

EPA's Confirmatory PA Analysis of DOE's Proposed Run-Of-Mine Salt Panel Closure System for the WIPP – 14058

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is an underground repository for defense-related transuranic radioactive waste and operated by the Department of Energy (DOE). The repository is in a salt formation that will eventually “creep close” and encapsulate the waste. The waste is placed in rooms and multiple rooms form a panel, with each panel separated from others with panel closures. The DOE is required to demonstrate compliance with EPA's 40 CFR Part 194, and use an Option D panel closure design consisting of a 7.9 meter concrete monolith and a 3.7 meter explosion wall. DOE submitted a Planned Change Request (PCR) to EPA for approval to modify the panel closure design that consists of 30.5 meters of Run of Mine (ROM) salt. The ROM salt will consolidate within a few hundred years primarily due to creep closure. The PCR included a Performance Assessment (PA), denoted as the PCS-2012 PA. The results were compared with a comparison PA, the PABC-2009 PA. The PCS-2102-PA was similar to the PABC-2009 PA but had modifications where the temporal properties of the ROM salt were included. The PCS-2012 PA was intended to demonstrate compliance with EPA containment requirements via a Complimentary Cumulative Distribution Function (CCDF). The resulting CCDF from the PCS-2012 PA moved closer to EPA's regulatory limit but did demonstrate compliance.

EPA reviewed the PCS-2012 PA and focused on the modeling of the Disturbed Rock Zone (DRZ) located above and below the panel closure. The PCS-2012 PA assumed an anhydrite DRZ associated with the Option D design when the use of a halite DRZ may be more appropriate. EPA conducted a separate PA that used properties of a halite DRZ (e.g., lower permeability) and calculated releases similar to the PCS-2012 PA, though with an increase in spillings.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a disposal system located in southeastern New Mexico for defense-related transuranic (TRU) radioactive waste. The waste is disposed approximately 655 meters (2,150 feet) underground in a salt formation which will eventually “creep close” and encapsulate the waste. It is designed and operated by the Department of Energy (DOE). The WIPP Land Withdrawal Act (LWA) [1] provides

the Environmental Protection Agency (EPA) authority to oversee and regulate the WIPP per EPA's 40 Code of Federal Regulations (CFR) parts 191 [2] and 194, which limit releases over a 10,000 year time period. Compliance with the numerical requirements in 40 CFR 191.13 [3] (containment requirements) is demonstrated with a Complementary Cumulative Distribution Function (CCDF).

The repository design consists of ten separate waste panels mined into the salt and connected by access drifts. Each waste panel consists of seven rooms. When each panel is filled with waste the drifts are sealed with panel closures. Because panel closures are a feature of the repository and can affect post-closure performance, they need to be included in DOE's Performance Assessment (PA). A plan view of the repository is given in Figure 1. A PA is the method DOE uses to demonstrate compliance with EPA's containment requirements. DOE models repository performance in the waste area using a 2-D simplification of the repository layout with the numerical code BRAGFLO. BRAGFLO models brine and gas flow within repository rooms and repository vicinity. BRAGFLO outputs include repository pressures and saturations. The code also incorporates room closure processes, gas production and brine consumption derived from other models. The resulting conditions calculated by BRAGFLO are used as inputs to predict potential radionuclide releases. Releases mechanisms are long-term flow and transport if the repository is undisturbed, direct brine releases (DBR), cuttings and cavings (releases due to a borehole cutting through the waste itself), and spallings (entrained waste that flows up the borehole due to high repository pressures).

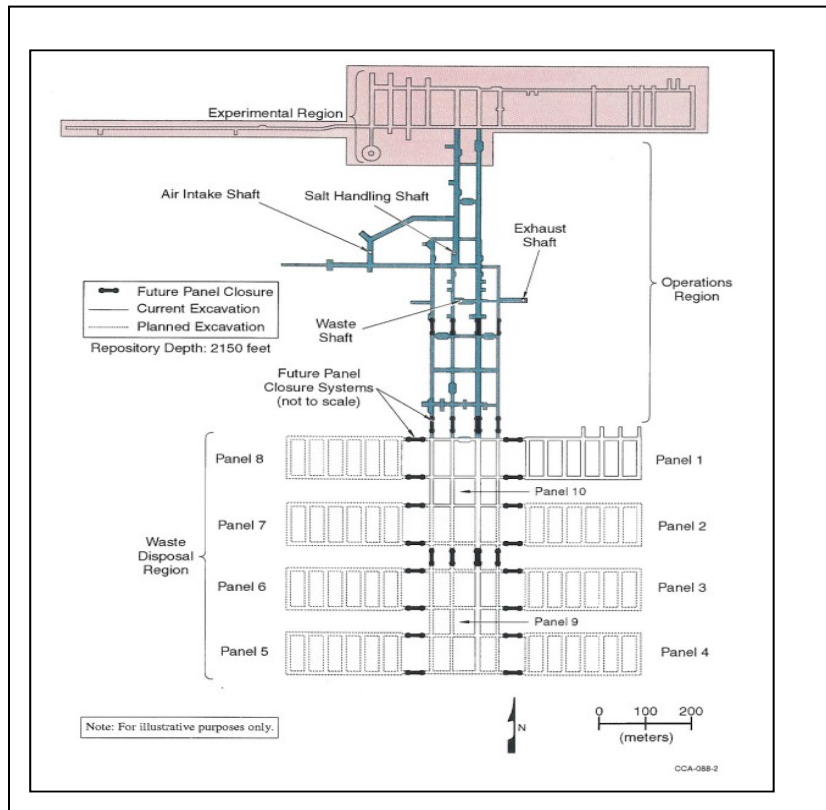
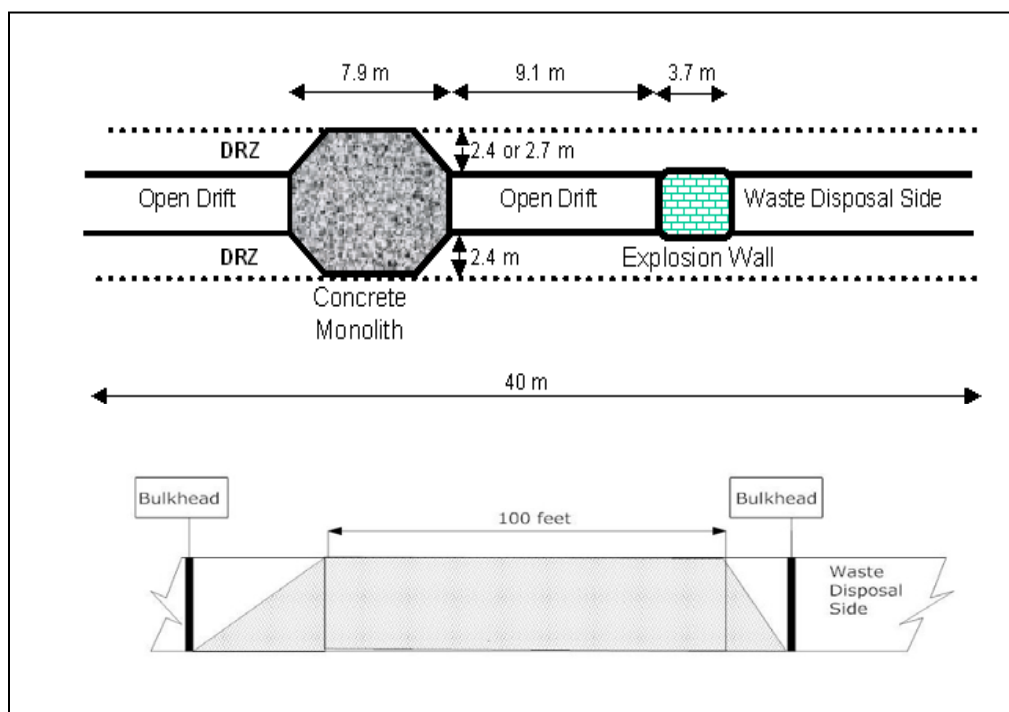


Fig. 1. Plan View of WIPP

In 1998 EPA certified DOE's Compliance Certification Application (CCA) [4] for the WIPP with the condition that DOE use a specified panel closure system (PCS) design, denoted as the Option D PCS design. The Option D design consists of an octagonal, ~7.9 meter long concrete monolithic plug, keyed into the halite above and below, and a 3.7 meter concrete explosion wall; both are separated by 9.1 meter void drift space. In September 2011 DOE submitted to EPA a Planned Change Request (PCR) [5] to replace the Option D design with a new design that consists of 30.5 meter run-of-mine (ROM) salt with two steel bulkheads placed at each end of the ROM salt. DOE's rationale to modify the panel closure design was based on the following; 1) the Option D design is extremely difficult and costly to install, and 2) the highly engineered design is unnecessary for either worker safety or environmental protection during the operational period. The two designs are depicted in Figure 2.



design (bottom).

DOE presented its analysis of the ROM salt panel closure in the performance assessment analysis, denoted as the PCS-2012 PA. DOE identified that WIPP complied with EPA's containment requirements with the ROM PCS. In addition, the results from the PCS-2012 PA were compared with results from the most recent approved PA, denoted as the PABC-2009, which used the Option D design. This paper provides an overview of specific aspects of EPA's analysis and review of the PCS-2012 PA results, including separate EPA calculations of the ROM salt panel closure design.

BACKGROUND

In past PAs the panel closure was modeled using properties appropriate to the concrete monolith; the explosion wall is assumed to fail after closure and does not influence long-term performance. Due to the concrete monolith's density, its rigidity, and engineering design, plus the fact that the disturbed rock zone (DRZ) around the monolith would be removed, the DOE had assessed that the monolith properties would not be impacted by repository creep closure, a process that occurs in halite soon after excavation. EPA had agreed with this assessment. Consequently, the monolith's properties have been modeled in prior PAs as constants for the 10,000 year regulatory period.

In contrast, the ROM PCS salt's properties will change with time. The salt will be installed as loosely placed material in the panel closure drifts. The salt will initially consolidate under its own weight then be compressed due to creep closure from the

surrounding halite. These two processes cause the ROM salt's properties to change with time so that its density is increased and porosity reduced, resulting in reduced permeability. DOE grouped the change in ROM salt properties into three general time periods, denoted as T1 (0-100 years), T2 (100 – 200 years), and T3 (200– 10,000 years). For the PCS-2012 PA, DOE only changed the panel closure property parameters for the properties (e.g., permeability) that characterized the ROM salt design and temporal changes to those properties. The disturbed rock zone above and below the ROM PCS (denoted as the DRZ_PCS) for T1 and T2 had properties of the DRZ above and below the waste panels, for T3 the DRZ_PCS adopted the values used in the PCS-2012 PA, other parameters were not altered.

EPA reviewed DOE's PCS-2012 PA input parameters and generally agreed, in principle, with DOE's adoption of the ROM salt properties. The CCDF for the PCS-2012 PA, illustrated in Figure 3, demonstrated that the total normalized releases did remain below the regulatory limit (remain left of the release limit dashed line on the right of Figure 3). However, the releases calculated with the ROM salt PCS increased when compared to the PABC-2009 PA.

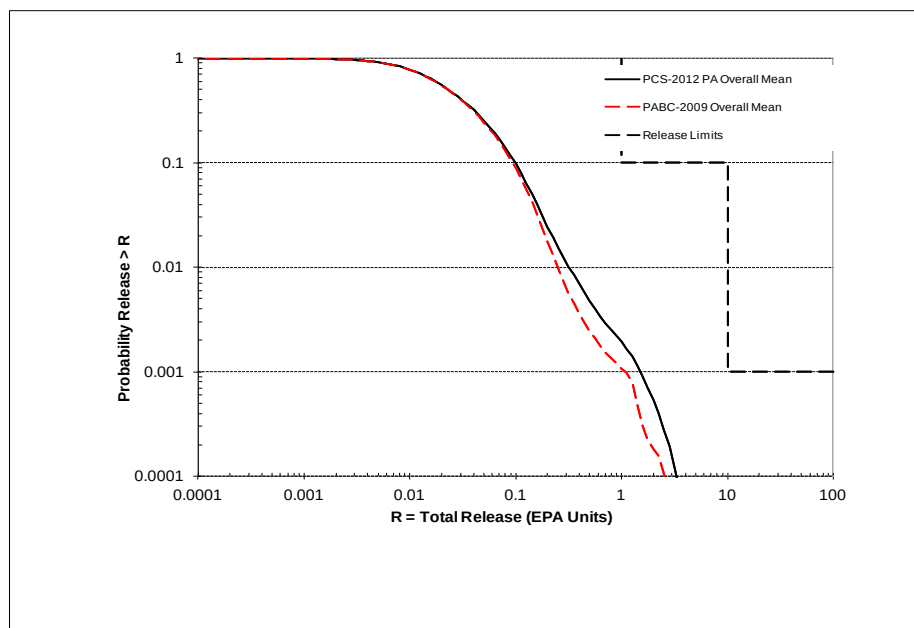


Fig. 3. PCS-2012 PA and PABC-2009 Overall Mean CCDFs, [6] Figure 5-28)

DOE attributed [6] the increased releases in this way: the ROM PCS creates higher waste panel pressures and higher waste panel brine saturations in some scenarios relative to the PABC-2009. The higher pressures in the PCS-2012 contribute to more spillings releases and the higher pressures and brine saturations contribute to higher direct brine releases in the PCS-2012 calculations relative to the PABC-2009. During the review of DOE's calculations, the Agency identified two issues for further

investigation. First, DOE had not invoked the two-phase flow mechanisms in the ROM salt PCS. (Flow of brine and gas is expected to occur through the panel closure system during the regulatory period. The presence of brine in the interstitial pores of the ROM salt could impede gas flow, and vice versa for brine.) Secondly, DOE's assumptions of the flow properties adopted for the DRZ_PCS were based on the rock type adjoining the Option D PCS- anhydrite. In the Option D design the DRZ along the closure drift was to be mined out to the anhydrite layers, located ~1.3 meters below the drift floor and ~2.6 meters above the drift ceiling. Removing the halite DRZ would result in minimal DRZ to exist in the closure drift prior to installing the monolith. In contrast, for the ROM PCS installation the halite DRZ will not be removed. There will be a dynamic relationship between the ROM salt and the halite DRZ that was not considered with the Option D PCS. The DRZ above and below the ROM salt can be considered an integral component of the panel closure system, especially during the 200 to 10,000 year time-frame when it is expected that the ROM salt will be fully consolidated. The DRZ_PCS should have properties that are more reflective of the end-point properties of healed halite, when ROM salt imposes back-stresses on the DRZ_PCS during the T3 time period. This would mean adopting DRZ_PCS flow properties similar to pre-damaged conditions once it is healed.

A brief overview of the mechanisms creating and healing the DRZ, and the impacts of ROM salt PCS has on these mechanisms, is given below.

Formation and Healing of the DRZ

During repository drift excavation lithostatic and compressive stresses are reduced, resulting in dilatant strain in the halite. This results in micro- and macro-fracture formation in the halite. The area where this occurs is denoted as the disturbed rock zone or DRZ. Dilatancy ceases when compressive stresses commence. Numerous laboratory and field tests indicate dilatant damage in halite is reversible under compressive stress via crack closure and healing [7, 8, 9, 10, 11]. These investigations estimate halite fractures will heal within a few tens to a few hundred years when compressive stresses are applied. Thus, healed DRZ changes in situ properties such as strength, density, and permeability would be expected to reverse as well [7] Pfeifle and Hurtado (1998)) predict healed halite DRZ permeabilities will be at least 90% of pre-damaged values within a few hundred years at repository pressures. Numerical analysis predicts ROM salt properties undergoing consolidation and compression will produce back stresses to the DRZ of around 10 MPa at approximately 200 years [12]. Between 200 and 500 years the back stresses imposed on the DRZ will increase to approximately 12 MPa. Based on the above studies, DOE has predicted that the DRZ will heal between 200-300 years, the onset of DOE's T3 time-period.

DOE's treatment of the DRZ_PCS properties in the 2009-CRA and the PCS-2012 PA is based on the conceptualization of a healed DRZ primarily composed of anhydrite, which was appropriate for the Option D PCS. Anhydrite is brittle, does not readily heal under

pressure, structurally it contains more interconnected flow paths than halite, resulting in permeabilities several orders of magnitude greater than halite. Because the permeability for the Option D PCS is similar to that of anhydrite [13] (DOE 2009, Appendix PA, and Section 4.2.8.3) the DOE considered this a reasonable representation of the DRZ_PCS and Option D, the two acting together as one unit [14]. The DOE adopted this same permeability range, representative of anhydrite, in the PCS-2012 PA for the DRZ_PCS during the T3 time period. This permeability range is three orders of magnitude greater than that of halite and does not capture the changes in properties that would be representative of a separate healed halite DRZ during the T3 time period. The DOE will not mine out the DRZ halite adjoining the ROM salt at the time of panel closure installation. Therefore the DRZ_PCS will be composed primarily of halite, not anhydrite. It is reasonable to represent the healed DRZ_PCS with properties more similar to halite than anhydrite. Additionally, it is reasonable to assume two-phase flow mechanisms would come into play during T3 for the DRZ_PCS, and in the ROM salt PCS, for all time periods. To investigate these issues and their potential impact on releases, the Agency conducted a DRZ Sensitivity Test PA where the DRZ_PCS properties are similar to intact halite and the two-phase flow is used for both the DRZ_PCS and the ROM salt. How the Agency modeled the DRZ_PCS for this Sensitivity Test PA follows.

INPUTS USED IN THE SENSITIVITY PA

The Agency treated the DRZ_PCS as a fractured medium for the first 200 years after repository closure—as was done in the PCS-2012 PA. During this first period, and as appropriate for fractured media, we believed permeability would be relatively high and two-phase flow mechanisms would not take place. Similar to the PCS-2012 PA, we assumed that DRZ_PCS would reconsolidate during the T3 time-period. However the flow properties adopted for the T3 time period would differ from what DOE had used.

In the DRZ Sensitivity Test PA, it was assumed the healed DRZ_PCS would approach that of intact halite. The permeability of the healed DRZ_PCS was somewhat greater (an order of magnitude) than the permeability of undisturbed intact halite. What is assumed is, in random areas along the fracture length, during fractures healing crystals will realign with slightly more interconnected porosity resulting in slightly higher permeability. The DRZ Sensitivity Test modifications to the DRZ_PCS during T3 are given in Table I.

TABLE I. DRZ Sensitivity Test Modifications Made to DRZ Properties Above the Panel Closure (DRZ_PCS) from 200 to 10,000 Years (T3)

Property	Modification			
Two Phase Flow Model	Modified Brooks-Corey Model ^a			
Pt = Threshold Pressure	A function of permeability (k) ^b			
Residual Saturation	Value > 0 for both gas and brine ^c			
Log Permeability (log m³)	Mean	Median	Minimum	Maximum
T3 ^d	-21.50	-21.505	-22.97	-20.01
Footnotes: a Recommend for DRZ_PCS during T3 in Camphouse et al., 2012, Tables 10 and 11 b Pt = a k ^{-b} , uses DOE's values reported in Hurtado et al. 1997 for linear parameter 'a' and '-b' exponent. c Residual gas saturation, 0.05; residual brine saturation, 0.1 d An order of magnitude greater than what DOE sampled value for halite.				

With the DRZ_PCS transitioning to healed porous media two-phase flow properties were invoked and using the following two-phase flow mechanisms: 1) flow passing through the healed DRZ would not occur if saturations were below a residual saturation, and 2) flow would not occur unless threshold pressures were exceeded—a function of permeability [15]. The full set of BRAGFLO calculations were performed with the DRZ_PCS parameters modified. As done in the PCS-2012 PA, these calculations included three replicates and six scenarios. Table II lists the six scenarios.

TABLE II. BRAGFLO Salado Flow Modeling Scenarios

Scenario	Description
S1-BF	Undisturbed Repository
S2-BF	Borehole Intersects Waste Panel and Castile Reservoir at 350 years (E2)
S3-BF	Borehole Intersects Waste Panel and Castile Reservoir at 1000 years (E2)
S4-BF	Borehole Intersects Waste Panel Only at 350 years (E2)
S5-BF	Borehole Intersects Waste Panel Only at 1000 years (E2)
S6-BF	Borehole Intersects Waste Panel at 1000 years and Castile Reservoir at 2000 years (E2, E1)
Modified From Camphouse et al. 2012, Table 5-1; BF= BRAGFLO	

RESULTS

A CCDF was generated using results from the DRZ Sensitivity Test PA and compared with that from DOE's PCS-2012 PA. Figure 4 illustrates changing the DRZ_PCS properties caused the total mean releases to slightly increase at the 0.1 probability and

decrease at the 0.001. The CCDF in Figure 4 includes all release mechanisms, including cuttings and cavings releases, which are dependent on the number of boreholes penetrating the waste and not impacted by sampled parameters affecting repository conditions. The release mechanisms most affected by the changes made in this study are spallings and direct brine releases. The CCDFs for these releases are given in Figures 5 and 6.

Figure 5 shows spallings releases were significantly affected given the study modifications. EPA units increased by ~ 81% at the 0.1 the probability, and ~32 % at the 0.001 probability. Figure 6 indicates these same modifications minimally affect Direct Brine Releases. Because pressure is a primary driving force in spallings releases of most interest was how pressures in the waste and experimental areas may differ between the DRZ Sensitivity Test and the PCS 2012 PA analyses. But first, for the readers edification, a brief description DOE's simplified representation of the repository in BRAGFLO simulations is given.

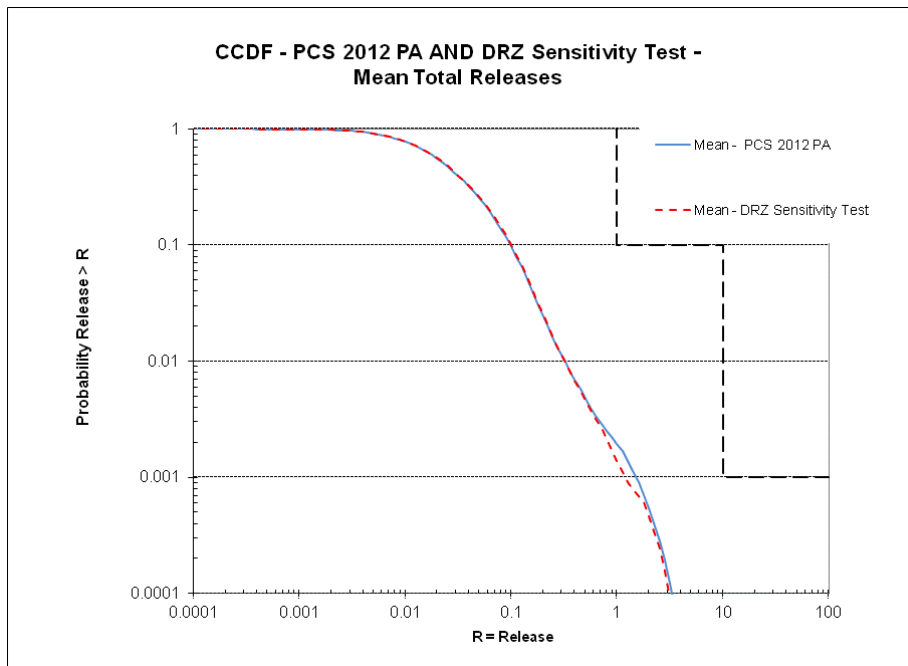


Fig. 4. PCS-2012 PA and DRZ Test, Mean Total Normalized Releases.

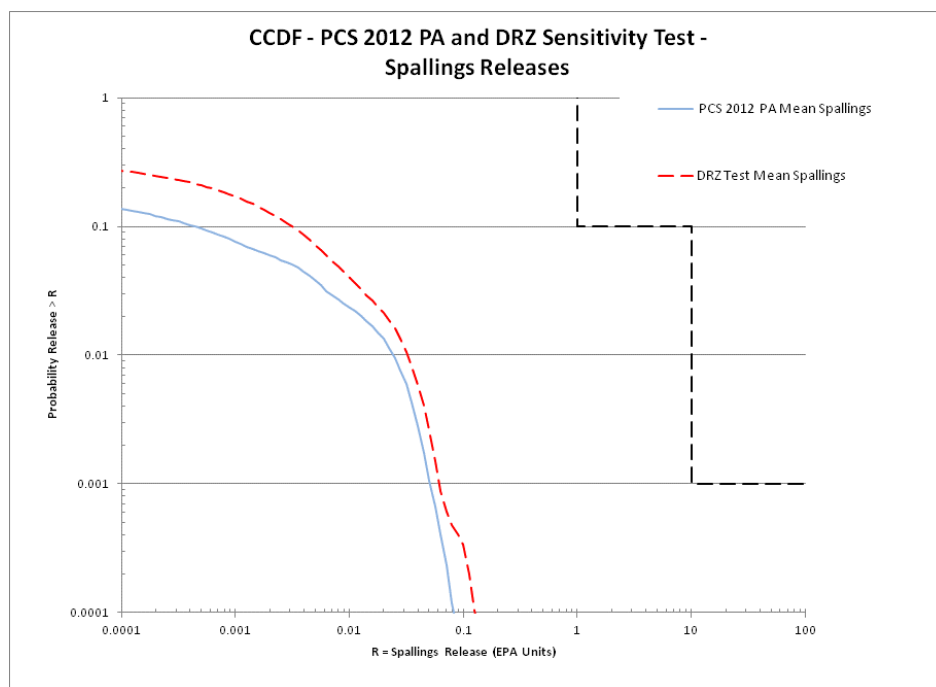


Fig. 5. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Spallings Releases

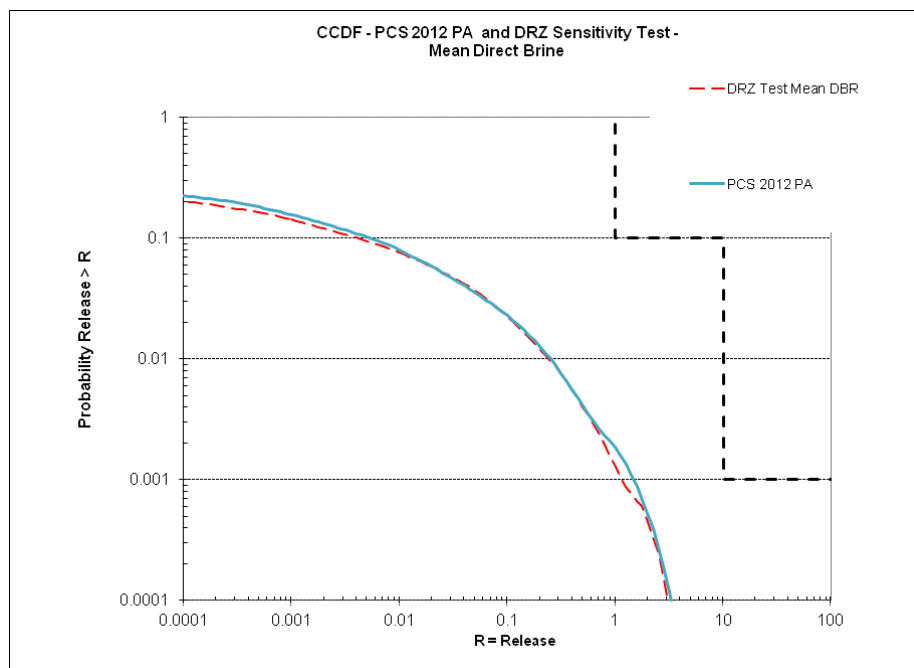


Fig. 6. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Direct Brine Releases.

DOE's representation of the repository is illustrated in Figure 7. The waste panels lying furthest south (to the left) are represented by a single waste panel. This is the panel in which an intrusion is modeled. The remaining waste panels, the interior waste panels, are simply represented by two regions denoted as the south and north 'rest-of-the-repository' (ROR) waste panels. Waste panels are separated by the panel closures. It is in the waste panels where gas is generated due to microbial degradation or steel corrosion. The operations area and experimental area are represented by two separate regions lying furthest north (to the right) on the grid and are separated by the repository shaft. The operations and experimental regions are important to repository performance because this is where gas produced in the waste panels can be stored. This storage space can potentially lower repository pressure and reduce releases for spillings and direct brine releases, as they are affected by pressure. Both gas and brine move between the waste panels and these other repository areas via the DRZ and the panel closure system. Therefore, if the DRZ_PCS variables are modified to restrict gas flow between the two regions then pressures in the waste panels would tend to be higher and pressures in the other repository areas lower.

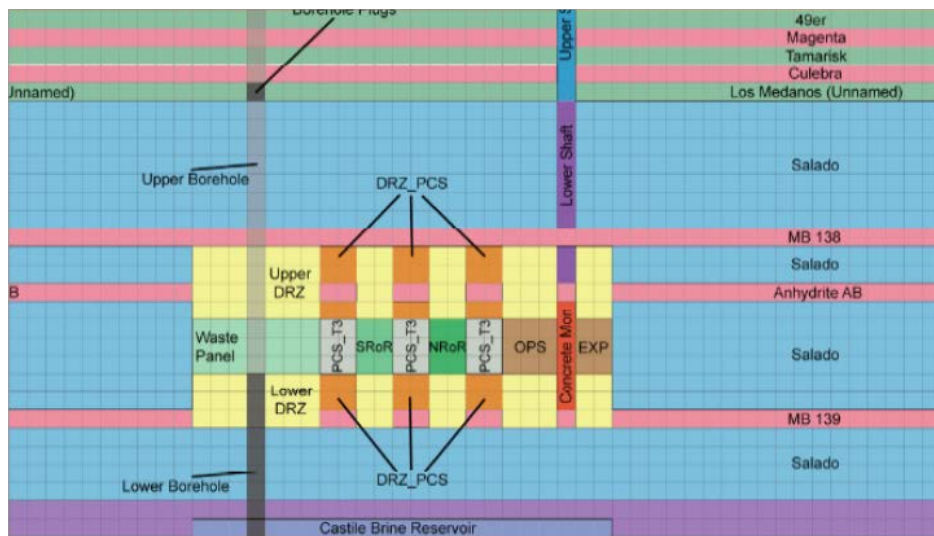


Fig. 7. BRAGFLO Representation of the Repository

Of the many BRAGFLO output variables examined, this paper focuses only on those affecting waste panels and the experimental pressures. Because these two areas are the furthest separated in the repository how their pressures differ from one another provides information of repository connectivity, and repository spatial and temporal behavior as a whole. We spent time looking at pressure differences between these two areas in the scenario where there has been an intrusion at 1000 years. One area of inquiry was to understand the relationship between total gas produced and pressure differences between the DRZ Sensitivity Test and the PCS-2012 PA. Table III gives the gas moles produced for the two analyses.

TABLE III. Cumulative Average Gas Moles Produced for S3-BF and S5-BF Scenarios, Replicate 1.

	BF-3			BF-5		
BRAGFLO Variable	PCS 2012 PA	DRZ Test	Percent Difference	PCS 2012 PA	DRZ Test	Percent Difference
Moles of Gas Produces	1.00×10^8	9.54×10^7	-4.81	7.76×10^7	7.85×10^7	1.15

Because there is ~ 5 % less gas moles produced in the DRZ for S3-BF scenario one would assume pressures in the waste and experimental regions to be lower in the DRZ Sensitivity Test case. In S5- BF Scenario 5 gas production is only ~ 1 % greater in the DRZ Sensitivity Test case, therefore equivalent or slightly higher waste panel and experimental room pressures are expected. However, waste panel and experimental room pressure curves, given in Figure 8, do not reflect these assumptions.

In S3-BF scenario (the top plot) there is a marked difference in room pressures between the DRZ Test case and the PCS-2012 PA analyses. The PCS-2012 PA analysis has approximately 5 % more gas produced yet the intruded waste panel pressures (the spiked curve) are lower for the majority of the modeled period than the DRZ Sensitivity Test case. The experimental area pressures (which do not have a spike) rise to that of the intruded waste panel by ~ 8000 years and indicate the repository as a whole is behaving more like one connected unit.

In contrast, the DRZ Sensitivity Test case has slightly higher intruded waste panel pressures than the PCS-2012 despite fewer moles of gas produced. The DRZ Sensitivity Test experimental area pressure does not equilibrate to that of the intruded waste panel, indicating impeded flow to the experimental area. In this case for the DRZ Sensitivity Test the repository behaves more like a set of isolated areas rather than one connected unit. This results in higher waste panel pressure and promotes higher spillings releases.

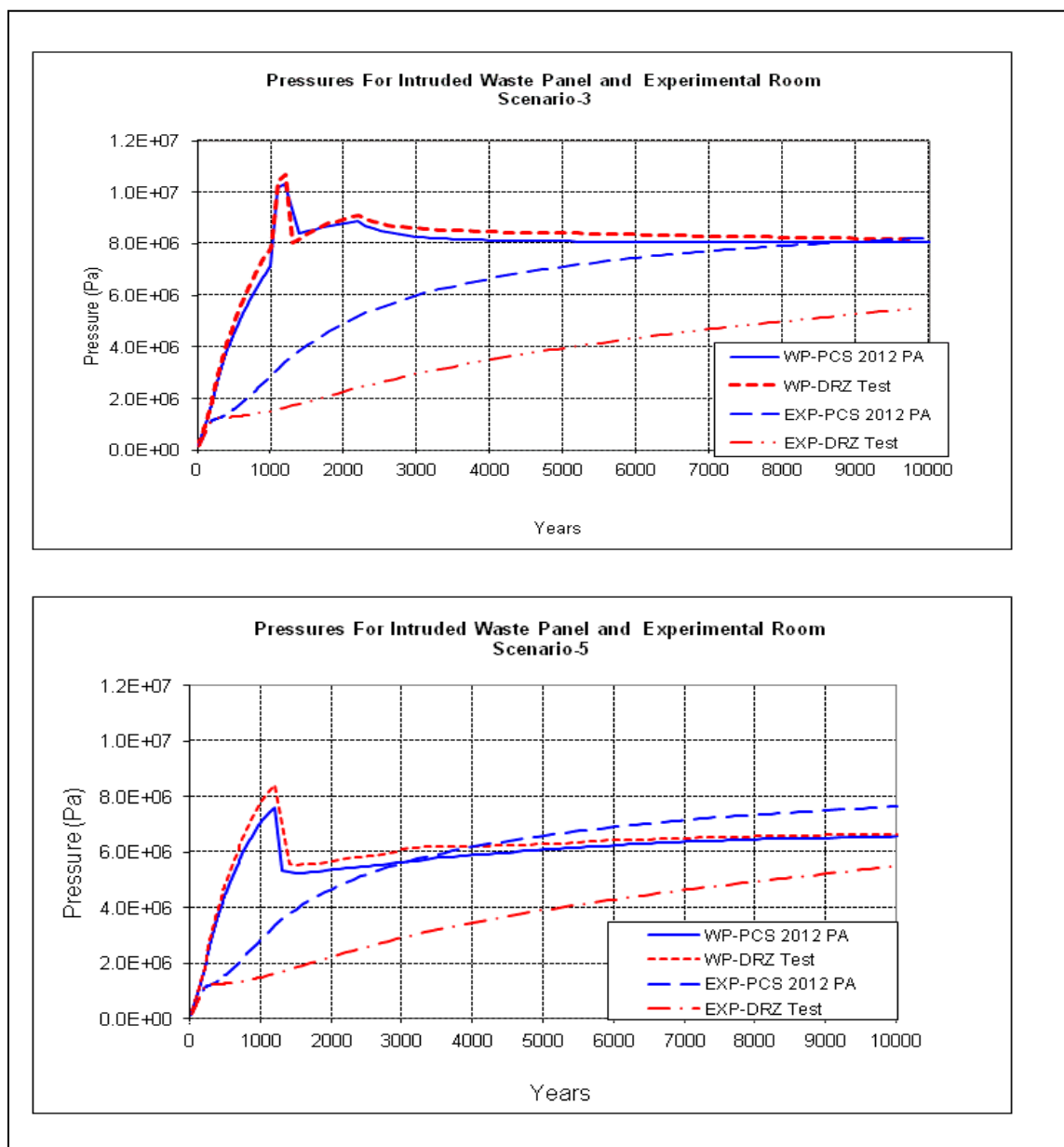


Fig. 8. Pressure Curves for the Down-Dip Waste Panel and The Experimental Room For the PCS-2012 PA and the DRZ Sensitivity Analyses, Scenarios S3-BF (top) and S5-BF (bottom)

Similar pressures differences are seen for Scenario 5 (the bottom plot in Figure 8). For this scenario, gas produced in the waste area is approximately 1 % greater in the DRZ Sensitivity Test case than in the PCS-2012 PA, yet waste area pressures for the test case are markedly higher. The experimental area pressures are always lower in the DRZ Sensitivity Test than those for the waste panel pressures.

In contrast, in the PCS-2012 analysis experimental area pressures rise and surpass the intruded panel pressure around 3,000 years. Like Scenario 3, the difference in pressure curves indicates gas produced in the intruded waste panel in the PCS-2012 PA migrates to the experimental area for storage causing the waste area pressures to be lower. This pressure difference is not seen in the DRZ Sensitivity Test case. Gas is impeded to flow to the experimental area and keeps waste room pressures higher than the experimental area throughout the modeled period.

Further evidence that gas generated in the waste panels tends to stay in the waste panel for the DRZ Sensitivity Test is illustrated with the pressure curves for the modeled interior waste panels—denoted as the NWP and SWP, given in Figure 9. S3-BF scenario is given in the top plot; S5-BF the bottom plot. It is the interior waste panels where the largest pressure difference is seen in areas where gas is produced, i.e., the waste panel. Pressures curves for the interior waste panels are greater in the DRZ Sensitivity Test case from those in the PCS-2012 PA. By 5,000 years the DRZ Sensitivity Test case has pressures that are at least ~ 10 % greater than the PCS-2012 for Scenario 3, and approximately 15% for Scenario 5. Because these middle waste panels are not intersected by a borehole the only path for gas to escape is through the DRZ or the panel closures. These pressure differences indicate the interior waste panels are not easily depressurized for the DRZ Sensitivity Test. Gas flow through in the DRZ_PCS is impeded in the DRZ Sensitivity Test compared to the PCS 2-12 PA and indicates an intrusion depressurizes the interior waste panels to a lesser extent. Consequently, a subsequent intrusion into an interior waste panel will encounter higher pressures and promote larger spallings releases.

Collectively, in the DRZ Sensitivity Test analysis pressure curves between the repository rooms indicate gas generated in the waste rooms tends to stay in the waste region and flow to the operations and experimental regions is also impeded. Since gas cannot readily flow out of the waste area to the rest of the repository waste room pressures are higher in the DRZ Sensitivity Test case than in the PCS-2012 PA despite less gas produced. Higher waste room pressures, observed in the DRZ Sensitivity Test Case, subsequently result in greater spallings releases when one of these interior waste rooms is breached by a second borehole.

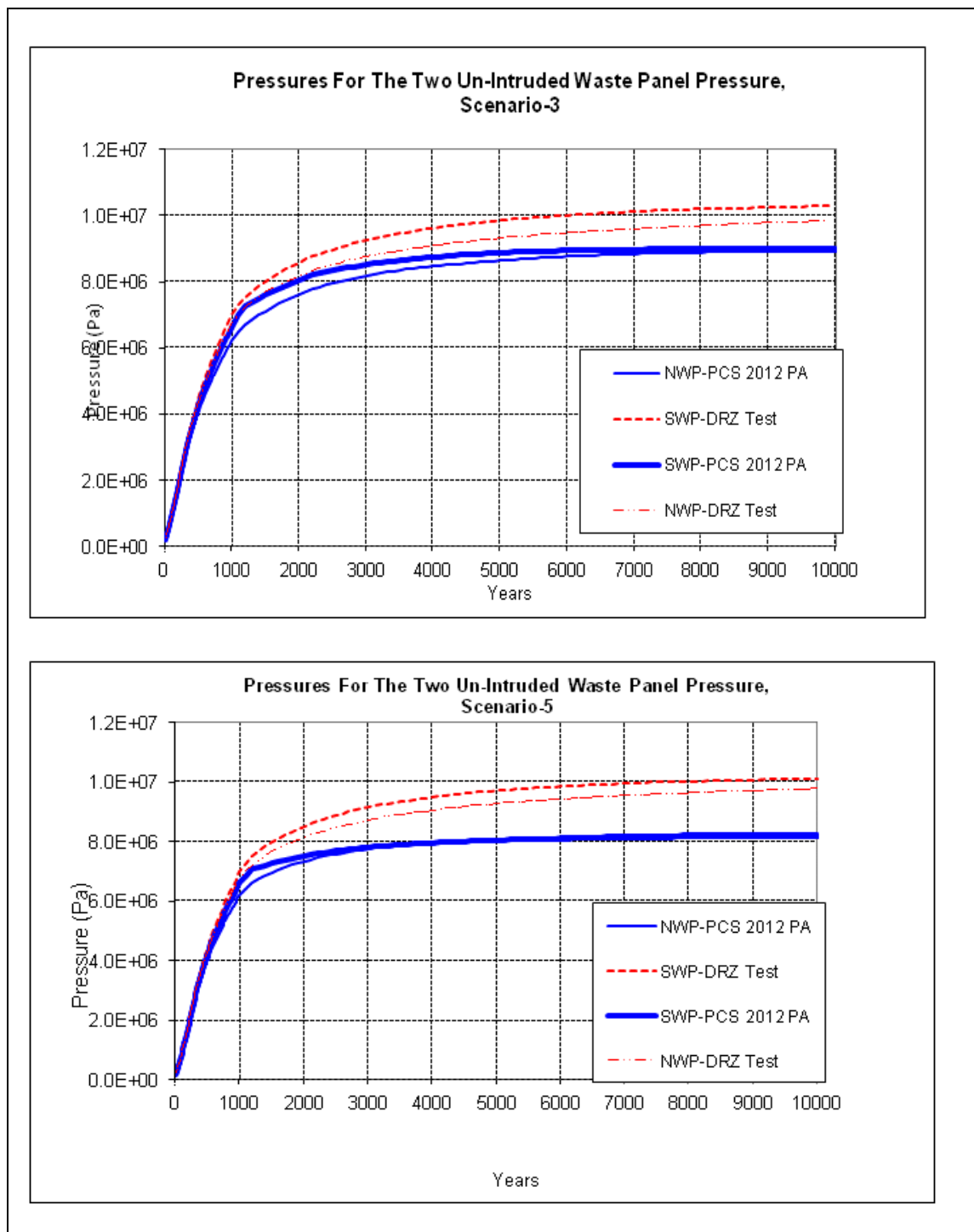


Fig. 9 Pressure Curves for South and North ROR Waste Panels for the PCS-2012 PA and the DRZ Sensitivity Analyses, Scenario S-3 (top) and Scenario S-5 (bottom)

CONCLUSION and SUMMARY

The DOE conducted a performance assessment to demonstrate that WIPP would still comply with EPA's radioactive waste disposal standards with the use of a proposed new panel closure design. The Agency closely examined the parameterization of the disturbed rock zone and two-phase flow. As part of the review, the Agency conducted a separate PA, denoted as the DRZ Sensitivity Test PA that assumed the DRZ properties adjacent to the ROM salt PCS are healed over the long-term. The DRZ_PCS properties adopted represent what would be expected of healed halite once the ROM salt PCS imposes back-stresses upon this region equivalent to repository pressures. In this analysis the Agency invoked two-phase flow in the ROM salt PCS during the entire modeled period and in the healed DRZ during the T3 time period. The DRZ Sensitivity Test showed that modifying the DRZ parameters above and below the ROM PCS during the T3 time period, combined with invoking the intended two phase flow parameters in the ROM panel closures, did slightly increase cumulative releases at the 0.1 probability and decrease releases at the 0.001 probability level. Looking separately at the primary release mechanisms there were significant increases only for the spallings releases. Direct brine releases decreased.

The increase in spallings releases was primarily due to an increase in waste area pressures. Gas generated in the waste rooms tends to stay in the waste region and does not migrate to the operations or experimental areas. Despite the increase in spallings releases, the overall mean results from DRZ Sensitivity Test remain below the containment requirements at 40 CFR 191.13. Results from this study also suggest, given the current repository configuration, mean total releases would continue to remain below the EPA regulatory limits over a range of DRZ permeability more representative of halite than anhydrite.

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