Effect of Increasing Cellulosics, Plastics, and Rubbers on WIPP Performance Assessment

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1.0 Introduction

1.1 Background

The Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico and 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) according to the regulations set forth in Title 40 of the Code of Federal Regulations, Parts 191 and 194 (US EPA 1993, US EPA 1998). The DOE demonstrates compliance with the containment requirements in the regulations by means of a performance assessment (PA), which estimates releases from the repository, under undisturbed and disturbed (e.g., penetration by drilling) conditions, for the regulatory period of 10,000 years after closure.

In March 2004, DOE submitted the Compliance Recertification Application (CRA) to the EPA, which included the results of PA analyses and modeling. The PA conducted for recertification was based on an updated inventory of the TRU waste (Downes and Guerin, 2003). During the EPA's review of the CRA, the EPA noted that the inventory of cellulosics, plastics and rubbers (CPR) did not include emplacement materials external to the waste containers (EPA, 2004). Additional CPR in the repository could result in greater volumes of gas generated by microbial action, which in turn could affect PA results. The EPA requested that DOE "...provide the volume and weight of all materials that are placed in the disposal system with the waste containers and ... account for their effects or justify why these additional materials are not expected to affect the behavior of the disposal system." (EPA, 2004). Leigh (2004) estimates the quantities of CPR that are emplaced external to the waste containers. This document demonstrates that the omission of these materials from the inventory used for the CRA does not affect the conclusions of the PA.

1.2 Purpose

This analysis illustrates the effects on PA results of a significant increase in CPR content of the repository. The analysis compares the results of two PA calculations that differ only in the quantity of CPR included in the calculation. The first analysis included a quantity of CPR approximately 250% greater than the inventory projection for the CRA. The second analysis used the correct inventory of CPR. In this report, the earlier PA with the erroneously large quantities of cellulosics and of CPR is termed AMW1, and the later PA with the correct quantities is termed AMW2. This comparison shows the effects of increasing CPR content and can be used to estimate the potential effects of errors or uncertainties in CPR quantity up to that level.

1.3 Analysis Plan

This analysis is supplementary to the CRA and is covered under AP-112, Analysis Plan For CRA Response Activities (Kirkes and Wagner, 2004). The analysis methodology and results are presented in this document. A specific analysis plan is not necessary.

2.0 Methodology

This analysis compares the results of two PA calculations that differ only in the quantity of CPR included in the calculation. The comparison uses the results of the PA performed to evaluate the effects on repository performance of emplacing supercompacted waste from the Advanced Mixed Waste Treatment Facility (AMWTF). This PA was initially completed in October 2003, and was reported in Hansen et al. (2003). Subsequently, it was found that the initial PA reported in Hansen et al. (2003) was completed with an erroneously large quantity of CPR in the waste (Hansen, 2003). After correction of the error (Dunagan and Garner, 2004) the PA was re-run and the results reported in Hansen et al. (2004). Differences between the results of these two PAs illustrate the effects of substantially increasing the quantity of CPR in the repository. This report shows that conclusions drawn from this comparison are applicable to the CRA PA.

Table 1 lists the masses of cellulosics and CPR that were used in the AMW1, AMW2 and CRA PAs. Microbial action is present in 50% of PA realizations. The two quantities are listed separately because in half of these realizations (25% of all PA realizations) only cellulosics can be consumed; in the other half of realizations with microbial action all CPR is available for consumption. The quantities of cellulosics and of CPR in the AMW1 PA are more than 2.5 times higher than those in AMW2 and the CRA PAs. For simplicity of presentation, hereafter in this report the term CPR refers to the material available for microbial degradation whether that material consists only of cellulosics, or of the combination of cellulosics, plastics and rubbers.

Table 1. Quantities of CPR used in AMW1 and AMW2 Performance Assessments.

	Cellulosics (kg)	CPR (kg)
AMW1 PA	2.54×10^7	7.48×10^7
AMW2 PA	9.83×10^6	2.89×10^7
CRA PA	9.83×10^6	2.89×10^7

Comparison of the AMW1 PA results with those of the AMW2 PA *illustrates* the possible effects of increasing CPR quantities. Increasing CPR in the repository may lead to larger volumes of gas and thus to higher gas pressures, potentially affecting transport, spallings and direct brine releases. Cuttings and cavings releases are not affected by gas pressure and thus are not affected by changes in the CPR inventory.

This comparative analysis illustrates the effects on PA of substantially increasing the CPR content of the repository, and thus it bounds the effects of relatively small increases in CPR. Inferences about the effects of increasing CPR quantities in the CRA PA can be drawn from conclusions about the comparison of the AMW PAs as long as other differences between the CRA PA and the AMW PAs are accounted for.

3.0 Analysis Results

The comparison of results between the AMW1 and AMW2 PA focuses on primary model outputs that may be affected by changes in the total gas generation within the repository. These outputs include pressure and saturation in the repository, brine flow out of the repository, as well as releases by processes dependent on pressure, saturation and brine flow. These processes are spallings, direct brine releases, and transport releases. The comparison concludes by examining total releases from the repository.

Spallings is discussed in detail in the User's Manual for CUTTINGS_S and its addendum (WIPP PA, 1996). CCDFGF is discussed in detail in Design Document and User's Manual for CCDFGF (WIPP PA, 2003b).

3.1 BRAGFLO Results

The BRAGFLO computer code was used to model the flow of brine and gas in and near the repository for the 10,000-year regulatory period. BRAGFLO results are used to determine the initial conditions for the models computing direct releases, and transport through the Salado to the Culebra and to the Land Withdrawal Boundary. The BRAGFLO output variables most important in calculation of releases are pressure and saturation in the waste filled regions, and brine flow up the borehole to the Culebra. Pressure and brine saturation are used as initial conditions in the model for direct brine releases; pressure is an initial condition in the model for spallings; and brine outflow is used as a boundary condition in the model for transport through the Culebra flow. BRAGFLO is discussed in detail in its User's Manual (WIPP PA, 2003a).

BRAGFLO is run for six scenarios. While all BRAGFLO results are used in the construction of releases, this analysis examines only the undisturbed scenario (S1 scenario) and the disturbed scenario (S2 scenario) in which a drilling intrusion at 350 years also intersects a brine pocket located below the repository. The S1 scenario illustrates long-term, undisturbed flow processes and is useful for identifying sensitivity of model outputs to uncertain inputs. The S2 scenario was chosen because this scenario results in the largest volumes of brine flow up the borehole. (Hansen et al., 2004; Stein and Zelinski, 2003).

Gas generation by microbial action is modeled with two uncertain parameters. The first parameter, WMICDFLG, is a discrete random variable that takes values of 0, 1, or 2, and selects one of three future states for microbial action:

0: no significant microbial action in the repository (probability 0.5);

1: microbial communities may consume cellulosics only (probability 0.25);

2: microbial communities may consume cellulosics, plastics and rubbers (probability 0.25).

Thus, in vectors for which WMICDFLG is zero, there can be no effect of increasing cellulosics or CPR quantities; in vectors for which WMICDFLG is one or two, larger quantities of gas can be generated, leading to higher pressures and thus altering brine saturations and brine flow.

3.1.1 Pressure

Figure 1 compares pressure in the representative waste panel (WAS_PRES) for the AMW1 and AMW2 analyses for the undisturbed (S1) scenario. In this scenario, vectors with low and mid-range pressures are similar in both analyses, but high-pressure vectors have higher pressures in the AMW1 analysis than in the AMW2 analysis. The highest AMW1 pressures are about 3 MPa greater than the highest AMW2 pressures. This result is consistent with the increase in CPR quantity; the high-pressure vectors are those in which microbial action consumes CPR, and thus an increase in CPR leads to greater gas generation, and higher pressures. In contrast, low-pressure vectors are those in which microbial action is not present in the repository; thus, there is no difference between AMW1 and AMW2 results for these vectors. Figure 2 compares mean, 90th and 10th percentiles for the distribution of pressure for the AMW1 and AMW2 results. The 90th percentile for the distribution of pressure in AMW1 is also about 3 MPa higher than those for the corresponding distributions of AMW2, while the mean is about 1.5 MPa higher, and 10th percentiles for the distributions of pressure are very similar.

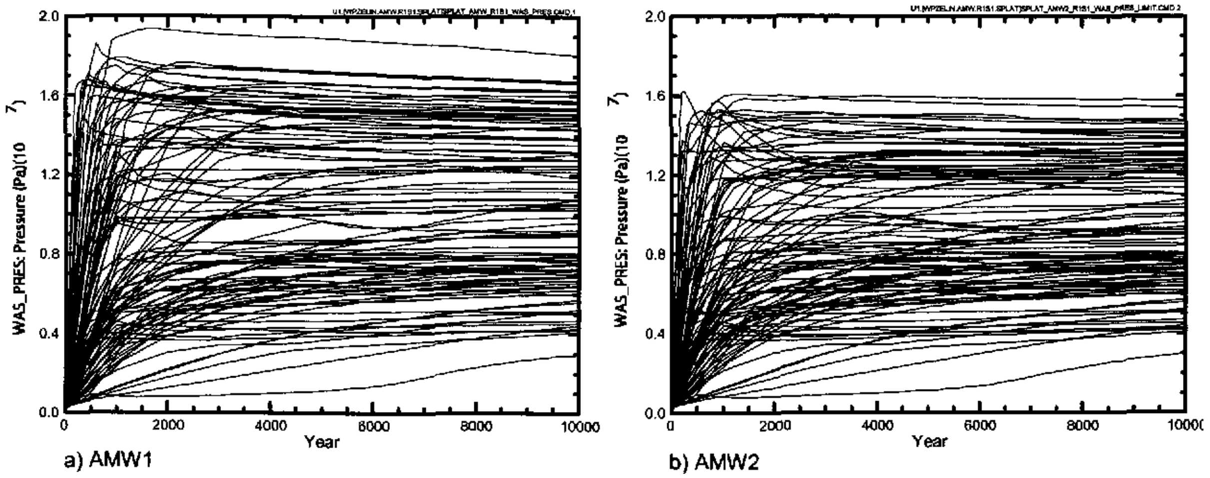


Figure 1. Pressure in the Waste Panel (WAS_PRES), S1 Scenario.

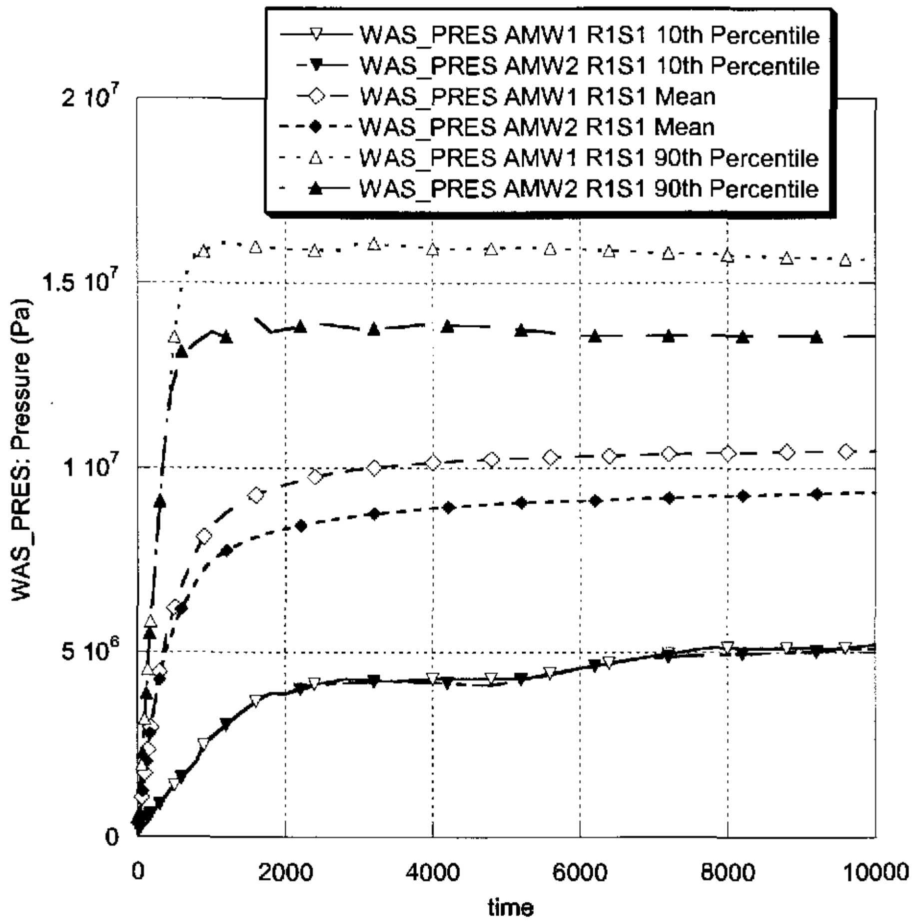


Figure 2. Mean, 90th and 10th Percentiles of Pressure in the Waste Panel (WAS_PRES), S1 Scenario.

Variability in CPR inventory has less effect on pressure in the disturbed (S2) scenario, because the borehole connection to the surface helps to relieve pressures in the repository, thus preventing the high pressures attained in the undisturbed (S1) scenario of AMW1. However, pressure in highest-pressure vectors of the S2 scenario is higher in the AMW1 analysis than in the AMW2 analysis by about 1 MPa (Figure 3). The plot of the means, 90th and 10th percentiles show that the 90th percentile values of the AMW1 distributions are higher by as much as 2 MPa than those of the corresponding AMW2 distributions (Figure 4).

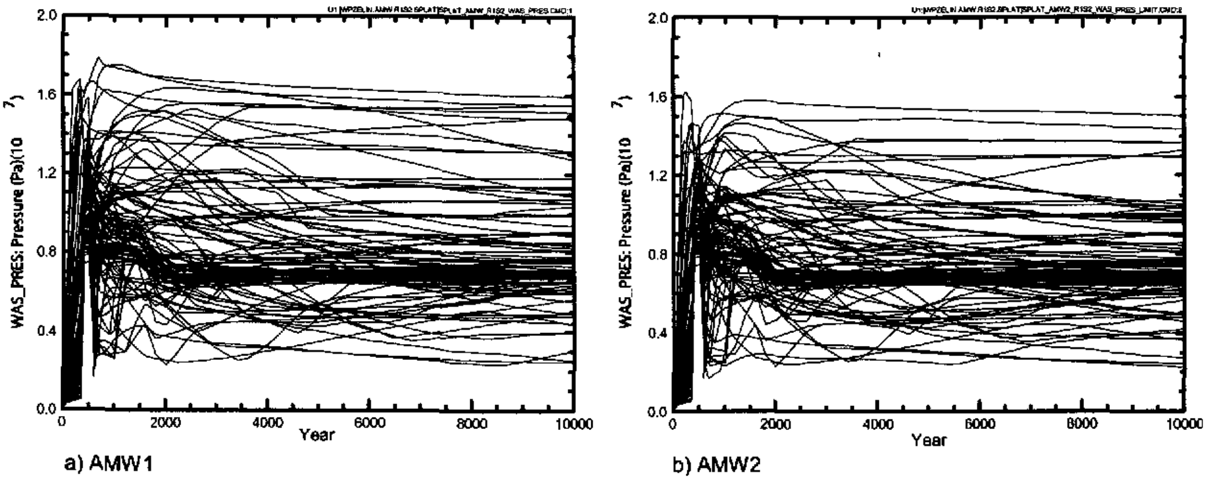


Figure 3. Pressure in the Waste Panel (WAS_PRES), S2 Scenario.

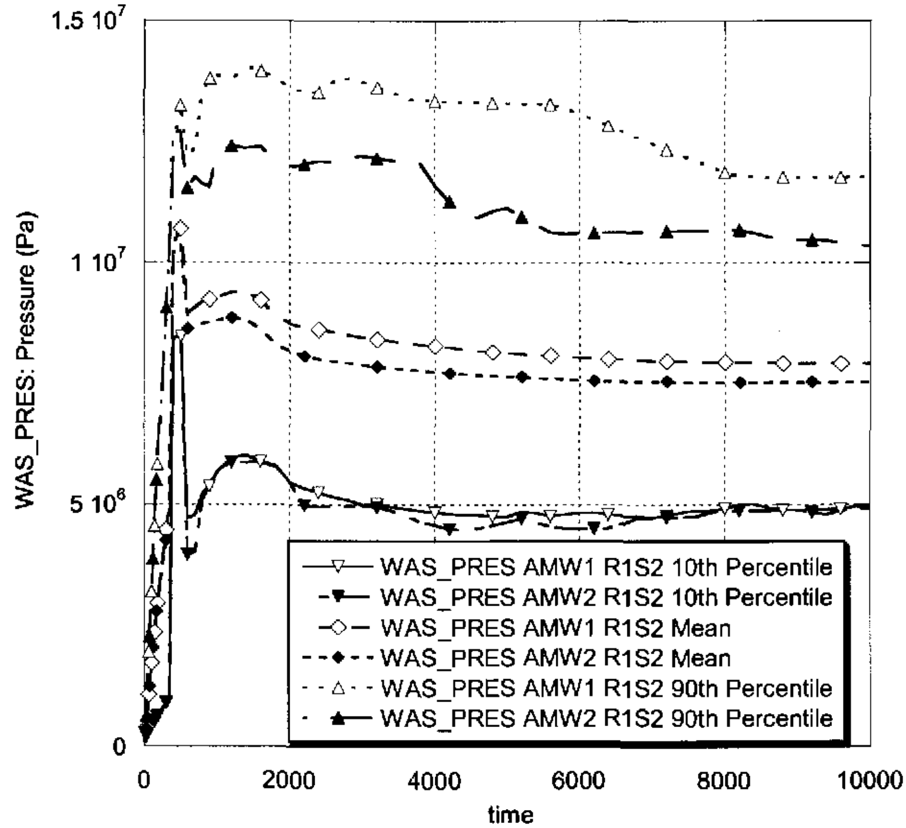


Figure 4. Means, 90th and 10th Percentiles of Pressure in the Waste Panel (WAS_PRES), S1 Scenario.

3.1.2 Brine Saturation

Figure 5 compares brine saturation in the representative waste panel (WAS_SATB) for the AMW1 and AMW2 analyses for the undisturbed (S1) scenario. Most vectors show low brine saturation in both analyses. The ranges and patterns of values are similar for both analyses, although the AMW1 analysis shows a few more vectors with brine saturation exceeding 0.20. Figure 6 compares the means, 90th and 10th percentiles for the distributions of brine saturation in the waste panel, and shows that the distributions are quite similar for the two analyses.

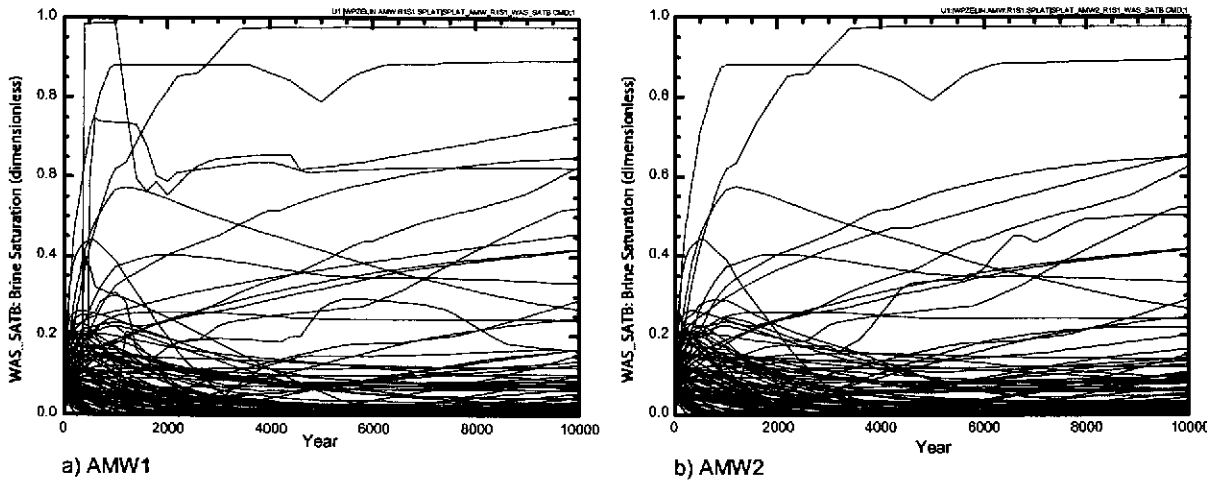


Figure 5. Brine Saturation in the Waste Panel (WAS_SATB), S1 Scenario.

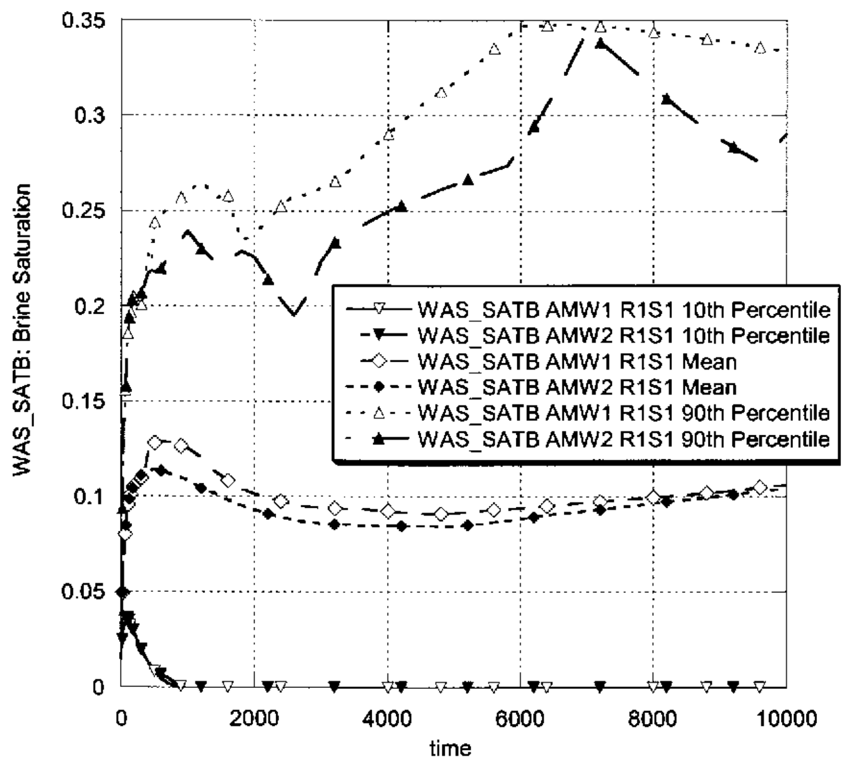


Figure 6. Means, 90th and 10th Percentiles of Brine Saturation in the Waste Panel (WAS_SATB), S1 Scenario.

There are even fewer differences in brine saturation results for the disturbed (S2) scenario. In this scenario, brine flow from the Castile overwhelms the effect of repository conditions. Figure

7 compares brine saturation in the waste panel for the AMW1 and AMW2 analyses for the disturbed (S2) scenario; Figure 8 shows the means, 90th and 10th percentiles for the distributions of brine saturation in the waste panel. The increased gas generation from increased CPR quantities has little effect on brine saturation in the waste panel. Vectors with low brine saturation due to relatively low pressure in the brine pocket show slightly lower brine saturation in AMW1 than in AMW2 due primarily to lower pressure in a few vectors.

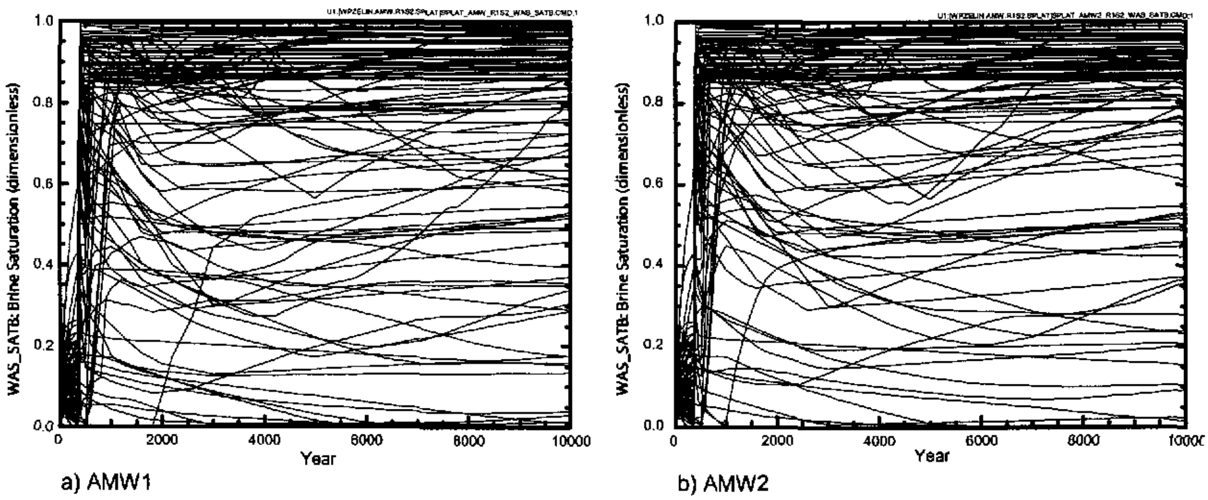


Figure 7. Brine Saturation in the Waste Panel (WAS_SATB), S2 Scenario.

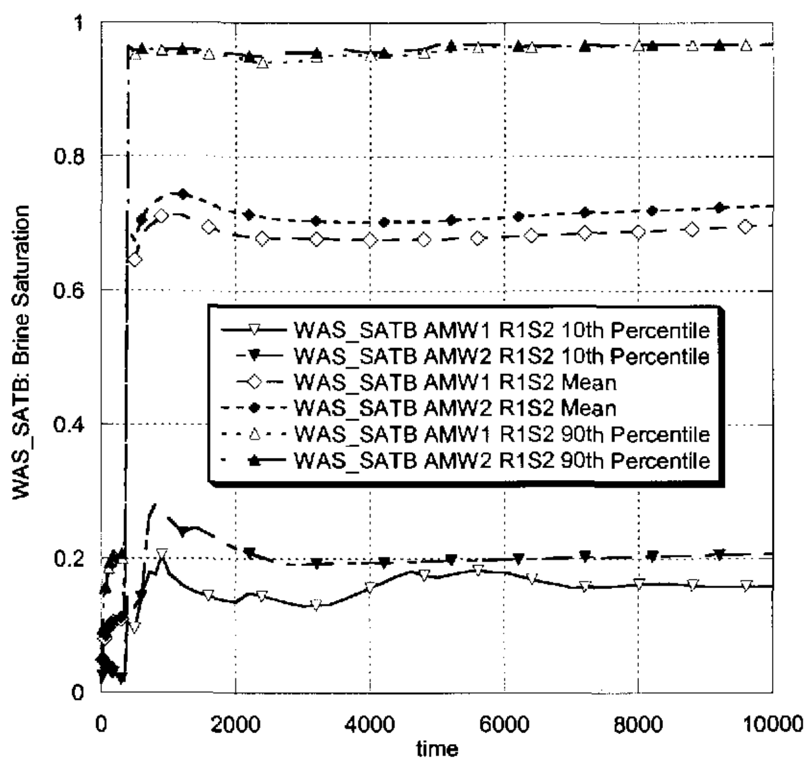


Figure 8. Means, 90th and 10th Percentiles of Brine Saturation in the Waste Panel (WAS_SATB), S2 Scenario.

3.1.3 Brine Flow Away from the Repository

Most vectors in either the AMW1 or AMW2 analyses have little to no brine outflow in the undisturbed (S1) scenario (Figure 9). For the few vectors that have significant brine outflow, the outflow volumes (BRNREPOC) are about three times larger in the AMW1 analysis than in the AMW2 analysis. The larger flow volumes are the result of higher pressure in the repository in the AMW1 analysis, which is caused by the larger quantity of CPR in the repository. In the undisturbed scenario, brine flows away from the repository through the marker beds, principally through Marker Bed 139 below the waste panels. Brine outflow is largely controlled by the hydrological parameters of the surrounding geologic materials. Higher pressure in the repository increases brine outflow, but not dramatically. Figure 10 compares the means, 90th and 10th percentiles for brine outflow volumes for the AMW1 and AMW2 calculations, and shows that brine outflow volume is somewhat increased by the increase in CPR quantity. The effects of larger brine outflows on transport releases in the undisturbed scenario are described later in this report.

In the disturbed (S2) scenario, borehole permeability rather than pressure is the dominating factor affecting brine flow (Stein and Zelinski 2003). Figure 11 compares brine outflow for the AMW1 and AMW2 analyses in the disturbed (S2) scenario. As in the undisturbed scenario, the range and distribution of values is similar in the two analyses (Figure 12), but there are a few vectors with conspicuously higher outflow volumes in the AMW1 analysis. In the disturbed scenario, brine flows predominantly up the borehole to the Culebra. The effect of larger brine outflow volumes on transport releases through the Culebra is discussed later in this report.

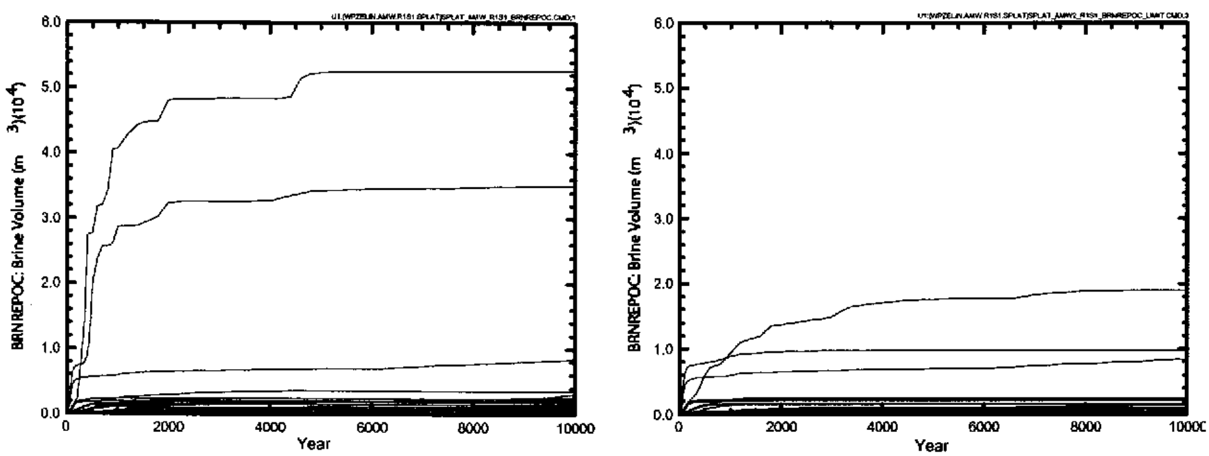


Figure 9. Brine Outflow (BRNREPOC), S1 Scenario.

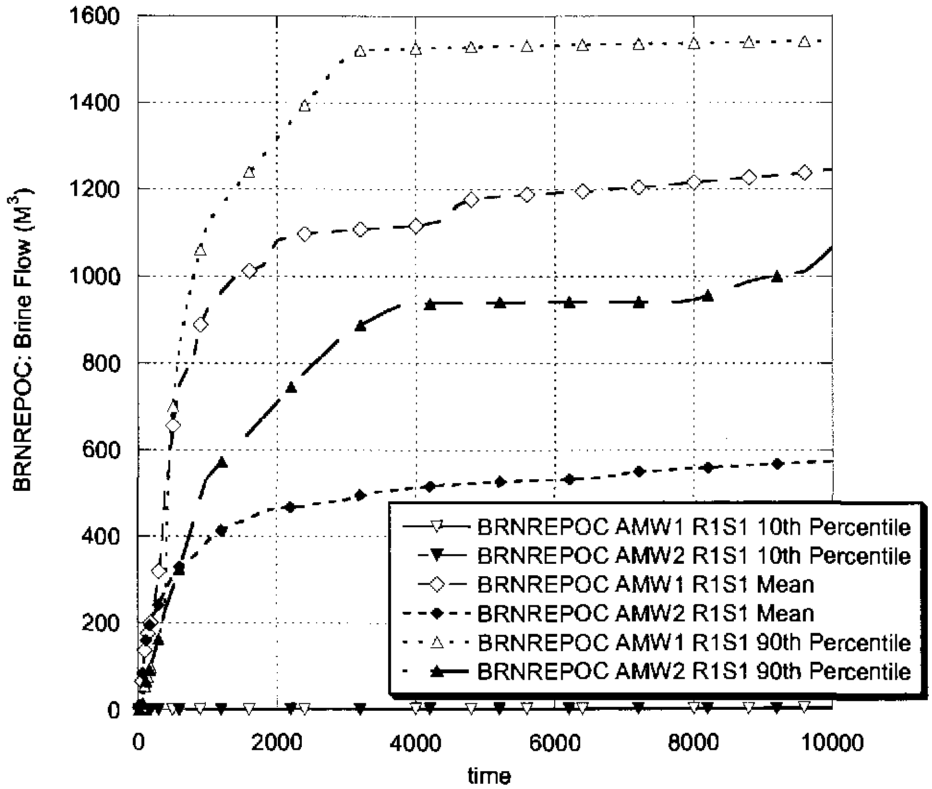


Figure 10. Means, 90th and 10th Percentiles of Brine Outflow (BRNREPOC), S1 Scenario.

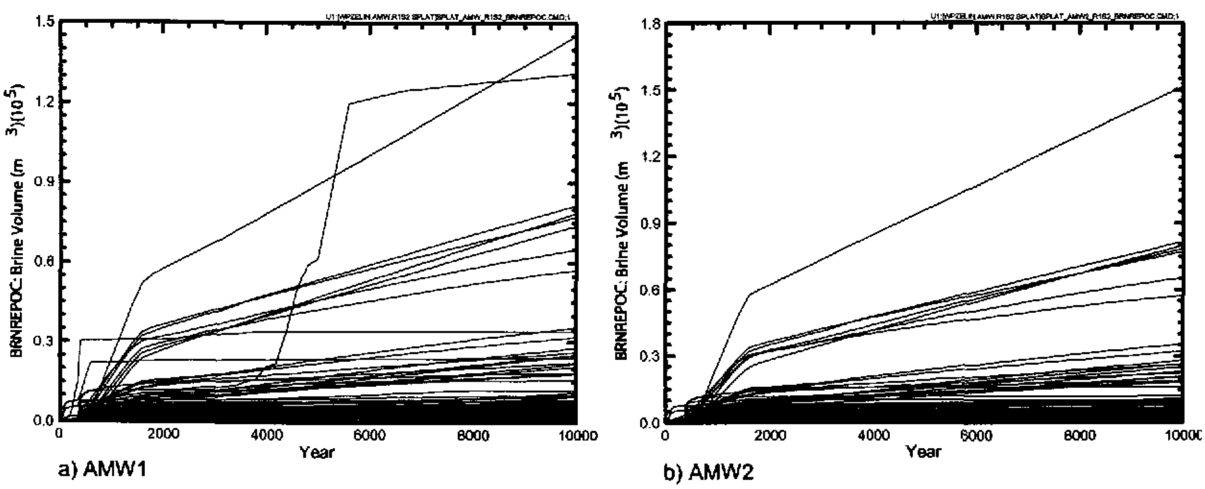


Figure 11. Brine Outflow (BRNREPOC), S2 Scenario.

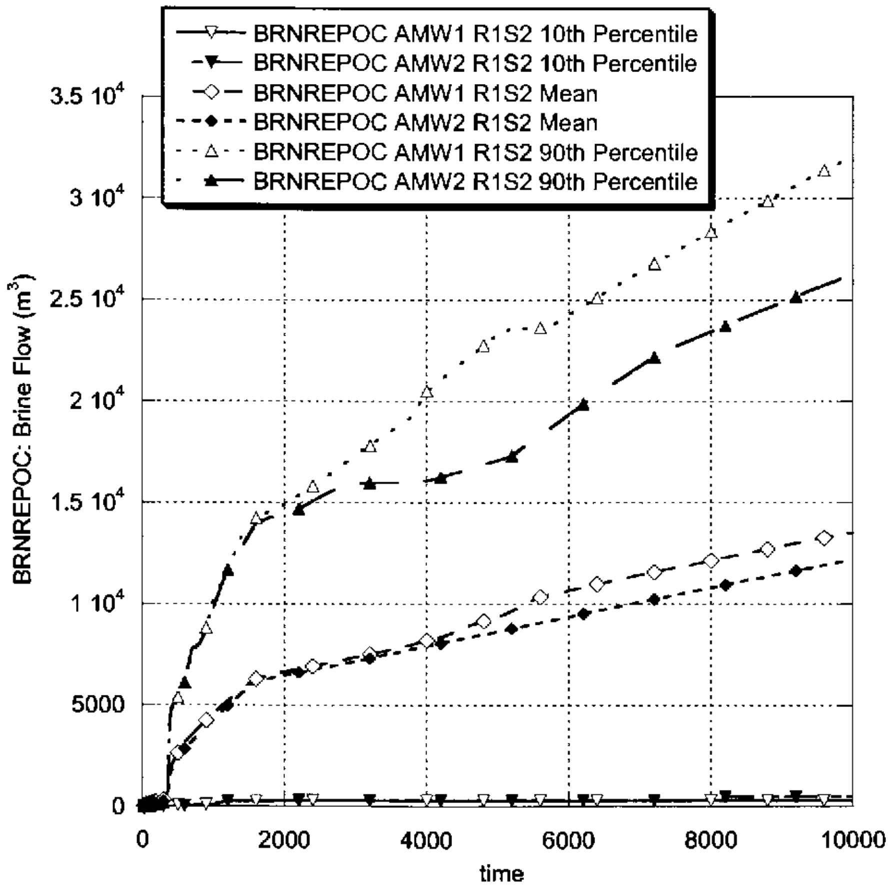


Figure 12. Means, 90th and 10th Percentiles of Brine Outflow (BRNREPOC), S2 Scenario.

3.2 Comparison of Releases

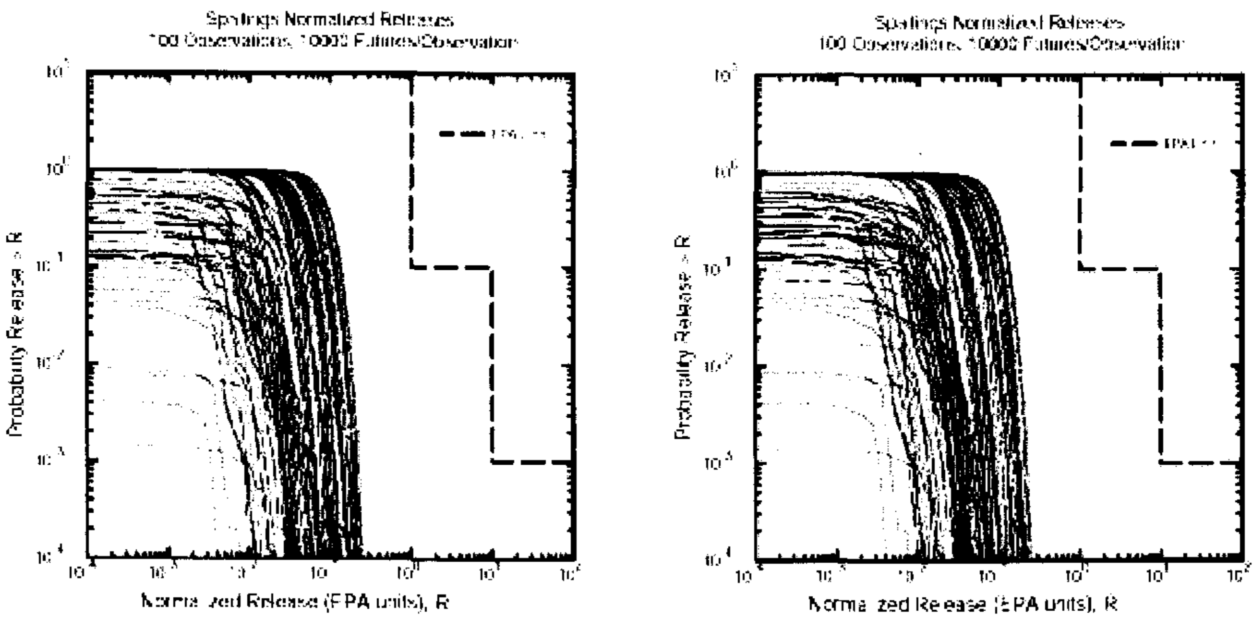
Releases from the repository can be categorized as direct releases and transport releases. Direct releases occur at the time of a drilling intrusion, and include cuttings and cavings, spallings, and direct brine releases. Cuttings and cavings releases are solids removed by the action of the drill bit and drilling fluid. Cuttings and cavings releases are not affected by pressure and brine saturation in the waste and thus cannot be affected by changes in the quantity of CPR. Spallings and direct brine releases may be affected by changes in pressure and saturation.

Transport releases are divided into two categories: transport through the Salado and transport through the Culebra. Transport releases use the brine flows calculated by BRAGFLO to compute the quantities of radionuclides that transport through the Salado, or up the borehole to the Culebra and then through the Culebra.

3.2.1 Spallings Releases

Both the AMW1 and AMW2 analyses used the simplified spallings model from the PAVT. In this model, spallings releases occur if the pressure in the repository exceeds 8 MPa at the time of intrusion. Otherwise the spallings release is zero. If spallings occur, the volume of material released is independent of repository pressure.

As described in Section 3.1.1, pressure in the repository was generally higher in AMW1 than in AMW2. This increase in pressure causes spallings releases to occur for a larger fraction of intrusions. The pressures of AMW1 exceed the threshold in the spallings model, 8 MPa, more frequently than in AMW2, resulting in larger cumulative spallings releases. Figure 13 compares the complementary cumulative distribution functions (CCDFs) for spallings releases for the AMW1 and AMW2 calculations, and shows that the general form of each CCDF is similar in both calculations. Figure 14 shows the median, 90th and 10th percentile CCDFs for spallings in the AMW1 and AMW2 calculations, and demonstrates that spallings releases are increased only slightly by the increase in CPR quantity.



a) AMW1

b) AMW2

Figure 13. Spallings Releases.

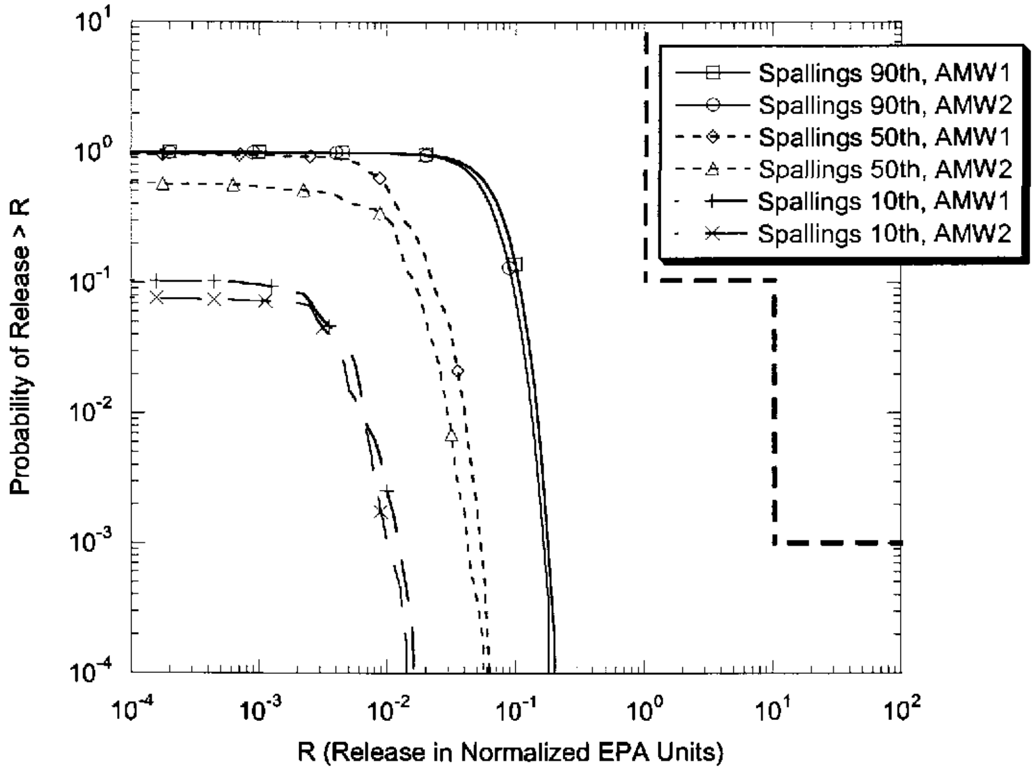
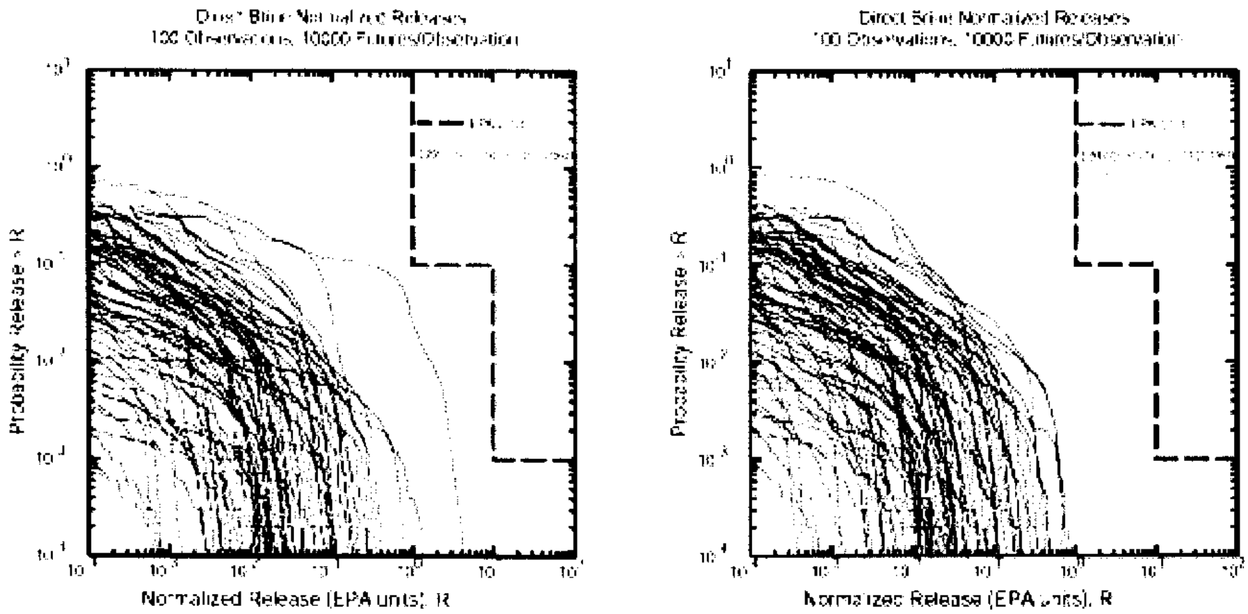


Figure 14. Median, 90th and 10th Percentile CCDFs for Spallings Releases.

3.2.2 Direct Brine Releases

Both the AMW1 and AMW2 analyses used the same model for direct brine releases. This model, described in detail in DOE (2004), computes the volume of brine released from the repository at the time of an intrusion due to pressure in the repository. As described in Section 3.1.1, pressure in the repository was generally higher in AMW1 than in AMW2 and brine saturation was similar between the two calculations. Consequently, direct brine releases may be larger and more likely in the AMW1 calculation.

Figure 15 compares the CCDFs for direct brine releases for the AMW1 and AMW2 calculations. Except for a single vector, the CCDFs for direct brine releases are very similar. The single vector that differs has much larger releases in the AMW1 calculation than in the AMW2 calculation. This vector (vector 22) was analyzed in the report for the AMW1 calculation (Hansen et al., 2003). In the AMW1 calculation, the presence of additional CPR in the repository combined with the use of alternate porosity surfaces increased pressure and brine saturation after the first intrusion, and resulted in large direct brine releases from the second intrusion (Hansen et al., 2003). In contrast, this vector does not show large DBR volumes in the AMW2 calculation, indicating that the lower mass of CPR precludes the conditions that led to large DBR volumes.



a) AMW1

b) AMW2

Figure 15. Direct Brine Releases.

Figure 16 shows the median and 90th percentile CCDFs for direct brine releases in the AMW1 and AMW2 calculations, and demonstrates that the distribution of direct brine releases is not generally affected by the increase in CPR quantity. The effects of increasing CPR are evident only in a single vector. The 10th percentile CCDF for direct brine releases does not plot on the scale of Figure 16.

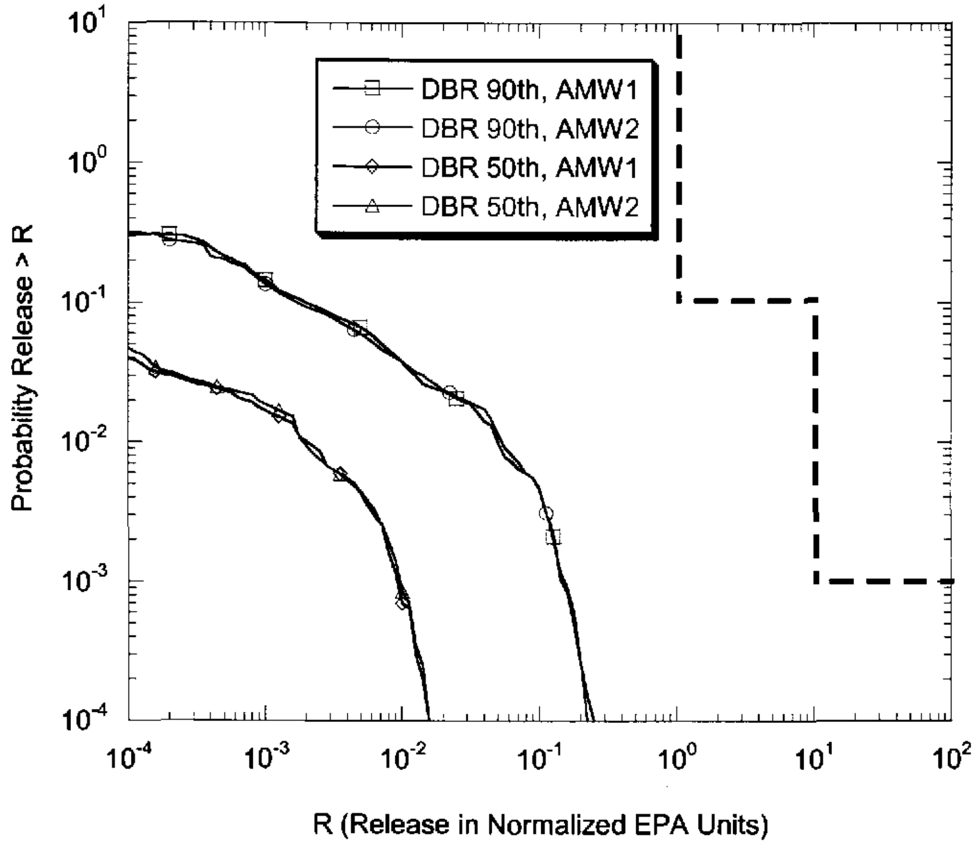


Figure 16. Median and 90th Percentile CCDFs for Direct Brine Releases.

3.2.3 Transport Releases

The code NUTS uses the brine flows calculated by BRAGFLO to compute releases by transport through the Salado. In the AMW1 calculation, only a single vector (vector 82) showed releases through the Salado to the Land Withdrawal Boundary (LWB) (Dunagan, 2003). However, these releases were several orders of magnitude below the threshold defined by the individual and groundwater protection requirements for the WIPP. In the AMW2 calculation, no vector showed releases through the Salado to the LWB (Dunagan, 2004). Therefore, large increases in CPR content do not lead to releases by transport through the Salado that even approach the compliance limit.

The code SECOTP2D computes transport through the Culebra, using flow fields computed for the AMW1 and AMW2 by SECOFL2D, with the quantities of radionuclide introduced to the Culebra computed by the codes NUTS and PANEL. In neither the AMW1 nor AMW2 calculationdid any vector show releases through the Culebra to the LWB that exceeded 10^{-4} EPA units at a probability exceeding 10^{-4} (Hansen et al., 2003; 2004). Therefore, although increasing CPR quantity in the repository increases brine flow to the Culebra, transport through the Culebra remains many orders of magnitude below the threshold established in the containment requirements for the WIPP.

3.2.4 Total Releases

Figures 17 and 18 show the total releases in EPA units for the AMW1 and AMW2 calculations (Hansen et al., 2003; 2004). The larger CPR values in AMW1 have a noticeable effect on only one vector (vector 22), in which direct brine releases were significantly increased. Despite the increase in direct brine releases, total releases remain below the limit in the AMW1 calculation. Therefore, a large increase in CPR quantity does not significantly increase total releases from the repository for most realizations, nor do the increased releases in a few realizations exceed the containment requirements.

Figures 19 and 20 show the mean CCDFs for total releases and for components of total releases. The transport releases are too small to plot on the scale of these figures. Figures 19 and 20 demonstrate that the increase in CPR quantity does not alter the relative contribution of each component to total releases. The only effect of the increased CPR in the AMW1 calculation is to increase direct brine releases for a single vector, which affects the mean CCDF for direct brine releases at very low probabilities.

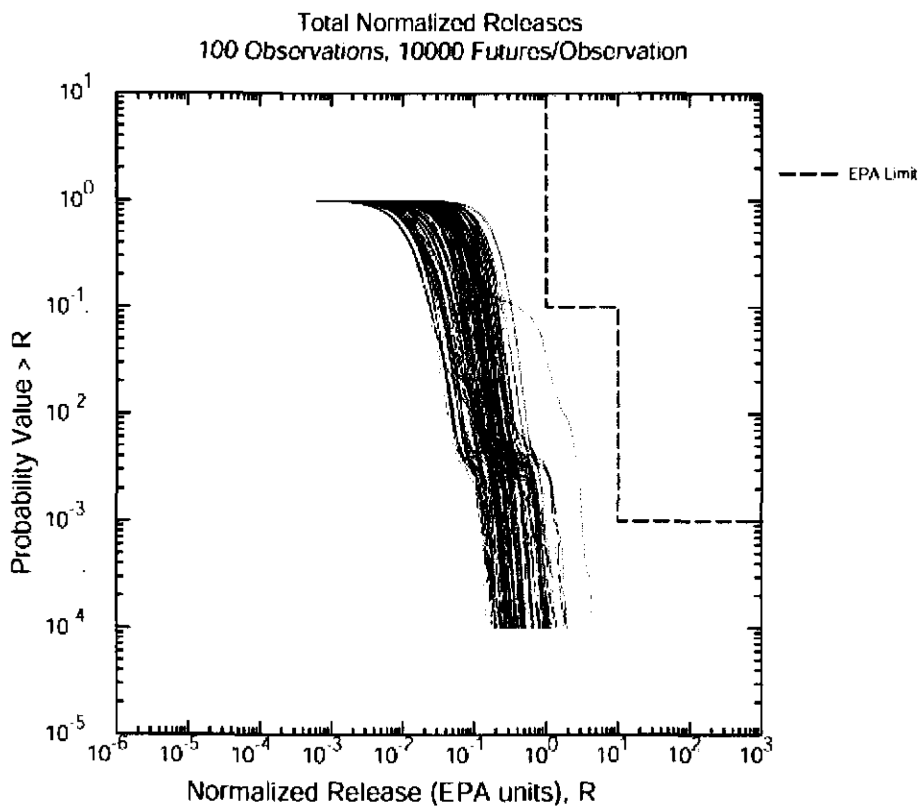


Figure 17. Total Releases, AMW1 Calculation.

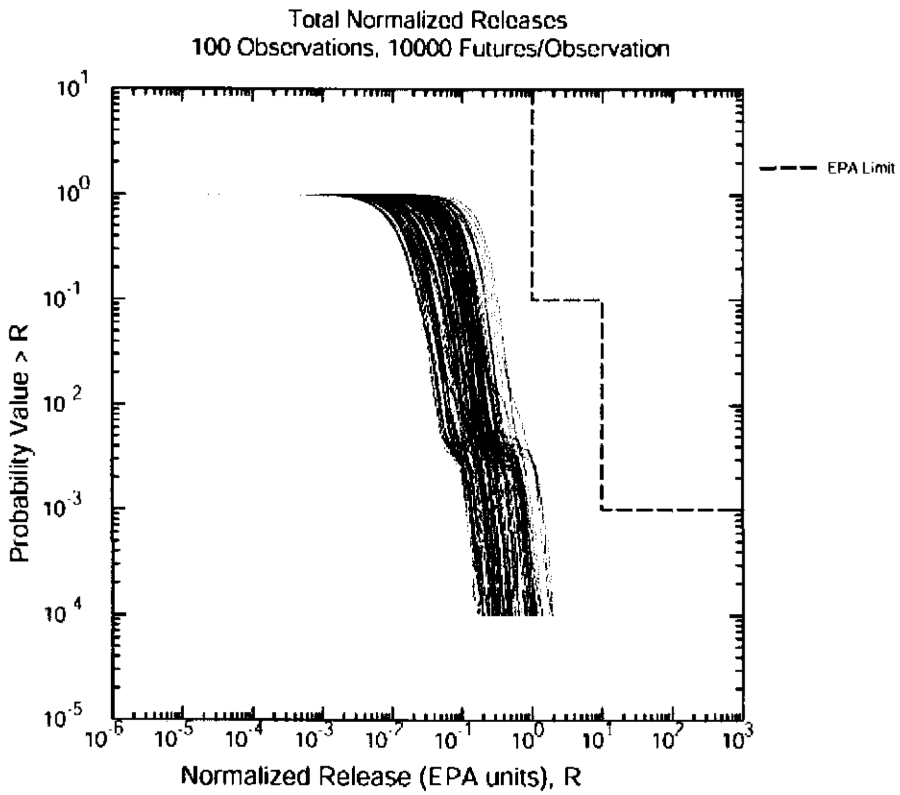


Figure 18. Total Releases, AMW2 Calculation.

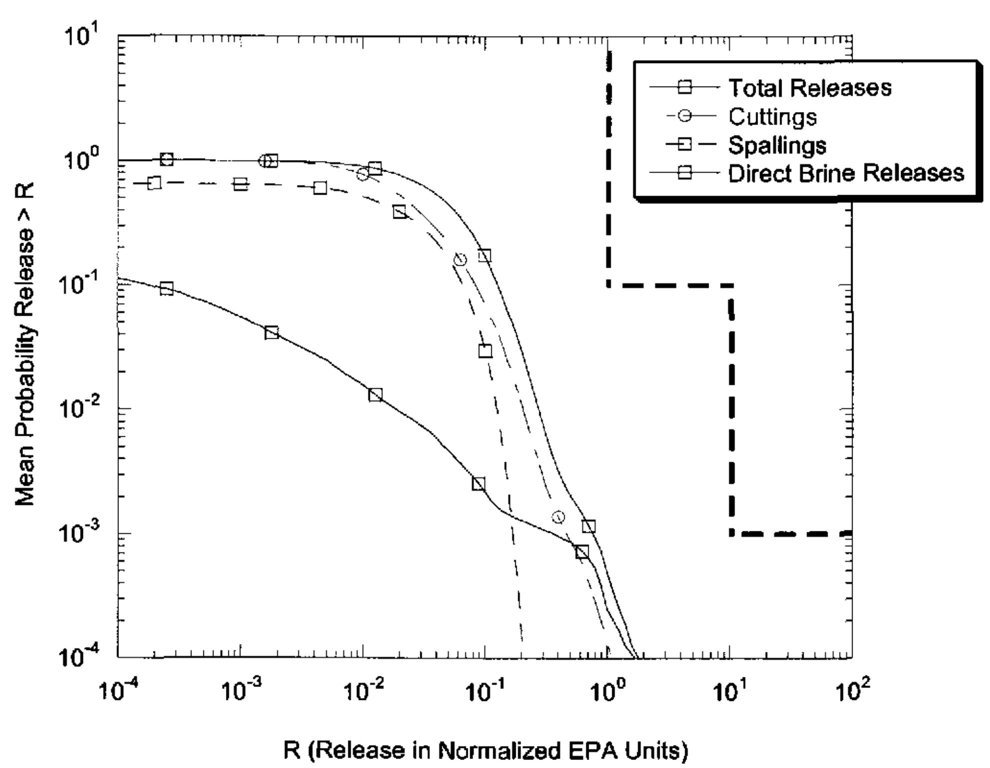


Figure 19. Mean CCDFs for Releases, AMW1 Calculation.

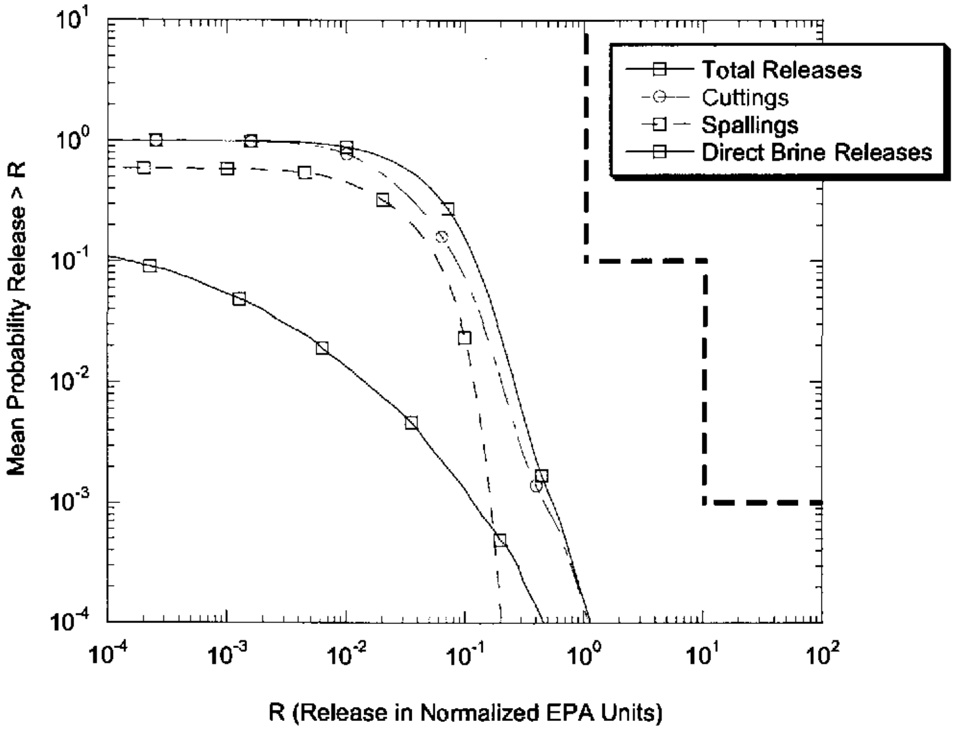


Figure 20. Mean CCDFs for Releases, AMW2 Calculation.

3.3 Summary of Conclusions from the AMW Analysis Results

The comparison of the AMW1 and AMW2 PAs demonstrates that the effect of a significant increase in CPR content (as much as 2.5 times the inventory estimate) does not greatly change the results and the conclusions of the performance assessment. Increasing CPR content generally increases pressure, and increases brine outflow for a few realizations. The increased pressure leads to general, but small, increases in spall releases; for a few vectors, the changes in pressure and brine saturation may lead to large increases in direct brine releases. However, even the largest direct brine release remains below the threshold established in the containment requirements of 40 CFR Parts 191 and 194. Moreover, total releases from the repository are generally unaffected by increased CPR content. Therefore, the comparison concludes that even a large increase in CPR content does not affect the conclusions of the performance assessment, namely, that the repository is in compliance with the containment requirements for the WIPP.

4.0 Comparison with the CRA

Conclusions about the effects of increasing CPR quantities in the AMW2 PA are also valid for the CRA PA as long as the differences between the two PAs are accounted for. Although the quantity of CPR is the same in the AMW2 PA and the CRA PA, these two analysis differ in three aspects:

1. The AMW2 PA accounted for spatial heterogeneities in emplacement of CPR within the repository, by distributing the CPR quantity unequally between model volumes representing the waste panels. Details of the CPR distribution are provided in Hansen (2004). In contrast, the CRA PA distributed the CPR homogeneously in all waste-filled volumes.

2. The AMW2 PA accounted for uncertainty and spatial heterogeneity in closure of waste rooms due to heterogeneity in waste structural properties. Details of waste room closure modeling are provided in Hansen et al. (2004). In contrast, the CRA PA applied creep closure uniformly in all waste-filled volumes.

3. The AMW2 PA used the simplified model for spallings releases that was implemented in the 1997 Performance Assessment Verification Test (PAVT). In contrast, the CRA PA used a more complex, physics-based model for spallings called DRSPALL (Lord et al., 2003; 2004).

Analysis of the AMW2 PA determined that releases were essentially insensitive to the effects of spatial heterogeneity in emplacement of CPR and the uncertainty and heterogeneity in room closure (Hansen et al., 2004). The AMW1 PA also demonstrated a similar lack of sensitivity to heterogeneous CPR emplacement and room closure, indicating that the lack of sensitivity holds for a wide range of CPR quantities. Hence, these two differences between the AMW2 PA and the CRA PA will not significantly affect any comparison between the AMW2 and CRA PAs.

The different spallings models used in the AMW2 and CRA PAs affect a comparison between the two analyses. The AMW1 and AMW2 PAs used the PAVT model for spallings, which assumes that spall releases occur if repository pressure exceeds 8 MPa at the time of an intrusion. In these analyses, larger quantities of CPR may lead to larger volumes of gas in vectors with microbial action, and thus result in higher pressures, generally increasing both the likelihood and magnitude of spall releases. In contrast, the CRA PA used a more complex spallings model, the results of which indicate that spall releases occur only for relatively unlikely combinations of uncertain waste material properties, and only at pressures exceeding 10 MPa (Lord et al., 2003). Increasing pressure in the CRA PA may increase the likelihood and magnitude of spall releases, but much less so than in the AMW2 PA. Therefore, any effect of increasing CPR on spall releases that is observed in the AMW2 PA will be an upper bound on the effect of increasing CPR on the spall releases in the CRA PA.

5.0 Summary and Conclusions

The AMW1 and AMW2 PAs are compared to determine the effects on PA results of increasing CPR quantities by as much as 250%. The comparison showed that increasing CPR affects pressure, saturation and brine outflow; however, for most realizations, the effects of increasing CPR are minor. The most prominent effect of increasing CPR quantity is elevated pressure in some vectors in the undisturbed scenario. This additional pressure results in increases in brine outflow for a few vectors. Brine saturation was not significantly affected. The effects of increasing CPR are much less noticeable in the disturbed scenario because increases in pressure are mitigated by the presence of the borehole, and saturation is primarily determined by flow from the Castile.

The increases in pressure and brine outflow are not sufficient to significantly affect releases from the repository. Using the PAVT model for spallings, spallings releases are slightly increased in likelihood and magnitude. The slight increase bounds any increase that would be observed if the DRSPALL model was used to estimate spallings releases. Direct brine releases increased substantially in a single vector; for the remaining vectors, the slight increase in pressure did not substantially alter direct brine releases.

The net effect on repository performance of increasing CPR content is not substantial. Total releases increase somewhat at low probabilities, reflecting the increase in direct brine releases for a single realization. In spite of the increased releases, all CCDFs for total releases fall below the limit specified in the containment requirements of 40 CFR 191 and 40 CFR 194. Because the excess CPR included in the AMW1 calculation is far larger than any omission or uncertainty in the current inventory, and because the releases remain well within the release limits, no further analysis is necessary to determine the effects of moderate increases in CPR.

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From: Zelinski, William P
Sent: Thursday, June 24, 2004 3:20 PM
To: Hansen, Clifford W; Chavez, Mario Joseph
Cc: Dunagan, Sean
Subject: signature authority

Clifford Hansen
7/1/2004

Cliff Hansen has signature authority to sign the "Effect of Increasing Cellulosics, Plastics, and Rubbers on WIPP Performance Assessment" report in my absence.