5. Session 3: Role & evolution of the safety case when moving to implementation

Changes in the performance assessment at WIPP over time

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Abstract

The Waste Isolation Pilot Plant (WIPP) in southeast New Mexico, United States, has been accepting defense transuranic waste for permanent disposal since 1999. Before the first compliance certification application (CCA) for certification (i.e. licensing) by the US Environmental Protection Agency (EPA), the US Department of Energy (DOE) used a performance assessment (PA) to demonstrate compliance with EPA's long-term radioactive waste disposal standards. The PA has changed over time to address changes in waste forms, containers, radionuclide inventories, facility design and operations, and our understanding of the disposal system. With each change, the DOE has had to demonstrate continued compliance of long-term performance with the EPA's disposal standards. Three Case Studies are used to illustrate how the PA has been used and changed to address changing repository circumstances. Case Study 1 describes the selection of magnesium oxide (MgO) backfill as an engineered barrier to lower dissolved actinide concentration by consuming carbon dioxide (CO_2), buffering pH, and reducing free water in the repository. Case Studies 2 and 3 exemplify the application of the regulatory-driven Planned Change Request (PCR) process to changes in facility design and operation by the DOE.

Introduction

The Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, United States is a deep geological repository designed for the safe disposal of defense-related transuranic (TRU) radioactive waste. The repository, which is owned by the US Department of Energy (DOE), is situated 655 meters deep within a bedded Permian salt formation (Salado Formation). The repository's post-closure performance is regulated under the WIPP Land Withdrawal Act (LWA), which mandates compliance with applicable environmental protection laws and regulations, implemented by federal and state agencies. Before WIPP could accept any TRU waste, the US Environmental Protection Agency (EPA) had to certify that the disposal system complied with its long-term radioactive waste disposal standards. The demonstration of compliance was based, in part, on the results of a 1996 performance assessment (PA) submitted in the first Compliance Certification Application (CCA) (DOE, 1996). As required by regulation, the PA calculates potential releases that could occur,

including those after a future inadvertent intrusion via oil or gas drilling. Actinides could be transported in groundwater to the overlying Culebra Dolomite aquifer and the accessible environment.

Per the LWA, the DOE must submit a compliance recertification application (CRA) every five years to demonstrate continued compliance with the EPA's disposal standards. In a CRA, the PA is updated to reflect changes in knowledge about the system. The DOE Manual 435.1, *Radioactive Waste Management*, also requires PA to be reviewed and revised when there are important changes (DOE, 2021). Inherent in the regulations and guidance is the allowance for the evolution of PA from limited available data with assumption-based calculations to evidence-supported calculations. Assumption-based PAs, which are typical in new facilities, rely heavily on professional judgment and simplified but scientifically acceptable models to predict the long-term behaviour of the disposal system. Evidence-supported PAs are grounded in empirical data and rigorous scientific methods. They aim to reduce uncertainties by collecting and analysing real-world information.

Since the first full PA was published in 1992, it has changed to address changes in our understanding of the disposal system and its impact on releases. More recently, changes in waste forms, containers, inventory, and facility design, in combination with features of the site, have altered site conceptual models and some conclusions about performance. The EPA's regulations allow the DOE to request approval of changes to the disposal system through a planned change request (PCR) process. This paper provides examples of the development of the first PA and describes its evolution, since the original certification application, to reflect changes in the disposal system, its operation, and our understanding of features events, and processes. This evolution is discussed in the context of three Case Studies, the selection of magnesium oxide (MgO) as an engineered barrier; the application of the PCR process to the DOE's plan to abandon Panel 9; and the application of the PCR process to the DOE's proposal for Panels 11 and 12 to replace waste disposal capacity.

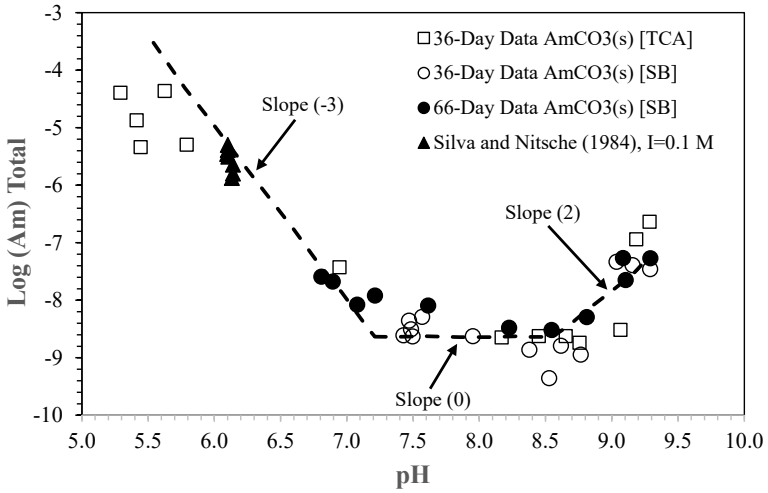
Case 1: Magnesium oxide as a chemical backfill and engineered barrier

Backfill materials were initially proposed for emplacement around and over the waste for fire protection and to improve confidence in the long-term mechanical, hydrologic, and chemical properties of the waste disposal area (Larson, 2000). The role of backfill in mitigating subsidence and fire propagation was subsequently found to be negligible (Rechard, 2000). In the 1996 PA to support the CCA, backfill was again considered but with a different function, i.e. to mitigate acidic conditions that could prevail following the intrusion of brine and its interaction with the waste.

The limited actinide solubility data in the literature for high-ionic strength brines and a wide range of plausible chemical conditions for the waste disposal area at the time contributed to solubility uncertainty. Gas generation (CO_2) from microbial degradation of cellulose, plastic, and rubber (CPR) was thought to be a potentially significant issue in the waste disposal rooms, based on existing microbial experiments. In addition, carbonate ions were known to bind to actinides forming stable, relatively soluble species. Both microbial activity and radiolysis could contribute to low pH conditions and thereby higher actinide solubilities (Figure 1) that could contribute to high radionuclide releases.

As a result, the DOE initiated an investigation of engineered barriers to control the disposal room chemistry. In the early stages of this effort, calcium oxide (CaO) was considered. Calcium oxide is readily available in bulk quantities, inexpensive, would limit pH to an alkaline range, and its efficacy in sequestering CO_2 is well documented. As the idea transitioned to an implementation discussion, WIPP operations personnel raised a handling concern. Calcium oxide is a sufficiently strong base that it is designated as a hazardous substance according to the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Figure 1: Combined solubility data for all AmCO3 precipitates and AmCO3 precipitates after 36 or more days of ageing. The solid line represents the solubility of Am(OH)3(am) in the absence of complexes other than Am-hydroxo species. Dashed lines of different slopes are for reference only (after Felmy et al., 1990).



This designation would have required waste handlers to wear protective equipment. in case of inadvertent dispersal. A more robust container (i.e. a stronger container than the proposed original supersack) was briefly considered to hold the CaO but the repository performance relied on the backfill package rupturing post-closure to facilitate mineral reaction with brine. Based on these operational and performance considerations, other bases were considered. A formal designation of a backfill material was not made until 1996 and magnesium oxide (MgO) pellets were chosen, for their chemical effects and reduced handling requirements, to control CO_2 concentrations and limit actinide solubility (Bynum et al., 1998).

An investigation into the specific effects of the MgO backfill began in 1996 and continues to this day. The MgO hydrates with its products sequestering CO_2 and buffering the disposal room pH in a mildly alkaline region ($8 \leq pH \leq 9$) to limit solubility (Figure 1). In contrast, the pH of a saturated solution of CaO in water is approximately that of a strongly alkaline solution ($12 \leq pH \leq 13$). As shown in Figure 1, data available at the time showed an increase in actinide solubility at pH > 9. Due to time pressures that hampered a full evaluation of the accessibility of MgO to brine and gaseous CO_2 within the disposal area, coupled with the uncertainty in CPR inventory, a protocol to place bulk bags of MgO on top of the stack of waste canisters with smaller sacks (known as minisacks) being stacked around the waste and hung on the side of the canisters was instituted. This protocol resulted in a large excess of MgO for the potential CO_2 (1.95 times on a molar basis), a broader spatial distribution, and assured its accessibility to react.

As knowledge of future waste streams and the disposal system evolved, including lower microbial gas generation identified in longer-term experiments, it became clear such a large excess of MgO was not necessary. This realisation, coupled with the safety principles to minimise radiation exposure to waste handlers (i.e. as low as reasonably achievable [ALARA]), led to a revision of the protocol. Because stacking and hanging the minisacks on and around the waste increased worker exposure without added disposal system performance, the minisacks were eliminated. Elimination of minisacks ensured ALARA and reduced costs without sacrificing repository performance, as demonstrated by PA. As the understanding of the disposal system performance and WIPP-bound inventory improved, other changes became possible in addition to the elimination of minisacks. Because the waste does not have a uniform distribution of CPR the generation of CO_2, and thereby the demand for MgO, varies among disposal rooms. This improved understanding

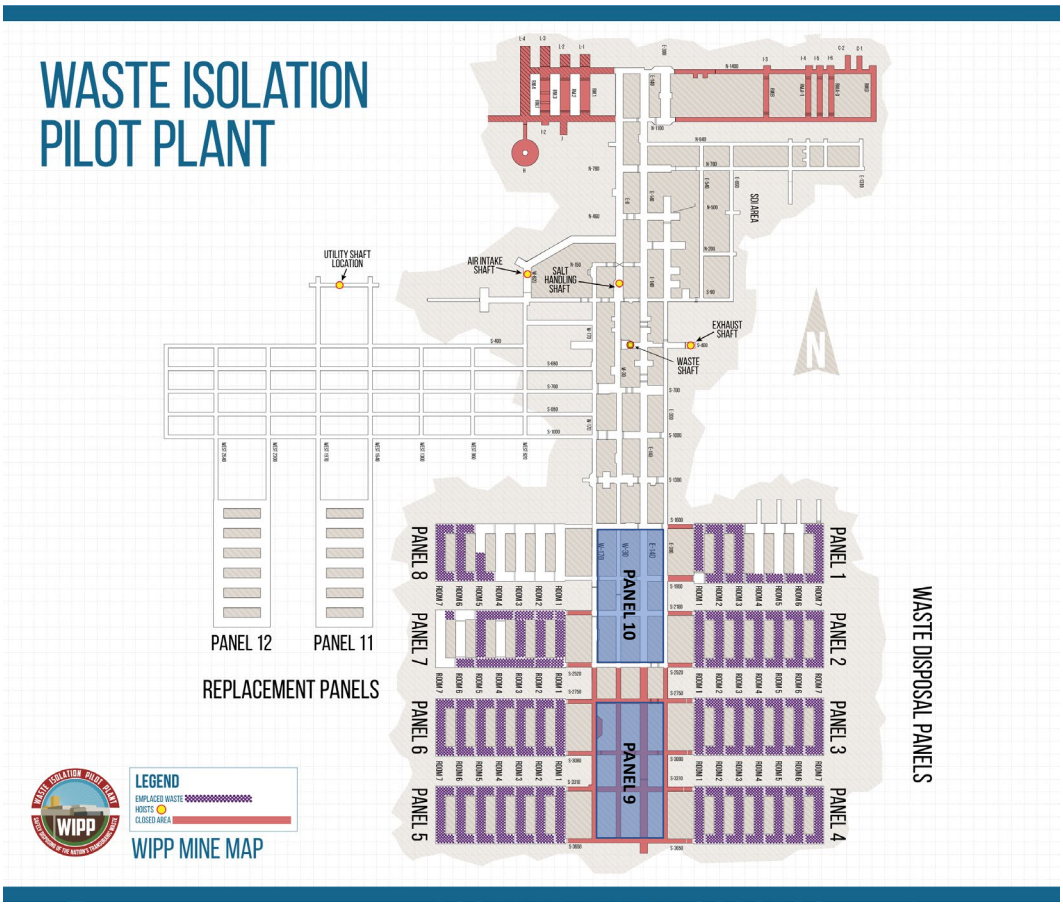
allowed the DOE to implement a formula to determine the amount of MgO required in each room, based on the CPR profile of the waste. The dual role of MgO in buffering pH and sequestering CO_2 led to the establishment of a room-specific limit of MgO to be added to each room.

Case 2: Radiological incident and the APCS performance assessment[2]

Case Study 2 is an example of the application of the PCR process to a DOE plan for changes in facility design and operation that required changes to the PA. In February 2014, a radiological incident at WIPP resulted in underground contamination and kept workers from conducting ground control for ~6 months. Consequently, in the interest of worker safety, the DOE was forced to abandon Panel 9 and omit panel closures for several other panels in the south-end waste panel access drifts (Figure 2). These actions were accompanied by a DOE decision to excavate a replacement for Panel 9. At the time the location was undetermined but conceptually it was northwest of the existing waste area at Panels 11 and 12 (Figure 2).

[2]The discussion in this section is derived in large part from EPA (2022).

Figure 2: Plan view of the WIPP repository showing waste disposal panels and equivalent Panels 9 and 10. A portion of Panel 7, and equivalent Panels 9 and 10 were abandoned due to radionuclide contamination.



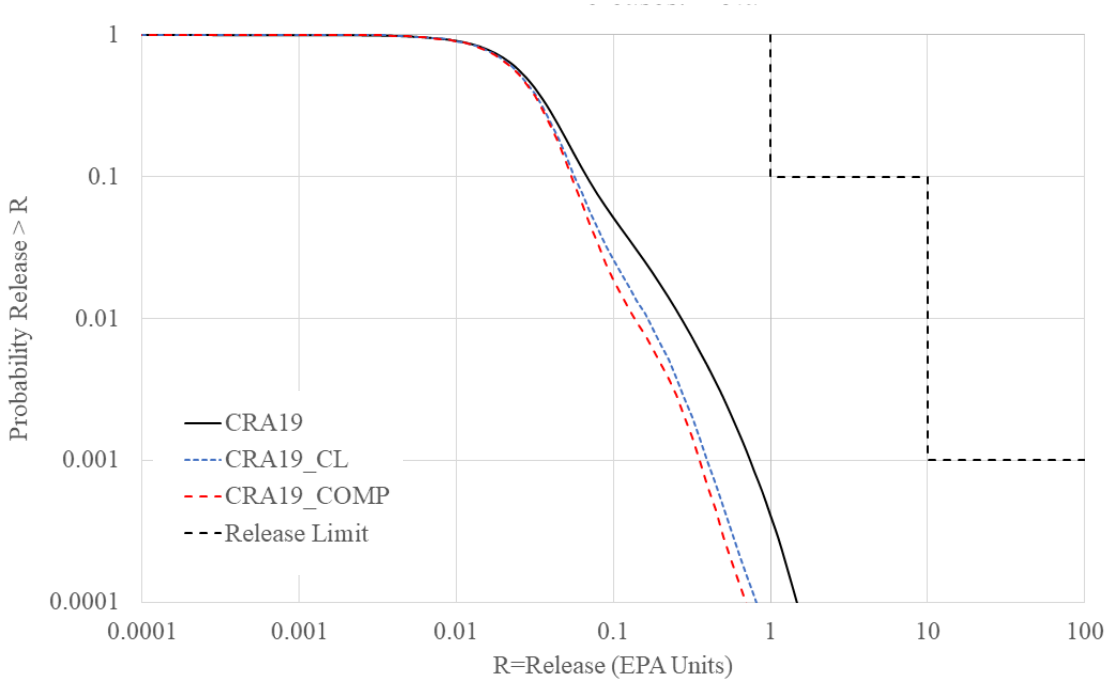
The DOE developed the "APCS (Abandonment of Panel Closures in the South) approach" to modify the existing models for the 2019 Compliance Recertification Application PA (CRA-2019 PA). The primary elements of this approach were to treat the abandoned Panel 9 as a surrogate for its replacement and to treat the now-empty waste panel access drifts as not creep closing but remaining open at relatively high porosities and permeabilities for the 10 000-year regulatory period. The EPA found that although the assumptions in the APCS approach were not physically realistic, they compensated for the uncertainties in treating the abandoned Panel 9 as a surrogate for its replacement.

One way that the DOE was able to demonstrate that the proposed approach was bounding for potential releases was to assume panels had closures close to the permeability of intact halite. This modelling demonstrated that isolated panels resulted in lower calculated releases than when the open panel concept in the APCS was used. The DOE's model to investigate the effects of modelling "open" areas of the repository in the CRA-2019 PA (CRA19_CL) was a separate, qualified analysis. The only differences from the CRA-2019 PA were that the open areas in the CRA-2019 PA (the Operations, Experimental, and open panel closure areas) were treated as immediately creep-closed at the time of repository closure, and panel neighbour relationships (used in modelling releases from drilling intrusions) were changed to reflect creep closure. Creep closure was approximated by assigning the very low porosity and permeability properties of intact Salado halite to the open areas for the 10 000-year simulation time.

The EPA found that the CRA19_CL model did not include rapid consolidation and healing of the disturbed rock zones (DRZs) surrounding these drifts. To consider DRZ healing, the EPA prepared the CRA19_COMP model, which was the same as the DOE's CRA19_CL

model but treated the DRZs as immediately creep closing to the same properties of intact halite as the empty rooms. The results showed that the CRA-2019 PA model, using the APCS approach, conservatively calculated greater repository releases than if the empty repository rooms and DRZs had been treated as creep-closed and healed (Figure 3). The EPA therefore accepted the DOE's APCS approach to PA modelling for the CRA-2019 as an interim measure intended to accommodate the immediate need to adapt the existing PA models to the new repository design in time for the 2019 recertification.

Figure 3: Mean total releases for the CRA19, CRA19_CL, and CRA19_COMP analyses. Source: EPA, 2022. The points of compliance are at (1, 0.1) and (10, 0.001). The EPA units are scaled to the repository inventory such that an EPA unit is about 1/10 000th of the radioactivity inventory. Release estimates to the left of those points indicate compliance with the EPA's numeric radioactive waste standard.



Case 3: The Replacement Panel Performance Assessment[3]

Case Study 3 is another example of the PCR process, applied to a proposed change that included revisions to the waste form, containers, radionuclide inventories, and facility design. The loss of disposal capacity due to the forced abandonment of equivalent Panel 9 (Case Study 2), coupled with the underutilisation of Panels 1 and 7 (Figure 2) resulted in a net loss of ~2 waste disposal panels. The original design of the WIPP repository consists of 10 Panels. Panels 1 through 8 consist of seven waste disposal rooms each; Panels 9 and 10 are made up of a portion of the main access drifts and crosscut drifts and are referred to as "equivalent panels" (Figure 2). Although the LWA established a total TRU waste limit of 175 564 m^3, there was no limit on the number of panels. The DOE proposed the addition of two panels (Panels 11 and 12) to replace the lost disposal capacity (Figure 3). These changes, coupled with an improved understanding of the performance of the disposal system, and conceptual and computer model updates, are under evaluation.

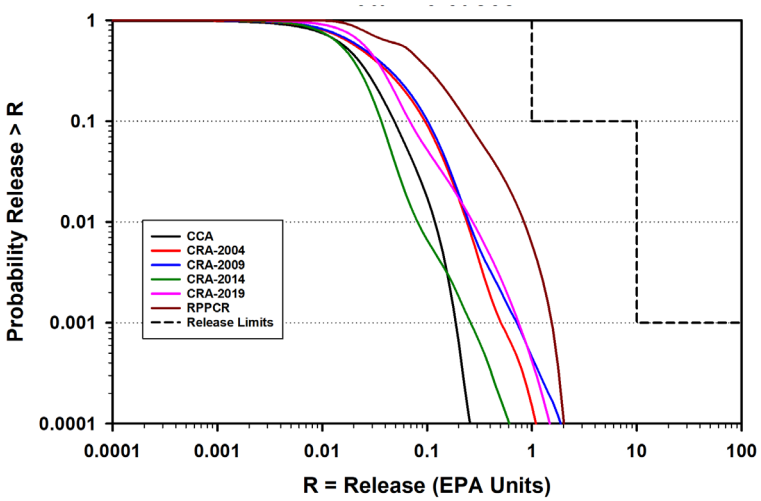
[3]The discussion in this section is derived mostly from DOE (2024).

Updating the PA to address the proposed change in facility design required a modification of three conceptual models, namely Repository Fluid Flow; Direct Brine Release (DBR); and Disposal System Geometry. The EPA relies on peer reviews to make informed decisions regarding WIPP compliance when there are changes in conceptual models. An independent peer panel reviewed the models, using applicable plans and procedures, to make sure they were built correctly and produced acceptable results. Results of the updated two-dimensional (2D) BRAGFLO code portion of the PA process models were corroborated against PFLOTRAN, another computer model used by DOE. The peer review determined that the changes to the three conceptual models were adequate and reasonable for their intended use (Falta et al., 2021). In their assessment of the peer review, the EPA concluded that it had been conducted following the requirements of 40 CFR §194.23(a)(3)(v) and 40 CFR §194.27 and fulfilled those requirements; the conclusions were reasonable and appropriate; and the results were acceptable. However, in anticipation of a Replacement Panels PCR from the DOE, the EPA described their expectations concerning data and information that would be needed (EPA, 2021). These expectations included information on (1) the future general design of the repository; (2) updated site characterisation information, including the potential for pressurised brine encounters during inadvertent drilling and hydrologic parameters; (3) an updated creep closure model for open areas; (4) the range of potential waste; and (5) an updated actinide solubility model.

The DOE submitted a replacement-panel PCR (RPPCR), including new PA calculations in March of 2024 for Panels 11 and 12 that addressed all of the EPA's expectations (DOE, 2024). It is known that a 12-panel repository (Figure 2) cannot accommodate an authorised LWA volume of TRU waste. The DOE has initiated an evaluation of up to seven "additional panels", i.e. a total of 19 panels, that may be needed for the total LWA waste volume. Because the conceptual 19-panel repository is the likely configuration at closure, PA calculations were performed for the 19-panel configuration with additional calculations done to examine the effects of a 12-panel repository (Figure 2). The PA also included several parameter changes, based on an improved understanding of the repository. Changes to accommodate waste Panels 11 – 19 included parameters related to the updated repository area and volume, computational grids for Salado flow and DBR models, and new release points for Culebra transport models. The DOE updated additional parameters to address site characterisation issues, chemistry-related changes; and the Salado flow model, including a new model of creep closure; along with standard updates to the drilling rate and waste inventory (DOE, 2024).

The PA calculations show that two replacement panels do not significantly change the repository behaviour or long-term performance. These panels do not alter physical release mechanisms; change chemical conditions or assumptions; interactions between waste areas and non-waste areas; or the conclusions of the PA (DOE, 2024). The 12-panel sensitivity analysis shows that the replacement panels behave similarly to the existing panels. The addition of Panels 11 and 12 and the associated changes to the repository footprint is not a significant contributor to releases from the undisturbed repository (Brunell et al., 2024). Disturbed releases were most affected by (1) the updated drilling rate; an anticipated waste stream with a generally higher plutonium activity; the updated disposal room porosity response surface; and the updated long-term borehole permeability probability distribution (Brunell et al., 2024). Upon incorporating these changes to the PA, releases from the disturbed repository continue to comply with the EPA's disposal standards (Figure 4).

Figure 4: BRAGFLO grid for the RPPCR with modelled area



As in the previous PAs dating back to the CCA, the mean total releases for the disturbed repository are dominated by cuttings and cavings releases at high probabilities, a direct consequence of the regulatory-prescribed drilling rate. Unlike previous PAs, in which mean total releases at low probabilities were dominated by DBRs, spallings and direct brine releases now contribute equally. This is attributed to lower borehole permeabilities, resulting from the updated model, and to the increased drilling rate. The EPA is conducting a technical review of the changes the DOE made to the calculations and will decide on the technical merits, accounting for public comment on the change.

Conclusions

The numerical long-term compliance of the DOE's WIPP with the EPA's regulatory standards is demonstrated using a Performance Assessment. Since the first Compliance Certification Application in 1996, the WIPP PA has changed to address changes in waste forms, containers, inventory, facility design, and the DOE's understanding of the disposal system. The WIPP PA has evolved from the early, heavily assumption-based calculations when there were limited data for PA and there was a need to rely on extensive professional judgment, to more evidence-supported empirical data and more rigorous scientific methods than at the time of the original CCA. However, data continue to be updated and models refined. Three Case Studies demonstrate changes to PA that have occurred since the CCA. These changes range from the final selection of an engineered barrier; to the omission of panel closures; and more recently to a change in conceptual models, requiring a peer review, and plans to excavate two replacement panels. The DOE's position is that with the changes, the PCR calculated releases continue to comply with the EPA's disposal standards. EPA is conducting a review of the PCR PA to determine if the Agency agrees with DOE.

References

Brunell, S., J. Bethune, P. Docherty, D. Kicker, S. Kim, S. King, J. Long and T. Zeitler, (2024), "Summary Report for the 2023 Replacement Panels Planned Change Request Performance Assessment", ERMS 581044. Revision 1. Sandia National Laboratories, Carlsbad, NM.

Bynum, R.V., C.T. Stockman, H.W. Papenguth, Y. Wang, A. Peterson, J.L. Krumhansl, E.J. Nowak, J. Cotton, S.J. Patchet and M.S.Y. Chu (1998), "Identification and evaluation of appropriate backfills

for the Waste Isolation Pilot Plant (WIPP)", in International Workshop on the Uses of Backfill in Nuclear Waste Repositories, Carlsbad, NM, 1998, R&D Technical Report P178.

DOE (1996), "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant", DOE/CAO-1996-2184, US Department of Energy, Carlsbad.

DOE (2021), "Radioactive Waste Management Manual", DOE M 435.1-1, Chg 3 (LtdChg), US Department of Energy, Washington DC., www.directives.doe.gov/directives-documents/400-series/0435.1-DManual-1-chg3-ltdchg-1/@@images/file.

EPA (2021), Letter from Lee Ann Veal, Direction, Radiation Protection Division, Environmental Protection Agency, to Mr Reinhard Knerr, Manager, Carlsbad Field Office, US Department of Energy, 20 April 2021, EPA-HQ-OAR-2024-0309-0012, US Environmental Protection Agency, Washington, DC.

EPA (2023), "EPA Review of DOE Peer Review of Conceptual Changes Incorporated in the APPA Model", EPA-HQ-OAR-2001-0012-0774, US Environmental Protection Agency, Washington, DC.

EPA (2022), "Technical Support Document for Section 194.23", Review of the APCS Approach to Analyzing WIPP Repository Performance in the CRA-2019 Performance Assessment, US EPA Air Docket No. EPA-HQ-OAR-2019-0534, US Environmental Protection Agency, Washington, DC.

Falta, R.W., M. Hu, E.M. Kwicklis, C.I. Steefel, S.C. Williams-Stroud and J.A. Thies (2021), "Waste Isolation Pilot Plant", Additional Panels Performance Assessment (APPA) Changed Conceptual Models Peer Review Report, US Department of Energy, Carlsbad, NM.

Felmy, A.R., D. Rai and R.W. Fulton (1990), "The Solubility of $AmOHCO_3$(c) and the Aqueous Thermodynamics of the System Na^+-Am^{3+}-HCO_3^--CO_3^{2-}-OH^--H_2O", *Radiochimica Acta*, 50(4):193-204.

Larson, K., (2000), "Development of the conceptual models for chemical conditions and hydrology used in the 1996 performance assessment for the Waste Isolation Pilot Plant", *Reliab. Eng. Sys. Saf.*, 69: 59–86.

Rechard, R. (1999), Historical background on performance assessment for the Waste Isolation Pilot Plant. *Reliab. Eng. Syst. Saf.,* 69: 5-46.

Rai, D, R.G. Strickert, D.A. Moore, J.L. Ryan (1983), "Am(III) Hydrolysis Constants and Solubility of Am(III) Hydroxide", *Radiochim. Acta,* 33, 201-206.

Silva, R.J. and H. Nitsche (1984), "Thermodynamic properties of chemical species of waste radionuclides", No. NUREG/CP-0052, US Nuclear Regulatory Commission.

Snider, A. (2002), "Hydration of Magnesium Oxide in the Waste Isolation Pilot Plant", *MRS Proceedings*, Vol. 757, https://doi.org/10.1557/PROC-757-II8.3.