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PERFORMANCE AND REGULATORY COMPLIANCE IMPACTS OF CHANGES INCLUDED IN THE 2014 WIPP COMPLIANCE RECERTIFICATION APPLICATION

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The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA). The DOE demonstrates compliance with the containment requirements by means of performance assessment (PA) calculations. WIPP PA calculations estimate the probability and consequence of potential radionuclide releases from the repository to the accessible environment for a regulatory period of 10,000 years after facility closure. WIPP PA models are used to support the repository recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999. The PA executed in support of the 2014 Compliance Recertification Application (CRA-2014) for WIPP includes a number of repository planned changes, parameter updates, and refinements to PA implementation. Among these changes is the incorporation of a new panel closure system design, additional mined volume in the north end of the repository, a refinement to the PA representation of WIPP waste shear strength, and a refinement to the gas generation rate associated with corrosion of emplaced steel waste materials. The CRA-2014 PA investigates the effect of these changes on repository performance, and demonstrates that the WIPP continues to satisfy regulatory containment requirements when these changes are included in the overall repository model.

I. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) consists of a deep underground mined facility located in a bedded salt formation in southeastern New Mexico, USA. Containment of transuranic waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA). The U.S. Department of Energy (DOE) demonstrates compliance with regulatory containment requirements by means of performance assessment (PA) calculations. The Land Withdrawal Act (U.S. Congress 1992) requires that the DOE apply for WIPP recertification every five years following the initial 1999 waste shipment. The 2014 Compliance Recertification Application (CRA-2014) is the third WIPP recertification application submitted by the DOE for EPA approval. The CRA-2014 PA includes a number of technical changes and parameter refinements, as well as a redesigned WIPP panel closure system. The current WIPP regulatory baseline was established by the 2009 Compliance Recertification Application Performance Assessment Baseline Calculation (PABC-2009) (Clayton et al. 2010). Results found in the CRA-2014 PA are compared to those obtained in the PABC-2009 in order to assess repository performance in terms of the current regulatory baseline.

II. CHANGES SINCE THE PABC-2009

Several changes are incorporated into the CRA-2014 PA relative to the PABC-2009, and include the following:

- Replacement of the “Option D” WIPP panel closure with a newly designed Run-of-Mine Panel Closure System (ROMPCS).
- Inclusion of additional mined volume in the repository north end.
- An update to the probability that a drilling intrusion into a repository excavated region will result in a pressurized brine encounter.
- Refinement to the corrosion rate of steel.
- Refinement to the effective shear strength of WIPP waste.
- Updates to drilling rate and plugging pattern parameters.
- Updates to WIPP waste inventory parameters.
- Calculation of radionuclide concentration in brine as a function of the brine volume present in repository waste regions.
- Updates to radionuclide solubilities and their associated uncertainty.

- Enhancement of the repository water balance implementation so as to include MgO hydration.
- Updated colloid enhancement parameters.

These changes and the motivations for making them are now discussed.

Replacement of Option D with the ROMPCS

WIPP waste panel closures comprise a feature of the repository that has been represented in WIPP PA regulatory compliance demonstration since the CCA (U.S. DOE 1996). The 1998 rulemaking that certified WIPP to receive TRU waste required DOE to implement the Option D panel closure system (PCS) at the WIPP. Following the selection of the Option D panel closure design in 1998, the DOE has reassessed the engineering of the panel closure and established a revised design which is simpler, cheaper, easier to construct, and equally effective at performing its operational-period isolating function. The DOE has submitted a planned change request to the EPA requesting that EPA modify Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194 (U.S. EPA 1998) for the WIPP, and that a revised panel closure design be approved for use in all panels (U.S. DOE 2011a). The revised panel closure design, denoted as the ROMPCS, is comprised of 100 feet of run-of-mine (ROM) salt with barriers at each end. The ROM salt is generated from ongoing mining operations at the WIPP while the barriers consist of ventilation bulkheads, similar to those currently used in the panels as room closures. The CRA-2014 PA representation of the ROMPCS incorporates material parameters and temporal behavior to account for the following physical processes and rock mechanics principles:

1. Creep closure of the salt rock surrounding panel entries will cause consolidation of ROM salt emplaced in panel entries.
2. Eventually, the ROM salt comprising the closures will approach a condition similar to intact salt.
3. As ROM salt reaches higher fractional densities during consolidation, back stress will be imposed on the surrounding rock mass leading to eventual healing of the disturbed rock zone (DRZ).
4. DRZ healing above and below the ROM salt panel closures will reduce DRZ porosity and permeability in those areas.

The ROMPCS properties are based on three time periods: from 0 to 100 years, from 100 years to 200 years, and from 200 years to 10,000 years. Three time periods are appropriate because the process to consolidate the ROM salt occurs over a primary time scale of approximately 100 years, while the process to heal fractures in the DRZ surrounding the PCS occurs over a longer time scale of approximately 200 years. Analyses and calculations have shown (Camphouse et al 2012a) that the time-dependent back stress imposed on the DRZ by the re-consolidated ROM salt panel closure does not become appreciable until roughly 200 years after emplacement of the ROM salt in the drift. As a result, it is reasonable and appropriate to maintain the same properties for the DRZ above and below the ROMPCS for the first 200 years after closure as are specified to the DRZ surrounding the disposal rooms. After 200 years, the DRZ above and below the ROMPCS is modeled as having healed.

Additional Mined Volume

Following the recertification of the WIPP in November of 2010 (U.S. EPA 2010a), the DOE submitted a planned change notice to the EPA that justified additional excavation in the WIPP experimental region (U.S. DOE 2011b) to be used for a Salt Disposal Investigations research project. An additional excavated volume of 60,335 m^3 in the WIPP experimental area is included in the CRA-2014 PA to account for this additional excavated volume.

Probability of a Pressurized Brine Encounter

Penetration into a region of pressurized brine during a hypothetical drilling intrusion into the WIPP can have significant consequences with respect to subsequent releases. A framework that provides a quantitative argument for refinement of the probability of a pressurized brine pocket encounter has been developed since the PABC-2009 (Kirchner et al. 2012). The refinement results from a re-examination of existing data and includes a greatly expanded set of drilling data for locations adjacent to the WIPP site than were available in 1998 when the original analysis was performed.

Steel Corrosion Rate Update

The interaction of steel in the WIPP with repository brines will result in the formation of H_2 gas due to anoxic corrosion of the metal. The rate of H_2 gas generation will depend on the corrosion rate and the type of corrosion products formed. A new series of steel and lead corrosion experiments has been conducted with the aim of directly determining steel and lead corrosion rates under WIPP-relevant conditions. Based on the newly obtained experimental corrosion data and it subsequent analysis, the anoxic corrosion rate for brine-inundated steel in the absence of microbially produced CO_2 is updated in the CRA-2014 PA to reflect the new experimental data (Roselle 2013).

Waste Shear Strength Refinement

WIPP PA includes scenarios in which human intrusion results in a borehole intersecting the repository. During the intrusion, drilling mud flowing up the borehole will apply a hydrodynamic shear stress on the borehole wall. Erosion of the wall material can occur if this stress is high enough, resulting in a release of radionuclides being carried up the borehole with the drilling mud. In this intrusion event, the drill bit would penetrate repository waste, and the drilling mud would flow up the borehole in a predominately vertical direction. In order to experimentally simulate these conditions, a flume was designed and constructed. In the flume experimental apparatus, eroding fluid enters a vertical channel from the bottom and flows past a specimen of surrogate WIPP waste (Herrick et al. 2012). Experiments were conducted to determine the erosive impact on surrogate waste materials that were developed to represent WIPP waste that is 50%, 75%, and 100% degraded by weight. The effective shear strength of WIPP waste is updated in the CRA-2014 PA to reflect the experimental flume results (Herrick 2013).

Drilling Rate and Plugging Pattern Parameters

WIPP regulations require that current drilling practices are assumed for future inadvertent intrusions in WIPP PA. The DOE continues to survey drilling activity in the Delaware Basin in accordance with the criteria established in 40 CFR 194.33. Results for the year 2012 are documented in the 2012 Delaware Basin Monitoring Annual Report (U.S. DOE 2012). Plugging pattern probabilities and the drilling rate are updated in the CRA-2014 PA to include information assembled through year 2012 (Camphouse 2013).

Waste Inventory Parameters

The waste information used in the CRA-2014 PA is updated from that used in the PABC-2009 calculations. The Performance Assessment Inventory Report (PAIR) – 2012 (Van Soest 2012) was released on November 29, 2012. The PAIR – 2012 contains updated estimates to the anticipated radionuclide content and waste material parameters, scaled to a full repository, based on inventory information collected through December 31, 2011. WIPP PA inventory parameters are updated in the CRA-2014 PA to account for this new information (Kicker and Zeitler 2013a).

Variable Brine Volume

The release of contaminated brine to the ground surface during a hypothetical drilling intrusion is termed a direct brine release (DBR). The conceptual model for direct brine releases (DBRs) is used to develop the minimum repository brine volume that can result in a DBR. In the PABC-2009 and the CRA-2014 PA, this minimum volume of brine is 17,400 m^3 (Clayton 2008). To date, the minimum brine volume necessary for a DBR has been used as an input to the radionuclide solubility calculation. The entire organic ligand inventory was assumed to be dissolved in the minimum necessary brine volume, and the resulting organic ligand concentrations were then used in the calculation of radionuclide solubilities. The WIPP organic ligand inventory has tended to increase over time. The use of a constant organic ligand concentration in brine that is independent of the actual volume of brine present in the repository has resulted in overall mass-balance errors. For large repository brine volumes, the use of ligand concentrations that correspond to the minimum brine volume necessary for a DBR yields greater quantities of dissolved organics in brine than are present in the waste inventory. The result is higher actinide concentrations in brine than are physically attainable when repository brine volumes are large. As a result, the calculation of base radionuclide solubilities is extended in the CRA-2014 so that they are dependent on the concentration of organic ligands which vary with the actual volume of brine present in the repository (Brush and Domski 2013a). Brine volumes of 1x, 2x, 3x, 4x, and 5x the minimum requisite repository brine volume for a DBR are used in the calculation of baseline radionuclide solubilities in the CRA-2014 (Brush and Domski 2013b). The organic ligand waste inventory is assumed to be dissolved in each of these multiples of the minimum necessary brine volume. The resulting organic ligand concentrations, now dependent on a range of brine volume, are then used to calculate baseline radionuclide solubilities corresponding to each brine volume. This approach keeps radionuclide mass constant over realized brine volumes, rather than keeping radionuclide concentration constant over realized brine volumes.

Radionuclide Solubilities and Uncertainty

The solubilities of actinide elements are influenced by the chemical components (for example organic ligands) of the waste. With the release of the PAIR - 2012 (Van Soest 2012), updated information on the amount of various chemical components in the waste is available. To incorporate this updated information, parameters used to represent baseline actinide solubilities are updated in the CRA-2014 PA. Baseline radionuclide solubilities are calculated in the CRA-2014 PA using multiples of the minimum brine volume necessary for a DBR to occur. Additional experimental results have been published in the literature since the PABC-2009, and this new information is used in the CRA-2014 PA to enhance the uncertainty ranges and probability distributions for actinide solubilities (Brush and Domski 2013b,c).

Repository Water Balance Enhancement

The saturation and pressure history of the repository are used throughout WIPP PA. Along with flow in and out of the repository, the saturation and pressure are influenced by the reaction of materials placed in the repository with the surrounding environment. As part of the review of the CRA-2009, the EPA noted several issues for possible additional investigation, including the potential implementation of a more detailed repository water balance (U.S. EPA 2010b). The repository water balance implementation is refined in the CRA-2014 PA in order to include the major gas and brine producing and consuming reactions in the existing conceptual model (Clayton 2013). In the expanded water budget implementation, MgO hydration consumes water and produces brucite. The carbonation of brucite forms hydromagnesite. Hydromagnesite dehydrates to form magnesite. Iron hydroxide sulfidation is also included as a mechanism for water production.

Updated Colloid Parameters

Colloid parameters are updated in the CRA-2014 PA to incorporate recently available data (Reed et al. 2013). Actinide colloid enhancement parameters were re-assessed and updated, as appropriate, to reflect recent literature and more extensive WIPP-specific data.

III. APPROACH

The aim of the CRA-2014 PA is to quantify regulatory compliance impacts associated with changes made since the PABC-2009. Impacts are determined by a direct comparison of CRA-2014 PA and PABC-2009 results. The approach taken in the CRA-2014 PA is to reasonably isolate impacts associated with these changes, and then to assess the combined impact when all are included in the PA. To that end, four individual cases are investigated in the CRA-2014 PA.

The first case considered in the CRA-2014 PA is used to compare the impact of a baseline set of changes relative to the PABC-2009. The name given to this case is CRA14-BL (for CRA-2014 Baseline). Regulatory compliance impacts associated with replacement of the Option D panel closure with the ROMPCS design were assessed in a PA termed the PCS-2012 PA. PCS-2012 PA results are discussed and compared to PABC-2009 results in Camphouse et al. (2012b). Similarly, impacts of additional mining in the WIPP experimental area are assessed via a comparison to PABC-2009 results in Camphouse et al. (2011). Consequently, these two planned repository changes are included in case CRA14-BL as their impacts have already been assessed via comparisons to the PABC-2009. In addition to these two planned changes, “standard” updates typically included in a re-certification PA are also be included in case CRA14-BL. These changes consist of updates to waste inventory parameters, baseline radionuclide solubilities (corresponding to the minimum requisite repository brine volume for a DBR), radionuclide solubility uncertainties, colloid enhancement factors, and updates to repository drilling rates and plugging patterns.

With the results of case CRA14-BL in hand, two parameter updates are added to the set of baseline changes so that their impacts can be determined. In WIPP PA, the parameter representing the waste shear strength is denoted as BOREHOLE:TAUFAIL. The parameter corresponding to the probability of encountering pressurized brine during a hypothetical drilling intrusion is denoted as GLOBAL:PBRINE. The addition of these two parameter updates, and their impact on regulatory compliance, are captured in case CRA14-TP (for CRA-2014 (T)AUFAUL (P)BRINE). Case CRA14-TP consists of a focused re-run of case CRA14-BL with updated distributions implemented for parameters BOREHOLE:TAUFAIL and GLOBAL:PBRINE.

The focus of case CRA14-BV (for CRA-2014 (B)rine (V)olumes) is to assess the impact of the variable brine volume implementation on results calculated in case CRA14-TP. Thus, case CRA14-BV consists of a focused re-run of case CRA14-TP, and incorporates radionuclide concentrations based on 1x, 2x, 3x, 4x, and 5x the minimum requisite brine volume for a DBR. Case CRA14-BV incorporates all changes included in case CRA14-TP as well as the implementation of variable brine volume in the calculation of radionuclide concentrations in brine.

Case CRA14-0 incorporates all changes included in the CRA-2014 PA. That is, case CRA14-0 includes all changes described for case CRA14-BV as well as the refinements to the steel corrosion rate and a water balance that includes MgO hydration.

III. COMPLIANCE METRIC

Results of WIPP performance assessments are assembled into complementary cumulative distribution functions (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events. The outcome of WIPP PA is a set of CCDFs that quantify release probabilities and their associated uncertainties. There must be at least a 95% level of statistical confidence that the mean of the population of CCDFs meets regulatory containment requirements for regulatory compliance of the facility to be demonstrated.

Overall, the behavior of the undisturbed repository results in extremely effective isolation of the radioactive waste. WIPP PA is required by the performance standards to consider scenarios that include intrusions into the repository by inadvertent and intermittent drilling for resources. Human intrusion by drilling may cause releases from the disposal system through five mechanisms:

1. Cuttings, which include material intersected by the rotary drilling bit
2. Cavings, which include material eroded from the borehole wall during drilling
3. Spallings, which include solid material carried into the borehole during rapid depressurization of the waste disposal region
4. Direct brine flows, which include contaminated brines that may flow to the surface during drilling
5. Actinide transport by long-term groundwater flow, which includes the contaminated brine that may flow through a borehole after it is plugged and abandoned

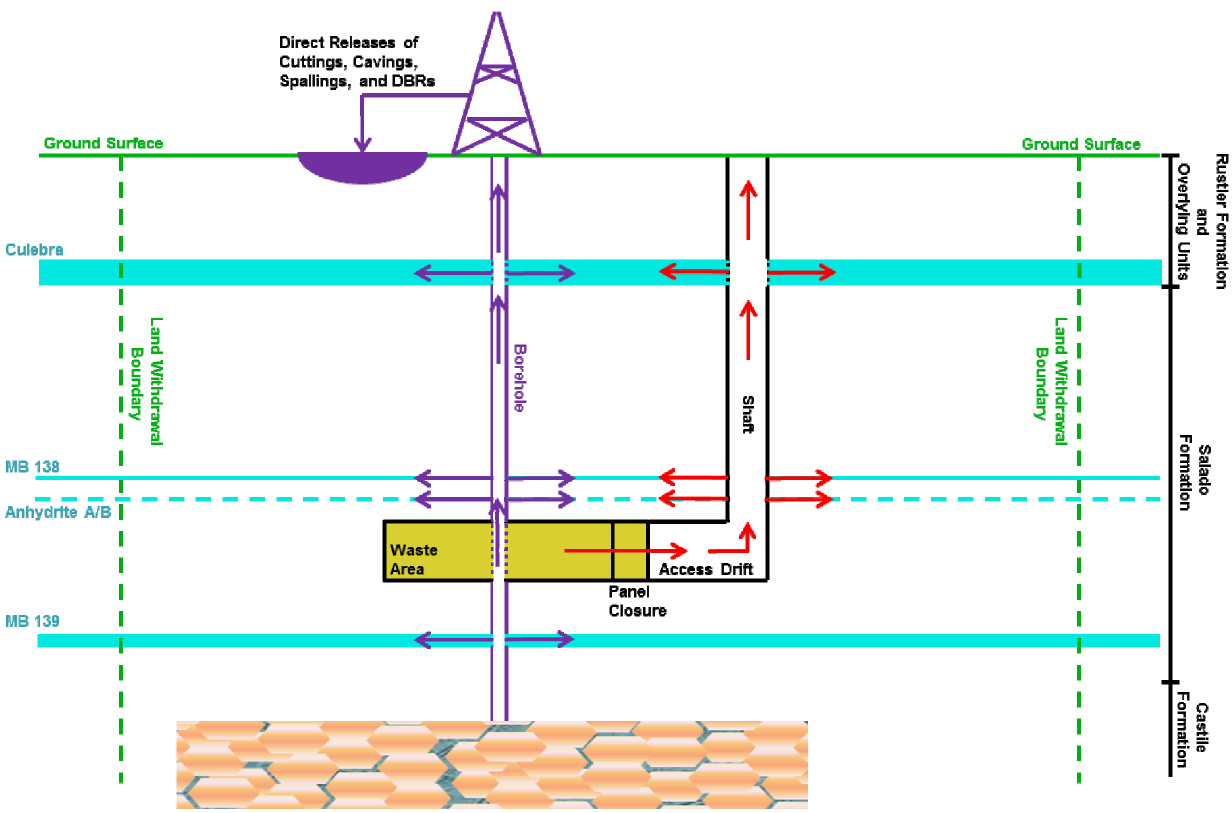

Figure 1: Possible Release Mechanisms after Human Intrusion

The first four mechanisms immediately follow an intrusion event and are collectively referred to as direct releases. The fifth mechanism, actinide transport by long-term groundwater flow in the Culebra Formation (hereafter referred to as the Culebra), begins when concrete plugs are assumed to degrade in an abandoned borehole and may continue throughout the 10,000-year regulatory period (Figure 1).

Releases are quantified in terms of "EPA units". Releases in EPA units result from a normalization by radionuclide and the total inventory. For each radionuclide, the ratio of its 10,000 year cumulative release (in curies) to its release limit is calculated. The sum of these ratios is calculated across the set of radionuclides and normalized by the transuranic inventory (in curies) of α-emitters with half-lives greater than 20 years. Mathematically, the formula used to calculate releases in terms of EPA units is of the form

$$R = \frac{1 \times 10^6 \text{ curies}}{C} \sum_i \frac{Q_i}{L_i}$$

where R is the normalized release in EPA units. Quantity Q_i is the 10,000 year cumulative release (in curies) of radionuclide i. Quantity L_i is the release limit for radionuclide i, and C is the total transuranic inventory (in curies) of α-emitters with half-lives greater than 20 years.

IV. RESULTS

Results obtained in the CRA-2014 PA are now presented. A comparison of the WIPP waste inventory (in EPA units) used in the PABC-2009 and the CRA-2014 PA is shown in Figure 2. The total number of EPA Units in the CRA-2014 PA waste inventory at the closure year of 2033 is 10,197 (Kicker and Zeitler 2013b). This number is slightly higher than the value of 10,080 EPA units corresponding to the PABC-2009 waste inventory at year 2033 (Fox and Clayton 2010). By 10,000 years post-closure, the total number of EPA Units in the CRA-2014 PA decreases to 2,388. The analogous number in the PABC-2009 is 1,680 EPA Units, indicating an increase in the CRA-2014 PA. As seen in Figure 2, the total EPA Units for both inventories start at similar levels, but the CRA-2014 PA inventory is higher after approximately 100 years and remains higher throughout the 10,000-year regulatory period. The increase seen in the CRA-2014 PA result is primarily due to an increase in ^{239}Pu inventory. Figure 3 to Figure 9 show mean CCDF results for total normalized releases obtained in the CRA-2014 PA. Total releases are calculated by forming the summation of releases across each potential release pathway, namely cuttings and cavings releases, spallings releases, direct brine releases, and Culebra transport releases.

Results for Case CRA14-BL are shown in Figure 3. The replacement of the Option D panel closure system with the ROMPCS results in similar, but slightly greater, total normalized releases than were seen in the PABC-2009. This is evident by comparing the red PCS-2012 PA CCDF and the blue PABC-2009 CCDF in Figure 3. The ROMPCS has lower long-term permeability characteristics (on average) than the Option D PCS, resulting in higher waste region pressure trends. Increases to waste region pressure increase spallings release volumes and typically increase DBR volumes as well. The revised CRA-2014 PA inventory, drilling rate, and actinide solubilities collectively yield an increase to total normalized releases in case CRA14-BL. As shown in Figure 2, the activity (in EPA units) of the CRA-2014 PA waste inventory is higher. The drilling rate is also increased in the CRA-2014 PA, resulting in an increased probability of a drilling intrusion event when calculating potential releases from the repository.

Results for case CRA14-TP are shown in Figure 4. The refinements to the waste shear strength and the probability of a pressurized brine pocket encounter during a hypothetical drilling intrusion lead to reductions in the mean CCDFs for cuttings/cavings releases and DBRs, respectively (Figure 5). The result is a reduced mean CCDF for total normalized releases in case CRA14-TP as compared to case CRA14-BL (Figure 4). When radionuclide concentrations are calculated over a range of brine volumes, the mean CCDF for DBRs is also reduced, resulting in further reduction to the mean CCDF for total normalized releases (Figure 6).

The revised iron corrosion rate implemented in case CRA14-0 translates to a reduction in repository gas generation, and consequently waste region pressure (on average). Water sequestration in the revised water balance implementation also contributes to a reduction in gas generation. These impacts reduce releases due to spallings and DBRs. The combined effect of these changes is a slight reduction to total normalized releases in case CRA14-0 as compared to case CRA14-BV (Figure 7).

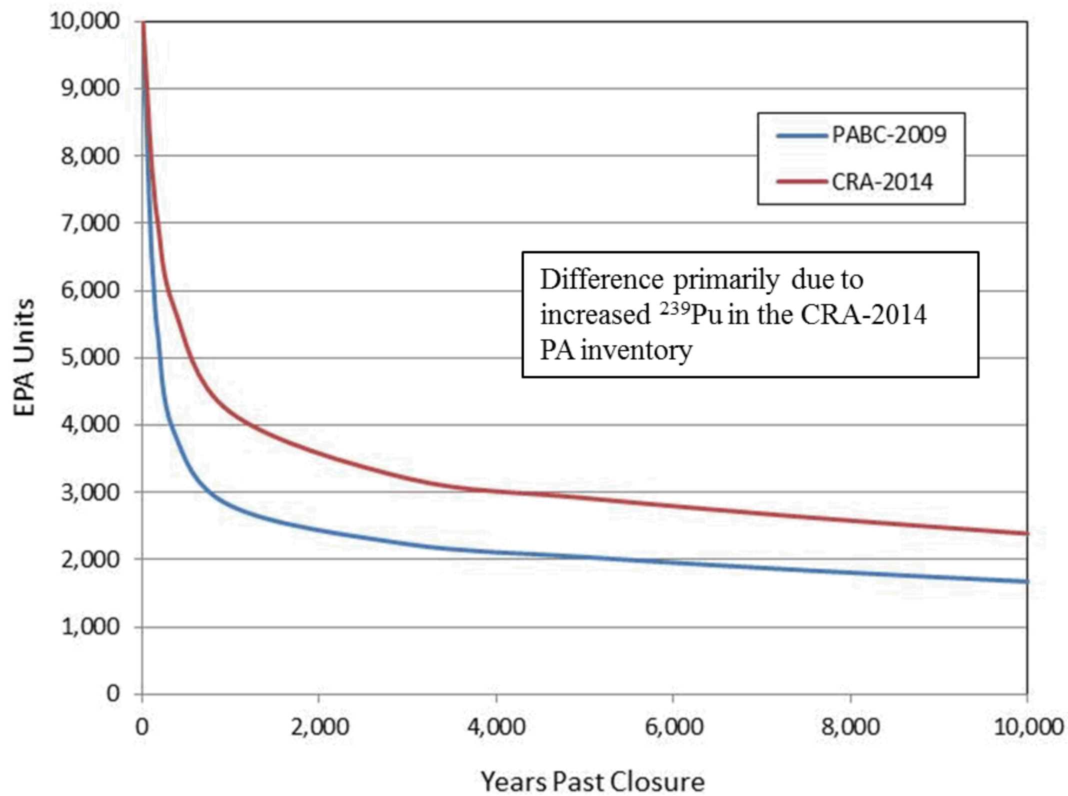

Figure 2: WIPP Waste Inventory Activity (in EPA Units) from Closure to 10,000 Years

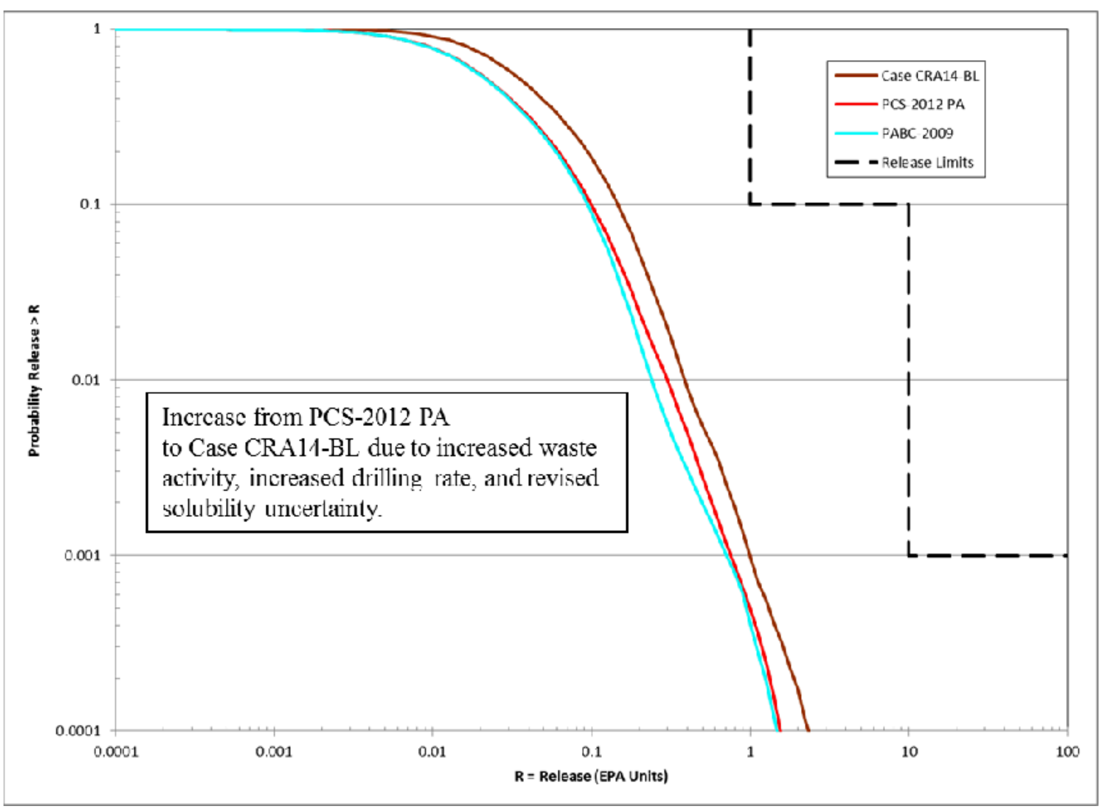

Figure 3: Total Normalized Release CCDF Comparisons for Case CRA14-BL

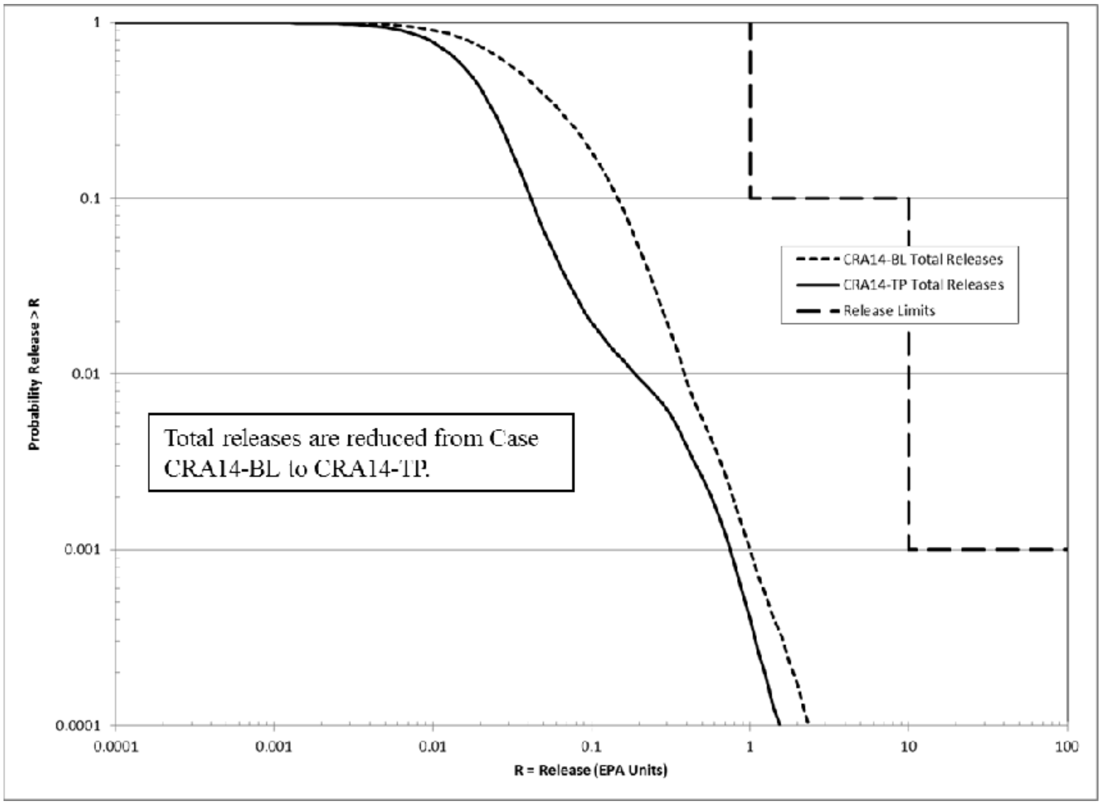

Figure 4: Total Normalized Release CCDF Comparisons for Case CRA14-TP

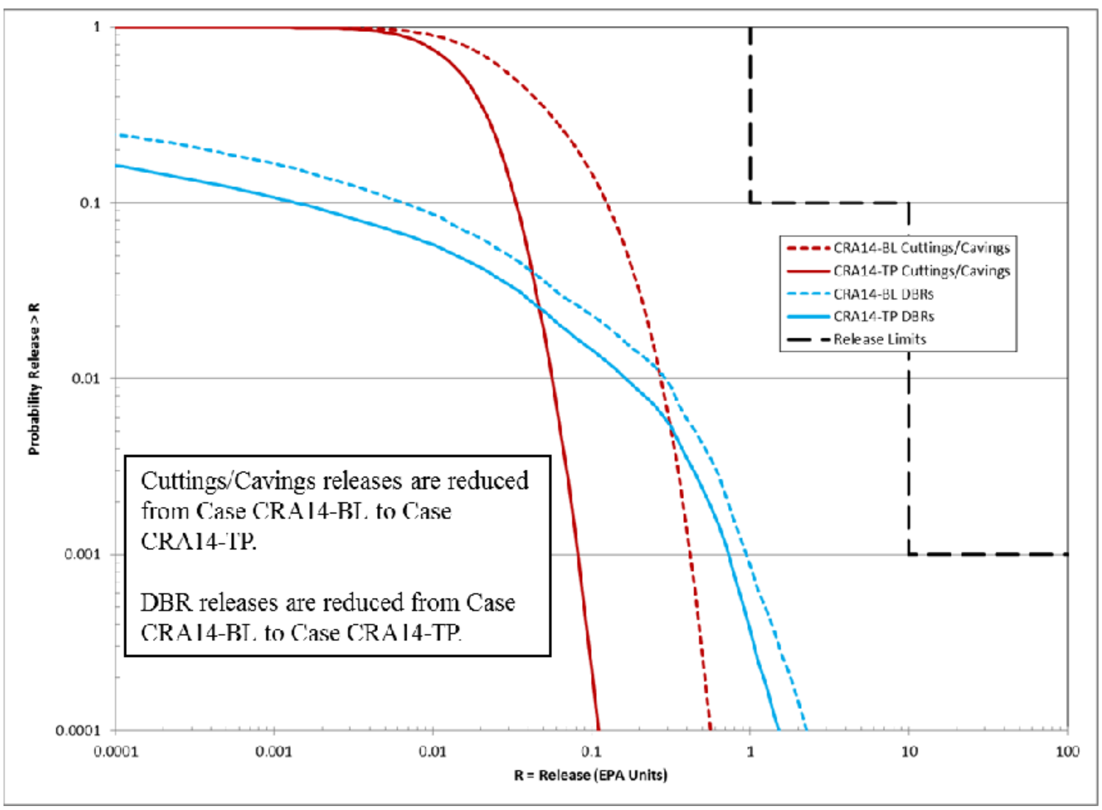

Figure 5: Mechanisms Contributing to CCDF Reductions in Case CRA14-TP

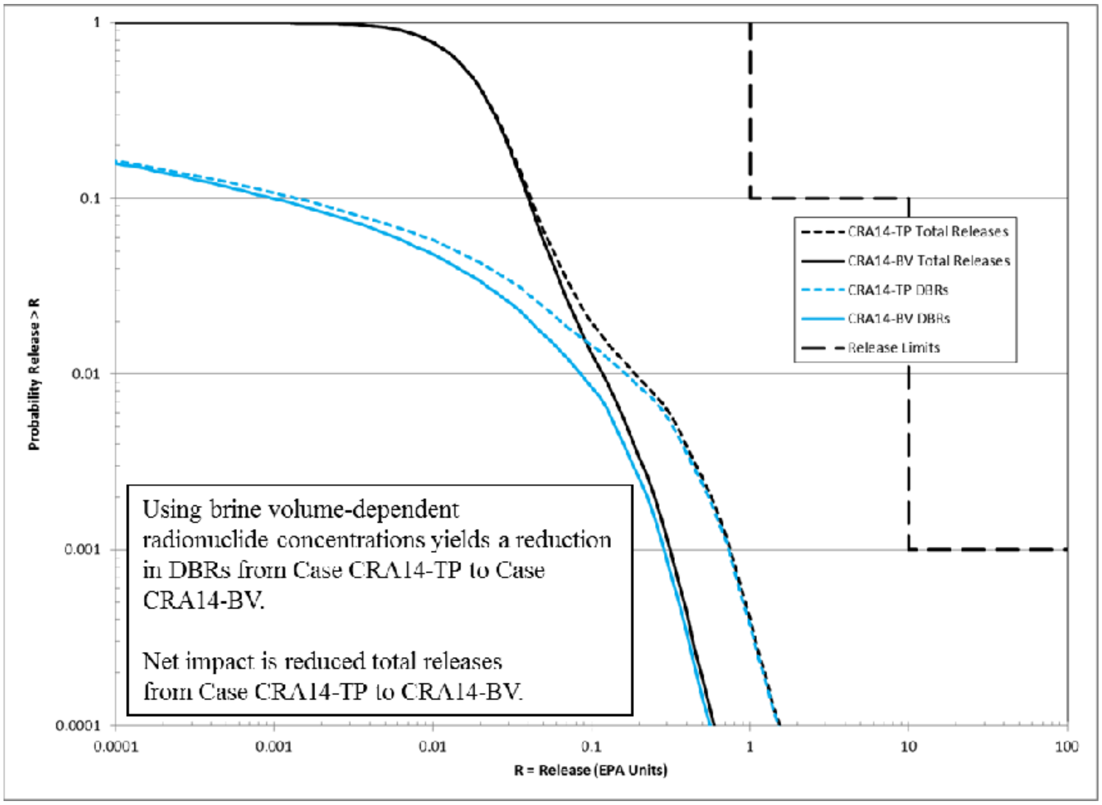

Figure 6: Total Normalized Release CCDF Comparisons for Case CRA14-BV

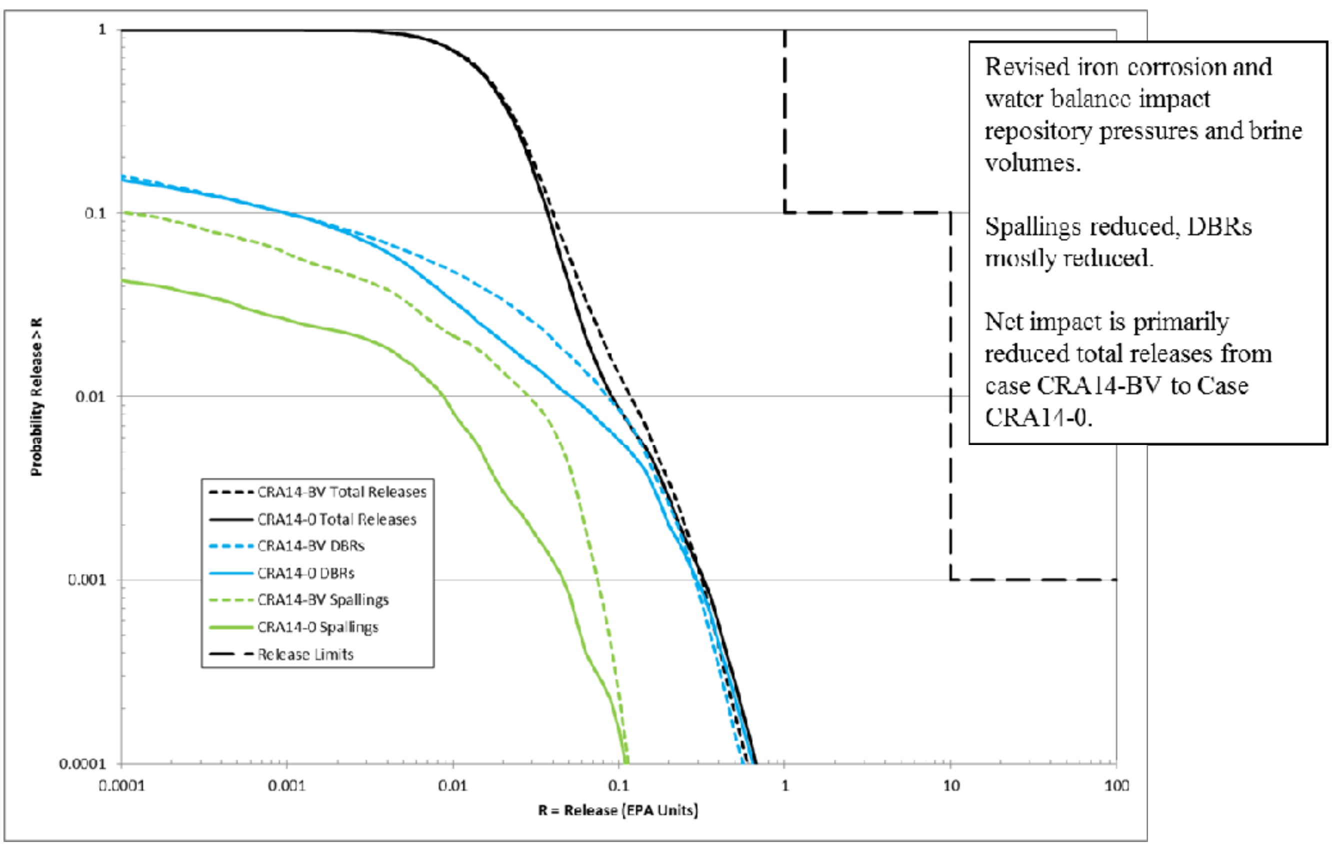

Figure 7: Total Normalized Release CCDF Comparisons for Case CRA14-0

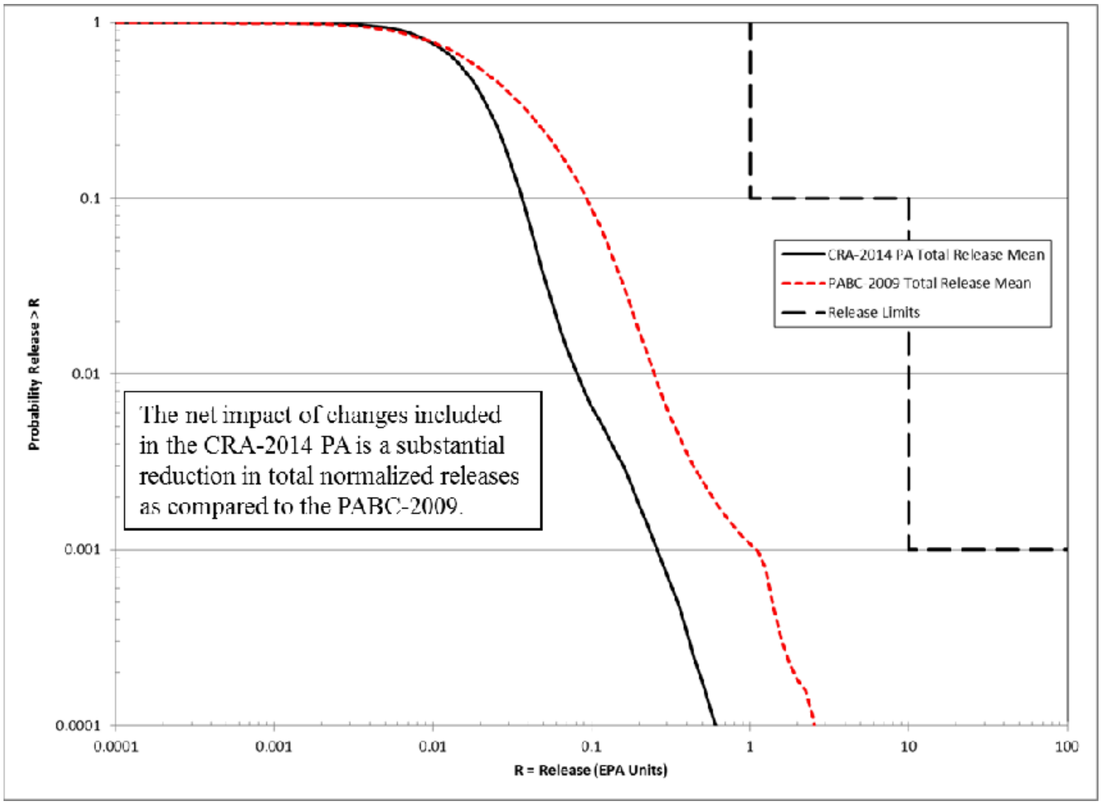

Figure 8: Comparison of Total Normalized Release CCDFs for the PABC-2009 and the CRA-2014 PA

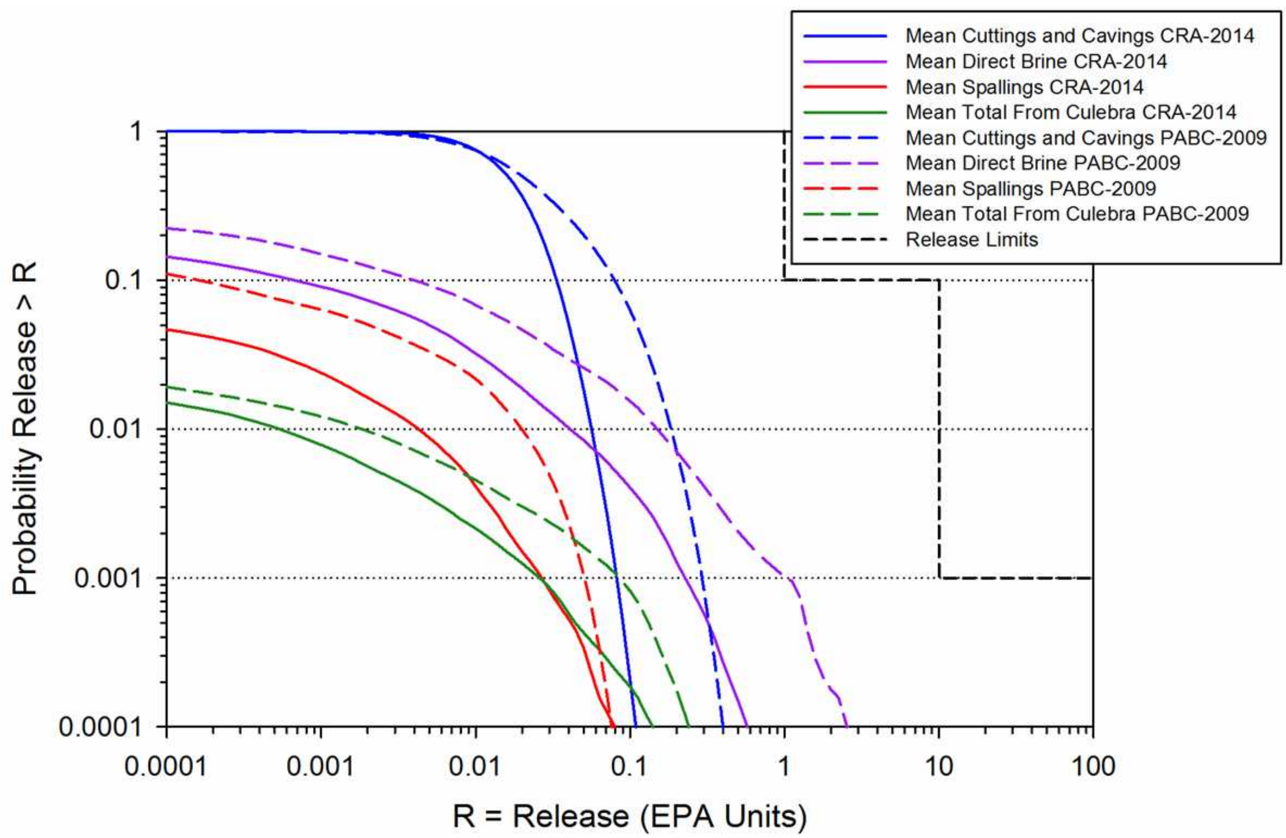

Figure 9: Comparison of Release Mechanism CCDFs for the PABC-2009 and the CRA-2014 PA

When all changes are included in the PA, the result is a substantial reduction to the mean CCDF for total releases in the CRA-2014 PA as compared to the PABC-2009 (Figure 8). Mean CCDFs for each release mechanism are reduced in the CRA-2014 PA as compared to the PABC-2009 (Figure 9).

V. SUMMARY

The current WIPP regulatory baseline was established by the PABC-2009. The CRA-2014 is the third WIPP recertification application submitted by the DOE for EPA approval. Several changes are incorporated into the CRA-2014 PA relative to the PABC-2009. These modifications are comprised of planned repository changes, parameter updates, and refinements to PA implementation. Total normalized releases obtained in the CRA-2014 PA are lower than those found in the PABC-2009, and continue to remain below regulatory limits. As a result, the CRA-2014 PA demonstrates that the WIPP remains in compliance with the containment requirements of 40 CFR Part 191. The changes included in the CRA-2014 PA yield reductions to release mechanisms that contribute to total normalized releases.

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