RENEWAL APPLICATION
ADDENDUM N1

300-YEAR PERFORMANCE DEMONSTRATION RE-EVALUATION

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300-Year Performance Demonstration Re-Evaluation

The 300-year performance demonstration has been updated as part of the renewal application for the Resource Conservation and Recovery Act (**RCRA**) Part B Permit for the Waste Isolation Pilot Plant (**WIPP**). The revised performance demonstration is based on the models and parameters in the Performance Assessment Baseline Calculation (**PABC**) (Leigh et al. 2005). The PABC is the performance assessment (**PA**) baseline for the EPA's latest recertification of the WIPP. This PA baseline represents DOE's current understanding of the processes and uncertainties that could affect the movement of hazardous waste or hazardous constituents from the WIPP facility, and is the most appropriate starting point for the revised performance demonstration.

The performance demonstration uses a subset of the PABC results. First, the PABC predicts repository performance over a 10,000 year period, but the performance demonstration focuses only on the results from the PABC for the first 300 years after facility closure. Second, the PABC predicts repository performance with and without borehole intrusions, but the performance demonstration only uses the PABC predictions without intrusions. This approach is consistent with U.S. Department of Energy (**DOE**) plans and commitments in the first RCRA Part B Permit Application for the WIPP:

> *"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. These plans are described in Chapter I"* (DOE 1996, Chapter D, Section D-9b(3))

The DOE plans are consistent with guidance on institutional controls from the U.S. Environmental Protection Agency (**EPA**) (EPA 2000). 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 results of the revised performance demonstration confirm the results of the original analysis in that there is no migration of fluid or gas away from the facility (see Figure 3). Therefore, no migration of hazardous materials occurs during the first 300 years after repository closure. Although this conclusion has not changed, the PABC includes two updates 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. In fact, a number of changes have occurred since the Part B permit was approved by NMED. One important change is to the conceptual model for gas generation that results from biodegradation of cellulosic, plastic and rubber materials. Full details on the model

changes with the potential to alter the performance demonstration are described in Attachment A, Technical Details of Changes for the PABC Performance Demonstration.

2. The PABC is based on the latest input parameters (DOE 2004, Appendix PA, Attachment PAR, and Leigh et al. 2006, Section 2.9), some of which differ from the input parameters for the original performance demonstration. 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, to name a few of the important processes in the repository. The input parameters can have constant values or can be defined by distributions that represent the uncertainty in their values. For example, the input parameters for the biodegradation rate, iron corrosion rate, actinide solubilities, anhydrite permeability, and halite porosity are defined as distributions in order to represent their uncertainty in the PA. The PABC is a robust starting point for the new performance demonstration because it captures the full variability of uncertain input parameters.

   The original performance demonstration was calculated using constant values of the input parameters. These constant values are generally based on the median values for parameters with uncertainty distributions (DOE 1996, Chapter D, Tables D-2 through D-5).

As will be seen in the following discussion, there are differences between the predicted responses of the original and the revised performance demonstrations. For example, the mean pressure in the repository at 300 years for the revised performance demonstration is about a factor of 3 less than the mean pressure from the original performance demonstration, as shown in Figure 1. This reduction in pressure provides an additional margin relative to release of hazardous waste or hazardous constituents from the repository, and confirms the conclusion from the original performance demonstration that there are no releases of hazardous waste or hazardous waste constituents during the 300-year period after facility closure.

<u>PABC Results and Comparison to the Original Performance Demonstration</u>

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 gas and fluids to migrate away from the repository. This is a reasonable approach because hazardous waste constituents can only migrate away from the repository in gas that is generated by the waste or in brine that first migrates into the repository or in water that is contained in the waste. More specifically, brine or gas may migrate away from the repository only if the repository pressure is greater than the pressure in the host rock surrounding the repository (i.e., lithostatic pressure), which is about 15 Megapascals (**MPa**) (2,200 psi) (DOE 2004, Chapter 2, Section 2.2.1.3).

The results from the PABC and original performance demonstrations for the average repository pressure, average gas generation per drum, average cumulative brine inflow into a panel, average pore volume in a panel, and average repository brine saturation are presented in Figures 1 through 5. Figures 1 through 5 contain similar information to Figures D-17B through D-17F of the original Part B permit application; although the logarithmic scales for time and pressure in the figures in the original permit application have been converted to physical values to simplify interpretation of results. The average values in Figures 1 through 5 are based on the average response of the undisturbed (or unintruded) waste panel in the 100 realizations for replicate 1 of the PABC.

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

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

The PABC performance demonstration has significantly lower pressure than the original performance demonstration throughout the 300-year period for several reasons. The original analysis is based on a conservative assumption of higher than expected gas generation rates (DOE 1996, 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 (Leigh et al. 2005 Section 2.3). These two effects reduce the mean brine-inundated gas generation rate from biodegradation by about a factor of 20 (see Attachment A), 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 of Figure 2. Figure 2 demonstrates that gas generation is significantly greater for the original performance demonstration than for the PABC performance demonstration 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.

Brine can flow from the rock surrounding the facility into the repository whenever the gas pressure in the waste panel is less than the pore pressure in the host rock. Figure 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 performance demonstration. 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 (DOE 1996, 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 closed facility. After the first 50 years, the cumulative brine inflow for the PABC performance demonstration increases significantly relative to the original performance demonstration because the reduced PABC pressure increases the inward pressure difference relative to the host rock, driving more brine from the host rock into the repository.

The as-emplaced waste has approximately 18% solid material and 82% free space by volume. This free space or void volume is expected to decrease as the waste is compressed by the inward movement of the rock walls due to creep of halite. This inward movement is also referred to as creep closure of the rooms. The decrease in void volume is a result of the complex interaction between creep closure, gas pressure, and brine inflow.

Figure 4 compares the void volumes for the PABC and original performance demonstrations. The total void volume decreases from 39,100 m^3 to 17,700 m^3 after 50 years for the PABC performance demonstration. The corresponding values for the original performance demonstration are from 36,900 m^3 to 16,600 m^3 during the first 50 years (DOE 1996, Chapter E, Table E1-2). All other factors being equal, the void volume in the waste for the PABC performance demonstration would be expected to be less than the volume for the original performance demonstration because there is less gas pressure retarding room closure. However, the initial void volume for the PABC performance demonstration is approximately 2,000 m^3 greater than for the original performance demonstration. The net effect of these two competing factors is that there is little difference in void volume for the first 50 years between the original performance demonstration and the PABC, as illustrated in Figure 4. After the first 50 years, the reduced repository pressure for the PABC consistently results in smaller void volumes than 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. Figure 5 demonstrates that brine saturation in the waste panel increases slowly in the PABC performance demonstration to a maximum value of 0.16 at 300 years after closure. This increase is caused by brine inflow from the rock (see Figure 3) and by creep closure decreasing the void volume in the waste (see Figure 4).

The original performance demonstration reaches a maximum brine saturation of about 0.05 at about 50 years and decreases thereafter because brine inflow becomes almost constant after 50 years (see Figure 3), because there is less room closure than for the PABC (see Figure 4), and because brine is consumed by steel corrosion. For comparison, the brine saturation in the PABC performance demonstration is 0.075 at 50 years and increases throughout the 300-year period. Lower gas generation rates for the PABC performance demonstration maintain lower pressure (see Figure 1), resulting in more brine inflow (see Figure 3) and less pore volume (see Figure 4) for the PABC. The increased brine inflow for the PABC appears to be great enough to exceed the consumption of brine by iron corrosion, resulting in continuously increasing brine saturation throughout the 300-year period.

The original Part B Permit Application for the WIPP (DOE 1996) 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. The results from the PABC performance demonstration, particularly the facility pressure and the cumulative inflow of brine during the 300-year period after closure (see Figure 3), confirm the conclusions in the original RCRA 300-year performance demonstration that there is no outward migration of hazardous waste or hazardous waste constituents along surface water, soil, groundwater, or air/gas pathways during the first 300 years after repository closure.

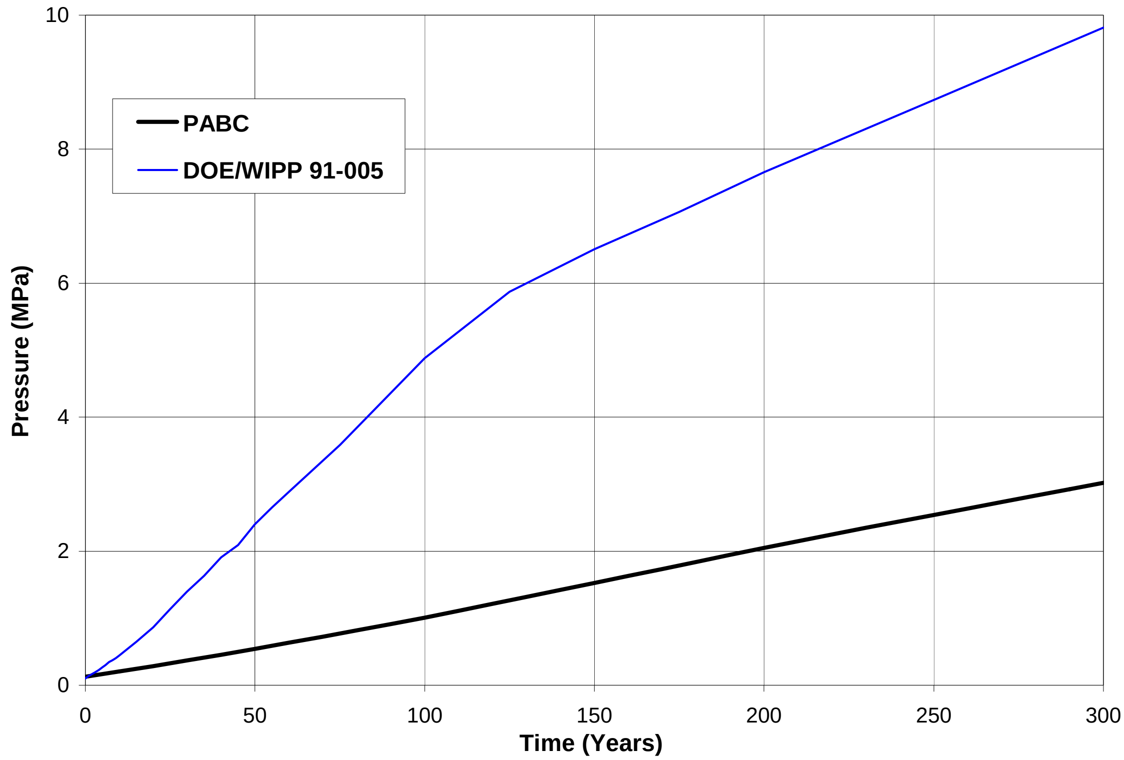

Figure 1. Predicted Change in Repository Pressure Following Closure for the PABC and Original Performance Demonstrations

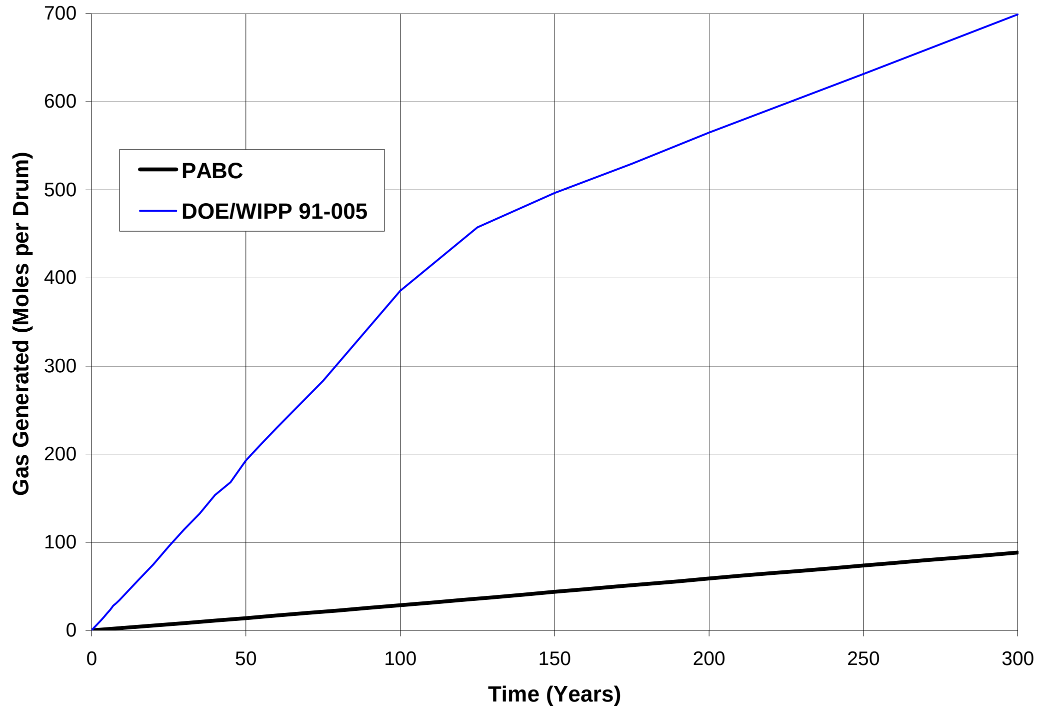

Figure 2. Predicted Cumulative Moles of Gas Generated Per Drum of Waste for the PABC and Original Performance Demonstrations

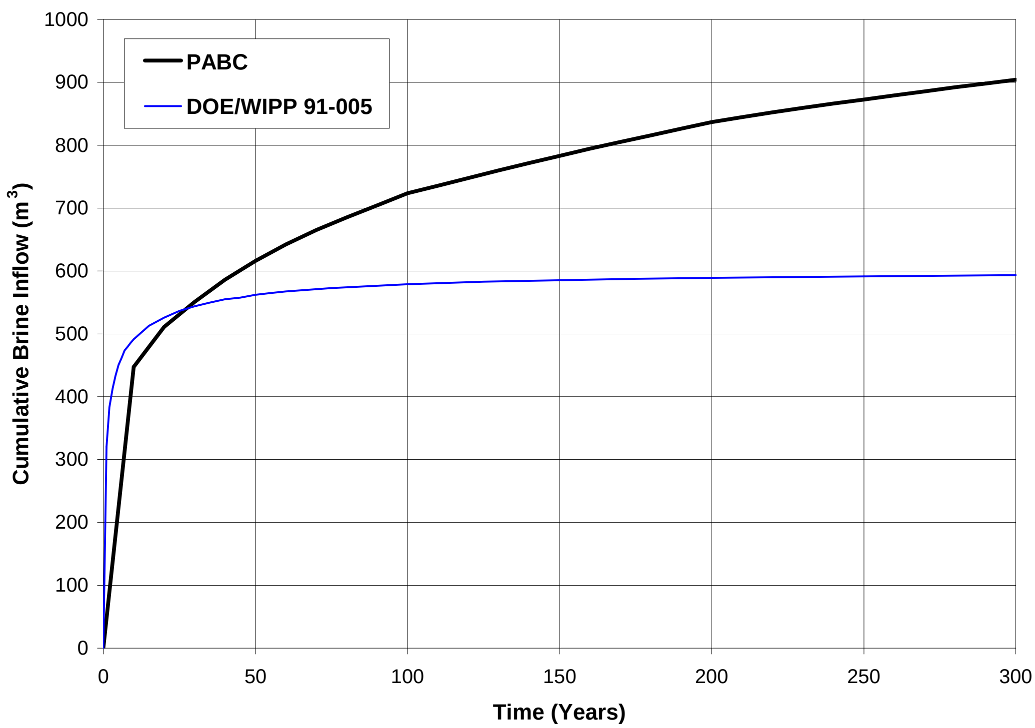

Figure 3. Predicted Cumulative Brine Inflow into a Closed Waste Panel for the PABC and Original Performance Demonstrations

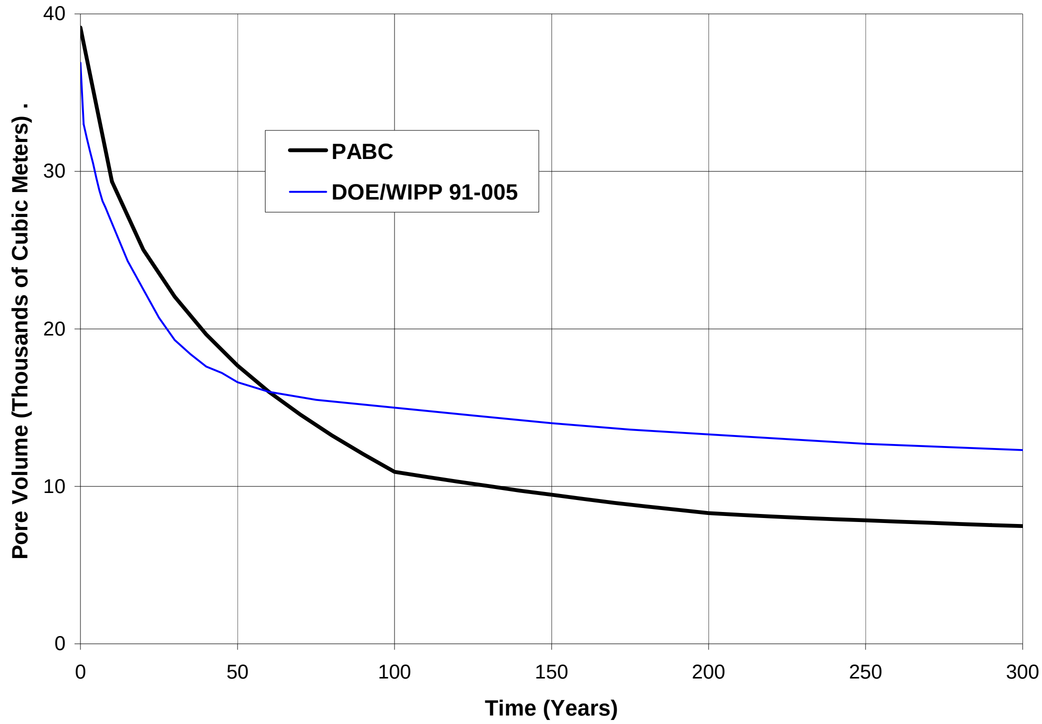

Figure 4. Predicted Change in Panel Pore Volume Due to Creep Closure for the PABC and Original Performance Demonstrations

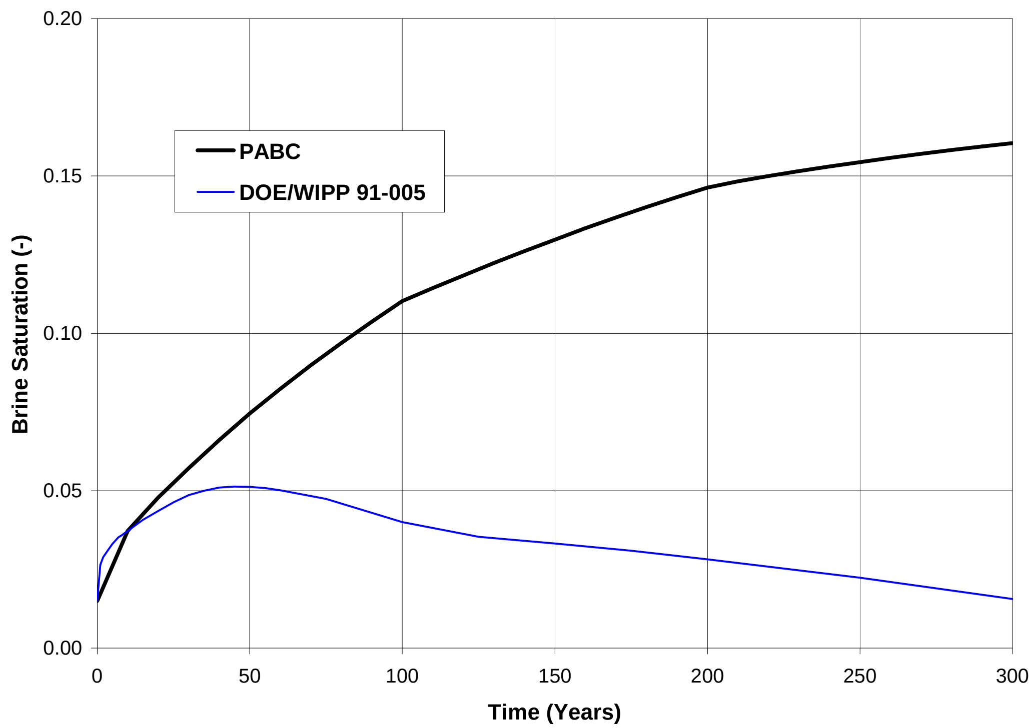

Figure 5. Predicted Average Brine Saturation in the Panel for the PABC and Original Performance Demonstrations

Attachment A

Technical Details of Changes for the PABC Performance Demonstration

The 300-year performance demonstration has been updated as part of the renewal application for the Part B Permit. The revised performance demonstration is based on a similar approach to that used in the original Part B application, but includes the latest conceptual models, codes, and parameters used in the Performance Assessment Baseline Calculation (**PABC**) (Leigh et al. 2005). The PABC is the performance assessment (**PA**) baseline for the EPA's latest recertification of the WIPP[1]. This PA baseline represents DOE's current understanding of the processes and uncertainties that could affect the migration of hazardous waste or of hazardous constituents from the WIPP facility, and is the most appropriate starting point for the revised performance demonstration.

Since the original RCRA 300-year performance demonstration was prepared in 1996 for the WIPP Part B Application, there have been many changes to the conceptual models and parameters used by performance assessment (**PA**) to represent long-term performance of the repository. The individual changes that are relevant to the PABC performance demonstration are described here, with a qualitative estimate of the significance of the change for the performance demonstration. Given the number of changes to conceptual models and the potential for complex interactions between brine inflow, gas generation, room closure, and the DRZ, it is appropriate to use the results of the PABC to predict the quantitative response of the WIPP facility for the 300-year performance demonstration.

The following changes for the PABC are directly relevant to the new demonstration analysis:

(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 (DOE 1996, 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 (Leigh et al. 2005, Section 2.3), while the original performance demonstration uses a constant biodegradation rate (DOE 1996, Chapter D, Table D-2). Two more examples are: (1) the PABC uses distributions for the porosity and permeability of halite (DOE 2004, Appendix PA, Attachment PAR.7, parameter names S_HALITE/POROSITY and S_HALITE/PRMX_LOG), while the original performance demonstration uses constant values for halite porosity and permeability (DOE 1996, Chapter D, Table D-3); and (2) the PABC uses distributions for the permeability and compressibility of anhydrite (DOE 2004, Appendix PA, Attachment PAR.7, parameter names S_MB139/PRMX_LOG and S_MB139/COMP_RCK), while the original performance demonstration uses constant values for halite permeability and halite porosity (DOE 1996, Chapter D, Table D-4).

(2) The original performance demonstration 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 (DOE 1996, Chapter D,

[1] Demonstration of compliance with the disposal standard 40 CFR 191 and its criteria, 40 CFR 194.

Section D-9b(1)(a)). The PABC demonstration uses both inundated and humid rates. The PABC demonstration 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 (Leigh et al. 2005, Sections 2.2 and 2.3).

(3) Microbial gas generation rates are revised for the PABC. The repository is pre-charged at T=0 to represent initial gas production in the new multi-rate gas generation model, and the long-term gas generation rate is reduced, based on 10 years of experimental data (Leigh et al. 2005, Section 2.3).

(4) Microbial degradation occurs through denitrification and sulfidization for the PABC. The multi-step biodegradation reactions are not allowed to progress to methanogenesis (Leigh et al. 2005, Section 2.4).

(5) 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 (DOE 2004, Chapter 6, Table 6-19). On average, this change makes little difference. However, the low and high ends of the distribution will result in less and more brine inflow, respectively, for the same pressure differential between the waste panel and the rock surrounding the repository.

(6) The inundated corrosion rate for iron-based materials without carbon dioxide was changed from a constant value of 7.94×10^{-15} m/s (DOE 1996, Chapter D, Table D-2) to a uniform distribution with a range of 0 to 3.17×10^{-14} m/s (DOE 2004, Chapter 6, Table 6-12). This change increases the gas generation from iron corrosion, all other factors (such as brine saturation) being equal.

(7) 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 (DOE 2004, Chapter 6, Section 6.4.3.2 and Table 6-10). This change has an insignificant effect on Salado flow because the waste permeability is orders of magnitude greater than the permeabilities of the surrounding halite and anhydrite (DOE 2004, Chapter 6, Tables 6-16 and 6-17).

(8) The modeling of the four shafts connecting the repository to the surface has been simplified (DOE 2004, Chapter 6, Section 6.4.4 and Appendix PA, Section PA-4.2.7). The planned design of the shaft seals involves numerous materials including earth, crushed salt, clay, asphalt, and Salado Mass Concrete. For the original compliance demonstration, each material in the shaft seal design was represented in the BRAGFLO grid (DOE 1996, Chapter D, Section D-9b(1)(b)(ii) and Table D-5). The simplified shaft model for the PABC divides the shaft into three sections: an upper section (shaft seal above the Salado), a lower section (within the Salado), and a concrete monolith section within the repository horizon. This simplification is reasonable because no significant flow of gas or brine occurs within the shaft seal system over the 10,000 year regulatory period (DOE 2004, Appendix PA, Section PA-4.2.7).

(9) The grid geometry and repository layout were changed in the BRAGFLO model, including revised radial flaring in the BRAGFLO grid (DOE 2004, Appendix PA, Attachment MASS, Section MASS-4.2). This had an insignificant effect on Salado flow (Stein and Zelinski 2003).

(10) Representation of panel closures was changed from a generic design to the Option D panel closure design. This change also included a fracture model for the DRZ above

the closures. This change affected pressures and saturations in the waste emplacement areas and operations/experimental areas of the repository (DOE 2004, Chapter 6, Section 6.4.3).

(11) 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.

(12) The waste inventory was changed for the PABC. The amounts of cellulosic, plastic, and rubber materials have changed and include emplacement materials. The new values for radionuclide inventory and waste material parameters for the PABC are defined in Leigh, Trone, and Fox (2005).

(13) The residual saturation and rock compressibility parameters for MB 138/139 and Anhydrite A&B have changed for the PABC (Leigh et al. 2005, Table 2-1).

<u>References</u>

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