DOE/CBFO-11-3479

Panel Closure System Design

Planned Change Request to the

EPA 40 CFR Part 194 Certification of

the Waste Isolation Pilot Plant

September 26, 2011

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Acronyms

CBFO	Carlsbad Field Office
CCA	*Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant* (DOE, 1996)
CCDF	Complementary Cumulative Distribution Function
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
DRZ	Disturbed Rock Zone
EPA	U.S. Environmental Protection Agency
NMED	New Mexico Environment Department
OPC	Ordinary Portland Cement
PA	Performance Assessment
PABC	Performance Assessment Baseline Calculations
PAVT	Performance Assessment Verification Test
PCS	Panel Closure System
PCR	Planned Change Request
PC3R	Panel Closure Redesign and Repository Reconfiguration Performance Assessment
RCRA	Resource Conservation and Recovery Act
ROM	Run-of-Mine
ROMPC	Run-of-Mine Panel Closure
SMC	Salado Mass Concrete
TRU	Transuranic
VOC	Volatile Organic Compound
WIPP	Waste Isolation Pilot Plant

Glossary of Terms

40 CFR Part 191	Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule (EPA, 1993).
40 CFR Part 194	Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations: Certification Decision; Final Rule (EPA, 1998a).
Certification	Any action taken by the Administrator of the U.S. Environmental Protection Agency under Section 8(d) of the Waste Isolation Pilot Plant Land Withdrawal Act.
Run-of-mine (ROM) salt	Salt produced from mining operations in the WIPP facility underground without undergoing any additional treatment.

Executive Summary

The U.S. Department of Energy (DOE) Carlsbad Field Office (CBFO) requests that the U.S. Environmental Protection Agency (EPA) modify Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194 (EPA, 1998a). This condition specifies that the Panel Closure System (PCS) to be used in the Waste Isolation Pilot Plant (WIPP) repository should be the one designated as "Option D" in the Compliance Certification Application (CCA) (DOE, 1996), and that the concrete components of that closure should be constructed using Salado Mass Concrete (SMC). In the 12 years since the WIPP facility commenced waste handling operations the DOE has acquired considerable experience in the behavior of the underground, and in the nature and behavior of disposed transuranic (TRU) waste, including the potential for generation of explosive gases. In addition large scale testing has demonstrated that SMC cannot meet the design requirements for the closure as specified in the original certification application (WTS, 2003). The DOE has established a revised design which is much simpler and easier to construct. Accordingly the DOE is requesting that Condition 1 be changed, and that the new closure design be approved for use in all panels.

The DOE is making this proposal based on the following rationale:

The primary purpose of the PCS is to meet the Resource Conservation and Recovery Act (RCRA) requirements for closure of a disposal unit as defined in the WIPP Hazardous Waste Facility Permit (Permit). As noted in the CCA (Section 3.3.2), "Panel closures have been included for the purpose of Resource Conservation and Recovery Act (RCRA) disposal unit closure and to prevent potentially unacceptable levels of volatile organic compound release during waste management operations."

The panel closure system was not designed or intended to support long-term repository performance. However it is important to be able to represent the long-term behavior of the closure system in performance assessment (PA) calculations, in so far as it affects the flow of brine between waste panels under the various PA scenarios.

Attempts to develop SMC have shown that the material as specified did not meet the performance requirements laid out in the design specifications (WTS, 2003).

The simpler design will meet the same operational performance requirements of the Option D closure and will be simpler construction, will have less adverse impact on waste disposal operations and will be less expensive to construct.

The analyses provided with this planned change request (PCR) demonstrate that long-term releases are insensitive to a broad range of panel closure permeabilities, and that the impact of the proposed new closure design on long-term performance is negligible.

The revised design, known as the Run-of-Mine Panel Closure (ROMPC) comprises 100 ft of run-of-mine (ROM) salt backfill placed between two typical underground bulkheads. The construction methods and materials to be used to implement the design have been proven in previous mining and construction projects. The fabrication, installation, and maintenance of bulkheads are standard mining practices. The ROM salt backfill will be pushed up tight to all salt surfaces of the drifts, including the back or roof. Over time creep closure of the drifts will cause the salt backfill to consolidate to a condition approaching intact salt with a low permeability.

Performance Assessment (PA) results demonstrate that the long-term performance of the revised design will be essentially the same as that to be expected from the Option D closure. Based on an analysis of creep and salt consolidation data, the permeability of the ROMPC is expected to fall within the range analyzed in earlier PAs. That is the short-term permeability might be high, but after 100 years, as the salt backfill consolidates further under the influence of creep closure of the entries, the permeability will approach that assumed for the Option D closure. A recent PA termed the Panel Closure Redesign and Repository Reconfiguration Performance Assessment (PC3R) has been run which combines a proposed reconfiguration of the repository as well as the modified panel closure system. Comparison of the PC3R results with that included in the most recent recertification (PABC-2009; DOE, 2009) indicated that the overall mean complimentary cumulative distribution functions (CCDF) obtained in the two analyses are virtually identical. The panel closure design and repository configuration changes investigated in the PC3R PA therefore have only a very minor impact on performance. It is also noted that the results of an earlier impact analysis in which a panel closure system consisting of 100 ft of ROM salt and a 30 ft explosion wall give a similar result (Vugrin and Dunagan, 2006). In this PA it was assumed that the explosion wall had no influence on long-term permeability which was given the same values as in PC3R. These results indicated that without the reconfiguration included in the PC3R PA the change in panel closure design had only a minor effect on long-term performance.

Based on these analyses and results, the DOE is requesting that the EPA remove Condition 1 as presented in the Final Rule (EPA, 1998a), and accept the revised design for panel closures as described herein.

1.0 Introduction

The U.S. Department of Energy (DOE) Carlsbad Field Office (CBFO) is submitting this Planned Change Request (PCR) to the U.S. Environmental Protection Agency (EPA) to request modification of Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194.

Specifically, the Final Certification Rulemaking, Appendix A (EPA, 1998a), states:

In accordance with the Agency's authority under 194.4(a), the certification of compliance is subject to the following conditions:

Condition 1: 194.14(b), Disposal system design, panel closure system. The Department shall implement the panel seal design designated as Option D in Docket A-93-02, Item II-G-1 (October 29, 1996, Compliance Certification Application submitted to the Agency). The Option D design shall be implemented as described in Appendix PCS of Docket A-93-02, Item II-G-1, with the exception that the Department shall use Salado mass concrete (consistent with that proposed for the shaft seal system, and as described in Appendix SEAL of Docket A-93-02, Item II-G-1) instead of fresh water concrete.

The Option D closure consists of the installation of a concrete block explosion isolation wall, removal of the majority of the disturbed rock zone (DRZ) in the area of the closure, and emplacement of a large Salado Mass Concrete (SMC) monolith. This closure would be installed in each panel of the repository after waste emplacement in that panel is completed.

In addition to specifying the use of the "Option D" Panel Closure System (PCS) design in Condition 1, the EPA allowed the DOE to revisit the design of the PCS. Specifically, in the preamble to the Final Certification Rulemaking (EPA, 1998a), the EPA stated:

Nothing in this condition precludes DOE from reassessing the engineering of the panel seals at any time. Should DOE determine at any time that improvements in materials or construction techniques warrant changes to the panel seal design, DOE must inform EPA. If EPA concurs, and determines that such changes constitute a significant departure from the design on which certification is based, the Agency is authorized under 194.65 to initiate a rulemaking to appropriately modify the certification.

Based upon 12 years of experience in the disposal of waste in the underground, including observation and monitoring of the behavior of active and closed panels, together with engineering issues associated with Option D closure construction with SMC, the DOE has reassessed the engineering of the panel closure. As a result, the DOE has developed an alternate design which will not have an effect on the long-term performance of the repository, and will meet the requirements of the New Mexico Environment Department (NMED) in regard to operational period performance. Additionally, this new design will be simpler and can be installed at a significantly lower cost than the currently approved design. Accordingly, the DOE is requesting that this revised design be approved and Condition 1 of the 1998 Certification Decision be modified as appropriate.

The revised panel closure design, known as the Run-of-Mine Panel Closure System (ROMPC), was developed as part of CBFO's ongoing review of engineering aspects of the repository. The design involves the use of bulkheads at either end of a 100 foot backfill comprised of run-of-mine (ROM) salt. The ROM salt backfill will be pushed up tight to all salt surfaces of the drifts, including the back or roof.

Section 2.0 of this request provides a description of the nature and scope of the proposed change to the design of the closure system. Section 3.0 provides an analysis of the long-term performance of the repository using this design, and discusses the results of recent performance assessment (PA) calculations which evaluate this performance. The analyses provided with this request demonstrate that long-term repository releases are unchanged over a broad range of panel closure permeabilities, and that the impact of the proposed new closure design on long-term performance is negligible relative to the performance of the Option D design.

In addition, three attachments are included with this request. Attachment A, *Radiolytic Hydrogen Generation and Methanogenesis in WIPP: An Empirical Point of View* summarizes monitoring data from closed panels, and Attachment B, *Effective Permeability of the Redesigned Panel Closure*, describes the expected behavior of the ROMPC in the context of the modeling results. Attachment C, *Summary Report for the AP-151 (PC3R) Performance Assessment Revision 1*, provides the results of the recent PA calculations conducted to demonstrate the performance of this closure.

1.1 PCS Background

The Compliance Certification Application (CCA: DOE, 1996) in Chapter 3 and Appendix PCS established the purpose of installing panel closures. The introduction to the facility description in Chapter 3 states,

> *The DOE will close each panel of waste with a panel closure system to provide for operational protection of workers, the public, and the environment from emplaced waste.*

In addition, Section 3.3.2 states:

> *Panel closures have been included for the purpose of Resource Conservation and Recovery Act (RCRA) disposal unit closure and to prevent potentially unacceptable levels of volatile organic compound release during waste management operations. The panel closure system was not designed or intended to support long-term repository performance.*

In the design report included in the CCA as Appendix PCS several designs were presented (Options A – D). These designs were to be used depending on the age and condition of the panel entries. The design report specified the use of Ordinary Portland Cement (OPC) for the concrete elements, but allowed the use of Salado Mass Concrete (SMC) as an option. SMC is a salt saturated concrete developed for use in the Shaft Seals and described in Appendix SEAL of the CCA. As noted above, in its Final Rule (EPA, 1998a) the EPA specified the use of Option D for all closures, and also the use of SMC rather than OPC.

During a series of test pours, it was determined that SMC as formulated would not be able to meet the specification requirements in the design report (WTS, 2003). As a result the DOE has, with the approval of EPA and NMED, emplaced temporary closures in various filled panels while gathering information for a revised final closure. Panels 1 and 2 have used the explosion wall component from Option D, combined with periodic monitoring and assessment of the closure performance. Panels 3 – 4 use a simpler temporary closure comprising a ventilation bulkhead and a substantial barrier. These simpler closures have been used, again with the approval of EPA and NMED, to allow monitoring of potential explosive gas generation in the closed panels. This monitoring has established that the measured concentrations of methane and hydrogen are far below the minimum explosive concentrations for these gases, thereby allowing simplification of the design which is presented here (Attachment A). Panel 5 is currently undergoing closure, beginning with the explosion wall component. Option D continues to be the WIPP baseline panel closure design while the EPA considers this PCR.

2.0 Nature and Scope of This Request

2.1 Scope of the Proposed Design Change

The proposed design change presented here affects only the design of the panel closure system, as detailed in Condition 1 of the Final Certification (EPA, 1998a) and in the Permit (NMED, 2010) issued by the NMED. Condition 1 currently prescribes the installation of Option D with SMC. This design consists of emplacing a 12-foot concrete block explosion wall, removing most of the DRZ in the area of the closure, and emplacing a large concrete monolith (26 feet long). The concrete monolith would be keyed into the surrounding salt and the upper concrete/salt interface would be grouted. Figure 1 is a schematic representation of Option D provided in the CCA, Attachment PCS (DOE, 1996).

During the time since the initial certification of the WIPP facility, the DOE has reviewed various aspects of the required design and as a result has developed a new design which will be, easier to install, and less expensive while still achieving the performance objectives of protecting workers, the public and the environment. Information developed during this period include the testing of the SMC formulation specified in the CCA, Appendix SEAL and the development of a monitoring program to establish whether explosive concentrations of gas could develop in closed panels. The SMC testing (WTS, 2003) showed that the material as specified could not meet the performance requirements outlined in Appendix PCS, while the gas monitoring has shown that neither methane nor hydrogen concentrations approach anywhere near the lower explosive limits of these gases (Attachment A). Specifics of the rationale for the design change are given in the next section.

As a result of these activities, as well as the monitoring of the repository performance during its 12 years of operation, it has been determined that a simpler design is appropriate, and will be equally effective in meeting the performance requirements of the closure system. The ROMPC, shown in Figure 2, has two components: two bulkheads and a ROM salt backfill. The construction methods and materials to be used to implement the design have been proven in previous mining and construction projects. The ROM salt backfill will be pushed up to be in contact with the salt surfaces of the drifts, including the back or roof. A variety of techniques are available for placing the ROM salt. The bulk of the salt can be placed using load-haul-dump units and final placement against the back could use flingers or blowers. The ROM salt will be placed until the entire drift is filled over a minimum distance of 100 feet. Over time, creep closure of the drifts will ensure that the salt backfill consolidates to a condition approaching intact salt with a low permeability (Attachment B). The fabrication, installation, and maintenance of ventilation bulkheads, such as those proposed for the closure, are standard practices at the WIPP facility.

2.2 Rationale for the Proposed Request

The CBFO is making this proposal based on the following rationale:

The primary purpose of the PCS is to control volatile organic compound (VOC) emissions during the operational life of the facility. The panel closure system was not designed or intended to support long-term repository performance. However it is important to be able to represent the long-term behavior of the closure system in performance assessment (PA) calculations, in so far as it affects the flow of brine between waste panels under the various PA scenarios.

Attempts to develop SMC have shown that the material as specified did not meet the performance requirements in Appendix PCS if prepared according to the specifications in Appendix SEAL (WTS, 2003).

An evaluation of the construction means and methods required to emplace Option D have determined that it will be hazardous to those involved in its construction, while the proposed simpler design will meet the same operational performance requirements of this closure (NMED Attachment G, see G-1e(1)).

The design of the ROMPC reduces complexity, enhances constructability, reduces the impacts on on-going repository operations, and reduces construction cost.

The analyses provided with this request, discussed in Section 3, and Attachment C, demonstrate that long-term releases are insensitive to a broad range of panel closure permeabilities, and that the impact of the proposed new closure design on long-term performance is negligible relative to the performance of the Option D design.

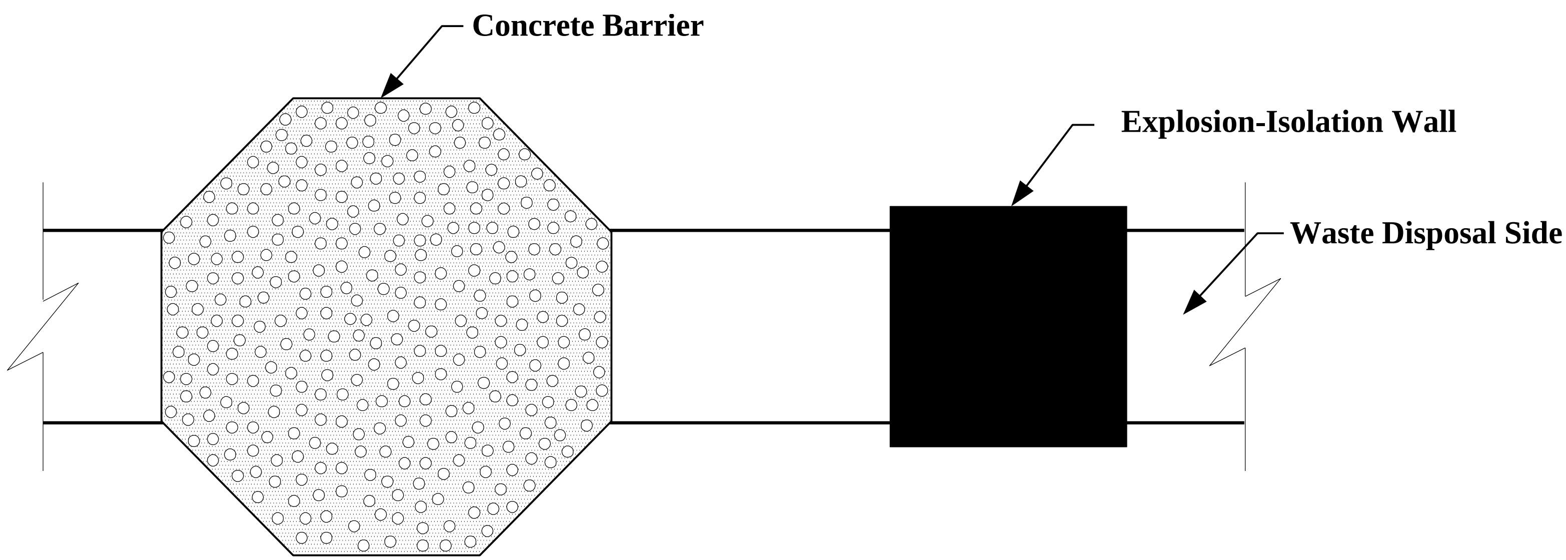

Figure 1. Option D Panel Closure System

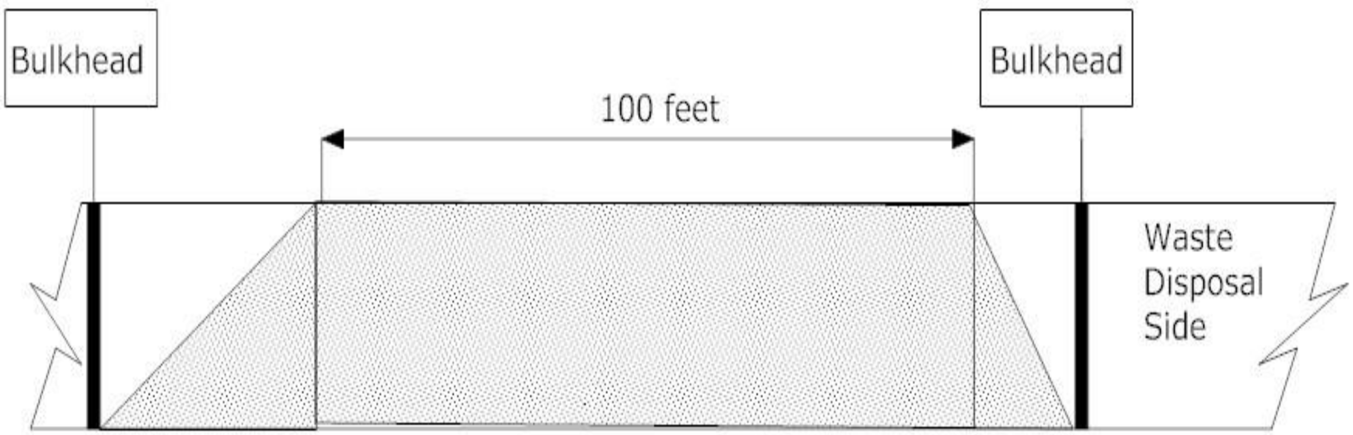

Figure 2: Proposed Run of Mine Panel Closure

3.0 Long-Term Performance of the ROMPC

3.1 Earlier Panel Closure Investigations

During the certification process in 1996 for the CCA, the CBFO used a model for the PA calculations with equal panel closure and DRZ permeability of 10^{-15} m^2 to demonstrate compliance with 40 CFR Part 191, Subparts B and C. As part of the EPA certification decision, a second EPA-mandated PA was run, the Performance Assessment Verification Test (PAVT) (McKinnon and Freeze, 1997a and 1997b) in which the panel closure retained a permeability of 10^{-15} m^2, but the DRZ was represented by a permeability which could vary between $10^{-12.5}$ and $10^{-19.4}$ m^2. The Option D panel closure design, mandated by EPA in Condition 1 of its certification of the WIPP in 1998, was not explicitly represented in the PA for the CCA or for the PAVT.

The Option D panel closure was introduced explicitly in an impact assessment in 2002 (Hansen, 2002). This assessment analyzed the panel closure's effects on repository performance. In this analysis, two panel closure cases were considered: one case represented the mandated Option D panel closure design, and a second case is based on the generic panel closure included in the PAs conducted for the CCA and the PAVT. The primary distinction between these two panel closure cases is the permeability of the panel closure material, which is quite low in the case of the Option D panel closure to fairly permeable in the CCA and PAVT panel closure case.

This impact assessment used the PAVT grid and developed an effective permeability for the panel closure. This effective permeability is a combination of the permeability for the concrete monolith and the open drift/explosion wall permeabilities surrounding the monolith. The concrete permeability was assigned a constant value equal to the mode of the distribution for SMC, 1.78 x 10^{-19} m^2. The effective permeabilities, the porosity, and the initial brine saturation of the two closures are shown in Table 1. It was found that releases for the Option D panel closure case and for the CCA/PAVT panel closures were nearly identical. This analysis concluded that releases from the repository were not sensitive to the permeability of the panel closures (Hansen 2002, Executive Summary).

Table 1. Effective Panel Closure Properties for the Panel Closure Impact Assessment.

Parameter	CCA/PAVT Closure	Option D Closure
Permeability (along the drift)	10^{-15} m^2	9.01 x 10^{-19} m^2
Permeability (perpendicular to the drift)	10^{-15} m^2	1.93 x 10^{-13} m^2
Porosity	0.075	0.15
Initial Brine Saturation	0.99	0.21

The results of this modeling established the long-term performance of the repository within a broad range of permeabilities for different panel closure configurations. Modeling completed with the Option D design represents a low-permeability closure, and the original PA results for the CCA and PAVT represented a high-permeability closure.

Based on an analysis of creep closure and salt consolidation data (Attachment B), the long-term permeability of the ROMPC is expected to fall near a value analyzed in the impact assessment. Within the first 100 years after closure installation, the effective permeability would be relatively high, but after 100 years, as the salt backfill consolidates further under the influence of creep closure of the entries, the permeability will fall near the value assumed for the Option D closure in the 2002 PA. For this reason the influence of the ROMPC design on long-term repository performance is expected to be negligible, similar to the results for other closure designs assumed in earlier PAs. This result is again confirmed by the most recent PA calculations, as discussed below.

3.2 Recent PA Analysis

The DOE is in the process of submitting two PCRs to the EPA that propose changes to the repository. The first PCR is that discussed here, centered on the new design of the WIPP panel closure system. The second PCR (DOE, 2011) 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 panel closures installed only at the end of filled waste panels. In order to evaluate the effects of these changes on long-term performance, the DOE has conducted a single PA, called the PC3R 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 normalized releases and probabilities to those calculated in the current PA baseline from the second recertification application (DOE, 2009), called the Performance Assessment Baseline Calculation-2009 (PABC-2009) (Clayton et. al., 2009). The results from the PC3R PA and a comparison with the PABC-2009 are discussed in Camphouse et al., 2011 "*Summary Report for the AP-151 (PC3R) Performance Assessment, Revision 1"* which is included as Attachment C, and the results are briefly summarized here.

In the PC3R PA Panels 9 and 10 are relocated south of panels 4 and 5 and are denoted as panels 9A and 10A. This new configuration is shown in Figure 3. In addition to this reconfiguration, the PC3R PA changes the representation of the panel closures for panels 1through 8, 9A, and 10A. Panel closures are proposed to be modified from the current "Option D" design to that of a new design consisting of 100 feet of ROM salt emplaced in front of a bulkhead on the waste disposal side. The majority of PC3R PA parameter changes are due to the changes in the panel closure design, as discussed below.

The PC3R PA representation of the panel closure system has initial and short-term permeabilities and porosities that are significantly different from the permeabilities and porosities expected to be present for the vast majority of the 10,000 year regulatory timeframe. The short-term permeability of the panel closures is assumed to be controlled by the bulkheads at either end of the ROM salt backfill, and will have a high value, assumed to be 10^{-11} m^2. It is assumed that this permeability value will remain in effect for an initial time period of 100 years after closure. This initial time period is selected to be consistent with the length of time required for the porosity of the ROM salt used in the panel closures to consolidate to less than 5 percent, and is based on numerical simulations which have demonstrated 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 impact assessment for the 2002 panel closure redesign (Hansen and Thompson, 2002: Attachment B).

The permeability of the panel closure after 100 years is assumed to have decreased significantly due to the consolidation of the ROM salt driven by the creep closure of the entries. The values used for this permeability have been based on a panel closure redesign impact assessment performed in 2006 (Vugrin and Dunagan, 2006). In that analysis, the panel closure design consisted of 100 feet of ROM salt emplaced against a 30-foot mortared, solid concrete block wall on the waste disposal side. The parameter distributions for the long-term permeability of the ROM salt component developed during the impact assessment in 2006 (Vugrin, Hansen, and Thompson, 2006) are used to describe the long-term permeability of the panel closure implemented in the PC3R PA. The resulting probability distribution is shown in Table 2.

The value for permeability of the portion of the DRZ directly above and below the panel closure system is based on the analysis of Stein (2002). In the PC3R analysis the properties of this portion of the DRZ were prescribed 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 ROM salt panel closures are reconsolidating, it is assumed that the DRZ directly above and below the panel closure is unaffected by the changing panel closure properties. Values used in this time frame are given in Table 2. After the first 100 years, permeability values of the DRZ above and below the panel closure are prescribed so as to be consistent with the permeabilities of the reconsolidated panel closures; that is, it is assumed that the creep closure which consolidates the ROM salt also leads to backpressure that facilitates the healing of the DRZ. As a result, the DRZ permeabilities around the closure are assigned the permeability distributions given to material PCS_T2 as shown in Table 3.

Table 2: Log of Intrinsic Permeability Values used for the DRZ-PCS around the 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

Table 3: Log of Intrinsic Permeability Values used for the long-term PCS 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

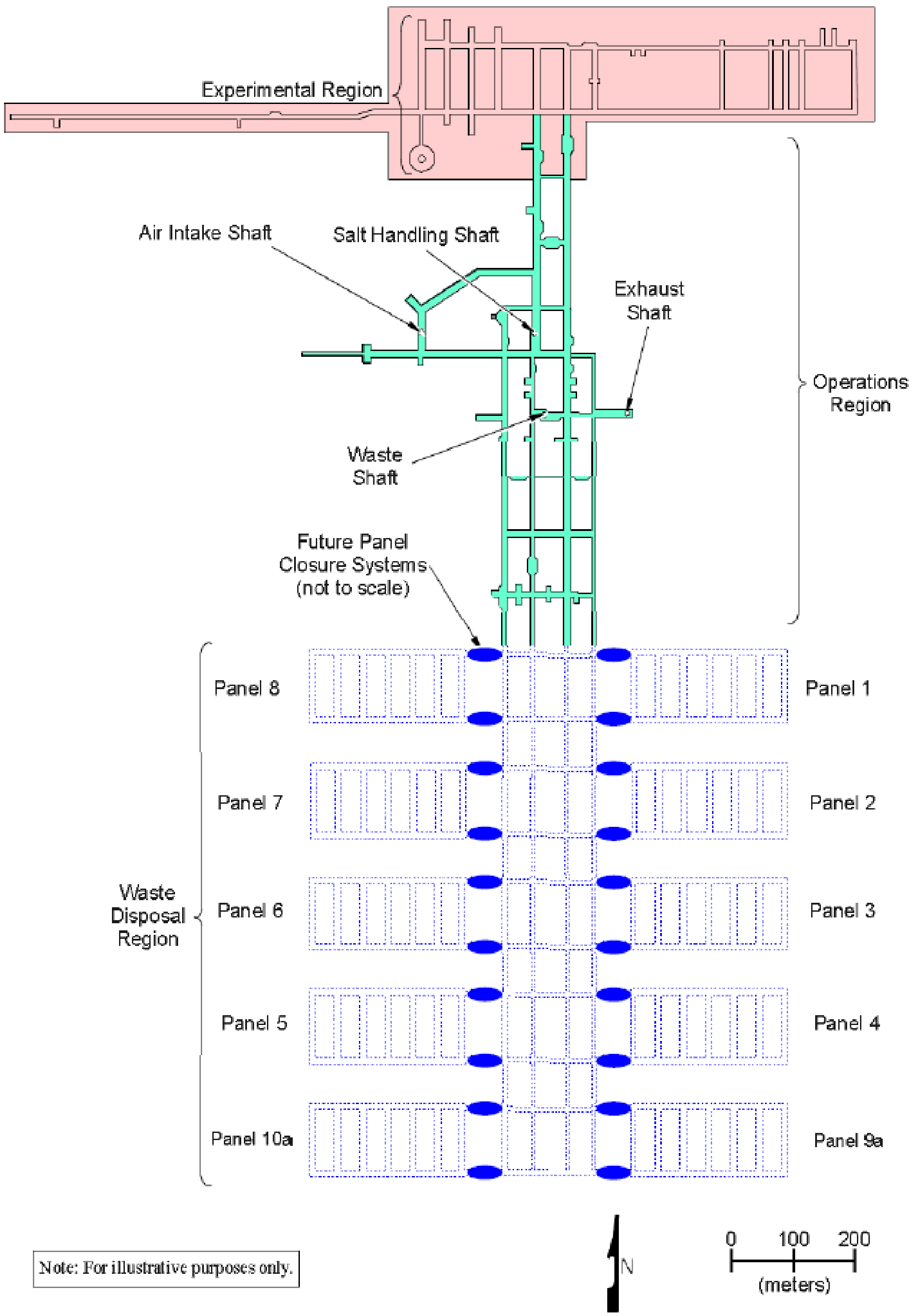

Figure 3: WIPP Layout Modeled in PC3R PA

3.3 Results from the PC3R PA

The total normalized releases for the PC3R PA, which combines the proposed reconfiguration of the repository and the modified panel closure system, are represented in Figure 4 as a mean CCDF. This figure also presents the results of the most recent recertification PA (PABC-2009, Clayton et al., 2009) which used the Option D panel closure design. As seen in that figure, the total mean normalized releases obtained in the two analyses are virtually identical for normalized release values less than approximately 0.1 EPA units. For normalized 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. The results from the PC3R PA demonstrate that the cumulative changes for the new panel closure design and for the revised repository configuration produce only slight changes in total mean normalized releases relative to the current PA baseline, the PABC-2009. The small differences between the PABC-2009 and the PC3R PA are due to changes in direct brine releases, as discussed in Camphouse et al., 2011 (Attachment C).

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 4. 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 direct brine releases (DBRs) in the PC3R PA results in a decrease in the mean total release by approximately 0.21 EPA units. Reductions are also seen in the upper and lower 95% confidence limits at a probability of 0.001 when compared to the PABC-2009 results.

Table 4: 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	90^{th} 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

Finally it is noted that the results of the earlier impact analysis in which a PCS consisting of 100 ft of ROM salt and a 30 ft explosion wall also found that normalized releases were insensitive to the panel closure design (Vugrin and Dunagan, 2006). In this 2006 impact analysis, it was assumed that the explosion wall had no influence on long-term permeability of the panel closure system, and the ROM salt backfill had the same permeability values as in the PC3R PA. These results indicated that, without the reconfiguration included in the PC3R PA, the change in panel closure design had only a minor effect on long-term performance.

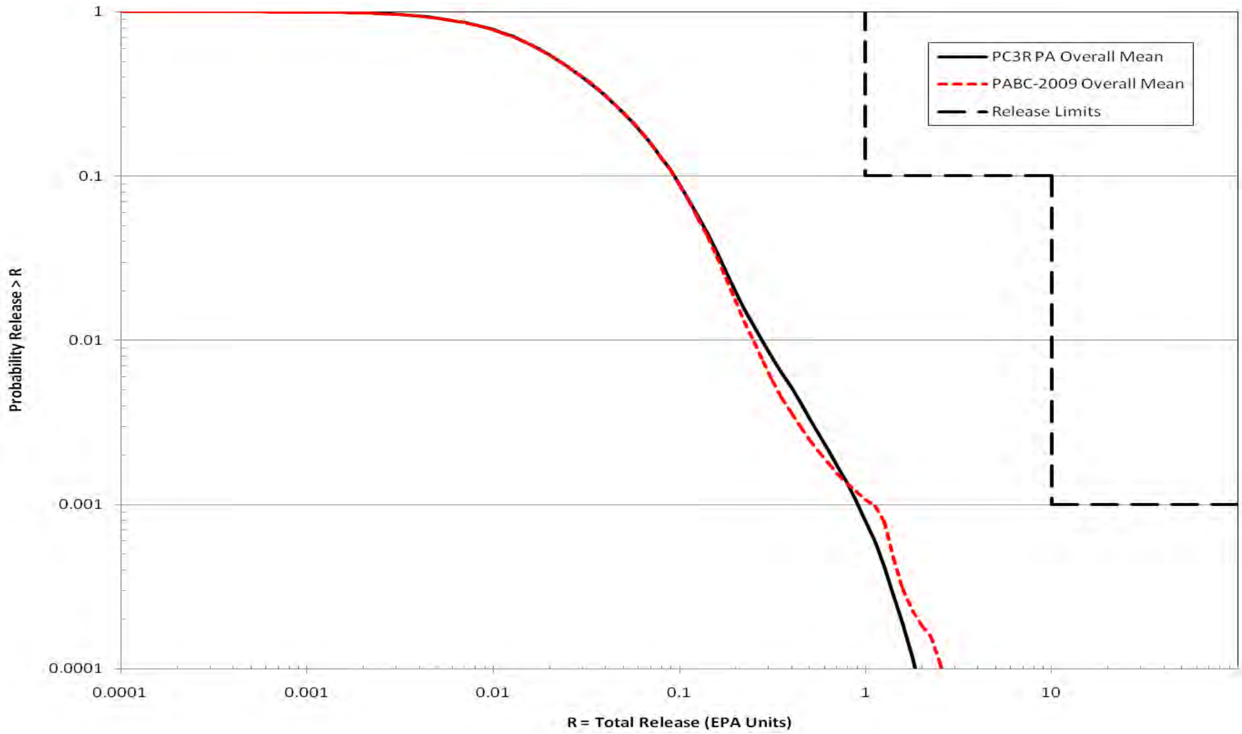

Figure 4: PC3R PA and PABC-2009 Overall Mean CCDFs for Total Normalized Releases

4.0 Conclusions

As a result of increased understanding of the repository and the stored waste obtained over 12 years of operation, the DOE has determined that a revision of the approved panel closure design can be made. The revised design described in this PCR will enhance constructability, reduce the impacts on on-going repository operations, and reduce construction cost. A change in the design specified in Condition 1 of the Final Rule (EPA, 1998a) is also required because of the problems in manufacturing SMC to the specifications in the CCA while meeting the design requirements of the Option D design.

An analysis of the results of earlier PAs suggests that this revised design will have essentially the same impact on long-term performance as the option D design. This is supported by new PA results in which the performance of the revised design is explicitly modeled, together with a proposed reconfiguration of Panels 9 and 10.

Based on these analyses and results, the DOE is requesting that the EPA remove Condition 1 as presented in the Final Rule (EPA, 1998a), and accept the revised design for panel closures as described herein.

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ATTACHMENT A

Radiolytic Hydrogen Generation and Methanogenesis in WIPP: An Empirical Point of View

Radiolytic Hydrogen Generation and Methanogenesis in WIPP: An Empirical Point of View – 11040

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ABSTRACT

Geologic disposal of radioactive waste is internationally recognized as the most prudent management approach to the back end of the nuclear fuel cycle. Alpha-emitting isotopes in waste matrices containing hydrogenous materials generate radiolytic hydrogen, which must be managed to ensure concentrations never exceed flammability limits. In addition, past concerns have been raised that methanogenesis could also present explosion hazards during a geologic repository's operational lifetime.

Early (pre-operational) planning for the Waste Isolation Pilot Plant (WIPP) lead its original design to include explosion walls as part of the closure design in the event of a build-up of hydrogen or methane. This conservative approach simply assumed explosive gases could be present without detailed prediction of their concentration and extent. As the Department of Energy (DOE) emplaced waste after opening, the first two disposal panels were isolated from the ventilation circuit with the previously planned 4-meter thick explosion walls of robust concrete blocks. A separate requirement for an additional massive panel closure structure, which would make the closure system even more robust is also required, however a regulatory decision on their need is proposed for the near future.

When the third disposal panel was filled (WIPP plans a total of 10), DOE petitioned its primary repository regulators (The New Mexico Environment Department – NMED, and the Environmental Protection Agency – EPA) to allow monitoring of gases interior to the disposal panel in lieu of installing explosion walls. DOE argued that by routine monitoring, it could determine if flammable gases were building to potentially explosive levels or not. If concentrations approached action levels or if the monitoring system failed, DOE proposed to construct the explosion walls as originally conceived. This approach allowed DOE to conduct monitoring to potentially demonstrate that explosion walls, and eventually even more robust panel closures, might not be necessary for safe operation of the repository.

This paper describes the results of the first 3 years of hydrogen and methane monitoring in Panels 3 and 4 at WIPP. Flammable volatile organic compounds are also present in many of the waste streams emplaced at WIPP, but liquids are prohibited. Measurements of these flammable organic compounds are also made, but they play a minor role in the argument to eliminate explosion walls as part of the closure design at WIPP. Over 1000 air samples from all interior reaches of Panels 3 and 4 have been collected to date. Every single methane sample has been determined as "Non Detectable" at detection levels of about 30 parts per million. Radiolytically generated hydrogen in these same samples was typically found at levels in the few hundred parts per million, well below the action levels specified in the permit (~4 parts per thousand). The monitoring results indicate that the initial WIPP planning was overly conservative and that explosion walls and robust panel closures may not be needed during the operational lifetime of WIPP.

INTRODUCTION

WIPP was constructed and its first disposal panel mined by the end of 1988. Although DOE considered WIPP ready for waste receipt, an 11-year period of regulatory licensing and permitting passed before the first shipment arrived for emplacement (1999). During this delay, several iterations of planning for final disposal panel closure resulted in a design for the panel closures that was based on very conservative assumptions [1].

With limited data on the expected concentrations of volatile organic compounds (VOCs) in the diverse array of transuranic (TRU) waste streams, and limited understanding of the potential for gas generation within the waste, conservative calculations resulted in a proposed design that included a massive concrete structure to be placed in the inlet and outlet drifts of each disposal panel. An assumed potential for a build-up of explosive gases within each panel also led to the proposal to install a massive explosion wall that would itself protect the panel closure from the blast effects so that the closure would continue to serve as a barrier to the VOCs.

In retrospect, these very conservative assumptions and calculations now appear unnecessary. It is prudent to re-examine the need for such robust structures to avoid cost and industrial accident vulnerability. Based on all the monitoring (both within the waste drums before ever shipping to WIPP, and monitoring of conditions in the filled disposal rooms of the repository), it is likely that a much lower cost closure can protectively serve the purpose.

GAS GENERATION MECHANISMS

This section describes the 3 primary sources of flammable gases that might pose a risk to WIPP workers and, to a much lesser extent, potentially exposed members of the public.

Potential Sources of Hydrogen

Hydrogen can be generated by two widely different radiological and chemical processes:

1) Radiolysis (ionizing radiation breaks bonds as it slows in hydrogenous materials), and
2) Corrosion of iron based materials under inundated conditions (no oxygen present).

Of the three primary types of ionizing radiation, radiolytic production of hydrogen is dominated by alpha radiation because of its high energy deposition rate as the alpha particles slow down in a solid matrix. This high energy deposition rate also comes with a short stopping range. The reader may recall their high school physics lesson when shown that a piece of paper is adequate to shield from alpha radiation. All the hydrogen bonds that the alpha particle can break are in the first few microns of the sheet of paper because the alpha radiation does not penetrate further into the solid. This short range also leads to another attribute of radiolysis in a solid matrix that is typically ignored. Because there is no physical movement of the matrix to expose new hydrogen atoms within the solid, radiolytic hydrogen generation rates monotonically decrease over time in all solids. This effect, known as “matrix depletion” occurs because the alpha radiation is coming from a solid source. In the case of transuranic (TRU) waste destined for disposal in WIPP, the dominant source of radiation is plutonium. Plutonium in intimate contact with organic matter (e.g., paper or plastic) will generate hydrogen at a rate that continually declines over time as more and more available hydrogen is released from the matrix. Because the source doesn’t move with respect to the available hydrogen atoms, the probability of breaking a hydrogen bond and releasing that proton declines over time (and in direct proportion to cumulative dose deposited.

Note this decline in hydrogen generation rate is not associated with the radioactive lifetime of the source. The matrix depletion effect is more a measure of the homogeneity of mixing the radioactive source material within the hydrogenous matrix than of the specific radioactivity of the source [2].

In addition to radiolysis, hydrogen can be generated by anoxic (without oxygen) corrosion of various metal components of the waste and packaging (primarily iron and aluminum based materials). Anoxic conditions can only be expected under inundated conditions, where brine has somehow accumulated and completely surrounds the waste [3]. It should be noted that aluminum and aluminum alloy corrosion rates are much slower than those for iron based materials. Estimates of the rates of hydrogen production under anoxic and fully brine inundated conditions may be made, however these rates are quite uncertain in the short-term during disposal operations, and the likelihood of inundating brine accumulation in this time frame is highly unlikely in light of its observed absence since the first disposal rooms was mined over 20 years ago.

Other arguments against significant hydrogen generation by corrosion include the obvious fact that waste containers (typically drums) are painted. Initially corrosion will be inhibited until painted drum surfaces become exposed and internal steel components become accessible. In addition, after initial closure of a panel, oxygen-rich conditions will prevail, and the iron will oxidize (rust) with no hydrogen generation possible until all of the oxygen has been consumed. The oxidation rate is highly dependent on humidity as well [4]. The low humidity in deep reaches of the WIPP (away from fresh air intakes) minimizes oxidation, even of unpainted steel surfaces. This is evidenced from observation of un-rusted surfaces on many pieces of equipment or structures installed when the first openings were mined at WIPP in the early 1980's. In the routinely low humidity levels found in WIPP, steel surfaces become passivated and oxidation slows. Therefore, oxygen depletion in closed disposal panels is not expected quickly. But only after oxygen is depleted and in the presence of brine, could anoxic corrosion be expected to generate significant hydrogen.

In 2007, a calculation was made to bound the upper limit of hydrogen generation in panel 3 [5]. This radiolysis estimate was based on the actual waste types that had been emplaced at the time, and used the actual hydrogen measurements of head-space gas in individual payload containers made to demonstrate compliance with the license requirements of the shipping containers. That conservative estimate of the production rate of hydrogen by radiolysis was about 4.5E-05 moles per second for the entire inventory of waste in panel 3 (about 1 ml/s). Generation at this rate would lead to an average concentration of 4% by volume in an air-tight sealed panel in about 20 years (neglecting any loss of hydrogen by diffusion). This should be considered a lower bound on the time required to reach a lower flammability limit since the accumulation of hydrogen is mitigated by its ease of diffusion through even highly impermeable materials. The reader is also reminded of the many fractures and openings in the disturbed rock zone of a salt mine, which will not completely heal for many decades after disposal operations cease.

Potential Source of Methane

Methanogenesis or biomethanation is the formation of methane by microbes known as methanogens. Methanogenesis in microbes is a form of anaerobic respiration [6]. Methanogens do not use oxygen to breathe; in fact, oxygen inhibits the growth of methanogens. Organisms capable of producing methane have been identified only from the domain Archaea, a group phylogenetically distinct from both eukaryotes and bacteria, although many live in close association with anaerobic bacteria. The production of methane is an important and widespread form of microbial metabolism. In most environments in the biosphere, it is the final step in the decomposition of biomass.

In addition, methanogenesis also requires the presence of liquid water, within which the methanogens metabolize. If there is oxygen present, methanogenesis is not. Conversely, if liquid water is not present, neither is methanogenesis. Therefore, just like hydrogen generation via anoxic iron corrosion, no methane can be expected as long as oxygen is present and inundating brine is not.

Flammable Volatile Organic Compounds

There are flammable VOCs in the waste. However these represent a fixed source which will deplete over time, and a source which is limited to levels well below flammability by the transportation requirements. Thus, flammable VOC components in filled panels are expected to remain quite small and further diminish over time. Hence they are not considered a significant issue related to the development of an explosive atmosphere in a full panel.

GAS MONITORING PROGRAM DESCRIPTION

In 2001, the National Academy of Sciences recommended DOE conduct pre-closure monitoring of gases in WIPP [7]:

> *The committee recommends pre-closure monitoring of gas generation rates, as well as the volume of hydrogen, carbon dioxide, and methane produced. Such monitoring could enhance confidence in the performance of the repository, especially if no gas generation is observed. Observation should continue at least until the repository shafts are sealed and longer if possible. The results of the gas generation monitoring program should be used to improve the performance assessment for recertification purposes.*

Then in 2003 [8] and again in 2004 [9], Congress directed the DOE to change the process used to characterize waste for WIPP (these statutes are referred to as Section 311 in this paper). Using nearly identical language in both years, Congress stated:

> *(a) The Secretary of Energy is directed to file a permit modification to the Waste Analysis Plan (WAP) and associated provisions contained in the Hazardous Waste Facility Permit for the Waste Isolation Pilot Plant (WIPP) …. (b) Compliance with the disposal room performance standards of the WAP hereafter shall be demonstrated exclusively by monitoring airborne volatile organic compounds in underground disposal rooms in which waste has been emplaced until panel closure.*

Section (b) essentially directed DOE to monitor VOC concentrations in the WIPP underground in lieu of the intrusive sampling and analysis required under the permit from the NMED. This gave DOE a way to conduct the hydrogen and methane monitoring recommended by the National Academy of Science by using the same sampling lines that were mandated by Section 311 for monitoring VOC concentrations in closed disposal rooms. While unrelated, the Section 311 permit modification was linked to approval to dispose of remote-handled waste at WIPP, which was strongly rejected by WIPP critics. This delayed implementation of the sampling program until the modification became effective in October 2006, and sampling for VOCs began shortly thereafter in Panel 3, the active disposal unit at that time. It took several more months to obtain a permit modification to delay construction of explosion walls in panel 3 and begin making hydrogen and methane measurements in lieu of installing explosion walls. Sampling for hydrogen and methane began in August 2007.

The sampling is performed using long stainless steel tubing with a passivated inner surface and ~7mm in diameter. Sampling tubes were installed along the outer walls of each disposal room after panel excavation, and before waste emplacement operations began. There are two sampling tubes per disposal room; one that terminates at the inlet side of each room and another that terminates at the outlet side. Each sampling line terminates at a 3-way splitter that allows air to be simultaneously drawn from locations about 50 cm above the floor, 50 cm below the roof, and approximately at the mid-height of each room. Figure 1 schematically shows the sampling line network in a typical disposal panel (blue diamonds represent sample intake locations).

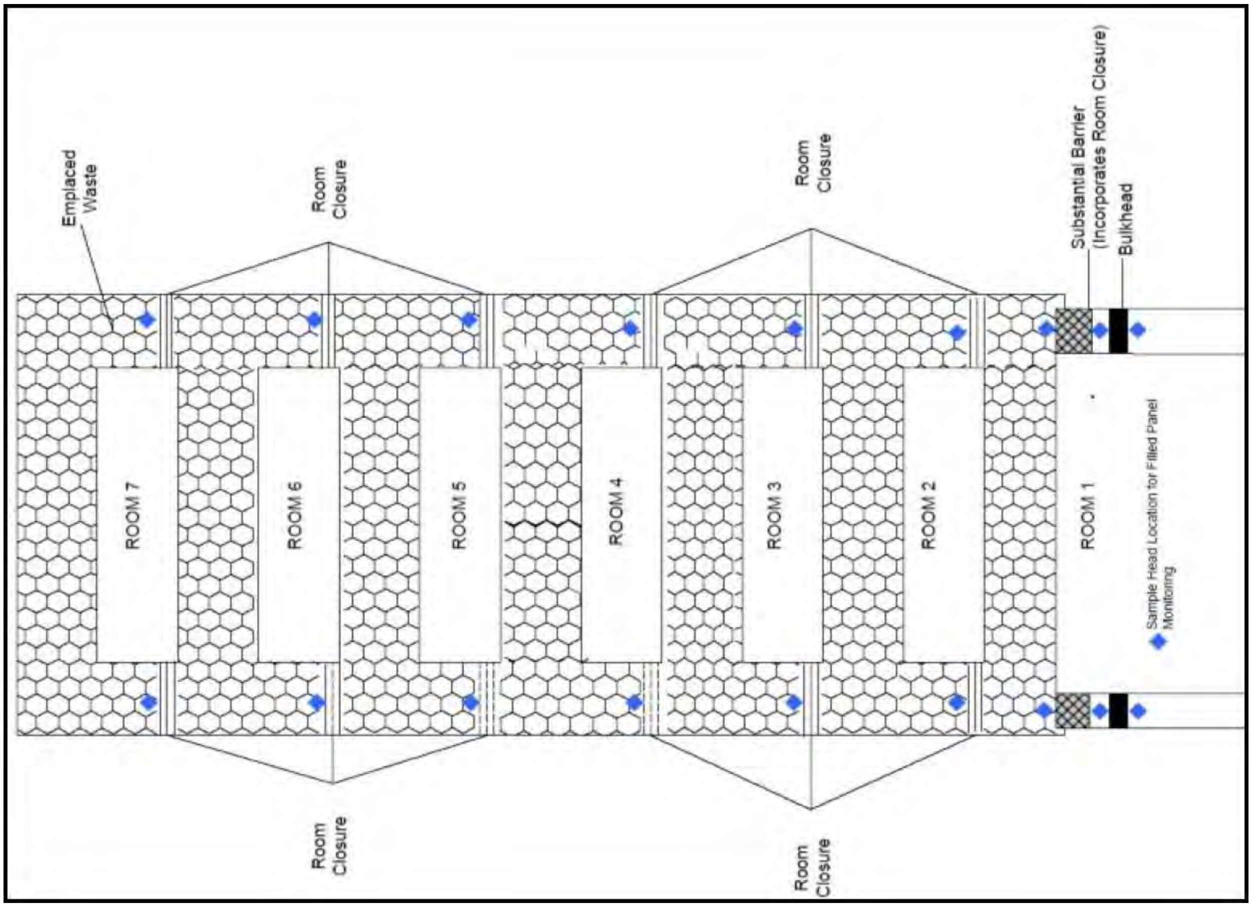

Fig. 1 Plan view of typical disposal panel showing disposal rooms separated by brattice cloth ventilation barriers (room closures) and gas sampling locations in the inlet and outlet sides of each of the seven disposal rooms.

In addition to the VOC monitoring lines, five more sampling locations are used to monitor for hydrogen and methane. These additional locations use a single inlet sampling point placed near the roof and include:

- the inlet of room 1,
- the waste side of the exhaust bulkhead,
- the accessible side of the exhaust bulkhead,
- the waste side of the intake bulkhead,
- the accessible side of the intake bulkhead.

Samples for analysis of hydrogen and methane concentrations are collected using the sub-atmospheric pressure grab sampling technique described in EPA Method TO-15 [10]. This method, which is the same for VOC sampling, uses an evacuated canister under vacuum (~0.05 mmHg) to draw an air sample through sample lines into a ~6 liter stainless steel canister with passivated interior surfaces. The passivation of tubing and canisters effectively seals the inner walls and prevents compounds from being retained on the surfaces of the sampling equipment. Sample lines are purged prior to collection as recommended by the method (about 3 times the sample line volume). At the end of each sampling period (about 6 minute grab sample at ~1 lpm), the canisters reach near atmospheric pressure.

There are no EPA-specific analytical methods which address hydrogen or methane. However, non-EPA methods are available. For the hydrogen and methane sampling, DOE uses a specially developed analytical test method for determination of hydrogen and methane using Gas Chromatography/Thermal Conductivity Detection.

The permit provisions include Action Levels based on the lower flammability limits for hydrogen and methane, referred to in the permit as lower explosive limits (LELs). In air, the lower flammability limit for hydrogen is generally considered to be 4 percent while that for methane is 5 percent. Both limits assume atmospheric oxygen levels are present.

The permit Action Level 1 for hydrogen and methane in a panel is 10 percent of the LEL which, for hydrogen, is 0.4 percent or 4000 ppm and for methane is 0.5 percent or 5000 ppm. If this Action Level is reached or exceeded, the monitoring will be increased to weekly. If the concentrations measured in subsequent sampling fall back below Action Level 1, the sampling frequency relaxes back from weekly to monthly.

Action Level 2 for hydrogen and methane in a panel is 20 percent of the LEL which, for hydrogen is 0.8 percent or 8000 ppm and for methane is 1 percent or 10,000 ppm. If Action Level 2 is achieved or exceeded for two successive weekly samples, the permit requires that monitoring cease and DOE is required to install the explosion isolation walls within 180 days.

When two flammable gases are mixed, the mixture may exhibit a different LEL than the individual gases. This is referred to as the composite LEL for the mixture. DOE evaluated whether or not the composite LEL should be used in determining the Action Levels and concluded that using the 10 percent and 20 percent thresholds was sufficiently conservative to assure action would be taken before potentially explosive levels of hydrogen or methane built up in filled panels. The additional conservatism added by using the composite LEL was not justified considering the additional complexity for demonstrating compliance (i.e., compliance using the composite value is based upon application of a mathematical formula and not on fixed, tabulated values in the permit).

As waste emplacement operations progress and each disposal room is filled within a panel, the filled room is cut off from ventilation by a barrier called a brattice curtain (or cloth), which is a simple canvas-like cloth suspended from the roof and attached to the sides and floor of the drift to effectively cut off the filled room from air ventilation underground. While some attention is given to sealing air flow from going around the barrier, the brattice cloth is by no means an air-tight seal. Small (millimeter scale) gaps remain. After panels 3 and 4 were filled, a metal bulkhead was constructed in both the inlet and outlet drifts (see Figure 1). This final ventilation barrier in each panel was augmented by a rubber (conveyor belt material) gasket bolted to the salt and bulkhead to form a seal. Again, small gaps remained. The reader is reminded that the salt creep process results in fractures and partings within the rock salt walls themselves that make the concept of a perfect gas seal impossible during the operational phase of the repository. Figure 2 shows photos of typical brattice cloth and metal bulkhead construction in WIPP.

Fig. 2 Photos of a typical ventilation barrier called a brattice curtain (top) separating each disposal room, and of a typical metal bulkhead (bottom) “sealing” the inlet and outlet drifts of each disposal panel from ventilation air in the rest of the mine.

DOE believes the use of the bulkhead, the accompanying monitoring, and related Action Levels will maintain safe and protective operations by ensuring that:

- physical access to the full panel is prevented,
- the panel is removed from active ventilation, and
- conditions inside the panel are regularly monitored so that preventive actions can be taken well in advance of the existence of a hazardous condition.

MONITORING RESULTS

Panel 3 was filled and closed in August 2007, while panel 4 was filled and closed in May 2009. Monthly hydrogen and methane sampling began in both panels the same month they were closed. Two results from over 1,000 samples collected since then stand out:

- All samples assayed less than the minimum detectable level for methane (<~20-30 ppm).
- Hydrogen results typically assay at several hundred ppm, when detected at all.

The monthly monitoring results for hydrogen in panels 3 and 4 are presented in Figures 3 and 4, respectively.

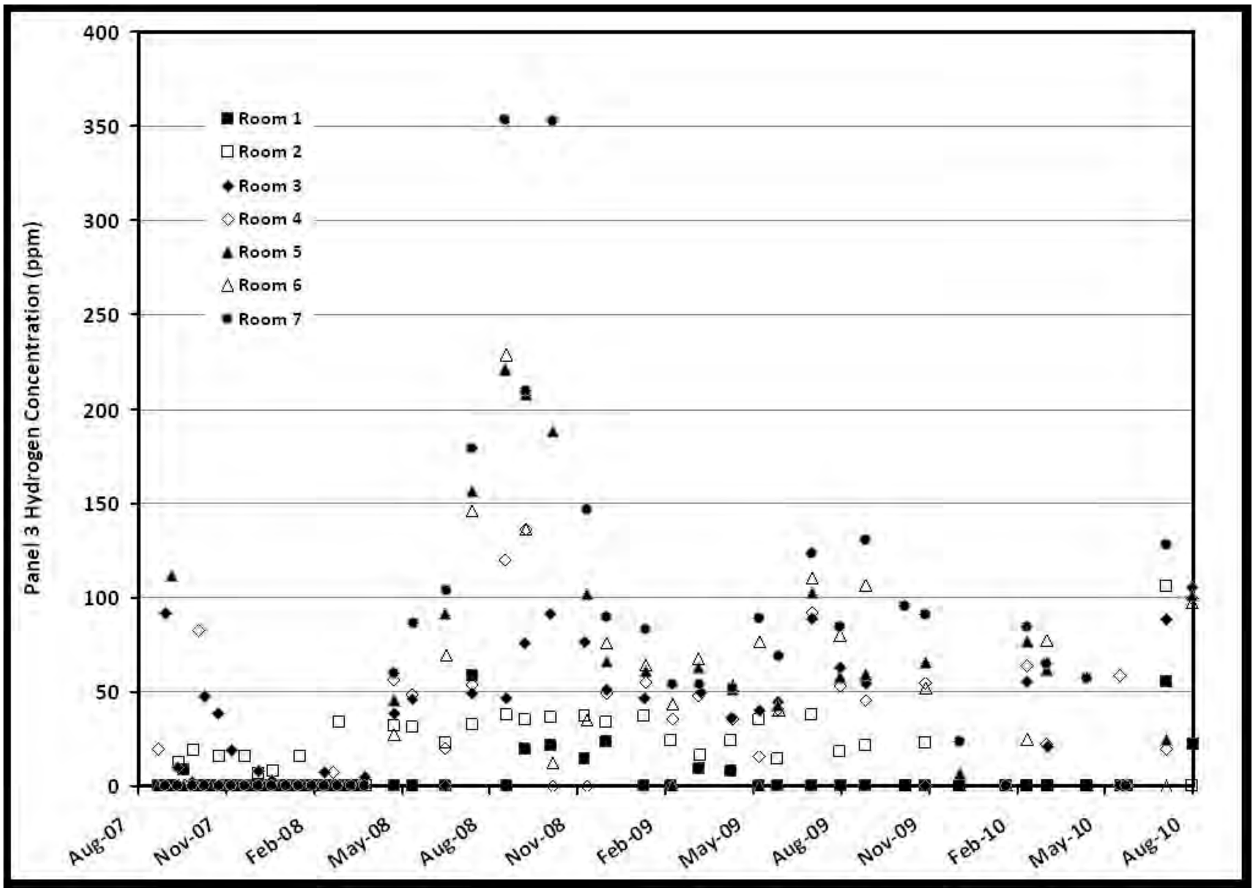

Fig. 3 Time series history of hydrogen monitoring results taken from the outlet sides of disposal rooms in closed panel 3 over a 3-year period.

In these time series plots, only the results from sampling the outlet sides of each disposal room are plotted. Only a handful (out of over 500) of samples taken from the inlet side assayed above the minimum detectable limit for hydrogen (~20-30 ppm), and therefore are not plotted. When outlet sample results assayed below the minimum detectable limit, the value was plotted at a concentration of zero in Figures 3 and 4.

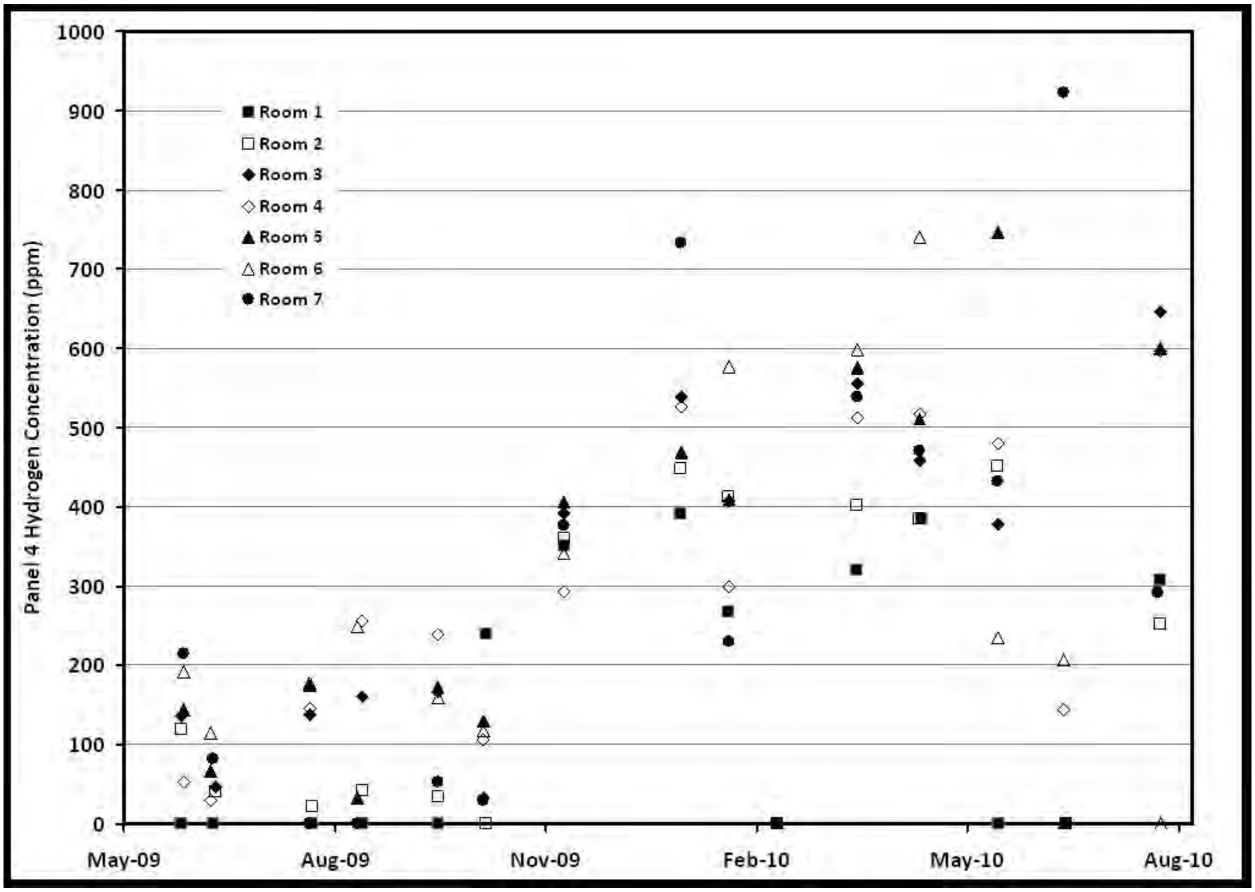

Fig. 4 Time series history of hydrogen monitoring results taken from the outlet side of disposal rooms in closed panel 4 over an 18-month period.

Interpreting these results is easy. There is no detectable methanogenesis occurring in either panels 3 or 4, and thereby by inference, no methanogenesis in panels 1 or 2 either. In contrast hydrogen generation by radiolysis is occurring and at levels easily detected by the analytic method used for assay. No steadily rising concentrations imply that the hydrogen is removed from the disposal rooms on a continuous basis. The removal process appears to be two-fold. The fact that the results from samples collected on the inlet side almost always assay below minimum detectable limits and those from the outlet side typically range in the few hundred ppm levels implies that there is a leakage flow due to differential pressure between the inlet and outlet sides of each disposal panel. The high sample-to-sample variability from each location implies that the release of hydrogen from the waste containers themselves varies over periods of weeks to months. This can be explained by normal barometric breathing.

The highest value of hydrogen measured to date was 923 ppm at the outlet side of room 7 (furthest into the disposal panel) in panel 4 in June 2010. This value is 25% of the Action Level 1 for hydrogen established in the permit (which in turn is 10% of the concentration considered flammable - if oxygen were present at atmospheric levels). It should be noted that actions to minimize leakage ventilation through panel 4 began in earnest in November 2009, when running annual average carbon tetrachloride levels in the exhaust flow from the entire underground began climbing. A companion paper in session 063 (11039) at this symposium describes this effort in more detail [11].

Active disposal operations with high carbon tetrachloride content were ongoing in panel 5 at that time, but it was prudent to assume that some of the carbon tetrachloride originated from leakage flow through closed panel 4 since it held some of the high carbon tetrachloride waste as well. Therefore, DOE built an additional bulkhead at the inlet and outlet drifts of panel 4 and made extra efforts to seal panel 4 from leakage ventilation. These efforts were coincident with the slight step increase in the peak hydrogen concentration results as seen in Figure 4 in November 2009. The apparent increase may be attributed to the enhanced sealing efforts to minimize carbon tetrachloride leakage out of panel 4. However, the fact that hydrogen concentrations vary so much from one sample to the next indicates that it easily escapes the systems designed to block the carbon tetrachloride.

ELIMINATING EXPLOSION WALLS AND OPTIMIZING PANEL CLOSURES

Based on the monitoring results from 2007 to date, it would seem that massive panel closures and explosion walls to protect those closures might not be necessary and yet still be protective of workers and the environment. A companion paper in session 063 at this symposium discusses DOE's plans to seek regulatory approval to modify the massive closure design and replace it with a simple 30 meter long wall of run of mine salt [12]. Such a panel closure would likely be a better barrier in preventing panel-to-panel hydrologic communication in an assumed future human intrusion scenario, and would be a lot less costly. Upon filling a disposal panel with waste, the run of mine salt closure would simply be placed in the inlet and outlet drifts. A blower may be used to bring the pile up to the full height of the drifts. While this closure would not be air-tight, it would behave at least as well as the metal bulkheads in panels 3 and 4 described herein (the same leaky pathways around the closure through the disturbed rock zone would exist). Over time (a few decades), the salt creep closure would compact and begin reconsolidating the run of mine salt. Within a few hundred years, this panel closure would resemble the properties of intact salt. In contrast a massive monolith of concrete (the current panel closure stipulated for WIPP by its regulators) would not exhibit the immeasurably low permeability of healed intact salt, but would be considered more permeable.

CONCLUSIONS

Although basic knowledge and laboratory measurements made during the licensing and permitting phase showed that little or no gas generation would occur during the operational life of WIPP, in an abundance of caution, DOE and its regulators still proposed massive panel closures and large explosion walls to protect them. Based on monitoring results (at least for panel 3 and 4), these do not appear to be necessary, since levels of flammable gases and VOCs are present in only trace levels. The only VOC present in significant amounts in the TRU waste stream inventory (and then only in a small fraction of drums) is carbon tetrachloride, which ironically is not flammable.

Over 1000 gas samples collected in all areas of panels 3 and 4 show undetectable levels of methane, thereby confirming the expectation that methanogenesis is not occurring (oxygen is present, and brine inundation is not). Hydrogen levels in those same samples are in the few hundred ppm range and vary significantly from sample to sample, thereby implying a continuous source, but an intermittent pathway out. This is consistent with barometric pumping of waste containers, superimposed on a steady leakage air flow, even through the further back disposal rooms in a panel.

DOE will continue to monitor for flammable gases in filled disposal panels and take steps to protect workers and the environment if levels rise and explosions walls become necessary. In the meantime, DOE will continue to make the case that there are more prudent and cost effective panel closure designs that should be considered.

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ATTACHMENT B

Effective Permeability of the Redesigned Panel Closure System

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

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date: August 29, 2002

to: Paul E. Shoemaker, MS-1395 (6820)

from: F.D. Hansen, MS-1395 (6822)
T.W. Thompson, Golder Associates

subject: Effective Permeability of the Redesigned Panel Closure System

Introduction

This memorandum estimates permeabilities for the redesigned panel closure system described in the *Design Report for a Revised Panel Closure System at the Waste Isolation Pilot Plant* (Design Report) (Saeb and Case, 2002). This redesigned panel closure system consists of a mortared, solid concrete block wall placed in the panel entries over a length of 30 ft, and run-of-mine salt backfill placed on the outer side of this wall for a length of 100 ft. This backfill is not placed to any particular specifications, but it will be placed up to the back in the entry, and up to the ribs. The design report estimates the mortared block wall would exhibit a permeability of the order of 10^{-15} m^2 as emplaced. This wall is designed to continue to function throughout the operational period of 35 years, and it's permeability may be expected to remain relatively constant over this period. Beyond the 35 years the concrete wall may be expected to undergo progressive material failure and the permeability will gradually increase as the concrete block wall fractures and fails. However, the permeability of the salt backfill will reduce over time from the estimated as-emplaced value of 10^{-11} m^2 (Saeb and Case, 2002) as the loose salt consolidates. In the absence of pore pressure development, which could slow or impede consolidation, the mine-run salt may be expected to compress to very low permeability in less than 100 years. As discussed later it is not anticipated that significant pore pressures will be generated in the backfill until permeabilities of less than 10^{-15} m^2 are achieved.

The intent of this memorandum is to establish the order of magnitude of permeability of this redesigned closure as a function of time. Specifically, it demonstrates that in a fairly short time, of the order of 100 years or less, the closure system will achieve a permeability of lower than 10^{-15} m^2, and that the closure system permeability will be in the range of 10^{-15} to 10^{-19} m^2 beyond that time. The redesigned closure therefore will have a permeability in the range examined in the accompanying impact analysis (Hansen, 2002), so that the conclusions in that analysis regarding system performance can be applied to the redesigned closure. It should be noted, however, that while this memorandum demonstrates an expected range for the panel closure permeability, it is not intended to be used to define a permeability parameter for use in future Performance Assessment (PA) calculations.

Panel closure design

As noted in the introduction, and described in detail in the design report (Saeb and Case, 2002), the closure comprises a mortared, solid concrete block wall 30 ft. long, and run-of-mine salt backfill 100 ft long placed to leave no gaps against the roof and ribs (Figure 1).

The resistance to fluid flow of this closure system will be a composite of the resistance to flow of the different elements, including the wall, the crushed salt and the surrounding disturbed rock zone (DRZ). Each of these components will vary in its flow resistance over time, and each will dominate over a particular time period. Since the intent of this memorandum is to review the flow resistance of the closure itself for comparison to the range examined in the impact analysis, the effect of the DRZ is not considered here, although it will be relevant to overall performance.

During the operational period the conductivity of this closure will be dominated by the mortared cement block wall, which is estimated in the design report to have a permeability of $2x10^{-15}$ m^2. Over time the concrete wall will gradually fracture and fail under the loads applied by the creep of the surrounding salt, and its permeability will gradually increase. However, the same creep closure which causes the concrete block wall to fail will also gradually compact the salt backfill, thus slowly decreasing its permeability and this element will come to dominate the flow performance of the closure system.

It should be noted that the relevant parameter for flow performance is in fact the flow conductance, which is a function of permeability, area, and length. However the length of the closure considered in the Compliance Certification Application (CCA) and Performance Assessment Verification Test (PAVT) calculations, and in the accompanying impact analysis, is 40 m or 131 ft, which is essentially the same as the redesigned closure, while the area is the same in the CCA, PAVT and for the redesigned closure, so the comparison may be made on the basis of permeability alone.

Salt Consolidation

Closure of the entry due to creep around the crushed salt backfill will cause the backfill to consolidate leading to loss of porosity, increase in density and reduction in permeability. The backfill void volume will be approximately 33% when placed, this being a typical value for loosely emplaced disaggregated materials and being in the range anticipated by Saeb and Case (2002). When the salt is compressed and the porosity is reduced, its permeability decreases appreciably. It has been shown that when crushed salt re-consolidates to a density approaching 95% of intact salt, its permeability is approximately 10^{-19} m^2 (Hurtado et al., 1997). It has been postulated and confirmed that consolidation of granular rock salt occurs by two primary mechanisms: grain boundary pressure solution and dislocation creep (Spiers and Brzesowsky, 1993). As crushed salt is loaded, the principal densification mechanism of fluid-phase grain boundary solution/redeposition is rampant. As consolidation proceeds, the material attains sufficient density so that its response assumes the constitutive response of intact salt, and dislocation creep becomes important. Estimates of the rate of closure and the resulting loss of permeability can be made using measured closure rates from the Panel 1 entries and laboratory data on salt consolidation.

Data on the relationship between porosity and permeability of crushed salt have been obtained in a number of laboratory experiments evaluating the behavior of backfill material in rooms and of shaft seal components. A comprehensive data set is reported by Hurtado et al., (1997) and is included as Figure A7 in Appendix SEAL of the CCA (DOE, 1996). These data are presented in Figure 2, and show that for fractional densities above about 0.9 (equivalent to a porosity of 10%) permeabilities may be expected to be 10^{-15} m^2 or lower. If, as noted above, the run-of-mine salt is expected to have a porosity of the order of 33%, then to reach a porosity of 10% will require a volume strain of the order of 23%.

Unimpeded closure of entry drifts has been modeled and shows closure of the order of 10% in 10 years (Hansen et al., 1993). Actual measurements of roof-to-floor and rib-to-rib closure in the entries corroborate these closure rates. Figures 3 and 4 show closure data for S1600 (the Panel 1 exhaust drift) and S1950 (the Panel 1 intake drift) respectively. These data are from the E407 monitoring point which is located approximately midway between the E300 main entry and Panel 1, or in the center of the proposed panel closure locations (DOE, 2001). These data indicate that closure rates, which are summarized in the following table, are reasonably stable, and uniform, and are similar for the mid and third points of each entry. If it is assumed that the rates measured over the last ten years will continue, then the volume closure expected of the two entries is as shown in Figure 5, with closure by 25% in between 20 or 30 years.

Closure Measurement Location	Exhaust Drift (S1600) (in/day)	Air Intake Drift (S1950) (in/day)
Vertical (Center)	0.00203	0.00364
Vertical (S. third point)	0.00185	0.00300
Vertical (N. third point)	0.00196	0.00365
Mean Vertical	0.00195	0.00333
Horizontal (Upper third point)	0.00230	0.00250
Horizontal (Center)	0.00216	0.00266
Horizontal (Lower third point)	0.00200	0.00261
Mean Horizontal	0.00215	0.00259

Closure to this extent in the presence of crushed salt may be expected to be slower for three reasons. First, it is likely that a long-term slow down of closure rates may be expected, although closure by 25% in say twice the calculated time, or 40 – 60 years, is not unreasonable. Second, as the backfill consolidates it may be expected that it will stiffen and apply some back stress that will slow the closure. Case (1994) used data from Holcomb and Hannum (1982) to estimate consolidation pressure-strain curves for loosely placed backfill (Figure 6), indicating that at strains of the order of 25% imposed under rapid loading quasi-static conditions back stress of the order of 2500 psi may be expected. However creep tests carried out on similar materials by Holcomb and Hannum show that under constant stress of this magnitude the crushed salt will consolidate over time (Figure 7). This creep will result in relaxation of any potential stress build up over the tens of years being considered here, so the potential for large back stresses being induced is small. Note that this behavior is confirmed by numerical calculations of the closure of backfilled rooms (Figure 8) (Callahan and DeVries, 1991) which show closure to very low porosities in a matter of a few tens of years, and by calculations of the consolidation of dynamically emplaced crushed salt in the shaft at a depth of 600m (Figure 9).

Third, back pressure could also be applied as a result of pore pressure build-up due to gas generation in the waste. Any microbial gas generation will occur fairly rapidly, at least within the time frame discussed here, and this gas may be expected to flow through the concrete wall and into the salt backfill. However through the early parts of its consolidation, where the permeability was greater than or equal to 10^{-15} m^2, any gas generated will flow out of the backfill into any remaining void space adjacent to the closure. As the permeability reduces still further the crushed salt may resist further consolidation, but the permeability will still be in the range estimated here.

Conclusion

When the redesigned closure is emplaced the flow resistance will be controlled by the mortared concrete block wall, and is expected to be of the order of 10^{-15} m^2. This permeability will be maintained at least through the operational period of 35 years. After this time the permeability of this element may be expected to increase somewhat as the wall degrades on an unknown time frame under creep load. At the same time the run-of-mine salt backfill will be consolidating under the creep closure of the salt surrounding the entry. Extrapolation of existing closure data suggest volume closure of the order of 25% would occur in as little as 20 to 40 years; however it is likely that this will take longer as creep closure rates will probably reduce somewhat over time. Back stress due to the consolidation is expected to be minimal over the time scales of interest (tens of years) since any tendency for stress build up will be relaxed by creep consolidation of the backfill. Once a fractional density of about 0.9 (representing a porosity of about 10%, or about 25% closure from an original porosity of 35%) is reached permeabilities of the order of 10^{-15} m^2 may be expected, and it is reasonable to expect these conditions to be reached in a maximum of 100 years. Beyond that time, permeability may be expected to decrease further with additional consolidation and values of the order of 10^{-19} m^2 may be achieved. If gas generation occurs and the gas penetrates the backfill, then as the permeability decreases, pore pressures may build up leading to a slowing or stopping of consolidation. However this will not occur until the backfill permeability reaches at least 10^{-15} m^2: at higher permeabilities the pore pressures will be relieved by flow of gas. The permeability of the closures will therefore be expected to fall in the range covered in the accompanying impact assessment, i.e. 10^{-19} to 10^{-15} m^2.

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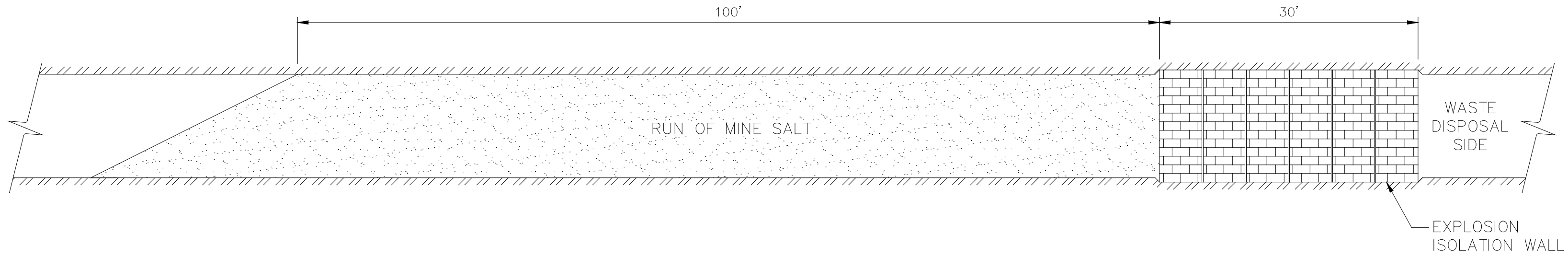


Figure 1. Explosion Isolation Wall in Combination with the Run-of-Mine Salt Backfill (Saeb and Case, 2002)

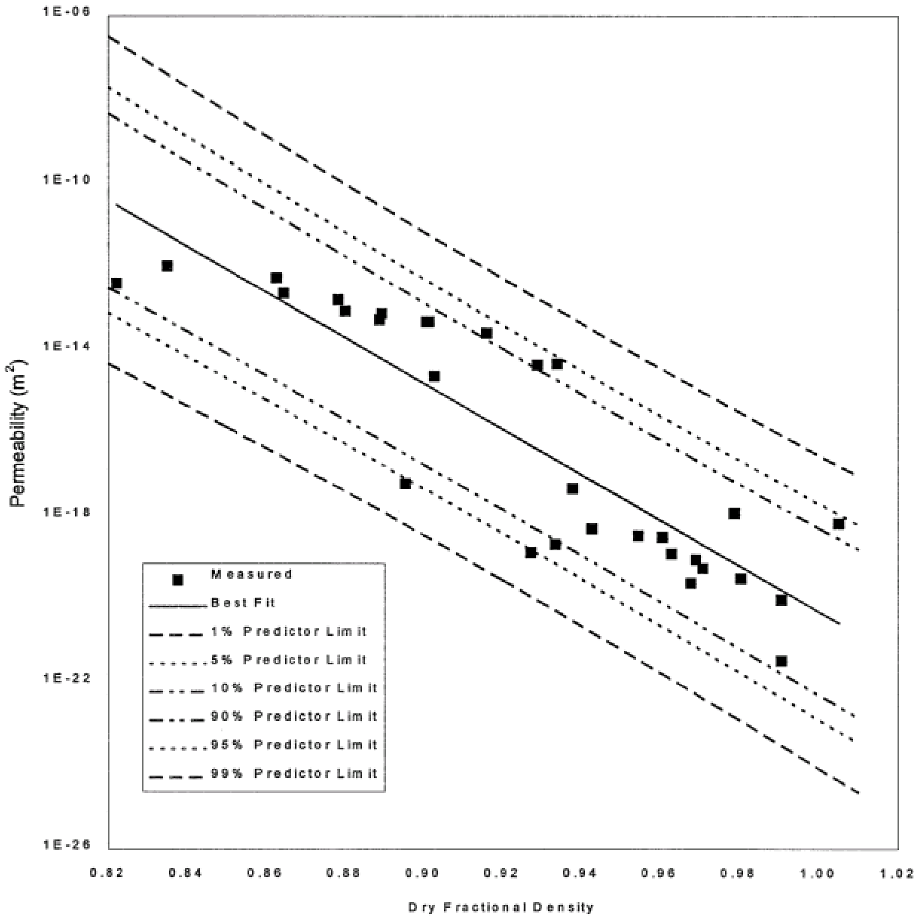
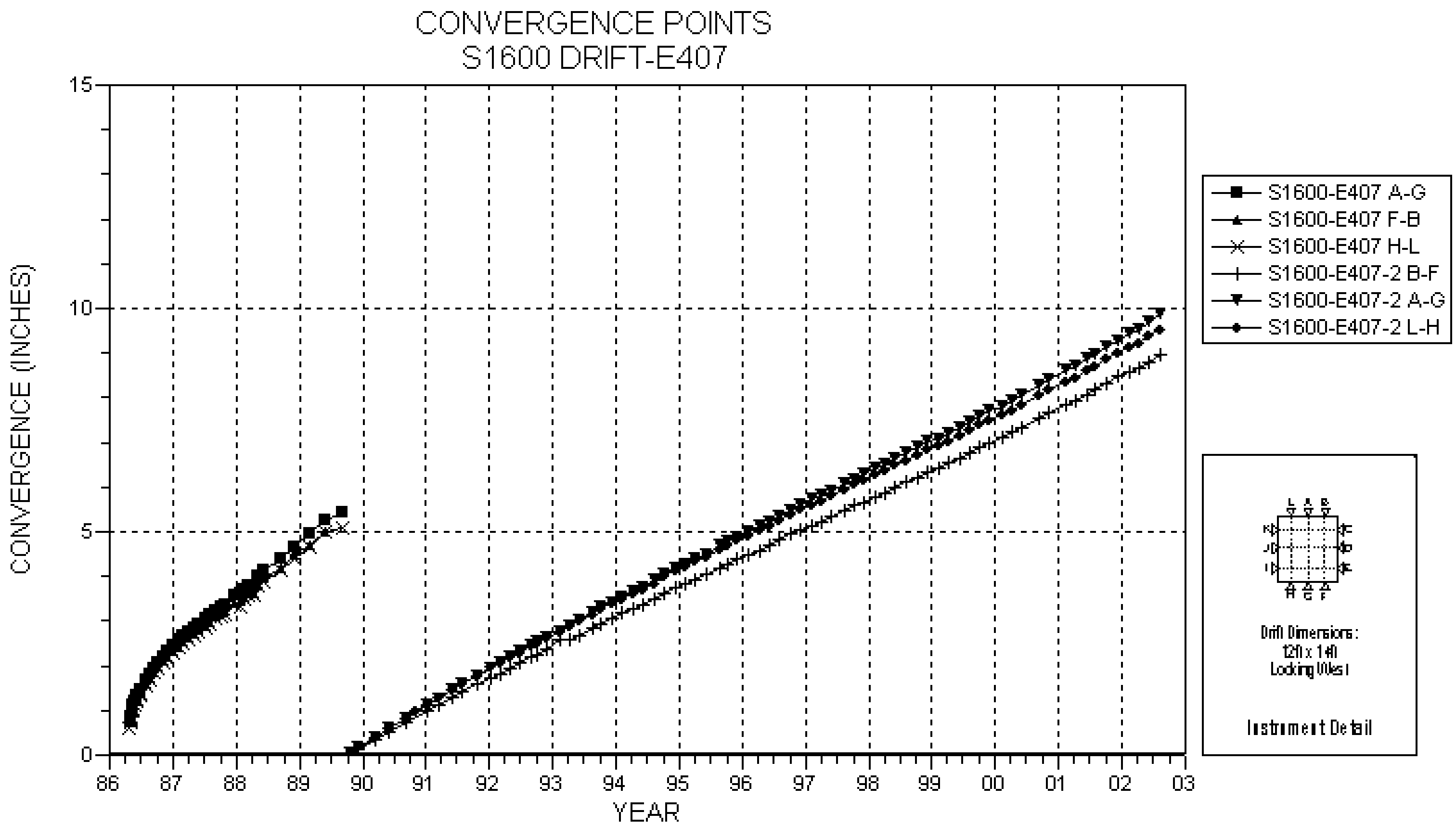


Figure 2. Permeability of Consolidated Crushed Salt as a Function of Fractional Density (DOE, 1996)



NOTES:
1. Excavation date: April 1986.

Figure 3: Closure Data for the Exhaust Drift (S1600) (DOE, 2001)

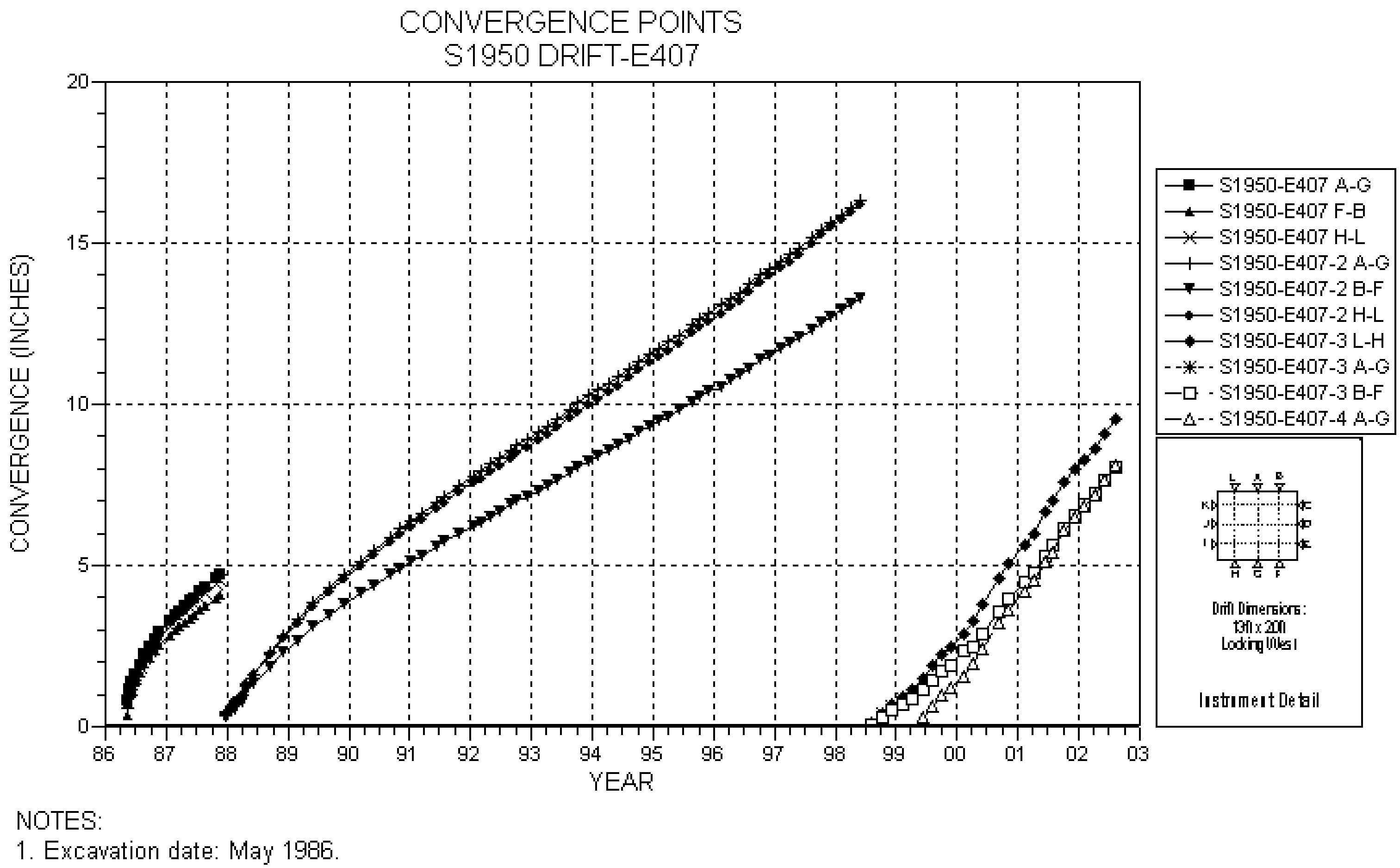


Figure 4: Closure Data for the Air Intake Drift (S1950) (DOE, 2001)

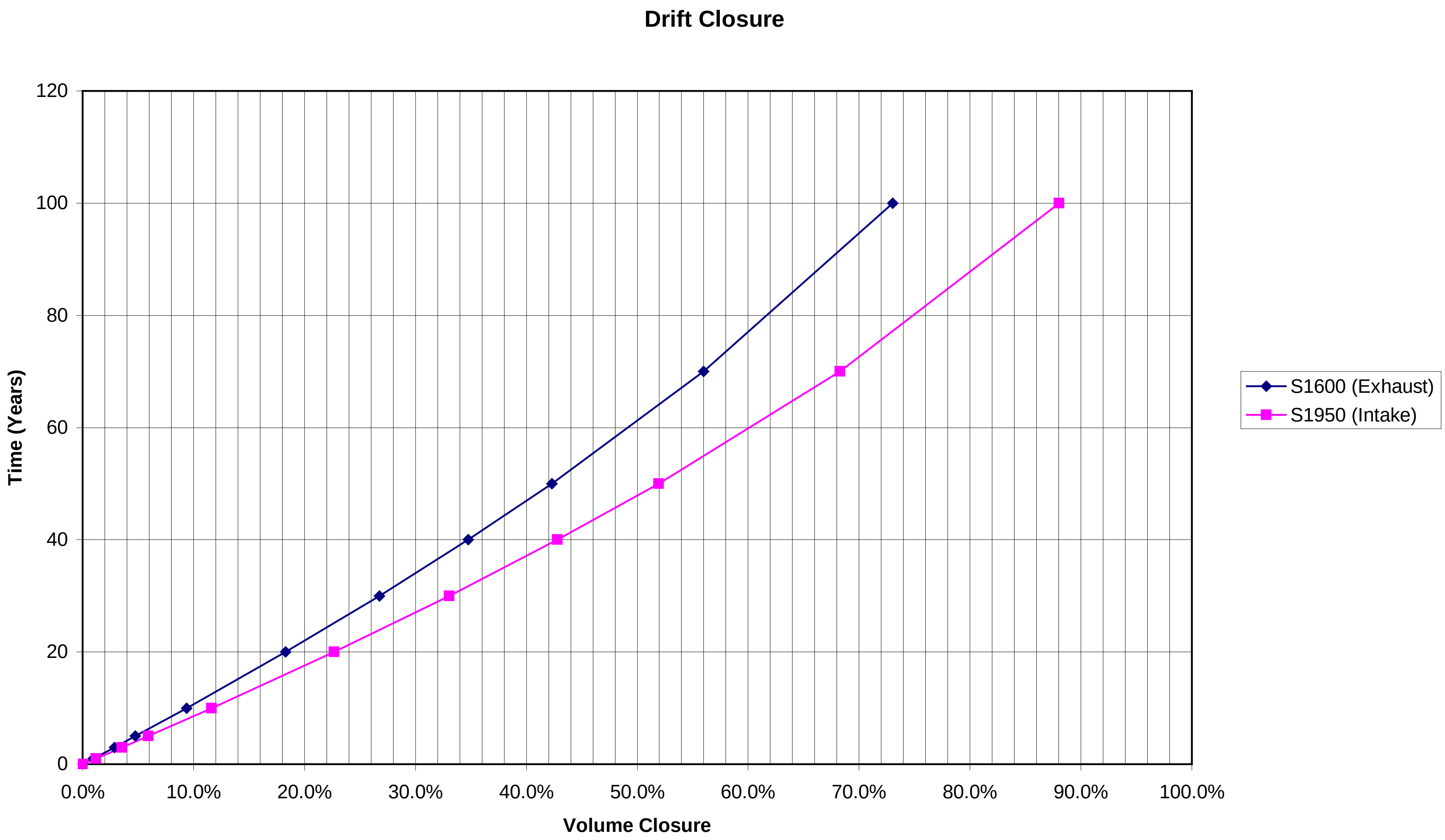


Figure 5. Calculated Drift Closure Assuming Constant Closure Rates and no Backstress

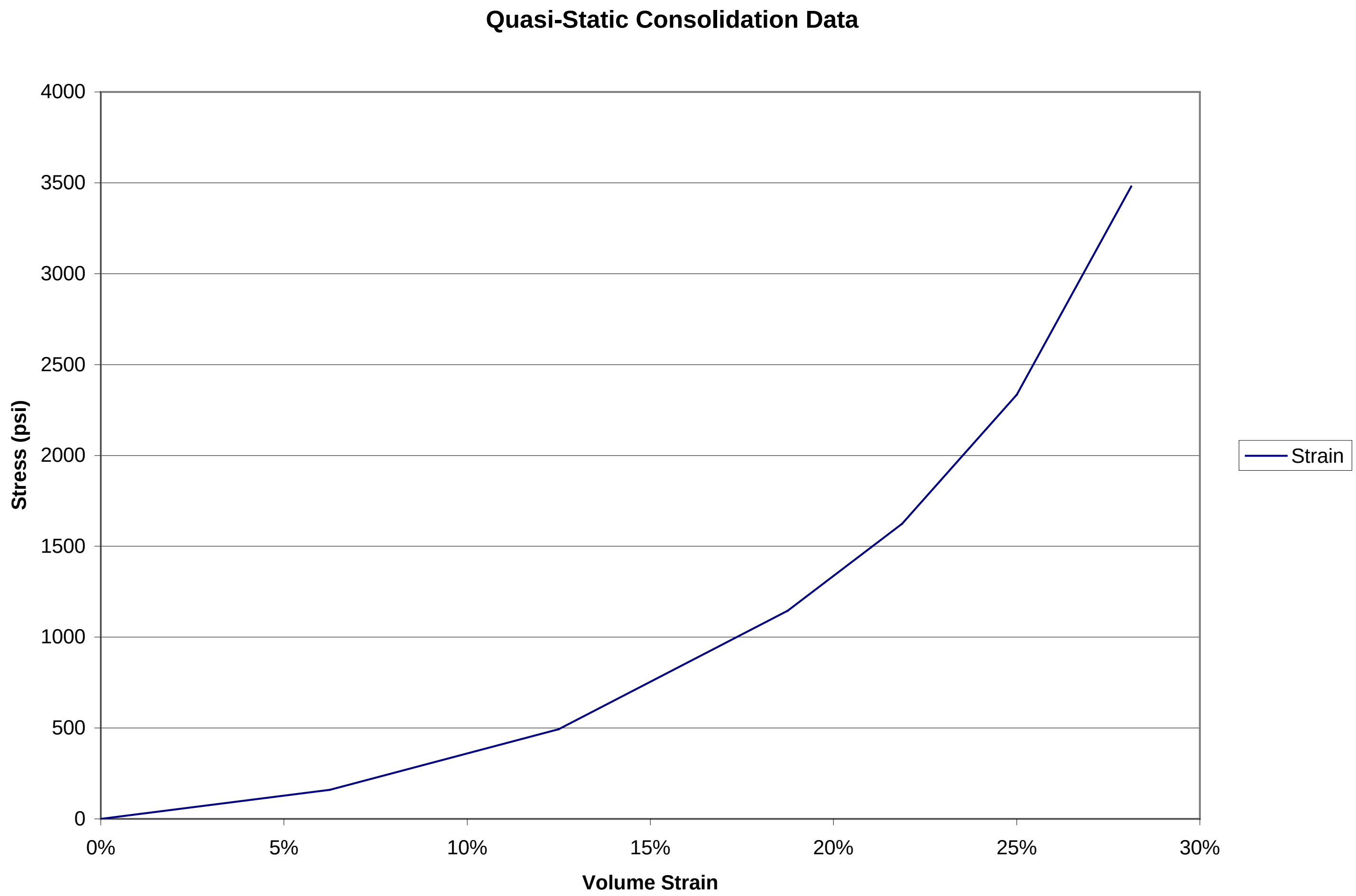


Figure 6: Quasi-Static Consolidation Data for Dry Crushed Salt (after Holcomb and Hannum, 1982 and Case, 1994)

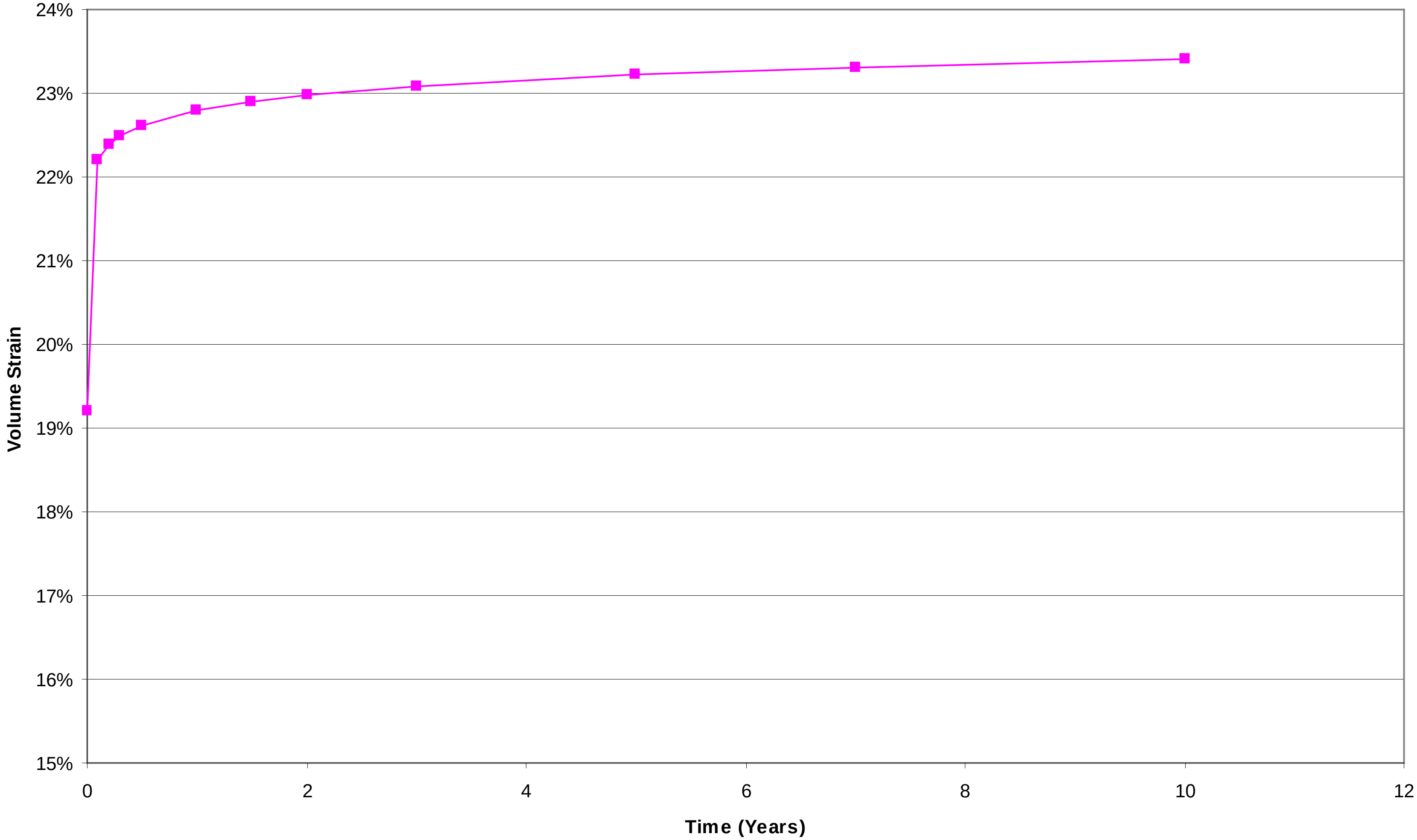


Figure 7: Creep Consolidation Data for Dry Crushed Salt (after Holcomb and Hannum, 1982)

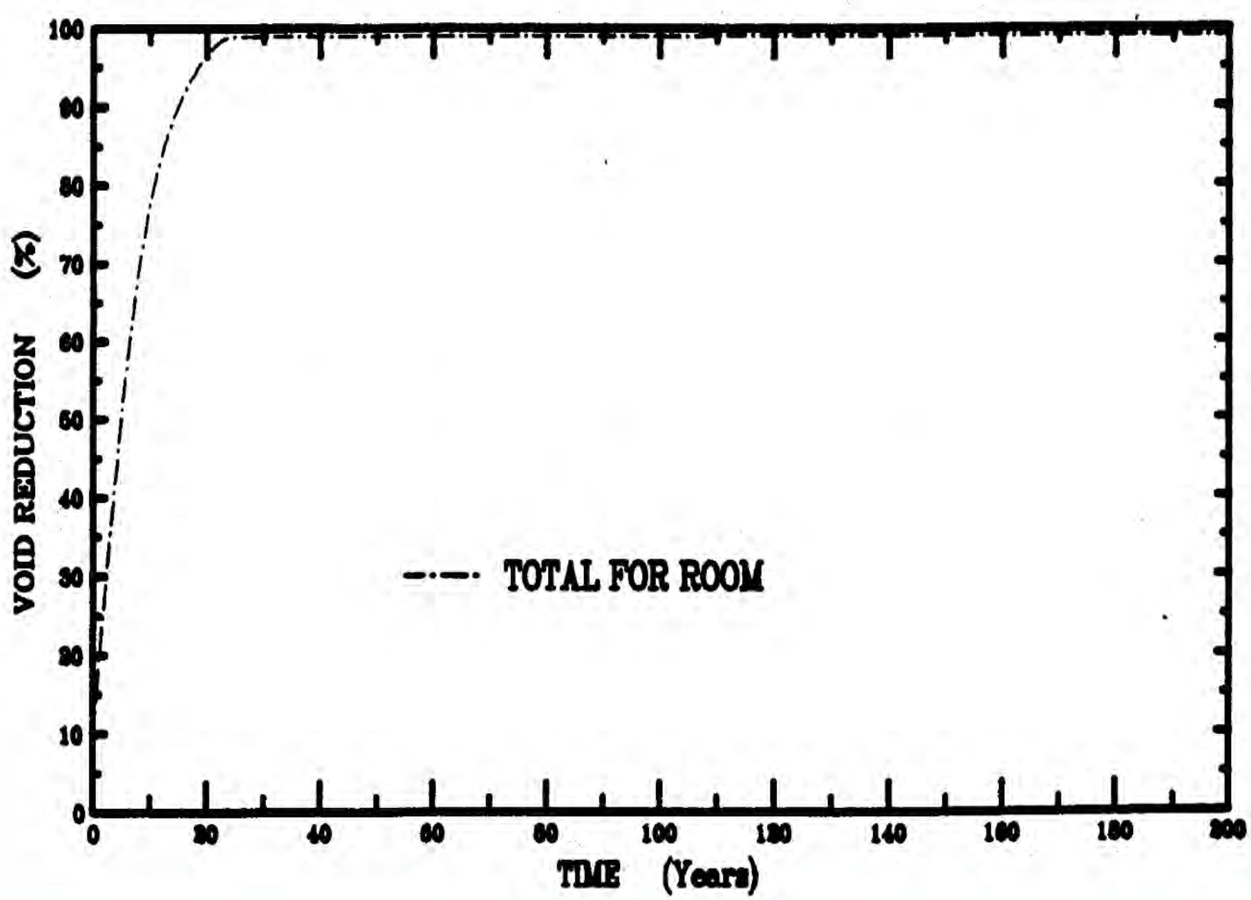


Figure 8. Void Reduction in a Disposal Room filled with Crushed Salt as a Function of Time (Callahan and DeVries, 1991).

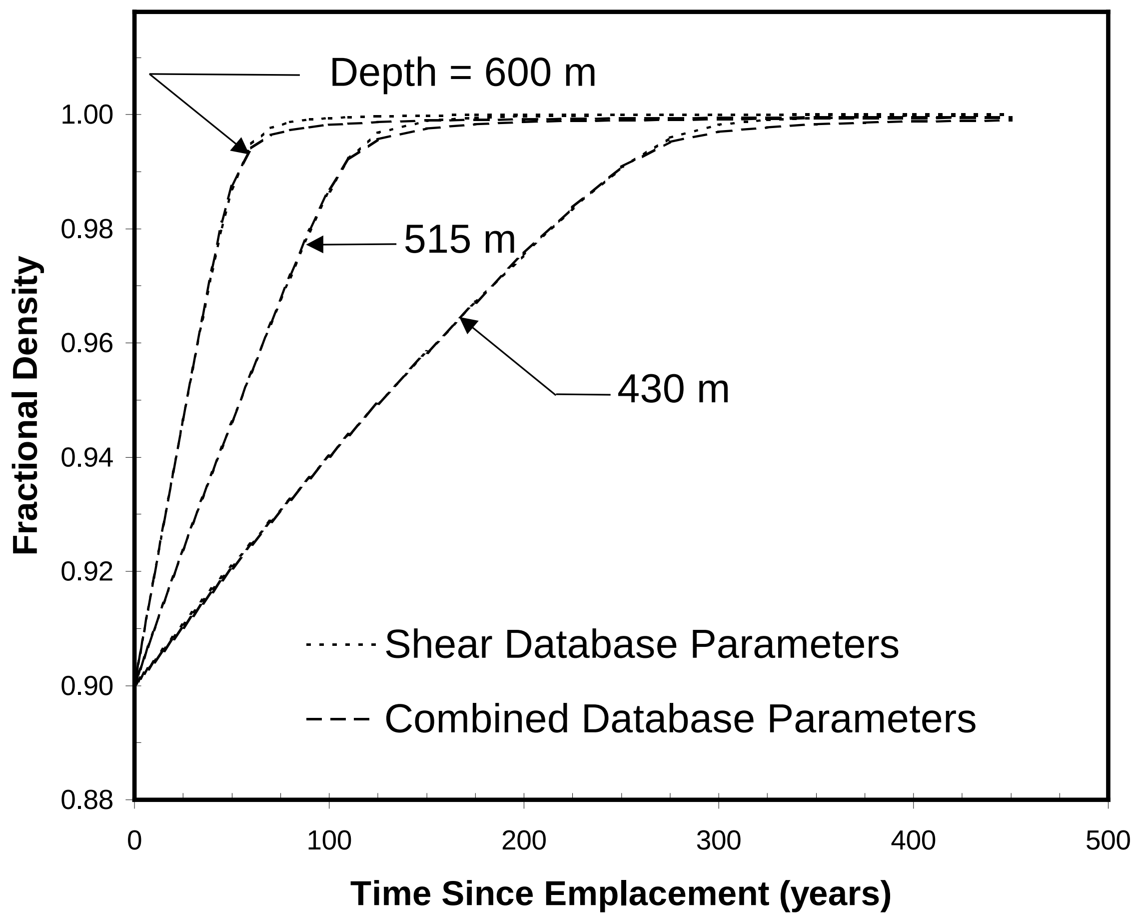


Figure 9. Calculated Fractional Density Versus Time for Crushed Salt Compacted in the Shaft.

ATTACHMENT C

Summary Report for the AP-151 (PC3R) Performance Assessment, Revision 1

555489

Sandia National Laboratories
Waste Isolation Pilot Plant

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

Revision 1

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WIPP:1.4.1.2:PA:QA-L:554612

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Acknowledgement

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.

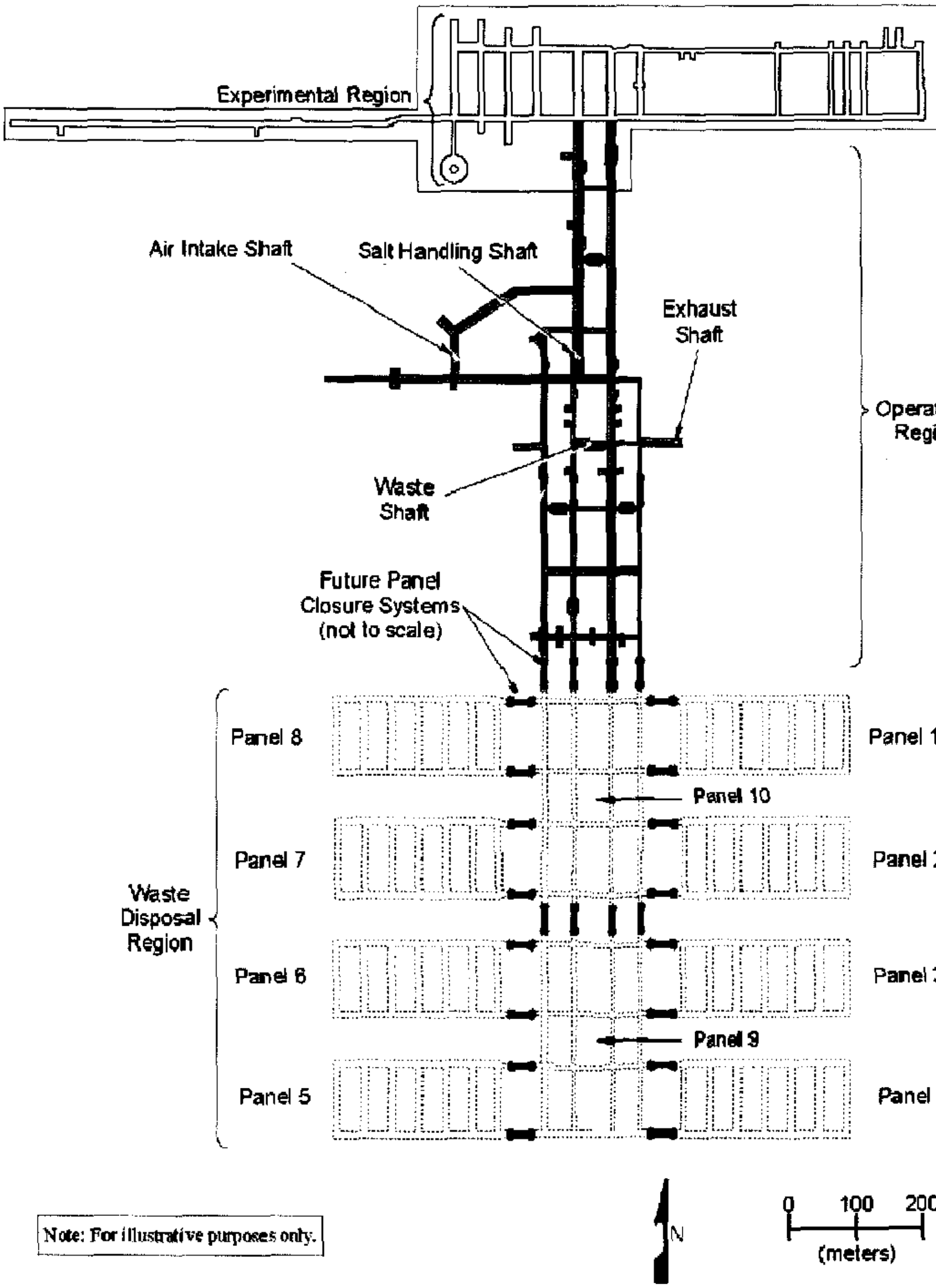

Figure 2-1: Historical WIPP Repository Layout

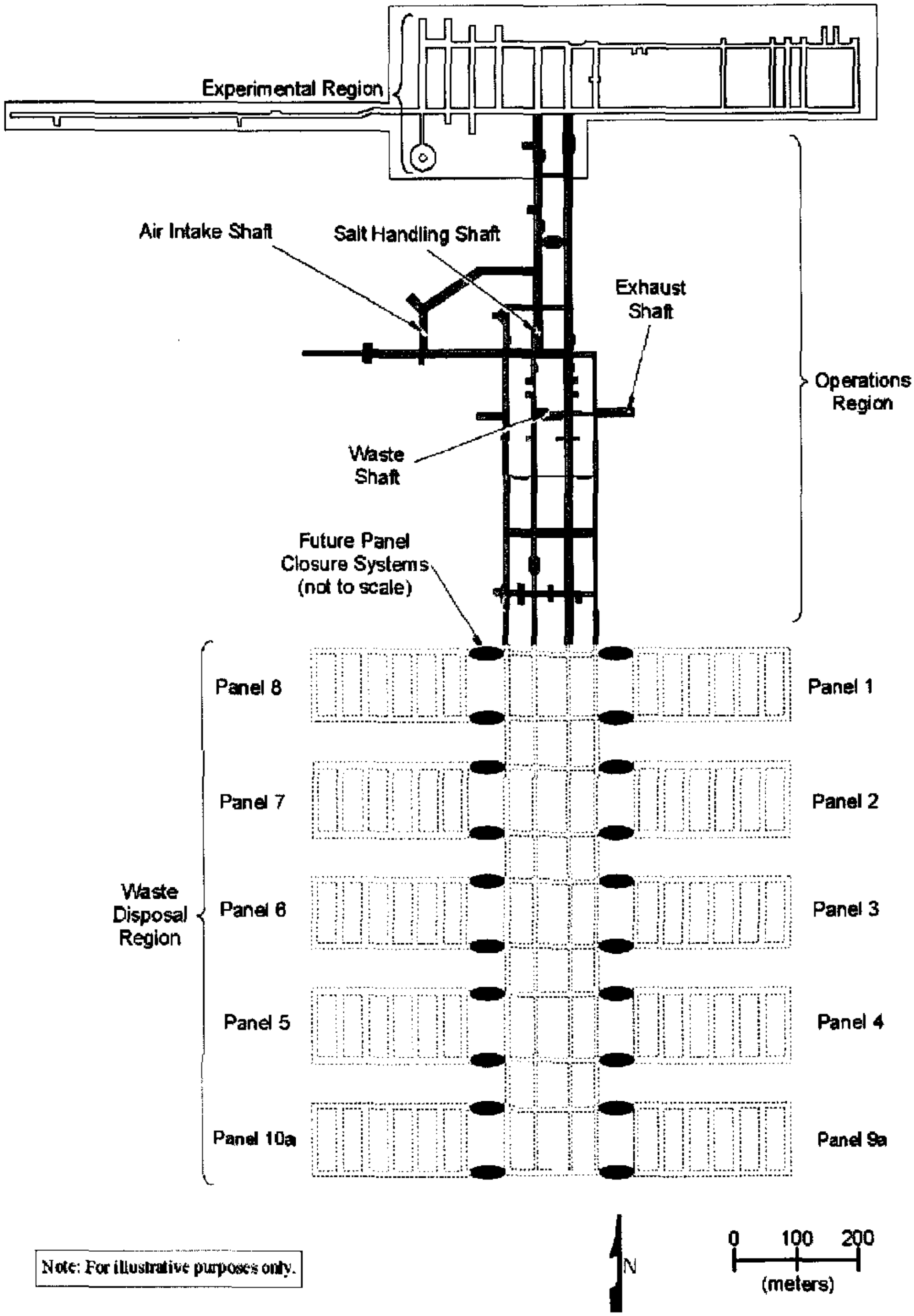

Figure 2-2: WIPP Layout Modeled in PC3R PA

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	8×10^{-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	1×10^{8}
PCS_T1:PO_MIN (Pa)	Minimum brine pressure for capillary model KPC=3	1.01325×10^{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.

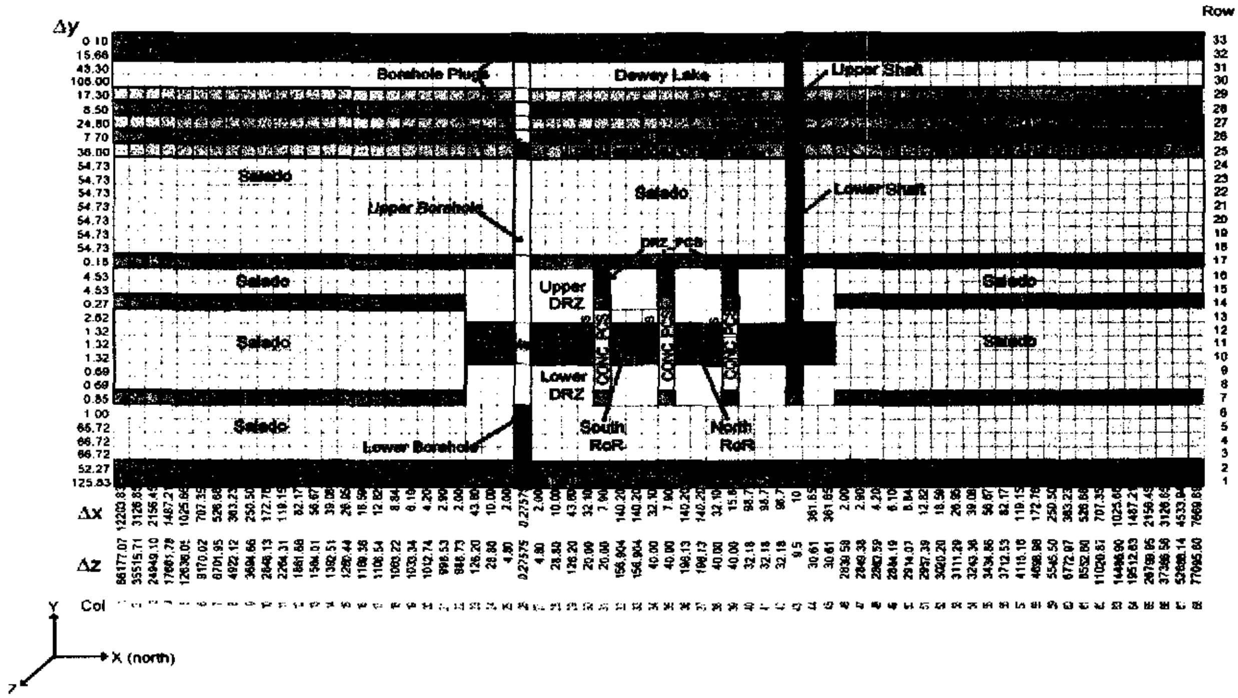

Figure 2-3: PABC-2009 BRAGFLO grid (Δx, Δy, and Δz dimensions in meters).

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.

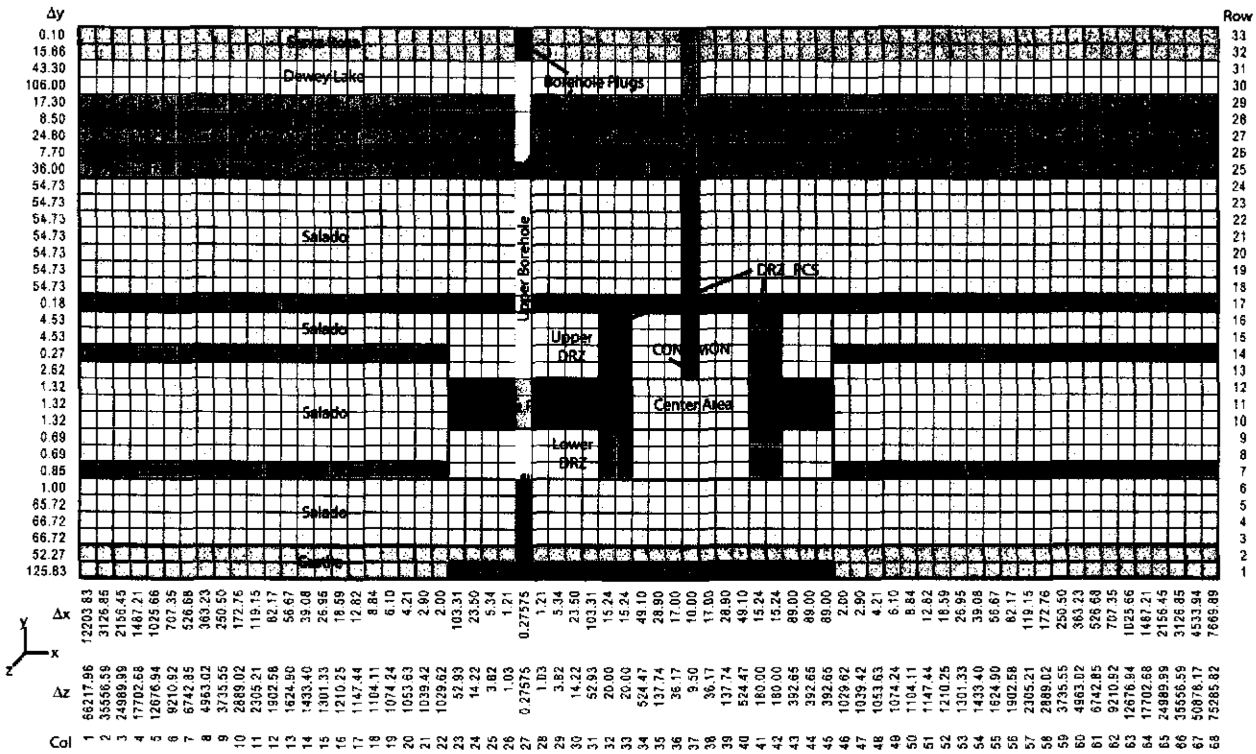

Figure 2-4: PC3R PA BRAGFLO grid (Δx, Δy, and Δz dimensions in meters).

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.

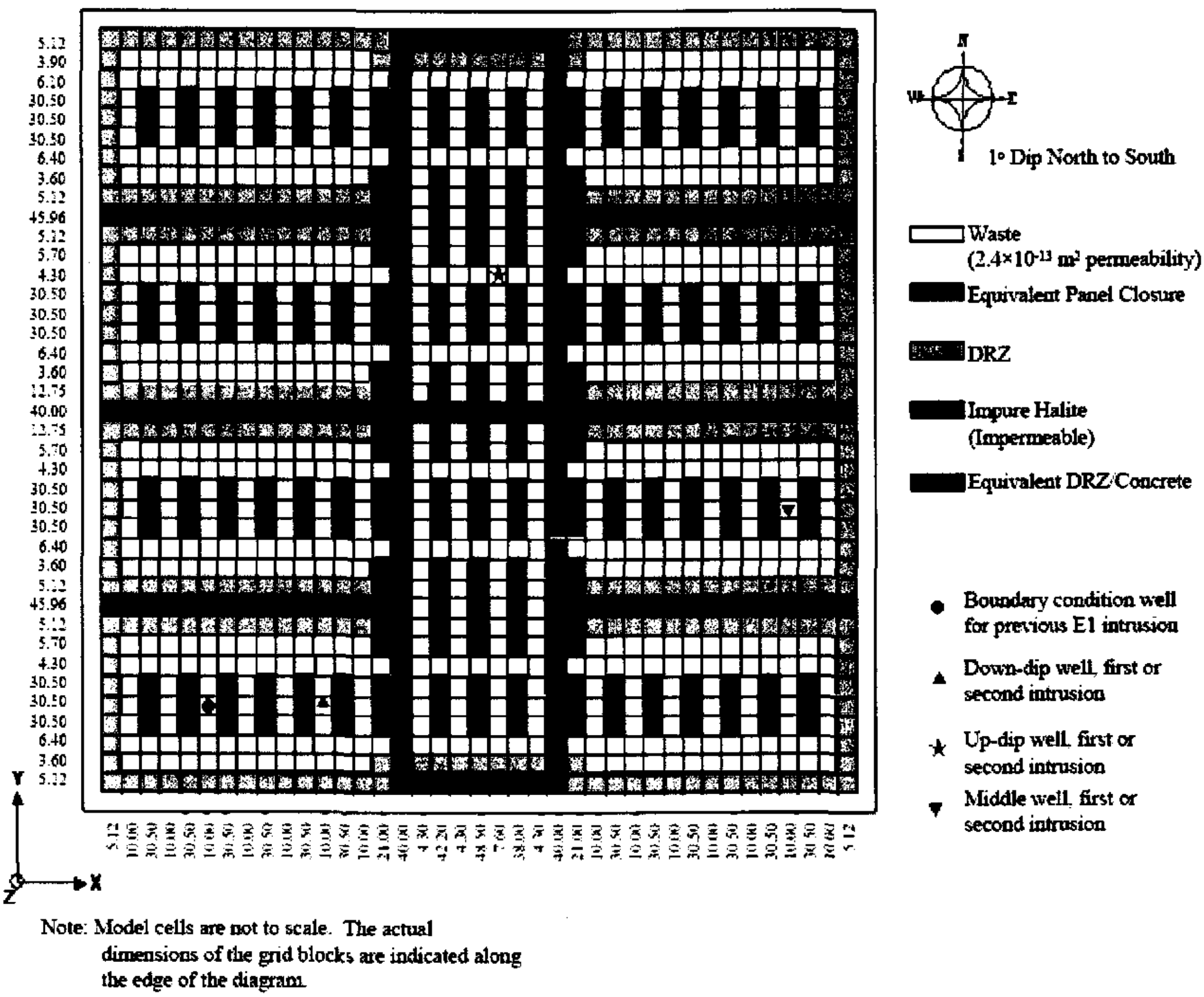

Figure 2-5: PABC-2009 DBR material map (logical grid).

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.

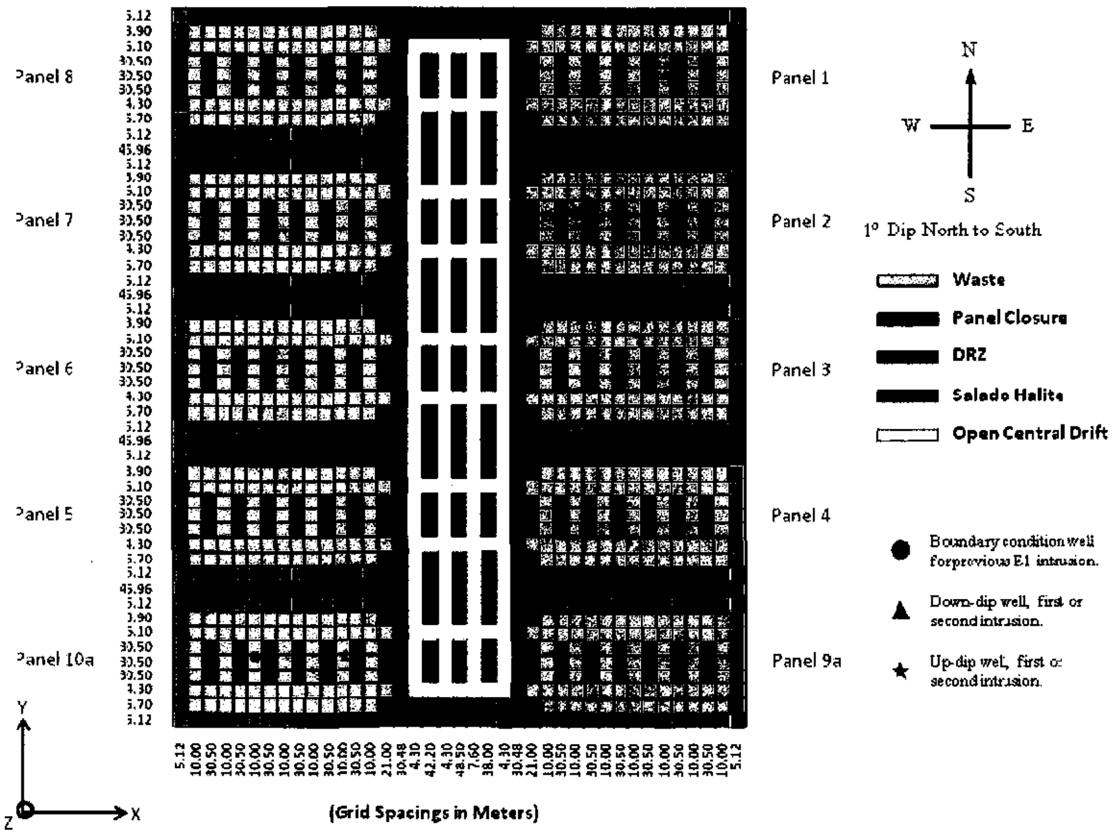

Figure 2-6: PC3R PA DBR material map (logical grid).

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.

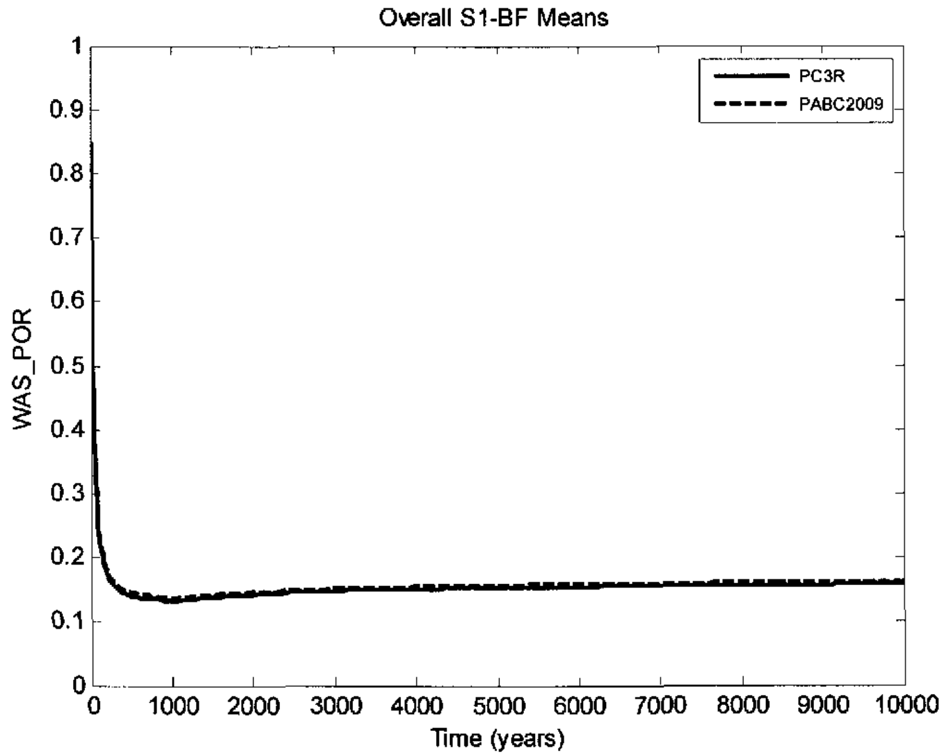

Figure 5-1: Overall Means of Volume Averaged Porosity for the Waste Panel, Scenario S1-BF

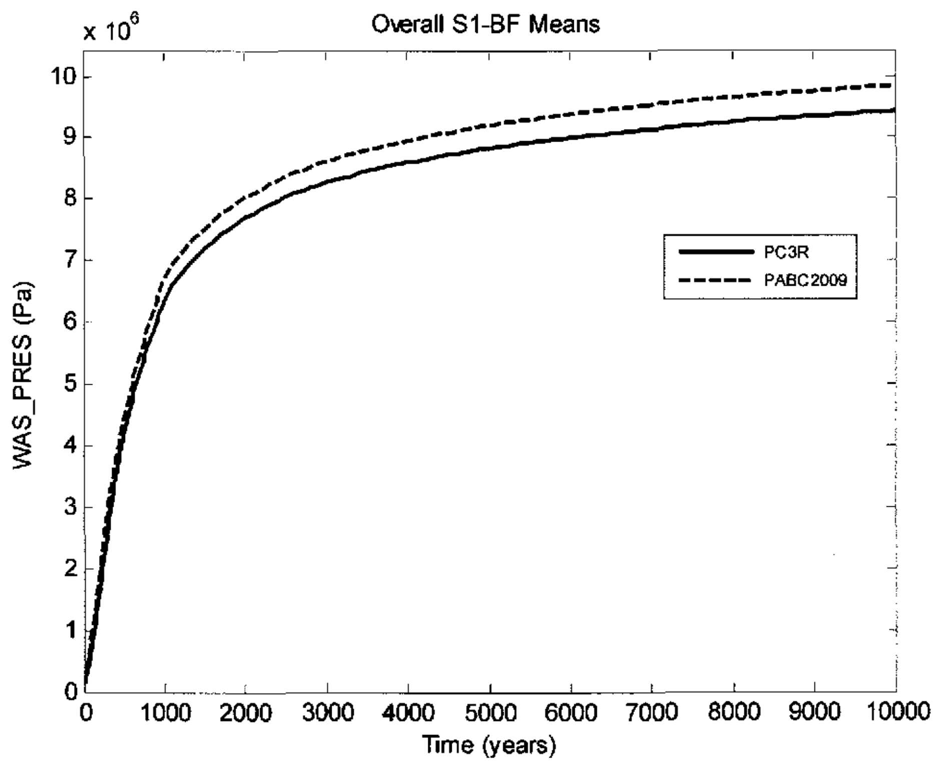

Figure 5-2: Overall Means of Volume Averaged Pressure for the Waste Panel, Scenario S1-BF

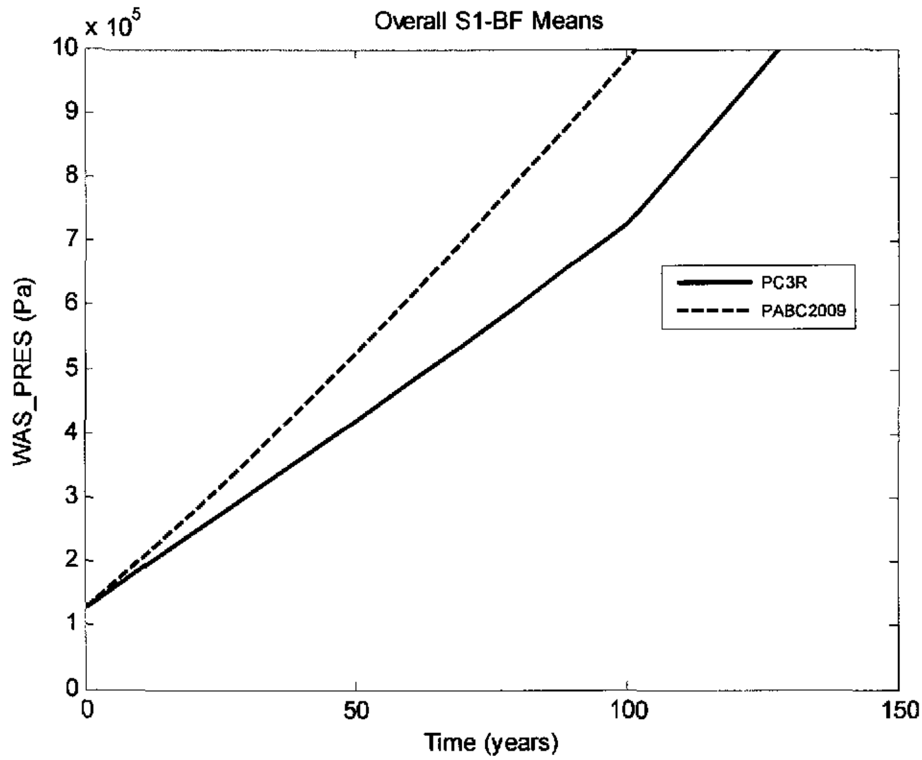

Figure 5-3: Overall Means of Volume Averaged Pressure for the Waste Panel During the First 150 Years After Closure, Scenario S1-BF

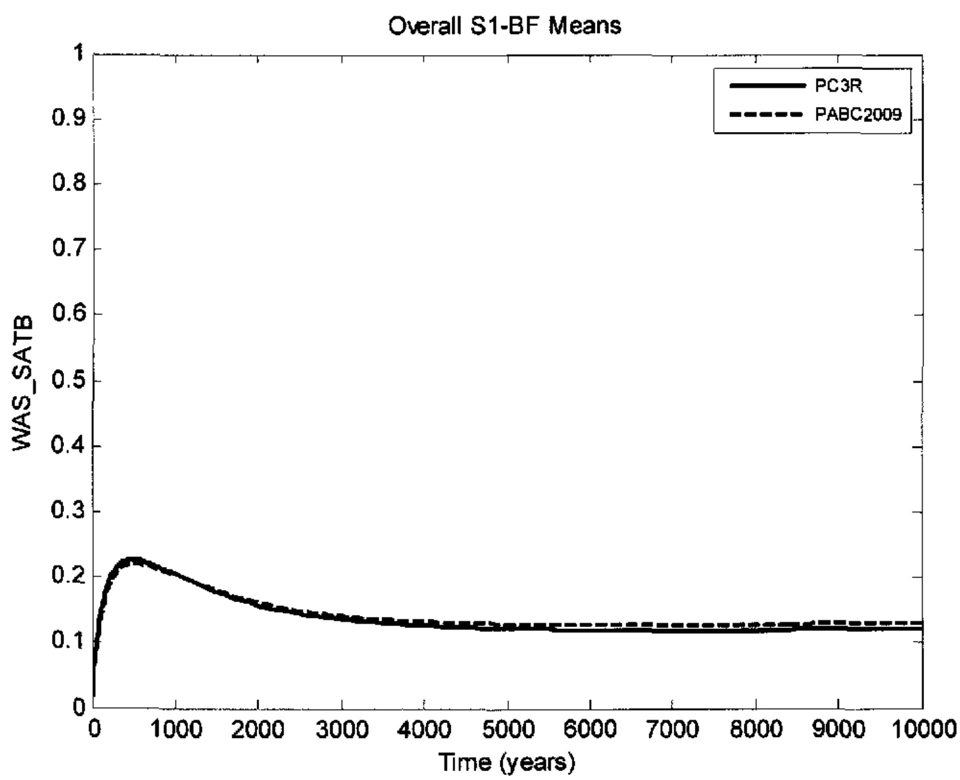

Figure 5-4: Overall Means of Brine Saturation in the Waste Panel, Scenario S1-BF

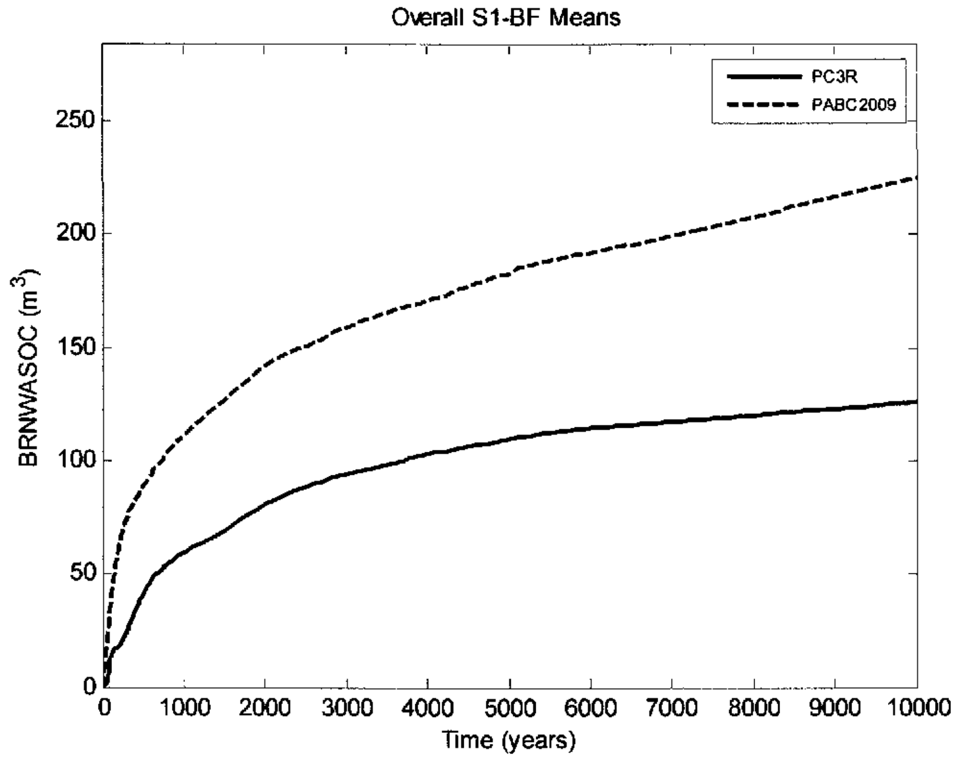

Figure 5-5: Overall Means of Total Brine Flow Out of the Waste Panel, Scenario S1-BF

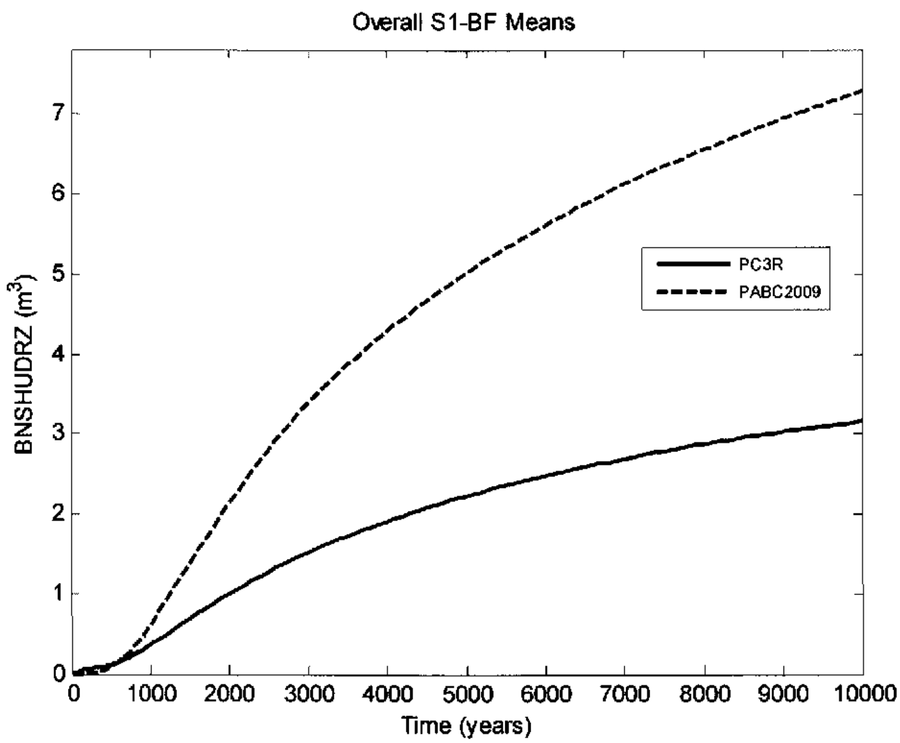

Figure 5-6: Overall Means of Total Brine Flow Up the Shaft, Scenario S1-BF.

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.

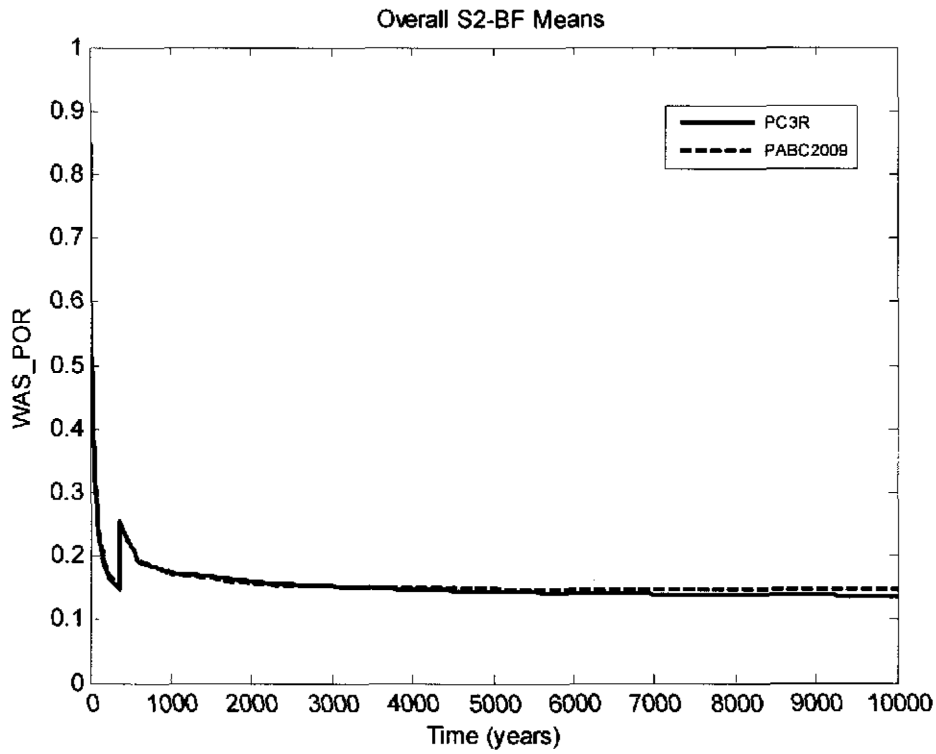

Figure 5-7: Overall Means of Volume Averaged Porosity for the Waste Panel, Scenario S2-BF

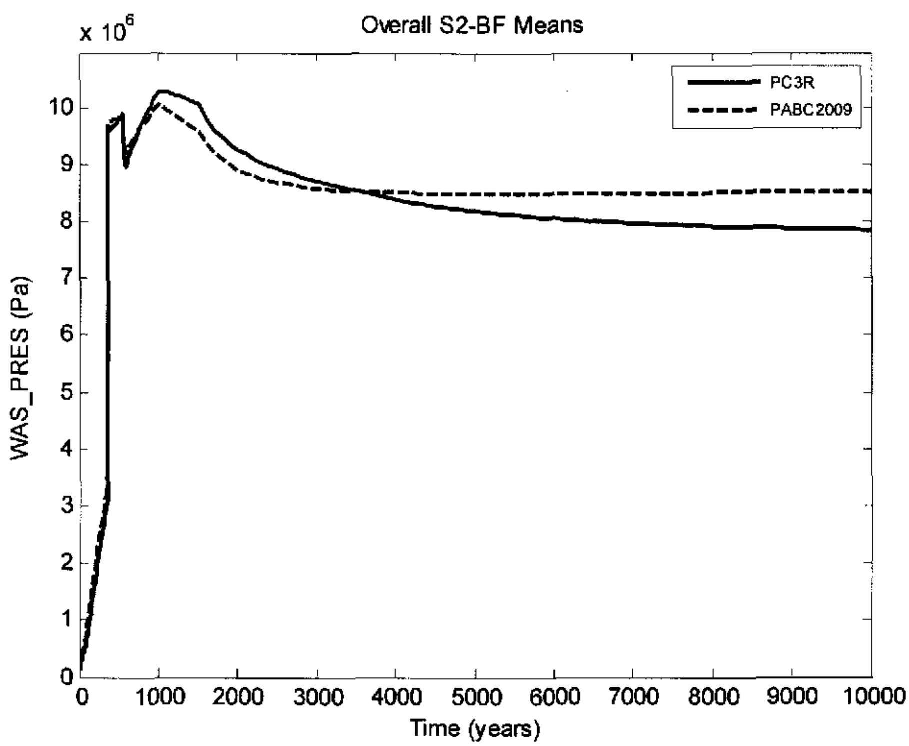

Figure 5-8: Overall Means of Volume Averaged Pressure for the Waste Panel, Scenario S2-BF

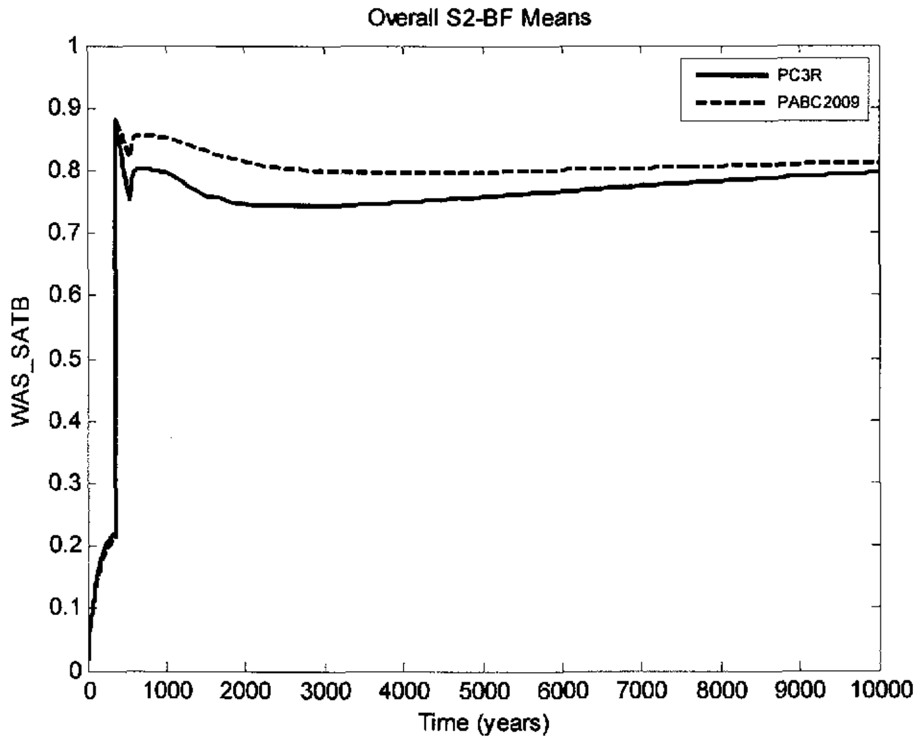

Figure 5-9: Overall Means of Brine Saturation in the Waste Panel, Scenario S2-BF

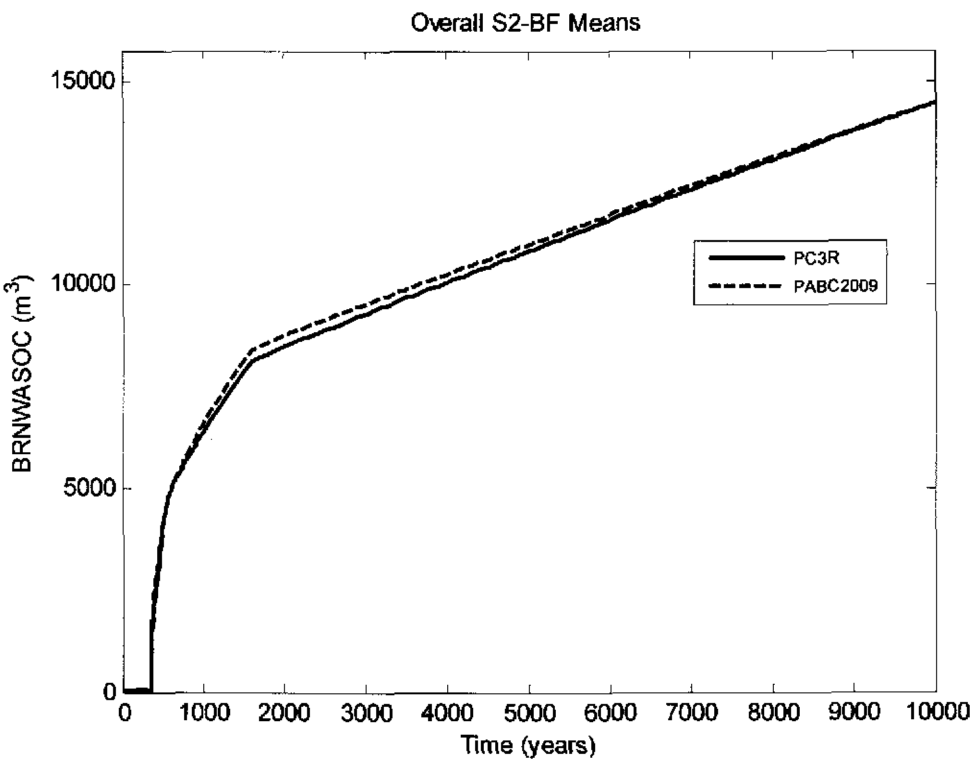

Figure 5-10: Overall Means of Total Brine Flow Out of the Waste Panel, Scenario S2-BF

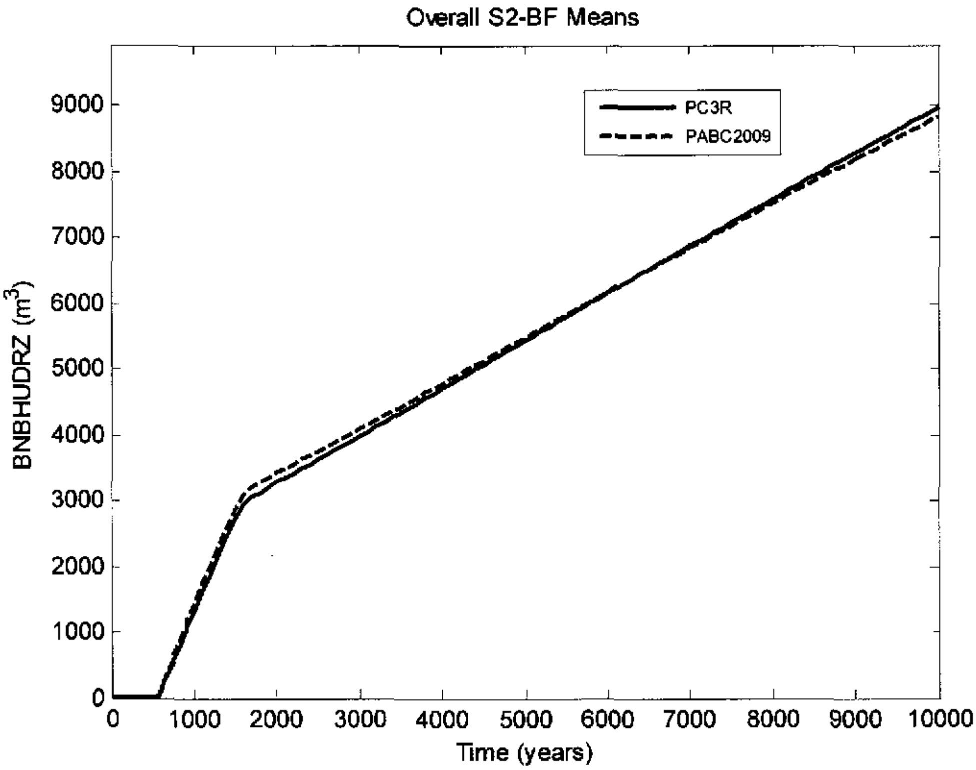

Figure 5-11: Overall Means of Total Brine Flow Up the Borehole, Scenario S2-BF

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.

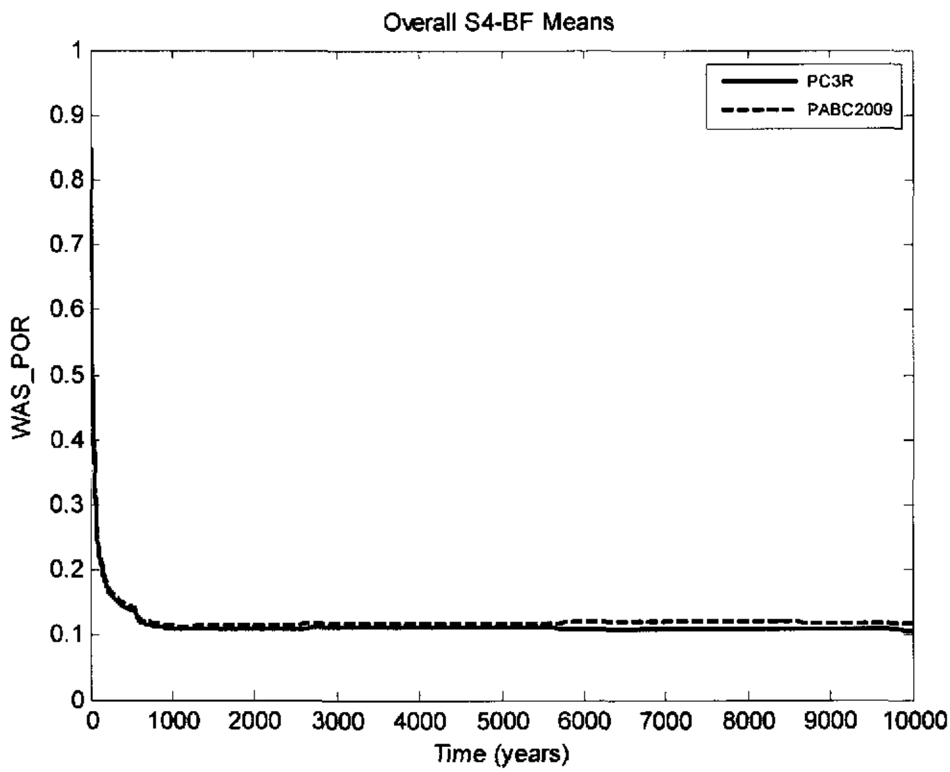

Figure 5-12: Overall Means of Volume Averaged Porosity for the Waste Panel, Scenario S4-BF

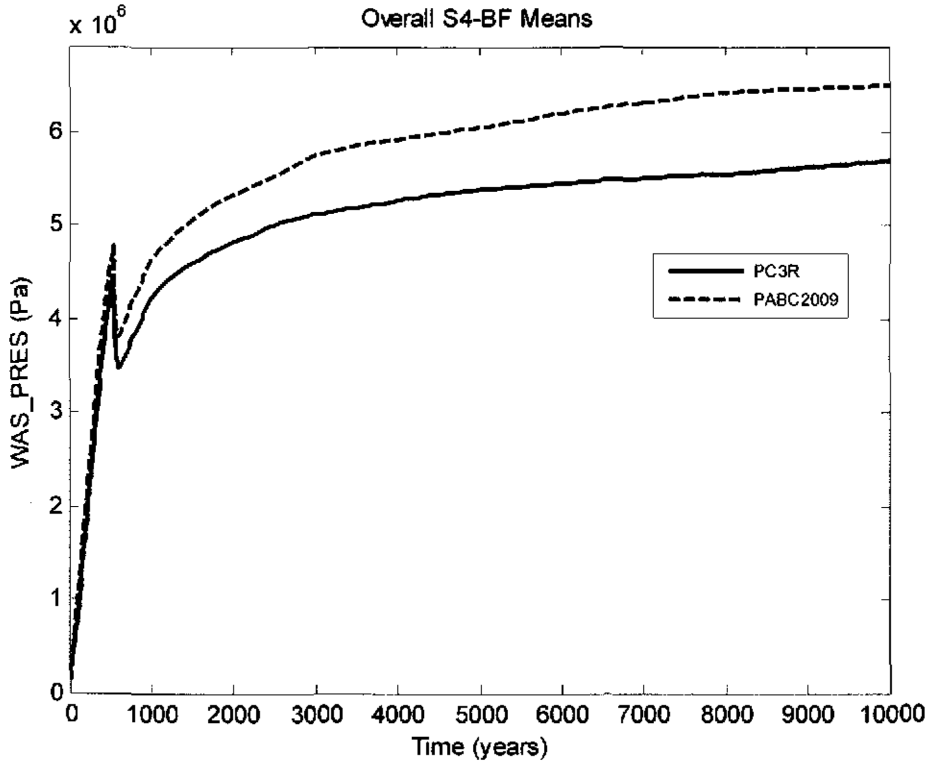

Figure 5-13: Overall Means of Volume Averaged Pressure for the Waste Panel, Scenario S4-BF

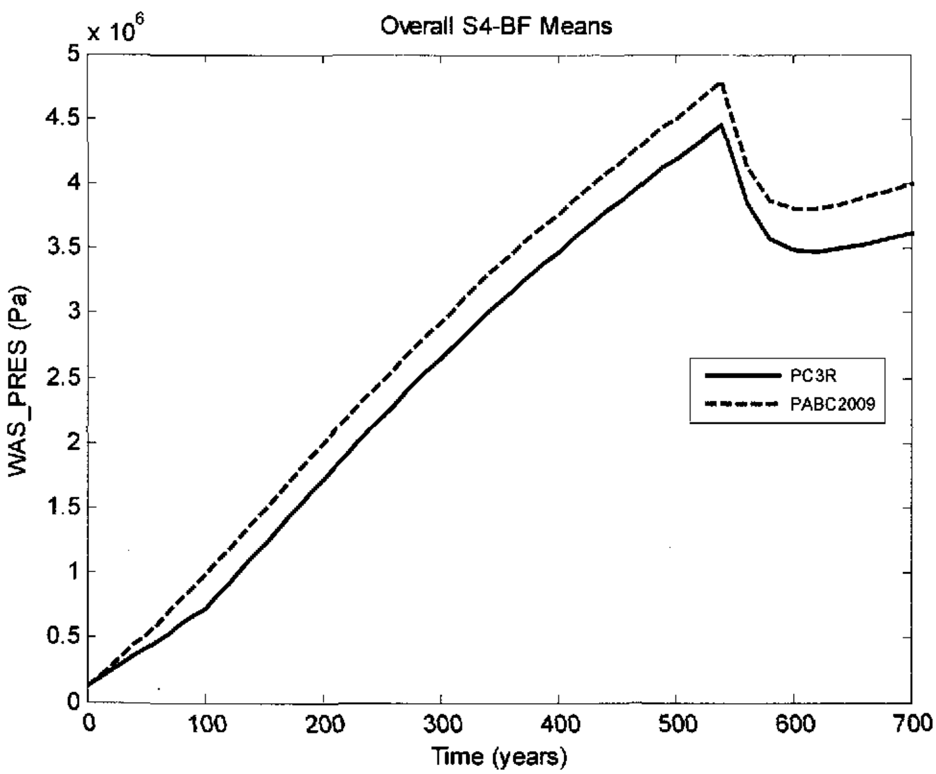

Figure 5-14: Overall Means of Volume Averaged Pressure for the Waste Panel During the First 700 Years After Closure, Scenario S4-BF

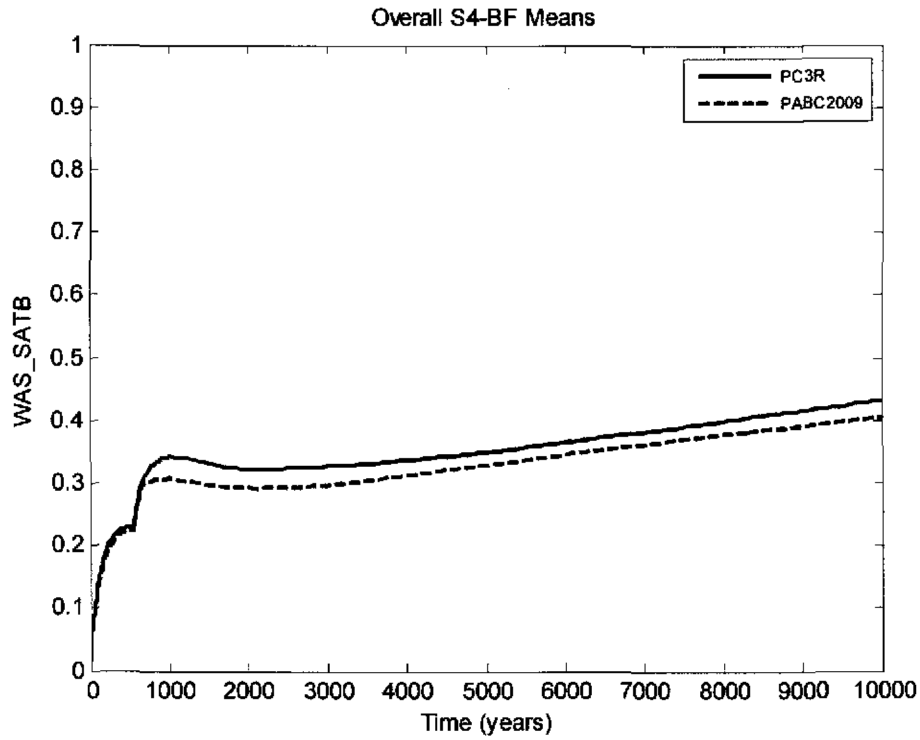

Figure 5-15: Overall Means of Brine Saturation in the Waste Panel, Scenario S4-BF

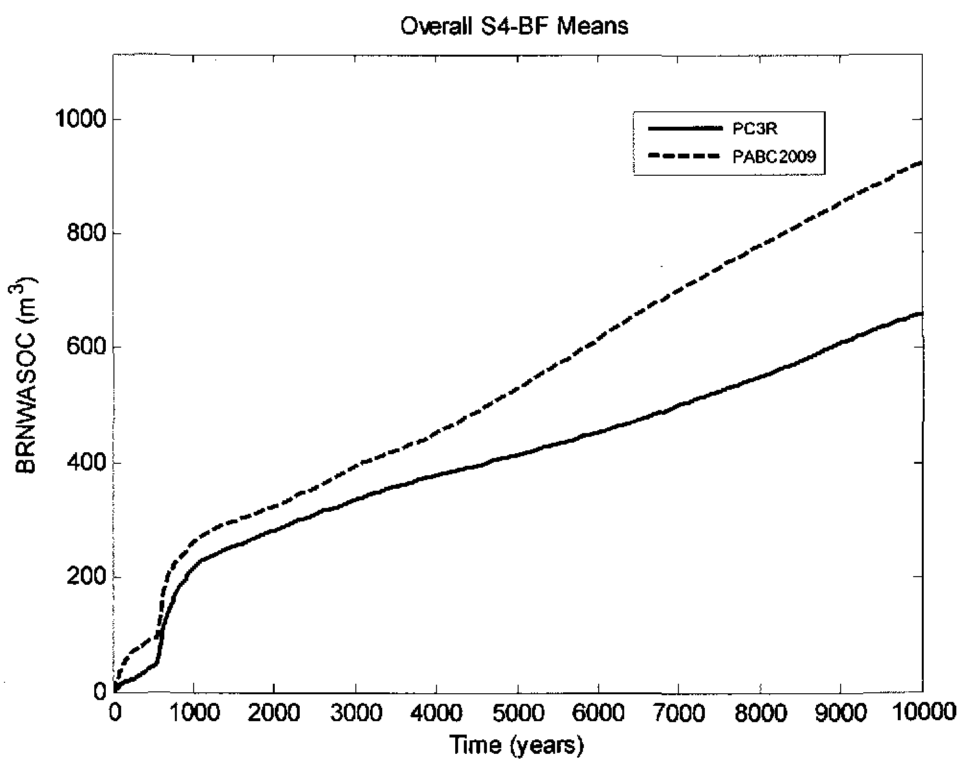

Figure 5-16: Overall Means of Total Brine Flow Out of the Waste Panel, Scenario S4-BF

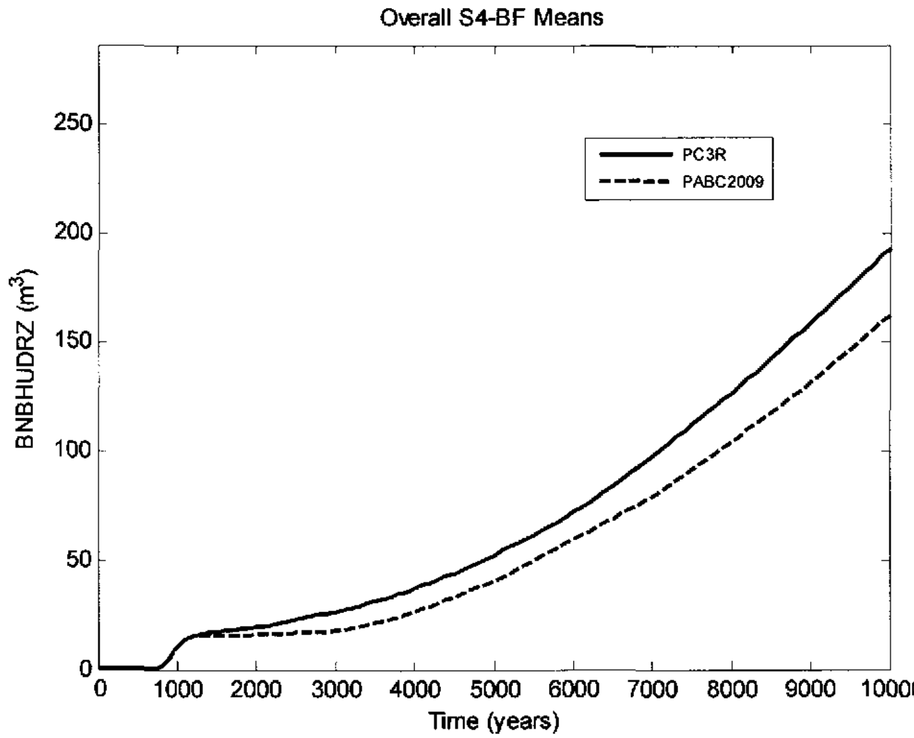

Figure 5-17: Overall Means of Total Brine Flow Up the Borehole, Scenario S4-BF

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.

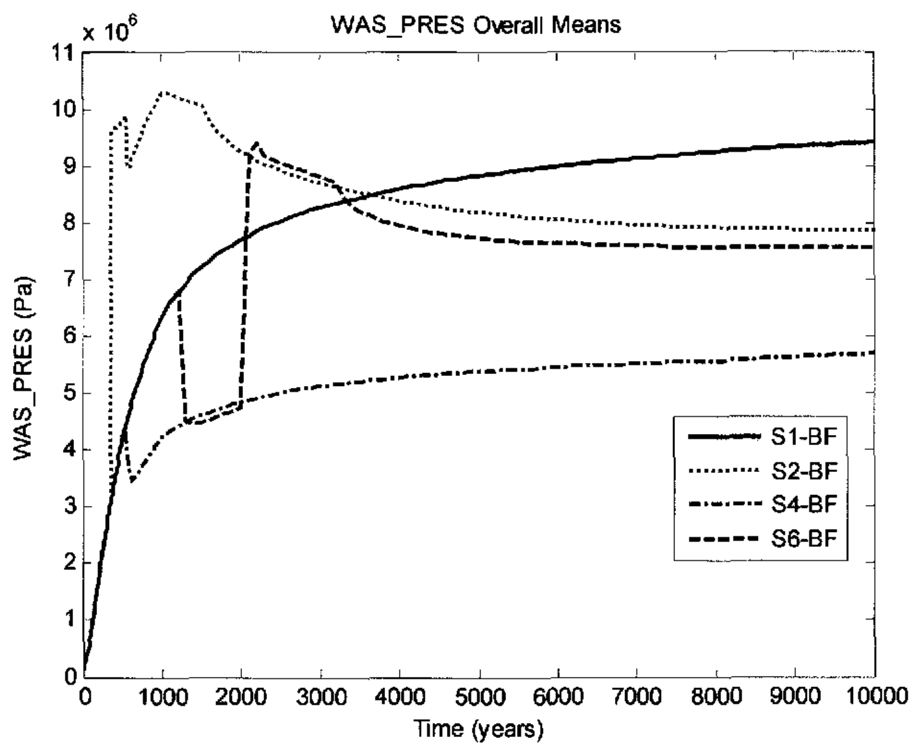

Figure 5-18: PC3R PA Overall Waste Panel Pressure Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

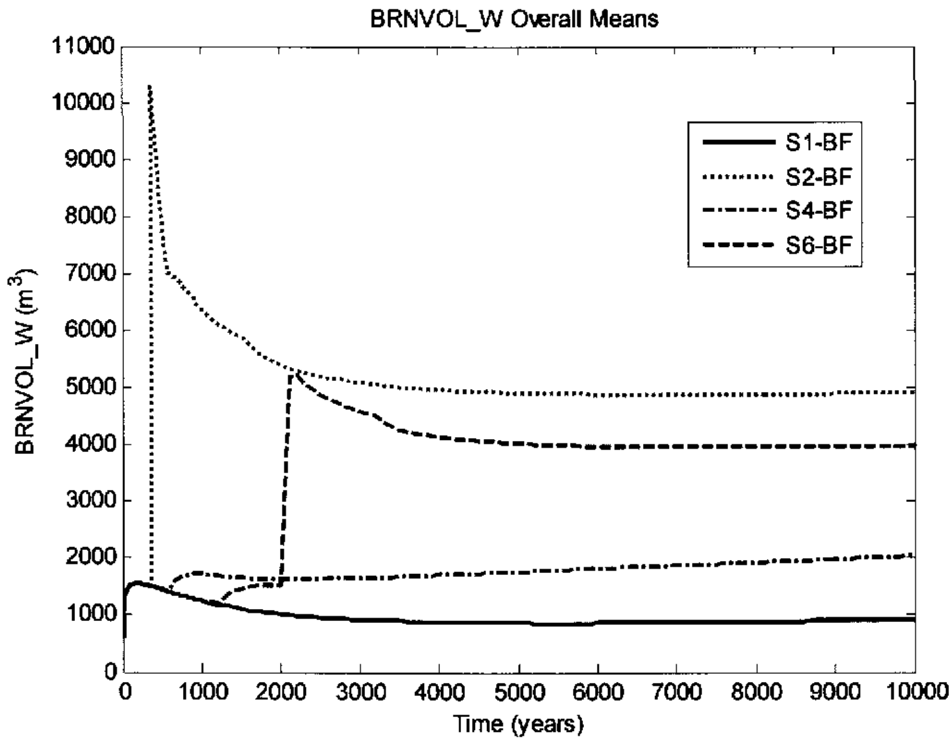

Figure 5-19: PC3R PA Overall Waste Panel Brine Volume Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

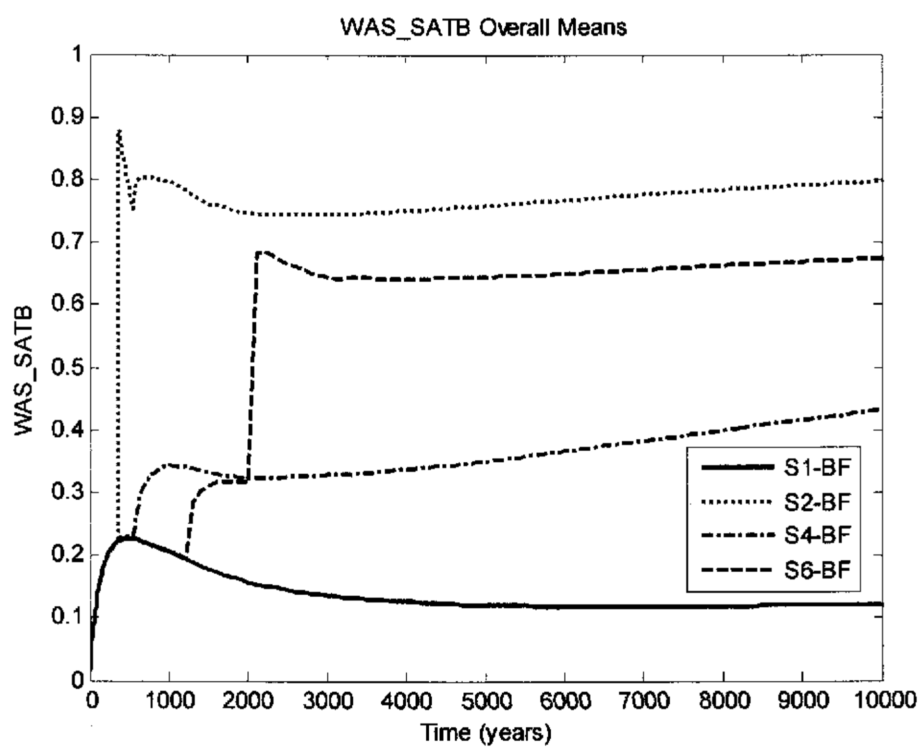

Figure 5-20: PC3R PA Overall Waste Panel Brine Saturation Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

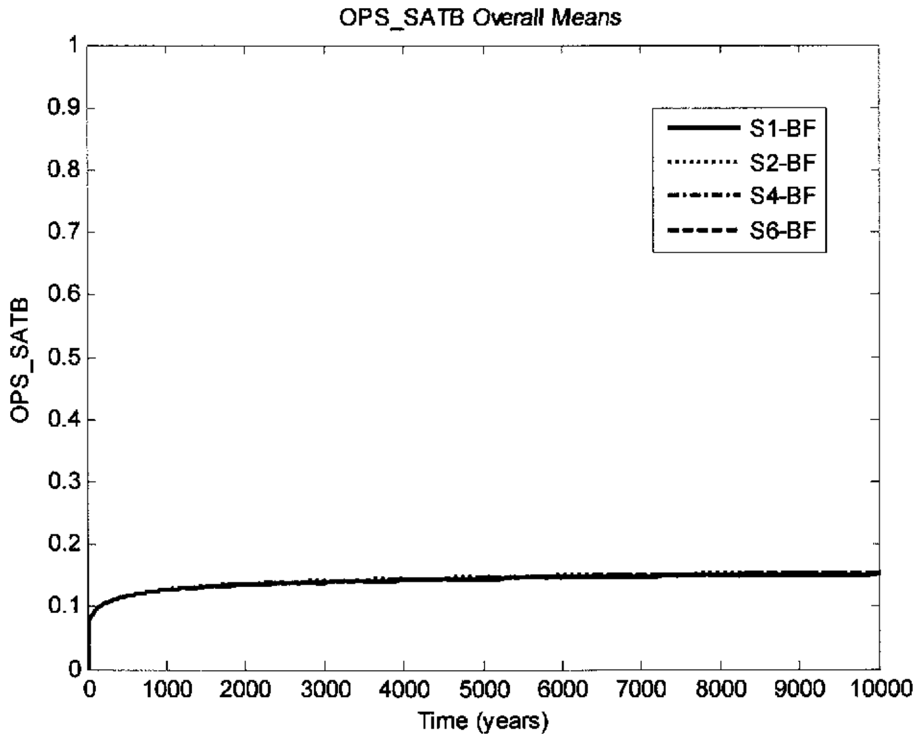

Figure 5-21: PC3R PA Overall Central Region Brine Saturation Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

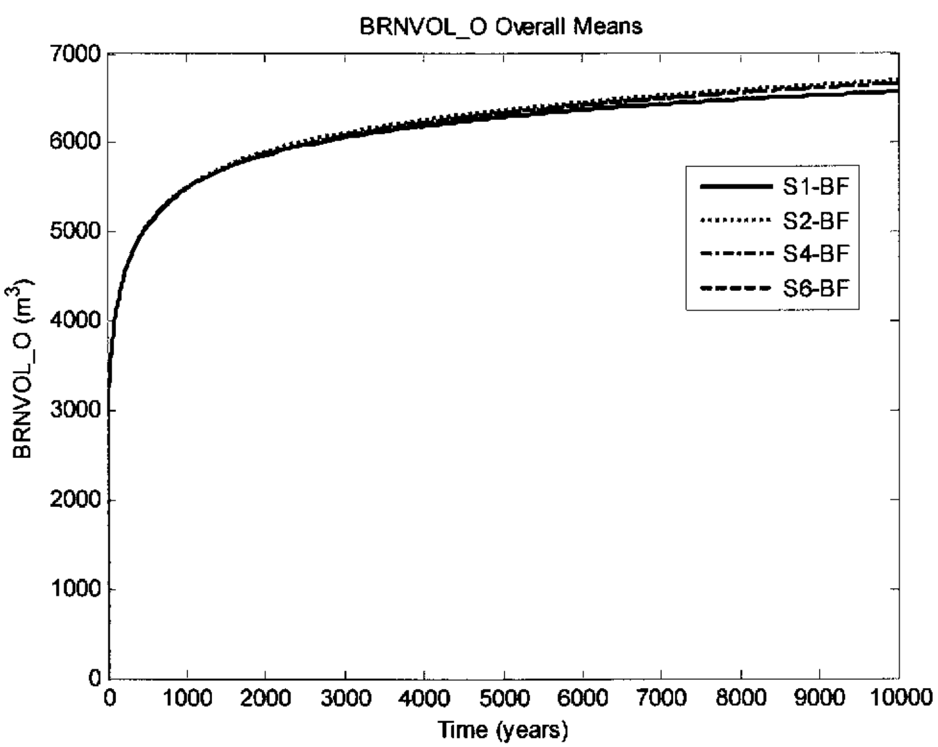

Figure 5-22: PC3R PA Overall Central Region Brine Volume Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

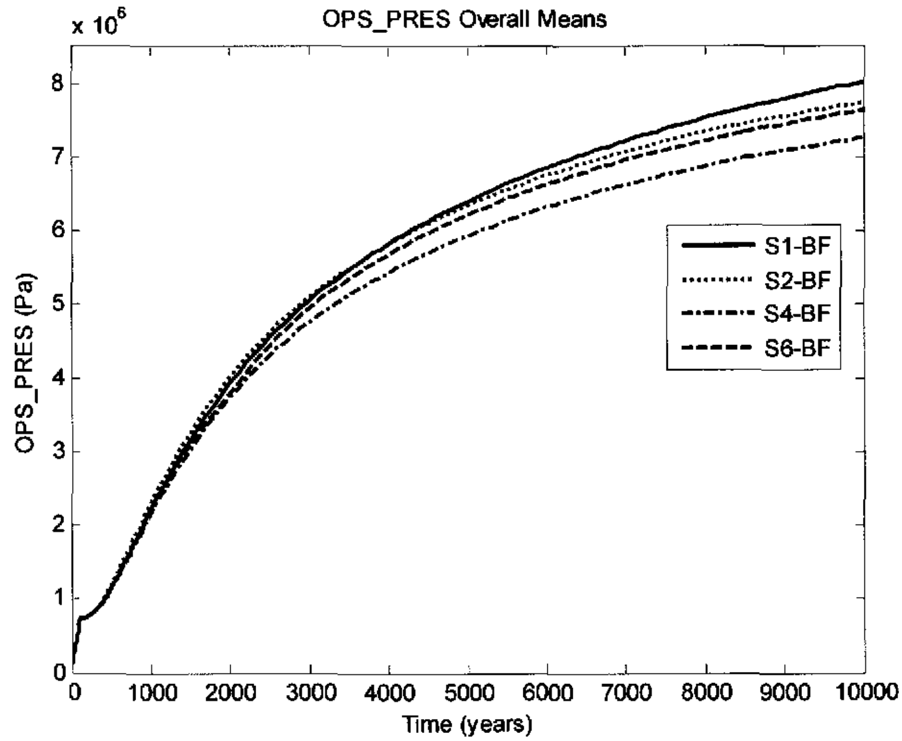

Figure 5-23: PC3R PA Overall Central Region Pressure Means, Scenarios S1-BF, S2-BF, S4-BF, S6-BF

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.

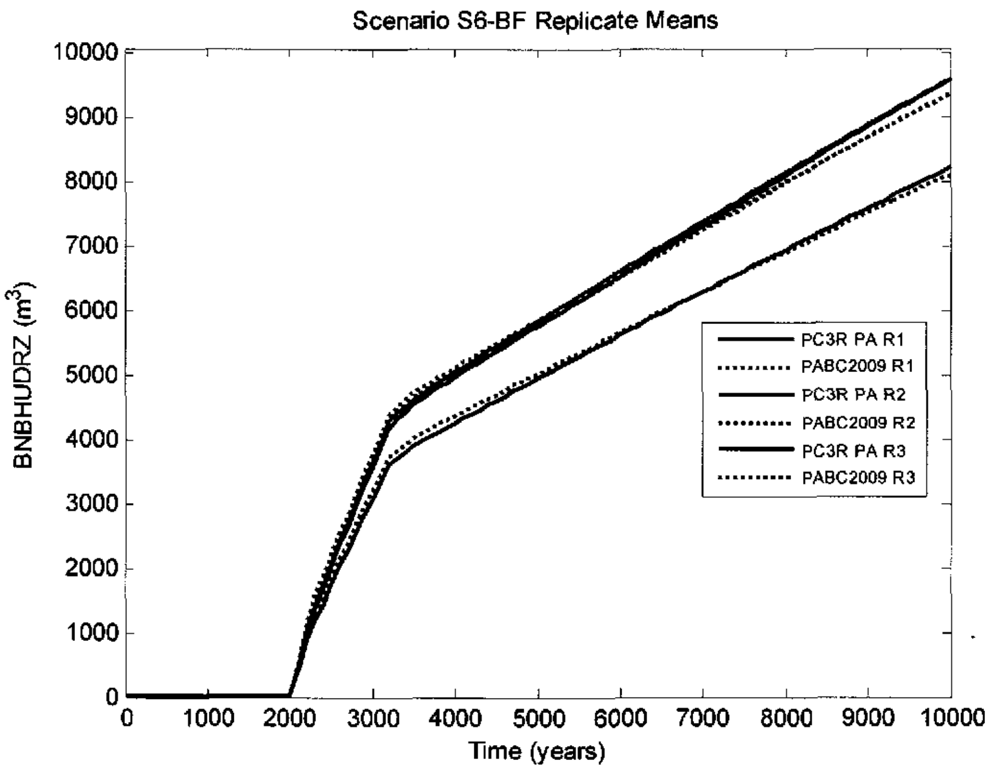

Figure 5-24: PC3R PA and PABC-2009 Replicate Means of Cumulative Flow up the Borehole

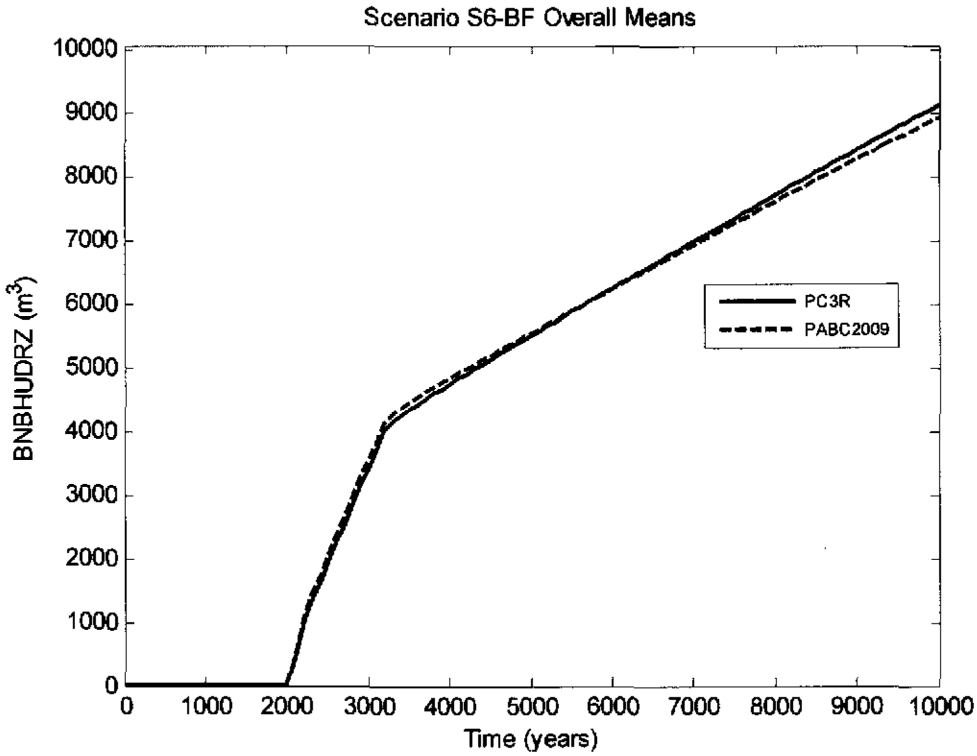

Figure 5-25: PC3R PA and PABC-2009 Overall Means of Cumulative Flow up the Borehole

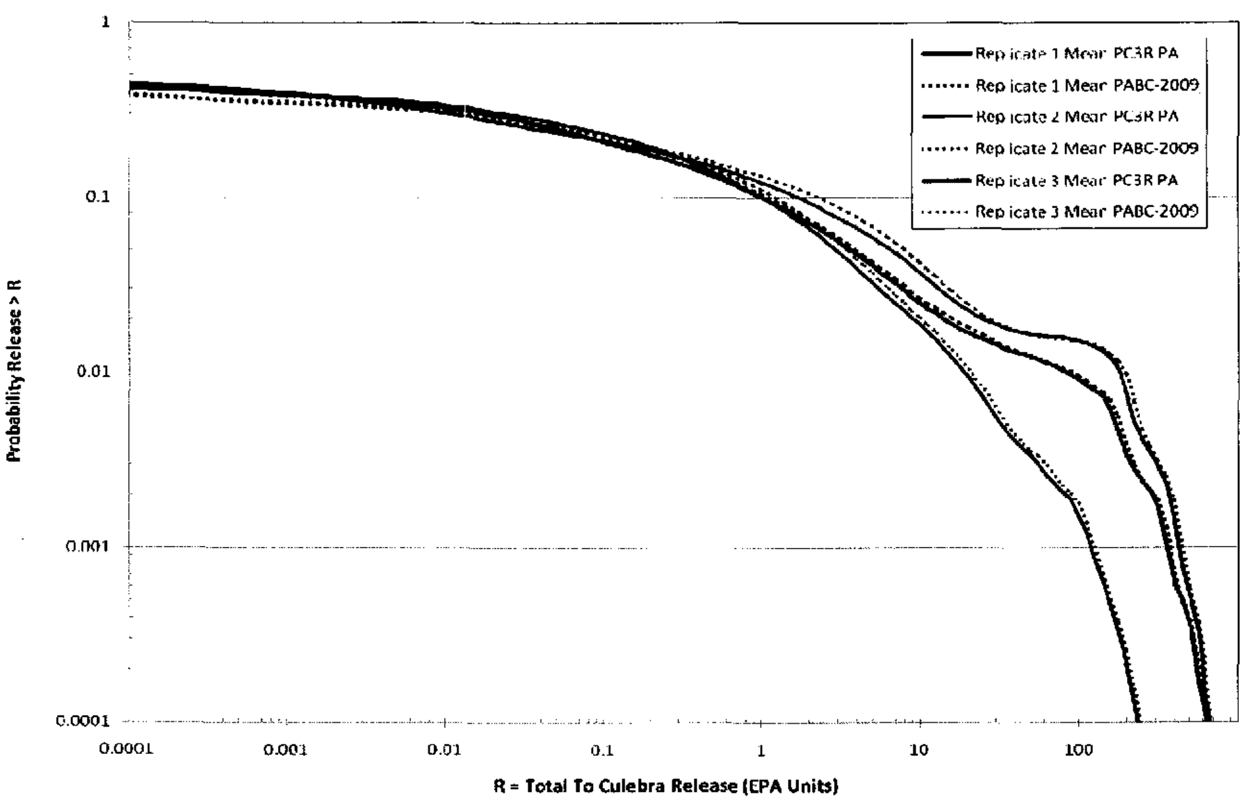

Figure 5-26: PC3R PA and PABC-2009 Replicate Mean CCDFs for Normalized Transport Releases to the Culebra

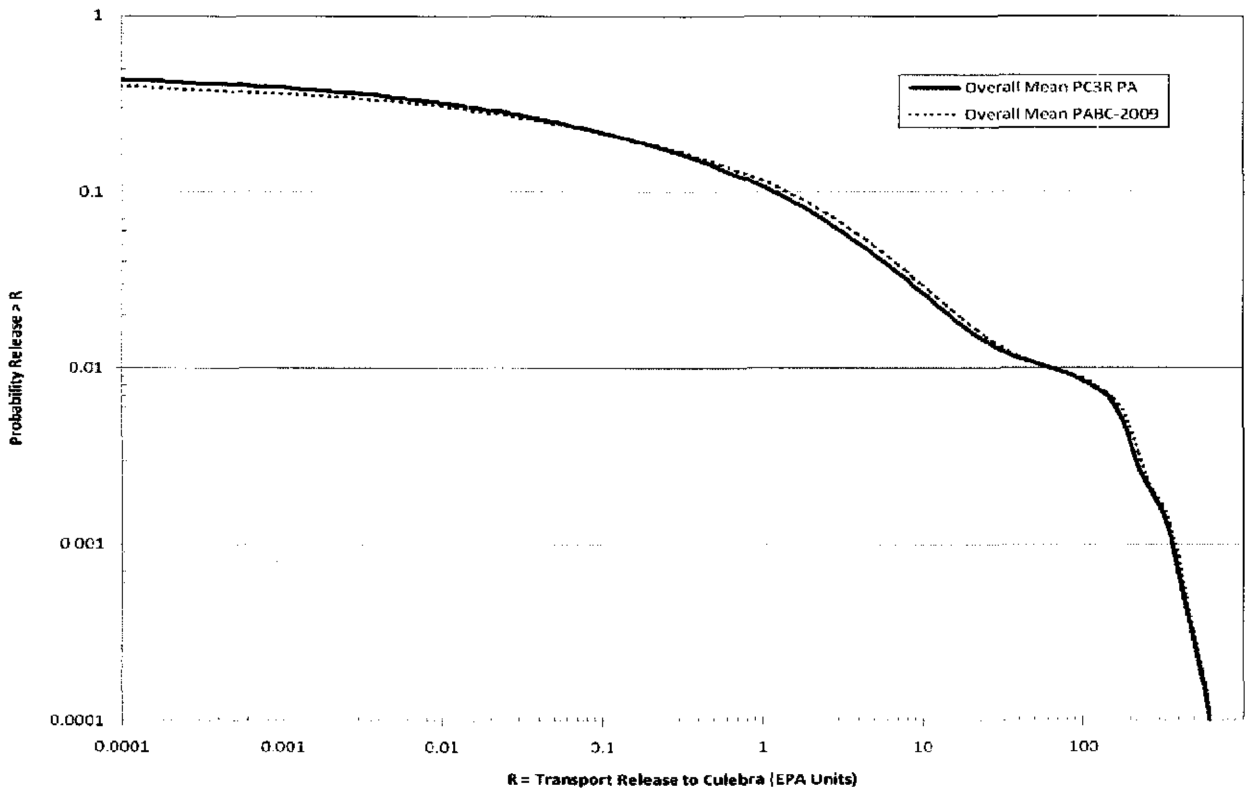

Figure 5-27: PC3R PA and PABC-2009 Overall Mean CCDFs for Transport Releases to the Culebra

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).

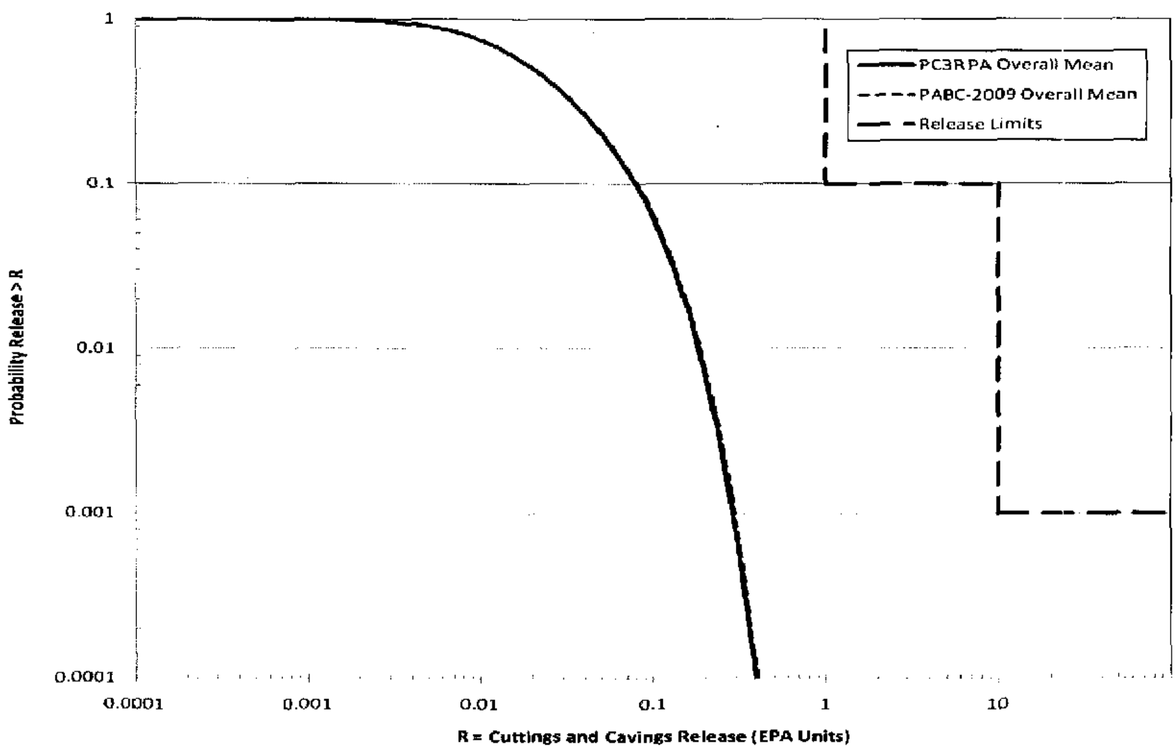

Figure 5-28: PC3R PA and PABC-2009 Overall Mean CCDFs for Normalized Cuttings and Cavings Releases

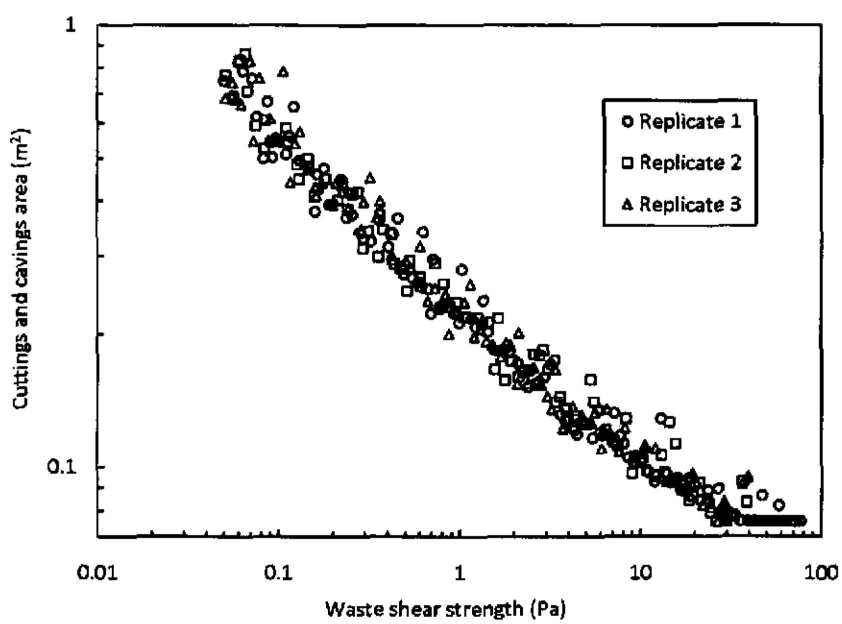

Figure 5-29: Cuttings and Cavings Area as a Function of Waste Shear Strength

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.

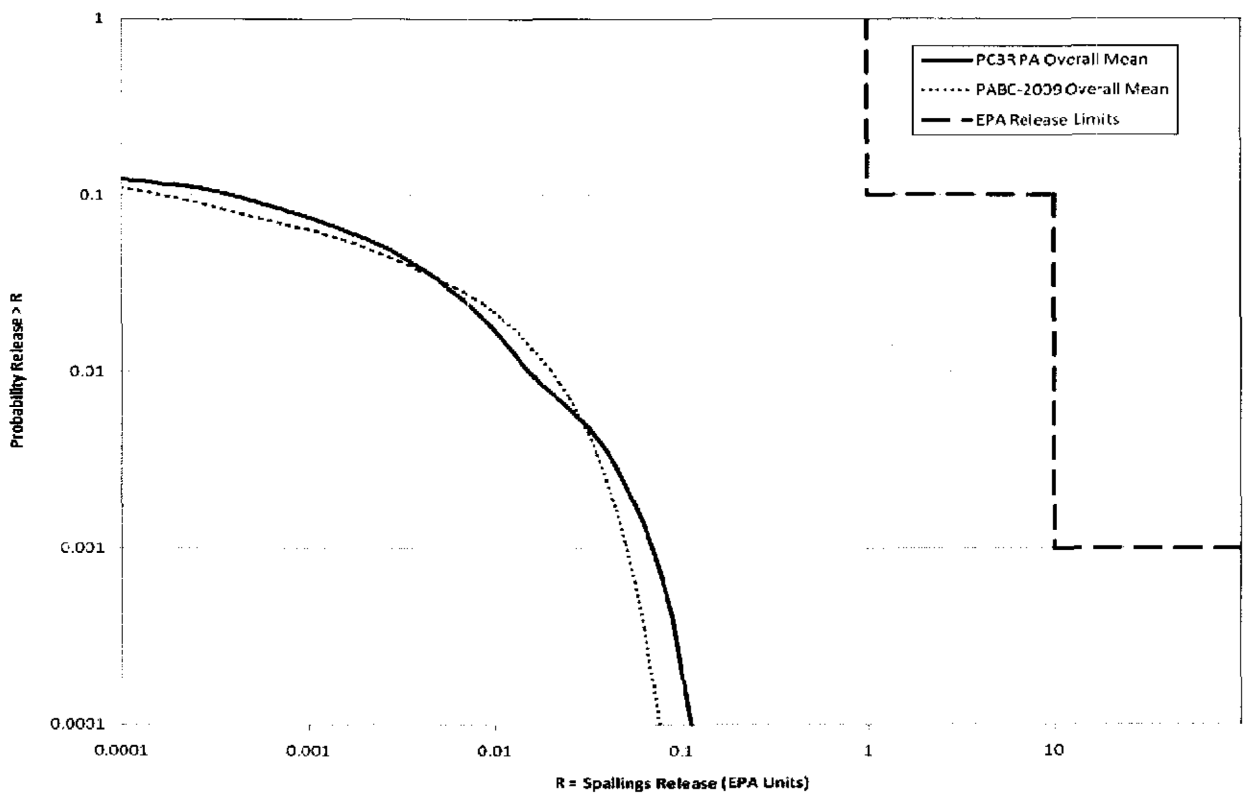

Figure 5-30: PC3R PA and PABC-2009 Overall Mean CCDFs for Normalized Spallings Releases

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.

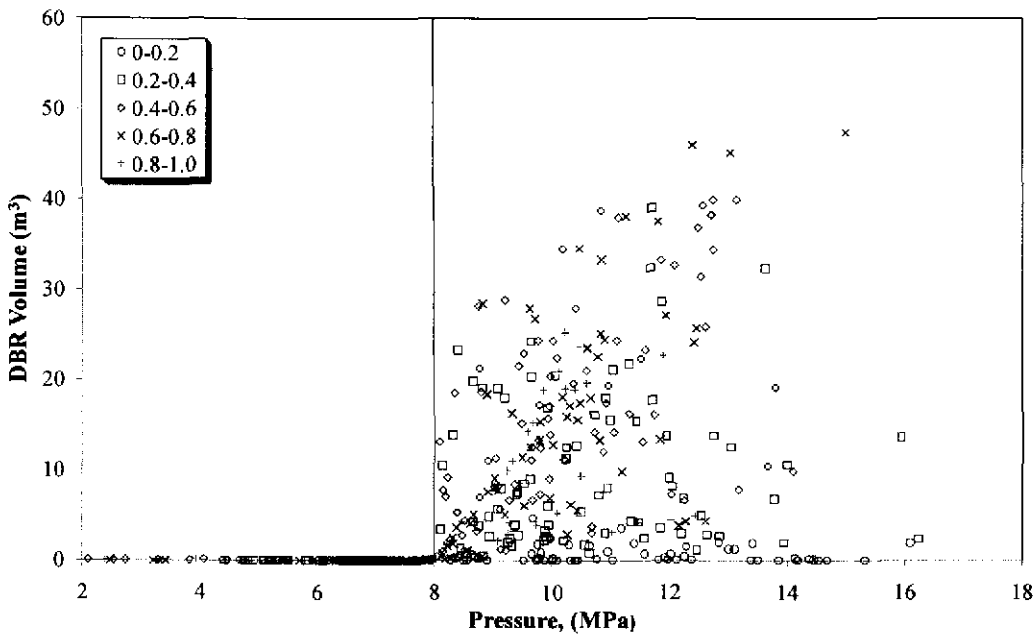

Figure 5-31: DBR Volume vs. Pressure, Scenario S2-DBR, Replicate 1, Lower Intrusion, PC3R PA

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.

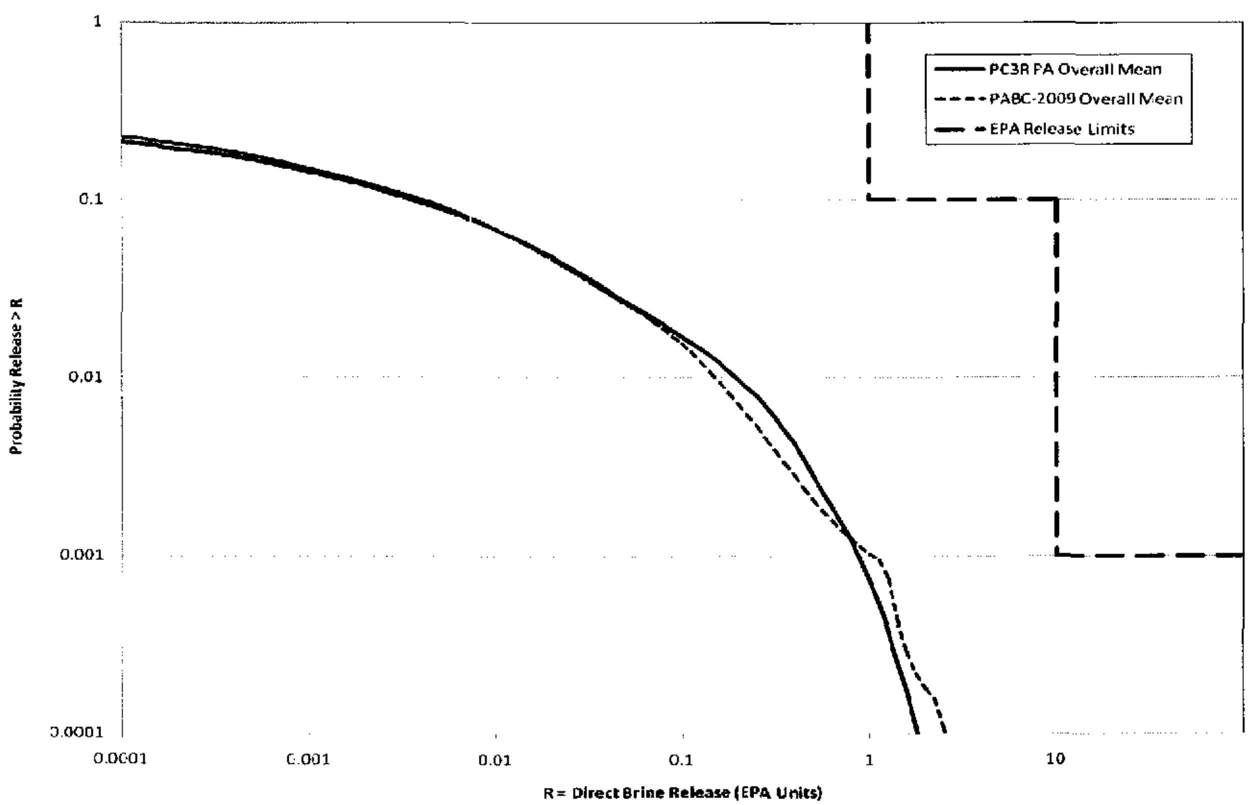

Figure 5-32: PC3R PA and PABC-2009 Overall Mean CCDFs for Normalized Direct Brine Releases

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

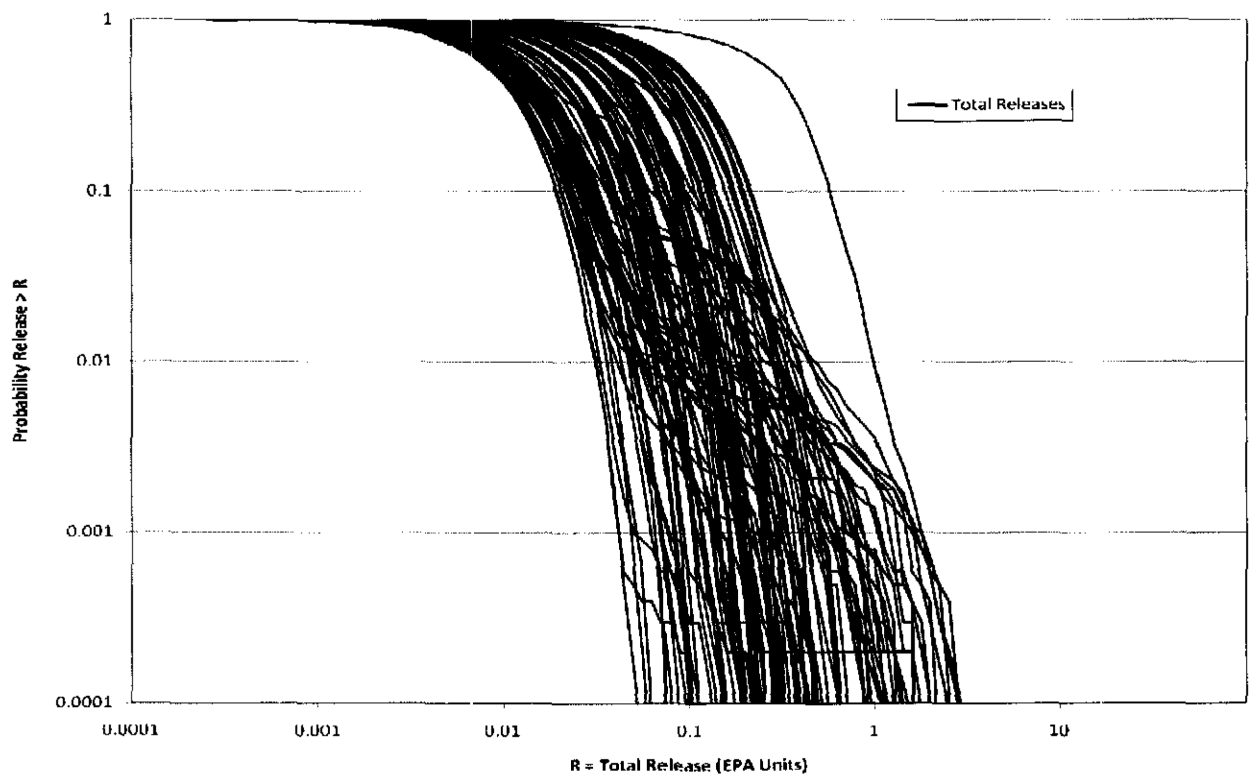

Figure 5-33: PC3R PA Replicate 1 Total Normalized Releases

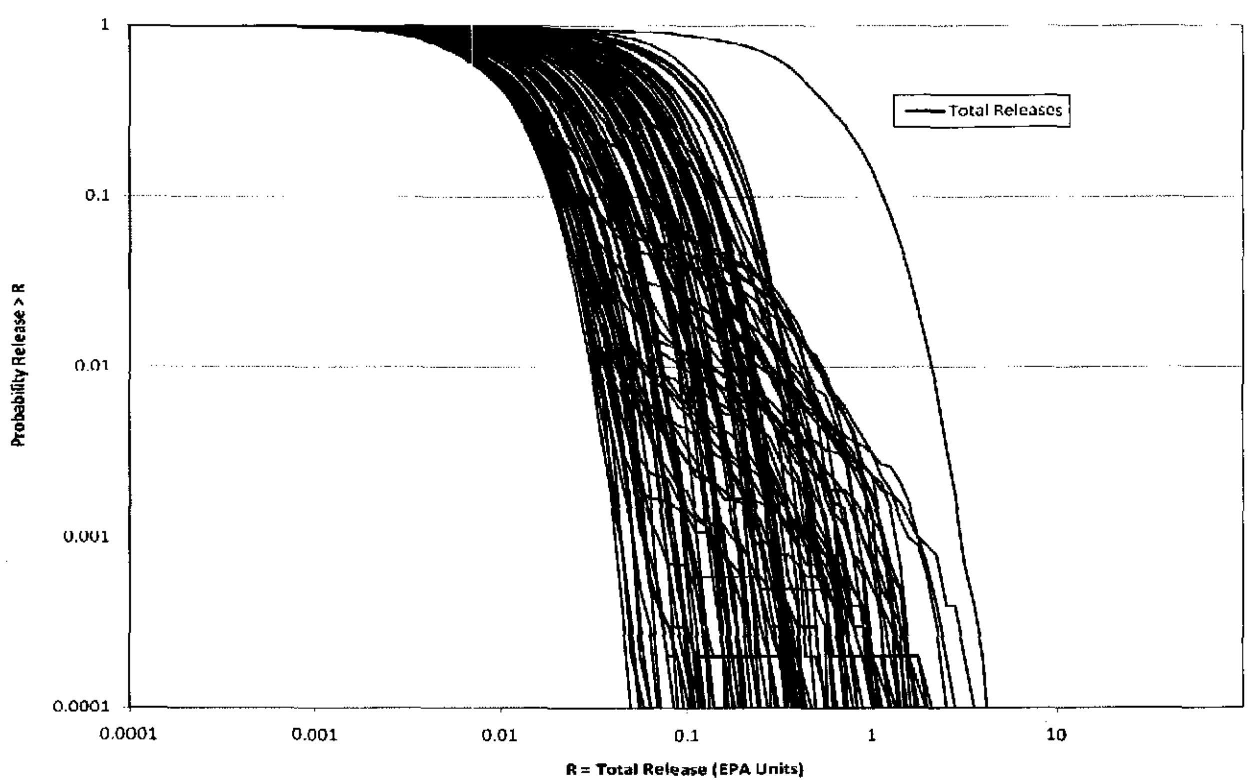

Figure 5-34: PC3R PA Replicate 2 Total Normalized Releases

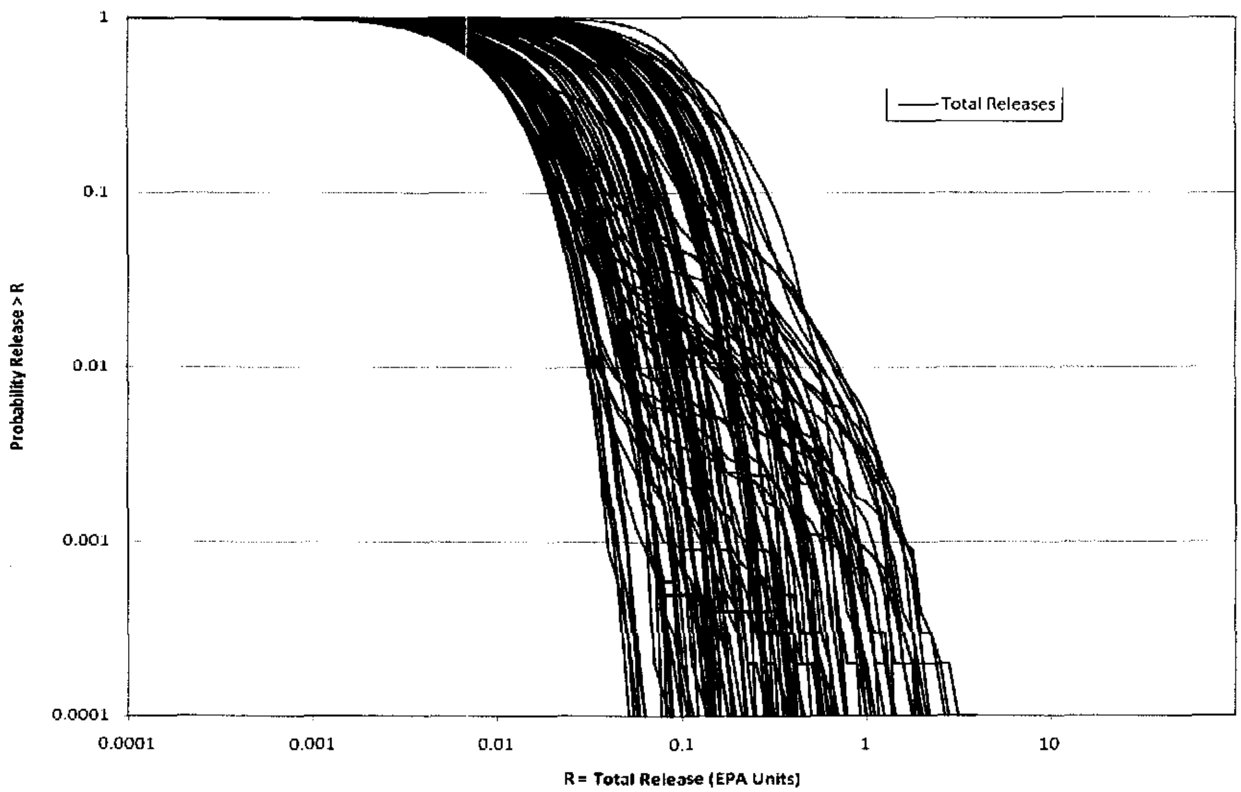

Figure 5-35: PC3R PA Replicate 3 Total Normalized Releases

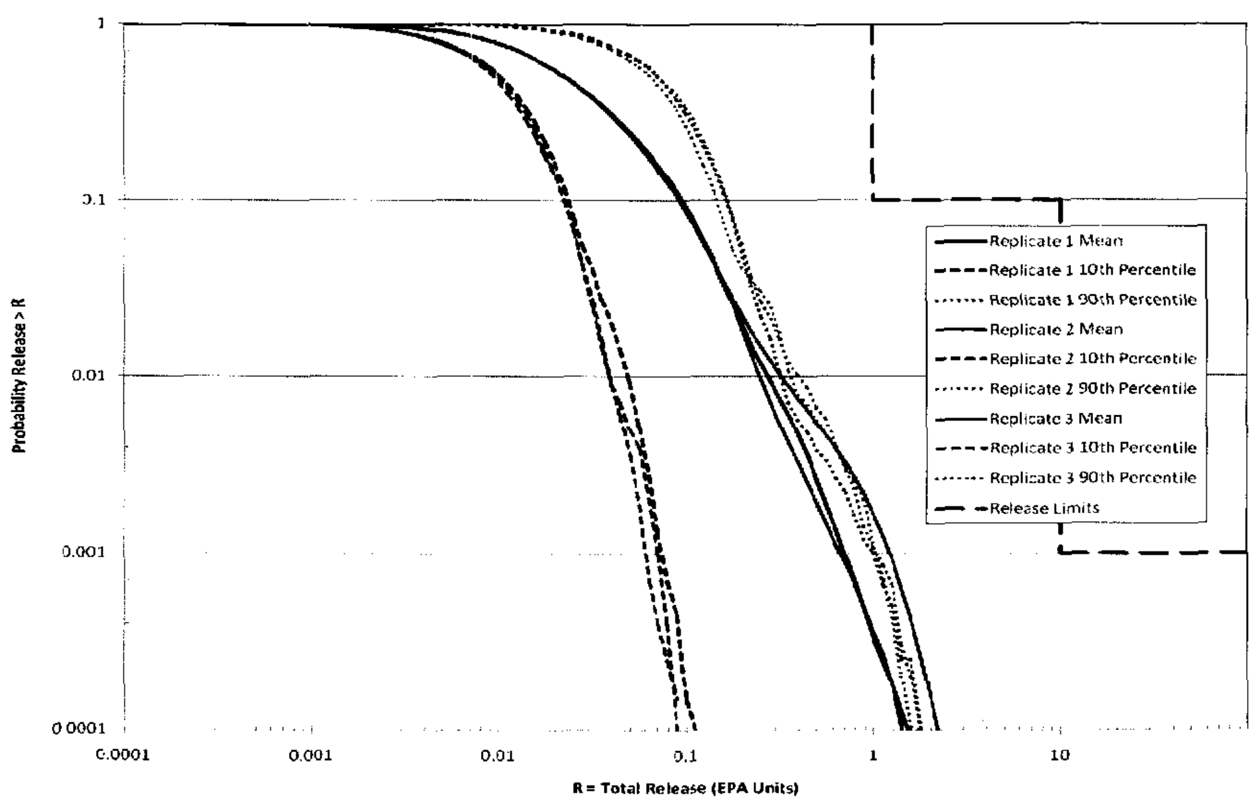

Figure 5-36: PC3R PA Mean and Quantile CCDFs for Total Normalized Releases, Replicates 1-3

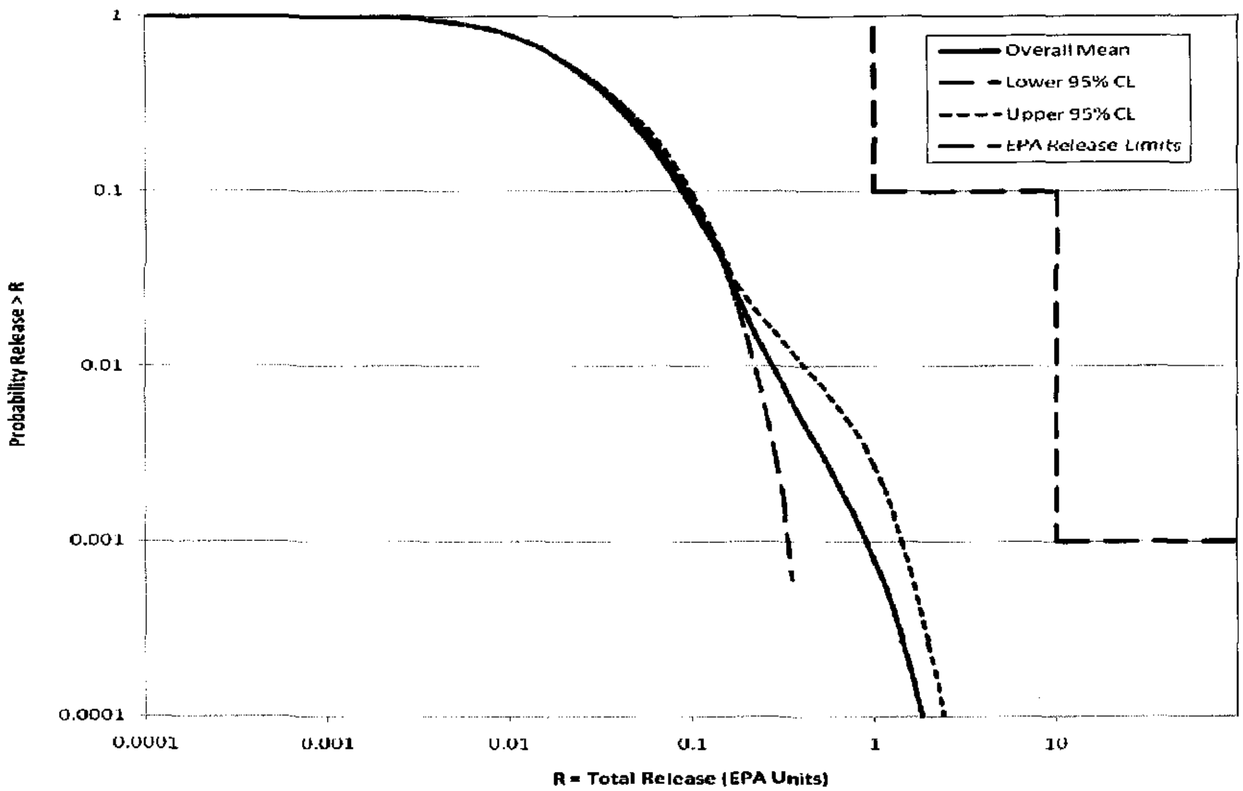

Figure 5-37: PC3R PA Confidence Limits on Overall Mean for Total Normalized Releases

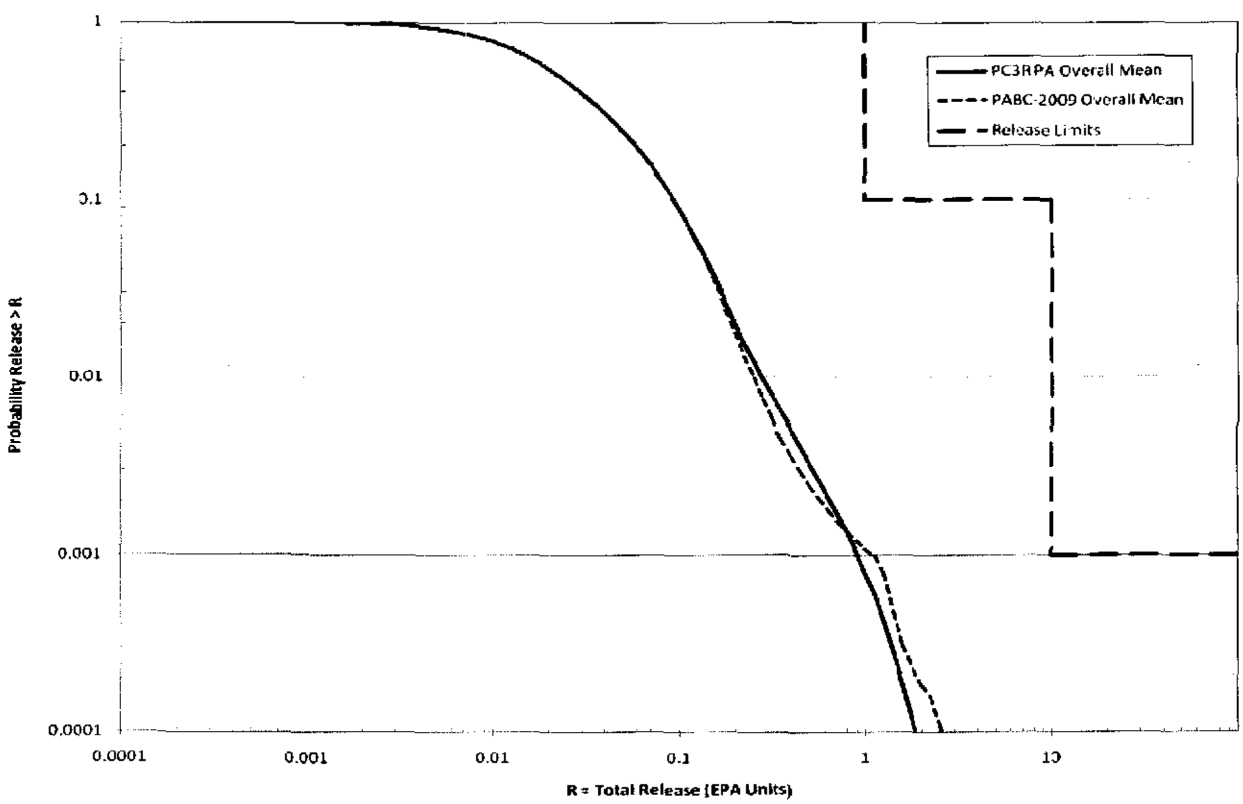

Figure 5-38: PC3R PA and PABC-2009 Overall Mean CCDFs for Total Normalized Releases

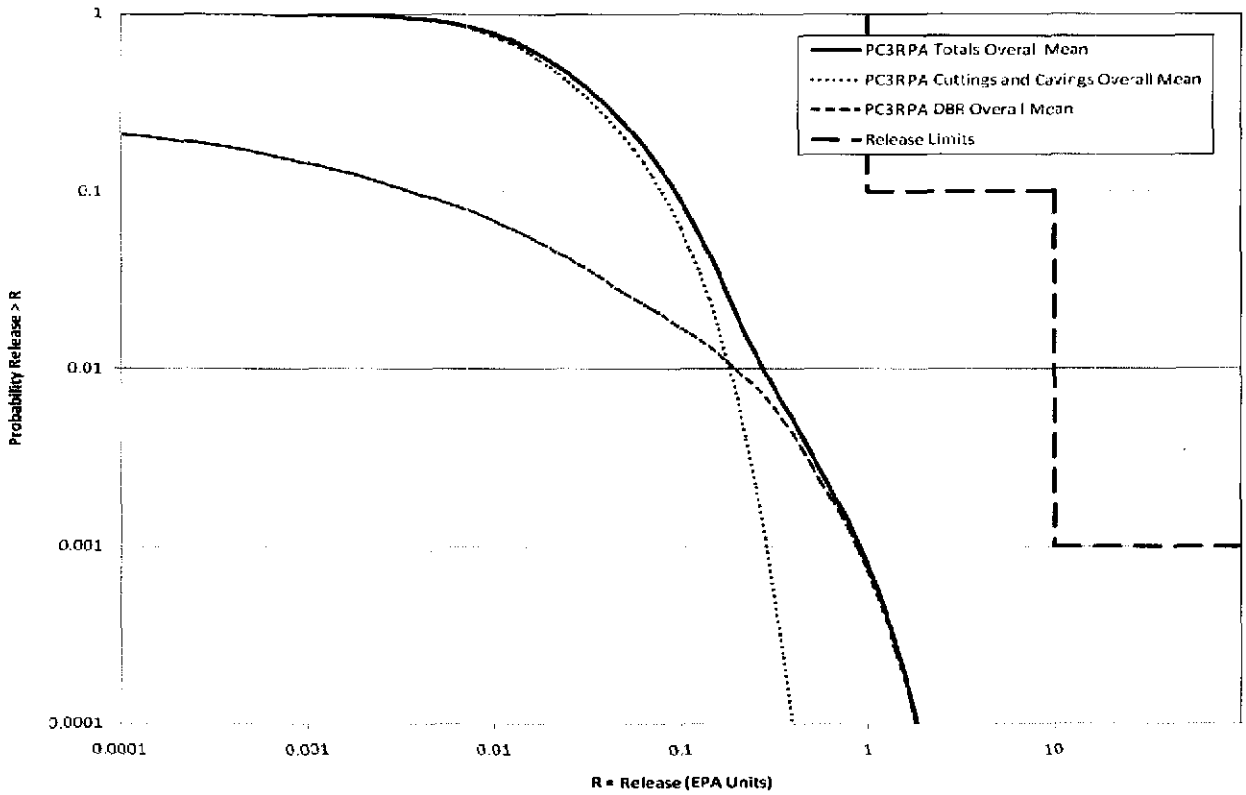

Figure 5-39: PC3R PA Primary Components Contributing to Total Releases

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

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