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Sandia National Laboratories
Waste Isolation Pilot Plant

Summary Report for the AP-151 (PC3R) Performance Assessment

Revision 1

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A portion of this summary report was written by James W. Garner. James became unavailable during the review and comment phase of report preparation, and was not available to sign the title page of the final document.

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EXECUTIVE SUMMARY

Following the recertification of the WIPP in November of 2010 (U.S. EPA 2010), the DOE will submit two PCRs to the EPA that propose changes to the repository. The first PCR is centered on a new design of the WIPP panel closure system. The panel closure "Option D" design considered in the PABC-2009 (Clayton et al. 2010) is modified to a configuration consisting of 100 feet run of mine salt emplaced against a "significant barrier" on the waste disposal side. The second PCR proposes the relocation of future waste panels 9 and 10 to the south end of the repository where they are denoted as panels 9a and 10a. With panels 9 and 10 relocated, the current repository configuration is modified to one with an open central drift area with installed panel closures located only at the end of filled waste panels. The DOE has requested that SNL conduct a single PA to determine the overall impact of the repository changes proposed in the two PCRs. Impacts of these changes are determined by way of a comparison of results obtained with the reconfigured repository and panel closure redesign to those calculated in the PABC-2009. This report summarizes the results of the panel closure redesign and repository reconfiguration performance assessment, henceforth referred to as the PC3R PA.

Total normalized releases calculated in the PC3R PA remain below their regulatory limits. As a result, the panel closure design and repository configuration changes investigated in the PC3R PA would not result in WIPP non-compliance with the containment requirements of 40 CFR Part 191. Cuttings and cavings releases and direct brine releases are the two primary release components contributing to total releases in the PC3R PA. Cuttings and cavings releases are indistinguishable from those calculated in the PABC-2009. Changes in total releases are attributed to changes calculated in direct brine releases from the PABC-2009 to the PC3R PA. Differences are observed in PC3R PA spallings releases as compared to the PABC-2009, but these differences are relatively minor and do not have a significant impact on the overall total normalized releases found in the PC3R PA.

1 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Part 191. The DOE demonstrates compliance with the containment requirements according to the Certification Criteria in Title 40 CFR Part 194 by means of performance assessment (PA) calculations performed by Sandia National Laboratories (SNL). 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. The models are maintained and updated with new information as part of a recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999.

In addition to its role in certification decisions for the repository, PA is used to determine the impacts of repository modifications proposed by the DOE as part of planned change requests (PCRs). Previous analyses have been performed to assess the impacts of modifications to the panel closure system implemented in the repository (Hansen 2002, Vugrin and Dunagan 2006). The 1998 rulemaking that certified WIPP to receive TRU waste had several conditions, one of which involved the design of the panel closure system. The EPA based its certification decision on the condition that the DOE implement the most robust panel closure design, referred to as the "Option D" design in the CCA (U.S. EPA 1998). With the recertification of the WIPP in November of 2010 (U.S. EPA 2010), a new PA baseline was established by the 2009 Performance Assessment Baseline Calculation (PABC-2009).

Following recertification of the facility, the DOE plans to submit two PCRs to the EPA that propose changes to the repository. The first PCR is centered on a new design of the WIPP panel closure system (PCS). The panel closure "Option D" design considered in the PABC-2009 (Clayton et al. 2010) is to be modified to a configuration consisting of 100 feet run of mine salt emplaced against a "significant barrier" on the waste disposal side. The second PCR proposes the relocation of future waste panels 9 and 10 to the south end of the repository, i.e. south of panels 4 and 5, where they will be denoted as panels 9a and 10a. With panels 9 and 10 relocated, the current repository configuration will be modified to one with an open central drift area with installed panel closures located only at the end of filled waste panels. The DOE has requested that SNL conduct a single PA to determine the overall impact of the repository changes proposed in the two PCRs. Impacts of these changes are determined by way of a comparison of release probabilities to those calculated in the PABC-2009. This report provides a summary of calculations and analyses performed in the panel closure redesign and repository reconfiguration performance assessment, henceforth referred to as the PC3R PA.

The work undertaken in the PC3R PA is prescribed in AP-151, *Analysis Plan for the WIPP Panel Closure Redesign and Repository Reconfiguration Performance Assessment* (Camphouse 2010a), which was specifically written to determine the impact of changes proposed in the two PCRs on long-term repository performance. In order to isolate the impacts of the repository configuration and panel closure design changes, the PC3R PA was designed to deviate as little as possible from the PABC-2009 implementation. In particular, the PC3R PA utilizes the same waste inventory information, drilling rate and plugging pattern parameters, and radionuclide solubility parameters as were used in the PABC-2009. The PC3R PA examines all aspects of repository performance that are potentially impacted by the proposed changes to the repository.

2 REPOSITORY CONFIGURATION CHANGES

The following sections detail the changes to the repository configuration and panel closure design investigated in the PC3R PA. Following the discussion of the repository changes, the impacts of these changes on the parameters and computational grids used in the PC3R PA are presented.

2.1 Repository Reconfiguration

A schematic that depicts the WIPP spatial layout as it has been modeled in PA is shown in Figure 2-1. As seen in that figure, the waste disposal region consists of 10 waste panels. Panels 1-4 are located east of the central area with panels 5-8 located to the west. Panels 9 and 10 are located in the center area between panels 1-4 and panels 5-8. Additionally, panel closures are located at the innermost ends of panels 1-8. A set of panel closures is located between waste panels 9 and 10. Another set of closures is located between panels 1-10 and the southern end of the operations region. A final set of closures is located in the operations region south of the repository shafts. These locations of waste panels and panel closures have been implemented in the models used in performance assessments since the original CCA, including the PABC-2009.

The changes to the repository configuration that are modeled in the PC3R PA include the relocation of panels 9 and 10, the removal of panel closures in the central drift area, and a redesign of panel closures that remain. Panels 9 and 10 are relocated south of panels 4 and 5 in the PC3R PA and denoted as panels 9a and 10a. In effect, the waste area is lengthened with duplicate copies of panels 4 and 5, and their corresponding panel closures, located at the southernmost end of the repository. The resulting waste panel configuration consists of panels 1-4, 9a east of the central area and panels 10a, 5-8 west of the center. Panels 1-8, 9a, and 10a are modeled as having identical panel closures located at their innermost ends.

With the relocation of panels 9 and 10 to the southernmost end of the repository, panel closures located in the central drift area are removed. Consequently, the set of panel closures located between current panels 9 and 10, between the waste disposal region and the operations area, and between the southern portion of the operations area and the repository shafts are not present in the PC3R PA representation of the repository.

Finally, the representation of panel closures that remain for panels 1-8, 9a, and 10a is changed in the PC3R PA. "Option D" panel closures were modeled in the PABC-2009, and are represented in Figure 2-1 by black segments at the ends of waste panels and at appropriate locations in the central drift area. Panel closures are proposed to be modified from the current "Option D" design to that of a new design consisting of 100 feet of run of mine salt emplaced against a significant barrier on the waste disposal side. As the characterization of the significant barrier is still underway, the redesigned panel closures are modeled in the PC3R PA as consisting solely of 100 feet of run of mine salt. The reconfigured repository modeled in the PC3R PA is shown in Figure 2-2, where redesigned closures are depicted by oval segments at the innermost ends of waste panels.

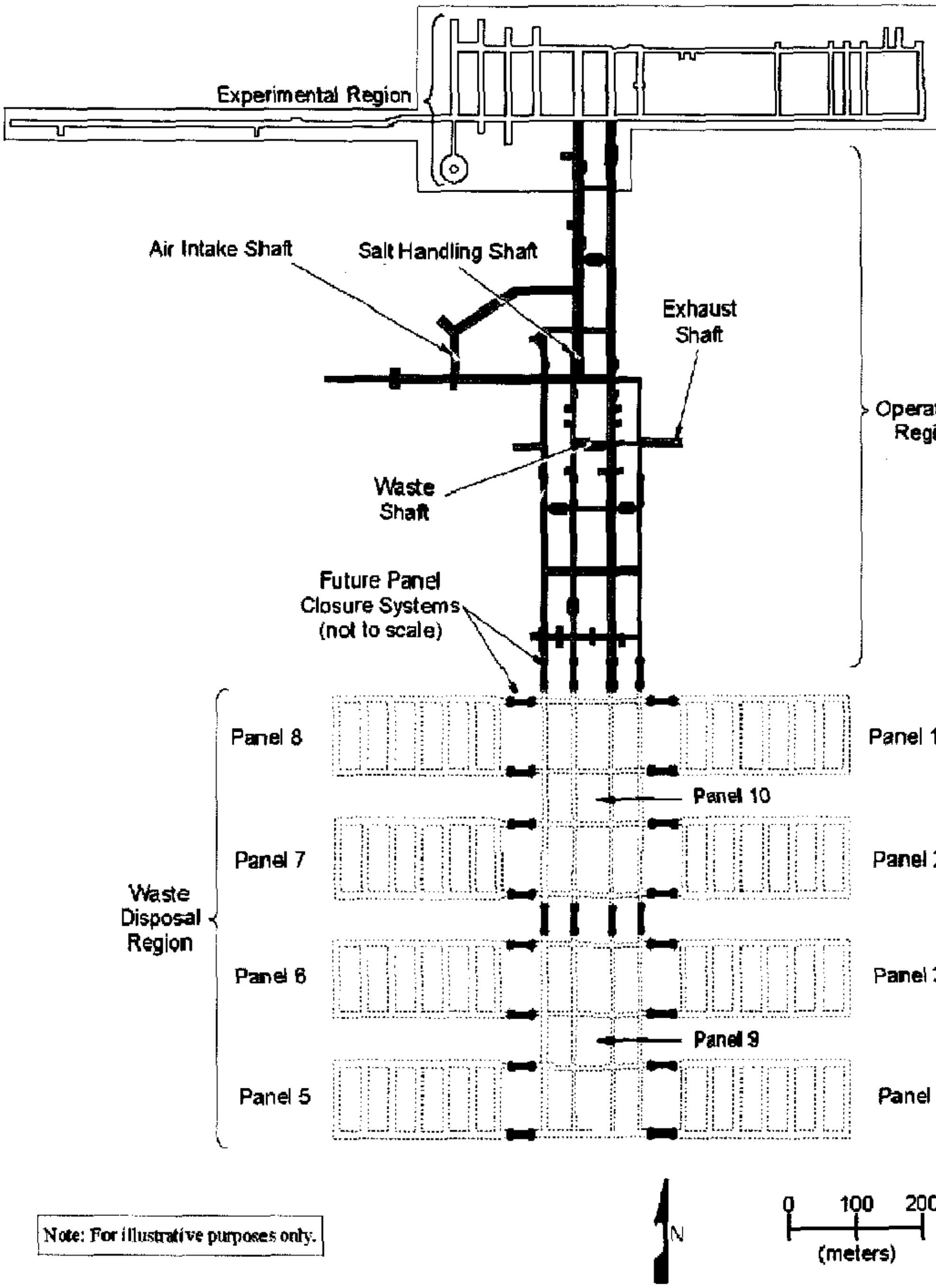

Figure 2-1: Historical WIPP Repository Layout

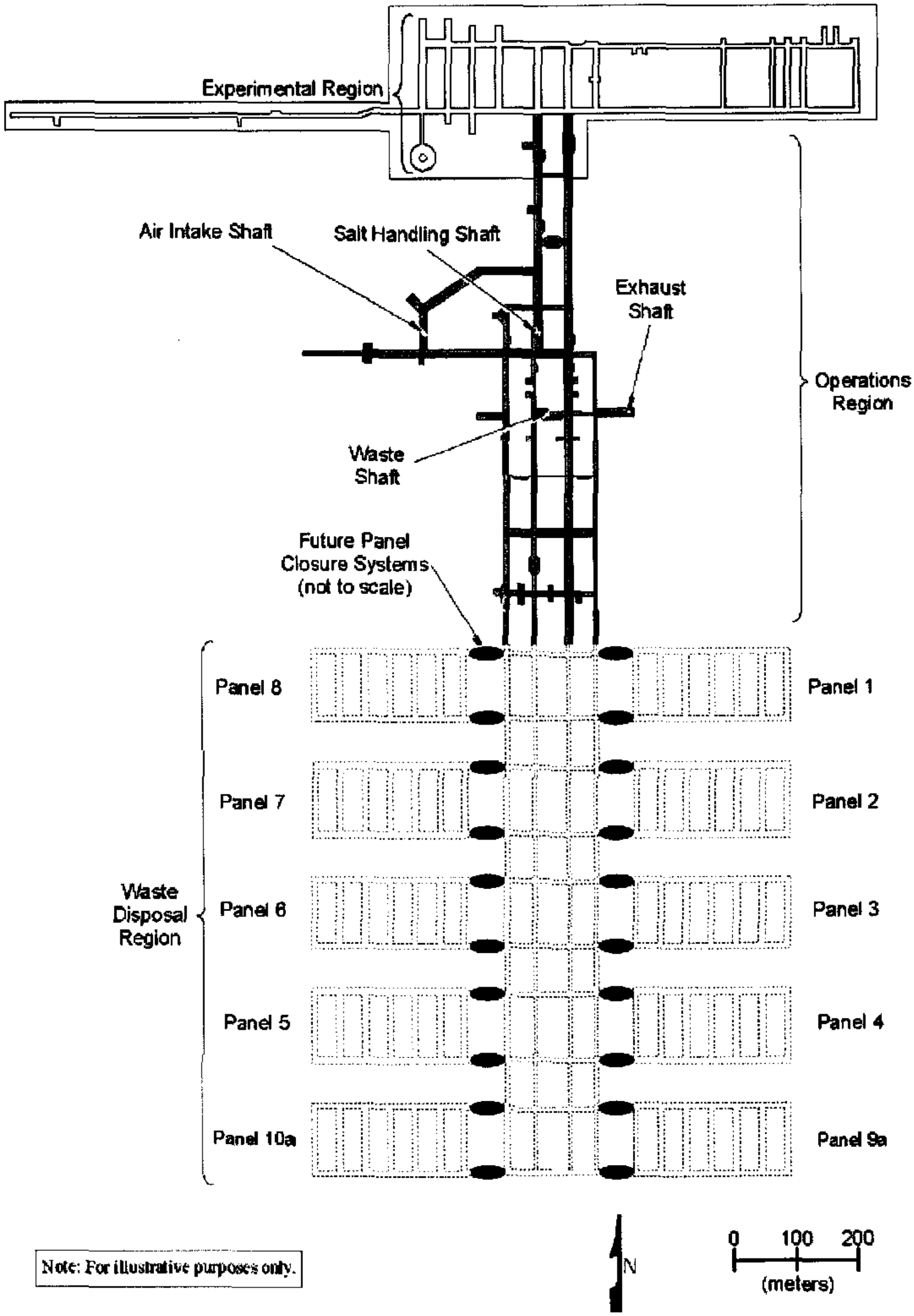

Figure 2-2: WIPP Layout Modeled in PC3R PA

2.2 Parameters

In order to isolate the impacts of the repository changes discussed above, the PC3R PA was designed to deviate as little as possible from the PABC-2009 implementation. However, changes due to the reconfigured waste panel and closure arrangement, as well as the implementation of panel closures consisting of 100 feet of run of mine salt, impact a subset of the parameters prescribed in the PABC-2009. Justifications of new and modified parameters used in the PC3R PA are provided in Camphouse (2010b, 2010c, 2011a). The same material property values and ranges used in the PABC-2009 were also used in the PC3R PA, with the exception of the material and property changes discussed below.

Panel Closure Parameters

The majority of PC3R PA parameter changes are due to the incorporation of run of mine salt panel closures, and these changes are now discussed. The PC3R PA panel closure system has initial permeabilities and porosities that are significantly different than the permeabilities and porosities expected to be present for the vast majority of the 10,000 year regulatory timeframe. In other words, PC3R panel closures have "short-term" initial characteristics and "long-term" characteristics. As a result, two materials are used to describe PC3R panel closures. Material PCS_T1 is the material used to represent panel closures for an initial time period of 100 years. Material PCS_T2 is the material used to represent closures for the remaining 9,900 years. Initial and long-term time periods are selected to be consistent with the lengths of time required for the porosity of the run of mine salt used in the panel closures to fall below 5 percent. Numerical simulations demonstrate this period of time to be less than 100 years (Callahan and DeVries 1991). This time duration is also consistent with that proposed during the 2002 panel closure redesign impact assessment (Hansen and Thompson 2002).

Constant values and probability distributions used for parameter sampling were established for properties associated with materials PCS_T1 and PCS_T2. Constant values and probability distributions corresponding to material PCS_T1 are shown in Table 1 and Table 2, respectively. Constant values and probability distributions established for material PCS_T2 properties COMP_RCK, SAT_RBRN, SAT_RGAS, RELP_MOD, CAP_MOD, KPT, PC_MAX, PO_MIN, PCT_A, PCT_EXP, and PORE_DIS are identical to those established for material PCS_T1. The value specified for the porosity of material PCS_T2, i.e. parameter PCS_T2:POROSITY, is 0.05 (dimensionless).

The panel closure redesign impact assessment performed in 2006 (Vugrin and Dunagan 2006) also used materials PCS_T1 and PCS_T2 to model the changing material properties of the panel closure as a function of time. In that analysis, the panel closure design consisted of 100 feet of run of mine salt emplaced against a 30 foot mortared, solid concrete block wall on the waste disposal side. Parameter distributions for the long-term permeability of the run of mine salt component were developed during the 2006 impact assessment (Vugrin, Hansen, and Thompson 2006). The permeability distribution developed in that analysis is used to describe the long-term permeability of the panel closure implemented in the PC3R PA. The resulting probability distribution used to specify the log of intrinsic permeability of material PCS_T2 is shown in Table 3.

Stein (2002a) introduced material DRZ_PCS as the portion of the disturbed rock zone directly above and below the panel closure system. This material is used in PA to describe temporal characteristics of the DRZ about a panel closure. For the 100 foot run of mine salt panel closures implemented in the PC3R PA, the properties prescribed to material DRZ_PCS were done so as to reflect the changing material properties of the redesigned closure system as a function of time. During the first 100 years while the run of mine salt panel closures are reconsolidating to their steady-state properties, material DRZ_PCS is specified to have identical properties to the remaining DRZ. In other words, it is assumed that the DRZ directly above and below the panel closure is unaffected by the changing panel closure properties during the first 100 years. The permeabilities prescribed for material DRZ_PCS during the first 100 years are identical to those prescribed to the DRZ overall, i.e. those specified for PA material DRZ_1. These permeability distributions are given in Table 4. After the first 100 years, permeability values of material DRZ_PCS are prescribed so as to be consistent with the permeabilities of the reconsolidated panel closures. As a result, they are assigned the permeability distributions given to material PCS_T2 as shown in Table 3.

Table 1: Constant Parameters Used for Material PCS_T1

Parameter (units)	Description	Value
PCS_T1: COMP_RCK (Pa^{-1})	Bulk compressibility	$8x10^{-11}$
PCS_T1:POROSITY (n/a)	Effective porosity	0.33
PCS_T1:PRMX_LOG ($log(m^2)$)	Log of intrinsic permeability, x,y,z directions	-11.0
PCS_T1:PRMY_LOG ($log(m^2)$)		
PCS_T1:PRMZ_LOG ($log(m^2)$)		
PCS_T1:SAT_IBRN (n/a)	Initial brine saturation	0.054
PCS_T1:RELP_MOD (n/a)	Model number, relative permeability model	4.0
PCS_T1:CAP_MOD (n/a)	Model number, capillary pressure model	1.0
PCS_T1:KPT (n/a)	Flag for permeability determined threshold	0.0
PCS_T1:PC_MAX (Pa)	Maximum allowable capillary pressure	$1x10^8$
PCS_T1:PO_MIN (Pa)	Minimum brine pressure for capillary model KPC=3	$1.01325x10^5$
PCS_T1:PCT_A (Pa)	Threshold pressure linear parameter	0.0
PCS_T1:PCT_EXP (n/a)	Threshold pressure exponential parameter	0.0

Table 2: Sampled Parameters Used for Material PCS_T1

Parameter (units)	Description	Distribution	Statistic	Value
PCS_T1: SAT_RBRN (n/a)	Residual Brine Saturation	Cumulative with (Prob.,Value) Pairs (0,0) (0.5,0.2) (1.0,0.6)	Mean	0.25
			Median	0.2
			Stan. Deviation	0.176
			Minimum	0.0
			Maximum	0.6
PCS_T1: SAT_RGAS (n/a)	Residual Gas Saturation	Uniform	Mean	0.2
			Median	0.2
			Stan. Deviation	0.1155
			Minimum	0.0
			Maximum	0.4
PCS_T1: PORE_DIS (n/a)	Brooks-Corey pore distribution parameter	Cumulative with (Prob.,Value) Pairs (0,0.11) (0.5,0.94) (1.0,8.1)	Mean	2.52
			Median	0.94
			Stan. Deviation	2.48
			Minimum	0.11
			Maximum	8.1

Table 3: Log of Intrinsic Permeability Values used for Material PCS_T2 in the PC3R PA

Parameter (units)	Description	Distribution	Statistic	Value
PCS_T2:PRMX_LOG ($\log(m^2)$) PCS_T2:PRMY_LOG ($\log(m^2)$) PCS_T2:PRMZ_LOG ($\log(m^2)$)	Log of intrinsic permeability, x,y,z directions	Triangular	Mean	-20.2
			Mode	-20.2
			Stan. Deviation	1.06
			Minimum	-22.8
			Maximum	-17.6

Table 4: Log of Intrinsic Permeability Values used for Material DRZ-PCS in the PC3R PA for the first 100 years.

Parameter (units)	Description	Distribution	Statistic	Value
DRZ_PCS:PRMX_LOG ($\log(m^2)$) DRZ_PCS:PRMY_LOG ($\log(m^2)$) DRZ_PCS:PRMZ_LOG ($\log(m^2)$)	Log of intrinsic permeability, x,y,z directions	Triangular	Mean	-16.0
			Median	-16.0
			Stan. Deviation	2.0
			Minimum	-19.4
			Maximum	-12.5

Panel Reconfiguration Parameters

The relocation and re-sizing of current panels 9 and 10 to their 9a and 10a counterparts invoked modifications to some of the reference constants (material REFCON) used in the PABC-2009 as well as an updated value for parameter DRZ_1:EHEIGHT. Moreover, in the PC3R PA, the central drift area was assigned properties corresponding to material OPS_AREA in the PABC-2009. As the central drift area in the reconfigured repository has a much larger extent than did OPS_AREA in the PABC-2009, and is located between west and east waste panels, a new parameter OPS_AREA:EHEIGHT was established for use in the PC3R PA. The values specified for these remaining parameters in the PC3R PA are shown in Table 5.

Table 5: PC3R PA Parameters Updated/Created Due to the Repository Reconfiguration

Parameter (units)		Description	Value
REFCON:VREPOS	(m^3)	Excavated storage volume of repository	4.609765×10^5
REFCON:FVW	(n/a)	Fraction of repository volume occupied by waste in CCDFGF	0.367
REFCON:AREA_CH	(m^2)	Area for CH Waste Disposal in CCDFGF	1.164×10^5
REFCON:ABERM	(m^2)	Berm Area	7.85625×10^5
DRZ_1:EHEIGHT	(m)	Effective height of the disturbed rock zone for DBR calculations	41.3

OPS_AREA:EHEIGHT (m)	Effective height of the operations area for DBR calculations	10.7

2.3 Computational Grid Changes

PA code BRAGFLO is used in two ways in WIPP PA calculations. First, it is used to calculate the flow of brine and gas in and around the repository for undisturbed and disturbed conditions. Second, it is used for the calculation of direct brine releases (DBRs). These two uses of BRAGFLO require different computational grids. The grid used to calculate brine and gas flow in and around the repository is different than that used to calculate DBRs. However, results obtained from the brine and gas flow calculation are used to initialize conditions in the DBR calculation. The changes proposed to the WIPP repository configuration impact the computational grids used in both applications of BRAGFLO. For the sake of completeness in this summary report, these changes are now briefly discussed. More detailed discussions of the PC3R PA BRAGFLO computational grids, and their differences in regard to the grids used in the PABC-2009, can be found in Camphouse and Clayton (2011) & Pasch and Camphouse (2011).

The historical WIPP configuration shown in Figure 2-1 has been the underlying motivation for the repository representation in prior BRAGFLO numerical grids, including the PABC-2009. Using that configuration, panel closures located in the central drift area were used to decompose the repository waste area into three regions in the PABC-2009. The southwest panel, panel 5 in Figure 2-1, was the panel in which inadvertent human intrusion was modeled in BRAGFLO. As a result, the southwest panel was modeled separately from the rest of the waste area. The remaining waste panels comprised two additional waste regions in the PABC-2009 BRAGFLO grid, namely the south rest of repository (SROR) (panels 3, 4, 6, and 9), and the north rest of repository (NROR) (panels 1, 2, 7, 8, and 10), with each region being separated by a panel closure. The location of a panel closure slightly south of the waste shaft resulted in the operations (Ops) and experimental (Exp) regions being separated by a material combining panel closure and waste shaft properties. The PABC-2009 BRAGFLO grid is shown in Figure 2-3. In that figure, regions labeled DRF_PCS and CONC_PCS represent components of "Option D" panel closures.

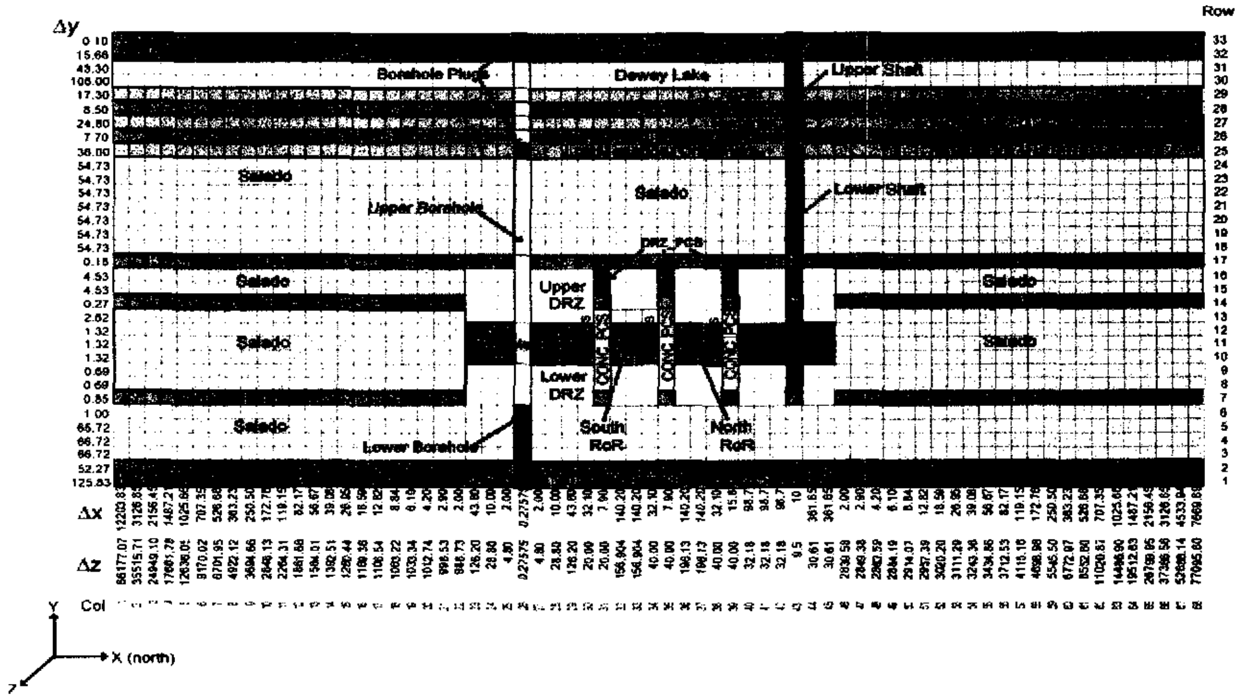

Figure 2-3: PABC-2009 BRAGFLO grid (Δx, Δy, and Δz dimensions in meters).

Following a similar strategy as for the historical WIPP layout shown in Figure 2-1, the reconfigured repository shown in Figure 2-2 guides the BRAGFLO computational grid implementation in the PC3R PA. In the PABC-2009, panel closures in the central area provided a natural way to demarcate the repository into northern and southern regions. In the reconfigured repository layout, the open central drift region between west and east waste panels results in a BRAGFLO grid with a west-to-east orientation. Panel 10a is used to model inadvertent human intrusion. This waste panel is separated from the remaining panels by the open central drift area. As a result, remaining panels are lumped together in a rest of repository (ROR) region in the PC3R PA BRAGFLO grid. The waste panel, center area, and ROR are separated by panel closures comprised of 100 feet run of mine salt. The PC3R PA BRAGFLO computational grid is shown in Figure 2-4.

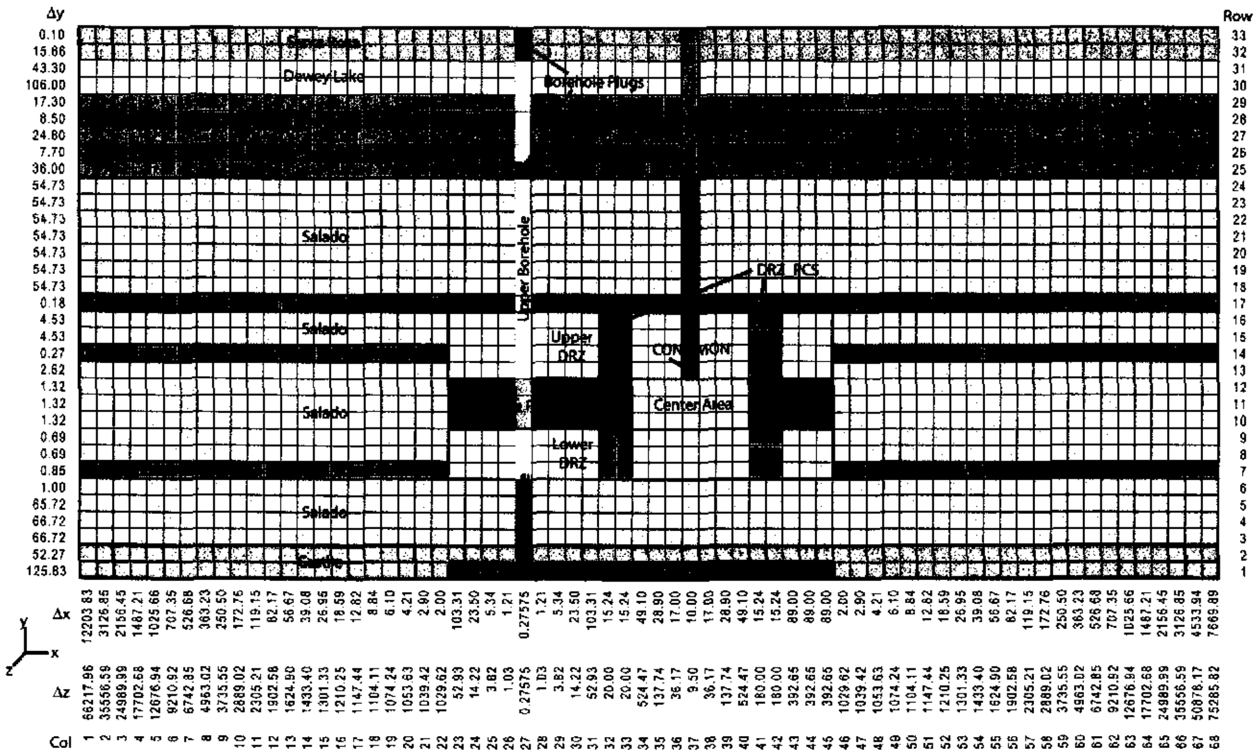

Figure 2-4: PC3R PA BRAGFLO grid (Δx, Δy, and Δz dimensions in meters).

Results from the PABC-2009 BRAGFLO calculation were used to initialize conditions in the PABC-2009 DBR calculation. The representation of the waste area by three waste regions in the PABC-2009 BRAGFLO grid yielded initial conditions to waste regions comprising the waste panel, the SROR, and the NROR in the PABC-2009 BRAGFLO DBR calculations (Clayton 2010). The initialization of these three regions in the DBR calculation resulted in the consideration of drilling intrusions into these regions in the PABC-2009 DBR analysis. These locations can be seen in the PABC-2009 DBR computational grid of Figure 2-5.

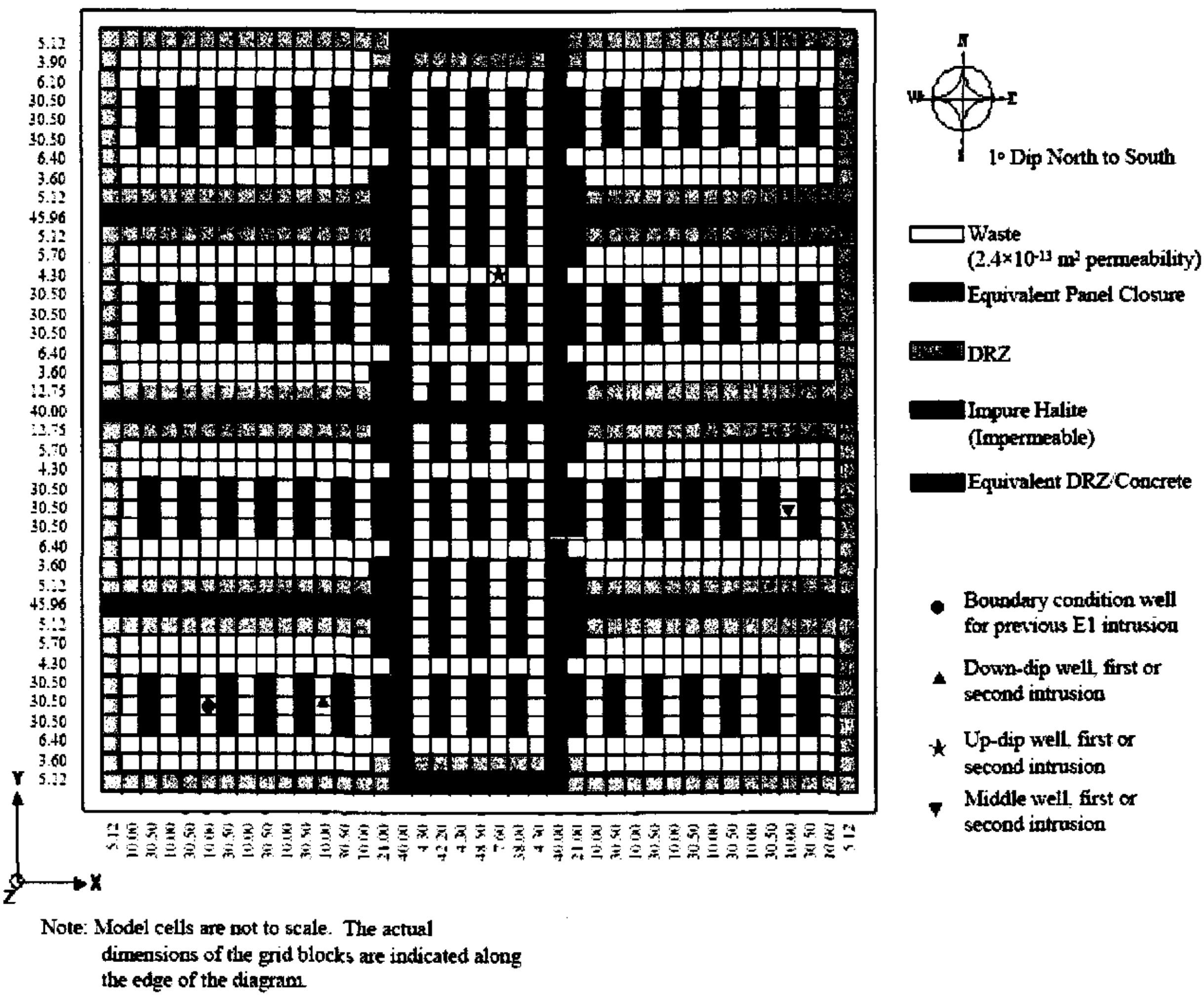

Figure 2-5: PABC-2009 DBR material map (logical grid).

The reconfigured repository seen in Figure 2-2 resulted in several changes to the numerical grid used to analyze direct brine releases in the PC3R PA. First, waste panels 9 and 10 were removed from the central drift area, relocated to the southernmost end of the repository, and denoted as panels 9a and 10a. As panels 9 and 10 have slightly less area than waste panels 1-8, panels 9a and 10a were resized to have areas equal to those of panels 1-8. Second, "Option D" panel closures in the PABC-2009 were replaced by panel closures consisting of 100 feet run of mine salt with properties corresponding to materials PCS_T1 and PCS_T2. Third, panel closures located in the central drift area in the PABC-2009 DBR grid were removed in the PC3R PA DBR grid. Fourth, the representation of the waste area by two regions in the PC3R PA BRAGFLO grid resulted in two drilling locations, an upper and a lower location, in the direct brine release analysis undertaken in the PC3R PA. These locations can be seen in the PC3R PA DBR computational grid of Figure 2-6.

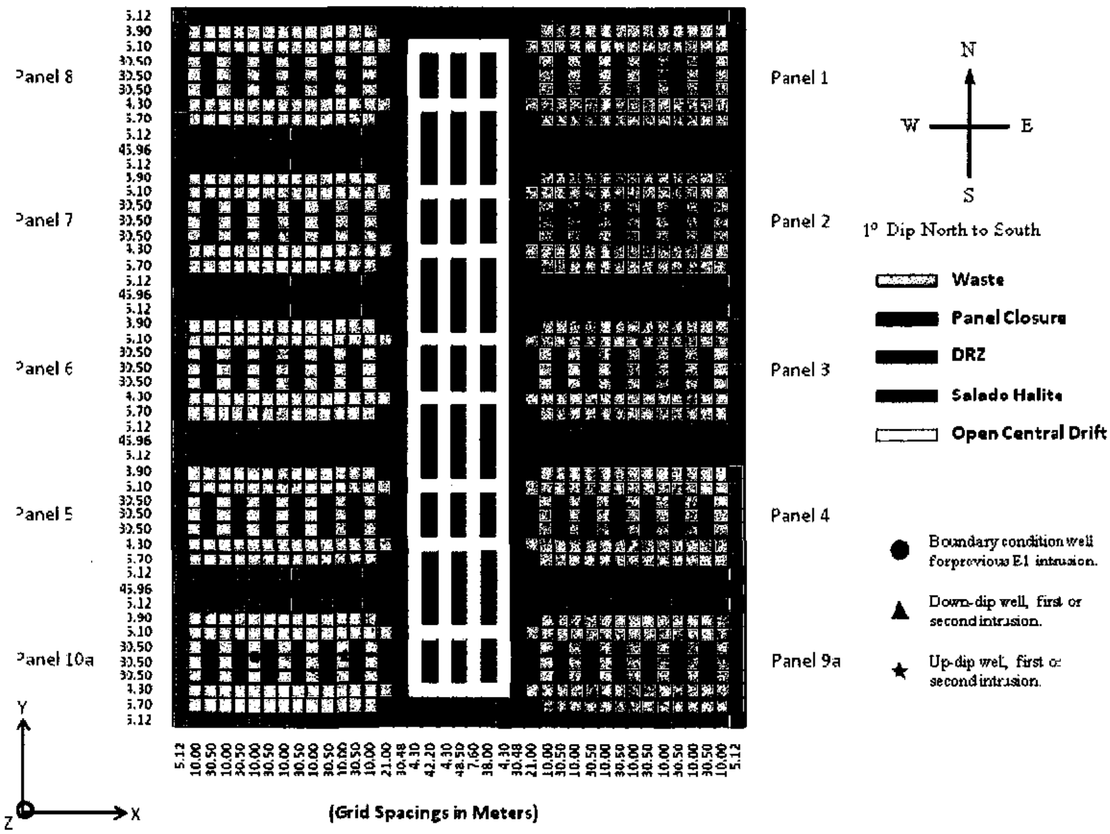

Figure 2-6: PC3R PA DBR material map (logical grid).

Material properties for the open central drift area in the PC3R PA are assigned values corresponding to the operations area (material OPS_AREA) in the PABC-2009. Parameter OPS_AREA:EHEIGHT was established for use in the PC3R PA DBR calculations in order to achieve agreement between the three-dimensional representation of the central region in BRAGFLO and the two-dimensional representation of this region in the DBR numerical grid. This property provides a means of matching porosity and pore compressibility in the central drift region across the BRAGFLO and DBR calculations. Its value is given in Table 5.

In both the PABC-2009 and the PC3R PA, consideration of drilling events was restricted to those repository regions with emplaced waste. Waste is not emplaced in the operations and experimental areas of the historical WIPP repository configuration, nor in the central drift area of the PC3R PA configuration. As a result, potential drilling intrusions into these areas will not result in cuttings, cavings, or spallings releases. Potential releases following an intrusion into these areas require that they contain a sufficient volume of waste-contaminated brine under sufficient pressure. For this to occur, brine must interact with waste in a panel and migrate to a non-waste containing region to be available for release at the time of intrusion. In all cases investigated in the Salado flow modeling of the PC3R PA (see Section 5.1 of this summary report), the total flow of brine out of the waste panel was reduced (on average) when compared to results obtained in the PABC-2009. The panel closure redesign and repository configuration implemented in the PC3R PA does not result in an increase in contaminated brine leaving a waste panel. Furthermore, as discussed and demonstrated in Section 5.2, an intrusion into a waste panel will not result in a consequential increase in brine volume in the central drift area to later be released to the surface by a subsequent intrusion in that area. The brine available for release to the surface following a drilling event into the central drift region is brine present under undisturbed conditions, regardless of previous intrusions into a waste panel. In addition, drilling intrusions into the central drift region can only *reduce* releases following an intrusion into a waste panel. For quantification of releases, the consideration of drilling intrusions into waste-containing regions is sufficient, and is conservative.

2.4 FEPS Re-assessment

An assessment of the FEPs baseline was conducted to determine if the current FEPs basis remains valid in consideration of changes introduced by the PC3R PA, and was performed according to SP 9-4, *Performing FEPs Impact Assessment for Planned or Unplanned Changes.* The FEPs analysis concludes that no additional FEPs are needed to accurately represent the changes that represent the repository layout (including the location of the PCS) and the PCS design and construction. Additionally, no FEPs screening arguments and associated screening decisions require modification to account for the changes represented in the PC3R PA (Kirkes 2011).

3 METHODOLOGY

The performance assessment methodology accommodates both aleatory (i.e. stochastic) and epistemic (i.e. subjective) uncertainty in its constituent models. Aleatory uncertainty pertains to unknowable future events such as intrusion times and locations that may affect repository performance. It is accounted for by the generation of random sequences of future events. Epistemic uncertainty concerns parameter values that are assumed to be constants and the constants' true values are uncertain due to a lack of knowledge about the system. An example of a parameter with epistemic uncertainty is the permeability of a material. 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 PC3R PA, models were executed for three replicates of 100 vectors, each vector providing model realizations resulting from a particular set of parameter values. Parameter sampling performed in the PC3R PA is documented in Camphouse (2011b), and the sensitivities of variable output to sampled parameters are documented in Hansen (2011). A sample size of 10,000 possible sequences of future events is used in 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.

For a random variable, the complementary cumulative distribution function (CCDF) provides the probability of the variable being greater than a particular value. By regulation, performance assessment results are presented as a distribution of CCDFs of releases (U.S. EPA 1996). Each individual CCDF summarizes the likelihood of releases across all futures for one vector of parameter values. The uncertainty in parameter values results in a distribution of CCDFs.

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

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

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

The PC3R PA was developed so that the structure of calculations performed therein was as similar as possible to that used in the PABC-2009. PABC-2009 calculated results potentially impacted by the repository reconfiguration and panel closure redesign discussed above were updated, while the results from previous PAs were used for individual numerical codes not affected by these changes. The PC3R PA utilized the same waste inventory information, drilling rate and plugging pattern parameters, and radionuclide solubility parameters as were used in the PABC-2009. In addition, transport releases through the Culebra calculated in the PABC-2009 were also used in the PC3R PA. Separate documentation was prepared describing calculations performed and results obtained for each code executed in the PC3R PA. Citations for this additional documentation are included in the references section of this summary report, and are indicated in the list below.

- Parameter Sampling (Camphouse 2011b)
- Sensitivity Analysis (Hansen 2011)
- Salado Flow (Camphouse and Clayton 2011)
- Cuttings, Cavings, and Spallings (Kicker 2011)
- Actinide Mobilization and Transport (Camphouse and Garner 2011)
- Direct Brine Releases (Pasch and Camphouse 2011)
- CCDF Normalized Releases (Camphouse 2011c)

4 RUN CONTROL

Execution of Performance Assessment Codes for the WIPP Panel Closure Redesign and Repository Reconfiguration (Long 2011) provides documentation of run control and code execution for the PC3R PA. This document contains:

1. A description of the hardware platform and operating system used to perform the calculations.
2. A listing of the codes and versions used to perform the calculations.
3. A listing of the scripts used to run each calculation.
4. A listing of the input and output files for each calculation.
5. A listing of the library and class where each file is stored.
6. File naming conventions.

5 RESULTS

Summary results obtained from PC3R PA calculations are broken out in subsections below, and are compared to PABC-2009 results. Salado flow modeling results are presented in Subsection 5.1. The effectiveness of the redesigned panel closures in regard to the isolation of drilling intrusion effects is discussed in Subsection 5.2. Impacts of the repository reconfiguration and panel closure redesign on actinide mobilization and transport are shown in Subsection 5.3. Results obtained for cuttings and cavings are presented in Subsection 5.4. Spallings results are presented in Subsection 5.5. Direct brine releases are presented in Subsection 5.6. The impact of the changes investigated in the PC3R PA on regulatory compliance is discussed in terms of total normalized releases in Subsection 5.7. As the CCDF is the regulatory metric used to demonstrate compliance, comparisons of CCDFs obtained in the PC3R PA and the PABC-2009 are compared for each component of release in the appropriate subsection.

5.1 Salado Flow Results

The BRAGFLO software calculates the flow of brine and gas in the vicinity of the WIPP repository over the 10,000-year regulatory compliance period. During BRAGFLO calculations, stochastic uncertainty is addressed by defining a set of six scenarios for which brine and gas flow is calculated for each of the vectors generated via parameter sampling. The total number of BRAGFLO simulations executed in the PC3R PA is 1,800 (300 vectors times 6 scenarios).

The six scenarios used in the PC3R PA are unchanged from those used for the PABC-2009. The scenarios include one undisturbed scenario (S1-BF), four scenarios that include a single inadvertent future drilling intrusion into the repository during the 10,000 year regulatory period (S2-BF to S5-BF), and one scenario investigating the effect of two intrusions into a single waste panel (S6-BF). Two types of intrusions, denoted as E1 and E2, are considered. An E1 intrusion assumes the borehole passes through a waste-filled panel and into a pressurized brine pocket that may exist under the repository in the Castile formation. An E2 intrusion assumes that the borehole passes through the repository but does not encounter a brine pocket. Scenarios S2-BF and S3-BF model the effect of an E1 intrusion occurring at 350 years and 1000 years, respectively, after the repository is closed. Scenarios S4-BF and S5-BF model the effect of an E2 intrusion at 350 and 1000 years. Scenario S6-BF models an E2 intrusion occurring at 1000 years, followed by an E1 intrusion into the same panel at 2000 years. Transport releases to the Culebra are captured in Scenario S6-BF. Scenario S6-BF is used for determining the radionuclide source term to the Culebra in the PA code PANEL, and results of this scenario are discussed in Subsection 5.3. Table 6 summarizes the six scenarios used in this analysis.

Table 6: BRAGFLO Modeling Scenarios

Scenario	Description
S1-BF	Undisturbed Repository
S2-BF	E1 intrusion at 350 years
S3-BF	E1 intrusion at 1,000 years
S4-BF	E2 intrusion at 350 years
S5-BF	E2 intrusion at 1,000 years
S6-BF	E2 intrusion at 1,000 years; E1 intrusion at 2,000 years.

Computed results are presented for the PC3R PA and compared with those obtained in the PABC-2009. Results are discussed in terms of overall means. Overall means are obtained by forming the average of the 300 realizations calculated for a given quantity and scenario. Results are presented for undisturbed scenario S1-BF. Intruded results are presented for scenarios S2-BF and S4-BF, as these are representative of the intrusion types considered in scenarios S2-BF to S5-BF with the only differences being the timing of drilling intrusions. The computational grids used to generate Salado flow results in the PABC-2009 and the PC3R PA are shown in Figure 2-3 and Figure 2-4, respectively.

Undisturbed Scenario S1-BF

Scenario S1-BF overall means of porosity in the waste panel, quantity WAS_POR, for the PC3R PA and the PABC-2009 are shown together in Figure 5-1. As is clear from that figure, there is very little difference in the time-histories of waste panel porosities for both analyses. Porosities in both analyses reduce rapidly, with the average porosity nearing its steady-state value within hundreds of years following facility closure.

Overall means of volume-averaged pressure in the waste panel, quantity WAS_PRES, for the PC3R PA and the PABC-2009 are shown together in Figure 5-2. As seen in that figure, the volume averaged pressure for the PC3R PA is slightly lower than that seen in the PABC-2009. The reason for this reduction is seen in Figure 5-3. In Figure 5-3, the overall mean of quantity WAS_PRES is plotted on a time scale of 0 to 150 years for both the PC3R PA and the PABC-2009. As the porosity of the waste panel rapidly decreases in the time period immediately after facility closure, the higher permeability and porosity of the run of mine salt panel closure for the first 100 years allows the increasing pressure to be released into the open central area between the waste panel and the rest of the repository. At t = 100 years, the porosity and permeabilities of the panel closures are reduced to their steady-state values. At t = 100 years in Figure 5-3, there is a distinct increase in the rate of pressure rise in the waste panel. By this time, however, the porosity in the waste panel is nearing its steady-state value, and so much of the increasing pressure in the waste panel responsible for the decreasing porosity has been vented into the open central area. The net effect is a slightly reduced volume-averaged pressure in the waste panel for the PC3R PA.

The overall mean of brine saturation in the waste panel, quantity WAS_SATB, is shown in Figure 5-4. As seen in that figure, waste panel brine saturation results obtained in the PC3R PA for the undisturbed repository condition are nearly identical to those found in the PABC-2009.

The overall means of total brine flow out of the waste panel, quantity BRNWASOC, is shown in Figure 5-5. As seen in that figure, the brine flow out of the waste panel decreased for Scenario S1-BF in the PC3R PA. This reduction is due to the lower waste panel pressure as compared to the PABC-2009. The slightly lower long-term permeabilites of the PC3R PA panel closures also contributed to the reduction of brine flow out of the waste regions. While the larger initial porosity and permeabilities of the panel closures investigated in the PC3R PA allow pressure release from the waste panel into the center area for the first 100 years, their use does not result in an increase in brine flow out of the waste panel.

Overall means of total brine flow up the shaft, quantity BNSHUDRZ, are shown in Figure 5-6. In the PC3R PA, the shaft is directly above the open central region in the BRAGFLO grid. The open central region contains the open volume of the operations and experimental area as well as the open volume associated with panels 9 and 10 in the PABC-2009 grid. The increase in volume translates to a reduction in pressure in the center area. The total brine flow up the shaft decreased for Scenario S1-BF in the PC3R PA due to the lower pressure in the open central region.

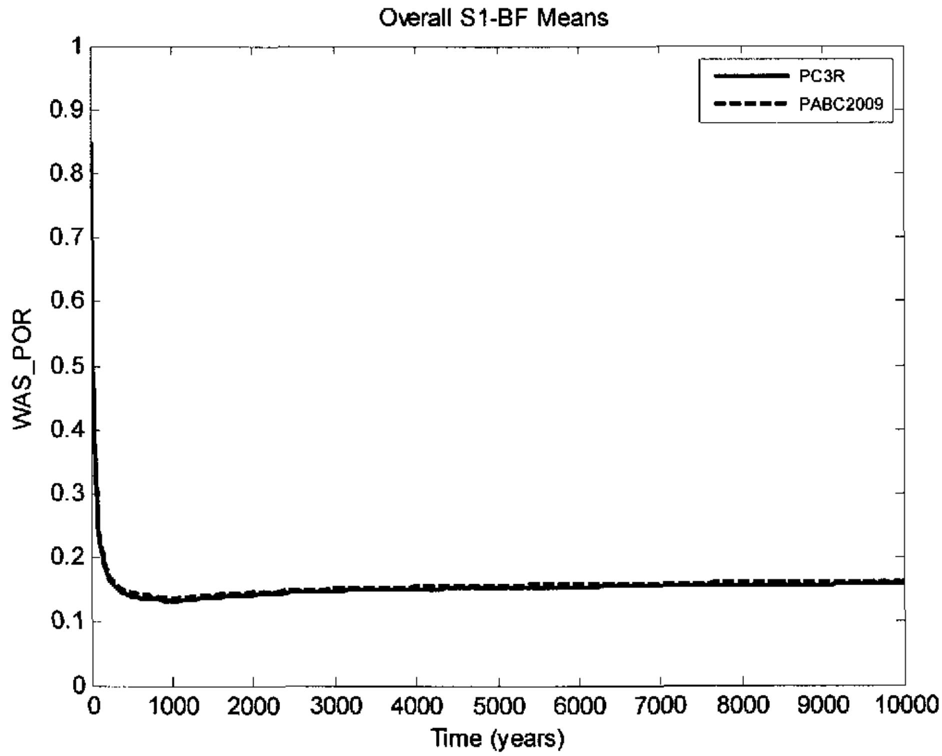

Figure 5-1: Overall Means of Volume Averaged Porosity for the Waste Panel, Scenario S1-BF

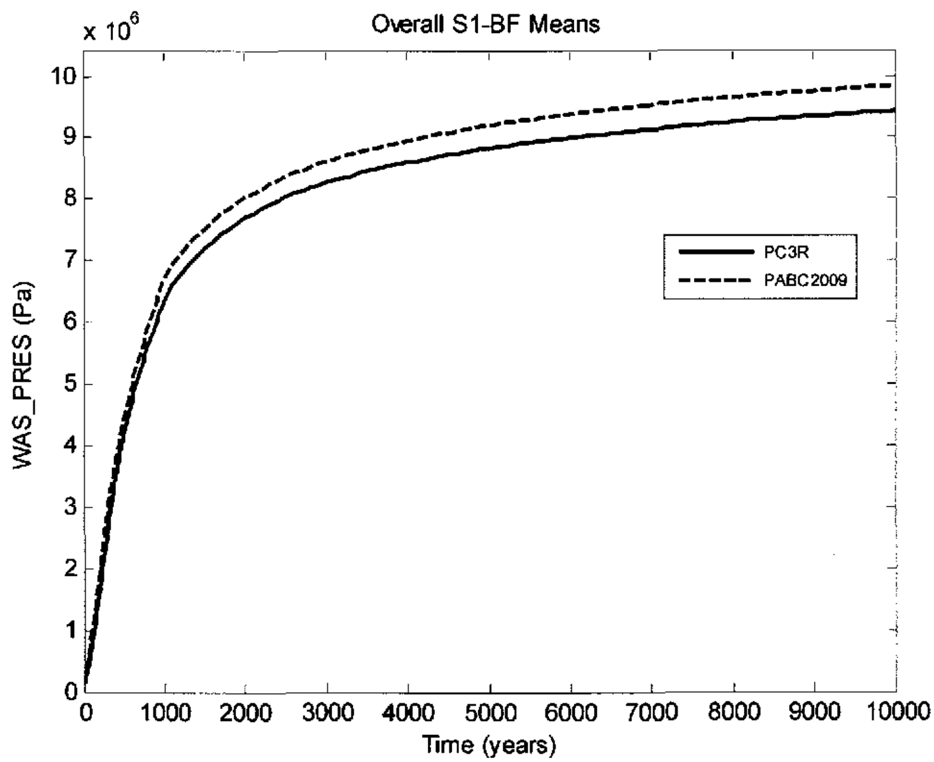

Figure 5-2: Overall Means of Volume Averaged Pressure for the Waste Panel, Scenario S1-BF

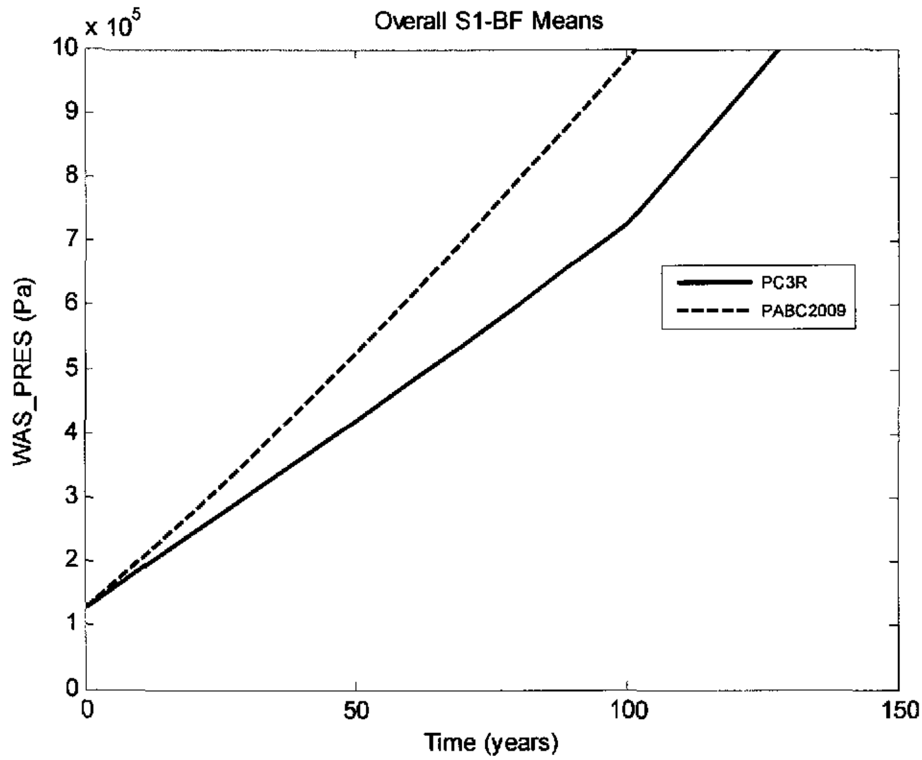

Figure 5-3: Overall Means of Volume Averaged Pressure for the Waste Panel During the First 150 Years After Closure, Scenario S1-BF

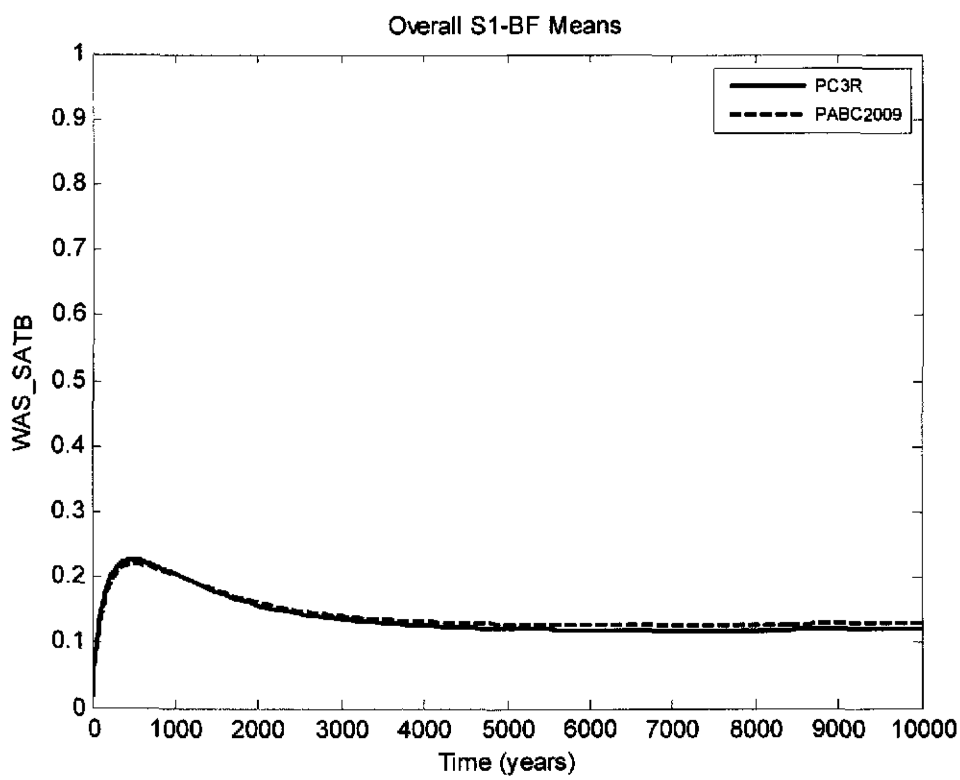

Figure 5-4: Overall Means of Brine Saturation in the Waste Panel, Scenario S1-BF

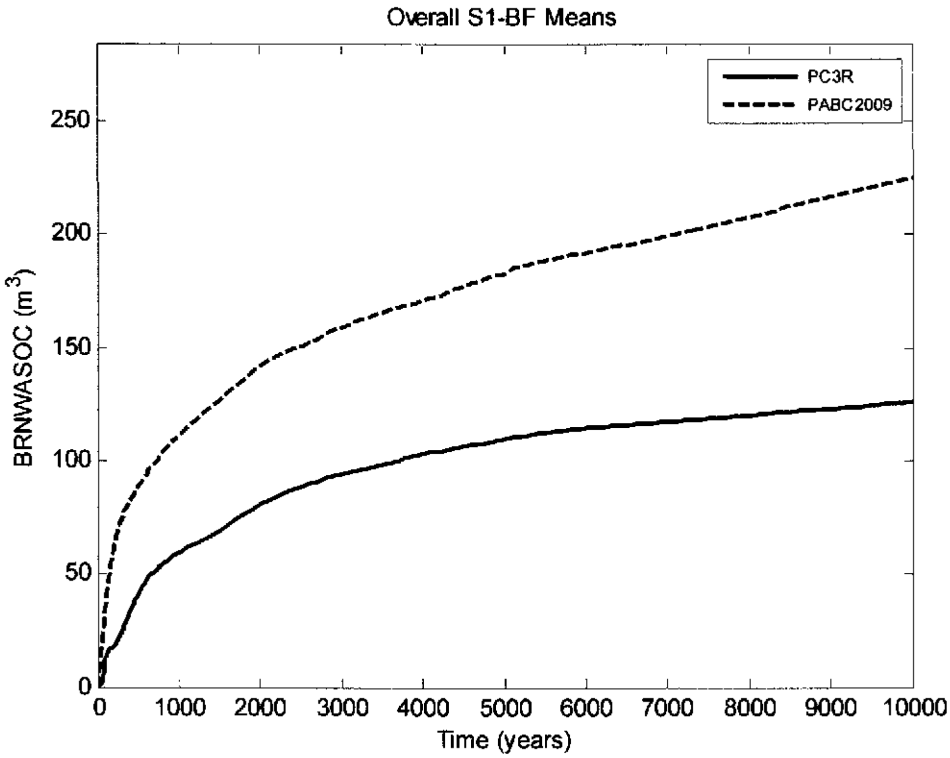

Figure 5-5: Overall Means of Total Brine Flow Out of the Waste Panel, Scenario S1-BF

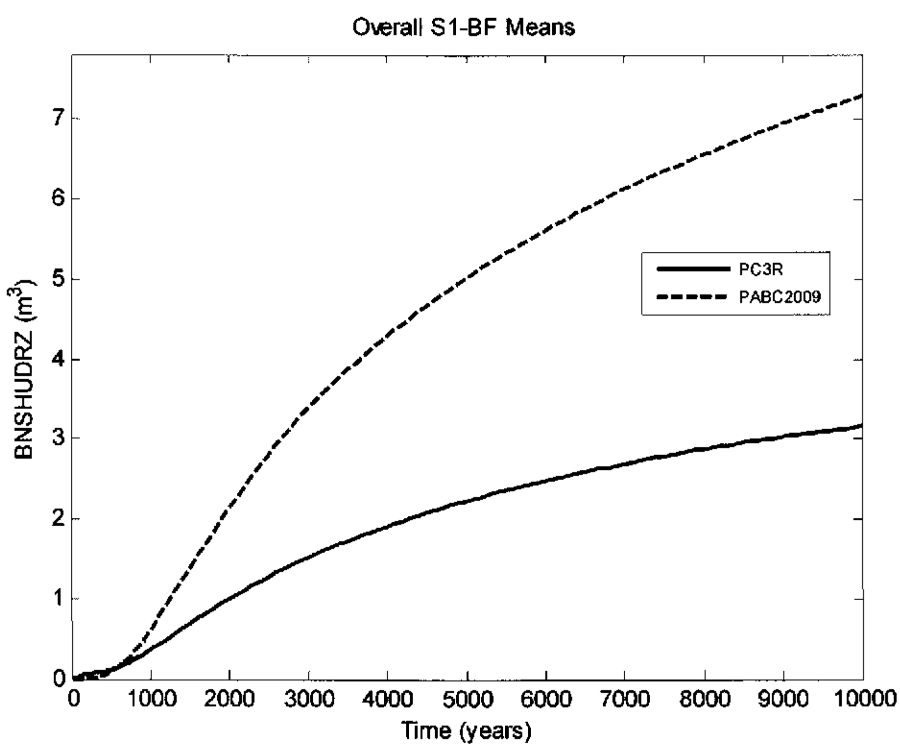

Figure 5-6: Overall Means of Total Brine Flow Up the Shaft, Scenario S1-BF.

Disturbed Scenario S2-BF

PC3R PA results for intrusion scenario S2-BF are now presented and compared with results obtained in the PABC-2009. As before, comparisons are made by use of overall means obtained in both analyses. A comparison of the PC3R PA and the PABC-2009 overall means of volume average porosity in the waste panel is provided in Figure 5-7. As can be seen in that figure, there is very close agreement between the porosities obtained in both analyses.

The overall means of volume averaged pressure obtained in the PC3R PA and the PABC-2009 are shown together in Figure 5-8. As seen in that figure, there is an increase in pressurization of the waste panel for a period of time following the drilling intrusion. This increase is due to the lower long-term permeability ranges of the PC3R panel closures. The result of this increased pressure, in combination with the "tighter" panel closures, is a reduction (on average) in the volume of brine in the waste panel. The reduction in waste panel brine volume as compared to the PABC-2009 yields a corresponding reduction in brine saturation, as seen in Figure 5-9. Gas generation processes in the waste panel require the availability of brine to proceed. The reduction in brine saturation seen in the PC3R PA for intrusion Scenario S2-BF results in an overall decrease in gas generation in the waste panel. The result is a gradual decrease over time in the volume-averaged pressure seen in the waste panel in the PC3R PA as compared to the PABC-2009, with the pressure seen in the PC3R PA eventually falling below that of the PABC-2009.

The overall means of total brine flow out of the waste panel for intrusion Scenario S2-BF are shown in Figure 5-10 for both the PC3R PA and the PABC-2009. As seen in that figure, there is very good agreement between the PC3R PA and PABC-2009 results, with a slight reduction evident in the average total flow out of the intruded waste panel for the PC3R PA. The repository configuration and panel closure design implemented in the PC3R PA does not result in an increase in brine flow out of the waste panel for E1 intrusion scenarios.

The overall means of total brine flow up the borehole, quantity BNBHUDRZ, are shown together for both analyses in Figure 5-11. As is clear in that figure, very good agreement is apparent between the PC3R PA and PABC-2009 results.

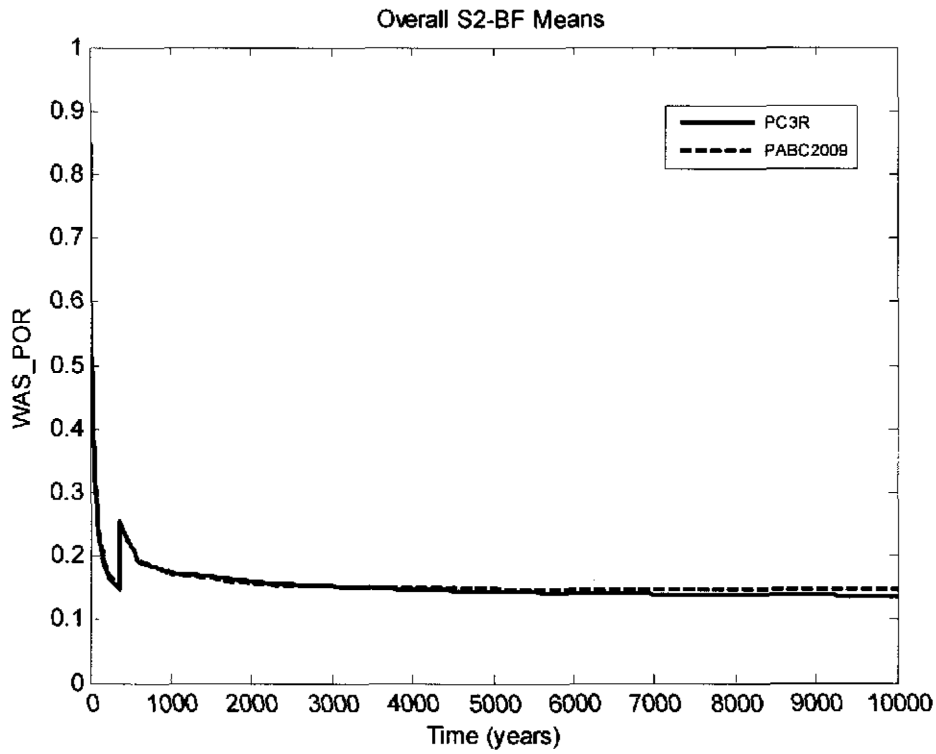

Figure 5-7: Overall Means of Volume Averaged Porosity for the Waste Panel, Scenario S2-BF

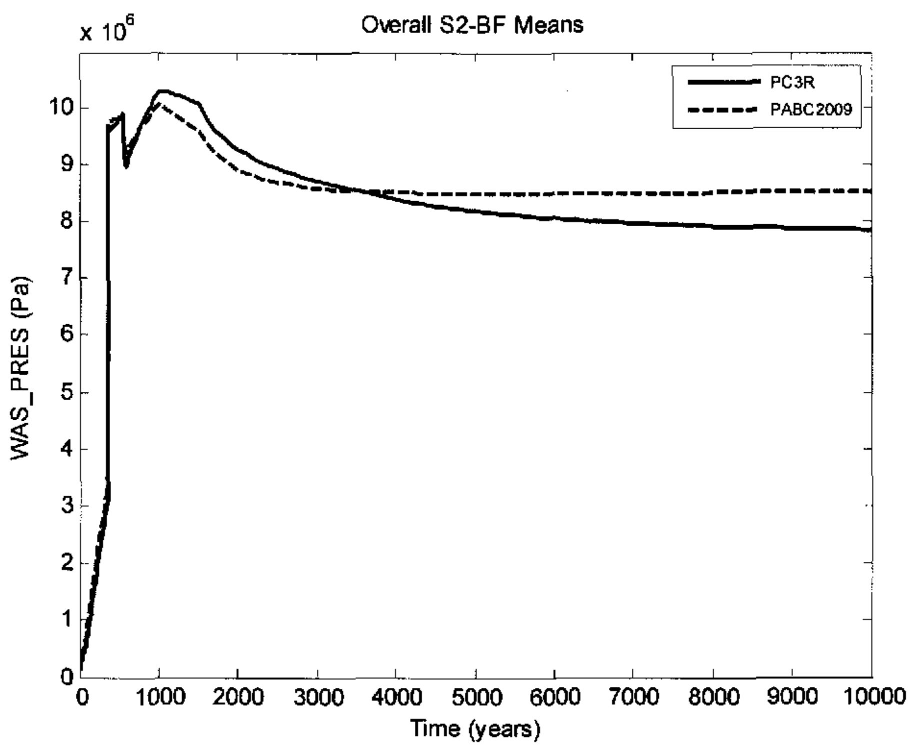

Figure 5-8: Overall Means of Volume Averaged Pressure for the Waste Panel, Scenario S2-BF

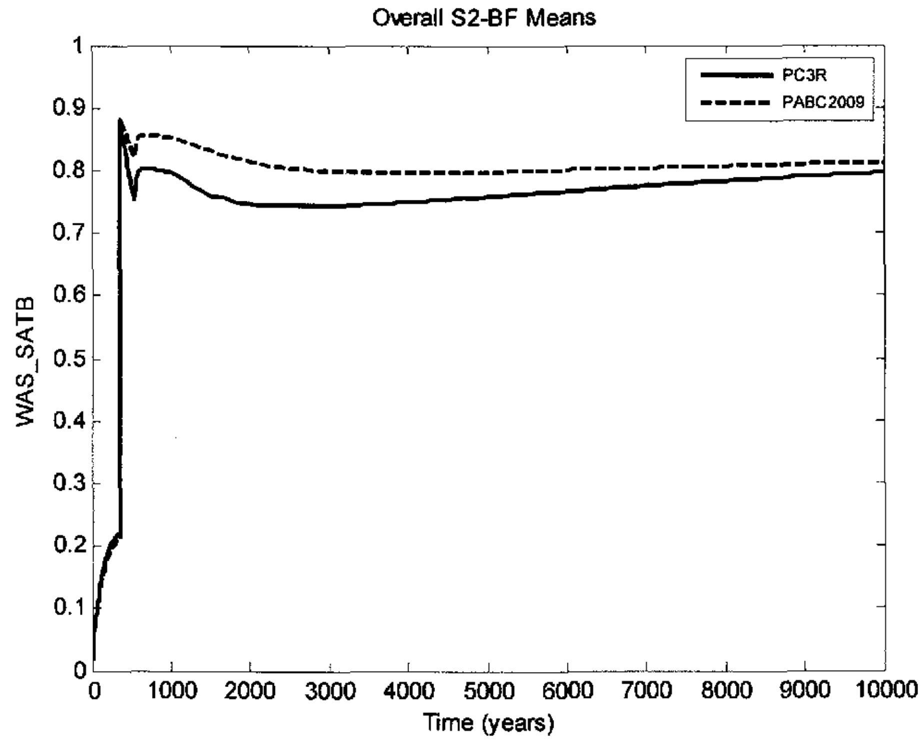

Figure 5-9: Overall Means of Brine Saturation in the Waste Panel, Scenario S2-BF

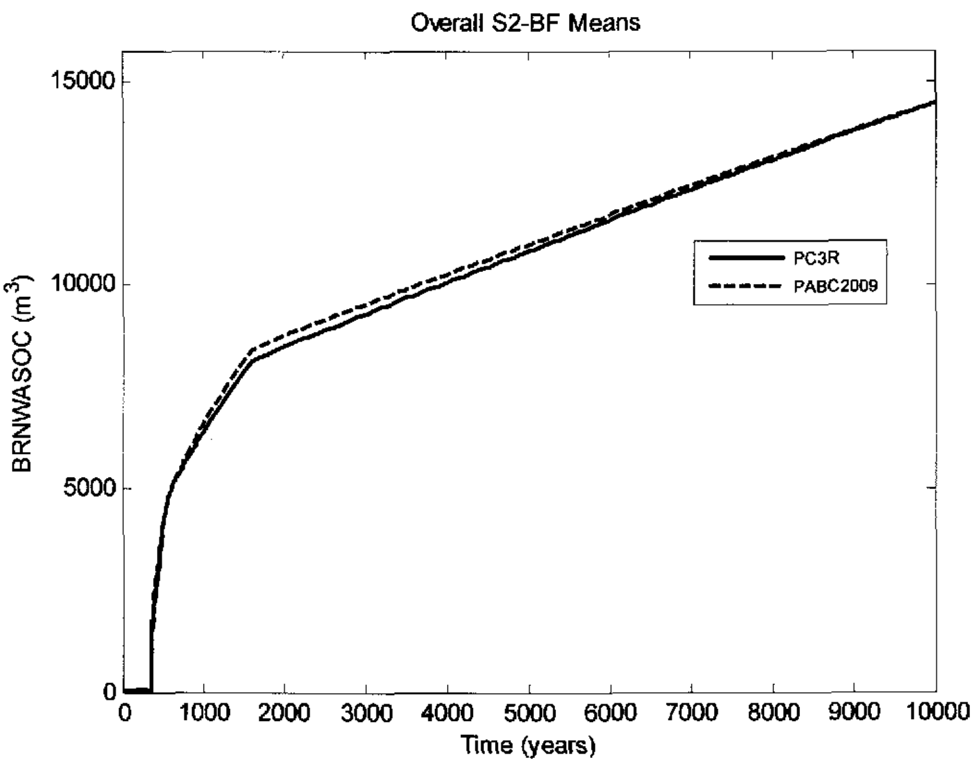

Figure 5-10: Overall Means of Total Brine Flow Out of the Waste Panel, Scenario S2-BF

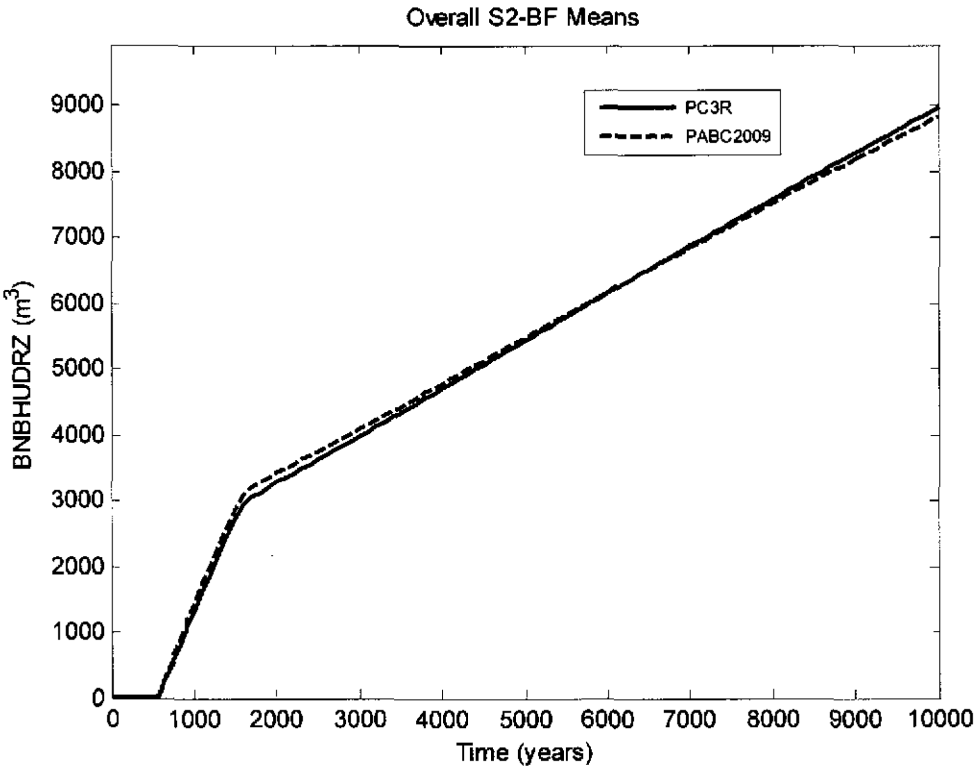

Figure 5-11: Overall Means of Total Brine Flow Up the Borehole, Scenario S2-BF

Disturbed Scenario S4-BF

PC3R PA results for intrusion scenario S4-BF are now presented and compared with results obtained in the PABC-2009. As before, comparisons are made by use of overall means obtained in both analyses. The overall means of volume averaged porosity for the waste panel in Scenario S4-BF are shown together in Figure 5-12 for both the PC3R PA and the PABC-2009. As seen in that figure, there is very close agreement in this quantity across both analyses, with the mean obtained in the PC3R PA attaining a slightly lower value by the end of the 10,000 year regulatory period.

The overall means of volume averaged pressure for the waste panel found in Scenario S4-BF for the PC3R PA and the PABC-2009 are shown in Figure 5-13. As seen in that figure, the waste panel mean average pressure found in the PC3R PA is lower than that seen in the PABC-2009. As discussed for Scenario S1-BF, the higher permeability values of the PC3R PA panel closures during the first 100 years allows some pressure release from the waste panel to the center region. The effect of this in Scenario S4-BF is clearly seen in Figure 5-14. In that figure, the rate of pressure increase in the waste panel found in the PC3R PA is lower during the first 100 years than that seen in the PABC-2009. The net result is a reduction in the overall mean pressure in the waste panel by the time the panel closures attain their long-term permeabilities. This reduced pressure is maintained after the Scenario S4-BF drilling intrusion at 350 years, resulting in lower average pressure in the waste panel for the remaining duration of the 10,000 year regulatory period.

The waste panel pressure reduction seen in the PC3R PA calculations results in a corresponding slight increase in brine volume in the waste panel. The slight increase in brine volume translates to a slight increase in the mean brine saturation as seen in Figure 5-15. The lower mean pressure seen in the PC3R PA combined with the lower long-term permeabilities of the panel closures implemented therein results in an overall reduction in the overall mean of total brine flow out of the waste panel, as is illustrated in Figure 5-16. The repository configuration and panel closure design implemented in the PC3R PA did not yield an increase in brine flow out of the waste panel for E2 intrusion scenarios.

A slight increase was seen in the overall mean of total brine flow up the borehole in the PC3R PA as compared to the PABC-2009, as is shown in Figure 5-17, most likely due to the slight increase in the waste panel brine volume seen in the PC3R PA. This increase is slight, however, amounting to less that 50 m^3 by the end of the 10,000 year regulatory period.

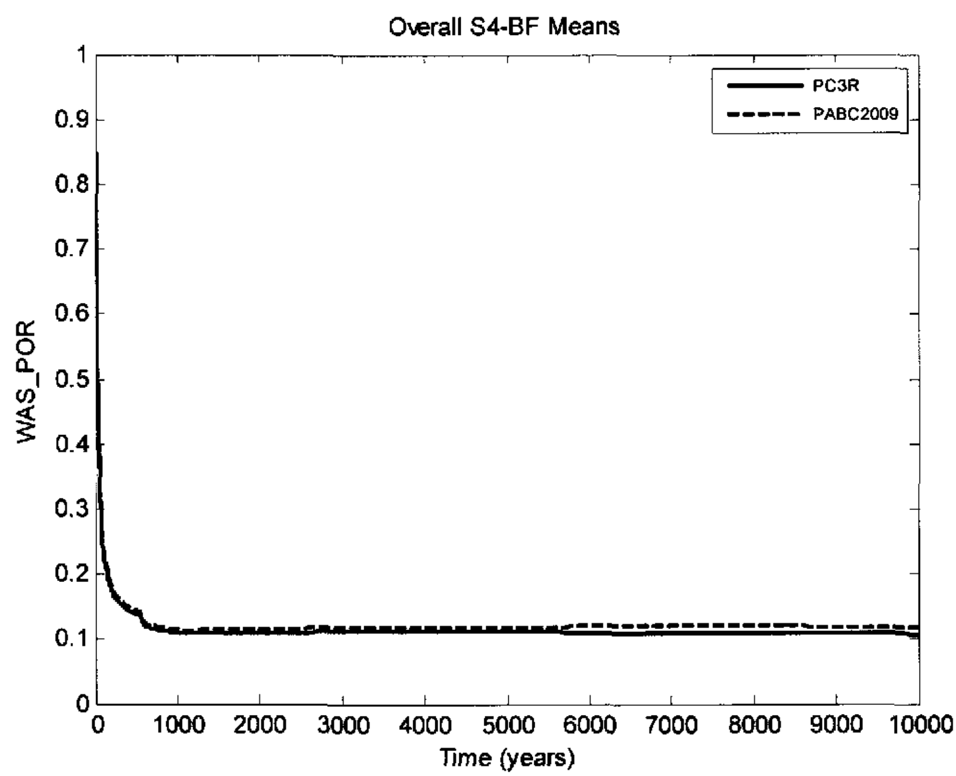

Figure 5-12: Overall Means of Volume Averaged Porosity for the Waste Panel, Scenario S4-BF

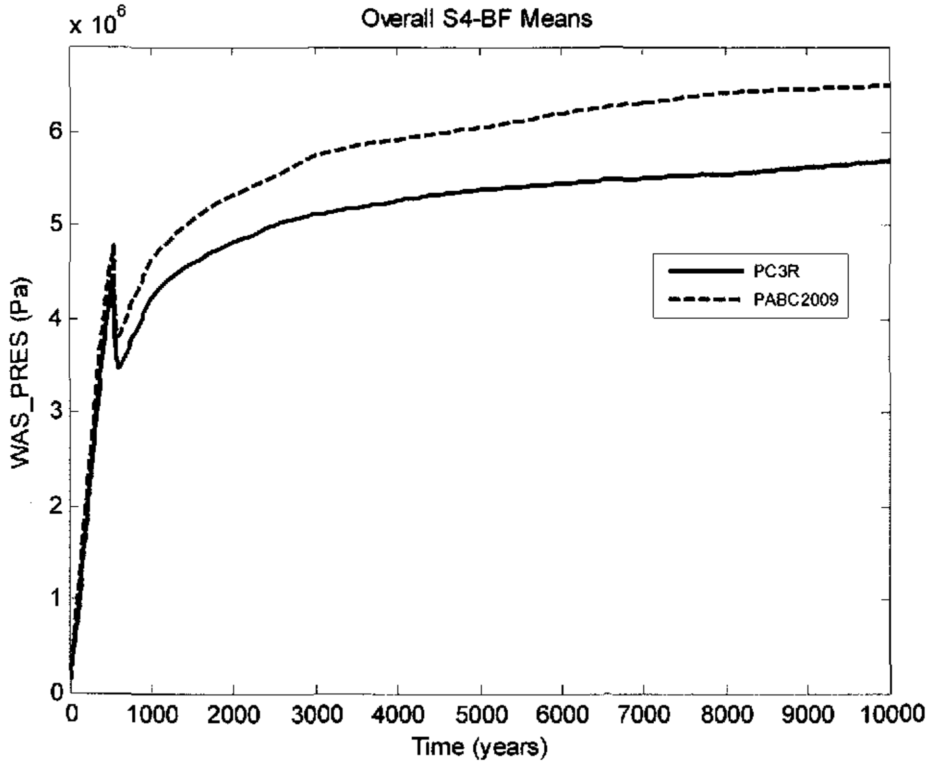

Figure 5-13: Overall Means of Volume Averaged Pressure for the Waste Panel, Scenario S4-BF

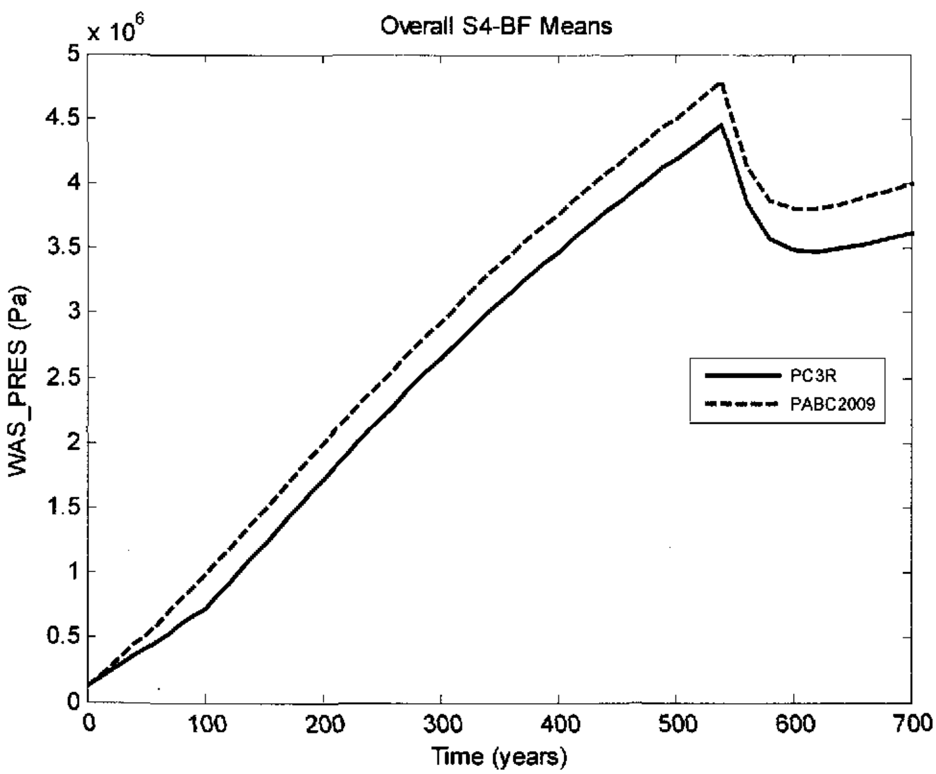

Figure 5-14: Overall Means of Volume Averaged Pressure for the Waste Panel During the First 700 Years After Closure, Scenario S4-BF

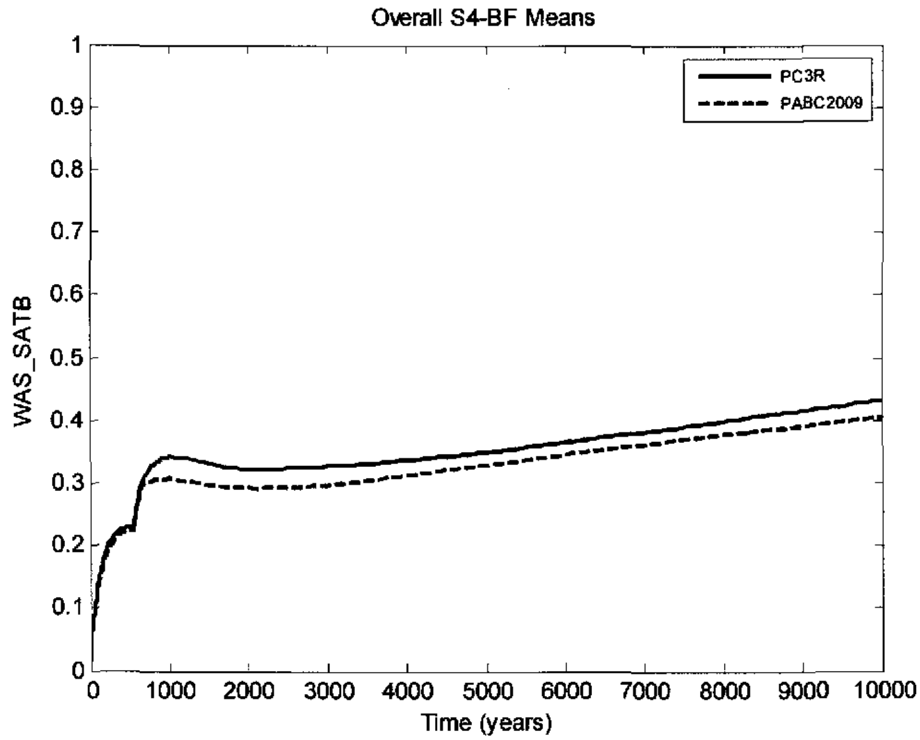

Figure 5-15: Overall Means of Brine Saturation in the Waste Panel, Scenario S4-BF

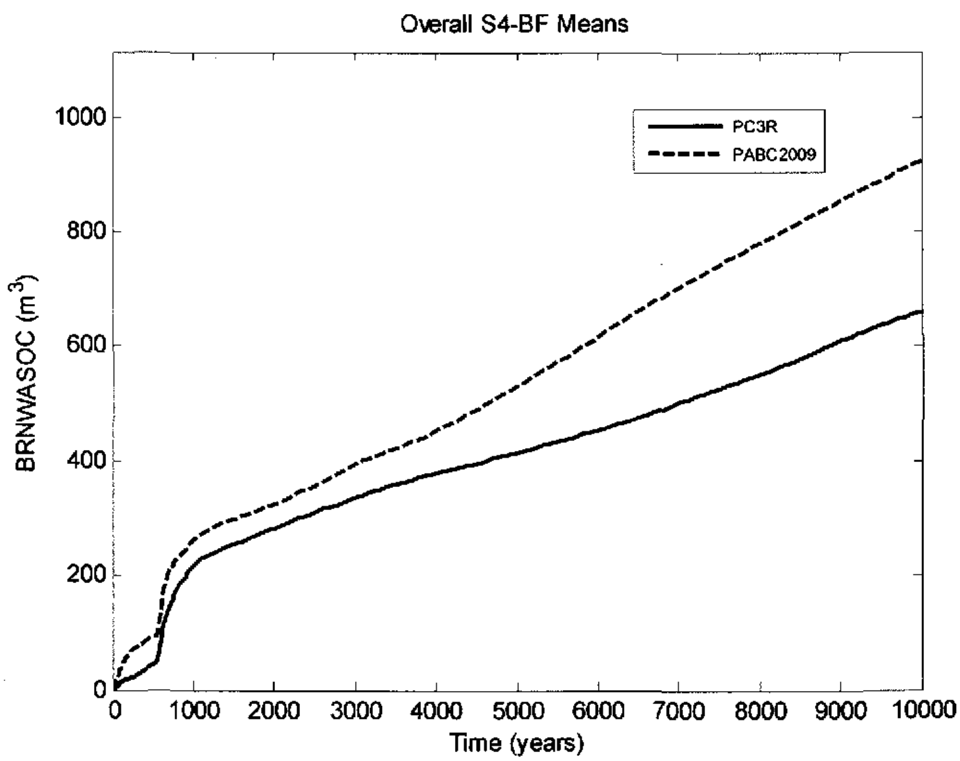

Figure 5-16: Overall Means of Total Brine Flow Out of the Waste Panel, Scenario S4-BF

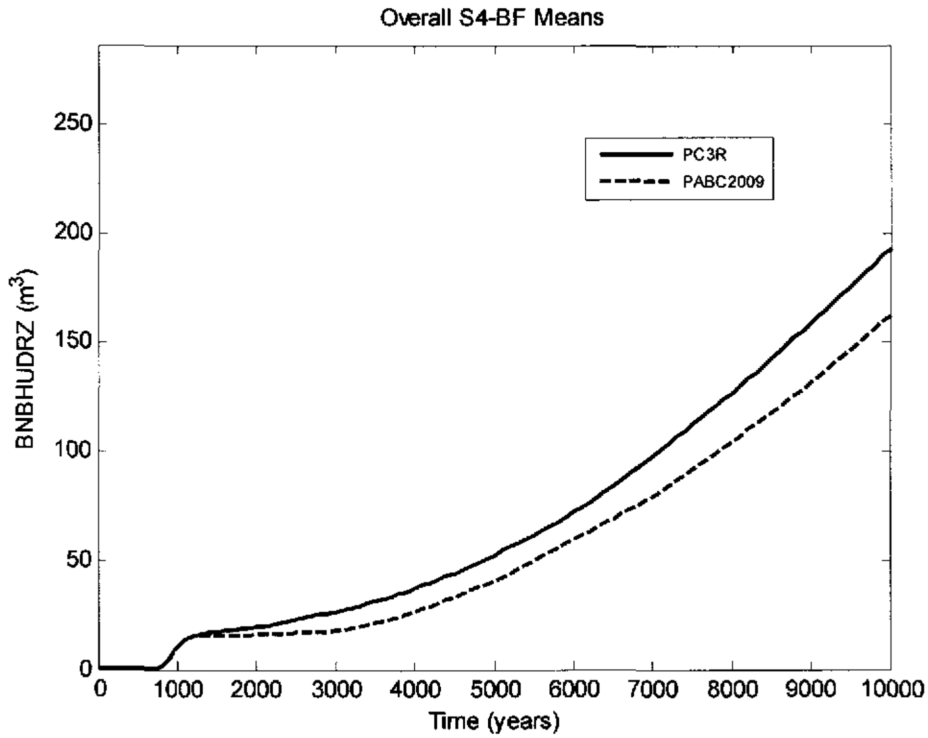

Figure 5-17: Overall Means of Total Brine Flow Up the Borehole, Scenario S4-BF

5.2 Brine Isolation after Intrusion

As discussed and demonstrated in the PC3R PA BRAGFLO results above, the cumulative brine flow out of an intruded waste panel was reduced on average as compared to the PABC-2009 results. One may also ask how the presence of relatively high pressures and brine volumes on one side of a redesigned panel closure impact brine volumes and saturations on the opposite side. In particular, is additional brine in the waste panel following an intrusion relocated to the central drift area where it can be released to the surface by a subsequent drilling intrusion in that region?

To answer this question, the PC3R PA overall pressure means in the waste panel for the undisturbed scenario and intrusion scenarios S2-BF, S4-BF, and S6-BF are shown together in Figure 5-18. As seen in that figure, there is significant variance in the average waste panel pressure in the scenarios considered. During the time duration of 0 to 2,000 years, for example, the average waste panel pressure varies from 0 Pa to over 10 MPa. Similar variance is seen in the average brine volume in the waste panel, as shown in Figure 5-19. Over the same time period of 2,000 years, the average brine volume in the waste panel varies from 0 m^3 to over 10,000 m^3 for intrusion scenario S2-BF. These substantial pressure and brine volume changes result in similar changes in the average waste panel brine saturation. As seen in Figure 5-20, the average brine saturation in the waste panel varies in the first 2,000 years from a value of 0 to a value of nearly 0.9, representing nearly saturated conditions. Obviously, the influx of additional brine in the waste panel following an intrusion has a corresponding impact on the brine saturation therein. Moreover, there is a direct correspondence in the shape of the average brine volume curves of Figure 5-19 and the brine saturation curves of Figure 5-20. Time values at which brine volumes substantially increase correspond to time values at which brine saturations also increase. From these results, it is reasonable to conclude that an influx of brine into the center area following an intrusion in the waste panel would result in a corresponding change in the brine saturation of the central area.

The brine saturation for the central drift area is denoted by quantity OPS_SATB in the PC3R PA as that region is assigned material properties corresponding to the operations region of the PABC-2009 repository configuration. The overall PC3R PA brine saturation curves obtained for the central drift area for undisturbed scenario S1-BF and disturbance scenarios S2-BF, S4-BF, and S6-BF are shown together in Figure 5-21. As is clear in that figure, there is no discernable difference in the average brine saturation obtained in the central drift region for all scenarios considered, regardless of pressure and brine volume/saturation changes in the intruded waste panel. Brine saturation curves obtained for the central drift area in all intrusion scenarios are virtually unchanged from the brine saturation curve obtained for undisturbed conditions. Furthermore, as seen in Figure 5-22 there is very close agreement in the overall average brine volume in the central drift area, denoted as BRNVOL_O, for the undisturbed and all intrusion scenarios considered. All curves obtained for the average brine volume in the central drift area for all conditions considered are nearly identical to the curve obtained for undisturbed conditions. The reasonable conclusion to make is that changing repository conditions following an intrusion on one side of a redesigned panel closure do not result in consequential brine saturation and volume changes on the opposite side of the closure. More specifically, an E1 or E2 drilling intrusion into the waste panel will not result in a consequential increase in brine volume inside the central drift region to later be released to the surface by a subsequent intrusion in that area. The brine available for release to the surface following a drilling event into the central drift region is brine present under undisturbed conditions, regardless of previous intrusions into a waste panel.

While a drilling intrusion into a waste panel has an inconsequential impact on brine volumes and saturations in the central drift region, a waste panel intrusion does have an impact on pressure in the central region. The overall PC3R PA average pressures obtained for the central drift region, denoted as quantity OPS_PRES, for undisturbed scenario S1-BF and disturbance scenarios S2-BF, S4-BF, and S6-BF are shown together in Figure 5-23. As seen in that figure, there is actually a *reduction* in the average pressure of the central drift region for all intrusion scenarios considered as compared to undisturbed scenario S1-BF. This is due to eventual reductions in waste panel pressures following an intrusion as compared to undisturbed conditions. Given sufficient time, the tendency is for pressure on opposite sides of a panel closure to equilibrate. A pressure reduction on one side of a panel closure corresponds to an eventual pressure reduction on the opposite side.

From the discussion above, a drilling intrusion on one side of a panel closure results in a reduction in pressure on the opposite side, but no consequential change to brine volume or brine saturation. As a result, it can be concluded that drilling intrusions in the central drift region will not impact brine volumes and saturations in a waste panel, but will cause reductions in pressure. Pressure reductions translate directly to reductions in spallings releases. Likewise, pressure reductions without an accompanying increase in brine saturation can only result in a reduction in direct brine releases. Therefore, drilling intrusions in the central drift region can only *reduce* releases due to a waste panel intrusion. For the quantification of releases in the PC3R PA, the consideration of drilling intrusions into waste-containing regions is sufficient, and is conservative.

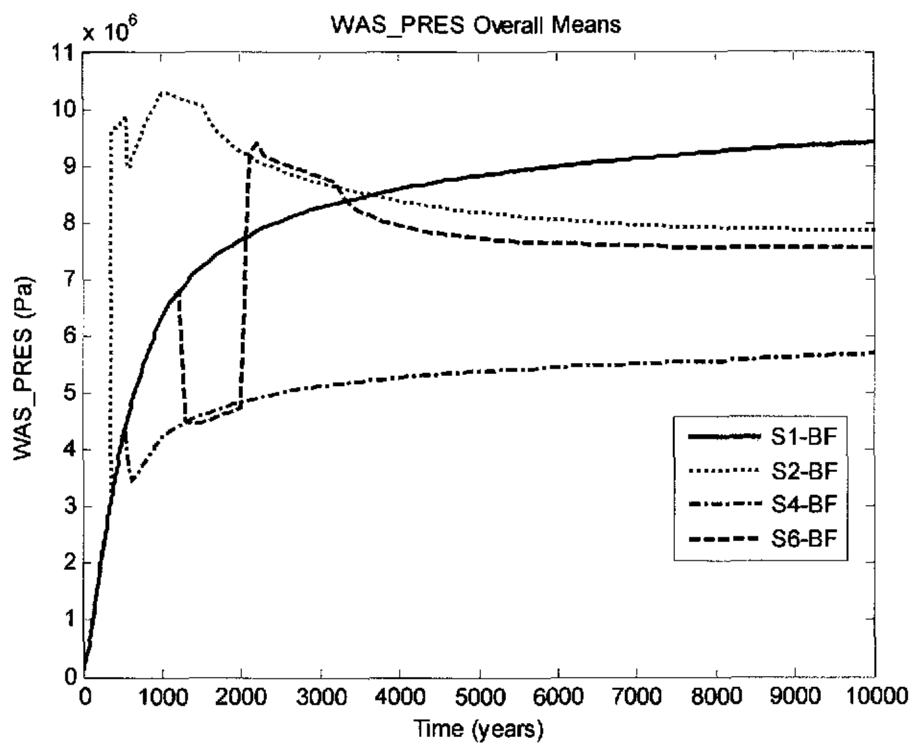

Figure 5-18: PC3R PA Overall Waste Panel Pressure Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

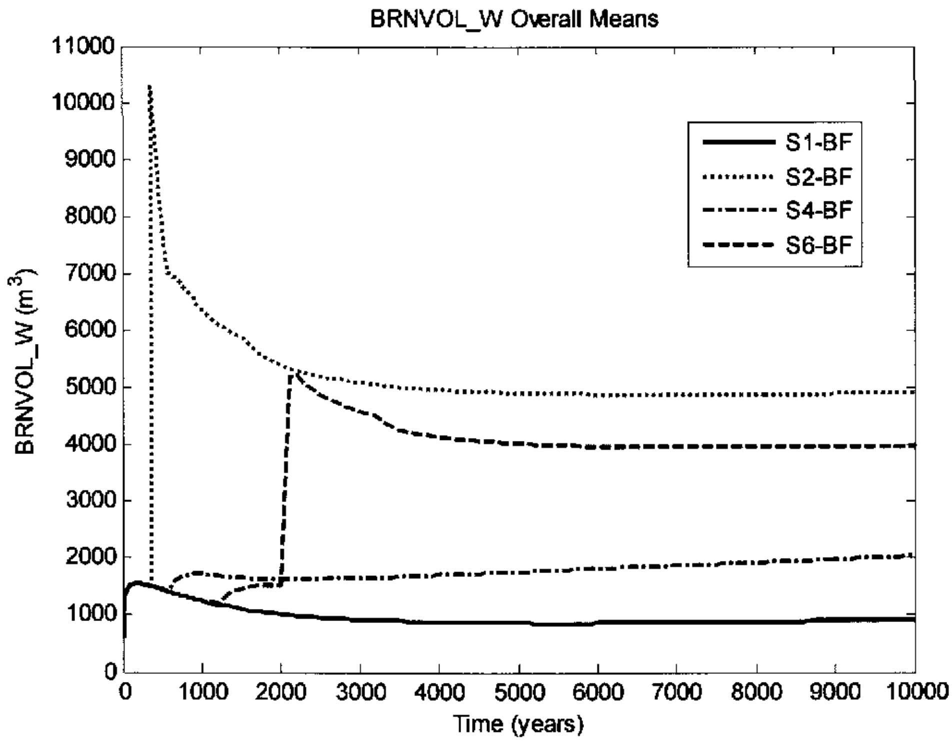

Figure 5-19: PC3R PA Overall Waste Panel Brine Volume Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

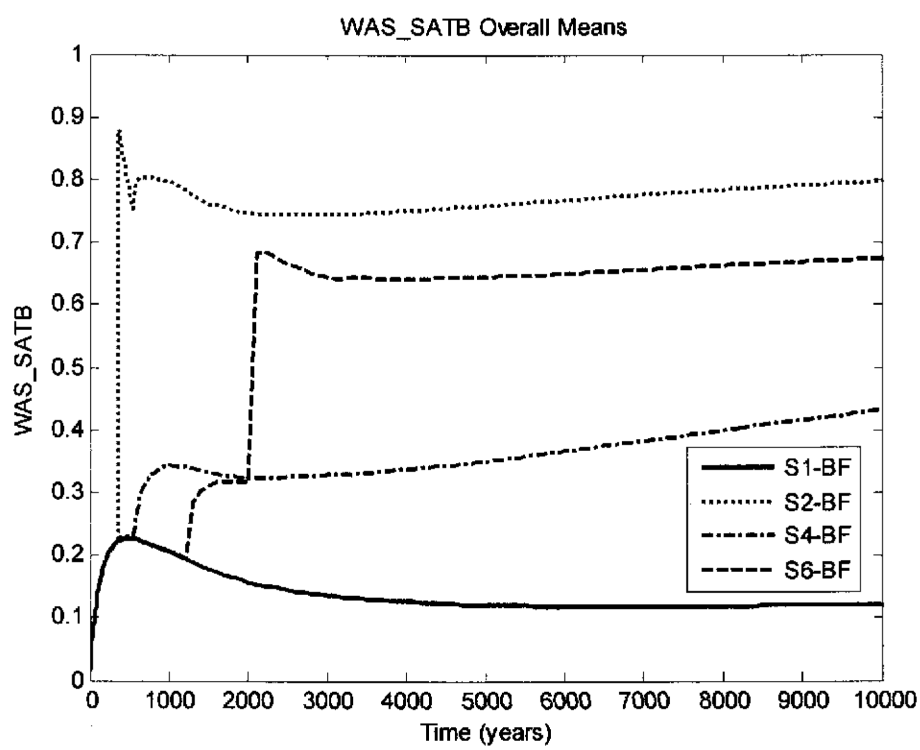

Figure 5-20: PC3R PA Overall Waste Panel Brine Saturation Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

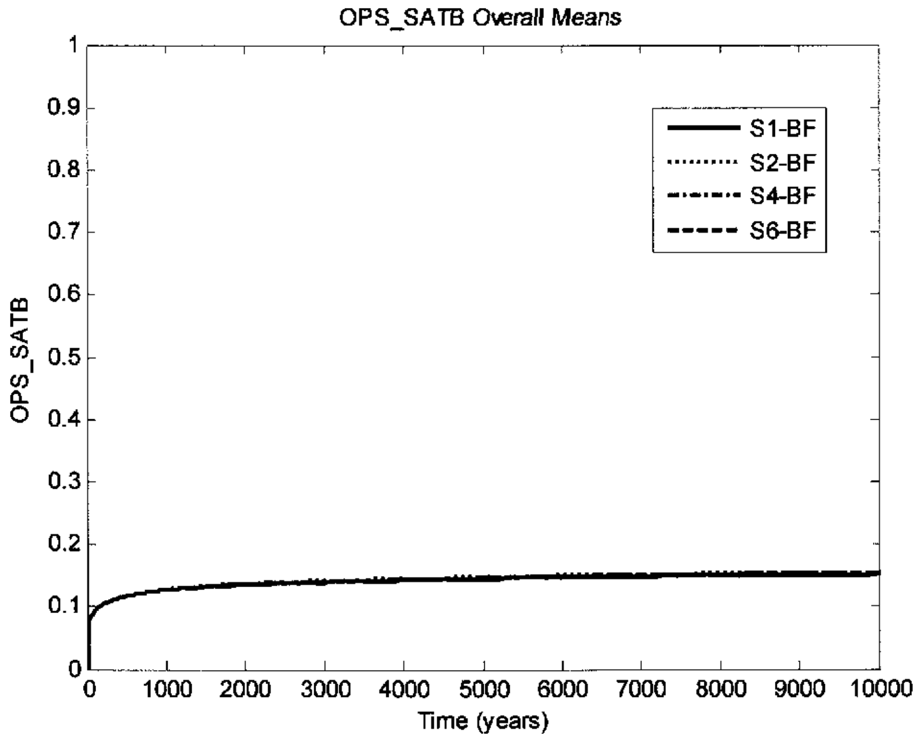

Figure 5-21: PC3R PA Overall Central Region Brine Saturation Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

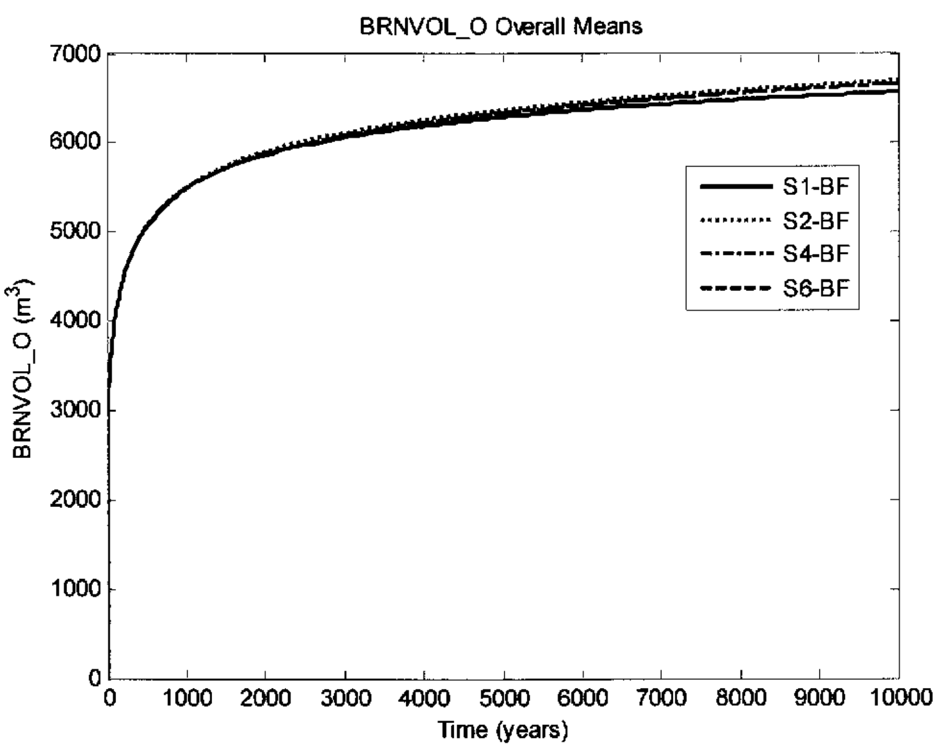

Figure 5-22: PC3R PA Overall Central Region Brine Volume Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

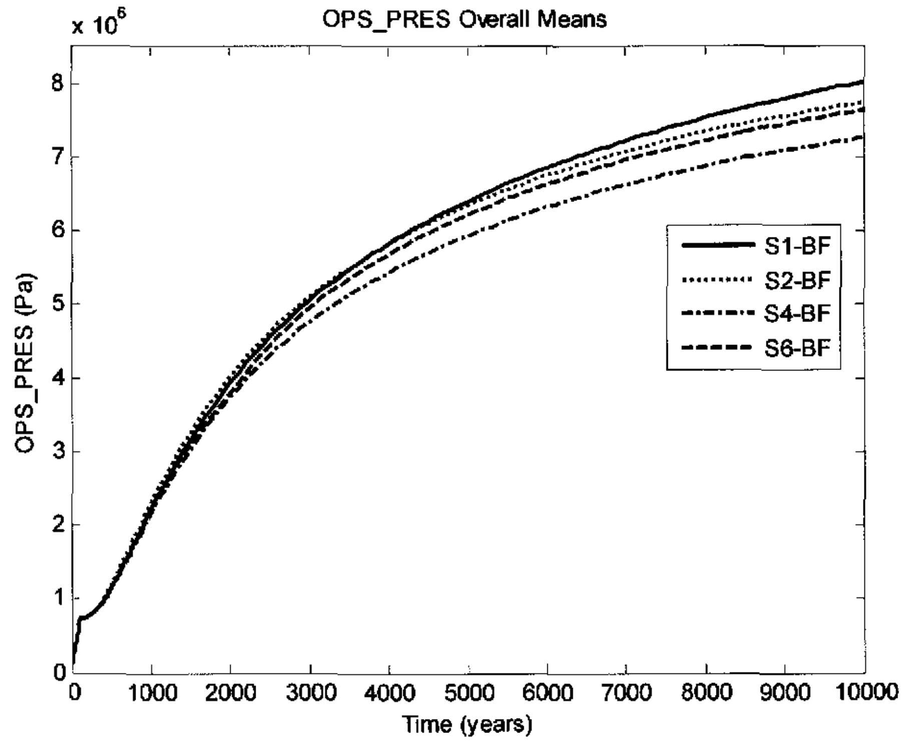

Figure 5-23: PC3R PA Overall Central Region Pressure Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

5.3 Actinide Mobilization and Transport

Waste panels 9a and 10a in the reconfigured repository are slightly larger than their 9 and 10 counterparts in the historical WIPP configuration, and are of identical volume to panels 1-8. As a result, the waste inventory of a standard panel in the PC3R PA is exactly 10% of the overall inventory, a slight decrease from the value of 10.53% implemented in the PABC-2009. As the repository waste inventory, and corresponding actinide solubilities, used in the PABC-2009 were also prescribed in the PC3R PA calculations, the slight decrease in waste panel inventory has practically no impact on actinide concentration curves obtained in the two analyses. For all practical purposes, the concentration curves obtained in the two analyses are the same. As a result, changes in the amount of brine volume flowing up a borehole following an intrusion is the primary indicator of changes in transport releases between the PC3R PA and the PABC-2009. Consequently, Salado modeling results obtained for quantity BNBHUDRZ in intrusion scenario S6-BF are now presented and compared with their PABC-2009 counterparts.

The scenario S6-BF means of BNBHUDRZ for replicates 1 – 3 are shown in Figure 5-24 and compared to their PABC-2009 counterparts. In that figure, solid curves represent replicate means obtained in the PC3R PA. Dashed curves denote replicate means obtained in the PABC-2009. As is evident, there is very close agreement between the replicate means obtained in the two analyses. The PC3R PA and PABC-2009 overall means of brine volume up the borehole, calculated over all 300 vector realizations, are shown together in Figure 5-25 for intrusion scenario S6-BF. Again, there is very close agreement between PC3R PA and PABC-2009 results.

As the volumes of brine flow up the intrusion borehole obtained in the PC3R PA and the PABC-2009 are very similar for intrusion scenarios S2-BF to S6-BF, it is concluded that transport releases obtained in these two analyses are also very similar as the waste inventory and corresponding actinide solubilities were unchanged from the PABC-2009 to the PC3R PA. This conclusion is further supported by the CCDF curves of normalized releases to the Culebra shown in Figure 5-26 and Figure 5-27. As seen in Figure 5-26, the replicate means of normalized transport releases to the Culebra obtained in the PC3R PA and the PABC-2009 are nearly identical. The same is true of the overall mean CCDF curves for transport releases to the Culebra, as evident in Figure 5-27.

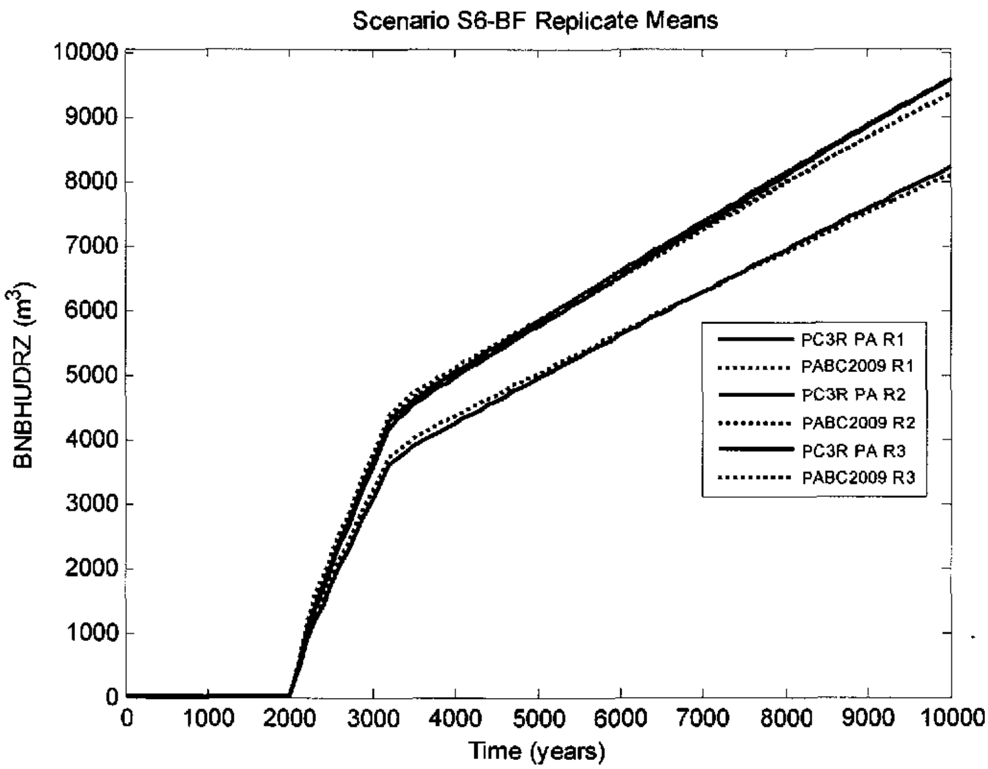

Figure 5-24: PC3R PA and PABC-2009 Replicate Means of Cumulative Flow up the Borehole

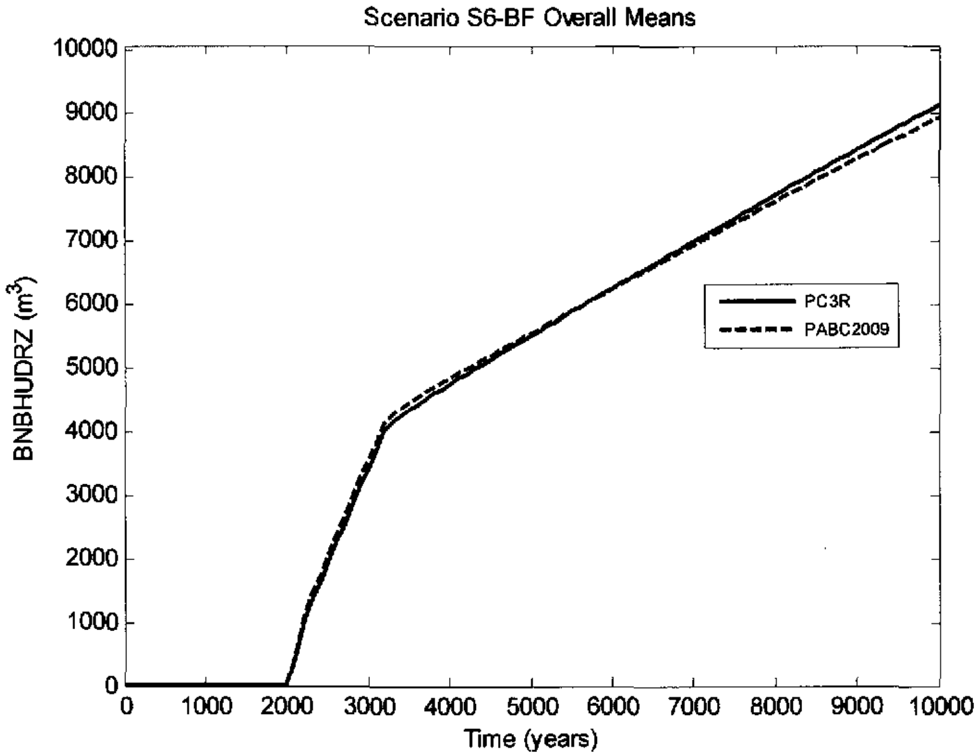

Figure 5-25: PC3R PA and PABC-2009 Overall Means of Cumulative Flow up the Borehole

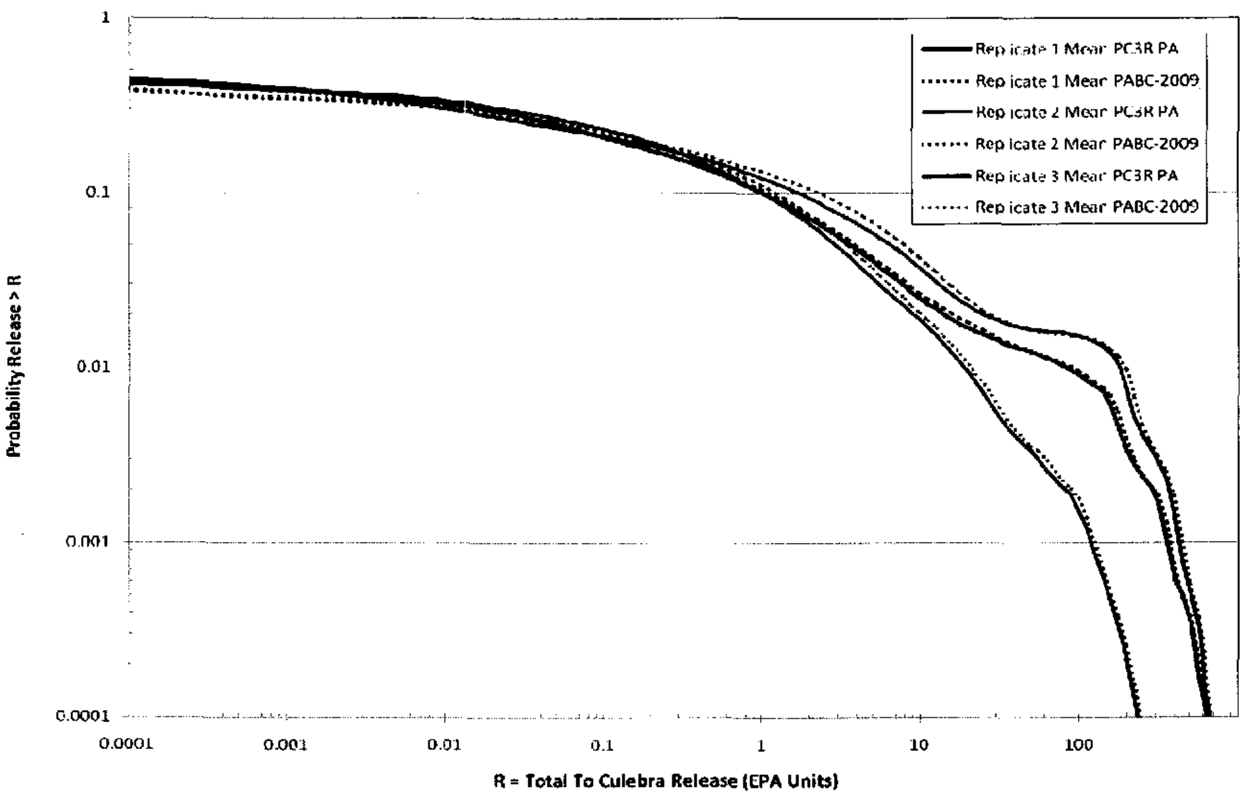

Figure 5-26: PC3R PA and PABC-2009 Replicate Mean CCDFs for Normalized Transport Releases to the Culebra

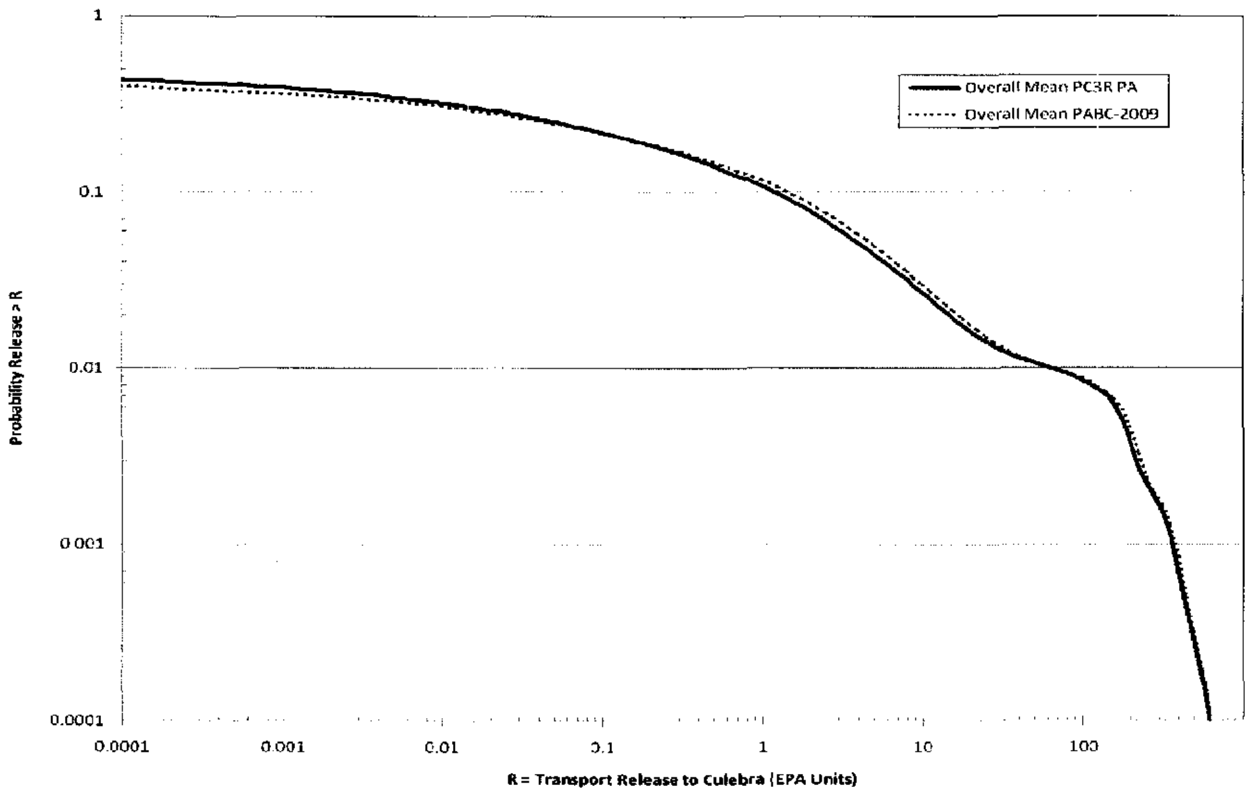

Figure 5-27: PC3R PA and PABC-2009 Overall Mean CCDFs for Transport Releases to the Culebra

5.4 Cuttings and Cavings

Cuttings and cavings are the solid waste material removed from the repository and carried to the surface by the drilling fluid during the process of drilling a borehole. Cuttings are the materials removed directly by the drill bit, and cavings are the material eroded from the walls of the borehole by shear stresses from the circulating drill fluid. The volume of cuttings and cavings material removed from a single drilling intrusion into the repository is assumed to be in the shape of a cylinder.

The PA code CUTTINGS_S calculates the cuttings and cavings areas removed for a set of vectors, scenarios, times, and locations. Results obtained by BRAGFLO in scenarios S1-BF to S5-BF are used to initialize the flow field properties necessary for the calculation of DBRs. This requires that results obtained on the BRAGFLO grid be mapped appropriately to the DBR grid. Code CUTTINGS_S is used to transfer the appropriate scenario results obtained with BRAGFLO to the DBR grid. These transferred flow results are used as initial conditions in the calculation of DBRs. As a result, intrusion scenarios used in the calculation of cuttings and cavings correspond to those used in the calculation of DBRs. Five intrusion scenarios are considered in the DBR calculations, and are listed in Table 7.

Table 7: PA Intrusion Scenarios Used in Calculating Direct Solids Releases

Scenario	Conditioning (or 1st) Intrusion Time (year) and Type	Intrusion Times – Subsequent (year)
S1-DBR	None	100, 350, 1000, 3000, 5000, 10000
S2-DBR	350, E1	550, 750, 2000, 4000, 10000
S3-DBR	1000, E1	1200, 1400, 3000, 5000, 10000
S4-DBR	350, E2	550, 750, 2000, 4000, 10000
S5-DBR	1000, E2	1200, 1400, 3000, 5000, 10000

While CUTTINGS_S uses these standard DBR scenarios as a basis for its calculations, it does so to provide flow field results (generated with BRAGFLO) as initial conditions to the DBR calculation at each subsequent intrusion time. CUTTINGS_S does not model the intrusion scenario itself. Scenario S1-DBR corresponds to an initial intrusion into the repository, with repository flow conditions at the time of intrusion transferred from BRAGFLO scenario S1-BF results. Scenarios S2-DBR through S5-DBR are used to model an intrusion into a repository that has already been penetrated. The times at which intrusions are assumed to occur for each scenario are outlined in the last column of Table 7; six intrusion times are modeled for scenario S1-DBR, while five times are modeled for each of scenarios S2-DBR through S5-DBR.

Cuttings and cavings results obtained for the PC3R PA are the same as for the PABC-2009, as is evident in the results of Table 8 and the CCDF curves of normalized cuttings and cavings releases shown in Figure 5-28.

Table 8: Cavings Area Statistics for the PABC-2009 and PC3R PA

Replicate	Cavings Area (m^2)		Vectors with no Cavings
	Maximum	Mean	
R1	0.748	0.177	9
R2	0.785	0.175	10
R3	0.753	0.178	11

Two uncertain sampled parameters affect the cavings calculations. The uncertainty in cavings areas arises primarily from the uncertainty in the shear strength of the waste (Kicker 2011). Lower shear strengths tend to result in larger cavings as is evident in Figure 5-29. The uncertainty in the drill string angular velocity has a smaller impact on the cavings results, but the combination of a low angular velocity and high shear strength can prohibit cavings from occurring. In fact, cavings did not occur in ten percent of all vectors (Table 8).

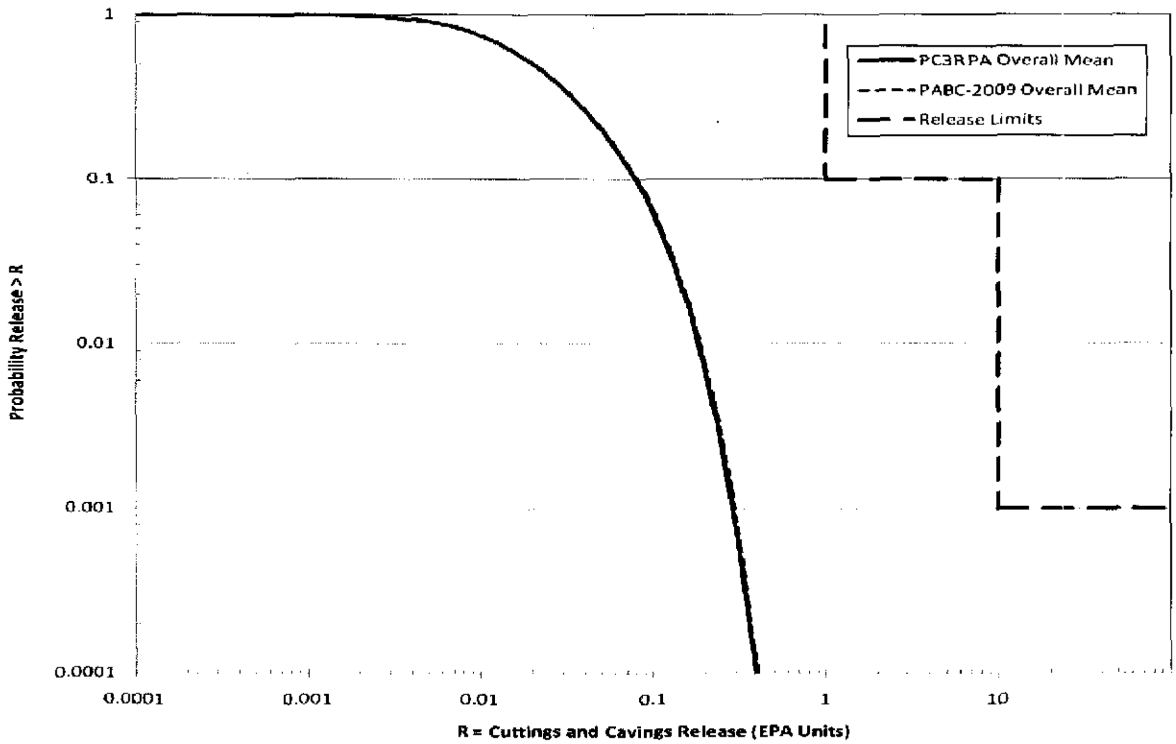

Figure 5-28: PC3R PA and PABC-2009 Overall Mean CCDFs for Normalized Cuttings and Cavings Releases

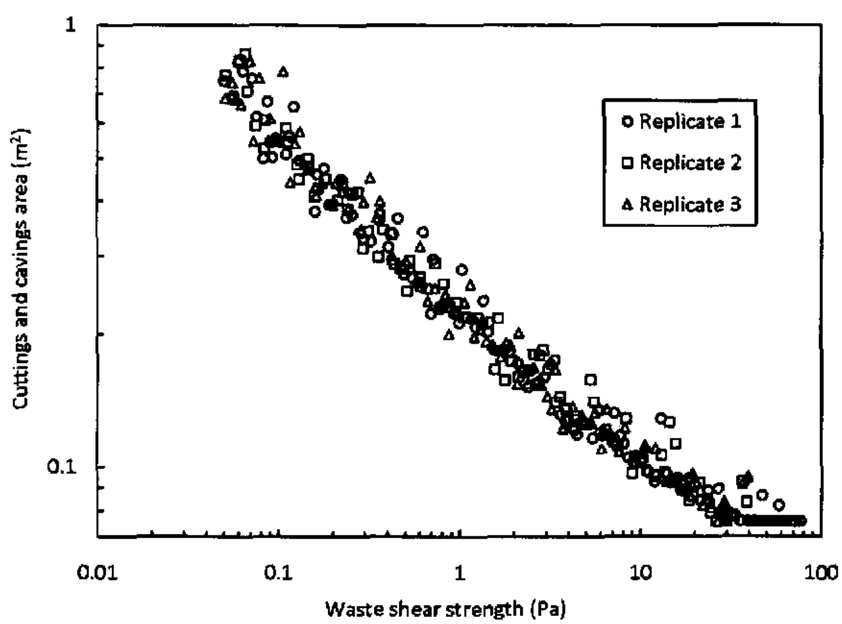

Figure 5-29: Cuttings and Cavings Area as a Function of Waste Shear Strength

5.5 Spallings

Calculation of the volume of solid waste material released to the surface from a single drilling intrusion into the repository due to spallings is a two-part procedure. The code DRSPALL calculates the spallings volumes from a single drilling intrusion at four values of repository pressure (10, 12, 14, and 14.8 MPa). The second step in calculating spallings volumes from a single intrusion consists of using the code CUTTINGS_S to interpolate the DRSPALL volumes. The spallings volume for a vector is then determined in CUTTINGS_S by linearly interpolating the volume calculated by DRSPALL based on the pressure calculated by BRAGFLO.

Table 9: Summary of Spallings Releases by Scenario

		Scenarios					Total
		S1-DBR	S2-DBR	S3-DBR	S4-DBR	S5-DBR	
PC3R PA							
R1	Maximum [m^3]	1.67	13.56	12.70	1.67	1.67	13.56
	Average nonzero volume [m^3]	0.31	0.74	0.78	0.27	0.30	0.53
	Number of nonzero volumes	84	102	86	40	53	365
	Percent of nonzero volumes	7.0%	10.2%	8.6%	4.0%	5.3%	7.0%
R2	Maximum [m^3]	1.43	8.48	6.64	0.60	0.60	8.48
	Average nonzero volume [m^3]	0.22	0.40	0.34	0.23	0.22	0.30
	Number of nonzero volumes	89	114	96	36	53	388
	Percent of nonzero volumes	7.4%	11.4%	9.6%	3.6%	5.3%	7.5%
R3	Maximum [m^3]	5.00	6.80	4.52	3.93	4.52	6.80
	Average nonzero volume [m^3]	0.42	0.59	0.39	0.37	0.32	0.44
	Number of nonzero volumes	79	98	83	33	51	344
	Percent of nonzero volumes	6.6%	9.8%	8.3%	3.3%	5.1%	6.6%
PABC-2009							
R1	Maximum [m^3]	2.24	8.29	7.97	1.67	1.67	8.29
	Average nonzero volume [m^3]	0.37	0.54	0.50	0.30	0.37	0.43
	Number of nonzero volumes	142	117	111	59	77	506
	Percent of nonzero volumes	7.9%	7.8%	7.4%	3.9%	5.1%	6.5%
R2	Maximum [m^3]	2.36	2.76	1.86	2.26	1.93	2.76
	Average nonzero volume [m^3]	0.32	0.39	0.37	0.50	0.47	0.39
	Number of nonzero volumes	168	122	122	57	84	553
	Percent of nonzero volumes	9.3%	8.1%	8.1%	3.8%	5.6%	7.1%
R3	Maximum [m^3]	4.91	6.23	2.62	1.47	1.49	6.23
	Average nonzero volume [m^3]	0.53	0.39	0.28	0.30	0.28	0.38
	Number of nonzero volumes	156	113	118	45	72	504
	Percent of nonzero volumes	8.7%	7.5%	7.9%	3.0%	4.8%	6.5%

DRSPALL volumes used in the PABC-2009 were also used in the PC3R PA. Utilizing these volumes and the PC3R PA repository pressures calculated by BRAGFLO, the impact of the repository reconfiguration and panel closure design on spallings volumes can be determined. Average and maximum statistics of spallings volumes for the intrusion scenarios considered by

CUTTINGS_S are shown in Table 9 for both the PC3R PA and the PABC-2009. While the results for the PABC-2009 and the PC3R PA calculations are similar for some scenarios, some significant differences in the spallings volumes are noted. For scenarios S2-DBR and S3-DBR, in which the borehole intrusion encounters a pressurized brine pocket, a sharp increase in spallings volume occurs across all three replicates. The results for scenarios S1-DBR, S4-DBR, and S5-DBR are mixed compared to the PABC-2009, showing both increases and decreases in spallings volume. Overall, the general trend shows a slightly higher average nonzero spallings volume, a larger maximum volume, and a larger percentage of vectors with spallings considering the total from all scenarios across all three replicates.

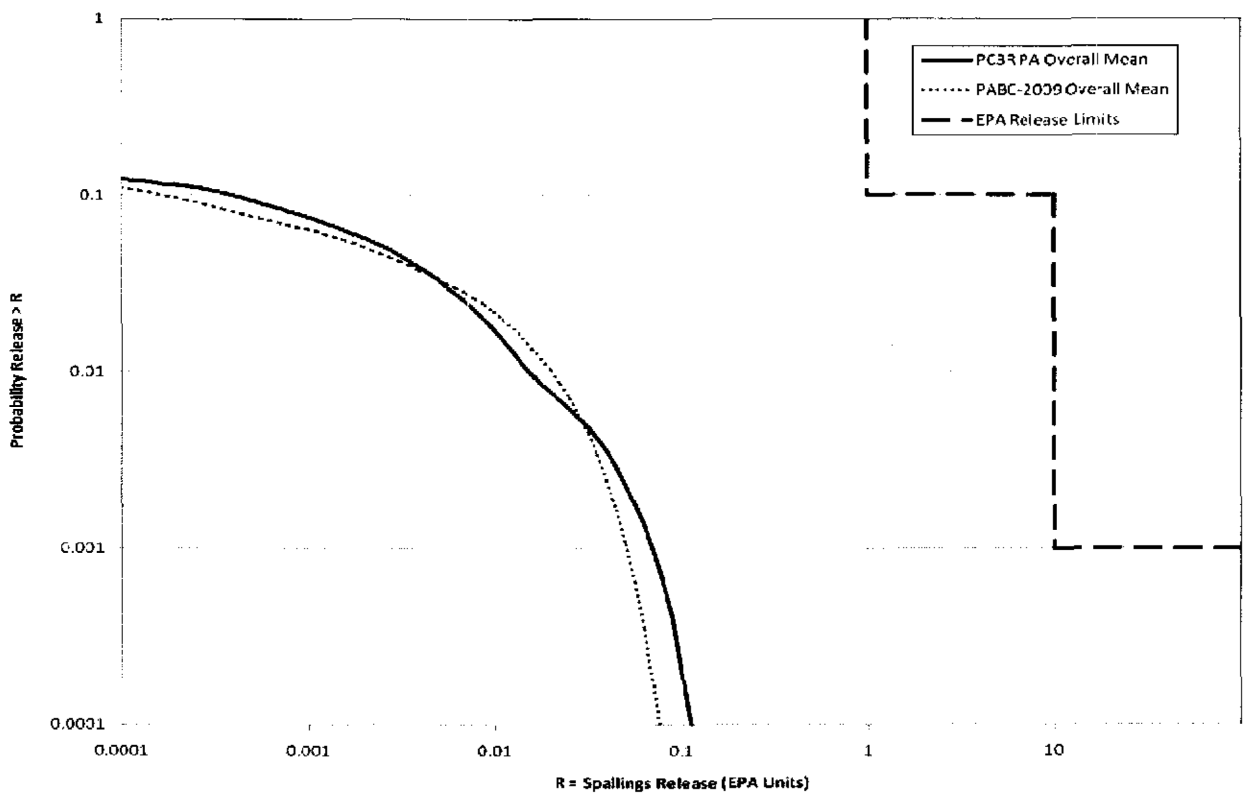

Figure 5-30: PC3R PA and PABC-2009 Overall Mean CCDFs for Normalized Spallings Releases

Spallings volumes are a function of repository pressure. The change in spallings volumes between the PC3R PA and the PABC-2009 is the result of changing repository pressures observed in BRAGFLO calculations for the PC3R PA. For intrusion scenarios that involve an encounter with a pressurized brine region below the repository, the slight reduction in the long-term PC3R PA panel closure permeabilities resulted in a slight increase in pressurization of the waste panel for a period of time following the intrusion. Since there is a minimum threshold pressure required to create spallings, an increase in repository pressure also increases the percentage of vectors with spallings. Repository pressures are also impacted by the slight increase in repository volume resulting from the slightly larger volumes of panels 9a 10a.

The impacts of the changes in spallings volumes on the overall mean CCDF for normalized spallings releases obtained in the PC3R PA can be seen in Figure 5-30. As seen in that figure, the CCDFs of spallings releases obtained in the PABC-2009 and the PC3R PA are similar. However, the PC3R PA CCDF curve shown in Figure 5-30 exhibits both increases and decreases in spallings releases when compared to PABC-2009 results. These changes are due to the spallings volume changes seen in the PC3R PA.

5.6 Direct Brine Releases

In this subsection, DBR results from the PC3R PA and the PABC-2009 are compared. Summary statistics of the calculated DBR volumes for replicates 1-3 and scenarios S1-DBR to S5-DBR are provided in Table 10. In that table, maximums shown are the maximum DBR volumes over all replicates, times, vectors and drilling locations. As seen by the statistics for the maximum DBR volumes in Table 10, the panel closure redesign and repository configuration implemented in the PC3R PA resulted in an increase in the maximum DBR volume as compared to the PABC-2009. The maximum DBR volume realized in the PABC-2009 was 48.2 m^3 while that seen in the PC3R PA is 52.0 m^3. However, the average DBR volume remained equal or decreased in the PC3R PA for all scenarios considered except for scenario S5-DBR. When calculated over all intrusion scenarios, the average volume reduced from a value of 1.34 m^3 in the PABC-2009 to a value of 1.14 m^3 in the PC3R PA. This reduction in the average DBR volume seen in the PC3R PA is a result of the lower number of vectors producing nonzero DBR volumes in that analysis. In the PABC-2009, a total of 2,474 vectors resulted in a nonzero DBR volume realization. The number of vectors resulting in nonzero DBR volumes in the PC3R PA is 2,273, a reduction by 201 vectors when compared to the PABC-2009 results.

Table 10: PABC-2009 and PC3R PA DBR Volume Statistics

Scenario	Maximum Volume (m^3)		Average Volume (m^3)		Number of Vectors	
	PABC-2009	PC3R PA	PABC-2009	PC3R PA	PABC-2009	PC3R PA
S1-DBR	21.9	29.7	0.1	0.1	258	257
S2-DBR	48.2	52.0	4.2	3.7	1071	962
S3-DBR	40.6	49.7	2.2	1.6	791	682
S4-DBR	20.4	28.1	0.1	0.1	145	148
S5-DBR	21.1	24.0	0.1	0.2	209	224
S1-DBR to S5-DBR	48.2	52.0	1.34	1.14	2474	2273

DBR releases are less likely to occur during upper drilling intrusions when compared with the lower drilling location. Of all the intrusions that had a non-zero DBR volume for the PC3R PA, 74.8% occurred during a lower drilling intrusion. Furthermore, of all the intrusions that had a non-zero DBR volume and occur during a lower drilling intrusion, 82.8% are found in scenarios S2-DBR and S3-DBR. Therefore, the majority of the non-zero DBR volumes occur when there is a previous E1 intrusion within the same panel. Not only are DBRs less likely to occur during upper drilling intrusions, but also the DBR volumes from such intrusions tend to be much smaller than DBR volumes from lower drilling intrusions. For all three replicates of the PC3R PA, the maximum DBR volume for the upper drilling location is 22.0 m^3 compared to 52.0 m^3 for the lower drilling location (Pasch and Camphouse 2011). These observations support the conclusion that lower drilling intrusions are the primary source for significant DBRs.

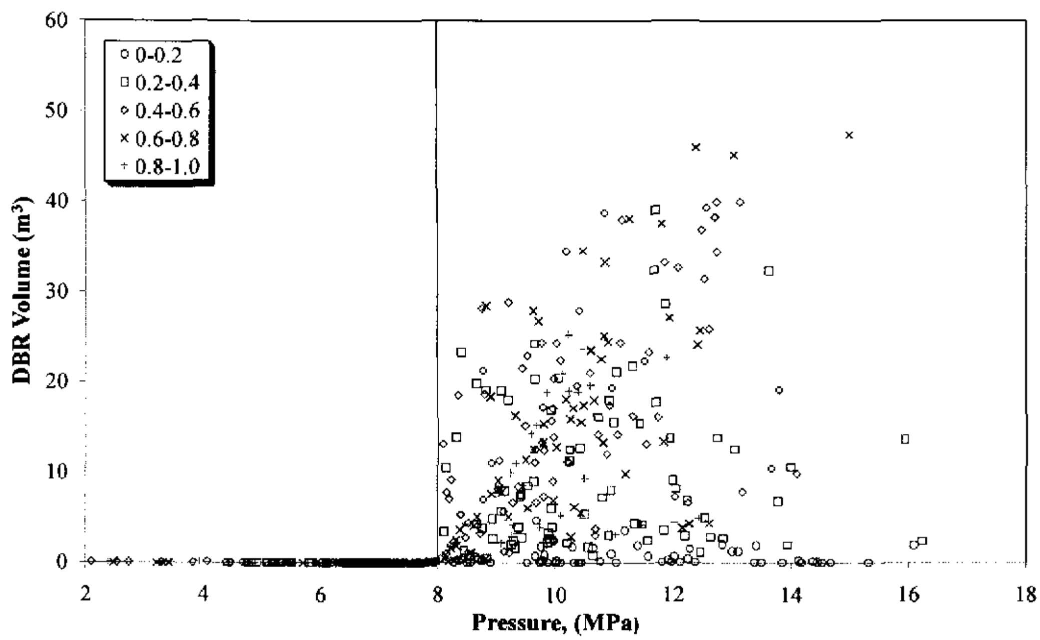

Figure 5-31: DBR Volume vs. Pressure, Scenario S2-DBR, Replicate 1, Lower Intrusion, PC3R PA

The combination of relatively high pressure and brine saturation in the intruded panel is required for direct brine release to the surface. Figure 5-31 shows a scatter plot of DBR volume versus pressure in the intruded panel at different intrusion times for the S2-DBR scenario, replicate 1, lower drilling intrusion for the PC3R PA. In that figure, symbols indicate the value of the mobile brine saturation, defined as brine saturation minus residual brine saturation in the waste. As prescribed by the conceptual model, there are no DBRs until pressures exceed 8 MPa as indicated by the vertical line in that figure. Above 8 MPa, a significant number of vectors have zero volumes; these vectors have mobile brine saturations less than zero and thus no brine is available in a mobile form to be released. Figure 5-31 shows a high concentration of results that are near a line extending from (8 MPa, 0 m^3) to (12 MPa, 30 m^3). As mobile saturation increases, the correlation between pressure and DBR volumes also increases.

To further facilitate comparisons of DBRs calculated in the PC3R PA to those obtained in the PABC-2009, the overall mean CCDFs obtained in these two analyses are plotted simultaneously in Figure 5-32. As seen in that figure, the CCDF curves obtained for direct brine releases in the

PABC-2009 and the PC3R PA are very similar. For releases up to roughly 0.1 EPA units, the CCDF curves obtained in both analyses are virtually identical. For releases between 0.1 and 1 EPA unit, the CCDF curve obtained in the PC3R PA is slightly above that calculated in the PABC-2009. For releases greater than 1 EPA unit, the CCDF curve obtained in the PABC-2009 is higher than that obtained in the PC3R PA. The decrease in the number of realizations with a nonzero DBR volume in the PC3R PA combined with the slight increase in the maximum DBR volume is most likely the cause for the differences observed in the DBR CCDF curves obtained in the PABC-2009 and the PC3R PA.

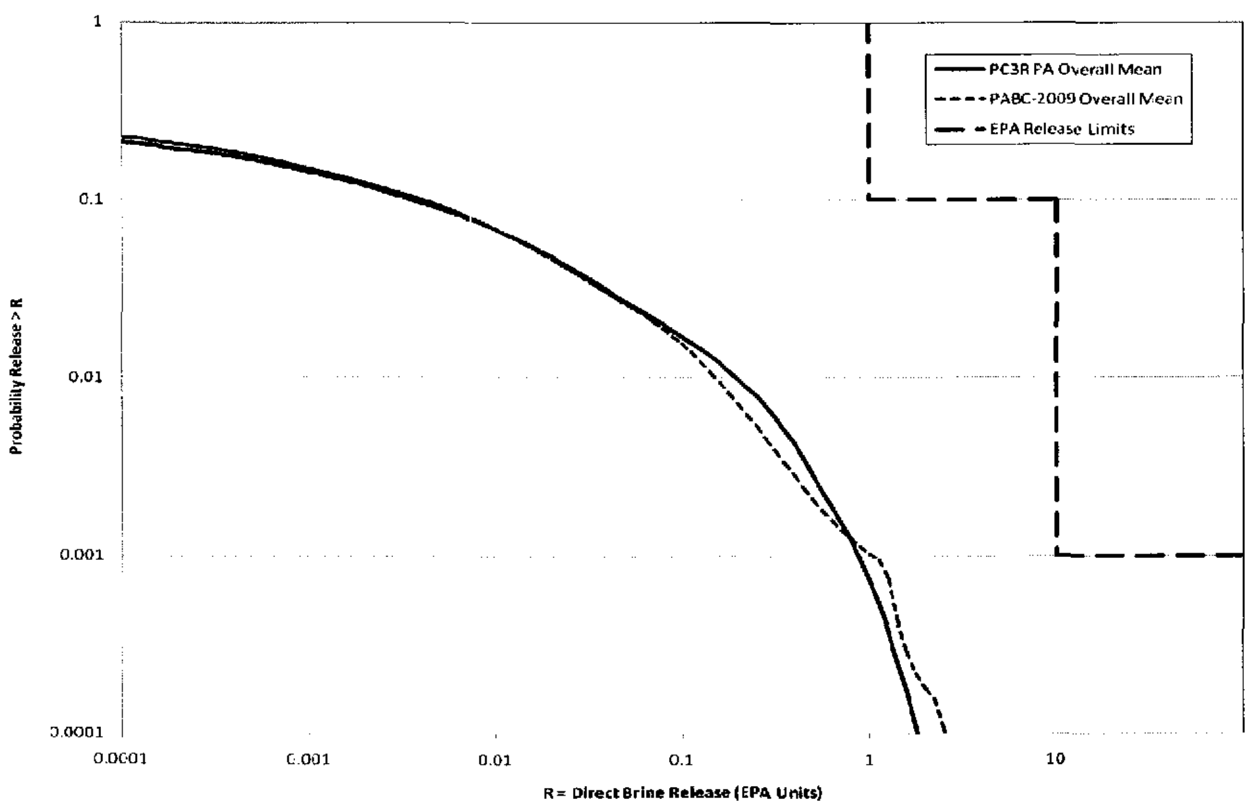

Figure 5-32: PC3R PA and PABC-2009 Overall Mean CCDFs for Normalized Direct Brine Releases

5.7 Total Normalized Releases

Total normalized releases for PC3R PA are presented in this section and subsequently compared to results obtained in the PABC-2009. 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 transport releases. As prescribed in AP-151 (Camphouse 2010a), transport results obtained in the PABC-2009 were used in the PC3R PA. PC3R PA CCDFs for total releases are presented in Figure 5-33, Figure 5-34, and Figure 5-35 for replicates 1, 2, and 3, respectively. Mean and quantile CCDF distributions for the three replicates are shown together in Figure 5-36. Figure 5-37 contains the 95 percent confidence limits about the overall mean of total releases. As seen in Figure 5-37, the overall mean for normalized total releases and its lower/upper 95% confidence limits are well below acceptable release limits. As a result, the panel closure design and repository configuration changes investigated in the PC3R PA do no result in WIPP non-compliance with the containment requirements of 40 CFR Part 191.

PC3R PA and PABC-2009 overall mean CCDFs for total releases are shown together in Figure 5-38. As seen in that figure, the overall mean CCDFs obtained in the two analyses are virtually identical for release values less than approximately 0.1 EPA units. For releases between 0.1 and 1.0 EPA units, the overall total release mean CCDF curve obtained in the PC3R PA is slightly above that calculated in the PABC-2009. For releases greater than 1 EPA unit, the CCDF curve obtained in the PABC-2009 is higher than that found in the PC3R PA. These trends correspond exactly to the differences found for direct brine releases between the two analyses as discussed in Section 5.6 and illustrated in Figure 5-32. Indeed, as seen in Figure 5-39, cuttings and cavings releases and direct brine releases are the two primary release components contributing to total releases found in the PC3R PA. PC3R PA cuttings and cavings results are unchanged from those found in the PABC-2009. The panel closure design and repository configuration changes investigated in the PC3R PA have a slight impact on direct brine releases. The changes in the overall mean of total releases from the PABC-2009 to the PC3R PA are due to the changes in direct brine releases calculated in those analyses.

A comparison of the statistics on the overall mean for total normalized releases obtained in the PC3R PA and the PABC-2009 can be seen in Table 11. At a probability of 0.1, values obtained for mean total releases are identical in both analyses. At a probability of 0.001, the decrease in DBRs seen at that probability in the PC3R PA result in a decrease in the mean total release by approximately 0.21 EPA units. Reductions are also seen in the 90th percentile and the 95% confidence limits when compared to the PABC-2009 results.

Table 11: PC3R PA and PABC-2009 Statistics on the Overall Mean for Total Normalized Releases in EPA Units at Probabilities of 0.1 and 0.001

Probability	Analysis	Mean Total Release	90th Percentile	Lower 95% CL	Upper 95% CL	Release Limit
0.1	PC3R PA	0.09	0.16	0.09	0.10	1
	PABC-2009	0.09	0.16	0.09	0.10	1
0.001	PC3R PA	0.89	1.00	0.34	1.41	10
	PABC-2009	1.10	1.00	0.37	1.77	10

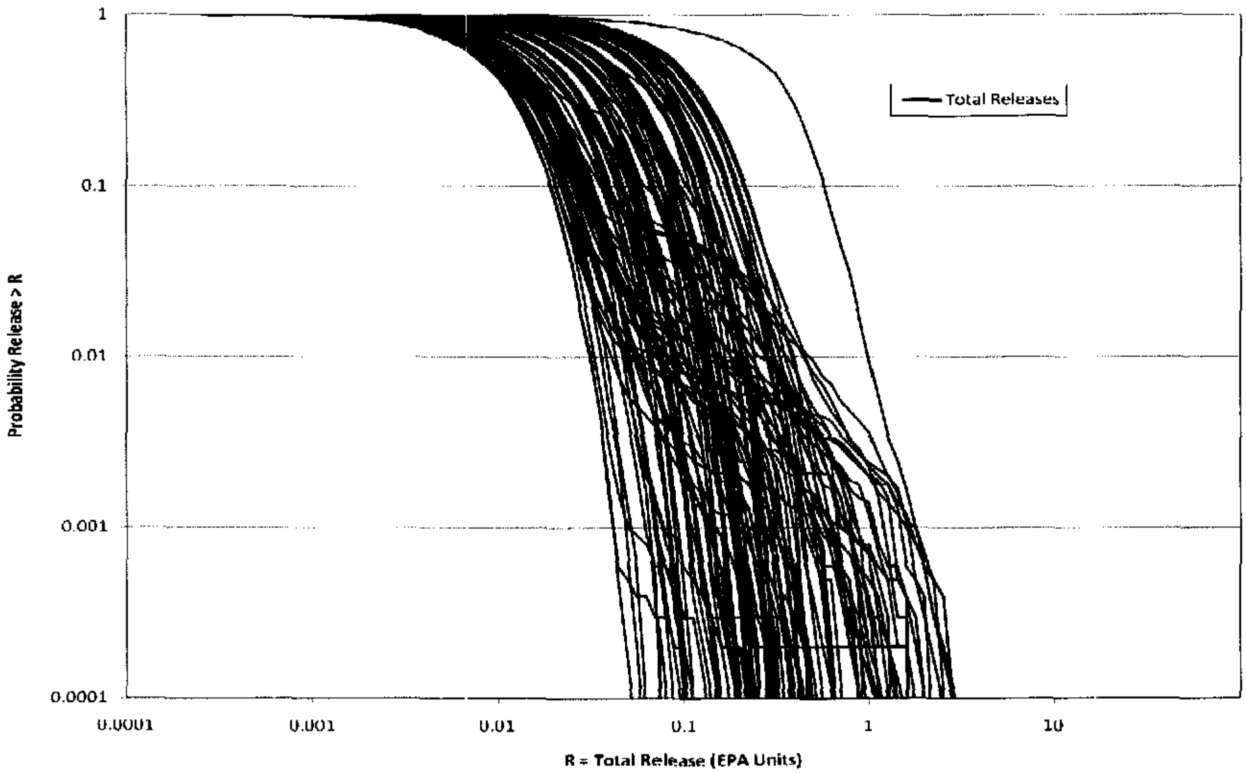

Figure 5-33: PC3R PA Replicate 1 Total Normalized Releases

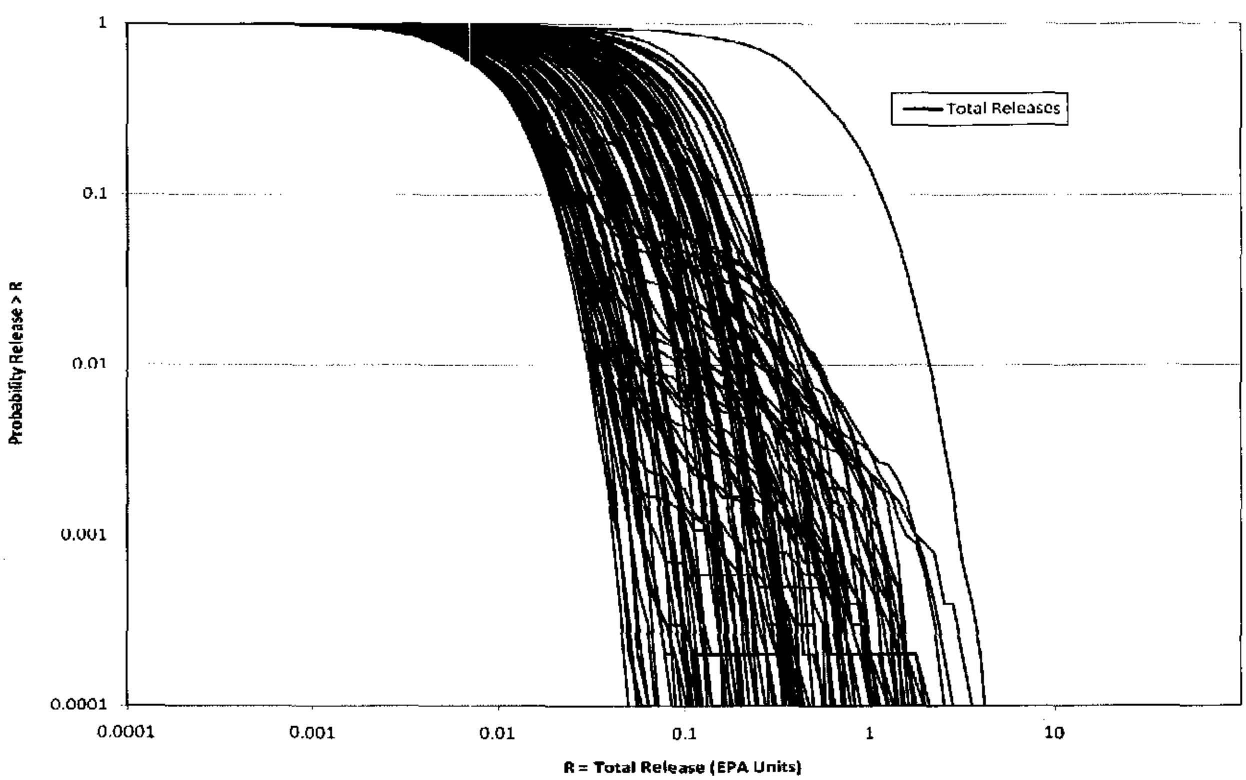

Figure 5-34: PC3R PA Replicate 2 Total Normalized Releases

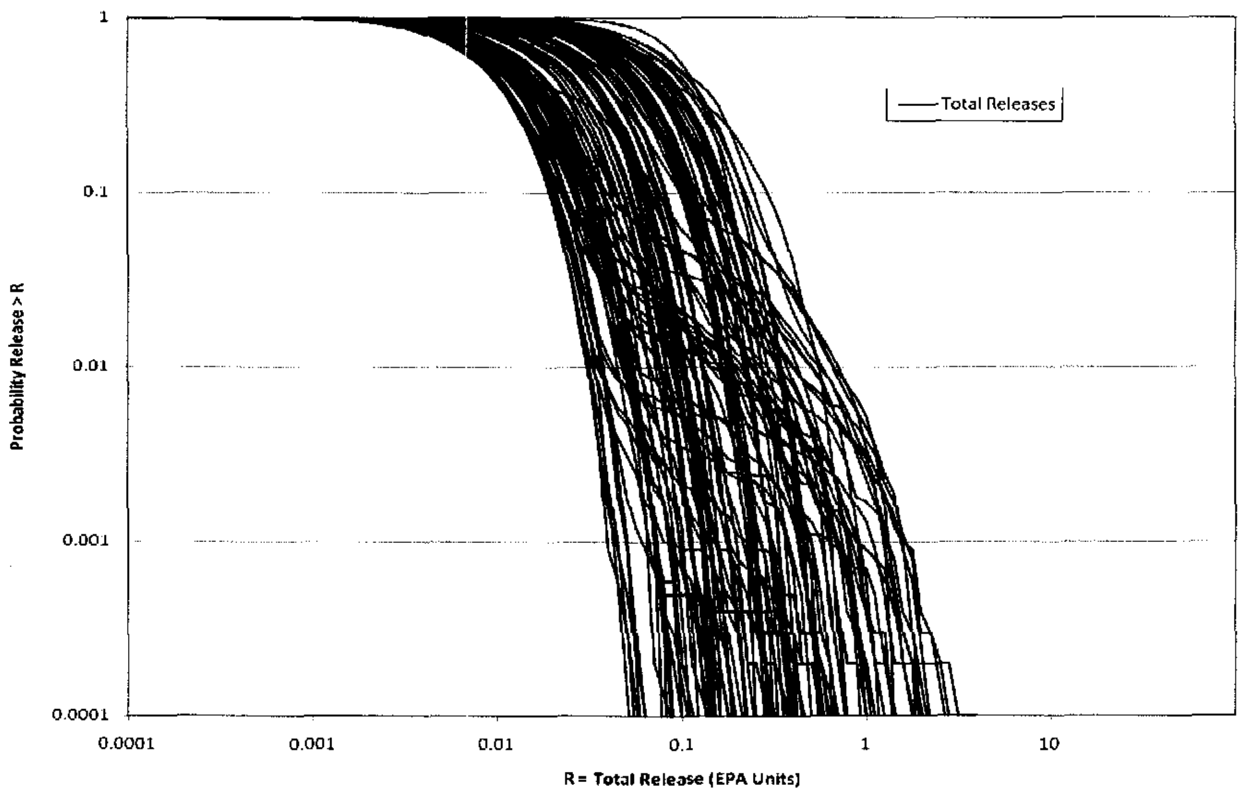

Figure 5-35: PC3R PA Replicate 3 Total Normalized Releases

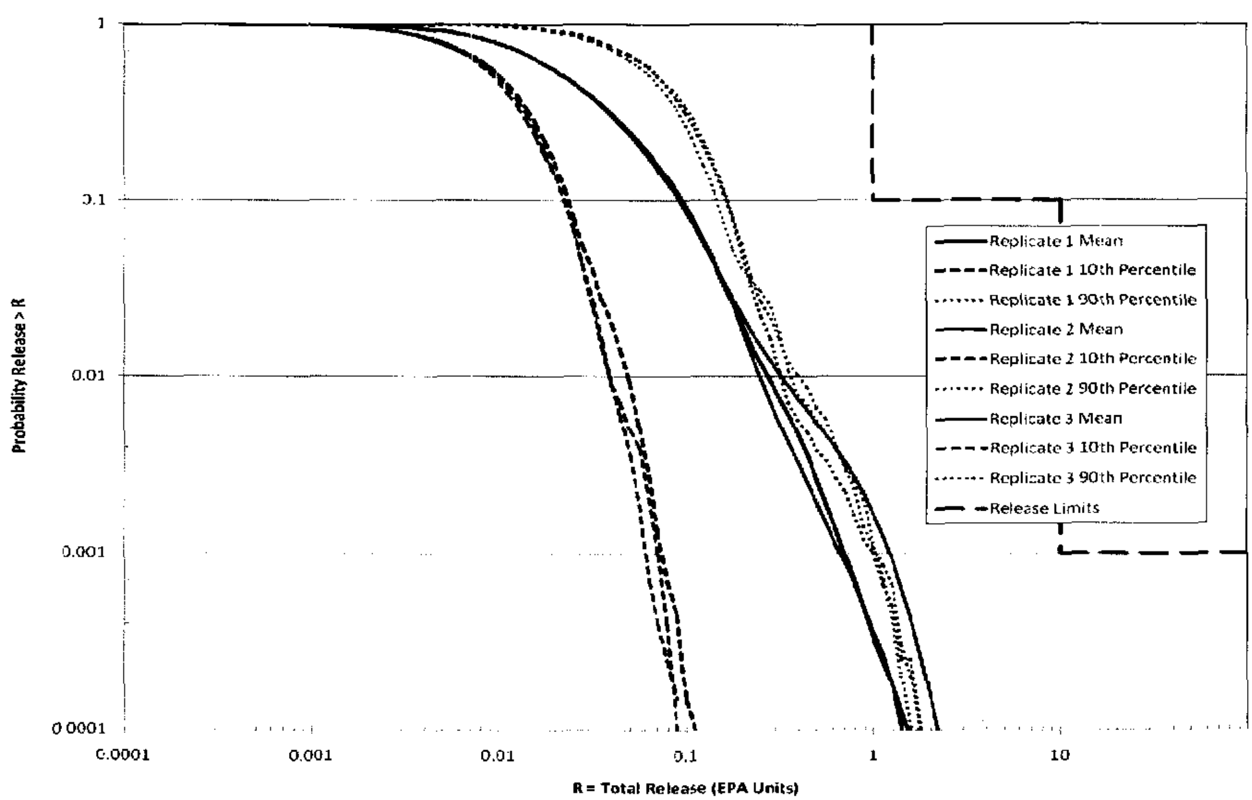

Figure 5-36: PC3R PA Mean and Quantile CCDFs for Total Normalized Releases, Replicates 1-3

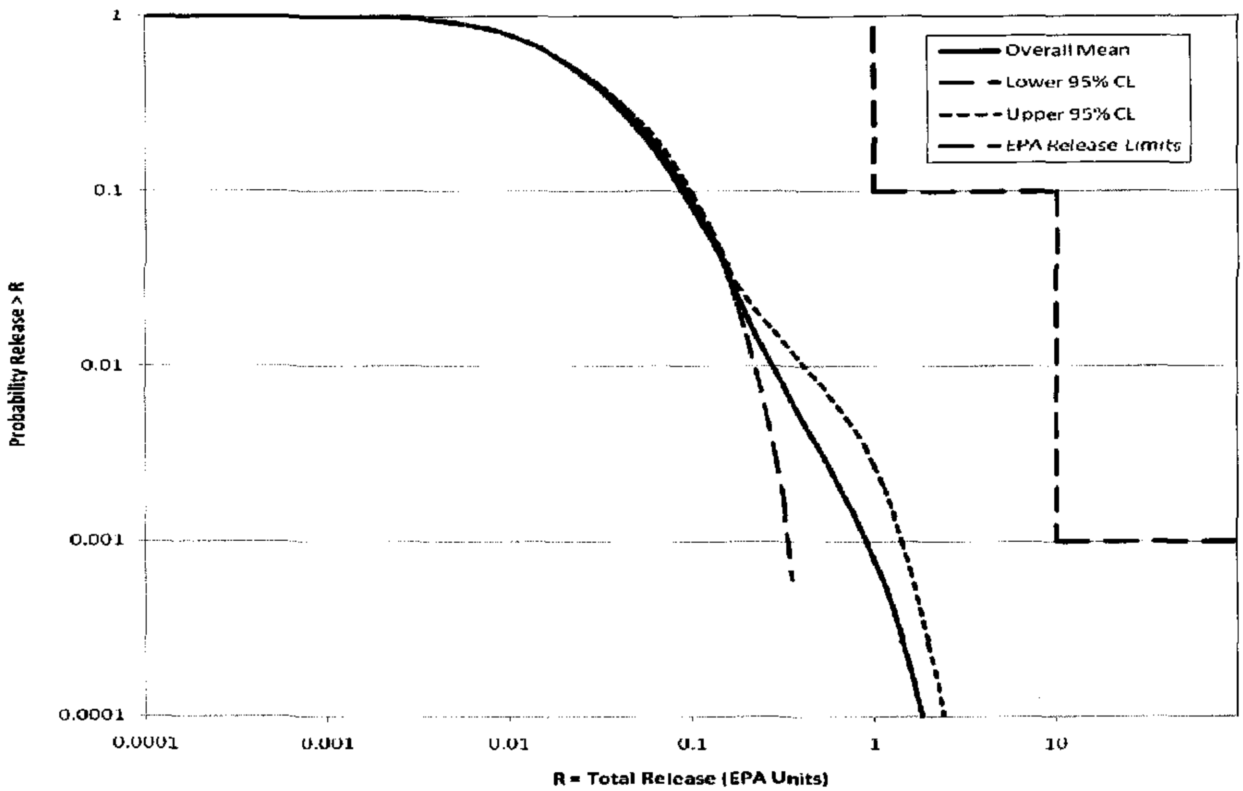

Figure 5-37: PC3R PA Confidence Limits on Overall Mean for Total Normalized Releases

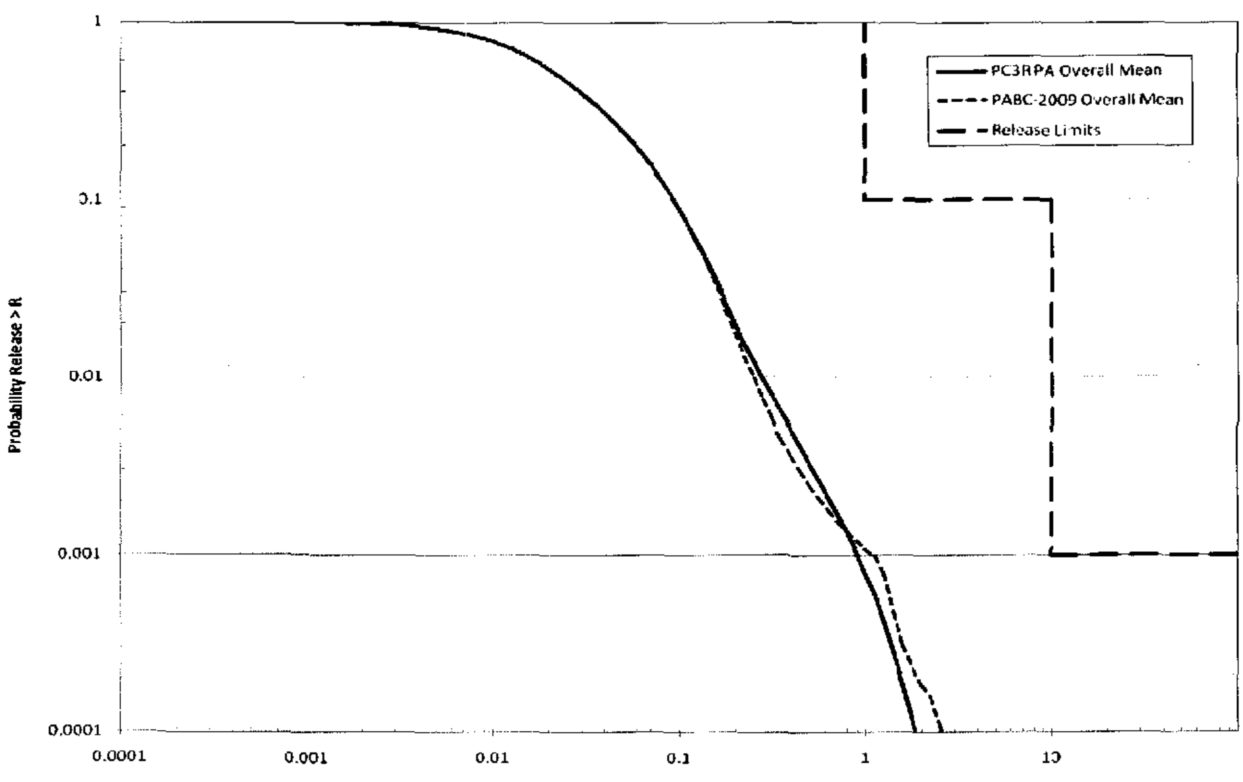

Figure 5-38: PC3R PA and PABC-2009 Overall Mean CCDFs for Total Normalized Releases

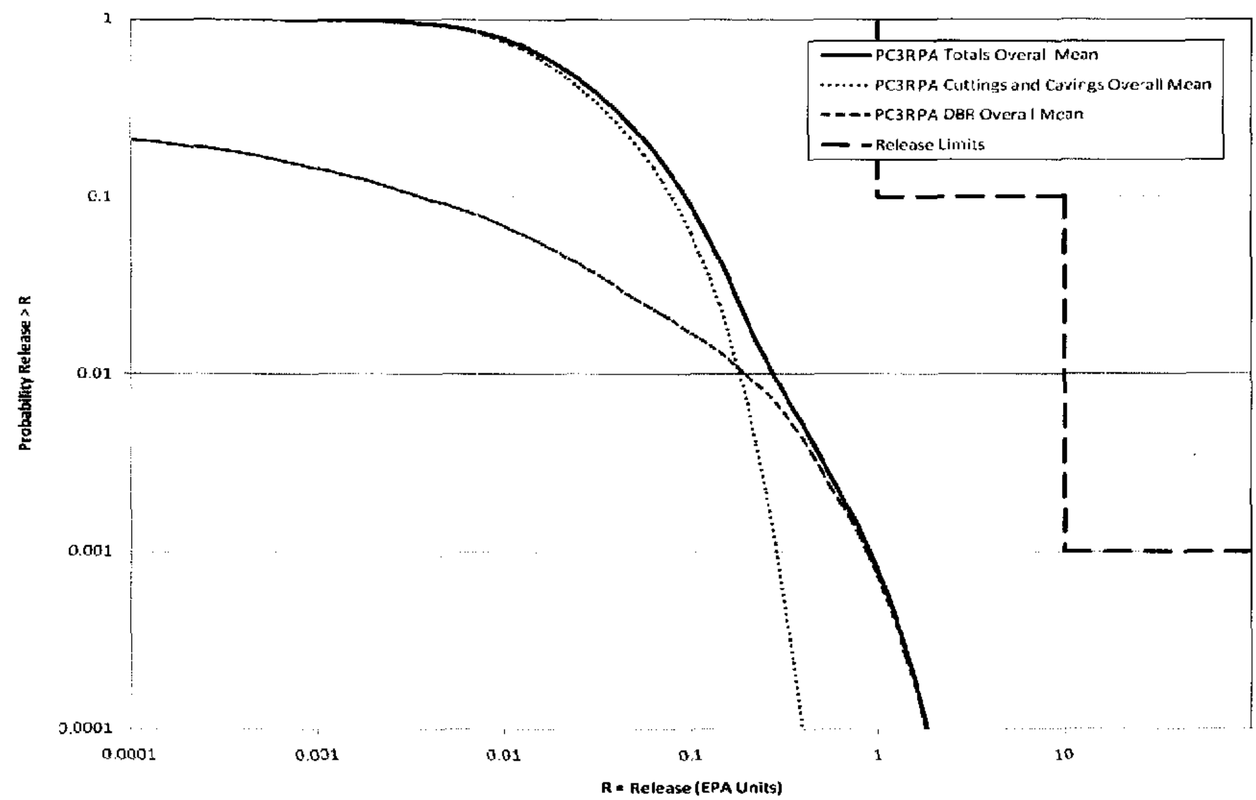

Figure 5-39: PC3R PA Primary Components Contributing to Total Releases

6 SUMMARY

Total normalized releases calculated in the PC3R PA remain below their regulatory limits. As a result, the panel closure design and repository configuration changes investigated in the PC3R PA would not result in WIPP non-compliance with the containment requirements of 40 CFR Part 191. Cuttings and cavings releases and direct brine releases are the two primary release components contributing to total releases in the PC3R PA. Cuttings and cavings releases are unchanged from those calculated in the PABC-2009. Changes in total releases are attributed to changes calculated in direct brine releases from the PABC-2009 to the PC3R PA. Differences are observed in PC3R PA spallings releases as compared to the PABC-2009, but these differences are relatively minor and do not have a significant impact on the overall total normalized releases found in the PC3R PA.

Several conclusions can be made regarding the impact of the panel closure redesign, the open central drift region, and the placement of panel closures in the reconfigured repository. Most significant among these are the following:

- The combination of initially high panel closure permeability and comparatively low pressure in the central drift region allows for pressure release from the waste regions into the central drift area until the panel closures attain their steady-state permeability values at 100 years.

- The reconfigured repository and the redesigned panel closures implemented therein do not result in an increase in brine flow out of the waste regions when compared to the PABC-2009.
- The redesigned panel closures in combination with their placement in the repository reconfiguration effectively limit the impacts of drilling intrusion to the region being intruded. In particular, the brine available for release to the surface during a drilling event into the central drift region is equal to that present under undisturbed conditions, even if there have been prior intrusions into a waste panel.

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Camphouse, Russell Chris

From: Clayton, Daniel James
Sent: Tuesday, April 05, 2011 1:37 PM
To: Camphouse, Russell Chris
Subject: RE: sig authority

I give R. Chris Camphouse signature authority for the PC3R PA summary report

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From: Camphouse, Russell Chris
Sent: Tuesday, April 05, 2011 1:36 PM
To: Clayton, Daniel James
Subject: sig authority

Hi Dan,

Can you send someone signature authority for the title page of the summary report?

Thanks,

Chris

--------------rccamph@sandia.gov------------------
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Carlsbad Programs Group
Performance Assessment and Decision Analysis Department

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