Modifications Implemented for the 2014 WIPP Compliance Recertification Application and their Impacts on Regulatory Compliance

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The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico of the United States (U.S.), has been developed by the U.S. Department of Energy (DOE) for the geologic disposal of transuranic (TRU) waste. The DOE demonstrates compliance with the WIPP 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 (in part) 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 parameter, implementation, and repository feature changes. Among these changes are 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 gas generation rate refinement. These changes are briefly discussed, as is their cumulative impact on regulatory compliance for the facility. The federal recertification status of the WIPP is also discussed.

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 U.S. Land Withdrawal Act 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, and most recent, WIPP recertification application submitted by the DOE for EPA approval. The current WIPP regulatory baseline was established by the 2009 Compliance Recertification Application Performance Assessment Baseline Calculation (PABC-2009)[1]. Results found in the CRA-2014 PA[2] are compared to those obtained in the PABC-2009 in order to assess repository performance in terms of the current regulatory baseline. Modifications incorporated into the CRA-2014 PA consist of planned repository changes, parameter updates, refinements to PA implementation, and include the following:

- Replacement of the approved WIPP panel closure system 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 actual brine volume present in the waste panel.
- Updates to radionuclide solubilities and their associated uncertainty.
- Implementation of a more detailed repository water balance that includes MgO hydration.

II. COMPLIANCE METRIC

The WIPP PA methodology accommodates both aleatory (i.e. stochastic) and epistemic (i.e. subjective) uncertainty in its constituent models. Epistemic uncertainty is accounted for by sampling of parameter values from assigned distributions. One set of sampled values required to run a WIPP PA calculation is termed a vector. In the CRA-2014 PA, models were executed for three replicates of 100 vectors. A sample size of 10,000 possible sequences of future events is used in WIPP PA calculations to address aleatory uncertainty. The releases for each of 10,000 possible sequences of future events are tabulated for each of the 300 vectors, totaling 3,000,000 possible sequences.

Results of WIPP PAs 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. Compliance demonstration requires a 95% level of statistical confidence that the mean of the population of CCDFs meets regulatory containment requirements.

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 also consider scenarios that include disruptive events such as hypothetical 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 releases (DBRs), 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.

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.

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

$$R = \sum_i \left(\frac{Q_i}{L_i} \right) \left(\frac{1 \times 10^6 \text{ Ci}}{C} \right) \qquad (1)$$

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.

III. CHANGES IN THE CRA-2014 PA

A brief discussion of several changes included in the CRA-2014 PA is now presented.

III.A. Waste Panel Closure Redesign

WIPP waste panel closures comprise a feature of the repository that has been represented in WIPP PA regulatory compliance demonstration since the original WIPP Compliance Certification Application. The 1998 rulemaking that certified WIPP to receive TRU waste required the DOE to implement a specific panel closure system at the WIPP. Following the selection of this 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 submitted a planned change request to the EPA requesting that EPA modify Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194 for the WIPP, and that a revised panel closure design be approved for use in all panels[3]. The EPA approved the request by DOE to implement the new panel closure design and amended the WIPP Compliance Criteria to allow an EPA-approved panel closure other than the currently-required design.

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 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.

Many of the parameters used to define the material and temporal characteristics of the ROMPCS are derived via sampling. For example, uniform distributions are specified for material properties such as porosity and permeability. Latin Hypercube Sampling is then performed using these distributions to obtain sufficient realizations of ROMPCS behavior over the range of parameter uncertainty.

III.B. Refinement to the Effective Shear Strength of WIPP Waste

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. 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. A description of the vertical flume, the experiments conducted in it, and conclusions to be drawn from those experiments are discussed in Herrick et al.[4]. Based on these experiments, the probability distribution specified for the shear strength of WIPP waste was changed. A loguniform distribution having a minimum of 0.05 and a maximum of 77, with units of Pa was prescribed for this parameter in the PABC-2009. Using the results developed from the flume experiments, a uniform distribution having a minimum of 2.22 Pa and a maximum of 77 Pa was specified for the WIPP waste shear strength in the CRA-2014 PA.

III.C. Implementation of Variable Brine Volume if the Calculation of Radionuclide Concentration

In the PABC-2009, the minimum necessary brine volume in the repository for a direct brine release (DBR) to occur was established as 17,400 m^3. This value was also used in the CRA-2014 PA as no changes warranting an update to it have occurred since the PABC-2009.

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 waste inventory was assumed to be dissolved in the minimum necessary DBR brine volume, and the resulting organic ligand concentrations were then used in the calculation of radionuclide solubilities. The WIPP organic ligand inventory has increased over time, resulting in mass-balance issues when determining radionuclide concentrations from only the minimum brine volume necessary for a DBR. As a result, the calculation of radionuclide solubilities was extended in the CRA-2014 PA so that organic ligand concentrations used in their calculation are more directly linked to the actual volume of brine present in the repository.

Using results from previous WIPP PA calculations, waste region brine volumes that result in a DBR are between the minimum necessary for a DBR and five times the minimum necessary volume. As a result, brine volumes of 1x, 2x, 3x, 4x, and 5x the minimum necessary volume were used in the calculation of radionuclide solubilities in the CRA-2014 PA. The organic ligand inventory is dissolved in each of these multiples of the minimum necessary brine volume. The resulting organic ligand concentrations, now dependent on a range of brine volumes, were then used to calculate radionuclide solubilities. This approach keeps radionuclide mass constant over realized brine volumes, rather than keeping radionuclide concentration constant over realized brine volumes. The use of five multiples of the minimum necessary DBR volume provides a sufficient range with which to calculate solubilities while keeping the additional solubility calculation workload at a feasible level.

III.D. Updates to Radionuclides and their Associated Uncertainty

The solubilities of actinide elements are influenced by the chemical components (e.g. organic ligands) of the waste. Updated waste inventory information was used to revise parameters that represent actinide solubilities in the CRA-2014 PA. Solubilities are calculated in the CRA-2014 PA using five multiples of the minimum brine volume (17,400 m^3) 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 to refine the uncertainty ranges and probability distributions for actinide solubilities in the CRA-2014 PA. The developments of baseline solubilities and their uncertainty distributions in the CRA-2014 PA are given in Brush and Domski[5,6].

III.E. Additional Mined Volume

In 2011, the DOE submitted a planned change notice (PCN) to the EPA that explained additional excavation in the WIPP experimental area. The volume of the experimental region implemented in the PABC-2009 was 87,675 m^3. The added volume that results from additional excavation in the experimental area is 60,335 m^3. As a result, the target volume of the experimental region implemented in the CRA-2014 PA is 87,675 m^3 + 60,335 m^3 = 148,010 m^3. To achieve this value, numerical grid cells used to represent the experimental region in the CRA-2014 PA are modified to yield an experimental region with a volume of 148,011 m^3, one cubic meter greater than the target value.

III.F. 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 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 its 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. A description of the new experiments and the use of their results to determine an updated steel corrosion rate are presented in Roselle[7]. These results yield changes to both the distribution type and values used to represent anoxic steel corrosion in the CRA-2014 PA.

III.G. Refinement to the Probability of Encountering Pressurized Brine

Penetration into a region of pressurized brine during a WIPP drilling intrusion can have significant consequences with respect to releases. In the current regulatory baseline established by the PABC-2009, a uniform distribution between 0.01 and 0.60 with a mean value of 0.305 is assigned to the parameter representing the probability of a pressurized brine encounter during a drilling intrusion. Initial development of this distribution was the result of an analysis of time domain electromagnetic (TDEM) survey data. A framework that provides a quantitative argument for refinement of this parameter has been developed[8]. This refinement results from a re-examination of the TDEM data while also including a greatly expanded set of drilling data for locations adjacent to the WIPP site than were available when the original analysis was performed in 1998. A sub-region exhibiting a high-density cluster of drilling intrusions was used to provide a conservative estimate of the probability of brine pocket intrusion based solely on the drilling data and to estimate a probability of encountering a brine pocket given that a well is drilled into a TDEM-identified region. The resulting normal distribution with a mean of 0.127 and standard deviation of 0.0272 was used in the CRA-2014 PA. As shown in Kirchner et al.[8], this distribution yields simulated frequencies of brine intrusions that cover the same range as that produced using the former uniform distribution.

III.H. 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. 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. 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.

IV. CRA-2014 PA RESULTS

Normalized releases for each of the four release mechanisms (cuttings and cavings, spallings, DBRs, and transport releases) are now presented, followed by a discussion of total normalized releases. In the results that follow, the overall mean CCDF is computed as the arithmetic mean of the mean CCDFs from each replicate.

IV.A. Cuttings and Cavings Normalized Releases

The overall mean CCDFs for cuttings and cavings releases obtained in the PABC-2009 and the CRA-2014 PA are plotted together in Fig. 1. Overall, cuttings and cavings normalized releases calculated for the CRA-2014 PA are smaller than those for the PABC-2009. The activity of the CRA-2014 waste inventory is greater over time than that implemented in the PABC-2009. The drilling rate per unit area is also increased in the CRA-2014 PA, which increases the number of drilling events into repository waste areas. Although the changes in waste inventory and drilling rate both serve to increase cuttings and cavings releases, the effect of the CRA-2014 PA waste shear strength refinement is to reduce cavings release volumes, and hence cuttings and cavings volumes overall, enough so that normalized releases due to cuttings and cavings in the CRA-2014 PA fall below those seen in the PABC-2009.

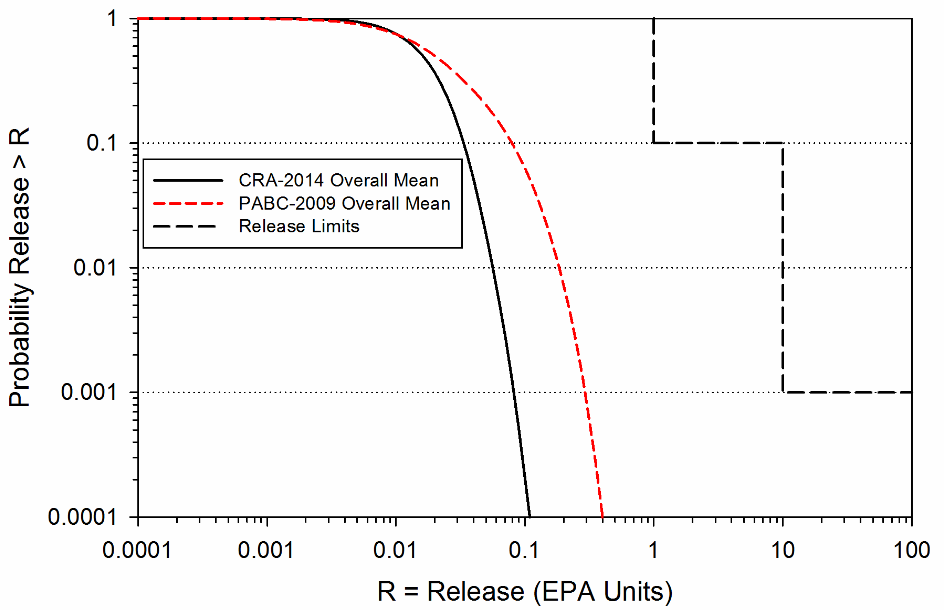

Fig. 1. CRA-2014 PA and PABC-2009 Overall Mean CCDFs for Normalized Cuttings and Cavings Releases

IV.B. Spallings Normalized Releases

The overall mean CCDFs for spallings normalized releases obtained in the PABC-2009 and the CRA-2014 PA are plotted together in Fig. 2. Spallings release volumes directly depend on repository pressure at the time of intrusion. Despite the modified panel closure system, which serves to increase waste panel pressures (on average), the updated steel corrosion rate, additional excavation in the WIPP experimental area, and the updated repository water balance implementation each contribute to a trend toward decreased waste panel pressures in the CRA-2014 PA. This trend toward lower waste panel pressure directly translates to a trend toward decreased spallings release volumes from the PABC-2009 to the CRA-2014 PA. The result is an overall reduction in spallings normalized releases, despite an increase in waste inventory activity, due to a decrease in the number of nonzero spallings volumes.

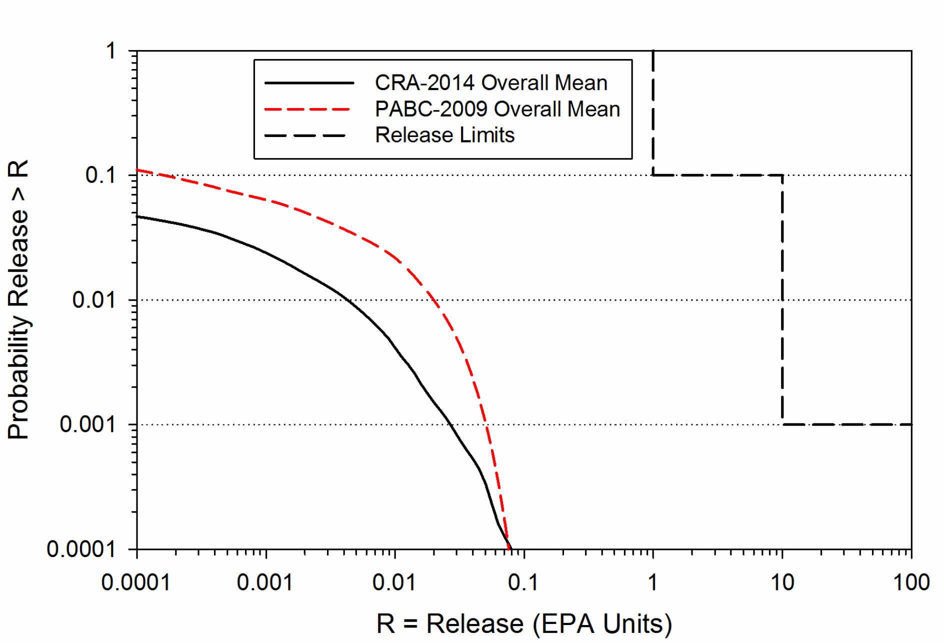

Fig. 2. CRA-2014 PA and CRA-2009 PABC Overall Mean CCDFs for Normalized Spallings Releases

IV.C. Normalized Culebra Transport Releases

Culebra transport releases found in WIPP PA do not contribute significantly to total normalized releases. Results obtained in the CRA-2014 PA for Culebra transport releases do not alter this trend. The net effect of changes included in the CRA-2014 PA is a reduction in the mean CCDF for normalized Culebra transport releases in the CRA-2014 PA as compared to the PABC-2009.

IV.D. Normalized Direct Brine Releases

The overall mean CCDFs for normalized direct brine releases obtained in the PABC-2009 and the CRA-2014 PA are plotted together in Fig. 3. Overall, there is a decrease in normalized DBRs from the PABC-2009 to the CRA-2014 PA. Several changes included in the CRA-2014 PA contribute to this reduction. The refinement to the probability that a drilling intrusion results in a pressurized brine pocket encounter yields an overall reduction to DBR volumes in the CRA-2014 PA results. The variable brine volume implementation maps radionuclide mobilized concentrations in brine to volumes of brine released. Radionuclide mobilized concentrations in brine decrease as brine volume increases in the CRA-2014 PA, whereas mobilized concentrations in brine remained fixed (for each vector) in the PABC-2009, regardless of the actual brine volume being released. There is a consistent increase in maximum DBR volumes from the PABC-2009 to the CRA-2014 PA. However, the variable brine volume implementation results in lower mobilized radionuclide concentrations in these larger brine volumes. The revised steel corrosion rate and water balance implementation used in the CRA-2014 PA also lead to an overall reduction in the number of vectors that yield a DBR. In total, the combined impact of changes included in the CRA-2014 PA is an overall net reduction to normalized direct brine releases as compared to the PABC-2009.

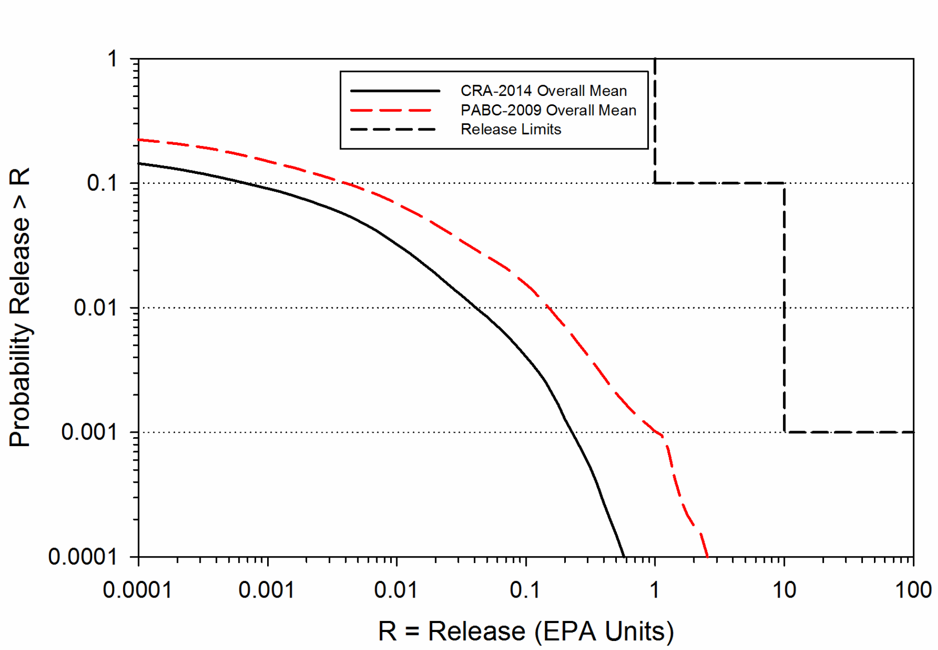

Fig. 3. CRA-2014 PA and CRA-2009 PABC Overall Mean CCDFs for Normalized Direct Brine Releases

IV.E. Total Normalized Releases

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. Total normalized releases obtained in the CRA-2014 PA are dominated by cuttings and cavings releases and DBRs. Contributions to total releases from spallings and Culebra transport are much less significant. Reductions are seen in cuttings and cavings releases and DBRs in the CRA-2014 PA as compared to the PABC-2009. These reductions are reflected in the total normalized releases for the CRA-2014 PA, shown in Fig. 4.

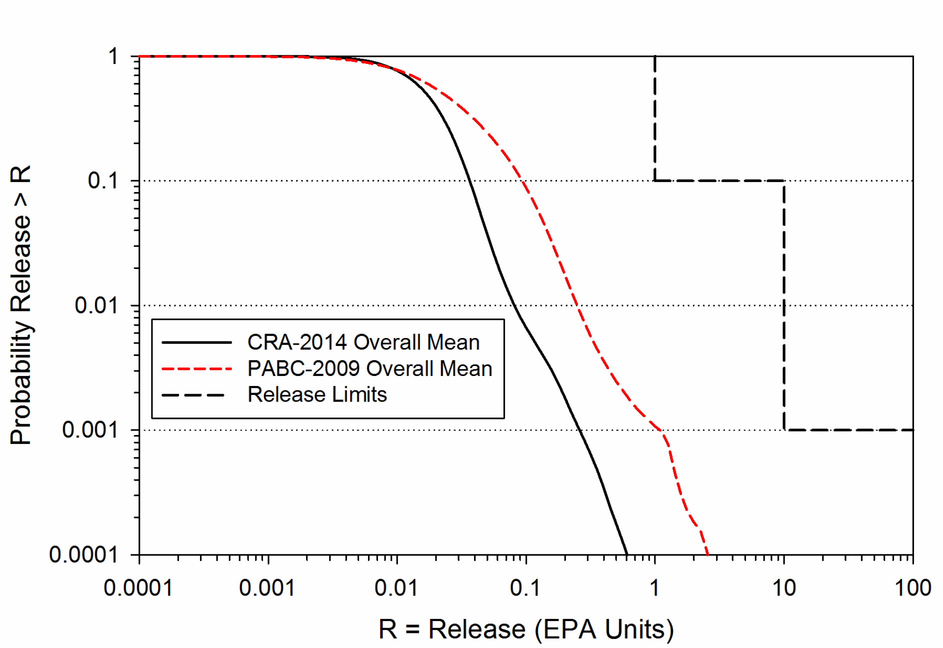

Fig. 4. CRA-2014 PA and CRA-2009 PABC Overall Mean CCDFs for Total Normalized Releases

V. RECERTIFICATION STATUS

The DOE submitted the 3rd WIPP Compliance Recertification Application to the EPA on March 26, 2014. The CRA-2014 PA was a fundamental component of that submission. Since receiving the recertification application, the EPA has generated 81 clarifying questions and requested that the DOE address them. The DOE has addressed these 81 questions. The EPA has also requested that the DOE conduct two sensitivity studies. The first sensitivity study investigates potential impacts associated with modifications to parameters and temporal behaviors used to model WIPP non-waste regions. This sensitivity study is completed, and demonstrates no appreciable impact to regulatory compliance. The results of the first sensitivity study are discussed in Day et al.[9]. The second sensitivity study requested by the EPA investigates impacts associated with modification to parameters and temporal behaviors used to model the ROMPCS. The DOE has commenced work on this second sensitivity study.

VI. CONCLUSIONS

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. Total normalized releases obtained in the CRA-2014 PA are lower than those found in the current regulatory baseline, 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. Since receiving the CRA-2014, the EPA has generated 81 questions, to which the DOE has responded. The EPA has also requested the completion of two sensitivity studies. The first of these studies has been completed by the DOE, with results showing no appreciable impact to regulatory compliance of the facility. The DOE has commenced work on the second sensitivity study.

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