The Application of Performance Assessment to Make Regulatory and Operational Changes in an Operating Nuclear Waste Repository - 8339

Russ Patterson
Department of Energy, Carlsbad Field Office
4021 National Parks Highway, Carlsbad, NM 88220

Ross Kirkes
John Hart and Associates, P.A.
2815 Candelaria Road, NW
Albuquerque, NM 87107

ABSTRACT

This paper describes how performance assessment (PA) is used to support changes to the regulatory basis of the Waste Isolation Pilot Plant (WIPP). The WIPP, located near Carlsbad, New Mexico is operated by the U.S. Department of Energy (DOE) as the nation's only deep geologic repository for the disposal of transuranic nuclear waste. In 1998, the Environmental Protection Agency (EPA) certified that the WIPP met the performance requirements of 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.* [1] A PA analysis of long term (10,000 year) repository performance successfully demonstrated that the probability and consequences of potential long-term releases of radionuclides to the accessible environment would be well below the established limits. These results were key in obtaining WIPP's initial certification, allowing the first shipment and disposal of nuclear waste in March of 1999.

As disposal operations have taken place over the last eight years, changes have been identified in the regulatory and operational realms of the facility that would enhance waste disposal efficiency. Such changes, however, cannot be made without prior consent of the EPA. Therefore, changes planned by the DOE must be thoroughly described and supported by varying degrees of the same type of analyses that were conducted to demonstrate the WIPP's containment capabilities as presented in the initial compliance application submitted to EPA in 1996. Such analyses are used to identify the impacts or benefits of implementing the planned change. The DOE has successfully used performance assessment analyses for the approval of changes such as:

1) the disposal of super-compacted waste forms, and;
2) the adoption of new parameters and modeling assumptions

In some cases the planned changes are simpler in nature than those listed above, and therefore only require targeted or simplified PA analyses to demonstrate the effect on performance. Targeted analyses have been used to successfully gain approval of the following:

1) a reduction in the amount of magnesium oxide (MgO) chemical buffer backfill that must be emplaced in the repository
2) a change in the repository mining/disposal horizon

In addition to these approved changes, the DOE has used PA analyses to support the following planned change requests that await EPA's approval:

1) panel closure redesign
2) further reduction in the MgO-to-waste ratio

Finally, this paper will discuss some of the changes that the DOE is currently preparing and plans to submit to the EPA for approval in the near future. This paper will describe how a set of analytical tools initially used to open the WIPP continues to have a role in making the repository more efficient and adaptable as variations in waste streams, operational demands, and other dynamic forces change the operating environment over time.

WIPP PA AND THE COMPLIANCE BASELINE

The DOE has used PA as an analytical tool to predict the long-term performance of the WIPP repository since the early 1990s. [2,3] During the development of the WIPP PA, the models that comprise the WIPP PA system were critiqued by external groups, peers, and WIPP scientists. After several iterations of review and enhancement, the PA system was determined by the DOE and the Scientific Advisor (Sandia National Laboratories (SNL), or "Sandia"), to be robust enough to proceed with calculations suitable for submission to the EPA in a demonstration of compliance with the long-term containment requirements of 40 CFR Part §191.13. These calculations were included in the DOE's 1996 Compliance Certification Application (CCA), [4] and demonstrated that the WIPP complied with the containment requirements of 40 CFR §191.13 by a demonstrable margin.

The basis and results of these performance predictions were the focus of intense review by the EPA. During this review, the EPA took exception to some of the input parameter values used in the CCA PA, and requested changes to values of their preference. PA calculations were again performed using these EPA-mandated parameter values. This PA was termed the "Performance Assessment Verification Test" or "PAVT." [5] The PAVT results were very similar to those presented by the DOE in the CCA, and verified the WIPP's compliance with the long-term disposal requirements of 40 CFR Part 191. The new calculations and results of the PAVT are considered to be the basis of EPA's certification decision that was issued in May 1998 and were considered the "compliance baseline" at that time. Based on this certification, the disposal of transuranic (TRU) waste at the WIPP began in March 1999. Thus, the compliance baseline defines the operational boundaries within which the DOE operates the WIPP, and departures from this baseline must follow a specific protocol.

PROPOSED CHANGE REQUEST PROCESS

The Certification Criteria of 40 CFR §194.4 specify the process for making changes to the compliance baseline. Changes are approved based on a graded approach, where "significant" changes are reviewed and approved through a rulemaking process much the same as the initial certification. [6] As the regulator, the EPA determines the significance of a given change. Changes of lesser significance are approved through a thorough review process, but do not require a formal rulemaking process where public comments on the proposed actions are solicited in the Federal Register. Instead, these "non-significant" changes are processed through: 1) official correspondence between the DOE and the EPA, 2) formal meetings in which the public may attend, and 3) informal "technical exchanges" where technical experts discuss details of the proposed change and any impacts to performance or the specific models that predict performance. To date, the EPA has approved several changes through this process, and no changes have been deemed sufficiently significant to require rulemaking.

PROPOSED CHANGE REQUESTS

While the EPA will ultimately decide if a given change is significant or not, the DOE must also determine the significance of the change, as it is the DOE and its contractors that prepare the initial proposal requesting permission from the EPA to implement the change. The planned change request (PCR) is transmitted by the DOE to EPA and describes the change in detail, and provides any analyses necessary to demonstrate the impacts, if any, on repository performance. In addition, the PCR identifies all components of the compliance baseline that are affected by the change. Such components may include PA parameter values, PA conceptual and computational models, or the change may only affect assumptions that relate to these components. It is in the best interest of the both DOE and the EPA that the PCR accurately and thoroughly represent the impacts of the change to the compliance baseline. In this way, EPA may approve the request in a timely manner. Furthermore, underestimating the significance of a change may result in EPA upgrading the change to one that requires rulemaking, significantly increasing the time before the change may be implemented.

As part of EPA's review of a given change, questions often arise regarding the impact of the change to predicted performance of the repository. "How does this change affect performance?" is a relevant and important inquiry. In response to this question, the DOE and Sandia may develop a modified PA that represents the essence of the change within the relevant aspects of the PA system model, holding the unaffected aspects of the model static; i.e., consistent with the compliance baseline. In this case, the entire suite of PA models will be run, culminating with the construction of complimentary cumulative distribution functions (CCDFs). The CCDFs quantitatively and visually represent the predicted performance of the repository with respect to the EPA's allowable release limits. These PA results are then compared to the PA baseline results, and the impact of the change may be analyzed and described.

For some changes, it is neither necessary nor appropriate to run the entire suite of PA models and codes. For example, the impact of most changes is so small that it cannot be detected on the overall measure of WIPP performance (i.e., the CCDF). In such cases, only the intermediate models are exercised as it is often here that the nuances of a given change may be seen and evaluated. In this case, intermediate model results from the modified or "test" case are compared with the corresponding intermediate model results from the compliance baseline.

SUPERCOMPACTED WASTE

One of the most extensive PCRs to date has been that requesting permission to dispose supercompacted waste from the Advanced Mixed Waste Treatment Plant (AMWTP) at the Idaho National Environmental Engineering Laboratory. Supercompacted wasted consists of 55-gallon steel drums of debris waste compressed vertically, resulting in flattened cylinders called "pucks." These pucks are placed in 100-gallon steel drums for shipping and disposal in the WIPP. Each 100-gallon drum may contain 3-5 compressed "pucks." In this PCR, the DOE and Sandia evaluated the impacts of emplacing supercompacted waste in the WIPP. This dense waste form had not been included in the CCA inventory, and therefore was not represented in the compliance baseline. For this PCR, the DOE initially submitted an analysis that demonstrated that the radiological characteristics were very similar to that already accepted in other waste streams, and that from a radiological perspective, the waste fit within the current baseline. The elevated concentration of steel present in the compacted containers was not thought to be of concern because steel has a beneficial effect on repository chemistry, and its physical effects (from a containment perspective) are conservatively ignored in PA. However, the EPA requested additional analyses that evaluate the physical characteristics of the waste more fully.

To address this request, the DOE and Sandia constructed a PA (called the AMW PA) that looked deeper into the various sub-models that represent the overall WIPP PA. Porosity of the disposal rooms was to be further investigated, as the porosity could be affected by stiff columns of supercompacted waste that resist room closure due to salt creep. Because supercompacted waste may also contain higher concentrations of cellulosic, plastic, and rubber, the quantities of gas generated through biodegradation were analyzed as well. Because the WIPP disposal room model is coupled and interdependent upon these and other factors, it was also important to evaluate each of the release mechanisms separately (i.e., cuttings, cavings, spallings, and direct brine release associated with an inadvertent human intrusion event).

The results of the AMW PA were compared to the PAVT, the compliance baseline at that time. These results are shown in Figure 1 and illustrate that while the addition of a new waste form such as supercompacted waste may seem important, there is a very small effect on PA results. [7]

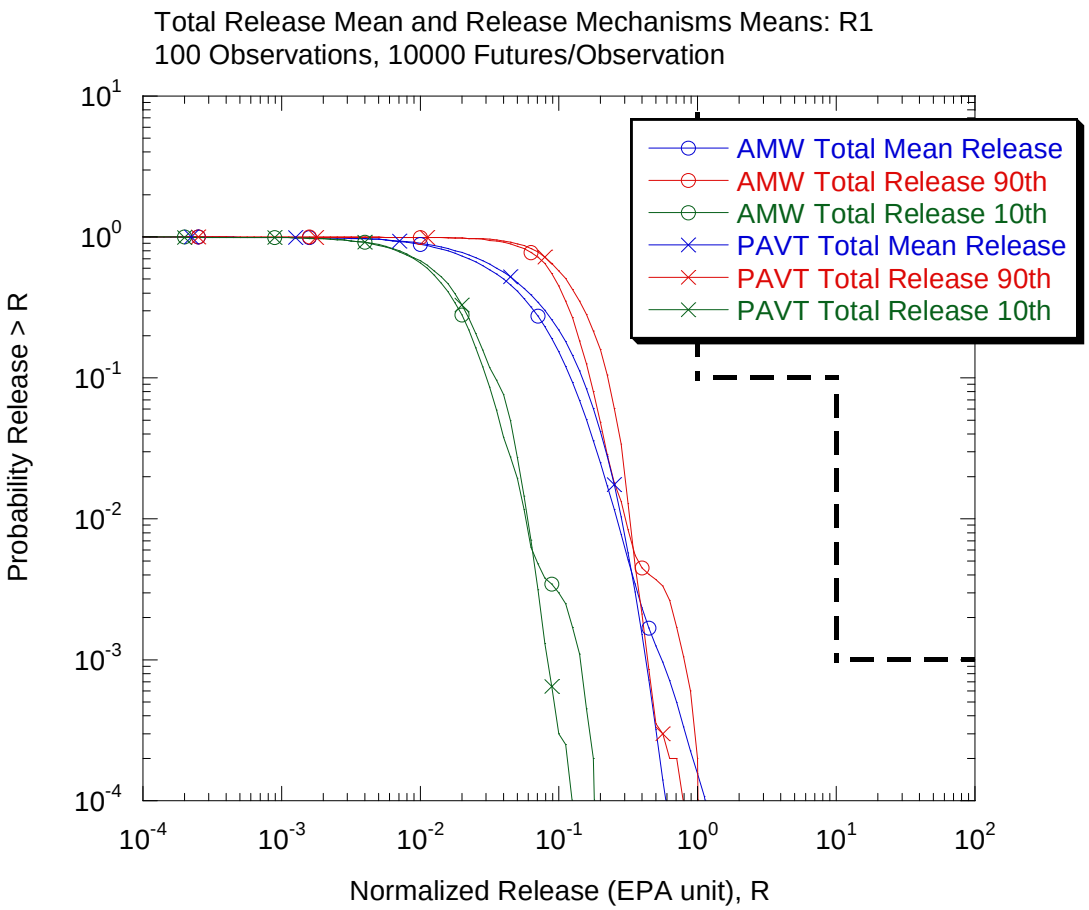

Figure 1. Comparison of AMW PA and PAVT (Replicate R1) Total Releases. [8]

Based largely on the AMW PA and its analyses, the EPA granted permission to dispose super-compacted waste in the WIPP March 2004. [9]

TECHNICAL BASELINE MIGRATION

After the completion of the CCA, the technical understanding of the physical and chemical processes that control releases to the environment advanced. In addition, post-submittal analyses and sensitivity studies identified several minor errors in the CCA and PAVT calculations. Therefore, the Technical Baseline Migration (TBM) was devised to consolidate the improvements and corrections in conceptual models and parameters in order to advance the WIPP's PA baseline.

Among the changes were:

- Incorporation of the Option D panel closure
- Minor changes to the physical and chemical processes that control releases
- Correction of minor errors found in CCA and PAVT calculations

In the CCA, the DOE presented four options for panel closure design. In their certification of the WIPP, EPA mandated the use of Option D as Condition 1 of the

Certification Decision. [1] However, a generic panel closure was represented in the CCA PA. In correspondence discussing the schedule for WIPP's first recertification and the content of the TBM, the EPA suggested that the Option D closure be represented in PA. [10] as it was believed that the Option D closure is more robust and would result in improved repository performance.

Results of the TBM PA show that there were no significant effects from refining the modeling grid, or from correcting input errors. [11] However, the calculations show that the Option D panel closure changes the dynamics within the repository by altering gas and brine flow patterns between adjacent waste panels. Because the Option D closure has lower permeability, less brine flows into the waste region of the repository, lowering saturations. One effect of lower saturations is to decrease some release mechanisms, such as direct brine release. However, despite these drier conditions, gas is still produced in these regions, and gas pressures can actually be higher than those in the PAVT. This is because the lower permeability closure restricts gas flow to other regions of the repository, thus maintaining slightly higher pressures. But, because direct brine release is one of the most insignificant release mechanisms, total releases are not appreciably different than those modeled in the PAVT.

The TBM results were provided to the EPA in a series of technical discussions, and became the basis of PA calculations presented in the CRA-2004. [12]

ELIMINATION OF MAGNESIUM OXIDE MINI-SACKS

As mentioned earlier, there are cases when changes do not require that all PA codes be run. Rather, intermediate models may be analyzed to determine the impact of a given change. In July 2000, the DOE requested that small bags of magnesium oxide (MgO) (called "mini-sacks") be eliminated from the waste-emplacement configuration. [13] DOE proposed to continue to emplace large sacks on top of stacks of waste in the repository, but the mini-sacks presented an operational burden and a worker exposure hazard. The quantity of the proposed MgO reduction was about 15% of that described in the compliance baseline.

To demonstrate that this reduction would not adversely impact performance, the DOE and Sandia described the gas generation model used in PA and demonstrated that the model was sufficiently conservative to account for a reduction in MgO of 15%. A "safety factor" was described that showed that even with the reduction of MgO in the repository, that there was up to 3.2 times more MgO than necessary.

The EPA reviewed this information and approved the elimination of MgO mini-sacks from the repository in January 2001. [14]

CHANGE IN MINING HORIZON

In June 2000, the DOE submitted a planned change to raise the repository horizon in Panels 3, 4, 5, 6, and 9 by approximately 2 m (6.6 ft) so that the back (roof) would be at

Clay Seam G. [15] Positioning the back at Clay Seam G results in a more stable back configuration and improves repository ground conditions. Raising the horizon also reduces the rate of roof-beam deformation and slows the development of fractures, thus reducing risks during mining and waste handling in the underground repository. This change also results in less maintenance being required to assure acceptable ground conditions. In a letter dated August 2000, the EPA agreed that this change will enhance operational safety without significantly affecting the long-term performance of the facility. [16]

Later, as part of the Salado Flow Peer Review in February 2003, the DOE performed an impact assessment on the possible effects of the horizon change to PA to better demonstrate the minimal impact of this change on long-term performance.

Two possible effects of this change on the results of PA were considered in this assessment. First, it was considered that the horizon change might influence the creep-closure porosity surface calculated by the code SANTOS and used by the BRAGFLO code to determine the porosity of the waste rooms. This possibility was considered by simulating creep closure around a WIPP disposal room raised to Clay Seam G. [17] The resulting Clay G porosity surface was then compared with the original porosity surface, which was used in the CCA. The differences were shown to be so minor that long-term performance would not be significantly altered. [18]

The second effect that was considered was the possibility that the thickness of the upper and lower disturbed rock zone (DRZ), as represented in the BRAGFLO grid, might change due to the horizon change. To assess whether such a change would affect long-term performance, Sandia ran a single replicate of 100 undisturbed BRAGFLO vectors in which the total pore volume in the DRZ was adjusted to account for the thickness changes. [19] Pressure and saturation results within the waste regions were compared to results assuming the original DRZ thicknesses. It was concluded from these comparisons that the effects of the DRZ thickness changes were very minor and not at all significant for long-term repository performance. [20]

The results of the impact assessment were presented to the Salado Flow Peer Review panel in February 2003. The panel accepted the position that the repository horizon change was adequately represented by the impact assessment and need not be implemented explicitly in the BRAGFLO grid for PA calculations. [21] Based on the results of this impact assessment and the acceptance of the Salado Flow Peer Review, the DOE determined that it is not warranted to include the change in the repository horizon to Clay Seam G explicitly in the BRAGFLO grid.

CHANGES CURRENTLY PENDING EPA DECISION – PANEL CLOSURES

As mentioned in a previous section, the current PA baseline represents the Option D panel closure, as dictated by Condition 1 of WIPP's initial certification. However, installing the Option D closure presents significant costs and operational complexity, while providing no beneficial effect on performance. To the contrary, the TBM results

presented above show that some release mechanisms actually have greater predicted releases, due to potentially higher repository pressures associated with the Option D closure. As such, the DOE has proposed to the EPA that less robust panel closures be installed in the WIPP.

Because previous baseline calculations exist that represent both high- and low-permeability closures (i.e., the CCA and TBM PAs, respectively), arguments have been prepared and submitted to the EPA that demonstrate the benefits of installing a lower permeability closure. However, a ruling in favor of a new panel closure design by the EPA is only one required regulatory approval. The primary role of the panel closure is to serve as a barrier during repository operations that protects workers and the public against volatile organic chemicals (WIPP is co-regulated as a hazardous waste facility under the Resource Conservation and Recovery Act [RCRA]). As such, the New Mexico Environment Department (the implementing agency for RCRA in New Mexico) must also approve this change prior to implementation.

Due to schedule conflicts and complications, the Option D proposal has been withdrawn from EPA's consideration. Details on the status of this change are provided in another paper presented at these proceedings.

CHANGES PENDING EPA DECISION – FURTHER REDUCTION IN MAGNESIUM OXIDE

As mentioned above, the DOE successfully demonstrated that WIPP performance would not be affected by the elimination of MgO mini-sacks. [13] In April 2006, the DOE submitted a PCR that would further reduce the amount of MgO in the repository. [22] This PCR used a risk-based approach to demonstrate that the risks associated with transporting and emplacing large quantities of MgO were not offset by an increase in WIPP performance associated by the required excess amount of MgO. EPA did not accept this argument and requested further investigations into the uncertainties associated with the repository chemistry and gas generation models within WIPP PA. [23]

The DOE responded with several targeted and combined analyses that identified and addressed the uncertainties associated with the repository chemistry conceptual model and its representation of gas generation and the expected role of MgO. Details on the status of this change are provided in another paper presented at these proceedings.

UPCOMING CHANGES – SHIELDED CONTAINERS

The DOE submitted in November 2007 a proposal to package and emplace a portion of the Remote-Handled (RH) TRU Waste in shielded containers at the WIPP. The use of the shielded containers will enable DOE to expedite the cleanup of various TRU waste sites by significantly increasing the rate at which portions of the RH waste can be received and emplaced at the WIPP. It is proposed that the shielded containers be managed and emplaced on the floor of the repository in a fashion similar to what is currently used for Contact Handled (CH) TRU waste. The robustness of the containers has been

demonstrated by passing the Department of Transportation (DOT) and the Nuclear Regulatory Commission (NRC) drop tests.

Candidate RH waste streams for shipment and disposal in shielded containers will be selected based on the requirement to keep the radiation surface dose rate below 200 millirems per hour (mrem/h). These waste streams and containers will remain designated as RH waste, although they will be emplaced as shielded containers on the floor and meet the surface dose requirement for CH waste.

As part of this proposed change, a PA analysis was conducted to evaluate the effect of emplacing shielded containers in the disposal rooms on long-term repository performance. [24] Bounding assumptions were used to evaluate the effects of emplacing various fractions of the RH waste in shielded containers in the repository. Results show that the repository performance is not adversely affected, and the WIPP will continue to comply with the containment requirements by a demonstrable margin.

For this analysis, the primary modification to the PA baseline is the re-location of the RH waste from the boreholes in the walls of the repository to the floor of the repository. This also requires the creation of new parameters to represent this change in certain PA models. These new parameters represent the fraction of repository volume occupied by waste and the area for RH waste disposal in the walls of the repository for scenarios that model the inclusion of shielded containers. It was determined that no other changes to the baseline were necessary to represent the presence of shielded containers, as the inventory has not changed, merely the placement of the RH waste within the repository.

The results of this analysis conclude that the packaging and emplacement of RH waste in shielded containers has no discernable impact on releases. This statement applies to all release pathways: cuttings and cavings, spallings, direct brine releases, groundwater releases, and total releases. This analysis is currently being reviewed by the EPA

CONCLUSION

The DOE uses PA on a cyclic basis to perform calculations for the Compliance Recertification Application, which must be submitted to the EPA every five years to demonstrate continued compliance with the containment requirements of 40 CFR §191.13. During interim periods between recertification applications, the DOE has identified areas where operational efficiencies could be realized. Because the WIPP operates under a strictly defined compliance baseline, changes that implement these operational efficiencies must first be proposed to the EPA. Requests for changes to this baseline must evaluate the effect the proposed change has on performance predictions. In some cases, these evaluations only require the analysis of discrete components of the PA system, while in other cases, the utilization of the entire PA system must be used to determine the impact of a change, depending on the complexity and breadth of the change, and requests by the regulator. Since the WIPP's initial certification in 1998, the DOE has effectively used PA as a tool to evaluate the effects proposed changes may have on the predicted performance of the WIPP repository. Approval of these changes by the

EPA has allowed the DOE to make changes that enhance worker safety and reduce potential occupational exposures, streamline and simplify the PA baseline, and meet DOE disposal objectives from an overall waste complex perspective.

ACKNOWLEDGEMENTS

This research is funded by WIPP programs administered by the Office of Environmental Management (EM) of the U.S. Department of Energy. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy National Nuclear Security Administration under Contract DE-AC04-94Al85000.

REFERENCES

1) U.S. Environmental Protection Agency (EPA), 40 CFR Part 194: "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the Disposal Regulations: Certification Decision; Final Rule." Federal Register, Vol. 63, No. 95, pp. 27396, May 18, 1998, Office of Radiation and Indoor Air, Washington, D.C., (1998).

2) Sandia National Laboratories, "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 1: Methodology and Results," SAND91-0893/1, Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM, (1991).

3) Sandia National Laboratories, "Preliminary Performance Assessment for the Waste Isolation Pilot Plant," December 1992, SAND92-0700, Vols. 1 - 5, Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM, (1992-1993).

4) U.S. Department of Energy (DOE), "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant," DOE/CAO-1996-2184, October 1996, Carlsbad Field Office, Carlsbad, NM, (1996).

5) U.S. Environmental Protection Agency (EPA), Letter from R. Trovato, Director, Radiation and Indoor Air, to G. Dials, Manager, Carlsbad Area Office transmitting parameters for the performance assessment verification test, dated March 19, 1997, U.S. Air Docket A-93-02, item II-I-27. Washington, D.C.

6) United States Code, Title 5, Section 553.

7) U.S. Department of Energy (DOE), Letter from Dr. I. Triay, Manager, Carlsbad Field Office to F. Marcinowski, Director, Radiation Protection Division, transmitting DOE evaluation of the impact of supercompacted

wastes from the Advanced Mixed Waste Treatment Project (AMWTP) on the long-term performance of the WIPP, December 10, 2002. Carlsbad, NM.

8) Dunagan, S., Memorandum from S. Dunagan to D. Kessel. "Comparison of AMW and PAVT Results, Revision 1," January 16, 2004, Sandia National Laboratories, Carlsbad Programs Group, Carlsbad, NM.

9) U.S. Environmental Protection Agency (EPA), Letter from F. Marcinowski, Director, Radiation Protection Division to R. Detwiler, Acting Manager, Carlsbad Field Office approving the disposal of compacted waste in WIPP, dated March 26, 2004, Washington, D.C.

10) U.S. Environmental Protection Agency (EPA), Letter from F. Marcinowski, Director, Radiation Protection Division to Dr. I. Triay, Manager, Carlsbad Field Office regarding recertification and the Technical Baseline Migration, dated August 06, 2002, Washington, D.C.

11) Hansen, C., C. Leigh, D. Lord, and J. Stein. "BRAGFLO Results for the Technical Baseline Migration, Revision 0," Sandia National Laboratories, Carlsbad Programs Group, Carlsbad, NM, (2002).

12) U.S. Department of Energy (DOE), "Title 40 CFR Part 191 Compliance Recertification Application for the Waste Isolation Pilot Plant," DOE/WIPP 2004-3231, 10 vols., Carlsbad Field Office, Carlsbad, NM, (2004).

13) U.S. Department of Energy (DOE), Letter from Dr. I. Triay, Manager, Carlsbad Area Office to F. Marcinowski, Director, Radiation Protection Division, transmitting DOE request for the elimination of magnesium oxide mini-sacks from the WIPP repository, dated July 21, 2000, Carlsbad, NM.

14) U.S. Environmental Protection Agency (EPA), Letter from F. Marcinowski, Director, Radiation Protection Division to Dr. I. Triay, Manager, Carlsbad Field Office approving the elimination of magnesium oxide mini-sacks from the WIPP repository, dated January 11, 20001, Washington, D.C.

15) U.S. Department of Energy (DOE), Letter from Dr. I. Triay, Manager, Carlsbad Field Office, to Mr. F. Marcinowski, Director, Radiation Protection Division proposing to raise back to Clay Seam G, dated June 26, 2000, Carlsbad, NM.

16) U.S. Environmental Protection Agency (EPA), Letter from F. Marcinowski, Director, Radiation Protection Division to Dr. I. Triay, Manager, Carlsbad Field Office transmitting decision on Clay Seam G proposal, dated August 11, 2000, Washington, D.C.

17) Park, B.Y., “Analysis Plan for Structural Evaluation of WIPP Disposal Room Raised to Clay Seam G, Rev 1,” AP-093, Sandia National Laboratories, Carlsbad, NM, (2002).

18) Park, B.Y., and Holland, J.F.," Analysis Report for Structural Evaluation of WIPP Disposal Room Raised to Clay Seam G," SAND 2003-3409, Sandia National Laboratories, Carlsbad, NM, (2003).

19) Stein, J.S., and Zelinski, W., “Analysis Plan for the Testing of a Proposed BRAGFLO Grid to be used for the Compliance Recertification Application Performance Assessment Calculations,” AP-106. Sandia National Laboratories, Carlsbad, NM, (2003).

20) Stein, J.S., and Zelinski, W., “Analysis Report for: Testing of a Proposed BRAGFLO Grid to be used for the Compliance Recertification Application Performance Assessment,” Sandia National Laboratories, Carlsbad, NM, (2003).

21) Yew, C., Hanson, J., and Teufel, “Spallings Conceptual Model Peer Review Report,” Time Solutions Corp., Albuquerque, NM, (2003).

22) U.S. Department of Energy (DOE), Letter from Dr. D. Moody, Manager, Carlsbad Field Office, to Mr. E. Cotsworth, Director, Radiation Protection Division proposing to further reduce the amount of magnesium oxide backfill in the repository, dated April 10, 2006, Carlsbad, NM.

23) U.S. Environmental Protection Agency (EPA), Letter from B. Gitlin, Acting Director, Radiation Protection Division to Dr. D. Moody, Manager, Carlsbad Field Office requesting additional analyses to support the reduction in magnesium oxide in the repository, dated April 28, 2006, Washington, D.C.

24) Dunagan, S. C., G. Roselle, E. Vugrin and J. Long, “Analysis Report for the Shielded Container Performance Assessment, Revision 1,” Sandia National Laboratories, Carlsbad Programs Group, Carlsbad, NM, (2007).