Re-Evaluation of the 300-Year Performance Demonstration for the WIPP - 11236

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ABSTRACT

This paper describes the 300-year performance demonstration in the Renewal Application for the Hazardous Waste Facility Permit for the Waste Isolation Pilot Plant (WIPP) and compares the methodology for and results from the demonstration to: (i) the previous 300-year performance demonstration from the initial permit application, and (ii) the long-term (10,000 year) performance assessment for WIPP under 40 Code of Federal Regulations (CFR) Part 191. Both performance demonstrations prove that the WIPP is very robust, in the sense that there is no migration of hazardous waste or hazardous constituents away from the WIPP facility because little brine flows inward to the WIPP facility and because brine or gas do not flow outward from the WIPP facility within the 300-year time period. Under these conditions, there is no release of hazardous waste or hazardous constituents from the WIPP via subsurface or surface groundwaters or via gases. Zero releases during the first 300 years after closure leads to the affirmation that the conclusion in the initial permit application remains valid, namely that there are no adverse effects on human health or the environment caused by migration of hazardous waste constituents in the subsurface, in surface waters, in wetlands, or on the soil surface from the WIPP.

INTRODUCTION

The U.S. Department of Energy/ Carlsbad Field Office (DOE) is required to renew the Hazardous Waste Facility Part B Permit (“the Permit”) for the Waste Isolation Pilot Plant (WIPP) facility every ten years. The DOE’s Renewal Application was submitted to the New Mexico Environment Department (NMED) on September 25, 2009 and NMED approved a new permit on November 30, 2010 [1].

The Renewal Application focuses on the regulated aspects of WIPP operations that are related to hazardous waste and that may be pertinent to the protection of human health and the environment during the operation of the facility and for 30 years after permanent closure. The Renewal Application includes a post-closure performance demonstration for the WIPP. Given the 2,150-foot depth of the WIPP facility, the performance demonstration considers the potential for releases to deep subsurface groundwater in addition to potential releases to surface waters, to wetlands, and to surface soils. The post-closure performance demonstration for WIPP has a 300-year duration to demonstrate the robustness of the facility well beyond the 30-year duration required for the Permit. This paper describes the methodology for and results from the revised performance demonstration in the Renewal Application, and explains the differences between the original and the revised demonstrations.

METHODOLOGY FOR THE 300-YEAR PERFORMANCE DEMONSTRATION

The revised performance demonstration is based on the models and parameters in the Performance Assessment Baseline Calculation (PABC) [2]. The PABC is the long-term performance assessment (PA) baseline for the current certification of the WIPP by the U.S. Environmental Protection Agency (EPA). This PA baseline represents the current understanding of the processes and uncertainties that could affect the movement of hazardous waste or hazardous constituents away from the WIPP facility. The PABC is therefore the appropriate starting point for predicting the potential pathways for exposure of humans or environmental receptors to hazardous waste or hazardous constituents and for predicting the potential magnitude and nature of such exposures after the closure of the WIPP facility, as required by 40 CFR Part §270.23(c) and 40 CFR Part §264.601.

The revised performance demonstration uses a subset of the PABC results. First, the PABC predicts repository performance over a 10,000 year period after closure, but the performance demonstration is limited to the first 300 years after facility closure. The 300-year duration was selected because it is ten times greater than the post-closure care period as required by 40 CFR 117, which is 30 years. By stating that there is no migration of hazardous waste constituents away from the hazardous waste disposal units (HWDUs) during the first 300 years after closure, it follows that there will be no migration away from the HWDUs up to and beyond 30 years after closure. The 300-year duration for the performance demonstration provides assurance that hazardous waste or hazardous constituents are not released from the WIPP facility well beyond the Permit-mandated regulatory timeframe.

Second, the PABC predicts repository performance with and without borehole intrusions, but the performance demonstration only uses the PABC predictions for a closed repository without intrusions. This approach is consistent with DOE's plans and commitments that were made in the first RCRA Part B Permit Application for the WIPP [3]:

> *"The DOE owns all of the lands needed to protect the WIPP repository and will retain this ownership in perpetuity. In this way, the DOE will protect the WIPP from future changes in land use that may alter the surface. In addition, the DOE has planned several active and passive institutional controls to assure that no one intentionally drills into the waste while seeking resources. …"* ([3], Chapter D, Section D-9b(3))

DOE's plans are consistent with guidance on institutional controls from the EPA [4]. As the result of these institutional controls, which meet the EPA's and NMED's expectations for preventing intrusion into the repository, intrusion scenarios are precluded from the performance demonstration for the closed facility.

The PABC includes two types of change relative to the original performance demonstration:

1. The PABC is based on the latest conceptual models in the PA baseline, which differ from the conceptual models for the original performance demonstration. A number of changes have occurred since the original Permit was issued by NMED. Important changes were made for the the gas generation model from biodegradation and for the model for

groundwater flow in the Salado Formation that surrounds the repository. Further details on these changes are described in the next section of this paper.

2. The revised performance demonstration is based on the input parameters for the PABC. Typical input parameters define the mechanical properties of the waste, the hydrologic properties of geologic materials surrounding the repository, and the chemical properties of radionuclides in the waste. The PABC input parameters differ from the input parameters for the original performance demonstration in two ways: (1) the values of some input parameters have been modified since the original performance demonstration was completed. For example, the timing and rates of gas generation from biodegradation of cellulosic, plastic and rubber materials has been changed since the original performance demonstration was completed; and (2) the revised performance demonstration uses the distributions in the PABC to represent uncertainty in the input parameters ([5], Appendix PA, Attachment PAR, and [2], Section 2.9). The changes to parameters are also described in the next section of this paper.

In summary, this methodology for the performance demonstration is attractive because: (1) it directly uses the results from the PABC, which is the PA baseline for the EPA's long-term PA and certification of the WIPP, and (2) incorporates the uncertainty in input parameters for the PABC into the performance demonstration. With this approach, the revised performance demonstration for the Renewal Application is identical with the response of the undisturbed scenario in the PABC for the first 300 years after closure.

CHANGES FOR THE PABC PERFORMANCE DEMONSTRATION

There have been many changes to the conceptual models and parameters used by performance assessment (PA) to represent long-term performance of the repository since the original 300-year performance demonstration was prepared in 1996 for the WIPP Part B Permit Application [3],. The individual changes that are relevant to the PABC performance demonstration are described below. Given the number of changes and the potential for complex interactions between brine inflow, gas generation, room closure, and the disturbed rock zone (DRZ), it is necessary to use a full PA, such as the PABC, to predict the quantitative response of the WIPP facility for the first 300 years after closure.

(1) Parameter uncertainties are addressed in the PABC by sampling distributions with a range of values, as opposed to the use of median values for the input parameters in the original performance demonstration ([3], Chapter D, Tables D-2 through D-5). For example, the PABC uses a sampled distribution for the biodegradation rate of cellulose, plastic, and rubber materials ([2], Section 2.3), while the original performance demonstration uses a constant biodegradation rate ([3], Chapter D, Table D-2). The use of distributions, rather than median values, is appropriate because it propagates the uncertainty in the parameter distributions into the results for the 300-year performance demonstration.

(2) The models/parameters for gas generation by biodegradation have been changed:

   a. The original performance demonstration conservatively assumed that gas generation from biodegradation always occurred at the fixed inundated rate, and that all cellulose, plastic, and rubber materials are available for consumption ([3], Chapter D, Section D-9b(1)(a)). The PABC uses both inundated and humid microbial degradation rates, and allows cellulose materials to degrade in 100% of the realizations, but only allows the plastic and rubber materials to degrade in 25% of the realizations ([2], Sections 2.2 and 2.3). The PABC also uses revised microbial gas generation rates, based on 10 years of experimental data ([2], Section 2.3), that reduce the long-term gas generation rates by a factor of approximately 7. These changes provide a more realistic representation of the data for microbial gas generation. These changes also reduce the gas generated by biodegradation and the gas pressure in the repository, all other factors (such as brine saturation) being equal.

b. Microbial degradation occurs through denitrification and sulfidization for the PABC. The multi-step biodegradation reactions are not allowed to progress to methanogenesis ([2], Section 2.4), maintaining a conservatism that was mandated by the EPA. This change is conservative for long-term performance because it increases the moles of gas produced by microbial degradation.

c. The molecular weight of cellulose was decreased from 30.026 g/mol to 27.023 g/mol, resulting in a slight increase of long-term pressure.

(3) Parameters distributions have been changed to better represent uncertainty:

a. The logarithm of the disturbed rock zone (DRZ) permeability was changed from a constant value of -15 (permeability units of m^2) to a uniform distribution ranging from -19.4 to -12.5 (permeability units of m^2), with a median value of -16 m^2 ([5], Chapter 6, Table 6-19). This change provides a better representation of the uncertainty in the DRZ permeability.

b. The inundated corrosion rate for iron-based materials without carbon dioxide was changed from a constant value of 7.94×10^{-15} m/s ([3], Chapter D, Table D-2) to a uniform distribution with a range of 0 to 3.17×10^{-14} m/s ([5], Chapter 6, Table 6-12). This change provides a better representation of the uncertainty in the data for inundated corrosion rate.

c. The waste permeability was changed from a constant value of 1.7×10^{-13} m^2 to a constant value of 2.4×10^{-13} m^2 ([5], Chapter 6, Section 6.4.3.2 and Table 6-10). This change corrects a minor error in the original model.

d. The residual saturation and rock compressibility parameters for MB 138/139 and Anhydrite A&B have changed for the PABC ([2], Table 2-1).

(4) The modeling of groundwater flow in the Salado formation surrounding the repository has been changed:

a. The representation of the four shafts connecting the repository to the surface has been simplified ([5], Chapter 6, Section 6.4.4 and Appendix PA, Section PA-4.2.7)

b. The representation of panel closures was changed from a generic design to the Option D panel closure design, which is the design mandated by the EPA's original certification of the WIPP. This change also included a fracture model for the DRZ above the panel closures. This change affected pressures and saturations in the waste emplacement areas and operations/experimental areas of the repository ([5], Chapter 6, Section 6.4.3).

c. The grid geometry and repository layout were changed in the BRAGFLO model. The change for grid geometry included revised radial flaring in the BRAGFLO grid to better represent the three-dimensional geometry of the repository ([5], Appendix PA, Attachment MASS, Section MASS-4.2). The changes for grid geometry have an insignificant effect on calculated flow in the Salado formation [6].

(5) The waste inventory was changed for the PABC, based on annual updates to the waste inventory data that the generator sites report to WIPP. The new values for radionuclide inventory and waste material parameters for the PABC are defined in Leigh et al. [7].

COMPARISON OF PABC & ORIGINAL PERFORMANCE DEMONSTRATION

The performance demonstration determines if gas or brine migrates away from the closed and sealed repository by analyzing the potential for repository gas pressure to exceed that needed for brine or gas to flow away from the repository. This is a reasonable approach because hazardous waste constituents can only migrate away from the repository in water that is initially in the emplaced waste, in gas that is associated with the waste, or in brine that first migrates into the repository before picking up contaminants and flowing outward. Most important, brine or gas may migrate away from the repository only if the repository pressure is greater than the pore pressure in the host rock surrounding the repository, which is the lithostatic pressure of about 15 Megapascals (MPa)(2,200 psi)([5], Chapter 2, Section 2.2.1.3).

Fig. 1 through Fig. 4 present the results from the PABC and from the original performance demonstration for repository pressure, gas generation per drum, cumulative brine inflow into a panel, and average brine saturation. The values in these figures are based on the average or mean response of the undisturbed waste panel (i.e., a waste panel without an intrusion borehole) in the 100 realizations for replicate 1 of the PABC.

Fig. 1 indicates that the predicted average pressure in the waste panel increases with time. The increase in pressure is caused by gas generation from corrosion and microbial degradation and by creep closure reducing the free volume for gas in each room. The pressure after 100 years for the PABC is predicted to be about 1 MPa (145 psi), while the pressure after 100 years in the original performance demonstration is about 5 MPa (725 psi) ([3] Section D-9b(1)(c) and Fig. D-17B). The predicted pressure for the PABC at 300 years is approximately 3 MPa (435 psi), while the pressure after 300 years in the original performance demonstration is about 10 MPa (1,450 psi).

The predicted pressure for the PABC at 300 years, 3 MPa (435 psi), is about a factor of 5 less than the lithostatic pressure of 15 MPa (2,200 psi), confirming that the average pressure in a waste panel is less than the lithostatic pressure in the host rock throughout the first 300 years after closure. In this condition, there will be no flow of brine or gas away from the facility after closure because the pressure differences driving brine and gas flows are always inward, from the rock surrounding the facility into the repository.

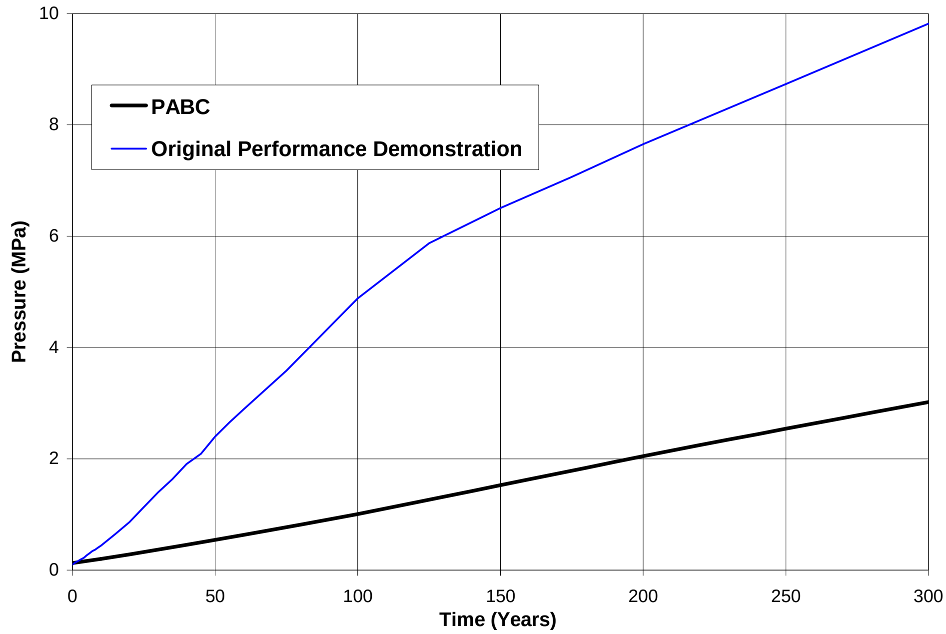

Fig. 1. Predicted Change in Average Pressure in the Closed Waste Panel for the PABC and for the Original Performance Demonstration

The PABC performance demonstration has significantly lower pressure than the original performance demonstration throughout the 300-year period. The original analysis is based on a conservative assumption of higher than expected gas generation rates ([3], Chapter D, Section D-9b(1)(c)), while the gas generation rates for microbial degradation have been reduced for the PABC, based on 10 years of experimental data ([2], Section 2.3, and item 2(a) in the previous section). These changes reduce the mean brine-inundated gas generation rate from biodegradation and are the likely cause of the drop in pressure for the PABC versus the original performance demonstration.

The reduction in gas generation rates is confirmed by the comparison shown in Fig. 2. Fig. 2 demonstrates that gas generation is significantly greater for the original performance demonstration than for the PABC throughout the 300-year period. Approximately 90 moles of gas per drum are predicted to be generated after 300 years with the PABC, while 700 moles of gas per drum are generated after 300 years in the original performance demonstration.

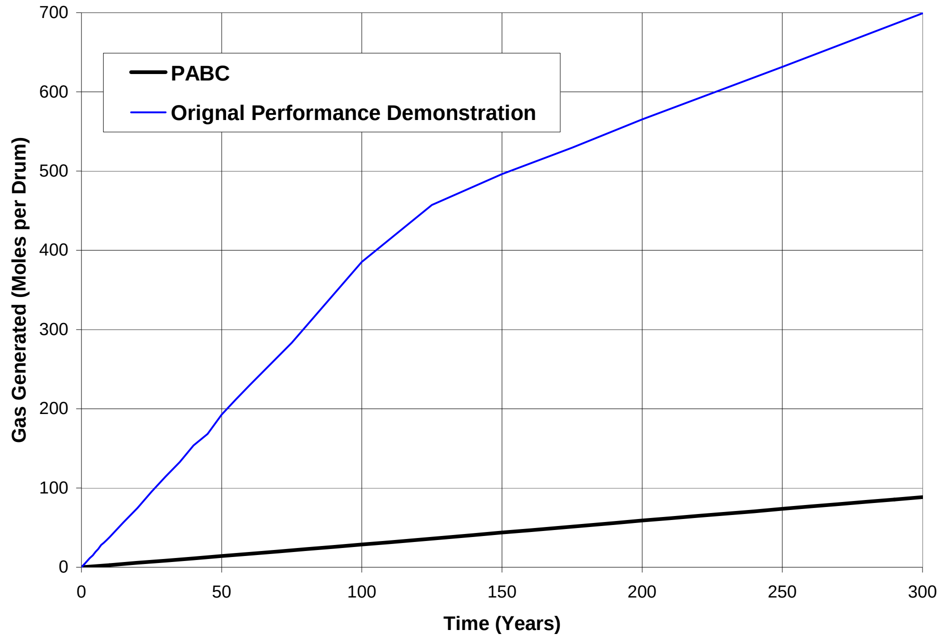

Fig. 2. Predicted Cumulative Moles of Gas Generated Per Drum of Waste for the PABC and for the Original Performance Demonstration

Brine can flow from the rock surrounding the facility into the repository whenever the gas pressure in a waste panel is less than the pore pressure in the host rock. Fig. 3 presents the mean brine inflow for the first 300 years after closure. The magnitude of the cumulative brine inflow to the waste panel is about 600 m^3 during the first 50 years for the PABC. For the original performance demonstration, the magnitude of the cumulative brine inflow to the waste panel is 562 m^3 during the first 50 years ([3], Chapter D, Section D-9b(1)(c)). The major source of brine inflow during the first 50 years is dewatering of the halite rock directly surrounding the excavations, called the disturbed rock zone (DRZ). The quantity of brine from the DRZ is similar for the original and PABC performance demonstrations. The inflow for the PABC performance demonstration is slightly greater during the first 50 years than for the original performance demonstration because the reduced pressure in the waste panel for the PABC increases the inward pressure difference between the host rock and the waste panel. After the first 50 years, the cumulative brine inflow for the PABC increases significantly relative to the original performance demonstration because the reduced pressure in the PABC waste panel increases the inward pressure difference relative to the host rock, driving more brine from the host rock into the repository.

Outward flow of brine or gas is always zero during the first 300 years after repository closure, consistent with the inward pressure gradient from the host rock into the waste panel. This plot is not shown.

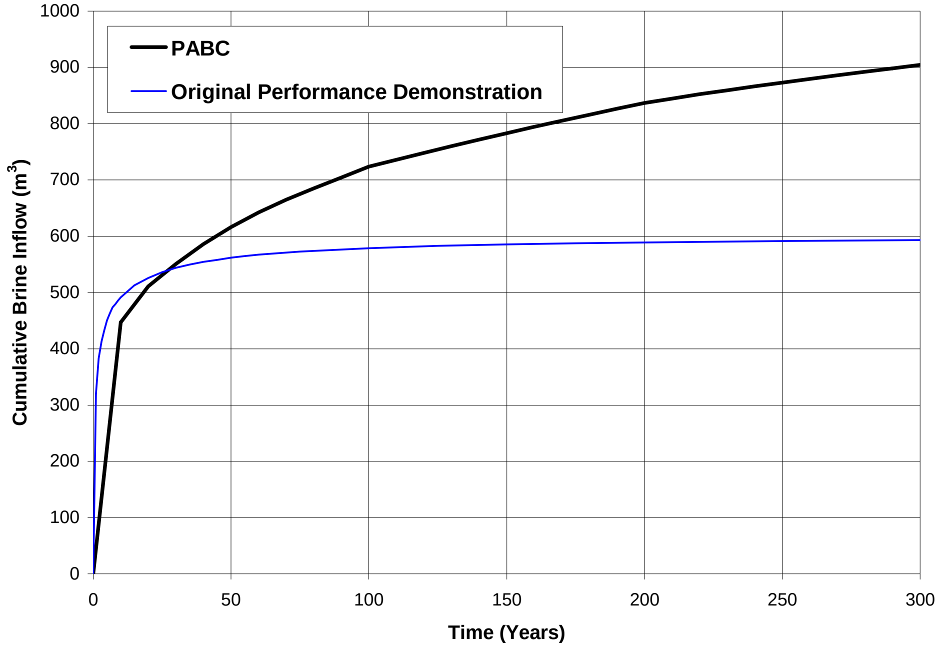

Fig. 3. Predicted Cumulative Brine Inflow into a Closed Waste Panel for the PABC and for the Original Performance Demonstration

Brine saturation is the fraction of the void volume that is filled with brine. In other words, brine saturation is equal to brine volume in the waste divided by the total void volume in the waste. Brine saturation varies between 0 for dry waste to 1 for waste that is completely saturated with brine. Fig. 4 shows that the initial brine saturation of the waste is assumed to be 0.015 (1.5%), which is essentially dry. Fig. 4 demonstrates that brine saturation in the waste panel increases slowly and continuously in the PABC performance demonstration to a maximum value of 0.16 at 300 years after closure. The increase in brine saturation from 50 to 300 years is caused by continuous brine inflow from the host rock (see Fig. 3) and by creep closure decreasing the void volume in the waste. The void volume or porosity in the waste decreases continuously in response to creep closure of the rooms because the pressure in the panel (see Fig. 1) is much less than lithostatic pressure (15 MPa) in the host rock. Both factors (brine inflow and porosity) act to increase the brine saturation for the PABC. On the other hand, brine saturation creases after 50 years for the original performance demonstration. The decrease is caused by several factors: brine inflow is very small after 50 years (see Fig. 3), anoxic corrosion of iron-based materials consumes free brine in the panel, and higher pressures for the original demonstration slow the reduction in porosity in the waste relative to the PABC.

In either calculation, the waste remains relatively dry even at 300 years, with a maximum brine saturation of 16% (about one sixth) of the void volume in the waste filled with brine. The waste remains relatively dry because the low permeability of the bedded halite formation restricts the inward flow of brine.

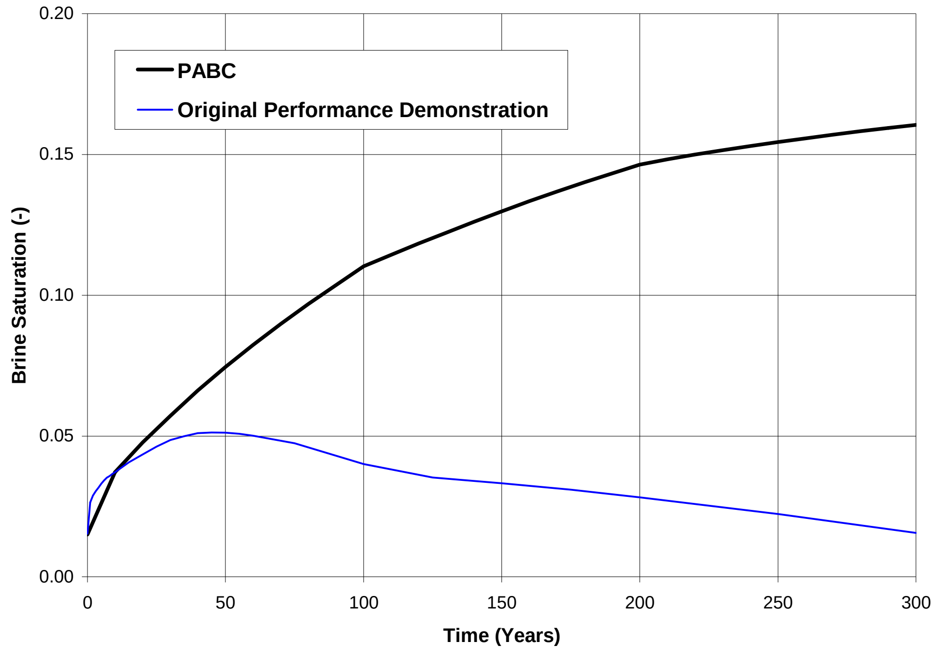

Fig. 4. Predicted Average Brine Saturation in the Closed Waste Panel for the PABC and Original Performance Demonstrations

CONCLUSION

The results of the PABC confirm the results of the performance demonstration for the original RCRA Part B permit application. That is, there is no migration of hazardous waste or hazardous constituents away from the WIPP facility because of the following general features of the repository:

- The WIPP waste is essentially dry (less than 1.5% saturation) when it is emplaced in the repository;
- The WIPP facility is located in bedded salt (halite). The bedded salt has a low permeability that restricts brine inflows from the host rock into the facility; and
- Gas/brine pressure in the disposal rooms remains low relative to the brine pressure in the salt formation for the first 300 years after repository closure. Brine or gas can only flow from high pressure regions to low pressure regions, so flow can be inward, toward the facility, but not outward during the first 300 years after closure.

The original Part B Permit Application for the WIPP ([3]) provided extensive discussion of waste management practices and demonstrated that, under normal operating conditions, there was no potential for release of hazardous waste from surface operations. Likewise, normal operations for emplacing waste in the underground repository minimized the potential for release via soils and groundwater and air. Since little brine flows inward (because of the low permeability in the salt) and since gas/brine do not flow outward (because of low gas/brine pressure in the facility), hazardous waste or hazardous constituents cannot be released from the

WIPP facility via brine or gas during the first 300 years after repository closure. The results from the PABC performance demonstration reconfirm the conclusions from the original performance demonstration that there is no outward migration of hazardous waste or hazardous waste constituents along surface water, soil, ground-water, or air/gas pathways during the first 300 years after repository closure, demonstrating that the WIPP facility is compliant with 40 CFR Parts §264.601 and §264.602.

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