996 Conceptual Models Peer Review Report remains deferred to the Repository Fluid Flow conceptual model discussions in Section 3.3 of this supplementary report.

3.2. Culebra Hydrogeology

3.2.1. Model Description

No changes have been identified to the Culebra Hydrogeology model as compared to the Panel's understanding of it from the original review. An error was identified in the application of the Culebra numerical flow model which consisted of a failure to change a boundary condition from no-flow to flow at the northeast corner of the modeled area during PA calculations. This region is an area of low transmissivity, making the change a very small one. Subsequent PA calculations showed no discernible impact from this small change.

3.2.2. Review of Criteria

The review of criteria of the Culebra Hydrogeology model remains unchanged.

3.2.3. Review of Responses to Panel Findings of July 1996

3.2.3.1. Summary of Findings

The Conceptual Models Peer Review Panel found that the Culebra Hydrogeology conceptual model, though it provided support for regional hydrogeologic interpretations and model boundary conditions, did not explain the variation of hydrologic properties in the Culebra at a scale useful for flow modeling at the site scale. Although the conceptual model could not be implemented to support flow modeling at the site scale, an areally extensive hydrologic testing program at numerous sites over a significant time period had been carried out. This testing program provided the database for apparently adequate numerical flow models of the site and the site region. On the basis of the existence of these flow models, the failure of the conceptual model to provide a basis for the detailed interpretation of the hydrogeology of the Culebra was found to be without consequence to facility performance assessment.

3.2.3.2. Summary of DOE Responses to Findings

The DOE responded to the findings of the Peer Review Panel by providing extensive additional information supporting the validity of the site and site region numerical hydrologic flow models. The additional information was mostly contained in Appendix TFIELD and in results of the performance assessment calculations, which permitted the comparison of head fields based on data supplemented by the generation of pilot points and the GRASP INV code with the original measured data. These documentary sources were supplemented by presentations by and conversations with SNL project personnel and contractors.

3.2.3.3. Panel Review of Responses

Appendix TFIELD contains an extensive explanation of the integration of regional hydrogeological concepts and the results of hydrologic testing to define general model boundary conditions, regional fields of hydrologic property variation, and preliminary fields of similar transmissivity. The measured data in transmissivity fields were augmented by the development of pilot points and Kriging, and flow model (1996 Culebra model) grids were populated following calibration (PAREST).

Measured and generated transmissivity values within each T field were sampled for PA calculations and maps, and the Panel reviewed 100 PA realizations of the head field maps for the unmined case. These were compared to the original testing measurements and to the United States Geological Survey (USGS) head field maps (Mercer 1983). The PA maps were well behaved, that is, there were no significant differences among the 100 maps reviewed, and they compared well to the original data and to the USGS maps based only on that data. This was despite the fact that the proportion of pilot points to actual data points was fairly high and that the number of adjustment steps to each point was limited. The vertical leakage to the Culebra from the overlying stratigraphic units was ignored because of the under-pressured state of the Culebra. Climatic change might make vertical leakage a significant factor in Culebra hydrology.

Detailed discussions were presented by SNL about the methods of determining the K_ds used in the range of values sampled for performance assessment and the Culebra retardation flow scenarios. The K_d values appear to be reasonable and the definitions of flow mechanisms are reasonable and typical of reflux dolomites. The proportion of flow ascribed to fractures (advection) and that to intercrystalline and intracrystalline matrix porosity (diffusion) appears to be uncertain and incompletely supported. This is in part a result of the lack of a complete hydrogeologic model and in part a function of the narrow range of inter-well distances in the multiwell tests. The scale of fracture length and the anisotropy of the fracture field are important factors in mid-distance transport, but are not likely to affect transport between the panel areas and the site margins.

In summary, it can be said that the Culebra numerical hydrologic flow model produces results that match the results of hydrologic testing well. The methodology used for generalizing the database over the T fields, the conceptual hydrologic support for the model, and the number and distribution of hydrologic tests in space and in time lend mutual support to the reasonableness of the model results. The results of the numerical flow model in performance assessment are reasonable and adequate with respect to their role in assessment of transport of radionuclides through the Culebra.

3.3. Repository Fluid Flow

3.3.1. Model Description

No changes have been identified in the Repository Fluid Flow model, and the description of the model remains unchanged.

3.3.2. Review of Criteria

The review of criteria for the Repository Fluid Flow model remains unchanged.

3.3.3. Review of Responses to Panel Findings of July 1996

3.3.3.1. Summary of Findings

The following key concerns were identified in the July 1996 Panel report for the Repository Fluid Flow model.

- The conceptual model and its two-dimensional numerical implementation may unrealistically restrict brine movement within the repository to the anhydrite interbeds because of the shallow depths of the borehole and shaft model cells. These restrictions could result in underestimating brine migration in the interbeds toward the accessible environment.

- The conceptual model and its two-dimensional numerical implementation do not include the presence of the unplugged ERDA-9 borehole within the wall of the operations area. This borehole could provide a pathway for gas and possibly brine to the ground surface, and no description of the plugging plan for this hole was seen in the documentation provided to the Panel.

- The sensitivity of model results to the selection of constant permeability values for the waste, panel seals, and repository disturbed rock zone (DRZ) has not been evaluated for the current performance assessment. Early time permeabilities may be significantly greater than the model parameter for each of these media, and could lead to underestimating radionuclide releases.

- The long-term performance of the panel closure seals has not been subjected to a detailed engineering evaluation of the type performed for the shaft seals. The role of the panel seals in restricting brine flow among the waste panels and into other parts of the repository is an important element of the conceptual model and its implementation in performance assessment.

3.3.3.2. Summary of DOE Responses to Findings

The initial DOE response to the first concern (potential restrictions to brine flow resulting from shallow cell depths in the two-dimensional BRAGFLO model) cites a similarity in fluid movement between the waste panels and the anhydrite interbeds and between other key macroscopic properties as predicted by the two-dimensional model and its three-dimensional counterparts (see FEP Screening Analysis S-1: Verification of 2D-Radial Flaring Using 3D Geometry, SWCF-A: 1.2.07.3: PA:QA:TSK:S1, February 19, 1996). In subsequent discussions, additional information was obtained from DOE on cumulative brine flow into the repository under undisturbed conditions.

In responding to the second concern, the DOE indicated that deep, unplugged boreholes within the Land Withdrawal Area, including WIPP 13, WIPP 12, ERDA 9, and DOE 1, will be plugged with a solid concrete plug through the salt section and any water-bearing horizon.

Separate responses were provided by the DOE for each aspect of the third concern (selection of constant permeabilities in the repository). For the waste, the effect of time-varying permeability was studied and found to have an insignificant effect on key waste room conditions (see FEP Screening Analysis DR-7: Permeability Varying with Porosity in Closure Regions, SWCF-A:1.1.6.3:PA:QA:TSK:DR-7, September 28, 1995). A similar study was performed for the DRZ and a similar conclusion was reached (see FEP Screening Analysis S-6: Dynamic Alteration of the DRZ/Transition Zone (TZ), SWCF-A: 1.1.6.3:PA:QA:TSK:S-6, December 21, 1995). For the panel seals, DOE considered that repository performance will not be sensitive to the expected permeability of 1×10^{-15} m^2 or lower because flow would be diverted through the surrounding higher permeability DRZ. In addition, the concrete panel seals were not expected to significantly degrade because of low brine flux through them. This information was supplemented by subsequent information on DRZ healing and panel seal degradation provided by SNL and Carlsbad Technical Assistance Contractor (CTAC) personnel.

The fourth concern, that of the apparent lack of an engineering design for the panel seals, was addressed by presenting seal design and performance information to the Panel. Chemical degradation of the concrete was found to be minimal; however, failure by surface spalling could occur within the regulatory time frame.

3.3.3.3. Panel Review of Responses

In evaluating the response to the first concern (potential restrictions to brine flow resulting from shallow cell depths in the two-dimensional BRAGFLO model), the Panel did not consider the comparison of two- and three-dimensional model results to be adequate because the analyses included an E2 intrusion at 1,000 years which would have caused radial flow, and because the comparison was based on combined inflows in the two-dimensional model into both the single panel and the “rest of the repository.” This comparison, therefore, included flow into the southern half of the single panel that did not cross the narrow constriction created by the borehole cells. Thus, it did not adequately test the ability of brine to cross that constriction and enter the “rest of the repository,” which constitutes approximately 90% of the waste area volume. A more robust test would have been a comparison under undisturbed conditions of flow to and from the “rest of the repository,” which would have evaluated non-radial flow crossing both the constriction at the shaft and that at the borehole. In addition, the constrictions could potentially introduce a significant systematic bias into the modeling results.

In subsequent discussion of the first concern with SNL personnel, it was recognized that the majority of the rapid, early-time brine flow into the undisturbed repository (up to about 20,000 m^3) occurs because of drainage from the DRZ (Figure 3-1), which is considerably larger than the volume (up to about 6,000 m^3) that results from inflow from all anhydrite interbeds (Figure 3-2). Considering only the shaft constriction, the maximum difference in both repository inflow and outflow between the two-dimensional and three-dimensional model results was identified in the aforementioned FEP S-1 study to be about 1×10^6 kg of brine, or about 800 m^3 at a brine density of 1,230 kg/ m^3. If both the shaft and borehole constrictions were considered, the difference is unlikely to exceed 2,000 m^3. This volume is small compared with the approximately 20,000 m^3 that can enter by drainage from the DRZ, and its importance would diminish further in any realization involving an intrusion because the two-dimensional model is designed to simulate the radial flow induced by those intrusions. The influence of the constrictions is significantly greater for brine outflow, where FEP S-1 results indicate that the actual outflow may be on the order of twice that predicted by the two-dimensional model. This is considered conservative, however, because the total outflow volume is relatively small (generally less than 2,000 m^3)

Figure 3-1. Cumulative total brine inflow into the undisturbed repository. Not available.(7)

Figure 3-2. Cumulative brine inflow into the undisturbed repository from all anhydrite interbeds. Not available.(8)

and the presence of extra brine in the repository is expected to increase calculated releases. In view of the relatively small fluid volume involved, this first issue is considered to be adequately resolved on the basis of a lack of consequence. However, if subsequent model modifications result in significantly smaller fluid volumes in the repository, the significance of this issue should be reevaluated.

The response to the second concern (plugging of deep, unplugged boreholes) was considered by the Panel to be entirely adequate.

The response to the third concern (selection of constant permeabilities in the repository) was separately addressed by the Panel for each of the three aspects. For the waste, the key Panel concern was underestimating the permeability in early times, and thereby potentially underestimating radionuclide releases at those times. The performance assessment results have shown that the waste is compressed relatively quickly, within the first few hundred years after closure, during a period when very few intrusions occur because exploratory drilling is minimized by active and passive institutional controls. The consequence of underestimating waste permeability during this period is therefore expected to be small. In later years, when exploratory drilling is more frequent, the waste is expected to have been compressed to the extent that the assigned constant permeability will be appropriate. This conclusion is supported by the aforementioned FEP DR-7 screening analysis.

For the DRZ, the situation is more complex. The assignment of constant permeability to the DRZ is one of the more dramatic departures from actual behavior in the performance assessment assumptions. While simplification may be justified because of the complexity of DRZ behavior, it is important to evaluate whether the assumed constant permeability is appropriate both in early times, when the actual permeability may be several orders of magnitude greater than the assumed permeability because of fracturing associated with expansion of the DRZ into the repository, and in later times, when the actual permeability may be several orders of magnitude less than the assumed value due to healing of the DRZ under lithostatic stress. In early times, the Panel's conclusions regarding the DRZ are similar to that for the waste. Even though the actual permeability may be higher than the modeled value, closure is expected to be fairly rapid and the DRZ permeability is expected to be reduced to the modeled value by the time significant exploratory drilling occurs. In later times, however, the actual permeability may be overestimated by the model and is not adequately addressed by the aforementioned FEP S-6 screening analysis, which focuses on whether the assumed DRZ permeability is high enough to allow relatively unimpeded flow between the repository and the interbeds. The impact of DRZ healing is separately addressed by the Panel for the DRZs adjacent to the roof, floor, walls, and panel seals.

Long-term maintenance of the relatively high-permeability repository DRZ assumed in the BRAGFLO model is important to performance assessment because it has been found to allow relatively unimpeded gas flow within the repository and between the repository and the interbeds. Such gas flow allows pressures within the entire repository to drop following a drilling intrusion in any part. If each waste panel were more effectively isolated, each drilling intrusion into a new panel would encounter higher, essentially undisturbed gas pressures and significantly greater releases would follow. Because of the importance of repository-wide pressure relief to long-term performance, it is necessary to evaluate the impact of the modeling assumption of constant permeability against the likelihood of DRZ healing to permeabilities several orders of magnitude lower than the assumed value.

The roof DRZ is most important to gas flow because brine that could impede such flow will tend to collect on the repository floor. Although the stress-induced fractures in that part of the roof DRZ consisting of halite are expected to heal to permeabilities approaching those of undisturbed halite, the boreholes drilled vertically through the halite for rock bolts and site characterization are not expected to close during the regulatory time frame because of their favorable orientation and circular shape. Boreholes for roof support are expected to be needed in each panel throughout the waste disposal area, and given the high conductance of an open hole, even a few such holes are expected to provide sufficient communication to the overlying anhydrite interbeds to compensate for the general loss of permeability in the halite. Because of their greater strength and reduced plasticity, deformation in the anhydrite interbeds in the roof DRZ is not expected to heal to the same extent as the halite, but rather, the interbeds are expected to retain permeabilities that are several orders of magnitude higher than their initial values. The permeability value of 1×10^{-15} m^2 assumed in performance assessment is an acceptable approximation of this disturbed anhydrite permeability. It may therefore be concluded that despite the general healing of the halite in the roof DRZ, higher conductivity flowpaths through boreholes and disturbed anhydrites will remain between the individual waste panels and single intrusion boreholes, supporting the adoption of a constant permeability of 1×10^{-15} m^2 for the roof DRZ.

The wall DRZ is not specifically addressed in BRAGFLO and plays no role in the current performance assessment. This assumption is appropriate because in the waste panels the wall DRZ is expected to heal rapidly as soon as a back stress is applied by the laterally expanding waste. This healing is expected to occur within a few hundred years of closure, during the period of active and passive institutional control.

Healing of the floor DRZ is expected to be incomplete because the high degree of brine saturation in that area will act to maintain a higher porosity as stresses resulting from creep closure are applied. The higher porosity is expected to result in a higher permeability, and the capture of that permeability in the model is important in providing a pathway for brine to enter and exit the repository through the underlying anhydrite interbed.

The panel seals will consist of approximately 8-m long concrete plugs within the approximately 40-m long access drifts to each panel. The plug will provide a relatively strong, unyielding surface against which the surrounding DRZ is expected to rapidly heal. The concrete itself is expected to have an initial permeability of about 5×10^{-17} m^2, while the rest of the drift will remain unbackfilled and will eventually be closed by creeping halite. Although the plug and surrounding DRZ are expected to quickly form a lower permeability impediment to fluid movement than is accounted for in the constant permeability of 1×10^{-15} m^2 assigned to both system components in performance assessment, the aforementioned higher permeability pathway afforded by boreholes and disturbed anhydrites in the roof DRZ are expected to continue to allow movement of gas within the repository.

Performance assessment modeling results have shown that at the assumed permeability of 1×10^{-15} m^2 , brine flow between panels is restricted, limiting direct brine releases to the brine within a single panel. Maintenance of the panel seal at or below this assumed permeability is therefore also important to repository performance. If the ends of the concrete plug remain unsupported, it could degrade within about 4,000 to 5,000 years due to progressive spalling of the ends from a combination of applied stresses and formation of expansive minerals within the concrete. The spall would form a fine-grained residue with an initial permeability of less than 1×10^{-14} m^2 , which is similar to that of a sand-clay mixture. Compaction of this material by an applied lithostatic stress, and the closure of the open drift on either side of the plug by halite creep, provide adequate assurance that the permeability of the materials in the access drifts will remain equal to or less than the assumed value of 1×10^{-15} m^2 during the regulatory time frame. In addition, any lateral confinement of the open ends of the plug by the creeping halite is expected to prolong the life of the plug.

The response to the fourth concern (lack of engineering analysis of the panel seals) was considered by the Panel to be adequate. Although the concrete plug used in the seal may degrade within the regulatory time frame, this degradation is not expected to impair repository performance as discussed above.

In summary, the Panel has found each of the four key concerns identified for the Repository Fluid Flow model in July 1996 to have been resolved.

3.4. Salado

There were no changes to this model and it continues to be acceptable for implementation.

3.5. Impure Halite

There were no changes to this model and it continues to be acceptable for implementation.

3.6. Salado Interbeds

3.6.1. Model Description

No changes have been identified in the Salado Interbeds model, and the description of the model remains unchanged.

3.6.2. Review of Criteria

The review of criteria for the Salado Interbeds model remains unchanged.

3.6.3 Review of Responses to Panel Findings of July 1996

3.6.3.1. Summary of Findings

This model was originally found to be well thought out and substantiated by *in situ* experiments. However, one issue in particular caused the model to be considered not adequate. The issue was:

- How do the physical properties of clay seams at the contact of the interbeds affect the fracture propagation and permeability of the model?

In addition, six other questions were posed by the Panel to enhance the clarity of the model. These are listed below:

- What is the mechanism for vertical crack propagation?
- What is the fluid storage capacity of the interbeds after dilation?
- Enhanced porosity and permeability are presumed to mitigate each other in terms of gas migration responses. How can this happen when permeability is a power function of porosity?
- What assumptions and limitations are made to represent the conceptual model by the

mathematical code?

- Why is the full fracture porosity increment of 23.9% for anhydrite beds a and b so different from the 3.9% for marker bed (MB) 138 and 139?
- What are the calculations that show the permeability increases by 10 orders of magnitude?

3.6.3.2. Summary of DOE Responses to Findings

The question that caused the model to be judged inadequate (clay seams) was specifically addressed by the DOE. The clay seams were noted to be preexisting planes of weakness. Because the *in situ* threshold pressure and permeability tests incorporated the clay seams in the test zones (which was validated by continuous core recovery), the interpreted results were considered to be representative of the combined anhydrite and clay units.

The other six questions posed to clarify the conceptual model were also answered in writing by the DOE. In summary, the abbreviated responses are listed in the same order as the questions above:

1) Fractures will propagate vertically if the least compressive stress is horizontal.

2) Simple calculations indicate storage enhancement by the following: 350% for MB 138 and 139, and 2170% for MB a and b.

3) Both permeability and porosity increase with pressure. Increased porosity provides more gas storage space and shorter migration distances. Increased permeability allows increased fluid mobility. DOE did not mean to imply that the two effects are equivalent and completely counteract each other.

4) DOE responded to this question with a description entailing two pages of the assumptions and limitations needed for the conceptual model to be represented by a mathematical code.

5) Fracture dilation is assumed to be confined to a 10 cm thickness, regardless of the thickness of the MB. Therefore, the percentage differences are based on the proportionality of the thickness differences of the interbeds (i.e., MB 138 and 139 are 5 times thicker).

6) The full fracture permeability is used as a fitting parameter so that the appropriate response is obtained. DOE believes that a ten order of magnitude permeability increase is unlikely to ever be achieved in the model.

3.6.3.3. Panel Review of Responses

The Panel has reviewed the responses by DOE on the above listed questions and finds that the model is now fully adequate for implementation.

3.7. Disturbed Rock Zone

3.7.1. Model Description

The Panel concluded that this conceptual model was adequate in its July 1996 report; however, the Panel expressed some concern for modeling the DRZ in the same manner for each of its location sites, particularly the roof and floor. The floor provides a principal repository access for brine and the roof provides a principal pathway for gas.

The DOE identified the following change. In the final CCA, the DRZ porosity was modeled as 0.29% greater than the sampled porosity of Salado impure halite, based on Room Q experimental results. At the time of the previous panel review, the DRZ porosity was not specifically linked to the halite porosity. DOE indicated that the increased porosity would increase the volume available for fluid storage in the DRZ and further delay the flow of brine into the repository. To compensate for this, the DOE assumed that the DRZ was initially saturated with brine, and concluded that the net effect of these assumptions was small.

3.7.2. Review of Criteria

The Panel agrees this change is not significant, and that this model remains adequate for implementation.

3.8. Actinide Transport in the Salado

3.8.1. Model Description

New information has been developed on this model since the Panel's July 1996 report. NUTS model runs are now performed initially in a fast tracer mode to identify BRAGFLO realizations and associated contaminated brine that never reach the top of the salt or the accessible environment in the Salado. If a tracer run indicates the possibility of a consequential release, a complete calculation of the full transport of each radionuclide is performed.

The tracer runs are performed in the following manner. The simulation considers an infinitely soluble, nondecaying, nondispersive, and nonsorbing species as a tracer element. The tracer is given a unit concentration (1 kg/m^3) in the waste disposal area. If the tracer does not reach the top of the Salado or the land withdrawal boundary in the Salado in a cumulative mass greater than or equal to 10^{-7} kg (1 x 10^{-6} EPA units) within 10,000 years, it is assumed that there is no consequential release to the boundary. If a mass greater than 10^{-7} kg is achieved in the tracer run, then a complete transport analysis is performed.

3.8.2. Review of Criteria

The use of NUTS as a tracer to identify which runs are capable of transporting consequential releases to the boundary is satisfactory and an efficient use of computing time. It does not detract from the model, and therefore this conceptual model is still found to be adequate.

3.8.3. Review of Responses to Panel Findings of July 1996

3.8.3.1. Summary of Findings

In the original Conceptual Models Peer Review Report of July 1996 this model was found to be adequate. However, questions were raised in the original review of the model concerning information that was not available. These questions are listed below:

1) Validity of model assumptions - Colloids are transported at the same rate as dissolved actinides. This assumption was made because sorption and filtration of colloids are not accounted for. The assumption was not validated.

2) Validity of model assumptions - Grid blocks and time steps of BRAGFLO are proper for use in NUTS. The assumption was not validated.

3) Uncertainties - Appendix NUTS, Section 6.4.11 of CCA, and Table 6-15 were not available for review.

4) Uncertainties - Transport of radionuclides in the waste panel, panel seals, DRZ, and undisturbed and fractured interbeds was not described.

5) Uncertainties - Radionuclide input to sealed boreholes and shafts to the Culebra were not discussed.

3.8.3.2. Summary of DOE Responses to Findings

Model runs were discussed in Panel briefings by DOE and indicate that the philosophy of transporting colloidal actinides with dissolved actinides is a reasonable assumption. This assumption was also borne out in the cumulative complimentary distribution function (CCDF) runs. One preliminary NUTS model run indicated that an E2 release to the Culebra would in fact transport 18 EPA units to this boundary interface with the Culebra. Appendix SA also indicated that the CCDF runs most likely to impact the assessment are the human intrusion events involving cuttings or spallings.

BRAGFLO grid blocks and time steps have been found to be reasonable and not excessively coarse.

Appendix NUTS and Sections 6.4.10-12 are now available and have adequate explanations of the numerical codes. Table 6-15 was not used in final CCA.

Questions involving long-term transport in the repository rooms, repository panel seals, DRZ, and undisturbed and fractured interbeds have been resolved to the satisfaction of the Panel.

Sealed boreholes and shafts to the Culebra will be treated as filled with sandy material when the plug degrades.

3.8.3.3. Panel Review of Responses

The Actinide Transport in the Salado conceptual model has not changed in an adverse manner and is considered adequate.

3.9. Units Above the Salado

3.9.1. Model Description

No changes have been identified to the model of the Units Above the Salado.

3.9.2. Review of Criteria

The review of the criteria of the model of the Units Above the Salado remains unchanged.

3.9.3. Review of Responses to Panel Findings of July 1996

3.9.3.1. Summary of Findings

The Conceptual Model Peer Review Panel found that the conceptual model of the Units Above the Salado was not adequate to explain the distribution of hydrologic properties in the Magenta Dolomite or the Dewey Lake Redbeds on the site or over the site region for the purpose of the assessment of transport of radionuclides to the accessible environment. Further, the hydrologic testing database in those units is not adequate to support a numerical hydrologic flow model of the kind developed for the Culebra. The Magenta Dolomite and the Dewey Lake Redbeds are the only stratigraphic units above the Salado having significant transmissivity with respect to potential releases of radionuclides.

The Magenta Dolomite appears to be less transmissive than the Culebra, on the basis of very limited hydrologic testing. The Dewey Lake Redbeds appears to have gypsum-filled fractures throughout its lower part (raising the elevation to which brine would have to rise to enter the formation) and contains ferrous minerals that might retard radionuclide transport. Despite these possible mitigating factors, the units above the Salado cannot be adequately modeled over the controlled area to permit reliable performance assessment. However, a finding of no consequence of the inadequacy of the model of the Units Above the Salado to the performance of the facility was made based on the failure of significant quantities of brine to rise above the Culebra in the long-term performance assessment of any intrusion scenario. Volumes and rates of brine flow up and down the borehole, Culebra hydrologic pressure, and the transmissivity of the Culebra at the borehole were the principal variables considered in the calculation.

3.9.3.2. Summary of DOE Responses to Findings

The DOE made presentations to support the mitigating aspects of Magenta and Dewey Lake Redbeds hydrogeology. In addition, further PA calculations were presented using minimum values of Culebra permeabilities at the point of penetration of the intrusion borehole (BRAGFLO code) to supplement the original calculation based on mean Culebra transmissivity.

3.9.3.3. Panel Review of Responses

The presentation by SNL on the hydrogeology of the Magenta and Dewey Lake Redbeds does provide additional reasons why these units may not be foci of concern about radionuclide releases, but does not constitute an adequate conceptual model to support PA transport modeling. The additional calculation of brine flow in the intrusion borehole through the Culebra provided additional assurance that no significant volume of brine reaches the stratigraphic units above the Culebra. The Panel's original finding that the absence of an adequate hydrogeologic conceptual model for the units above the Salado (excepting the Culebra) is of no consequence to the PA calculations is further supported by this response.

3.10. Transport of Dissolved Actinides in the Culebra

3.10.1. Model Description

This model uses a dual porosity calculation to estimate transport of dissolved actinides. DOE indicated that in implementing this conceptual model, a preliminary calculation was performed for a unit source of each of the soluble actinides, using the sampled range of K_ds based on experimental data. The results indicated an attenuation in the Culebra of more than sixteen orders of magnitude. Because of this result, DOE decided not to run the additional calculations needed to construct CCDFs for this transport pathway. DOE also stated there would be less than 1×10^{-6} EPA units of any of the actinides transported to the regulatory boundary through the Culebra. Additional interpretive results of hydropad tracer testing and laboratory measurements of K_ds have also become available since the Panel's July 1996 report. DOE has concluded that the Culebra could best be thought of as having several levels of advective and diffusive porosity, as shown in Figure 3-3. DOE believes that most of the flow and transport is through

Figure 3-3. Multiple scales of porosity in the Culebra.

approximately 16% of the dolomite, represented by lenses of interparticle porosity connected by vugs and fractures. The areas for adsorption are contained in these regions, as well as the intercrystalline porosity accessible only by diffusion of soluble species. This interpretation resulted from analysis of the hydropad testing that was completed after the performance assessment and the Panel's July 1996 report were completed. This added understanding was helpful in interpreting the wide range of K_ds measured.

3.10.2. Review of Criteria

The Panel in its July 1996 report concluded this conceptual model was acceptable for implementation, in that the dual porosity mathematical model provided a sufficiently accurate representation for performance assessment. However, the Panel expressed the view that the K_ds to be used needed to be properly chosen in light of uncertainties.

In its supplemental review, the Panel noted that K_ds from flow-through testing in crushed column and intact cores were significantly lower than K_ds from longer term contact testing with crushed dolomite. DOE provided information showing that the flow-through testing does not provide sufficient contact time to actually reach equilibrium values of K_d, and that therefore, the sampled ranges of K_ds provide conservative values for transport calculations.

The performance assessment used the range of K_ds from both batch tests and flow-through tests, whereas the batch test results should provide the better values. The higher K_ds were from the batch tests. However, as before, this Panel makes no conclusion on the acceptability of individual K_d values, per se, since there are other issues associated with those values that are not related to the conceptual model and that this Panel has not evaluated.

The Panel continues to find this model, as revised, adequate for implementation.

3.11. Transport of Colloidal Actinides in the Culebra

3.11.1. Model Description

DOE has identified conceptual changes in how colloids are transported, as a result of further analysis of experimental results since the Panel's July 1996 report was issued. DOE has also determined that explicit calculations of colloid transport are not needed based on this added analysis. DOE has examined the range of possible colloids by examining four specific representative types.

The model had included advective transport of colloids in advective porosity, and for small colloidal particles, diffusion followed by adsorption onto surfaces in diffusive porosity, as well as filtration of colloidal particles in pore throats. As a result of the reexamination, DOE has assigned a value of zero to K_ds for mineral fragments, microbial, and intrinsic colloids, has assigned filtration coefficients only for microbial colloids and mineral fragment colloids, and for humic colloids has assigned K_d values equal to those for soluble actinides since they are destabilized at Culebra pH conditions. The filtration coefficients are a result of the crushed column tests, and filtration was determined to be so effective at removing microbial and mineral fragment colloidal actinides that they are effectively removed in a short distance in the Culebra. The additional information not available to the Panel for its July 1996 report includes written descriptions of the various crushed dolomite column tests and core flow tests, and an improved presentation of the multiple scales of advective and diffusive porosity that are important in Culebra transport.

3.11.2. Review of Criteria

During the initial Panel review, there were some significant uncertainties that precluded a finding of adequacy for this model, particularly for the Validity of Model Assumptions. The more recent information provides the improved understanding needed for drawing conclusions.

3.11.3. Review of Responses to Panel Findings of July 1996

The Panel issues, a summary of the DOE responses, and the Panel review of the responses are provided below.

3.11.3.1. Summary of Findings

- The conceptual model does not adequately support the assumption that dissolved actinides will not interact with Culebra colloids. Ignoring this phenomenon could overestimate the travel time calculated for radionuclides to reach the accessible environment.
- The experimental K_ds determined for this model are not fully defensible. Such values may overestimate the retardation of actinides in the Culebra.
- Recent experimental work to support assumptions and data for this model has not yet been published and was not available for Panel review.

3.11.3.2. Summary of DOE Response to Findings

Regarding the assumption that dissolved actinides would not interact with Culebra colloids, DOE indicates that stable indigenous colloids in the Culebra are not expected, and that any that could be injected into the Culebra would be so rapidly filtered, based on experimental filtration coefficients, that it is conservative to assume they remain for transport only as soluble species.

Regarding the Panel-expressed issue with use of K_ds, DOE noted that values of zero were assigned to K_ds for mineral fragments, microbial colloids, and intrinsic actinides, and that for humic substances, values equal to dissolved K_ds were assigned because they would be destabilized in Culebra pH conditions and be transported as soluble species.

Regarding the lack of published reports on experimental work, published information in the CCA and its appendices responds to this issue.

3.11.3.3. Panel Review of Responses

The Panel has reviewed the changes to this model and the DOE responses to issues on this model, and concludes that these changes and responses adequately address the Panel issues of its July 1996 report. The Panel concludes that the model is adequate for implementation in performance assessment.

3.12. Exploration Boreholes

3.12.1. Model Description

No changes have been identified in the Exploration Boreholes model, and the description of the model remains unchanged.

3.12.2. Review of Criteria

The review of criteria for the Exploration Boreholes model remains unchanged.

3.12.3. Review of Responses to Panel Findings of July 1996

3.12.3.1. Summary of Findings

The following key concerns were identified in the July 1996 Panel report that were related to the Exploration Boreholes model.

- The potential for releases or changes in repository conditions from borehole penetrations in the operations and experimental areas of the repository does not appear to have been evaluated. Radionuclides that may have migrated into those areas through the panel closures by diffusion or other transport mechanisms could be released to the ground surface, and gas pressures could be relieved by such boreholes. Also, brine could migrate into those areas from a borehole and then into the waste panels.

- The assumption that shorter (40m) borehole plugs beneath the repository horizon will not significantly degrade during the 10,000-year regulatory time frame has not been adequately supported. For the two- and three-plug configurations, degradation of these plugs could result in creation of a low permeability pathway for fluid migration between the Bell Canyon and the repository. For the three-plug configuration, degradation could result in increased fluid migration from a Castile brine reservoir to the repository.

- The possibility that an effect on the repository could result from Castile brine encountered in an E1 borehole that is assigned a three-plug configuration does not appear to have been considered in the conceptual model. Castile brine could enter the repository during drilling before the borehole is cased and result in increased rates of corrosion, waste degradation, and gas production.

- The sensitivity of the performance assessment to the simplified approach taken to determine reference conditions for BRAGFLO output does not appear to have been evaluated for the current model configuration. If reference conditions are not provided at sufficiently frequent time intervals, the modeling results may be erroneous.

3.12.3.2. Summary of DOE Responses to Findings

The DOE response to the first concern cites the lack of significant consequence of borehole penetrations in the operations and experimental areas. Intrusion boreholes in those areas would have no associated cuttings, cavings, or spallings releases, and the direct brine release was stated to be negligible because of the relatively low volume of contaminated brine that would migrate through the panel seals into those areas from the waste disposal area, the dilution of radionuclide concentrations in the contaminated brine from mixing with uncontaminated brine in those areas, and the lower importance of direct brine releases to overall performance. In addition, ignoring the repository-wide gas pressure relief that would follow such intrusions would be conservative because high gas pressures are drivers for spallings and direct brine releases. In considering brine flow in the opposite direction (from the operations and experimental areas into the waste disposal area) DOE stated that the incremental volume of brine entering the waste area would not substantially add to the brine volumes already there, and that more than enough brine was already potentially available in the waste area from other sources to react with all the waste present.

In responding to the second concern, the DOE indicated that degradation of borehole plugs beneath the repository horizon is not expected during the regulatory time frame because the service life range of 500 to 50,000 years and best estimate of about 5,000 years cited by Thompson et al. (1996) is based on overly conservative assumptions that ignore a correlation between concrete porosity and permeability, assume an unrealistically low value for the minimum concrete porosity, and assume a relatively low number of pore flow volumes required for concrete degradation. In addition, a lack of reported failures of plugs at comparable depths was cited.

The response to the third concern (the effect of Castile brine entering the repository during drilling) was provided in the form of an estimate of the volume of such brine that would enter the repository during a three-day period when the borehole is uncased during drilling. Using conservative values for borehole and repository pressures, and the standard assumptions for waste permeability and waste panel geometry used in performance assessment, the inflow volume was estimated to be less than 100 m^3. Relative to the volumes of brine inflow potentially available from other sources, this volume was not considered significant.

The fourth concern (the sensitivity of performance assessment to the use of reference conditions in determining performance assessment results) was addressed by reviewing with the Panel the shapes of the undisturbed repository pressure curves upon which the two release values for intrusions at 350 and 1,000 years were superposed. Although the response included summaries of reference conditions for other models, including Cuttings and Cavings, Spallings, and Direct Brine Release, these are based on more than two values and were correctly identified as being of lesser concern to the Panel.

3.12.3.3. Panel Review of Responses

In evaluating the response to the first concern, the Panel concurs with the DOE that, based on the performance assessment modeling results, the consequences of borehole penetrations in the operations and experimental areas are not expected to be significant. It is agreed that no cuttings, cavings, or spallings releases would occur from such penetrations. DOE's response indicated that with very few exceptions, the maximum brine flow through a panel seal was found in modeling results to be about 12,000 m^3 following an E1 intrusion, and the expected flow would be about 3,000 m^3. Under undisturbed conditions, the cumulative brine inflow into the operations and experimental areas from all sources ranges from near zero to about 10,000 m^3 (see Figures 3-4 and 3-5). This flow would, on the average, be expected to result in approximately a twofold dilution of brine flowing in from the waste area following an E1 intrusion. Under disturbed conditions with intrusion boreholes penetrating the operations and experimental areas, the inflow of uncontaminated brine and the dilution of contaminated brine would be even greater.

In the event that the operations and experimental areas are penetrated by intrusion boreholes, approximately 12,000 m^3 of brine could conceivably flow from these areas into the waste area. Performance assessment results indicate that total cumulative brine flow into the waste area is typically

Figure 3-4. Cumulative brine inflow into operations area under undisturbed conditions. Not available.(9)

Figure 3-5. Cumulative brine inflow into experimental area under undisturbed conditions. Not available.(10)

about 40,000 m^3 following an E1 intrusion at 1,000 years and about 30,000 m^3 following an E2 intrusion at 1,000 years (see Figures 3-6 and 3-7). Given that about six borehole intrusions are expected to occur during the regulatory time frame, the total volume of brine potentially available to flow into the waste area could exceed 100,000 m^3. Although the actual volume of brine inflow will depend on the interrelationships among time of intrusion, repository creep closure, gas generation, repository pressure, and other factors, the modeling results indicate that sufficient brine is potentially available from other sources that an incremental supply of as much as 12,000 m^3 would have no consequential effect on performance assessment results. However, if subsequent model modifications result in significantly smaller fluid volumes in the repository, the significance of this issue should be reevaluated.

The Panel found that DOE's response to the second concern does not support an expected lower plug service life in excess of 10,000 years because it has not been adequately demonstrated that the lower bound of the expected plug life will exceed 10,000 years. While the 500-year lower bound of the range reported by Thompson et al. (1996) may be unrealistically low, it is difficult to disregard because both the permeability (5×10^{-17} m^2) and the porosity (2%) used to compute this lower bound were reported to have been determined from field tests of an actual Bell Canyon borehole plug. The consequence of plug failure would be to open a low-permeability pathway for brine movement between the repository and the underlying Bell Canyon Formation that is not considered in performance assessment. Brine could flow along this pathway in either direction depending on pressure conditions in the repository. The volume of upward flowing Bell Canyon brine moving into the repository is not expected to be significant compared with the aforementioned volumes potentially available from other sources. Similarly, the volume of Castile Brine that would move upward into the repository following failure of the middle plug in a three-plug scenario would also have insignificant consequences.

Brine flowing downward from the repository to the Bell Canyon would only be significant if it could reach the accessible environment within the regulatory time frame of 10,000 years. A rough estimate of travel time in the Bell Canyon was prepared by the Panel based on hydrologic information provided by the U.S. Geological Survey (Mercer 1983). Primary flowpaths in the

Bell Canyon are identified by the USGS as relatively isolated, permeable channel sandstones separated by siltstones and shales with negligible permeability. Assuming the maximum reported channel hydraulic conductivity of 5 x 10^{-2} ft/day, a hydraulic gradient of 0.0038 underlying the WIPP site (from Mercer 1983, Figure 9), and an effective porosity of 10%, the travel time to the edge of the Land Withdrawal Area 2 miles away is estimated to be 15,200 years. This estimate does not consider the additional effects of chemical retardation, the travel time in the borehole, and the likelihood that a borehole would intersect the negligible permeability siltstones and shales rather than a more permeable sandstone channel. Based on this information, the Panel's second concern is considered to be resolved, based on lack of consequence.

Figure 3-6. Cumulative brine flow into repository following an E1 intrusion at 1000 years. Not available.(11)

Figure 3-7. Cumulative brine flow into repository following an E2 intrusion at 1000 years. Not available.(12)

The response to the third concern (flow of Castile brine into the repository during drilling) was considered by the Panel to be adequate.

The fourth concern (sensitivity of performance assessment to the use of reference conditions) was addressed by DOE with reference to the plot of volume-averaged pressure simulations for an undisturbed waste panel shown in Figure 3-8. As previously stated, the Panel's primary concern was with the use of only two reference conditions (350 and 1,000 years) for evaluating E1 and E2 intrusions. These reference conditions were used by applying conditions at 350 years to intrusions occurring at or before 350 years, applying conditions at 1,000 years to intrusions occurring at or following 1,000 years, and linearly interpolating conditions for intrusions occurring between 350 and 1,000 years.

Both repository pressure and brine saturation results were reviewed by the Panel in addressing this concern.

As shown in Figure 3-8, undisturbed, volume-averaged pressures are steeply climbing in virtually all realizations prior to 350 years, and applying the value at 350 years is conservative. Between 350 and 1,000 years the increase is essentially linear, and the use of linear interpolation is appropriate. After 1,000 years approximately half the curves are reasonably flat; however, the other half of the curves show continuing pressure rises for the duration of the regulatory time frame. Because of this continuing pressure rise, the assumption of constant pressure after 1,000 years is nonconservative for many realizations and may not be appropriate. Undisturbed, volume-averaged brine saturations in the waste panel and rest of the repository are shown in Figure 3-9. Again, the Panel's greatest concern is with the adequacy of assuming constant conditions after 1,000 years. The performance assessment results, however, indicate that the consequences of this concern are expected to be low. The short-term cavings, spallings, and direct brine releases, which are of primary importance to waste isolation, are computed based on a larger number of reference conditions which the Panel expects to be adequate. The two cited reference conditions associated with this concern are used only to determine long-term releases and to provide a basis for calculating releases for second and subsequent intrusions for the short-term releases.

Figure 3-8. Volume-averaged pressure in undisturbed waste panel. Not available.(13)

Long-term releases occur via the Culebra or the anhydrite interbeds, and releases by these pathways were found in performance assessment modeling to be zero or insignificant. Second and subsequent releases were also found to not be significant because of repository pressure relief following the first penetration. Although the Panel continues to question the accuracy of results based on only two reference conditions, the concern has been adequately addressed on the basis of a lack of consequence.

In summary, the Panel has found each of the four key concerns identified for the Exploration Boreholes model in July 1996 to have been resolved.

3.13. Cuttings/Cavings

3.13.1. Model Description

DOE described a change to this model regarding the method of calculating the actinide concentration of waste that is released during drilling of exploration boreholes. Other aspects of the Cuttings/Cavings model were not changed.

Figure 3-9. Volume-averaged brine saturation in rest of repository and waste panel under undisturbed conditions. Not available.(14)

In the model as previously presented, the concentration of actinides was identified as the mean of all the concentrations of actinides in contact handled transuranic waste. DOE has revised the model to randomly sample concentrations from 569 waste streams for each of three drums assumed to be penetrated by an intrusion borehole. The average concentration from three sampled drums was used to represent the range of concentration of waste removed in Cuttings/Cavings, because the waste will be emplaced three drums high in the WIPP. DOE stated that this provides increased information on the uncertainty in waste activity levels. DOE also used nine reference times, instead of 15 reference times, to provide a basis for interpolating concentration decay curves to the random times used in CCDF construction. DOE indicates that this change does not significantly affect the model accuracy.

3.13.2. Review of Criteria

The Panel considered this model to be adequate in its July 1996 report. During review of the changes, the Panel obtained an evaluation of the significance of drilling through three drums from the same waste stream at the high end of the range of concentrations of contact handled waste, on the basis that this would be a possible, though not likely, event. DOE provided waste concentration distributions, probabilities, and corresponding releases that would result, and showed that this would not have a significant effect on the location of the highest CCDF curves.

In summary, the Panel believes this model to remain adequate, as changed.

3.14. Spallings

3.14.1. Model Description

No changes to the Spallings model have been identified as compared to the Panel's understanding of it from the original review.

3.14.2. Review of Criteria

The review of criteria for the Spallings model remains unchanged.

3.14.3. Review of Responses to Panel Findings of July 1996

3.14.3.1. Summary of Findings

Based on the three following issues, the Panel determined that this model was not adequate for implementation in performance assessment:

- The conceptual model for channel flow of gases toward an exploratory borehole appears to be valid, but has not been adequately evaluated. Spallings is a potentially important mechanism for direct waste release to the ground surface.
- The conceptual model for waste erosion by flowing gases has not been adequately defined. The model describing the source(s) of waste erosion resistance and the parameter(s) characterizing that resistance have not been adequately evaluated. Errors in this conceptual model could lead to overestimating or underestimating the volume of waste released in the spallings process.
- The waste has not been adequately characterized and the understanding of its physical properties in its decayed state has not been adequately developed to support the Spallings model. An adequate understanding of waste erosion processes requires an adequate understanding of the properties of the waste.

3.14.3.2. Summary of DOE Responses to Findings

In responding to the first concern, the DOE notes that their concept of channeling as the source of spallings release is primarily based on results of laboratory experiments conducted on graded, low-moisture silica sands. The tests showed that upon achieving a steady state gas flow rate with no additional material being removed, an irregular void space results. Plaster castings of this void show that some voids are radial channels and others are a series of thin layered lenses or shells. Data from these tests were used to calibrate the model by defining values for "effectiveness factors."

The experiments show channels that extend from the borehole outward as a result of eroding effects of flowing gas within weakened planes which result from local variations in initial porosity and permeability, or by tensile (or shear) failure resulting from pressure gradients. DOE also describes studies of *in situ* coal fracturing for methane production (Mavor and Logan 1994) by means of rapid drops in gas pressure in the borehole.

The DOE response to the second issue relates the effects of gas movement over a surface to the erosional effects from flow of liquids or gases through a pipe. This erosion is seen to be caused by a combination of shear and tensile stresses which can be related to the force required to dislodge particles from the surface into the fluid stream. This force is seen to be related to the tensile strength and density of the waste. A mathematical model was developed from first principles that relates the particle dislodging forces to the drag forces present from the flowing gas, which are a function of individual particle dimensions and fluid viscosity, density, and velocity. This equation, when "calibrated" by means of experimentally determined effectiveness factors, is believed to be an analogue to the erosional forces described above.

The model is predicated on the assumption that the bonding strength of the particle to the waste surface is related to the macroscopic tensile strength of the degraded waste. One pound per square inch was chosen as an appropriate value for the bonding strength of waste in the calculations. Data were supplied that show this value to be within the range of literature values for strengths of soils, lab mixtures of salt and clay, and various materials mixed with MgO (Bergland et al. 1996).

The third DOE response specifies that the spallings phenomenon occurs only when there is brine inflow and waste decomposition. DOE states that because both of these are unknowable, it is assumed that the decomposed state will be a graded granular material consistent with the granular nature of decomposed geologic materials and corresponding to the end state of the decomposition process.

3.14.3.3. Panel Review of Responses

In reviewing the response to the first issue, the Panel has several basic points of discussion relevant to the DOE's evaluation of the model for adequacy:

- The forces responsible for detaching the waste pieces from their mass do not include the gases exiting the mass into the open gas-filled cavity. The Panel believes this type of gas flow will be largely responsible for the force required to counteract whatever bonding force exists. Such a force might be analogous to the forces (i.e., pressure gradient) on particles or groups of particles at the upper surface of a packed bed nearing the point of fluidization.

- The data on tensile strengths were from static tests and were not shown to be applicable in this dynamic situation. It is noted that in the Cuttings/Cavings model, static shear strengths were modified to be applicable to the dynamic situation.

- There is no evidence found in the record that time effect considerations were evaluated in either the development of the equations or in the conduct of the experimental tests.

- The bounding equation as presented is not solidly verified, not only because of the lack of consideration for the former comments, but also because the testing results do not support the assumptions used in equation development. For example, the dropped g term dealt with cohesive forces such as water, while the only positive test results achieved were those with moisture-laden sand.

- The effect of cementation was added when formulating the final equations describing the Spallings model and the experimental work did not evaluate these effects.

- Evaluations of the models did not include analogues from other industrial or scientific disciplines to determine a basis for reasonableness. The DOE was apparently not as successful in conducting such an evaluation as it was for the Cuttings/Cavings model. The coal mining methane gas stimulation example is good; however, several others are expected to be applicable, such as chemical engineering processes (for example, fluidized beds) and the work over the years on particulate transport in volcanology. There may be existing correlations to these processes that are directly applicable.

- The experiments were basically quasi steady state, rather than demonstrating the dynamic situation. Uniform particle distribution was used, rather than a more realistic range of particle sizes. No control was maintained over the moisture content of the sand. All these issues would seem to impact the relationship between the experimental system and the repository.

- The experimental results should be subject to scaling, which was not found by the Panel to be addressed. Also, the data did not include measurements of pressure drops at various locations throughout the system (for example, at the cavity-waste interface). Both of these issues might be reanalyzed without further experimental work.

Review of the response to the second issue also raised several points for discussion relative to the design of the model.

- While the concept of cementation was included in the model, the process by which this cementation would occur was not addressed in the experimental program.

- Flow velocities that approach transonic or beyond have not been considered and, if velocities are transonic at times during the spallings process, might require a factor addressing increased effects on the pressure across the cavity-waste interface boundary.

- The process as modeled does not have a provision for processes occurring at times of high pressure gradients. It would appear realistic that some volume of the waste dislodged from the matrix would be a spall produced by a process largely unrelated to the gas velocity parallel to a surface.

Relative to the third issue, the DOE responses are acceptable as explanations of the state of the conditions bounding the effects of the Spallings model. It is important to note, however, that the assumption that the waste will be in a fully decomposed state consistent with the granular nature of decomposed materials could be unnecessarily conservative.

Following the Panel description to DOE of the above concerns, DOE provided a further verbal response addressing the conservativeness believed to exist in the Spallings model. DOE listed as conservative model elements use of a small particle diameter, constant pressure during spalling, ignoring capillary forces, tortuosity of the channels and possible plugging, channels too small or narrow to transport all the particles that may be dislodged, and the use of a low end value of the waste strength range found in the literature.

The Panel believes that because of the many unresolved issues of a fundamental nature, it cannot acknowledge that this model provides a conservative method of calculating Spalling releases.

Integration of the Spallings model in performance assessment revealed that this model is one of the major sources of radionuclide release to the surface. While changes might come about in further work relative to this model, it is realistic to expect that the Spallings model will continue to be important to the total release. Therefore, the Panel believes that this model is not adequate for predicting the future states of the repository.

3.15. Direct Brine Release

3.15.1. Model Description

Since the Panel's July 1996 report, the uncontrolled borehole flow period assumed in performance assessment was changed from 44 hours to a minimum of 72 hours (3 days) and a maximum of 11 days, depending on the rate of gas flow as determined in the model from repository pressure and gas volume. The borehole is assumed to remain uncontrolled for as long as the gas flow rate exceeds a threshold value, up to a maximum of 11 days.

3.15.2. Review of Criteria

The change in the conceptual model was based on current drilling practices in the Delaware Basin and is consistent with regulatory guidance. Although the modeling assumptions are conceptually valid, the validity of their implementation depends on current drilling practices, which are beyond the scope of the Panel to review.

3.15.3. Review of Responses to Panel Findings of July 1996

3.15.3.1. Summary of Findings

The following key concerns related to the Direct Brine Release model were identified in the July 1996 Panel report.

- The basis for the assumption that radionuclides do not accompany the direct discharge of

Castile brine has not been adequately supported. This assumption could lead to underestimating radionuclide releases.

- Radionuclide transport through entrainment of brine and waste solids in rapid, two-phase liquid/gas releases during inadvertent borehole intrusions does not appear to have been evaluated. This transport mechanism may be an important component of the conceptual model.

- Releases resulting from flow into an exploration borehole intersecting a disturbed rock zone in the wall of a waste panel do not appear to have been evaluated. Large, open fractures in the walls could significantly increase the local halite permeability, allowing gas and brine to migrate through the borehole to the ground surface.

3.15.3.2. Summary of DOE Responses to Findings

The DOE response to the first concern addressed the small likelihood that Castile brine flowing up an open borehole would circulate significantly within the repository, displacing contaminated repository brine, which would flow up the borehole. This was considered unlikely because of the unlikely set of pressure conditions that would first allow Castile brine to flow into the repository and then, a few hours or days later, would reverse and allow repository brine to flow into the borehole. Also, unless the pressure gradients were large, the volume of such flow would be small (as described in Section 3.12).

The initial response to the second concern (entrainment of solids in two-phase gas/brine flow) was addressed by modifying the fluid density in the spallings model to estimate the entrainment of solids in a fluid with the density of a gas-brine mixture. A second analysis was later provided at the Panel's request that modified both the fluid density and viscosity. This second analysis indicated that the overall effect of this change was to reduce the volume of solids from that released by the gas flow alone.

In responding to the third concern (releases from a borehole intersecting the DRZ within the wall of a waste panel), the DOE indicated that the wall DRZ is expected to heal soon after a backstress is provided by the compacted waste. This is expected to occur much more rapidly than the healing of the roof and floor of the waste panels and will be essentially complete during the period of active and passive institutional controls. Because drilling rates are very low during this period, few boreholes (if any) are expected to intersect the wall before the DRZ is healed, and the consequences of ignoring the wall DRZ are therefore not significant.

3.15.3.3. Panel Review of Responses

The DOE response to the first concern (entrainment of waste in Castile brine discharges during drilling) was considered to be adequate with regard to the circulation of Castile brine within the repository. However, the possibility of a cavings-type release through erosion of waste in the borehole wall by upward-flowing Castile brine was not addressed. In response to an information request submitted by the Panel, a conservative estimate of incremental cuttings and cavings releases was prepared by DOE. This estimate indicated an increase in releases for an E1 event ranging from 22% to 87%, depending on the assumed waste shear resistance. The average increase was reported to be 38%. If it is conservatively assumed that the repository is typically intersected by 6 boreholes during the regulatory time frame and that from 8% to 30% of these intersect a Castile brine reservoir, the net effect of borehole wall erosion by Castile brine would be to increase the cuttings and cavings releases by from 3 to 13%. While such an increase may be considered significant, in view of the overall uncertainties in the performance assessment model, such an increase is not expected to have a strong impact on the final CCDFs and the Panel considers this concern to have been adequately addressed.

The quantitative response to the second concern (entrainment of solids in a two-phase gas/brine mixture) was appreciated by the Panel, and the conceptual approach (that of employing the Spallings model to address the issue) was considered appropriate for scoping purposes, although adjustments were not made to the model for two-phase rather than single-phase flow and for liquid rather than gas flow. However, the appropriateness of the Spallings model itself is of concern to the Panel, as discussed in Section 3.14. Until the Spallings model is found to be adequate, the results obtained from the model in addressing this concern cannot be considered valid. The Panel has chosen to find the DOE response to this concern adequate on the basis that application of the Spallings model to this concern is conceptually appropriate in a scoping sense, rather than to determine that both the Direct Brine Release and Spallings models are inadequate on the same basis. However, the Panel believes that this concern should be reevaluated when an adequate Spallings model is developed.

The response to the third concern (releases from a borehole intersecting the DRZ within the wall of a waste panel) was considered by the Panel to be adequate.

In summary, the Panel has found each of the three key concerns identified for the Direct Brine Release model in July 1996 to have been resolved.

3.16. Castile and Brine Reservoir

3.16.1. Model Description

The 10% probability of encountering a brine reservoir provisionally assumed in the early performance assessment documents was changed in the final performance assessment to 8%.

3.16.2. Review of Criteria

The change in the conceptual model was based on results obtained from a geostatistical analysis of brine encounters in boreholes drilled near the WIPP site. The basis used by DOE for estimating this probability was identified as a key concern of the Panel in its July 1996 report and is discussed below.

3.16.3. Review of Responses to Panel Findings of July 1996

3.16.3.1. Summary of Findings

The following key concerns related to the Castile and Brine Reservoir model were identified in the July 1996 Panel report.

- The basis for excluding larger, potentially depressurized brine reservoirs from performance assessment has not been adequately supported. Larger reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.

- The basis for the concept of reservoir depletion through previous borehole penetrations has not been adequately supported. Non-depleted reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.

- The expected probability of encountering pressurized brine beneath the waste panels has not been adequately supported, nor has the basis for apparently ignoring the quantitative value of site-specific geophysical data been presented. Unrealistically low probabilities of encountering brine may result in underestimating radionuclide releases.

3.16.3.2. Summary of DOE Responses to Findings

The DOE response to the first concern (the exclusion of larger reservoirs from performance assessment) indicated that brine flow up the borehole was correlated to the product of reservoir volume and pore compressibility, rather than to the reservoir volume alone. DOE also acknowledged that its range of bulk rock compressibility values may be too large, and if the smaller range of 2×10^{-11} to 1×10^{-10} Pa^{-1} recommended by Popielak et al. (1983) were used, the maximum pore volume x compressibility, product used in performance assessment (6×10^{-2} m^3/Pa) would be equivalent to a reservoir pore volume of 5.5×10^6 m^3, assuming a porosity of 0.0087. This value is considerably larger than those identified in performance assessment, and is of the same order of magnitude as the pore volumes estimated for the reservoir encountered by WIPP-12.

The response to the second concern (basis for reservoir depletion assumptions from prior drilling) was addressed for reservoirs larger than the waste panel area. Because of their size, the areas of the larger reservoirs are predicted to be penetrated more than 1,000 times over a 10,000-year period under the assumptions presented in regulatory guidance. The initial DOE response to this concern was based on the assumption that all deep boreholes would penetrate and partially deplete such reservoirs. A revised response was provided to the Panel during oral briefings in which the assumption that only 8% of the drilled boreholes will actually encounter brine was included. With this revision, depletion of the larger reservoirs was less rapid and led DOE to conclude that the analysis did not strongly support the depletion concept. The DOE response did not address the assumptions presented in the CCA for depletion of reservoirs smaller than the waste panel area, and in subsequent oral presentations it was learned that those assumptions were made without quantitative basis.

In responding to the third concern (the probability of encountering pressurized brine beneath the repository), the DOE provided a summary of the geostatistical methods applied, as well as information indicating that the consequence of the assigned probability on performance assessment results was small. The small consequence was demonstrated by comparing the long-term effects of Castile brine flows on the key performance assessment parameters of net brine inflow, brine saturation, porosity, and gas generation in a penetrated waste panel, and total spallings releases.

3.16.3.3. Panel Review of Responses

The DOE response to the first concern (the exclusion of larger reservoirs from performance assessment) was considered by the Panel to be adequate. The compressibility range of Popielak et al. (1983) lies within the range used in performance assessment, and reservoir volume is estimated based on such compressibility data. Reservoir compressibility is acknowledged to be highly uncertain, and although the range proposed by Popielak et al. (1983) may be somewhat restrictive on the high end, minor increases in that range would not substantially alter the conclusion that if the smaller range of compressibilities were considered, the DOE *de facto* included consideration of reservoir volumes extending into the millions of cubic meters. Correlary to this issue is the likelihood that the incremental volume of brine flowing to the repository from a larger Castile reservoir would be small in comparison to the volumes potentially determined to be available in the current performance assessment (see Section 3.12) and would have no consequential effect on releases.

The response to the Panel's second concern (basis for reservoir depletion assumptions from prior drilling) was separately reviewed for reservoirs both larger and smaller than the WIPP waste area. Because their analysis did not support the assumption of depletion for the larger reservoirs, the Panel assumes that this aspect of the conceptual model will be withdrawn by DOE. The issue of depletion of these reservoirs is moot, however, because of the Panel's aforementioned conclusion that *defacto* consideration of larger reservoirs was included in the performance assessment model.

The smaller reservoirs explicitly assumed to exist beneath the waste area are assumed by DOE to range in volume from 32,000 m^3 to 160,000 m^3. Such reservoirs are assumed to be depleted to the point of no consequence by from 2 to 6 prior penetrations, which may occur from boreholes penetrating either the waste panels or the unexcavated halite within the waste area. Depletion of a 32,000 m^3 reservoir was included in the aforementioned DOE analysis. The results indicate that less than one borehole is expected to encounter brine in a reservoir of this size during the regulatory time frame because of the small surface area. Assuming the reservoir is 67 m thick, the average maximum total brine flow would be only about 400 m^3 to the surface during drilling and 1,200 m^3 to the Culebra during the following 10,000 years. Results for a 160,000 m^3 reservoir of the same thickness indicated a total brine flow of about 2,100 m^3 to the surface and 6,000 m^3 to the Culebra during the following 10,000 years. Because of the larger surface area of this reservoir, an average of 14.1 brine encounters were expected in that period. After about 6 brine encounters, the brine flow from this larger reservoir to the Culebra totaled 5,200 m^3, or about 87% of the total.

Based on these results, the Panel concurs that the DOE response to the second concern is adequate. The larger reservoirs are considered to have been included in the performance assessment by virtue of the selection of a narrower range of compressibilities, and the depletion assumptions for the smaller reservoirs are appropriate.

A related concern is the method used to determine the probabilities that the reservoir assumed to underlie the repository would be a certain size. The selected probabilities range from 1/32 for the largest reservoir (160,000 m^3) to 10/32 for intermediate size reservoirs (64,000 and 96,000 m^3). The basis for these assignments was an event tree approach in which the repository, including the operations and experimental areas, was divided into five sections, each with a 50% probability of having an underlying reservoir. This gave 32 possible combinations. Probabilities were then assigned based on reservoir area, with the lowest probability being assigned the largest reservoir (which would have to simultaneously underlie all five sections). The Panel considers this approach to be geologically unrealistic. However, because the brine volume that would be released from even the largest of these reservoirs is low compared with the total volume of brine available to the repository (see Section 3.12), the consequence of the assigned probabilities is considered to be low. However, if subsequent model modifications result in significantly smaller fluid volumes in the repository, the significance of this issue should be reevaluated.

The Panel considers the DOE response to the third concern (the probability of encountering pressurized brine beneath the repository) to have an inadequate technical basis, but finds the concern resolved due to a lack of consequence. The following technical concerns remain: (1) there is a lack of data on brine encounters and non-encounters in the vicinity of the WIPP Site to support the geostatistical analysis, and the adopted probability of 8% appears to be quite sensitive to this lack; (2) the Panel is not confident that non-reported brine can be assumed to be a “no hit”; (3) the concept that a borehole can miss an underlying brine reservoir because of vertical fracturing is conceptually reasonable but lacks quantitative support, yet it apparently provides the primary basis for discounting the quantitative value of the TDEM data; (4) the correlation between reservoir occurrence and geologic structure is conceptually reasonable but ignores other potential correlations; and (5) not enough geological information exists at the site to support such correlations.

A lack of consequence was demonstrated by DOE for the third concern by comparing the long-term effects on the repository and on spallings releases of E1 and E2 intrusions. These comparisons are intended to show that the differences between a reservoir hit and no-hit are not highly significant. Noting that the total number of boreholes penetrating the site is unchanged by this issue, by inference the differences created by increasing the number of hits and decreasing the number of no-hits should also not be significant. The differences between E1 and E2 intrusions are illustrated in Figures 3-10 through 3-18. The net brine inflow into the waste panel for E1 and E2 penetrations at 350 years is shown in Figures 3-10and 3-11. While the early-time results differ, the longer-term results are similar, although the net inflow is on the average about

1,000 m^3 higher for an E1 than an E2. The volume-averaged brine saturation in the waste panel for E1 and E2 penetrations at 350 years is shown Figures 3-12 and 3-13. Here the results are similar for both the short- and long-term, although the number of lower saturation, outlying curves is smaller for the E1 than the E2 intrusions. Cumulative brine flow up the borehole at the bottom of the waste panel for an E1 penetration at 350 years is shown in Figure 3-14. Because the E2 borehole does not encounter a brine pocket, the corresponding E2 flow would be zero and the figure shows the incremental brine available to the repository from an E1 intrusion. Although the maximum volume in excess of 50,000 m^3 is significant, the volume is more typically less than 10,000 m^3 and is not significant in comparison with the overall volume of brine potentially available to the repository (see Section 3.12). The volume-averaged porosity in the waste panel for E1 and E2 intrusions at 350 years is shown in Figures 3-15 and 3-16. The difference between the curves is negligible. The total gas generated in the entire repository is shown for E1 and E2 intrusions at 350 years in Figures 3-17 and 3-18. Again, the difference is negligible. Spallings releases were also reviewed by the Panel for second E1 and E2 intrusions (note that spallings releases for first intrusions would be identical for E1s and E2s).

Figure 3-10. Net brine inflow into waste panel for E1 penetration at 350 years. Not available.(15)

Figure 3-11. Net brine inflow into waste panel for E2 penetration at 350 years. Not available.(16)

Figure 3-12. Volume-averaged brine saturation in waste panel for E1 penetration at 350 years. Not available.(17)

Figure 3-13. Volume-averaged brine saturation in waste panel for E2 penetration at 350 years. Not available.(18)

Figure 3-14. Cumulative brine flow up borehole at bottom of waste panel for E1 penetration at 350 years. Not available.(19)

Figure 3-15. Volume-averaged porosity in waste panel for E1 intrusion at 350 years. Not available.(20)

Figure 3-16. Volume-averaged porosity in waste panel for E2 intrusion at 350 years. Not available.(21)

Figure 3-17. Total gas generated for E1 intrusion at 350 years. Not available.(22)

Figure 3-18. Total gas generated for E2 intrusion at 350 years. Not available.(23)

Because of the moderating effect of gas pressure reduction following the first intrusions, the differences between spallings releases for the second intrusions are not significant. In summary, the Panel agrees that the differences between E1 and E2 intrusions for key repository conditions and performance criteria are small and finds the DOE response to be acceptable on the basis of a lack of significant consequence. However, if subsequent model modifications result in significantly smaller fluid volumes in the repository, the significance of this issue should be reevaluated.

In summary, the Panel finds that each of the three key concerns identified for the Castile and Brine Reservoir model in July 1996 has been resolved.

3.17. Multiple Intrusions

No key concerns were identified for the Multiple Intrusions model in the Panel's July 1996 report.

3.17.1. Model Description

The number of reference conditions for determining releases to the Culebra was reduced from 14 to seven since the July 1996 Panel report was issued.

3.17.2. Review of Criteria

The Panel does not expect the reduction in the number of reference conditions to significantly affect modeling results, and finds the change acceptable.

3.18. Climate Change

3.18.1. Model Description

The description of the Climate Change conceptual model and use of the climate index remains substantively unchanged from the July 1996 review. The model continues to be adequate.

3.18.2. Review of Criteria

The review of criteria for the Climate Change model remains unchanged; however, two issues previously identified for this model were reviewed based on new information received.

3.18.2.1. Summary of Issues

The following two issues related to climate change were reviewed.

1) The absence of a consideration of vertical leakage in the Culebra, which might be considerably enhanced by future, more humid climatic conditions, may overlook significant effects on Culebra flow.

2) The potential change in flow directions in the Culebra associated with future wet climates may impact releases through the Culebra.

3.18.2.2. Summary of New Information

Several conversations with SNL personnel confirmed that the vertical leakage issue has not been specifically addressed. New discussions in the CCA documents address changes in flow direction noted in three-dimensional simulations associated with future wet climates. These changes were excluded from PA modeling for computational efficiency and because the changes in direction were toward regions of lower conductivities.

3.18.2.3. Panel Review of New Information

The FEP NS-9, SMOR of September 21, 1995, included in the recent materials provided to the Panel as CCA Appendix MASS, Attachment 15-7, states that vertical leakage into the Culebra is ignored in flow and transport calculations. The SMOR also states that the basis for the assumption that the two-dimensional model and its boundary conditions adequately represent flow-conditions in the Culebra has not been "systematically investigated or documented." The principles of regional groundwater flow in layered sediments suggest that vertical leakage may make a significant contribution to total inflow to the Culebra within the site area boundaries. While there is limited information describing the leakage, ignoring substantial leakage could introduce error into calibrated T fields, and the resulting two-dimensional flow fields may be erroneous.

While the FEP was reviewed by the Panel earlier, prior to preparing the Conceptual Model Peer Review Report of July 1996, the fact that the Culebra conceptual model was found to be inadequate (but inconsequential since the hydrologic data base supported numerical modeling) precluded further serious inquiry. The Panel's stated lack of suitability of the two-dimensional model for determining boundary conditions and estimating changes in the boundary conditions over time, and the absence of calculations supporting the assumed conditions, re-emphasize this source of uncertainty in the Culebra flow and transport calculations.

Additional calculations with GRASP-INV that would evaluate the sensitivity of T fields, release paths, and travel times to vertical leakage are planned, but are not complete at this time. Preliminary, one-dimensional calculations (not QA[d]) indicate that T field impacts would be less than 10%, although no inverse solution of the T fields has been completed. There are neither preliminary calculations nor reasoned arguments of sufficient strength to judge the impact of the issue with respect to flow fields. In summary, the Panel concludes that there are no appropriate supporting calculations or sufficient reasoned arguments to exclude vertical recharge from flow and transport modeling in the Culebra.

New discussions in CCA documents and additional documents made available to the Panel since the July 1996 Conceptual Model Peer Review Report emphasize potential changes in flow directions in the Culebra associated with future wet climates. The CCA (October 1996, Chapter 6, Section 6.4.9) states that changes in flow direction were noted in three-dimensional simulations associated with future wet climates. It also states that such changes were excluded from modeling for computational efficiency. The only support of the exclusion is the conclusion that the flow direction change is in the direction of lower conductivities and considering only the most conductive portion of the Culebra is conservative. The CCA Appendix MASS 14.2 and 17.1 also discuss changes in flow direction in the Culebra associated with future wet climates and state that the changes are not considered in modeling.

While the new discussions and additional documents mentioned above emphasize the potential for flow direction change, there are no new, reasoned arguments or PA calculations to support the conclusions that the impacts of flow direction change are insignificant. SAND96-2133 is a recent (since the July 1996 Panel report) publication that summarizes the role of the regional groundwater flow model in characterizing Culebra groundwater flow under various climatic conditions. It describes how the three-dimensional (3-D) regional model simulates changes in flow direction (flow paths) resulting from increased recharge during a future wet climate. The two-dimensional (2-D) model implements the increase through a spatially invariant surface function that does not require the precise definition of recharge points and locational inflows to the system. The resolution of the 3-D model includes only nine nodes within the site/regulatory boundary and therefore, the 2-D model, using numerous nodes, is employed to display the flow paths. The 2-D model is forced to display the flow paths simulated by the 3-D model by using boundary conditions and T fields from that model. As presented in Appendix MASS Attachment 15-7, the 2-D model is, at this point, well suited for the analysis of flow and transport, given the boundary conditions specified to produce the appropriate flow paths. The 2-D model is not suited to determining boundary conditions for climatic events and recharge conditions because those conditions might change over time.

The decision not to include flow direction change as a component of the Climate Change conceptual model is based on the reasoned argument that as the flow direction changes from a southeasterly to a southwesterly or westerly direction, the flow encounters lower permeability zones. With this illustration, it is considered conservative to allow the increased flow velocities associated with future wet climate scenarios to occur in the more permeable zones (more transmissive parts of the T fields). In addition, since performance assessment calculations include no realization where there is a release at the regulatory boundary under the conservative conditions, there is no consequence to excluding flow direction change from the simulations.

In the absence of specific PA calculations addressing the two remaining issues pertinent to this model, the reasoned arguments that the effect of both issues is small and that the PA calculations would not be sensitive to potential flow changes of the magnitude caused by these climatic responses at the regulatory boundary are accepted.

3.19. Creep Closure

There were no changes to this model and it continues to be acceptable for implementation.

3.20. Shafts and Shaft Seals

There were no changes identified for this model and it remains adequate for implementation.

3.21. Gas Generation

3.21.1. Model Description

There were no identified changes for this model. Additional information available since the Panel's July 1996 report is provided by performance assessment results and includes families of CCDFs, sensitivity studies among key parameters, and results related to gas generation. In particular, the results indicate that over 10,000 years, on the average less than 50% of the iron in the repository is corroded. This means that hydrogen generation is not limited by the amount of iron present but by other parameters, such as the amount of brine available. Also, the gas generated is sufficient to reach 12 MPa in many realizations, which is the value that would open and sequester additional gas in marker beds. Additional results depict the pressure after an initial borehole intrusion, indicating that even with introduction of Castile brine into the repository, subsequent pressures are substantially vented up the initial borehole. This information is useful in putting the output of the Gas Generation model in perspective with the results of the other linked models.

3.21.2. Review of Criteria

During the initial review, significant uncertainties precluded definite conclusions on some of the evaluation criteria, particularly Adequacy of Application, Accuracy of Results, and Validity of Conclusions. Four significant issues were raised, and the Panel concluded that without resolution of these issues, a conclusion on model adequacy and validity of conclusions would be speculative. The Panel therefore stated that the Gas Generation model was not adequate for implementation. The additional information now available, coupled with the responses to the Panel's specific findings, assisted the Panel in drawing conclusions on these criteria.

3.21.3. Review of Responses to Panel Findings of July 1996

The Panel issues, a summary of the DOE response, and the Panel assessment of the responses are provided below.

3.21.3.1. Panel Findings

- Analysis of hydrogen generation by corrosion of metals other than the steel in the waste is inadequate. Ignoring gases generated by corrosion of other metals could result in underestimating the gas pressure in the repository.

- Temperature increases in the repository due to corrosion and microbial degradation are not sufficiently analyzed or characterized. Higher ambient repository temperatures could increase the rates of chemical reactions, fluid flow, and halite creep.

- Due to uncertainties about the effectiveness of the magnesium oxide getter to completely remove CO_2, significant uncertainties exist regarding pH, CO_2 pressure, and actinide solubilities. The chemical conditions in the repository would significantly change if the MgO did not function as planned, and could result in underestimating radionuclide releases.

- Hydrogen and oxygen gas generation from radiolysis of dissolved and wetted particulate actinides have not been adequately evaluated. Radiolysis of cellulose and plastics without assuming local hydrogen depletion has also not been adequately evaluated. Ignoring the gases generated by these effects could result in underestimating the gas pressure in the repository.

3.21.3.2. Summary of DOE Responses to Findings

In Section 9 of the CCA and Appendices PEER and MASS, DOE responded to the Panel findings. Relative to the first finding, DOE provided additional information that the aluminum in the waste and steel in the rock bolts would add about 10 to 15% to corrodable metals which could potentially generate hydrogen. However, DOE showed results of the CCA calculations indicating that in all realizations over 10,000 years, the total available corrodable metals in the repository are not consumed due to an insufficient volume of brine inflow into the waste panels. Therefore, the amount of corrosion-produced hydrogen is not affected by not specifically accounting for corrosion of aluminum and rockbolts. Only in the event of borehole intrusions through a panel would gas generation become inventory limited, and only in that panel. However, due to the long-term gas flow out of the borehole, the added gas generation would be vented and not adversely affect repository performance.

Relative to the issue on potential for temperature increases due to exothermic reactions, DOE provided a conservative bounding analysis of corrosion heat generation and microbial heat generation in which water reaction was assumed to all be by corrosion of aluminum, which provides the most exothermic reaction. For this reaction, DOE stated that the maximum short-term temperature rise was estimated to be 5 to 7°K, and this is too small to have any significant effect on repository corrosion processes.

In response to the issue of uncertainties in the effectiveness of the MgO to effectively remove CO_2, DOE stated that the method of MgO emplacement within the waste room would ensure there are no brine flow paths that can bypass the backfill. DOE stated that twice as much MgO would be emplaced to react with the CO_2 produced if all the cellulosics, rubber, and plastics were consumed by microbial degradation. DOE stated that the rate of dissolution of MgO in brine is much faster than required to react with the maximum expected CO_2 generation rate.

In response to the issue regarding added gas generation due to radiolysis of water by undissolved but wetted actinide-containing particles, and due to radiolysis of cellulose and plastics, DOE did a bounding analysis based on the stoichiometry of the various possible reactions. DOE stated that if all the brine consumed by corrosion was instead consumed by radiolysis, twice as much gas would be available from this source. DOE also stated that if radiolysis of cellulose and plastics occurred instead of microbial degradation, twice as much gas would also be available from this source. Any CO_2 produced is assumed to be consumed by MgO. DOE states that the combined effect would result, at most, in a two- to threefold increase in total gas generation. DOE then stated that because at gas pressures above 12.7 MPa, gas would be vented into the interbeds, the maximum repository pressure would not exceed the values previously calculated for performance assessment (16.5 MPa). DOE states that radiolysis could result in pressures sufficient to cause spallings releases (above 8 MPa) in a greater number of realizations. However, DOE asserts this would not cause an increase in direct release because the data from performance assessment indicate no correlation between spallings releases and repository pressure, no correlation between moles of gas generated and repository pressure, and no correlation between direct brine release volume and repository pressure.

3.21.3.3. Panel Review of Responses

The Panel agrees with the DOE responses to the two Panel issues regarding added metal for corrosion, and the effect of exothermic reactions. The Panel did not accept that no correlation exists between repository pressure and the other parameters but accepts that these relationships do not adversely affect performance assessment. The Panel does not believe that the issue of total and rapid consumption of CO_2 by the MgO getter has been fully resolved, but it has been sufficiently resolved for purposes of the Gas Generation model because all that is needed is to substantially remove CO_2 as a pressure source and not remove all of the CO_2. The Panel believes that DOE has not ruled out the possibility that initial brine contact with the surface of MgO granules could somewhat reduce accessibility to the remaining MgO due to formation of phases having lower density and lower permeability to brine and CO_2, but the Panel believes sufficient access will be present to effectively remove most of the CO_2 produced. The Panel believes that since this is important to overall performance of the repository, not just for CO_2 pressure control, the DOE-planned pilot and engineering scale testing of the MgO backfill can provide the necessary assurance that the system will function as intended.

Regarding the DOE response to the issue of added gas generation if radiolysis were to occur, the Panel believes the DOE response is adequate because radiolysis is not likely to fully replace the other gas-producing mechanisms. The Panel also notes that the DOE has not fully accounted for sequestration of water by MgO, which could reduce the availability of brine needed for corrosion of iron, microbial action, or radiolysis.

In summary, the Panel believes the Gas Generation model is adequate based on the responses provided.

3.22. Chemical Conditions

3.22.1. Model Description

This conceptual model was listed as inadequate in the July 1996 Peer Review Report. Three major issues were identified; the most critical of these was the reliability of MgO as a backfill component. The DOE responses to the issues are discussed in Section 3.22.3. Subsequent to the July 1996 findings, two new pieces of information have been identified that are pertinent to the Chemical Conditions conceptual model: 1) a laboratory scoping study has been performed to identify if MgO mixed with CO_2 in a high ionic strength brine would produce carbonate, and 2) a series of CCDFs were prepared in June 1996 to illustrate repository performance with and without MgO backfill.

3.22.2. Review of Criteria

The first new piece of information provided to the Panel (the results of a scoping MgO experimental study) is reviewed under the criterion of "Validity of Model Assumptions." This experiment was performed to ascertain whether magnesium carbonates could be generated under the most optimum conditions. This same study was described as a precursor to future experiments laid out in a recently approved Test Plan (TP 97-01) intended to provide data needed to characterize the performance issues related to MgO. The scoping study looked for maximum results in a very limited time frame. In essence, MgO pellets were placed in applicable brine solutions (Salado or Castile) in a beaker, and then CO_2 gas was bubbled through the mixture to determine the effect of backfill on pH reduction and what magnesium carbonate phases would be produced.

This preliminary experiment showed some promising results. Two metastable magnesium carbonate phases (dipingite and nesquehonite) were produced under slightly varying initial chemical environments. Furthermore, the studies indicated that over a 13-day period the chemical systems increased in pH by approximately 2 orders of magnitude. Unfortunately, the scoping experiment did not reflect the conditions present in the repository with regard to either chemical parameters (especially fCO_2 and interaction with iron oxides), time (diffusion rates), or physical constraints (orientation of backfill containers, pathways for gaseous reaction). Therefore this scoping experiment does not provide a sufficient basis to conclude that the MgO backfill will perform as indicated by thermodynamic equations, or as assumed in performance assessment.

The second new piece of information was a series of CCDFs produced with and without the addition of MgO backfill. This issue was reviewed under the criterion "Accuracy of Results." Of particular interest are two CCDFs that predict "blowout" releases with and without MgO backfill. The Panel was not provided with the assumptions used in preparing these CCDFs and is not aware how other factors (chemical conditions, gas generation, actinide source terms, transport in Salado or Culebra) were varied in preparing these calculations. Because of this lack of information, the CCDFs did not provide an adequate basis for the Panel to conclude that the addition of MgO backfill was of no consequence to repository performance.

3.22.3. Review of Responses to Panel Findings of July 1996

3.22.3.1. Summary of Findings

Three issues were involved in the determination that this conceptual model was not adequate for implementation. Two of the issues were of relatively minor importance to the acceptability of the model, and are summarized as follows.

- The combined temperature increase (due to radioactive decay and exothermic reactions) and its effect on repository conditions has not been adequately addressed. Significantly higher repository temperatures could accelerate chemical reactions, fluid flow, and halite creep rates.

- Phase equilibria have not been critically assessed within the chemical parameters of the conceptual model. A major element stable phase that was overlooked could significantly alter the chemical conditions of the repository and vary the actinide source terms.

- The third issue was the concern raised over the use of MgO backfill. As discussed in the original peer review report, the thermodynamic equilibrium equations calculated for MgO reacting with CO_2 to produce magnesium carbonates (magnesite) and thereby buffer the chemical conditions, are reasonable and proper. However, the MgO backfill has not been demonstrated to be able to react completely with CO_2 generated by microbial action. If the MgO backfill did not react as planned, the pH-buffering capability of the repository would be significantly compromised, and could result in underestimating the actinide source term.

3.22.3.2. Summary of DOE Responses to Findings

The responses to this conceptual model that DOE presented to the panel were combined with responses to issues raised in the Gas Generation model. This was unfortunate, in that there are subtle differences in the questions raised. The first two concerns of this model were sufficiently similar to those of the Gas Generation model that the responses were not critically affected. However, the third issue, that of the effectiveness of the backfill, was not fully addressed. The actual DOE responses are summarized below.

DOE responded to the first concern with a series of calculations that centered on exothermic reactions and radioactive decay. The presentation was both thoughtful and appropriate. The final resolution was that there may be a 7° C increase in temperature if all the metal in the repository was aluminum, but that the increase would not affect the outcome of the conceptual model.

The second concern was that of phase stability and equilibria conditions in the repository. This information was thought necessary due to the large amount of MgO that would be emplaced in the waste cells. The phase diagram that was presented was limited to the system $MgO\text{-}CO_2$ (with excess H_2O) and only portrayed stable phases (Figure 3-19).

Figure 3-19. Phase diagram for the MgO - CO_2 system. Not available.(24)

The DOE response to the Panel's concern about MgO was based on two factors: thermodynamic equilibrium and calculations of Mg dissolution rates of the pellets. The theory that MgO would react with water to form $Mg(OH)_2$ and then react with CO_2 gas to create $MgCO_3$ was reviewed, along with the thermodynamic basis for the model. The DOE modeling calculations indicated that the MgO pellets would react completely with CO_2. Equations were developed to calculate the particle radius needed to accommodate the maximum CO_2 generation rate.

3.22.3.3. Panel Review of Responses

The first issue (temperature increases) was reasonably discussed by DOE and an appropriate resolution was obtained.

The second issue (phase equilibria) was not addressed in a vigorous manner. The DOE response on this issue was not exhaustive nor completely representative of the system. A more thorough representation would have been the system MgO-FeO-CaO-NaO-CO_2-Cl_2-SO_4 (with excess H_2O). The phase diagrams did not chart the existence of metastable phases in the system, which would have provided a clear visual representation of solid phases most likely to be formed (such as dipingite and nesquehonite) in low temperature systems. A more exhaustive series of phase diagrams would be extremely informative because metastable phases can exist for extremely long periods of time (millions of years) due to kinetics problems and lack of sufficient energy for transition to stable phases. To summarize, the phase stability discussion presented by DOE was only minimally adequate for the chemical system involved, and would lead to many instances where metastable phases (not discussed) would dominate the reactions. Therefore, the second issue (phase equilibria) was addressed in its most restrictive sense and, although not completely satisfying, the response provided sufficient information to resolve this concern.

The third, and by far most critical concern of the Panel centered around the fact that MgO had not been tested to ascertain its ability to effectively react with CO_2 in the repository system. The ability for the backfill to react properly and completely has ramifications to a multitude of other parameters. The buffering capacity of the backfill would theoretically fix many of the other chemical components such as the actinide source terms and gas generation rates. Such a critical interplay of the effect of MgO backfill on other conceptual models is further discussed in Section 4.

A possible shortcoming was identified in the equation developed to calculate MgO particle radius for dissolution. The value used for the density term was that of periclase (3.53 g/cm^3) when in fact it, would have been much more reasonable to use the density of brucite (2.39 g/cm^3). This difference would have increased the assumed particle radius to 0.55 cm, 1.5 times the radius used in the DOE calculation.

Much more important is the fact that DOE has not investigated diffusion rates into the MgO pellets instead of dissolution rates. This was clearly indicated by the fact that reaction rims were created on the exterior of the pellets used in the scoping experiment described in Section 3.22.2. Although dissolution may be the manner in which reactions could start, as soon as magnesium carbonates are formed on the exterior of the pellets, the dominant process to react the remaining $Mg(OH)_2$ would be diffusion of CO_2 into the interior of the pellets. This diffusion phenomenon has not been quantified by experiments.

The final factor that was not sufficiently investigated was whether the reaction to carbonate could seal off large percentages of the backfill, due to the engineering geometry involved, and render the unreacted MgO inert. No experiments to date have tried to duplicate the placement of the backfill in the repository and understand the effects of the expected volume increase due to the transition from oxide to carbonate. Such a volume increase may effectively block pathways for the CO_2 to reach the backfill. Once again, this emphasizes the need to understand and quantify the diffusion rates of CO_2 gas through the carbonate and into the pristine backfill material.

Many of the above stated issues are identified as factors to be quantified in the DOE Test Plan discussed in Section 3.22.2. The Panel has performed a cursory review of this Test Plan and believes that sufficient data can be extracted from the experimental results to determine if MgO will completely react with the CO_2 and therefore buffer the chemical conditions of the repository.

The critical issue, whether the backfill will react sufficiently with CO_2 to buffer the chemical system, has not yet been substantiated by experimental physical results that correctly simulate the repository. Because the backfill issue has so many ramifications to other conceptual models, it is critical to demonstrate that this material will in fact work properly. Therefore, the Chemical Conditions conceptual model is still not considered by the Panel to be adequate for its intended use in the performance assessment.

3.23. Dissolved Actinide Source Term

3.23.1. Model Description

In the time period between the Conceptual Models Peer Review Panel's July 1996 report and this supplementary review, the CCA and its Appendix SOTERM were produced. An addition to the original conceptual model is now described in Section SOTERM.5, Role of Organic Ligands. In essence, the model now takes credit for an abundance of dissolved transition metals (Fe, Ni, Cr, Mn) from waste drums and from backfill (Mg) in the repository brine. These cations would compete for binding sites on organic ligands and significantly reduce the ability of the ligands to complex with actinides. The conclusion of this section in Appendix SOTERM is that the organic ligands would not be available to complex with actinides and thus will not be a component of the dissolved actinide source term model.

3.23.2. Review of Criteria

Although it might be questioned how completely cations such as Ni prevent complexation of actinides by organic ligands such as EDTA, the Panel believes that this change to the conceptual model has only a slight bearing on the overall prediction of source term concentrations and is not unduly impacted by the backfill component because most of the cations involved with the ligands are transition metals. Therefore, this is viewed as a minor change that only impacts the model in a conservative manner. The Panel has concluded that this is not a significant change to the conceptual model and therefore the model remains adequate.

3.24. Colloidal Actinide Source Term

3.24.1. Model Description

A change to the conceptual model was indicated in Appendix SOTERM in Section SOTERM 6.3.3.1 where it is stated " …the high concentrations of Mg^{2+} in solution due to the presence of MgO backfill will compete with actinides for binding sites on humic substances and reduce the actinide uptake." This statement seems to imply that the source term value used is conservative and in essence overestimates the true humic component source term.

3.24.2. Review of Criteria

This model was originally determined to be adequate for implementation. Although there is now a statement that magnesium in solution will compete for humic acid binding sites, DOE did not take credit for this effect and therefore the model is still deemed adequate.

4.0 INTERRELATIONSHIPS AMONG CONCEPTUAL MODELS AND THEIR SENSITIVITY IN THE PERFORMANCE ASSESSMENT

4.1. Introduction

Most of the models reviewed by the Panel can be organized into a few interrelated groupings based on critical performance issues. Some of those groupings contain some of the same models as others, and some overlapping of issues is necessary. Gas pressures are the source of the driving energy for movement of radionuclides out of the repository, in most cases. The porosity surface look-up table integrates numerous and diverse parameters which interrelate repository volume and the gas pressure history in the repository. The porosity surface calculation, illustrated in Table 4.1, was reviewed and approved by the Engineering Systems Peer Panel Review. This table provides an organizing structure for the consideration of its component parameters.

Table 4.1. Porosity Surface Calculation — Gas Generation and Repository Gas Pressure History

Gas Generation Model ®	Porosity Surface Calculation ®	Performance Assessment Gas Pressure History
Parameters	**Parameters and Models**	**Calculations**
Waste Composition Brine Inflow Volumes Brine Composition Corrosion/Degradation Reactions MgO Effects	Room Closure Model Room Initial Dimensions Waste Initial Dimensions SANTOS Computational Configuration Halite Elastic Properties Halite Creep Properties Argillaceous Halite Creep Properties Anhydrite Properties Waste Composition Waste Solid Densities Waste Volume Fractions Waste Mechanical Properties Waste Pressure - Volume Relation Gas Generation - Constant Saturation Variant	BRAGFLO Code
Most of the parameters listed were reviewed by other panels.		

Gas pressure is also a critical element in the inflow of brine into the repository. High gas pressures retard the flow of brine from the surrounding Salado Formation through the disturbed rock zone, the Salado interbeds, and the matrix permeability of the impure halite. Brine is necessary to the reaction of the waste to generate gas. The coupling of gas pressure and brine inflow to the performance of the repository is illustrated in Table 4.2. The result of performance assessment calculations (100 realizations, using sampled values) is that the fraction of waste steel reacted may range from 0% to 100%. Waste steel is an important element in the gas generation model. It is a sensitive indicator of the overall waste reaction and the physical state of the waste. The great variance in this sensitive performance result is caused by the complex variability of the long chain of component models and the uncertainty in predicting the gas pressure history of the repository.

Table 4.2. Model Chain — Brine Inflow

Brine Availability	Processes	PA Results

The models show that there is enough brine available from the Salado Formation by flow through interbeds due to the permeability of the impure halite and by drainage of the DRZ to react all waste.	Gas pressure (limited by initiation pressure of interbeds) resists brine inflow → ← Inflow through DRZ, interbeds, from halite, and due to intrusion (long-term)	Wide variation in degree of brine consumption by chemical reactions in waste (Figures 4-1 and 4-2)
Models	**Models, Parameters, and Calculations**	**Calculations**
Salado Impure Halite Disturbed Rock Zone Salado Interbeds Repository Fluid Flow	Porosity Surface Calculations Salado Interbeds Gas Generation *Chemical Conditions Creep Closure DRZ Repository Fluid Flow Multiple Intrusions Exploration Boreholes SECO Code BRAGFLO Code	BRAGFLO code

*Model found inadequate for implementation and to have consequence in PA calculations.

It is the opinion of the Panel that the structure of the conceptual model integration used in performance assessment is reasonable. The source of uncertainty lies primarily in the individual models and is partly mitigated by the use of sampling techniques and by the interrelationships of model sensitivities within the performance assessment calculations in the cases of the conceptual models which are adequate for implementation.

There are four principal conceptual pathways for release of radionuclides to the accessible environment. Release through the Salado interbeds beneath the repository due to the transport of repository brine to the edge of the land withdrawal boundary is considered unlikely due to the very large storage volume available in the interbeds. All other credible release scenarios are the result of human intrusion by drilling through the repository. Release to the surface as a consequence of drilling (Table 4.3), release through the Culebra Dolomite due to long-term flow up an intrusion borehole (Table 4.4), and release through units above the Culebra (Magenta Dolomite and Dewey Lake Redbeds, Table 4.5) are the remaining credible pathways.

Table 4.3. Model Chain — Surface Releases During Drilling

PA Calculations: Source and Volume of Waste	Processes	Potential Impact

1. Solid Waste Carried to Surface 2. Dissolved Radionuclides Carried To Surface	Transport of solid, dissolved, and colloidal waste and waste products up borehole annulus during intrusion.	PA calculations predict that releases of waste are probable
Models and Calculations Cuttings and Cavings *Spallings Porosity Surface Calculation Gas Generation Direct Brine Release Multiple Intrusions Repository Fluid Flow Exploration Borehole Castile and Brine Reservoir *Chemical Conditions Dissolved Actinide Source Term Colloidal Actinide Source Term Creep Closure		
* Model found inadequate for implementation and to have consequences for PA calculations.		

Table 4.4. Model Chain — Release Through Culebra

PA Calculations: Volume of Brine at Culebra in Borehole ®	**PA Calculations: Brine Intrusion Into Culebra** ®	**PA Calculations: Radionuclide Content of Brine** ®	**PA Calculations: Transport in Culebra**
Models and Parameters	**Models and Parameters**	**Models and Parameters**	**Models and Parameters**
BRAGFLO Code Repository Fluid Flow Exploration Borehole Castile Brine Reservoirs Porosity Surface Calculations Gas Generation Exploration Boreholes Multiple Intrusions Creep Closure *Chemical Conditions	Culebra Hydrologic Model BRAGFLO-SECO Interface PA Calculations of Uphole and Downhole Flow Rates Climate Change	Dissolved Actinide Source Term PA Calculations of Uphole and Downhole Flow Rates	SECO Code Sorption Flow Scenario 1. Advection 2. Diffusion Culebra Hydrologic Model K_ds

*Model found inadequate for implementation and to have consequences for PA calculations

Table 4.5. Model Chain — Releases to Units Above Culebra

Issue	Additional Considerations
Performance assessment calculations show insignificant brine available above Culebra.	Intrusion into Magenta and Dewey Lake Redbeds may be inhibited by low permeability (Magenta) and filling of fractures (Dewey Lake Redbeds). Transport in the Dewey Lake Redbeds maybe inhibited by large hypothetical retardation on ferrous minerals.
Models and Parameters	
BRAGFLO Code Porosity Surface Calculation Repository Fluid Flow Exploration Boreholes Multiple Intrusions Gas Generation *Chemical Conditions PA Calculations (BRAGFLO) Brine Down Hole Brine Up Hole Injection of Brine into Culebra Room Closure Culebra Hydrologic Model	

* Model found inadequate for implementation and to have consequences for PA calculations.

Sensitivities, variability, and adequacy of individual conceptual models are discussed in Section 3. The sensitivity of the performance of the repository to gas pressure history, brine availability, and the models impacting the three intrusion-related release scenarios are discussed here.

4.2. Gas Pressure History — Porosity Surface Calculations and the Gas Generation Model

The porosity surface calculation is made with the SANTOS code prior to the performance assessment computations done with the BRAGFLO code. The porosity surface calculation describes the changes in repository volume with time for 13 instances of gas generation rate versus room closure resulting from halite creep. Room initial dimensions, waste dimensions, halite elastic and creep properties, waste densities, mechanical properties, and pressure/volume relations and gas generation rates form the Gas Generation model assuming complete and constant saturation are included as parameters. Brine inflow is not included in the porosity surface but is an important part of the Gas Generation model.

The porosity surface permits the calculation of repository volumes for gas pressures at thirteen times (SANTOS code). The integration of repository volume with gas generation history is accomplished in the performance assessment calculation (BRAGFLO code) by matching gas generation with the appropriate time steps generated in the porosity surface calculation.

The Gas Generation model combines the generation of gas through corrosion of metals and microbial degradation of organic constituents. Both processes are directly dependent on the volumes and compositions of brine entering the repository. During the first round of reviews, the Gas Generation model was found to be inadequate for implementation; however, subsequent review of additional information has shown that the conceptual model is adequate. The addition of MgO backfill is expected to reduce gas generation. The interaction between gas generation and brine inflow is difficult to define with respect to gas pressure. This is because of the absence of clearly defined capillary pressures for Salado halite and the multivariate nature of the repository volume/gas pressure interrelationships within the porosity surface calculation. This wide range of uncertainty is reflected in the wide range of degrees of probable waste degradation recognized in the performance assessment calculations (Figures 4-1 and 4-2).

In the undisturbed scenario, the variation of gas pressure due to brine inflow history has no effect on any probable release. In the release scenarios related to human intrusion, the gas pressure history is related to the potential impact of releases in both the short and long terms.

4.3. Release Through the Culebra

The transport of contaminated brine up an intrusion borehole in the long term is the primary source of radionuclides to be transported in the Culebra. Brine transport up the borehole (and down from units above the Culebra) is calculated in the performance assessment process using the BRAGFLO code. Transport evaluation is supported by SECO code calculations of transport within the Culebra, which neglect the brine volume injected into the Culebra. SNL asserts that this computational method has no effect on transport over the distance from the waste panels to the site boundary.

Vertical leakage from units overlying the Culebra may, especially if enhanced by water wells, raise the pressure in the Culebra. The Culebra is at present underpressured with respect to all other stratigraphic units above the Salado. This underpressure enhances the injection of brine into the Culebra and also helps to explain the insignificance of brine from the borehole in the overall flow in the Culebra. No significant volume of brine rises above the Culebra in the intrusion scenarios based on contemporary conditions. Extensive water well development and climate change are future events that may impact this aspect of Culebra hydrology.

Figure 4-1. Fraction of steel remaining in waste panel for undisturbed conditions. Not available.(25)

Figure 4-2. Fraction of steel remaining in waste panel for an E1 intrusion at 1000 years into the waste panel. Not available.(26)

There are four general sets of model interactions that impact transport of radionuclides in the Culebra. These are: 1) models contributing to brine volumes, gas pressures, and long-term flow up the borehole to the Culebra, 2) injection of brine from the borehole into the Culebra (entirely performance assessment calculations), 3) the Culebra hydrologic flow model and influences on that model such as climate change, and 4) flow scenarios and K_d values for retardation in the Culebra. There are significant uncertainties in each of these areas such as the influence of MgO backfill on gas generation, climate change, brine flows resulting from penetration of brine reservoirs below the repository, local impacts of brine injection from the borehole, and the proportioning of flow processes on retardation. In general, however, these uncertainties are either small in comparison to the transport distance from the waste panel to the site boundary or, as in the case of the MgO backfill, may have only beneficial impacts. SNL asserts that retardation in the Culebra is sufficient to prevent release even in the case of maximum brine flow and injection into the Culebra. Changes in flow direction resulting from climate change, related increases in recharge, changes in vertical leakage due to water well development to the Culebra, and the impact of brine injection on flow in the Culebra have not been specifically evaluated. Qualitative arguments that these sources of uncertainty are insignificant to a release through the Culebra from the waste panel area to the site boundary have been presented by SNL.

4.4. Release To Units Above The Culebra

The only two stratigraphic units above the Culebra that are permeable enough to cause concern about releases are the Magenta Dolomite and the Dewey Lake Redbeds. The primary reason for a finding of no consequence of release from these units is the performance assessment finding that no significant volume of brine rises past the Culebra in the intrusion borehole. The calculations used median and minimum Culebra permeabilities from the Culebra hydrologic model (T fields). The principal sources of uncertainty in the performance assessment calculation are those associated with models impacting brine volumes and gas pressures in the repository, which are listed in Table 4.2. Low permeabilities measured in the site region in the Magenta and gypsum-filled fractures in the lower Dewey Lake Redbeds are possible additional sources of protection against releases through these units.

4.5. Surface Releases

Four areas of model interactions are sources of uncertainty in the surface releases of radionuclides: 1) gas pressure and brine volumes in the repository, discussed elsewhere; 2) effectiveness of entrainment and transport of solid waste in brine or gas flowing up the borehole annulus; 3) solubility of radionuclides and the formation of actinide-bearing colloids in the brine in the repository; and 4) the effectiveness of the cutting/cavings and spallings processes to provide solid waste particles of an appropriate size for uphole transport.

The effectiveness of transport of both the solid and dissolved fractions of the radionuclides depends primarily on the velocity of gas or brine flow up the borehole annulus after the drilling mud has been blown out of the hole by repository gas. This set of scenarios has been treated in the performance assessment calculation and the Direct Brine Release model and gets its uncertainty mostly from the uncertainties in gas and brine pressure and volume.

The solubility of radionuclides and the formation of colloids have been adequately treated in the source term models, although the impacts on these models of MgO backfill have not been fully assessed in the Chemical Conditions model. The volumes of particulate waste generated by drilling are adequately addressed by the Cuttings/Cavings model. The volume of solid waste particles generated by spalling is not adequately resolved by the model at this time.

Spalling is sensitive to gas pressure, the moisture content of the waste, and the physical state of the degraded waste. The physical state of the waste, particularly grain size, cementation, and cohesion, are difficult to characterize. SNL has attempted to limit these parameters and to calculate waste release due to spalling through a model which relies on the erosion of channel-shaped voids in the waste by gas overflow. The Panel has found the model inadequate for implementation. The spalling process is also sensitive to the uncertainties contained in the gas pressure history of the repository. SNL is planning further laboratory experiments to support the modeling effort and has stated that the cementing of waste by the reaction with the MgO backfill may have beneficial effects on waste spalling.

Spalling is an important component of the release to the surface. The Panel believes that the development and testing of the Spallings model is currently inadequate to support its use in performance assessment.

4.6. Sensitivity of Performance Assessment to Conceptual Model Acceptability

Three classes of model acceptability result from the peer review process:

1) Model Acceptable. Some issues may be noted, but they are not important to the final application of the model.

2) Model Unacceptable and Has Performance Assessment Consequences. Two models were found unacceptable. The Spallings model appears to be incomplete and is not confirmed by experimental evidence or numerical analysis. Several issues and sub-issues remain to be addressed with respect to this model. This model has significant impact on release of radionuclides to the surface, the most significant release issue at WIPP.

   The Chemical Conditions model is unacceptable because it does not address the impact of MgO backfill on chemical conditions in the repository. Chemical conditions are a critical factor in the results of the application of several other models. These include: Gas Generation, Repository Fluid Flow, Actinide Source Terms, Direct Brine Release, and others. Chemical conditions indirectly impact the transport models and the other models related to surface release.

3) Model Unacceptable With No Performance Assessment Consequence. The Culebra Hydrogeology model was found unacceptable, but regional elements of the model, combined with an empirical site and site region hydrologic flow model based on testing data, have adequately replaced the missing elements of the conceptual model. The numerical hydrologic flow model and selected PA results were reviewed during this phase of review and found to be adequate.

   The Castile and Brine Reservoir model was unacceptable because the characterization of probability of reservoir interception was not adequately supported. However, the sensitivity of the performance assessment calculations to that probability were so small that the use of either the maximum or minimum conceptually defensible numbers for the probability of an intercept did not affect the computed brine volumes entering the repository. Such findings of no consequence are based on the insensitivity of the performance assessment model to the results of the conceptual model implementation within conceptually defensible limits.

   Some models, as in the case of the Exploration Borehole model, were shown to be of no consequence on the basis of conceptual elimination of the impact of specific issues. In this case, the lower borehole plug could not be shown to persist over the life of the repository. The potential consequence in this case is flow down the borehole to the Bell Canyon Formation and through this formation to the boundary of the accessible environment. A side calculation was made which shows that transport in the Bell Canyon is low enough that no radionuclides would be expected to be transported to the accessible environment if the lower borehole plug fails.

   Additionally, models were found to be acceptable based on no consequence due to low drilling rates in early repository time (for example, the assumption of constant permeability for repository waste), and models were found to be acceptable based on no consequence due to the relatively low additional brine volumes they would provide to the repository (for example, the assumption that borehole penetrations in the operations and experimental areas can be ignored).

In general, when a model is found to be inadequate it affects a chain of models bearing on a release scenario. Tables 4.2 through 4.5(27) are intended to show the associations that lead to these shared impacts for the release scenarios or parts of release scenarios that the Panel believes are the most important. No attempt has been made to propagate the resulting uncertainties through the performance assessment calculations. Such an evaluation is beyond the scope of the Panel’s responsibilities. However, two generalities can be drawn with respect to overall model integration. First, the structure of model interactions used in the PA calculations seems reasonable. Second, the variability of sampled parameters in the PA plots appears to capture the distribution of those parameters, as suggested by an inspection of model uncertainties and the complexity of sequences of uncertain models. An example is the wide distribution of waste consumption completeness represented in Figures 4-1 and 4-2. This result is related to uncertainties in the supporting models, which themselves have wide distributions of uncertain parameters. The wide variability of waste consumption results (0% to 100% consumed) appears to adequately reflect the accumulation of conceptually implied uncertainties in the supporting database.

4.7. Summary

In general, the structure of model interactions seems reasonable. The mitigating effect of sampling of uncertain variables and the sensitivity structure of the PA model may have made the compound uncertainties of complex chains of models manageable in the final performance assessment result. It is important that the effects of all future model changes be evaluated in the context of the integration of all models. This is especially important in the cases of models that were found to be inadequate but of no consequence to performance assessment. Shifts in the results of adequate models may change the sensitivity of performance assessment to models presently thought to be inconsequential.

5.0 SUMMARY OF REMAINING ISSUES

This section presents a summary of the supplementary evaluations of the WIPP Conceptual Models Peer Review Panel performed between October and December 1996. As stated in the Panel's July 1996 report, over 20 years of scientific effort have been expended on the WIPP characterization project and it is beyond the scope of the Panel to summarize all of the positive work that has been performed. This section is not intended to be a reiteration of comments and discussions on the 24 individual conceptual models, but instead to provide an overview of conclusions from the supplemental evaluations. For those models found to remain inadequate, the key concerns of the Panel are summarized. Of the remaining models, those that were found to have important technical concerns, but were nevertheless found to be adequate on the basis of a lack of consequence in modeling results, are also identified and discussed. The Panel believes that the opportunity to reconvene and review the final conceptual models, as developed by the DOE and implemented in the October 1996 Compliance Certification Application for the WIPP, has been beneficial. The DOE responses to the Panel's initial concerns, the changes that were made to the models since the Panel's July 1996 report was prepared, and the results obtained from implementing the models in performance assessment have enabled the Panel to resolve its concerns regarding all but two of the 11 models that were previously identified as inadequate. In addition, the new information obtained during this supplemental evaluation did not change the Panel's previous conclusions for the 13 models that were found to be adequate.

New information relative to the conceptual models was reviewed by the Panel and the adequacy of each model was again evaluated using the same criteria as applied in the initial review. Of the 24 models, 22 were found to be adequate for implementation in performance assessment for the WIPP. For most of the adequate models, minor Panel concerns still remain and are identified in

Section 3 of this report and of the July 1996 Panel report. These concerns primarily address issues of documentation gaps and issues with features, events, or processes that were not considered sufficiently important to find the model inadequate. The 22 models found to be adequate are listed below, and those that have important residual technical concerns but were found adequate based on a lack of consequence are identified.

1. Disposal System Geometry
2. Culebra Hydrogeology*
3. Repository Fluid Flow*
4. Salado
5. Impure Halite
6. Salado Interbeds
7. Disturbed Rock Zone
8. Actinide Transport in the Salado
9. Units above the Salado*
10. Transport of Dissolved Actinides in the Culebra
11. Transport of Colloidal Actinides in the Culebra
12. Exploration Boreholes*
13. Cuttings/Cavings
14. Direct Brine Release*
15. Castile and Brine Reservoir*
16. Multiple Intrusions
17. Climate Change
18. Creep Closure
19. Shafts and Shaft Seals
20. Gas Generation
21. Dissolved Actinide Source Term
22. Colloidal Actinide Source Term

Models identified with an asterisk (*) in the foregoing list had important technical concerns but were found to be adequate on the basis of lack of significant consequence to performance assessment. A brief statement of the basis for approving each of these models is provided below.

Culebra Hydrogeology. No conceptual model was developed that explains the variability of hydrologic properties and processes in the Culebra at a scale that is useful in correlating those properties in the numerical hydrologic flow model. This model was found adequate because an extensive hydrologic testing data base and an adequate numerical flow model were developed as a substitute to the conceptual model for performance assessment purposes.

Repository Fluid Flow. The two-dimensional numerical implementation of the conceptual model may unrealistically restrict brine movement between the waste panels and the anhydrite interbeds in undisturbed scenarios because of the shallow depths of the borehole and shaft model cells. This model was found adequate because the error in computed flow volumes appears to be small in relation to the total volume of brine available to the undisturbed repository from early-time drainage of the DRZ.

Units above the Salado. The conceptual model and the testing data base are inadequate to exclude the Dewey Lake Redbeds and the Magenta Dolomites as potential transport pathways for radionuclides in the event of an intrusion. This model was found adequate because performance assessment results indicate that the quantity of radionuclides reaching the region above the Culebra is negligible even under low transmissivity assumptions for the Culebra, and the hydrologic characteristics of the Dewey Lake Redbeds and Magenta units are therefore of no consequence to performance assessment.

Exploration Boreholes. The assumption that shorter (40 m) borehole plugs beneath the repository horizon will have a useful life of at least 10,000 years has not been adequately supported. This model was found adequate based on an estimated groundwater travel time in the Bell Canyon to the accessible environment in excess of 10,000 years, and leakage of small amounts of repository brine into that formation would therefore be of no consequence to performance assessment.

Direct Brine Release. The direct discharge of waste materials to the ground surface through enhanced cavings-type borehole wall erosion accompanying discharge of Castile reservoir brine during drilling has not been included in performance assessment. This model was found adequate based on DOE calculations showing that the incremental waste volume released over the regulatory period is small compared with the volumes currently estimated in performance assessment modeling.

Radionuclide transport through entrainment of waste solids in rapid, two-phase liquid/gas releases during drilling was evaluated by DOE using the Spallings model. DOE concluded it was of lower consequence than entrainment of solids in gas releases. Although the approach taken and results obtained support a conclusion of no consequence, the technical adequacy of the Spallings model itself has been questioned by the Panel and this transport concern should be reevaluated at the time the Spallings model is determined to be appropriate for performance assessment.

Castile and Brine Reservoir. The expected probability of 8% of encountering pressurized brine beneath the waste panels has not been adequately supported. DOE suggested that analyzing the differences between E1 and E2 borehole intrusions provides a basis for estimating the consequences of assuming larger probabilities. This model was found adequate based on a review of such differences, which showed that effects on key repository conditions and surface releases were small and of low consequence to performance assessment modeling.

The Panel wishes to emphasize that models were necessarily found adequate because of lack of consequence on an essentially independent basis. Determining the cumulative effect of a series of low consequence events on overall performance assessment results requires additional performance assessment modeling because of the complex interrelationships among the models and stochastic processes. Although many of the technical concerns for models found adequate on the basis of a lack of significant consequence could each result in increasing releases by a small amount, the Panel believes that unless changes are made in the modeling assumptions that significantly affect key model elements, such as repository pressure or brine saturation histories, the applied institutional controls, or the role of the Culebra as a transport pathway, the cumulative effect of these concerns with models found adequate would not significantly affect the overall performance assessment results.

The two models found to be inadequate are presented in the following paragraphs with brief discussions of the key concerns identified by the Panel. Although the consequences of the Panel's technical concerns for these two models are not known, they are believed by the Panel to be consequential because they significantly impact the release processes found in modeling results to be most significant to overall system performance. Comprehensive discussions of the specific issues on these models that were not adequately addressed are presented in Section 3.

Spallings. The number of remaining concerns for the Spallings model is extensive. Although these concerns have been generalized below for purposes of this summary, they should not be considered the Panel's formal statements of the Spallings issues. Such statements are presented in Section 3.

- An adequate basis for the parameters used in the mathematical expression of the model has not been developed. In particular, ignoring capillary forces and correlating tensile strength with surface erosion have not been adequately supported by either first principles or experiment.

- The principal assumptions upon which the mathematical model is based appear to be incomplete. Waste removal by entrainment in gas flow is expected to occur in a highly dynamic sequence principally involving a spalling process driven by gas flow out of the porous waste normal to the eroded surface. Subsequent erosion by gas flow parallel to the eroded surface in pathways that are not expected to be the primary effect controlling the volume of spall, particularly in early times. In addition, the DOE has not adequately shown that the steady-state assumptions of the model conservatively approximate releases associated with the dynamic process of spall, and the possibility of transonic velocities has apparently not been considered.

- The experiments conducted in support of this model appear to have been designed to reproduce the assumptions upon which the model is based, rather than to simulate the dynamic repository system. Although the experiments may support adoption of specific model parameters, they do not demonstrate that the model adequately represents future states of the repository.

Chemical Conditions. The ability of the MgO backfill to perform as assumed in performance assessment remains a Panel concern, as described below.

- The ability of the MgO backfill to react completely and rapidly with CO_2 to buffer the chemical system and limit actinide solubilities has not been adequately substantiated by experimental physical results that correctly simulate conditions in the repository. Although the pH buffering assumptions are of considerable importance to many other conceptual models, the conclusion that the MgO will in fact perform as assumed has not been adequately supported.

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ACRONYMS

CCA	Compliance Certification Application
CCDF	cumulative complimentary distribution function
CFR	Code of Federal Regulations
CTAC	Carlsbad Technical Assistance Contractor
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEP	features, events, and processes
MB	marker bed
PA	performance assessment
SNL	Sandia National Laboratories
TP	test plan
TZ	Transition Zone
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant