Prioritization of Technical Content and Impact Assessment for Changes to Performance Assessment at the Waste Isolation Pilot Plant (WIPP) – 8086

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ABSTRACT

Waste Isolation Pilot Plant (WIPP) performance assessment consists of twenty-four conceptual models that are used to describe repository performance during the 10,000 year regulatory time period following closure of the facility. Following the recertification of the repository in March of 2006, Sandia National Laboratories and the U. S. Department of Energy (DOE) began a set of activities to identify which models could be improved and updated by inclusion of data from recent repository investigations. Sandia initiated this process by conducting a review of the performance assessment models to determine which models should be updated. Sandia provided the DOE with a list of recommendations, and after discussions with the DOE, Sandia proceeded with a set of scoping calculations to identify the impacts of these changes on modeling repository performance. This paper describes the methodology that Sandia used to determine which changes should be proposed and the impact of some of these changes on estimates of radionuclide releases that could occur in the event of inadvertent human intrusion into the repository.

This paper is the first in a series of papers about the proposed changes. The other papers detail the specific changes and the justification for those changes to the models and parameters.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico and operated by the U.S. Department of Energy (DOE) as a disposal facility for transuranic (TRU) waste. The WIPP must comply with various environmental regulations, including 40 CFR 191, Subpart B, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, and 40 CFR 268.6, *Petitions to Allow Land Disposal of a Waste Prohibited Under Subpart C of Part* 268. These regulations require a risk analysis of releases of WIPP waste due to inadvertent human intrusion into the repository at some time during the 10,000-year regulatory period. Sandia National Laboratories (SNL) conducts performance assessments (PAs) of the WIPP using a system of computer codes in order to demonstrate compliance with these regulations.

In 1996 SNL completed a PA for the WIPP, and this PA was part of the Compliance Certification Application (CCA) [1] submitted to the U. S. Environmental Protection Agency (EPA). Based on the CCA and subsequent information and analyses, the EPA certified the WIPP's compliance in May 1998. As required by the WIPP Land

Withdrawal Act (Public Law 102-579 [as amended by Public Law 104-201]), DOE is required to submit documentation of continued compliance to the EPA for the recertification of the WIPP every five years following the first receipt of waste. In March of 2004, DOE submitted the Compliance Recertification Application (CRA-2004) [2], which included an updated PA conducted by SNL. During their review of the CRA-2004, the EPA requested that an additional performance assessment calculation be conducted with modified assumptions and parameter values. This PA is referred to as the 2004 Compliance Recertification Application Performance Assessment Baseline Calculation (CRA-2004 PABC) [3], and when the EPA recertified the WIPP in March of 2006, the CRA-2004 PABC was established as the new WIPP PA technical baseline.

This baseline consists of twenty-four, peer-reviewed conceptual models that were developed and selected by DOE through its scientific advisor, Sandia National Laboratories, and these models are implemented in the aforementioned computer codes. A conceptual model is a statement of how important features, events, and processes such as fluid flow, chemical processes, or intrusion scenarios, are to be represented in performance assessment, and each of these models describes a component of the future state of the WIPP disposal system for use in performance assessment. WIPP PA conceptual models are site-specific, and, when possible, the models have been developed using data that has been gathered from WIPP site characterization activities. Extensive site characterization activities were initiated in the 1970s, and they still continue today. The data from these activities provide a foundation for the development of the conceptual models and material properties that are used as model input parameters. It is the opinion of both DOE and SNL that inclusion of the results from these recent repository investigations in WIPP PA will result in a more accurate representation of the repository and better predictions of the long term performance of the repository. With this in mind, SNL and DOE began a set of activities to identify which models could be improved and updated by inclusion of data from recent repository investigations. Sandia initiated this process by conducting a review of the performance assessment models to determine which models should be updated. Sandia provided the DOE with a list of recommendations, and after discussions with the DOE, Sandia proceeded with a set of scoping calculations to identify the impacts of these changes on modeling repository performance. This paper describes the process that Sandia and the DOE used to determine which changes should be proposed and the impact of some of these changes on estimates of radionuclide releases that could occur in the event of inadvertent human intrusion into the repository.

PROPOSED MODIFICATIONS

Sandia Process for Proposing Changes

An informal decision analysis process was used to prioritize SNL recommendations for modifications to WIPP PA. The process consisted of the following steps: brainstorming to develop a complete list of recommendations for changes to PA, identification of the primary drivers for modification of PA (shown in Table I), evaluating the merits of suggested changes in relation to the identified drivers, and calibration of the recommendations with overall project goals and known budget and schedule limitations.

Altogether, more than forty suggested changes to PA were considered. Eleven SNL technical staff members who were involved in preparing the CRA-2004 PABC participated in the evaluations. Each participant evaluated the suggested changes by assigning qualitative assessments of merit for each of the identified drivers listed in Table I. These qualitative assessments were given numerical values, and these values were weighted. The results were then examined to see where a consensus among the eleven staff members might lie. The consensus position was then presented to a smaller group of participants which included SNL management to calibrate the results with overall project goals and known budget and schedule limitations.

Table I. Technical and Programmatic Drivers Used to Screen Potential Changes to WIPP PA.

Technical Drivers
Impact on Scientific Knowledge Base/Modeling Capability *(i.e. does the experimental program provide new information not available from other sources? Does the model/code provide new predictive capabilities?)*
Impact on Modeling Realism
Estimated Impact on releases
Impact on Process Model Complexity *(i.e. are their more/fewer physical or numerical parameters?)*
Impact on PA Conceptual Models *(i.e. is this a local or global change?, will it require a peer review or expert elicitation?)*
Impact on PA Modeling System *(i.e. impact on run control, parameter database, code testing/QA)*
Impact on Computational Resources
Programmatic Drivers
Estimated Resource Requirement
Regulator Interest
Customer interest

The result of the evaluation process was a list of four recommended modifications to PA. These include: new parameter values for the waste shear strength, new parameter values for the duration of direct brine releases (DBR), a new conceptual model for the evolution of the underground, and Panel Scale PA. These changes are discussed below.

New Parameter Value for the Waste Shear Strength

The waste shear strength enters WIPP PA through the cavings release model. Cavings releases occur when the repository is inadvertently intruded at some point during the 10,000 year regulatory period by a drilling rig in search of resources below the repository. Cavings are the waste material that erodes from a borehole wall due to shear stresses generated by the helical flow of the drilling fluid in the annulus between the borehole wall and the drill collar. The single most important parameter in the cavings model is the waste shear strength, which is the shear stress at which waste material becomes detached from the borehole wall.

Hansen [4] examined how the parameter values for the waste shear strength were established and concluded that the current values are excessively conservative, i.e., use of these parameters cause releases to be over-estimated. In addition, sensitivity analyses have shown that uncertainty in waste shear strength contributes to the vast majority of uncertainty observed in cavings and total releases.

Hansen [4] has described work that has already been done which provides a basis for a new distribution. Herrick et al. [14] expanded on this work by differentiating between the surficial bed shear strength and the shear strength of the bed as a whole. The surficial layer of a bed tends to have a much lower shear strength than that below the surface as the surficial layer has not been compacted by subsequent sediment deposition, and because in natural water ways the surficial layer is constantly being acted upon. The original 0.05 Pa minimum waste-shear strength used in PA is based on the minimum surficial shear strength of San Francisco Bay mud, which may not be relevant to a deep underground repository, where there is no long-term exposed surface and no flowing water ways.

The data justifying a new minimum shear strength comes from observed critical shear strengths of surrogate waste material measured via flume experiments [5]. The critical shear strength is a measure of the bed shear strength not the surficial shear strength. Analyses of the experimental data suggest that the minimum shear strength should be raised to at least 1.5 Pa, as opposed to the current value of 0.05 Pa. Use of the experimental results will require sufficient justification of how the surrogate waste material was developed, but a precedent for using this type of experimental approach in the development of parameter values was established in the development and peer review of the spallings release model [6].

This modification was deemed to be the highest priority since it was identified to be a rather simple change, require relatively few resources, and have a significant impact upon estimation of releases.

New Parameter Value for Direct Brine Release Durations

DBR is the release of actinide-contaminated brine that flows from waste panels up a borehole to the surface during drilling or shortly after drilling in WIPP disturbed performance scenarios. Flow of repository fluid into the borehole can only happen if 1) there is sufficient fluid present (i.e., sufficient repository saturation), and 2) repository pressure is greater than the hydrostatic pressure exerted on the repository by the column of drilling mud. Direct brine releases stop when one of the following occur: 1) repository pressure drops below the hydrostatic pressure of the drilling mud; 2) available repository fluid depletes; or 3) the intermediate section of the borehole is cased and cemented, isolating the waste panel from the borehole. Based on these constraints, PA requires that the length of a DBR event fall within a prescribed range. The minimum release duration is 3 days, and the maximum duration is 11 days.

According to 40 CFR 194.33, WIPP PA modeling of drilling events should be based on current drilling practice in the Delaware Basin, and consequently, so should the minimum and maximum DBR durations. The minimum is based on the time required to case the intermediate section of the borehole. However, it is SNL's position that the maximum duration value (currently 11 days) is excessive and not supported by actual experience since it is based on a gas well blow out [1] and not a brine flow caused by drilling into the Castile formation of the Delaware Basin.

A formal request was made to Washington Regulatory Environmental Services (WRES) for the most complete and recent data available on brine encounters in the portion of the Delaware Basin that is monitored by WRES. This data is reported annually in the Annual Delaware Basin Drilling Report. Based on this data, the parameter records package for DBR duration was reviewed, and supporting documentation for the current duration was evaluated for correctness and consistency with current drilling practices and experiences. SNL concluded that the maximum DBR duration should be decreased from 11 days to 4.5 days.

This modification was assigned the second highest priority because it is a simple change, conceptually as well as for implementation purposes, and would require little resources to implement.

New Conceptual Model for the Evolution of the Underground

The current conceptual model of the evolution of the underground is based on a set of conservative assumptions about the future state of the waste and the surrounding Salado rock formation. However, since the CCA was completed, knowledge of the physical, mechanical, chemical, and hydrological setting in the repository has improved because of continued repository science programs and because five years of operational experience allows a more definitive appraisal of various factors involved with disposal of radioactive waste. Based on these data, a more accurate representation of the evolution of the underground could be implemented in PA models. Hansen and Stein [7] have described changes, discussed below, needed to improve modeling of the evolution of the underground. These changes are: updated modeling of the Disturbed Rock Zone (DRZ), incorporation of MgO interactions with brine (hydration), and incorporation of solids production in the evolution of the waste filled areas.

Salt was originally chosen as the isolation medium for WIPP because of its ability to heal previously damaged areas. The healing mechanisms include microfracture closure and bonding of fracture surfaces. Evidence for microfracture closure and its effect on permeability has been obtained in laboratory experiments, small-scale tests at WIPP and through observations of natural analogs [8].

The DRZ is the portion of Salado (salt) rock directly surrounding the repository that has become damaged by unloading after excavation and damage due to excavation itself. The resulting microfractures in the DRZ increase its permeability and porosity. As currently modeled in PA, the properties of the DRZ control a significant portion of the brine that can flow into the waste rooms in the undisturbed scenario (i.e. before the repository has been drilled into by a drilling rig). The most important DRZ properties are extent, available water content, and permeability.

The current DRZ model includes a large zone of DRZ (extending 12 m above the room and 2 m below) for which a single permeability value is sampled and held constant for 10,000 years. The large extent was largely based on the concern that brine from anhydrite marker beds 12 meters above the repository could be a significant source of brine into the rooms.

Park et al. [8] have shown that a DRZ which extends 4.74 m above and 2.24 m below the room is more realistic than the 12 m above and 2 m below currently modeled in PA. This result is based on sonic velocity measurements that were performed in the rib of a underground room at WIPP, and decades of research on the behavior of salt. Clayton et al. [13] give evidence that the DRZ should experience a significant decrease in permeability over a period of several hundred years due to microfracture closure.

Magnesium oxide (MgO, or periclase) is added to the repository as the only EPA approved engineered barrier. MgO is added for the purpose of sequestering CO_2 and maintaining alkaline conditions thereby decreasing the aqueous solubility of the actinides (relative to acidic carbonate conditions). The source of CO_2 is the potential anaerobic microbial degradation of the cellulose, plastic, and rubber (CPR) materials that are part of the waste received at WIPP.

MgO hydration is the chemical process by which MgO consumes water to produce magnesium hydroxide (brucite), $Mg(OH)_2(s)$, which effectively sequesters one mole of water per mole of MgO unless $Mg(OH)_2(s)$ later becomes carbonated to become magnesite $MgCO_3(s)$, which produces water. At the current operations rate, nearly 70,000 metric tons of MgO will be placed in the ten waste panels, which would sequester a significant portion of brine that could enter the repository through a more reasonably sized DRZ.

The hydration reaction, along with others, generates solids which on average have a larger volume than the reactants. This includes salts precipitated from the brine as its water content is consumed. We expect that these solids will fill the interstitial spaces in the repository, thus lowering porosity and eventually lowering the disposal room permeability.

Implementing a new model of the evolution of the underground was determined to be the third highest priority. Its impact on realism and scientific knowledge were rated highly, but implementation of this change would be resource intensive because it would impact many different PA models and require a peer review before implementation in the WIPP PA baseline.

Panel-Scale PA

The assumption of a homogeneous distribution of waste has a wide-reaching impact on numerous PA models. However, since waste has been increasingly shipped to the WIPP in campaigns, the EPA has begun to ask the DOE to provide analyses aimed at assessing the impact of waste heterogeneity on repository performance [9,10,11]. Despite providing analyses that have shown that waste placement does not have a significant impact on releases [12], it is expected that the EPA will continue to question the DOE about this issue. One way to address this issue in PA is to model the repository as a set of homogenous waste panels (rather than a homogeneous repository). This idea is a means of introducing the concept of heterogeneity into PA and has been termed “Panel-Scale PA.”

Implementing panel scale PA has two additional benefits for WIPP PA. First, panel scale PA would add realism by incorporating knowledge about the waste distribution into PA, resulting in a more technically defensible PA. Additionally, it would provide the DOE with a more “flexible PA” methodology because it will allow the DOE to conduct analyses to address concerns about atypical (or typical) panel loading scenarios.

PA calculations would be done for each waste panel, instead of a representative panel, and parameters that are impacted by waste contents, such as CPR content, radionuclide content, etc., would be determined for each waste panel. This will require the introduction and justification of a set of waste-panel-dependent parameters. To run a PA, the number of calculations will significantly increase (up to a factor of 10), and the amount of analyses will increase, as well.

This modification was rated fourth highest. It was not expected to significantly affect estimated releases and would require significant resources to implement and maintain, but it was determined to be an important step towards adding realism in WIPP PA.

IMPACT ON RELEASES

Releases from the WIPP fall into two principal categories: (1) direct releases, which may occur at the time of a drilling intrusion or shortly thereafter, and (2) long-term releases, which may take place throughout the regulatory period but generally take hundreds, if not thousands, of years to reach the Land Withdrawal Boundary. Long-term releases have been shown to be insignificant [1,2,3], so we do not discuss them further. In this section, we discuss the expected impact of a new parameter value for the waste shear strength, a new parameter value for the duration of direct brine releases, and a smaller DRZ extent that exhibits a significantly lower permeability 200 years after repository closure. The effects on releases of implementing Panel-Scale PA or other facets of the evolution of the underground have not been examined yet.

Expected Impact on Direct Releases

Direct releases are subdivided into three components: cuttings and cavings, direct brine releases, and spallings. Cuttings are the waste removed directly by the cutting action of the drill bit passing through the waste, and cuttings and cavings releases are generally grouped together. As stated previously, the shear strength of the waste is a key variable that determines cavings releases, and it has previously been demonstrated that higher shear strength values typically result in smaller cavings releases [1,2,3]. Thus, it was expected that increasing the minimum waste shear strength would decrease cavings releases. The other PA modifications do not impact on cavings releases. The shear strength parameter is not used in the calculation of any other releases, so its modification would not affect other release mechanisms.

A decrease to the parameter representing the maximum length of time that a direct brine release can flow would clearly cause DBRs to decrease, but the impact of the DRZ modifications on DBRs is not as simple. The properties of the DRZ control a significant portion of the brine that can flow into the waste rooms, and reducing the extent of the DRZ and DRZ permeabilities could potentially reduce brine saturations in the waste rooms. The effect of the DRZ modifications on repository pressure is slightly more complex. Gas generating processes that are expected to occur in the WIPP, i.e., iron corrosion of waste materials and containers and microbial consumption of organic matter in the waste and waste packaging materials, require sufficient amounts of brine to proceed. A decrease in the quantities of brine in the waste area could cause a decrease in gas production and repository pressure. However, reducing the DRZ extent reduces the pore volume into which the gas in the waste areas can escape. The reduction in pore volume could cause repository pressures to increase. Thus, prior to running WIPP PA calculations, it was unclear what would be the ultimate impact of the DRZ modifications on DBRs.

A WIPP spallings event is a special case of the drilling intrusion in which the repository contains gas at high pressure. This highly pressurized gas is hypothesized to cause localized mechanical failure and entrainment of solid WIPP waste into and up the borehole, resulting in transport to the land surface. Since high repository pressures (> 8 MPa) are a prerequisite for spallings, the DRZ modifications had the potential to affect spallings releases.

Observed Impact on Releases

When the EPA developed the containment requirements for the WIPP, they acknowledged many sources of uncertainty that could affect estimates of radionuclide releases that could occur from an inadvertent drilling intrusion into the repository. Hence, the containment requirements for the WIPP are defined in terms of both release limits and corresponding probabilities, so WIPP PA creates complementary cumulative distribution functions (CCDFs) for radionuclide releases. For a given release value, the CCDF indicates the probability that cumulative releases from the WIPP during the 10,000 year regulatory time period will exceed that release value. To capture the full range of uncertainty in releases, WIPP PA generally runs simulations with hundreds of different input parameter combinations, resulting in an equal number of CCDFs. To determine compliance with containment regulations, a mean CCDF is created by averaging over the entire set of CCDFs, and the mean CCDF is compared with the prescribed release limits.

A scoping PA was performed to assess the impact of the proposed WIPP PA modifications on releases. The only significant differences between the scoping PA and the current WIPP PA baseline as implemented in the CRA-2004 PABC are the aforementioned modifications to the waste shear strength parameter, the DRZ size and permeability, and the maximum DBR duration. This section compares the mean CCDFs for all release mechanisms from the scoping PA and the CRA-2004 PABC analyses.

Fig. 1 contains the mean CCDFs for cuttings and cavings releases for the scoping PA and CRA-2004 PABC analyses. As expected, the mean cuttings and cavings releases are less than the CRA-2004 PABC mean cuttings and cavings releases at all probabilities. This decrease is attributed to the increase in the minimum waste shear strength value.

Fig. 2 shows the mean CCDFs for DBR releases for the scoping PA and CRA-2004 PABC analyses. The mean DBRs are less than those for the CRA-2004 PABC at all probabilities. Thus, the overall, combined impact of the DRZ and DBR flow parameter modifications is a decrease in mean DBRs. Clayton et al. [13] show that incorporating a smaller DRZ into PA with a lower permeability after 200 years leads to a drier repository and less CPR degradation, before the first human intrusion. A drier repository reduces DBRs in scenarios that do not encounter a pressurized brine reservoir.

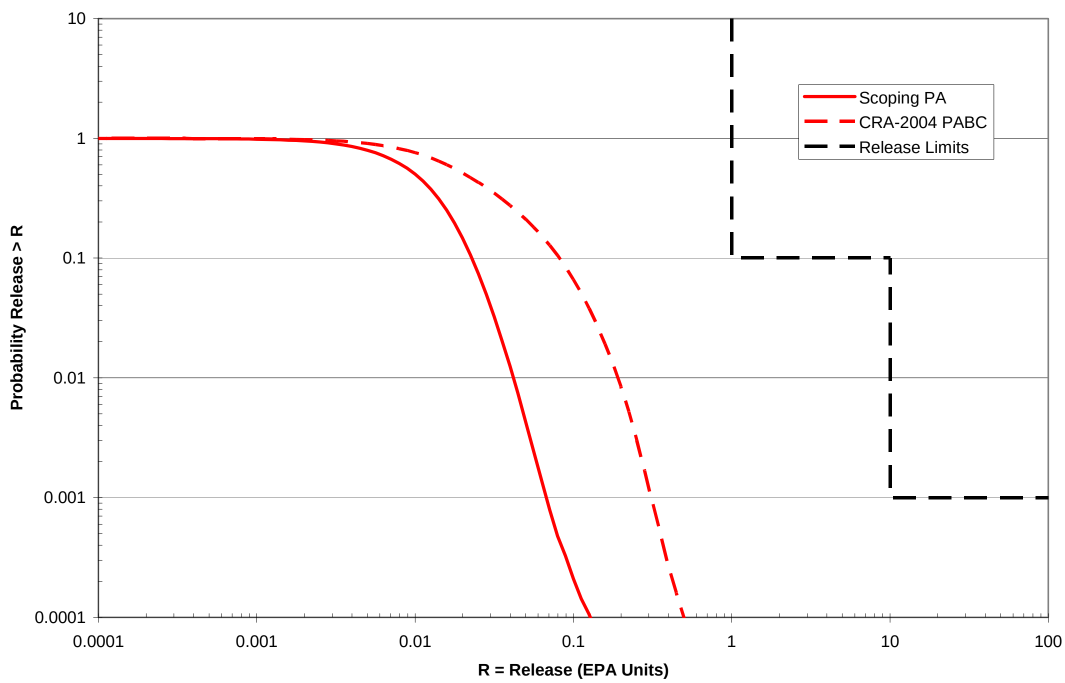

Fig. 1. Mean cuttings and cavings release CCDFs.

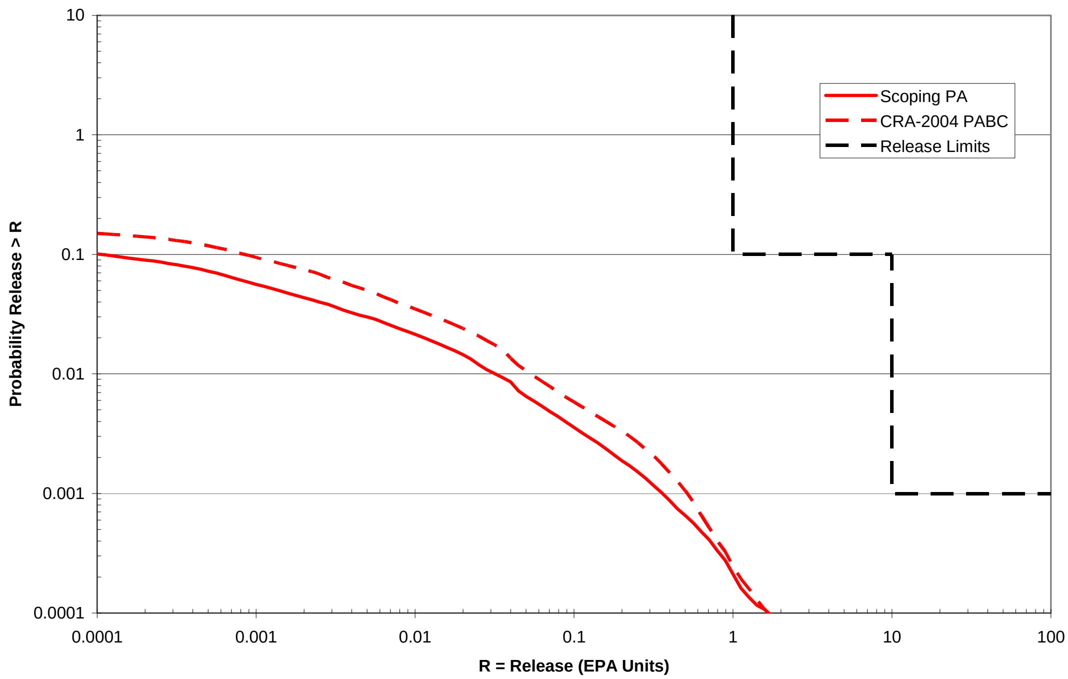

Fig. 2. Mean direct brine release CCDFs.

Fig. 3 contains the mean CCDFs for spallings releases for the PA and CRA-2004 PABC analyses. The CCDF for mean spallings releases generally lies to the right of the CCDF for CRA-2004 PABC mean spallings releases, but the difference between the mean CCDFs is small at most probabilities. Since the CRA-2004 PABC and scoping PA analyses used the same waste stream inventories, any differences in spallings releases between the two analyses can be attributed to changes in spallings volumes. Differences in spallings volumes between the two analyses reflects a change in repository pressures caused by changes made to the DRZ model. Thus, the impact of the DRZ modifications on mean spallings releases was generally to increase mean spallings releases, but only by a small amount.

The individual release pathways are summed to estimate total releases that are used to determine compliance with EPA regulations. Fig. 4 shows the mean CCDFs for total releases for the scoping PA and CRA-2004 PABC. Mean total releases for the scoping PA are less than the corresponding mean releases from the CRA-2004 PABC at all probabilities. The decrease in cuttings and cavings releases is the primary reason for the decrease in total releases at high probabilities. The decrease in mean total releases at low probabilities is attributed to the decrease in cuttings and cavings releases and DBRs at low probabilities. Changes in spallings releases had little impact on total releases since they are mostly an order of magnitude less than the dominant release mechanisms.

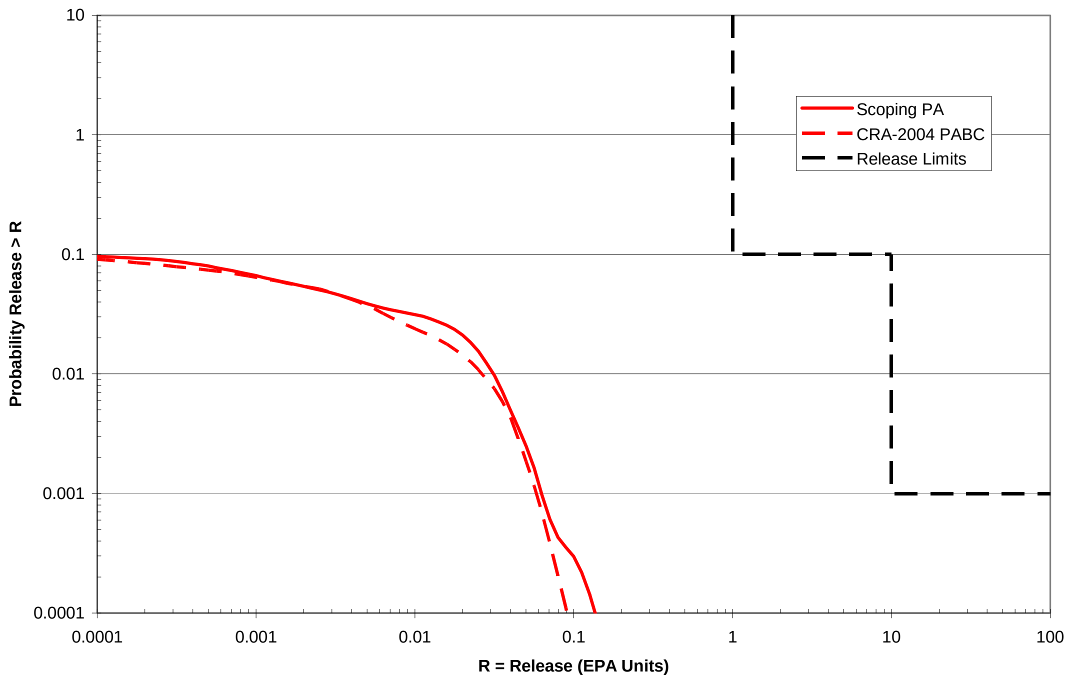

Fig. 3. Mean spallings release CCDFs.

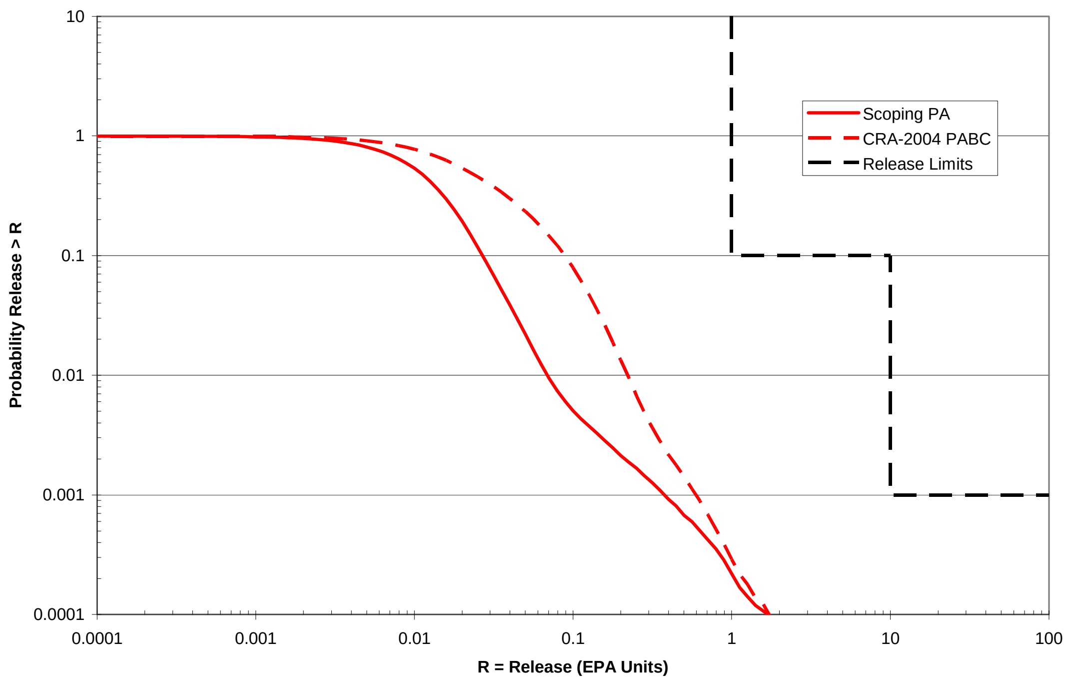

Fig. 4. Mean total release CCDFs.

SUMMARY AND CONCLUSIONS

Sandia and DOE went through a lengthy process to identify and prioritize areas of WIPP PA that could be improved by incorporating results from recent repository investigations into WIPP PA parameters and models. The set of modifications that were included in a scoping calculation include a revised waste shear strength parameter, a decrease to the parameter representing the maximum length of time that a direct brine release can flow, and modifications to the representation of the DRZ in WIPP PA models. Papers on the first three topics are given in [8,13,14]. A scoping PA was run to assess the impact of these modifications on repository performance, and it was determined that mean total releases decrease at all probabilities.

While conservative assumptions may seem appropriate for PA modeling in a highly regulated operation such as WIPP, it is often impossible to apriori determine what is a conservative assumption in a complex model such as PA. A case in point is the spallings releases discussed above, which unexpectedly increased as a result of the changes discussed herein. Therefore scientifically and regulatorily it is important to model the repository as realistically and unbiased as possible in performance assessment calculations.

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