II-G-21: Conceptual Models Second Supplementary Peer Review Report. January 1997

A Peer Review
Conducted By

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for

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EXECUTIVE SUMMARY

This report is a further 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. In its December 1996 supplementary report, the Panel stated that it continued to find two of the models not adequate to represent the future states of the repository. For the two models found not adequate, Spallings and Chemical Conditions, the Panel identified its remaining issues.

In this second supplementary report the Panel considers the U.S. Department of Energy's (DOE's) January 1997 responses to these remaining issues. The Panel's evaluation of these responses is presented in Section 3 of this report. Following review of the DOE responses, the Panel continues to find that the Spallings model and the Chemical Conditions model are not adequate to represent future states of the repository.

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 U.S. 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 U.S. 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's report identified 13 conceptual models as adequate for implementation in WIPP Performance Assessment and 11 as not adequate for implementation, based on information available to the Panel. The Panel's findings on each of the models judged inadequate were provided in the report. After that report was issued, DOE developed additional information, made changes to some of the conceptual models, and 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. In December 1996 the Panel issued a report supplementing the July 1996 report, that assessed the changes to the models and the DOE responses. The Panel found that two of the models, Spallings and Chemical Conditions, continued to be not adequate for implementation, and identified its remaining issues.

DOE again reconvened the Panel in January 1997 to review additional information developed in response to the remaining issues of the Panel on these two models. Therefore, this report is a further supplement to the Panel's July 1996 and December 1996 reports.

Section 2 of this report describes the process for this second supplementary review. Section 3 describes the additional information provided by DOE and the Panel assessment of that information.

2.0 SUPPLEMENTARY REVIEW PROCESS

The supplementary review was conducted in accordance with the DOE Quality Assurance requirements at Sandia National Laboratories (SNL) in January 1997. The Panel was provided responses to issues in its December 1996 report during briefings and in written material. This second supplementary review used the same review criteria to judge the acceptability of conceptual models as in the July 1996 report.

3.0 MODEL EVALUATIONS

3.1. Spallings

3.1.1. Model Description

No changes to this model were presented.

3.1.2. Review of Criteria

The review of criteria for the Spallings model remains unchanged.

3.1.3. Review of Responses to Panel Findings of December 1996

3.1.3.1. Summary of Findings

The Panel's December 1996 findings with regard to the Spallings model are summarized in Section 5.0 of that report and reproduced below. A complete statement of these findings is presented in Section 3.14 of the Panel's December 1996 supplementary report.

- 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 on 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 is 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 on 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.

3.1.3.2. Summary of DOE Responses to Findings

The DOE responded to the Panel's continued concerns through the SNL Spallings Release Position Paper (Hansen et al., 1997), oral presentations, subsequent discussions, and presentations of additional information. The position paper and initial oral presentations addressed the Panel's concerns by grouping them into the categories of waste characterization, analog comparisons, and conceptual model issues.

The waste characterization information included discussions of the physical condition of the waste that would be capable of release by a spallings process, the waste strength, and expectations of the significance of these results relative to spallings releases. Key points made were that any waste capable of spallings release would be at least partially degraded and have some moisture content, because without the presence of brine the elevated gas pressure that drives the spallings process could not exist. The model assumption that the degraded waste would have the average characteristics of a fine sand were considered by DOE to be highly conservative because not all of the waste would be expected to have degraded to that end state during the 10,000-year regulatory period. The 1 psi cementation strength assumed in the model was also considered conservative, and experimental results were presented showing that dried samples of sand that had been saturated with WIPP brine had indirectly determined tensile strengths that averaged 49 psi. Higher average tensile strengths ranging up to 114 psi were found when NaCl and MgO were added to the brine. The DOE concluded that waste strength dominates spallings releases, that the assumed waste strength of 1 psi was conservatively low, and that degraded waste will be heterogeneous and cemented, significantly impeding erosion.

Analog comparisons were presented for spallings-type releases induced by pressure surging to stimulate methane production from coal beds, industrial techniques to remove cuttings by air injection during borehole drilling, the downhole pressure gradient requirements for removal of hydrofracture proppants, wellbore stability and sand production as a function of fluid velocities, and the limitations of the borehole as a transport pathway. In addition, the mathematical model used by DOE to calculate spallings releases was compared to models for sediment erosion by moving fluids and to rock mechanics models for time-dependent tensile failure by fluid pressure gradients at the borehole boundary. The DOE believes that the available quantitative data (most notably from the coal bed methane analogs) suggest that the predicted WIPP spallings release volumes were probably larger than would actually occur. The DOE also believes that support was provided for the assumption that the void created by spalling will not continue to grow indefinitely, but will achieve an equilibrium state. Where quantitative data were not available, such as in the air drilling and hydraulic fracture proppant analogs, the comparisons were interpreted to indicate that the phenomenology included in the Spallings model is appropriate and probably conservative. Based on the comparisons with other models, the DOE concluded that the Spallings model has an appropriate functional form and is probably conservative.

The conceptual model and its mathematical expression were reviewed and confirmed by DOE to have an appropriate functional form for properly characterizing the end state of the spallings process in a slightly cohesive material. Experimental and analog evidence were used to support the assumption that the process reaches an equilibrium state, that the equilibrium state establishes the maximum volume of waste released, and that the equilibrium state determined by the erosional forces assumed in the model conservatively predicts the volume of waste released. In summary, the DOE response reiterated that cohesive forces dominate the calculated release, that many key assumptions in the mathematical formulation and parameterization are conservative, and that the releases predicted by the Spallings model are conservative.

In addition to the foregoing, model calculations of pressure transients in the repository were included in an oral presentation but not in the position paper. These analyses showed that depressurization of an isolated waste room is essentially complete within about 1,000 seconds (17 minutes) following borehole penetration of the room. The pressure profiles were interpreted by DOE to illustrate a gradual drawdown of pressure in the room, mitigating a possible spall event.

At the Panel's request, the DOE provided additional information in two areas: (1) a refined estimate of the capacity of the borehole to accommodate spallings releases under WIPP-specific conditions; and (2) an estimation of the pressure gradients required to cause tensile failure in the waste under WIPP-specific conditions. DOE's responses to these questions are summarized in the following paragraphs. The Panel also requested supplemental information in two additional areas that the DOE was unable to provide within the available schedule. These were (1) information that would further support the assumption that the equilibrium state determined by the model conservatively predicts the total volume of waste released in the spallings process; and (2) correlations between the cohesion of the degraded waste and the maximum cohesion found to exist in natural analogs where spallings releases are observed.

A more detailed analysis of the borehole capacity indicated that the borehole size was adequate to transmit spallings releases to the ground surface at the generation rates predicted by the model in the repository. The borehole was therefore determined to not be a limiting element in spallings releases.

A DOE team made preliminary scoping calculations using an elastic, Mohr-Coulomb model of waste that would be released by tensile failure using the pressure transient data described above and ranges of values for the key waste strength properties. Several cases were run in which assumed waste compressive strength and internal friction were varied. The details of these analyses are presented by Hansen and Knowles (1997). The results indicated that the volume released from a 1-m thick waste horizon (representing the fully compacted state of the waste) ranged from 0.37 to 0.59 m^3, and approached approximately 0.6 m^3 as the waste tensile strength approached zero. The limiting value of the release volume was determined by the fixed volume defined by the zone of tension around the borehole. In responding to additional questions posed by the Panel, the DOE emphasized that although the tensile failure results tended to support the model's conservatism by predicting a lower release volume, the tensile failure model results were considered to be scoping calculations providing order-of-magnitude approximations. The DOE also indicated that there were other factors likely to result in second order effects that were not incorporated into that model. Of particular significance was the consensus of the presenters that the continuing flow of gas through the waste following tensile failure could mobilize additional waste beyond the above quantities, through seepage and erosion processes.

3.1.3.3. Panel Review of Responses

The information presented by DOE in the aforementioned Position Paper and initial oral presentations was not considered by the Panel to adequately support the appropriateness of the Spallings model for use in performance assessment. While it is agreed that degradation of a significant part of the waste must occur to generate enough gas to cause a spallings release, implying that some moisture must be present, the cementation strength information presented to the Panel was determined from oven-dried samples with considerably lower moisture contents than would be expected under repository conditions. The ability of precipitates to cohesively bind a granular material may be significantly lower under partially saturated conditions than when the material is nearly dry. However, strength information for materials with higher degrees of saturation was not available. Although waste strength may be significant in estimating spallings releases, the assumed strength of 1 psi was not adequately shown by these experiments to be conservatively low under repository conditions. The Panel also agrees that the degraded waste will be heterogeneous and is likely to be at least partially cemented; however, the degree to which this would impede spallings releases was not demonstrated.

The analog comparisons presented appeared to have varying degrees of correlation with WIPP repository conditions, making it difficult for the Panel to directly use the comparisons in making definitive conclusions regarding the degree of conservatism in the model. The coal bed methane analogs were particularly useful in identifying limiting values of cohesion above which spallings-type releases are unlikely to occur and in identifying limiting sizes of artificially induced spallings cavities. However, without waste strength data to use as a basis, conclusions regarding spallings releases under WIPP repository conditions could not be made. Although the Panel agrees that the erosion phenomenon addressed in the Spallings model may occur under repository conditions, it was not adequately demonstrated to be of primary importance in spallings releases. The Panel has come to believe that the erosion process described in the Spallings model may actually be of secondary importance when compared with the waste volumes potentially released by tensile failure and seepage forces under high pressure gradients. Because of the foregoing concerns, the Panel could not conclude, based on the analog information presented, that the Spallings model was conservative. Conversely, the analog information was considered by the Panel to present information suggesting that the Spallings model is not appropriate.

The formulation of the Spallings model as a self-limiting process is based on an analytical statement of the relationships among void volume, gas velocity, and material strength. This formulation appears to be strongly contraindicated by analytical considerations of open completion of coal gas extraction wells. Such wells demonstrate that enlargement of a cavity ceases after a finite number of well pressure surges independent of the number, pressures, or duration of additional surges. The stabilization of cavity size despite the repetition, maintenance of, or increase in gas seepage pressures over time implies that cavity volume stability is related to stress conditions, and in particular to stress geometry and magnitude resulting from arching around the void. The Spallings model does not address the stress state around the wellbore and would not predict the stabilization of cavity volume under progressively increasing surge pressures. There is no mechanism or process in the Spallings model that would predict the cessation of cavity growth if gas seepage pressures were increased. For this reason it appears that the representativeness of the predicted releases due to spalling using the end-state modeling approach of the Spallings model cannot be evaluated because critical processes and local stress conditions are not specifically considered.

The Panel's belief that erosion is of secondary importance in spallings releases, and the lack of a critical comparison between the relative roles of erosional versus tensile and seepage failure mechanisms in such releases, makes it difficult for the Panel to support the credibility of the Spallings model as currently configured. Because the credibility of the basic model assumptions are being seriously questioned, demonstrations that key aspects of the model and its parameterization are conservative cannot be interpreted to conclude that the present model conservatively predicts the future states of the repository. Although erosion phenomena may be a later mechanism acting for dislodging waste in a spallings release, the early-time tensile failure of waste under high, transient pressure gradients may be capable of removing waste particles that would not have been predicted to be removed under the steady-state assumptions of the Spallings model, leading to underestimating the release volume. Because of these concerns, the Panel does not believe that it has been adequately demonstrated that the equilibrium state determined by the erosional forces assumed in the model conservatively predicts the volume of waste released.

Model calculations of pressure transients were new and helpful to the Panel in determining the time duration over which a spallings release may occur. However, the Panel could not concur with DOE's conclusion that the pressure gradients were sufficiently low to mitigate a spall event because of the results of the tensile failure analysis.

The new tensile failure results presented by the DOE provided insights into a failure mechanism considered by the Panel to be significant to the spallings process. The preliminary nature of the calculations, the possibility that an additional volume of waste would be released by seepage forces from subsequent gas flow in the porous waste, and the lack of information on associated effects (such as waste heterogeneity, stability of the waste cavity, the presence of moisture in the waste, and coupling between the cavity size and the stress and pore pressure fields) did not provide an adequate basis for the Panel to conclude that the spallings release volumes presented in the CCA were conservative. The tensile failure calculations did emphasize, however, the complexity of the spallings process, and are useful because they represent a phenomenologically appealing, more classical approach to such calculations. The tensile failure mechanism is more consistent with the mechanisms observed in the coal bed methane analogs.

In summary, the additional analog, waste strength, model descriptions, and calculational information provided to the Panel were either not adequately correlated with WIPP repository conditions or were not sufficiently complete or supported to provide the Panel with an adequate basis for determining that either the Spallings model or the results obtained from that model were conservative.

3.2. Chemical Conditions

3.2.1. Model Description

No changes to this model were presented.

3.2.2. Review of Criteria

The review of criteria for Chemical Conditions remains unchanged.

3.2.3. Review of Responses to Panel Findings of December 1996

3.2.3.1. Summary of Findings

In summary, the Panel's December 1996 findings were that the ability of the MgO backfill to react completely and rapidly with CO_2 to buffer the chemical system and limit actinide solubilities had 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 had not been adequately supported.

3.2.3.2. Summary of DOE Responses to Findings

The DOE provided a summary of a calculation of cumulative complimentary distribution functions (CCDFs) intended to show the importance of MgO on repository system performance. The CCDFs without MgO present showed increased releases as compared to those with MgO present. Releases with MgO present predominantly result from cuttings/cavings and spallings, but without MgO present the contribution from direct brine release significantly increases. DOE indicated that the mean CCDF without MgO present still remains lower than the EPA limit. DOE also provided additional results of experiments with MgO from the ongoing test program.

3.2.3.3. Panel Review of Responses

The Panel examined the various assumptions and parameters that were used in computing the CCDFs without MgO present and believes that the differences in CCDFs with and without MgO represent the degree of importance of the chemical getter to repository performance. The Panel believes that adding the MgO getter will positively benefit and not detract from the performance of the repository. However, the Panel identified a few additional factors that would need to be included for such a CCDF calculation to be definitive, including the effect on corrosion rates, gas generation rates, and pressures over time. However, inasmuch as calculations without MgO show that direct brine release would become an important contributor to overall releases, the Chemical Conditions model has been shown to be a significant contributor to the future states of the repository.

Furthermore, the additional results from the ongoing test program, while interesting, are not sufficient to resolve the Panel's concerns with the issue of MgO effectiveness. The results presented to the Panel concerned the effect of CO_2 diffusion into the MgO pellets. Test runs of 4 days followed by dye infusion indicate that in 24 hours the dye will travel through the reaction rims to the center of the pellet. However, the test runs were short, the reaction rims were thin and may not have been fully formed, and there were no transient information or bounding calculations to support a conclusion regarding the role of the reaction rims in impeding CO_2 diffusion. Information was not available on the diffusion rate of CO_2 into the MgO pellets, especially as a function of reaction rim thickening. The Panel believes that the aforementioned test program has not sufficiently progressed to provide a definitive verification that the MgO will perform as planned under repository conditions. Therefore, as a result of the Panel's review of the added information, the conclusion remains that the Chemical Conditions model is not sufficiently developed to adequately support performance assessment.

3.3. Summary

In summary, the Panel concludes that the Spallings model and the Chemical Conditions model remain inadequate to represent the future states of the repository.

4.0 REFERENCES

Hansen, F.D., M.K. Knowles, and T.W. Thompson, 1997. Spallings Release Position Paper. Prepared for the U.S. Department of Energy Carlsbad Area Office by Sandia National Laboratories, Albuquerque, NM. 17 January 1997.

Hansen, F.D., and M.K. Knowles, 1997. Response to inquiries by CMPRP for spallings. Memorandum to M.S.Y. Chu, Sandia National Laboratories, Albuquerque, NM. 23 January 1997.

ACRONYMS

CCA	Compliance Certification Application
CCDF	cumulative complimentary distribution function
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
SNL	Sandia National Laboratories
WIPP	Waste Isolation Pilot Plant

APPENDIX A - SIGNATURE PAGE

I acknowledge by my signature below that I concur with the findings and conclusions documented in this Conceptual Models Peer Review Second Supplementary Report.

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