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Review of DOE's Planned Change Request to Modify the WIPP Panel Closure System

Contract Number EP-D-10-042
Work Assignment No. 4-02

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November 20, 2013

131116.5

TABLE OF CONTENTS

Acronyms vi

Executive Summary viii

1.0 Introduction 1

1.1 Background 1

1.2 Relevant Regulatory Requirements 2

1.2.1 EPA – 40 CFR 194 2

1.2.2 40 CFR 191 Subpart A 4

1.2.3 40 CFR 264, 268 (RCRA) 5

1.2.4 Mine Safety and Health Administration 5

2.0 Brief History of PCS Design 6

2.1 Background 6

2.2 Pre-CCA Proposed Designs 8

2.3 Final Design – Option D Concrete Monolith 8

2.4 DOE Post-Option D Design Alternatives 10

2.4.1 2002 Proposed PCS Design Modifications 11

2.4.2 2006 Proposed PCS Design Modifications 12

2.5 2011 PC3R Planned Change Requests 13

3.0 2012 DOE Planned Change Request for PCS Design 16

3.1 Rationale for ROM Salt Design 16

3.2 ROM Salt Design Materials and Components 16

3.3 Analysis of Features, Events, and Processes 17

3.3.1 SNL's Identification of Potentially Relevant FEPs 18

3.3.2 EPA Review of SNL's FEP Assessment 20

3.3.3 Adequacy of SNL's FEP Review 22

3.4 Development of PCS-2012 Performance Assessment 22

3.4.1 ROM Salt PCS Design 22

3.4.2 ROM Salt Modeling 23

3.4.3 PCS DRZ Modeling 28

3.4.4 Development of the PCS-2012 PA Numerical Model 33

3.5 PCS-2012 PA Results and Analysis 42

3.5.1 Results Compared with PABC 2009 PA 43

3.5.2 Cuttings and Cavings Releases 53

3.5.3 Direct Brine Releases 53

3.5.4 Spallings Releases 55

3.5.5 Culebra Releases 56

3.5.6 Total Releases 57

3.6 SNL Parameter Sensitivity Analysis 60

3.6.1 Parameter Regression Results 61

3.6.2 Sensitivity of Cuttings and Cavings Releases 63

3.6.3 Sensitivity of Direct Brine Releases 64
3.6.4 Sensitivity of Spallings Releases 65
3.6.5 Sensitivity of Culebra Releases 67
3.6.6 Summary of Sensitivity Results 68
3.7 EPA Assessment of DOE's Analysis 69
4.0 EPA Sensitivity Analysis 70
4.1 Sensitivity to DRZ Permeability 70
4.1.1 Conceptualization of DRZ Healing 70
4.1.2 Parameters Modified for the DRZ Adjacent to the ROM Salt 72
4.1.3 Modified Parameter Values for Sensitivity Study 73
4.1.4 Results of DRZ Sensitivity Analysis 75
4.2 Sensitivity to Capillary Pressure in the ROM Salt 78
5.0 EPA Quality Assurance Review 82
5.1 Parameter Changes 82
5.2 Database Migration 83
6.0 Summary and Conclusions 85
7.0 References 87
Appendix A: Quality Assurance Review of the PCS-2012 PA Parameter Database 91
Appendix B: Review of WIPP Performance Assessment Computerized Database (PAPDB) Migration 92

LIST OF TABLES

Table 2-1. Panel Closure and DRZ Properties for the CCA and PAVT Analyses 10
Table 2-2. Panel Closure and DRZ Properties for Explicit Representation of the Option D PCS 11
Table 2-3. Panel Closure and DRZ Properties for the 2006 PCS PA 13
Table 3-1. FEPs Identified by SNL-Related to the Panel Closure Modification 19
Table 3-2. DCCA FEPs Excluded from the CCA that Relate to Panel Closures 19
Table 3-3. Two-Phase Flow Properties for the ROM Salt 25
Table 3-4. Two-Phase Flow Properties for the PCS DRZ 30
Table 3-5. BRAGFLO Salado Flow Modeling Scenarios 34
Table 3-6. Intrusion Scenarios Used in Calculating Direct Brine Releases 54
Table 3-7. Total Normalized Release Statistics for the PCS-2012 and PABC-2009 PAs 60
Table 3-8. Stepwise Ranked Regression Results for Mean Total Releases, PCS-2012 and PABC-2009 Replicate 1 62
Table 3-9. Stepwise Ranked Regression Results for Mean Total Releases, PCS-2012 Replicates 2 and 3 63
Table 3-10. Stepwise Ranked Regression Results for Mean Cuttings and Cavings Releases, PCS-2012 and PABC-2009 Replicate 1 64
Table 3-11. Stepwise Ranked Regression Results for Mean Cuttings and Cavings Releases, PCS-2012 Replicates 2 and 3 64
Table 3-12. Stepwise Ranked Regression Results for Mean Direct Brine Releases, PCS-2012 and PABC-2009 Replicate 1 65
Table 3-13. Stepwise Ranked Regression Results for Mean Direct Brine Releases, PCS-2012 Replicates 2 and 3 65
Table 3-14. Stepwise Ranked Regression Results for Mean Spallings Releases, PCS-2012 and PABC-2009 Replicate 1 66
Table 3-15. Stepwise Ranked Regression Results for Mean Spallings Releases, PCS-2012 Replicates 2 and 3 66
Table 3-16. Stepwise Ranked Regression Results for Mean Culebra Releases, PCS-2012 and PABC-2009 Replicate 1 67
Table 3-17. Stepwise Ranked Regression Results for Mean Culebra Releases, PCS-2012 Replicates 2 and 3 68
Table 3-18. Summary of Contributions to Variability for Parameters Related to the Proposed PCS Design Change 68
Table 4-1. Log Permeability Ranges for ROM Salt and the Adjacent DRZ from 200 to 10,000 Years, and for Intact Salado Halite 73
Table 4-2. Parameter Values Modified for the DRZ Sensitivity Study 74
Table 4-3. Total Normalized Release Statistics for the DRZ Test and PCS-2012 PA 75

LIST OF FIGURES

Figure 2-1. Plan and Cross Section Views of a Typical Waste Panel (Dimensions in feet) 7
Figure 2-2. Four Optional PCS Designs Presented in the 1996 WIPP Compliance Certification Application 9
Figure 2-3. Typical ROM Salt Panel Closure for Drifts without Explosion Walls 15
Figure 2-4. Typical ROM Salt Panel Closure for Drifts with Explosion Walls 15
Figure 3-1. Illustration of E1 and E2 Borehole Intrusions 34
Figure 3-2. PABC-2009 BRAGFLO Grid and Material Map 37
Figure 3-3. PCS-2012 BRAGFLO Grid and Material Map, Years 1 to 100 38
Figure 3-4. PCS-2012 BRAGFLO Grid and Material Map, Years 100 to 200 39
Figure 3-5. PCS-2012 BRAGFLO Grid and Material Map, Years 200 to 10,000 40
Figure 3-6. PCS-2012 BRAGFLO Grid and Material Map for an E1 Intrusion 41
Figure 3-7. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenario S1-BF 44
Figure 3-8. Overall Means of Waste Panel Brine Saturation (WAS_SATB), Scenario S1-BF 44
Figure 3-9. Overall Means of Waste Panel Gas Generation (GASMOL_W), Scenario S1-BF 45
Figure 3-10. Overall Means of Waste Panel Pressure (WAS_PRES), Scenario S1-BF 45
Figure 3-11. Overall Means of Waste Panel Pressure (WAS_PRES), Scenario S2-BF 46
Figure 3-12. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenario S2-BF 47
Figure 3-13. Overall Means of Waste Panel Brine Saturation (WAS_SATB), Scenario S2-BF 47
Figure 3-14. Overall Means of Waste Panel Gas Generation (GASMOL_W), Scenario S2-BF 48
Figure 3-15. Overall Means of Brine Flow up the Borehole (BNBHUDRZ), Scenario S2-BF 48
Figure 3-16. Overall Means of Waste Panel Pressure (WAS_PRES), Scenarios S1-BF and S4-BF for Years 0 to 1,000 50
Figure 3-17. Overall Means of Waste Panel Pressure (WAS_PRES), Scenario S4-BF 50
Figure 3-18. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenarios S1-BF and S4-BF for Years 0 to 1,000 51
Figure 3-19. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenario S4-BF 51
Figure 3-20. Overall Means of Waste Panel Brine Saturation (WAS_SATB), Scenario S4-BF 52

Figure 3-21. Overall Means of Waste Panel Gas Generation (GASMOL_W), Scenario S4-BF 52
Figure 3-22. Overall Means of Brine Flow up the Borehole (BNBHUDRZ), Scenario S4-BF 53
Figure 3-23. PCS-2012 PA and PABC-2009 Overall Mean CCDFs for Normalized Direct Brine Releases 55
Figure 3-24. PCS-2012 PA and PABC-2009 Overall Mean CCDFs for Normalized Spallings Releases 56
Figure 3-25. Overall Means of Brine Flow up the Borehole (BNBHUDRZ), Scenario S6-BF 56
Figure 3-26. PCS-2012 PA Primary Components Contributing to Total Normalized Releases 57
Figure 3-27. PCS-2012 PA Replicate 1 Total Normalized Releases 58
Figure 3-28. PCS-2012 PA Replicate 2 Total Normalized Releases 58
Figure 3-29. PCS-2012 PA Replicate 3 Total Normalized Releases 59
Figure 3-30. PCS-2012 PA Confidence Limits on Overall Mean for Total Normalized Releases 59
Figure 3-31. PCS-2012 PA and PABC-2009 Overall Mean CCDFs for Total Normalized Releases 60
Figure 4-1. PCS 2012 PA and DRZ Test, Mean Total Normalized Releases 76
Figure 4-2. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Spallings Releases 76
Figure 4-3. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Direct Brine Releases 77
Figure 4-4. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Cuttings and Cavings Releases 77
Figure 4-5. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized SPALLINGS Releases 79
Figure 4-6. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Direct Brine Releases 80
Figure 4-7. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Total Normalized Releases 80

ACRONYMS

CBFO	Carlsbad Field Office
CCA	Compliance Certification Application
CCDF	Complementary Cumulative Distribution Function
CFR	*Code of Federal Regulations*
CRA	Compliance Recertification Application
DBRs	direct brine releases
DCCA	Draft Compliance Certification Application
DOE	U.S. Department of Energy
DP	screened in for disturbed performance scenarios
DRZ	Disturbed Rock Zone
EPA	U.S. Environmental Protection Agency
ERMS	Electronic Record Management System
FEPs	Features, Events, and Processes
LWA	Land Withdrawal Act
m^2	square meter
m^3	cubic meter
mPa	Mega Pascal
MSHA	Mine Safety and Health Administration
Pa	Pascal
PA	Performance Assessment
PABC	Performance Assessment Baseline Calculations
PAPDB	Performance Assessment Parameter Database
PAVT	Performance Assessment Verification Test
PC3R	Panel Closure Redesign and Repository Reconfiguration Performance Assessment
PCR	Planned Change Request
PCS	Panel Closure System
PCSIA	Panel Closure System Impact Assessment
PMR	Permit Modification Request
QA	Quality Assurance
R^2	Coefficient of Determination
RCRA	Resource Conservation and Recovery Act

ROM	Run-of-Mine
SMC	Salado Mass Concrete
SNL	Sandia National Laboratories
SO-C	screened out based on no, low, or beneficial consequence
SO-P	screened out based on a very low probability of occurrence
SO-R	screened out based on a regulatory directive
SRRC	Standard Rank Regression Coefficient
TBM	Technical Baseline Migration
TRU	Transuranic
TSD	Technical Support Document
UP	screened in for undisturbed performance scenarios
VMPa	Milli Pascal
VOC	Volatile Organic Compound
VVP	Verification Validation Plan
WIPP	Waste Isolation Pilot Plant
WPC	WIPP Panel Closure

EXECUTIVE SUMMARY

In September 2011, the Department of Energy (DOE) submitted a Planned Change Request (PCR) to the Environmental Protection Agency (EPA) to modify the Panel Closure System (PCS) at the Waste Isolation Pilot Plant (WIPP). DOE proposed to replace the Option D design, which is required by Condition 1 of 40 CFR Part 194, Appendix A, with a new design called the Run-of-Mine Salt Panel Closure System (ROMPC or ROMPCS). DOE later submitted a performance assessment, the PCS-2012 PA, to demonstrate that with the redesigned panel closure, WIPP remains compliant with the disposal regulations at 40 CFR Part 191. This Technical Support Document discusses the Agency's review and approval of DOE's PCS-2012 PA.

A panel is a group of mined rooms in the WIPP underground, connected by two drifts. Following completion of waste disposal activities in each panel, DOE intends to seal these drifts with engineered structures called panel closures. DOE's previous Option D design included a concrete block explosion wall and a poured concrete monolith. The ROMPCS design consists of two steel bulkheads placed at each end of 30.5 meters (100 feet) of mined salt.

The approach used to develop the PCS-2012 PA was to maintain the same model input parameters and ranges used in the 2009 Performance Assessment Baseline Calculation (PABC-09) PA, with the exception of parameters that represent the panel closure system. Thus, the PCS-2012 PA results may be compared to those obtained in the PABC-2009 PA as a means to quantify changes in the PA results solely based on the panel closure design changes.

The Option D concrete monolith is a rigid mass with constant physical properties, whereas the ROMPC is emplaced as a relatively loose material which is compressed into a solid mass due to creep closure of the repository. The PCS-2012 uses three time periods to simulate the creep closure process. During the first time period (0–100 years), the salt begins to consolidate from an unconsolidated material to a rigid mass. During the second time period (100–200 years), the salt continues to consolidate and is in the process of healing. The third time period (200–10,000 years) represents a state of consolidation that approaches intact halite. A range of parameter values is used for each of the three specified time periods to capture uncertainties in the ROM salt properties as the panel closure system consolidates.

Since the panel closure is a system that includes both the closure itself and the surrounding disturbed rock zone (DRZ), the Agency closely examined the effects that the DRZ permeability has on repository performance during time period T3. The DOE assumes that the DRZ surrounding the panel closures will also heal with time.

EPA concurred with DOE's proposal to maintain the properties of the panel closure DRZ used to model the Option D PCS, but EPA also investigated the impact on PA results if the PCS DRZ was to heal even further and approach the permeability of intact salt.

The Agency concludes that DOE has successfully identified the principal features, events, and processes (FEPs) necessary to achieve the intent of the PCS-2012 PA, and agrees with DOE's use of three time periods to represent progressive salt consolidation. The Agency accepts the

values adopted for ROM salt density, porosity and permeability in the PCS-2012 PA and considers them to capture the range of uncertainty. Based on the information presented by DOE and the subsequent sensitivity analyses performed by the Agency, EPA is satisfied that the revised PCS-2012 PA provides an adequate performance measure for the implementation of the ROMPCS at WIPP. The Agency concludes that the results of DOE's PCS-2012 PA and the additional analyses conducted by the Agency adequately demonstrate that the containment requirements of 40 CFR Part 191.13 continue to be met with ROM salt as the primary material in the PCS. The Agency, therefore, accepts DOE's proposal to replace the mandatory Option D PCS design with the proposed ROMPCS design at WIPP.

1.0 INTRODUCTION

1.1 BACKGROUND

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the Department of Energy (DOE) for the deep disposal of transuranic (TRU) waste. The Environmental Protection Agency (EPA) regulates containment of TRU waste in accordance with EPA's radioactive waste disposal standards at Code of Federal Regulations (CFR), Title 40 Parts 191 and 194. Condition 1 of 40 CFR Part 194 (EPA 1998) specifies that the Panel Closure System (PCS) to be used in the WIPP repository is the one designated as "Option D" in the Compliance Certification Application (CCA) (DOE 1996a). The Option D design consists of a 3.7 meter (12 feet) thick concrete block explosion wall separated from a 7.9 meter (26 feet) thick Salado Mass Concrete (SMC) plug by a 9.1 meter (30 feet) open drift.

DOE submitted a PCR to the EPA in September 2011 (DOE 2011b) requesting Agency approval to modify the PCS from the Option D design to a design composed primarily of run of mine (ROM) salt. The PA submitted with that PCR is called the PC3R PA. It included the ROM salt PCS design as well as proposed alterations to the repository configuration. The Agency requested DOE to perform another PA where only the PCS was modified from the current PA baseline established by the 2009 Performance Assessment Baseline Calculation (PABC-2009).

Following a series of technical exchanges between EPA and DOE, DOE submitted the PCS-2012 PA. The major differences in the calculations from the PABC-2009 were (1) the parameterization of the panel closure based on salt instead of concrete, (2) the time dependence on the panel closure properties, and (3) the reduction in the DRZ permeability at 200 years.

This Technical Support Document (TSD) discusses the Agency's review and assessment of DOE's PCS-2012 PA supporting the request to modify the PCS design. The organization of this TSD is as follows:

Section 1.2 describes the original motivation for Condition 1, which requires the Option D panel closure, and discusses the regulatory requirements that impact the design of the panel closure.

Section 2.0 provides a brief history of the evolution of the PCS design and its representation in WIPP performance assessment prior to the current PCR and PA. Section 2.1 describes where the panel closures are to be installed in the waste panel access drifts.

Section 3.0 discusses in detail the rationale used by DOE to adopt the ROMPCS design, the materials and components used in the design, and parameterization, implementation, and results of the PCS-2012 PA.

Section 4.0 discusses two separate analyses performed by the Agency and compares their results with the PCS-2012 PA. Section 4.1 assesses whether lowering the long-term permeability of the healed PCS DRZ to values that approach those of intact halite affect repository containment requirements. Section 4.2 discusses an analysis to assess whether the modeling results are sensitive to capillary pressure in the ROM salt.

Section 5.0 describes the Agency's quality assurance reviews of DOE's database migration and of the parameter dataset used in the PCS 2012 PA. Detailed information on these reviews is included in Appendices A and B.

Section 6.0 presents EPA's overall summary and conclusions of DOE's PCS 2012 PA results. The Agency found that with a lowered PCS DRZ permeability, calculated average releases still remained below regulatory limits.

1.2 RELEVANT REGULATORY REQUIREMENTS

1.2.1 EPA – 40 CFR PART 194

DOE's original Compliance Certification Application (CCA) included panel closures in the design of the repository. As noted in EPA's documentation,

> [CCA] *Chapter 3.3.2 (p. 3-27) indicates that the original intention of the panel closure system was to support Resource Conservation and Recovery Act (RCRA) closure of the waste disposal panels and to prevent the release of potentially unacceptable levels of volatile organic compounds from the filled waste disposal panels during waste management operations in the remainder of the repository (up to 35 years). The CCA stated (p. 3-33) that although the design of the panel closure system was based on its need to protect human health and the environment during the operations period, the use of these systems will also influence fluid connections between panels during the post-closure phase.* (DOE 1996a, CARD 14, 45–46)

While panel closures are not considered engineered barriers per 40 CFR Part 191 because the presence of panel closures has potential to influence the behavior of the repository, and therefore long-term compliance, detailed information on the panel closure design was included in the CCA to satisfy 40 CFR Part194. Section 194.14, Content of Compliance Certification Application, requires:

> *(a) A current description of the natural and engineered features that may affect the performance of the disposal system. The description of the disposal system shall include, at a minimum, the following information:*
>
> *... (b)(1) "Information on materials of construction including, but not limited to: Geologic media, structural materials, engineered barriers, general arrangement, and approximate dimensions."*

Options for closing filled waste panels were described in *Detailed Design report for an Operational Phase Panel Closure System*, DOE/WIPP-96-2150 (DOE 1996b), included in the CCA as Appendix PCS. The contents of Appendix PCS are discussed in Section 3.0 of this document. Appendix PCS proposed a composite system including a concrete block isolation wall that would be installed between the waste face and the main drift immediately after the panel was filled, and a concrete monolith installed afterwards. The concrete block wall could be a thinner

"construction-isolation wall," or a thicker "explosion-isolation wall" to protect against a postulated hydrogen or methane explosion. Likewise, the monolith could be of simple rectangular construction, filling the open drift, or the disturbed rock zone (DRZ) could be excavated to remove fractures and an enlarged monolith installed to prevent further fracturing. The design options, according to DOE, were to "[provide] flexibility to satisfy the design limit for the flow of volatile organic compounds (VOCs) out of the panel" (Section 3.2.1). Appendix PCS proposed that DOE would determine which panel closure configuration to install at the time of closure based on the age of the drift being closed, the degree of fracturing, and the nature of the waste in the panel, but did not offer any specific criteria for making such a determination. Chapter 3.3.2 of the CCA (discussed on pages 114–115 of EPA's TSD for CARD 14) stated that the panel closures would maintain their structural integrity into the period of long-term compliance, that the permeability of the panel closure and surrounding DRZ will control long-term fluid flow into or out of the waste panel, and that degradation of the freshwater concrete barrier component may occur by interaction with brine. The CCA did not include any analysis of the impact of the panel closure design on long-term system performance. Without this information, the Agency felt it was necessary for panel closures emplaced in the repository to exhibit the physical properties that had been used to represent them in the compliant performance assessment. As stated in the Federal Register notice for certification:

> *Condition 1 of the certification relates to the panel closure system... The EPA based its certification decision on DOE's use of the most robust design (referred to in the CCA as "Option D)." The Agency found the Option D design to be adequate, but also determined that the use of Salado mass concrete – using brine rather than fresh water – would produce concrete seal permeabilities in the repository* ***more consistent with the values used in DOE's performance assessment****. Therefore, Condition 1 of EPA's certification requires DOE to implement the Option D panel closure system at WIPP, with Salado mass concrete replacing fresh water concrete* (*Federal Register*, Vol. 63, No.95, p. 27355). (Emphasis added.)

Thus, as part of EPA's certification decision, the following text was added to 40 CFR 194:

> *Appendix A,* Condition 1: §194.14.14(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.*

EPA's certification decision explicitly discusses the possibility of DOE proposing a re-engineered panel closure design, with the following language:

> *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 of 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 (*Federal Register*, Vol. 63 No.95, p. 27362).

DOE proposed and withdrew requests to modify the panel closure design in 2001, 2002, and 2006, including a request to defer entirely to NMED on the design of the panel closure. EPA declined to do so, and a letter from EPA to DOE from 2007 clearly articulates Agency's position on the regulation of panel closures. While acknowledging that panel closures are "primarily operational period features that are designed to control volatile organic compound emissions during disposal operations," and that "EPA's Compliance Criteria (40 CFR 194) do not require a panel closure system for WIPP, panel closures are part of the disposal system and their characteristics must be properly incorporated into performance assessment [under 40 CFR 194.14]." The letter also states that "EPA has determined that a change in the panel closure design is a significant departure from the most recent compliance application. Therefore, under §194.65, EPA is required to address the change in panel closure design through the Agency's rulemaking process" (Reyes 2007).

1.2.2 40 CFR Part 191 Subpart A

EPA's regulatory role at WIPP does not solely pertain to long-term performance. 40 CFR 191 Subpart A [40 CFR 191.03 (b)] sets dose limits to the public during the operational phase of the repository.

Subpart A does not prescribe how WIPP should meet the operational dose limits. EPA's approach has been to ensure that DOE has a reliable monitoring system in place to measure any releases and calculate any potential dose to the public [See Guidance for the Implementation of EPA's Standards for management and Storage of Transuranic Waste (40 CFR Part 191, Subpart A) and the Waste Isolation Pilot Plant, EPA 402-R-97-001]. EPA annually inspects DOE's monitoring system, as well as their operational safety and emergency response procedures.

Although the detonation or deflagration due to a buildup of explosive gases in a waste panel could theoretically result in a release, the CCA indicated that this is an extremely remote possibility. EPA accepted this, and has never considered the panel closure to be necessary for compliance with Subpart A. EPA's 2007 letter approved delaying installation of the final panel closures, stating that "EPA regulations do not require that any panel closure system be installed prior to closing of the disposal system. EPA believes DOE's proposed gas monitoring in the panels would provide useful information for long-term performance" (Reyes 2007).

The results of monitoring VOCs and explosive gases in Panels 3 and 4 are included in DOE's PCR (DOE 2011b). There is no indication that explosive conditions will be encountered in the underground. The Agency concludes that the proposed changes to the panel closure system do not impact DOE's ability to comply with 40 CFR Part 191 Subpart A.

1.2.3 40 CFR Parts 264, 268 (RCRA)

WIPP is subject to the Resource Conservation and Recovery Act (RCRA). As stated in Appendix PCS, the panel closure system was originally intended "to support a Resource Conservation and Recovery Act (RCRA) Part B permit application and a no-migration variance petition" [DOE/WIPP-96-2150 (DOE 1996b)]. At the time, DOE recognized that it would be exceedingly difficult to chemically treat mixed hazardous and transuranic waste to meet the land disposal restrictions found at 40 CFR Part 268, and instead sought a no-migration variance petition under §268.6 (DOE 1996a).

In 1996, Congress amended the WIPP Land Withdrawal Act (LWA) Section 9(a)(1) to exempt transuranic waste at WIPP from "treatment standards promulgated pursuant to section 3004(m)" and "the land disposal prohibitions in section 3004(d), (e), (f), and (g) of the Solid Waste Disposal Act," (1992, 104th Congress) obviating the need for a no-migration variance. The panel closure design remains a condition of WIPP's RCRA Part B permit to reduce the exposure of workers and the public to VOCs.

The State of New Mexico has adopted EPA's hazardous waste regulations (40 CFR Parts 264, 268, and 270) in title 20, Chapter 4, Part 1 of the New Mexico Administrative Code C 4.1 (Federal Register 60, No. 79 20240, April 25, 1995). A RCRA permit modification to allow the redesigned panel closure will be considered separately by NMED.

1.2.4 Mine Safety and Health Administration

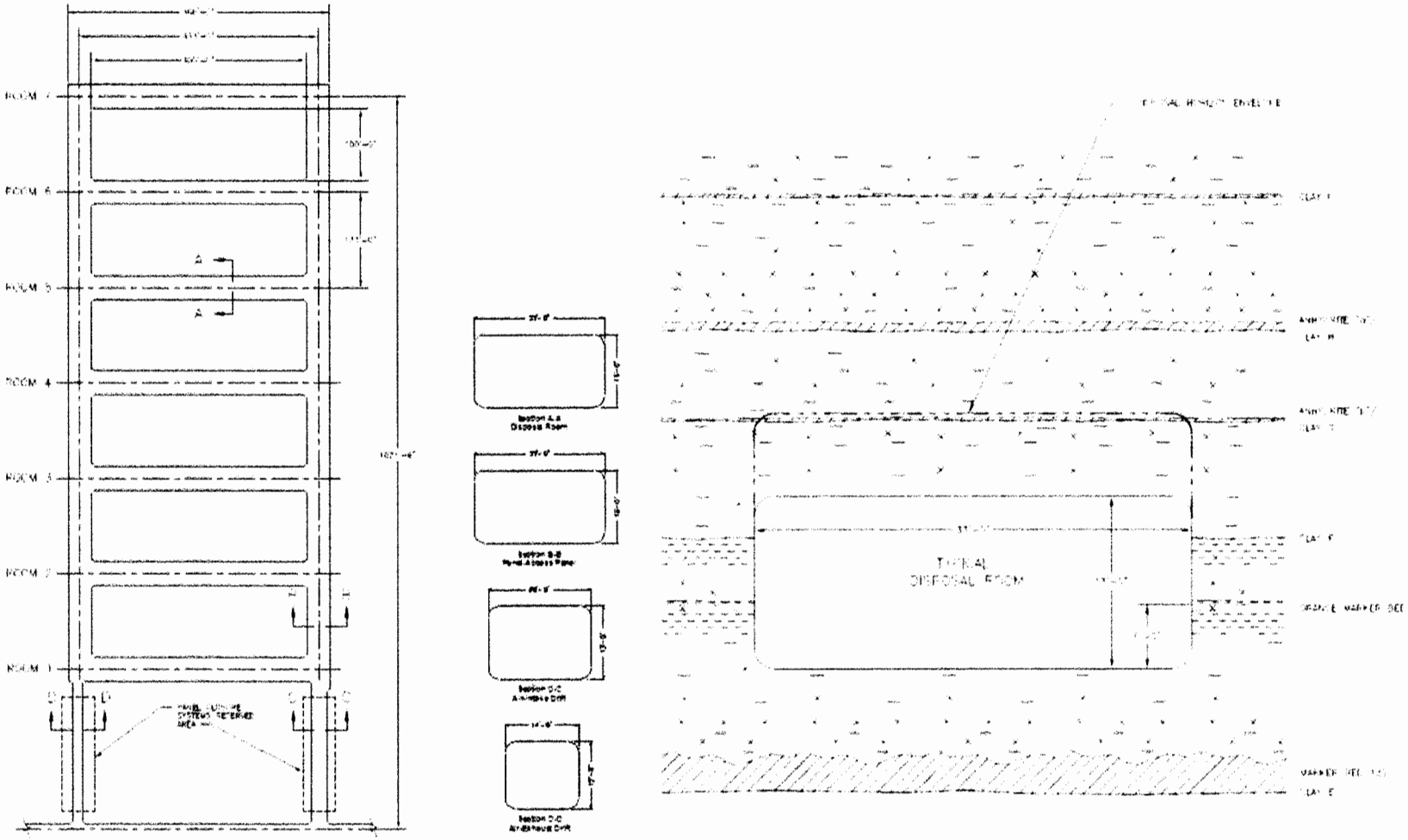
Section 11 of the WIPP LWA (P.L. 102-579) establishes that the Mine Safety and Health Administration (MSHA) as the regulator of mine safety at WIPP. According to the CCA, WIPP is Category IV mine under 30 CFR 57 Subpart T, meaning that non-combustible ore is extracted, and any methane liberated by mining is not capable of creating an explosive environment (DOE 1996a). In Category IV mines, Subpart T regulations require testing for methane at least once per shift (§57.22226), but do not specify requirements for the constructions of "barriers and stoppings" as they do for other mine categories. In its design documents, however, DOE has adopted the use of the term "substantial barrier." MSHA defines "substantial construction" as "Construction of such strength, material, and workmanship that the object will withstand air blasts, blasting shock, ground movement, pressure differentials, wear, and usage which may be expected to occur in the mining environment" (30 CFR §57.22002). DOE has stated that the "substantial barriers" referenced in the proposed panel closure design documents will be steel bulkheads.

2.0 BRIEF HISTORY OF PCS DESIGN

Section 2.0 provides a summary of the evolution of the PCS design and its representation in WIPP performance assessment. Alternative designs considered by DOE prior to the CCA are described, which led to four design options presented in the CCA. One of those designs, identified as Option D, was approved by EPA and NMED as suitable for licensing. Difficulties in implementing the Option D design were subsequently identified by DOE, and alternative PCS designs involving the use of ROM salt were proposed by DOE. This process culminated in the proposed ROMPCS design reviewed in this TSD. The Agency has followed the PCS design process, and both the Agency and DOE have gained an increased understanding of how the PCS impacts repository performance.

2.1 BACKGROUND

The rooms of each WIPP waste panel are connected to the main repository by two drifts, the air intake drift and the air exhaust drift. Following completion of waste disposal activities in a panel, the panel is closed by sealing these two drifts. Plan and cross section views of a typical waste panel are shown in Figure 2-1. The air intake and exhaust drifts are shown in Cross Sections C-C and D-D. As shown in the figure, the air intake drift is slightly larger than the air exhaust drift.



From DOE 2013

Figure 2-1. Plan and Cross Section Views of a Typical Waste Panel (Dimensions in feet)

2.2 PRE-CCA PROPOSED DESIGNS

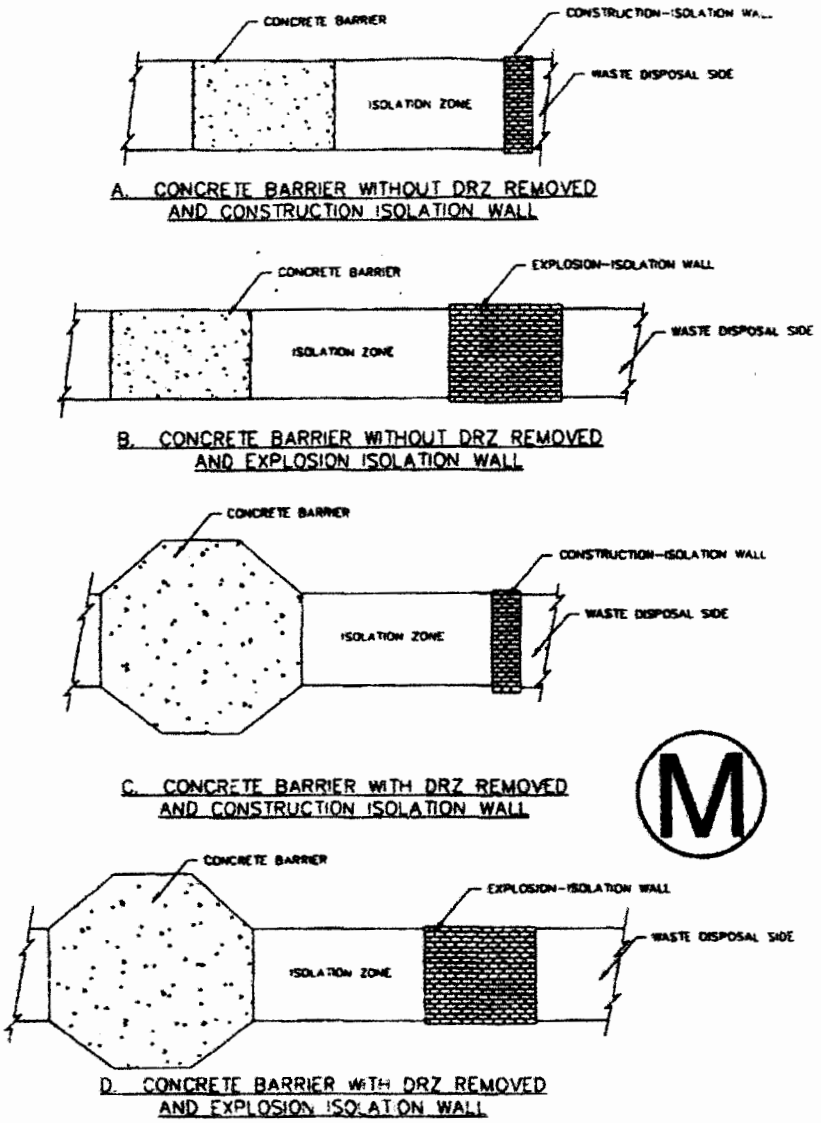
Various materials have been considered for the WIPP panel closures since repository design studies began. A 1986 design considered concrete, salt blocks, and bentonite fill (DOE 1986). A 1990 design considered two concrete plugs keyed into the drift walls with pre-consolidated salt (tamped salt with salt bricks) between them and crushed salt filling the drift on the outer sides (Nowak et al. 1990). A 1995 design consisted of a concrete block wall on the waste end, a 'simple crushed salt' fill extending 1.5 times the diameter of the drift, a construction bulkhead, and a 2-times entry diameter length of concrete with grouting of the DRZ (DOE 1995).

2.3 FINAL DESIGN – OPTION D CONCRETE MONOLITH

DOE's 1996 Compliance Certification Application (CCA) presented four optional PCS designs, shown in Figure 2-2. The designs consisted of concrete monoliths with and without removal of the surrounding DRZ, combined with thick explosion isolation walls or thin construction isolation walls constructed from concrete cinderblocks (DOE 1996a). These options included performing contact grouting around the concrete monolith as needed.

DOE stated that one of the four options would be selected for each filled waste panel based on ground conditions and timing of installation relative to repository closure (DOE 1996a). Although specific criteria for making the selection were not provided, DOE expected that the most robust panel closures would be needed for those waste panels that would be filled first because they would have the longest functional lives during repository operations. DOE concluded that "...Option D may be appropriate for panels whose entries require significant removal of the DRZ and whose closure will precede final facility closure by more than 20 years. Panel 1 is the most likely candidate for this type of closure" (DOE 1996a).

As described in Section 1.2.1 above, the Agency concluded that certification of compliance could not be granted when a potentially important feature affecting post-closure repository performance was not specified but left to future decisions based on incomplete criteria. The Agency therefore mandated the selection of PCS Option D and the use of Salado Mass Concrete (SMC) rather than fresh water concrete for the monolith as Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194 (EPA 1998). This decision was based on the conclusion that Option D represented the most robust of the alternative designs provided by DOE and that SMC, made with simulated Salado brine, would provide a long-term seal performance that was more consistent with the properties of the generic panel closure represented in DOE's CCA PA and PAVT (EPA 1998). The properties of the panel closure and surrounding DRZ used in the CCA PA and PAVT are presented in Table 2-1. In those analyses the DRZ around the panel closure was given the same properties as the DRZ around the waste panel and did not account for any possible healing that might occur. The panel closure design was not explicitly represented and the properties of both the panel closure and the DRZ were fixed for the entire 10,000-year regulatory time period.



From DOE 1996a

Figure 2-2. Four Optional PCS Designs Presented in the 1996 WIPP Compliance Certification Application

Table 2-1. Panel Closure and DRZ Properties for the CCA and PAVT Analyses

Property	Parameter Type	Parameter Value
Panel Closure (CCA and PAVT)		
Permeability (X, Y, and Z –directions)	Constant	1×10^{-15} m^2
Effective Porosity	Constant	0.075
DRZ (CCA)		
Permeability (X, Y, and Z –directions)	Constant	1×10^{-15} m^2
Effective Porosity	Cumulative	Min: 0.0029 Max: 0.0329 Mean: 0.0157
DRZ (PAVT)		
Permeability (X, Y, and Z -directions	Loguniform	Min: 3.98×10^{-20} m^2 Max: 3.16×10^{-13} m^2
Effective Porosity	Cumulative	Min: 0.0029 Max: 0.0329 Mean: 0.0157

From Vugrin and Wagner 2006; DOE 2011b; and Hansen et al. 2002.

2.4 DOE POST-OPTION D DESIGN ALTERNATIVES

After the CCA was approved by the Agency, DOE conducted studies of installation of the concrete monolith. In 2001, DOE proposed several modifications, including replacing SMC with generic, salt-based concrete, replacing fresh water grouting with salt-based grouting, using local carbonate river rock aggregate in lieu of crushed quartz, and an option to allow steel forms to be left in place or removed (Triay 2001). These modifications were accompanied by a PCR from DOE that was later withdrawn.

Representation of the Option D PCS in WIPP PA also evolved during this time. The Option D concrete monolith design was explicitly incorporated into the 2002 Technical Baseline Migration PA (Stein 2002). This representation was carried forward to the CRA-2004 and CRA-2009 PAs. The representation of Option D included the impacts of a rigid structure on the surrounding DRZ. The properties of the panel closure and surrounding DRZ used for explicitly representing the Option D PCS are presented in Table 2-2. The Option D panel closure permeability used in PA is a composite effective permeability of the concrete monolith, the open drift, and the explosion wall. The permeability of the concrete monolith alone was assigned a constant value of 1.78×10^{-19} m^2, equal to the mode of the distribution for SMC (DOE 2011b).

Table 2-2. Panel Closure and DRZ Properties for Explicit Representation of the Option D PCS

Property	Parameter Type	Parameter Value
Panel Closure		
Composite Permeability (along the drift)	Constant	9.01×10^{-19} m^2
Composite Permeability (perpendicular to the drift)	Constant	1.93×10^{-13} m^2
Effective Porosity	Constant	0.15
DRZ		
Permeability (X, Y, and Z –directions)	Triangular	Min: 2×10^{-21} m^2 Max: 1×10^{-17} m^2 Mode: 1.78×10^{-19} m^2
Effective Porosity	Cumulative	Min: 0.0039 Max: 0.0548 Mean: 0.0211

From DOE 2011b; Camphouse et al. 2012b.

The Agency received a PCR in 2002 proposing a PCS design consisting of an explosion wall and a closure of ROM salt. This design change was accompanied by a request for EPA to remove Condition 1 from the WIPP certification and to cede approval of the final PCS design to the New Mexico Environment Department (Triay 2002). The Agency informed DOE that the PCR would not be considered until after the 2004 Compliance Recertification Authorization (Marcinowski 2002). DOE resubmitted essentially the same 2002 PCS design in a new PCR in November of 2006, but eliminated the requests for removal of Condition 1 and ceding of approval (Moody 2006). This PCR was accompanied by a new performance assessment that indicated the repository would remain in compliance with the proposed PCS design modification (Vugrin and Dunagan 2006). DOE's proposed 2002 and 2006 PCS design modifications are described in the following paragraphs.

2.4.1 2002 Proposed PCS Design Modifications

DOE's proposed 2002 design modifications consisted of a 30-foot concrete block explosion wall constructed on the waste disposal side of the closure drift and 30.5 meters (100 feet) of ROM crushed salt placed against the outer side of the explosion wall (Saeb and Case 2002). This alternate design was called the WIPP Panel Closure (WPC) system. The rationale to adopt the WPC design instead of the Option D design was primarily based three considerations: (1) the WPC was simpler to engineer and install, (2) the MSHA specifications for mine safety during the operational phase could be met, and (3) long-term repository performance would not be negatively impacted over the regulatory time frame.

The characteristics of ROM salt behavior during the post-closure period differ from those of the concrete monolith in the Option D design. Because the ROM salt is easily compressed as the waste panel access drifts creep close, its density is increased and its permeability is reduced. In contrast, the properties of the rigid Option D cement monolith are expected to be relatively stable for 10,000 years. Consequently, assessments of the gradual decrease in ROM salt permeability with time were considered early on. The concrete block explosion walls were only intended to last during the 35 year operational period and these walls were therefore not taken into consideration in long-term PA modeling.

Hansen and Thompson (2002) estimated that consolidation of the ROM salt due to creep closure would reduce its density, approaching intact halite by 200 years. Since density and permeability are related for halite, once the ROM salt has reached a final density, its permeability would decrease no further. They estimated that the permeability of healed ROM salt would range between 10^{-15} and 10^{-19} m^2 during the 200 to 10,000 year time frame. Their estimates were based on observed salt creep measurements and laboratory experiments. By comparison, the effective permeability of the Option D PCS design along the drift was given a constant value of 9.01×10^{-19} m^2 for the entire regulatory time frame and took into account all three components of the Option D design - a 12 foot thick concrete block explosion wall, a 30 foot open area, and a 26 foot long concrete monolith (Hansen et al. 2002).

Two discrete time periods were modeled to capture the change in ROM salt properties during the regulatory time frame. The first time period, 0 to 200 years, was meant to capture the flow properties of a loose and less compact, lower density ROM salt. The second time period, 200 to 10,000 years, was meant to capture a range of uncertain end-point values when it was assumed the ROM salt would be compressed to its fully consolidated state.

SNL evaluated the impact of the proposed ROM salt PCS on repository performance by comparing the results of two PAs, one using the lower end-point PCS permeability of 10^{-19} m^2 representing the Option D design, and the other using a higher end-point PCS permeability of 10^{-15} m^2 representing the ROM salt design. This comparison was labeled the Panel Closure System Impact Assessment (PCSIA) PA. The PCSIA PA results indicated that even though the permeability of the two closure systems differed by four orders of magnitude, repository performance was nearly identical (Hansen 2002a; Hansen 2002b). However, due to scheduling and regulatory time constraints the WPC design was not formally presented to EPA. The Option D design therefore continued to be used in the 2004 Compliance Recertification Application (CRA).

2.4.2 2006 Proposed PCS Design Modifications

In 2006, DOE submitted another PCR to adopt a panel closure design that was the immediate predecessor to the 2012 design considered in this TSD. The 2006 design was similar to the ROM WPC design considered in the 2002 PCSIA PA and included an explosion wall and 30.5 meters (100 feet) of ROM salt (Vugrin and Dunagan 2006). The rationale to change from the Option D concrete monolith design to ROM salt was the same as in 2002; the ROM salt panel closure was cheaper and easier to install, and would provide the same safety during the operational period as the Option D design. A 2006 PA was conducted using ROM salt as the PCS material with a few modifications from the 2002 PA. The 2006 PA is called the PCS PA and the results were compared to the 2004 PABC.

The 2006 PCS PA was run using the same BRAGFLO grid as the 2004 CRA PA and PABC but modified to make the PCS permeability and porosity representative of ROM salt. By 2006 there was a better understanding of how the properties of ROM salt change due to consolidation. This resulted in modifying the estimated range of ROM permeability and porosity from that adopted in 2002. In the 2006 PCS PA, the end-point permeability was slightly lower than that assumed in the 2002 PCSIA PA. Similar to the PCSIA PA, creep closure compressed the ROM salt

properties to asymptotic values estimated around 200 years after repository closure. Two discrete time periods were adopted in both PAs to capture the change in ROM salt properties. The first modeled time period was 0 to 200 years and the second time period was 200 to 10,000 years (Vugrin and Dunagan 2006). Table 2-3 provides the porosity, and permeability values that were assigned to each time period.

Table 2-3. Panel Closure and DRZ Properties for the 2006 PCS PA

Time Period	Property	Parameter Type	Parameter Value
Panel Closure			
0-200 Years	Permeability (X-direction)	Constant	8×10^{-15} m^2
	Permeability (Y-direction)	Constant	8×10^{-12} m^2
	Permeability (Z-direction)	Constant	8×10^{-12} m^2
	Effective Porosity	Constant	0.27
200-10,000 Years	Permeability (X-direction)	Triangular	Min: 1.6×10^{-23} m^2 Max: 4.0×10^{-23} m^2 Mode: 6.3×10^{-21} m^2
	Permeability (Y-direction)	Constant	5×10^{-14} m^2
	Permeability (Z-direction)	Constant	5×10^{-14} m^2
	Effective Porosity	Constant	0.05
DRZ			
0-200 Years	Permeability (X, Y, and Z-directions)	Loguniform	Min: 4.0×10^{-20} m^2 Max: 3.2×10^{-13} m^2
	Effective Porosity	Cumulative	Min: 0.0039 Max: 0.0548 Mean: 0.0211
200-10,000 Years	Permeability (X, Y, and Z-directions)	Triangular	Min: 2×10^{-21} m^2 Max: 1×10^{-17} m^2 Mode: 1.78×10^{-19} m^2
	Effective Porosity	Cumulative	Min: 0.0039 Max: 0.0548 Mean: 0.0211

From Vugrin and Dunagan 2006; Camphouse et al. 2012b.

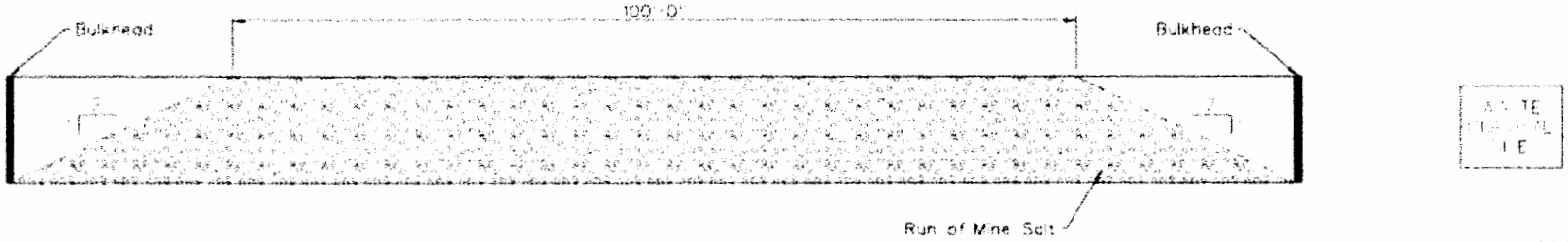
The 2006 PCS PA results showed that repository performance using the ROM salt PCS remained within the regulatory limits (Vugrin and Dunagan 2006). However, the 2006 PCR was withdrawn due to scheduling and time constraints, and the Option D PCS was again used in the PABC-2009 PA for the 2009 CRA.

2.5 2011 PC3R PLANNED CHANGE REQUESTS

The PC3R PA was prepared by SNL to evaluate the combined impacts on long-term WIPP repository performance of two PCRs submitted to EPA by DOE in 2011. These PCRs consisted of a proposal to relocate future waste Panels 9 and 10 to the south end of the repository and a proposal to replace the Option D PCS design with an ROM salt design (DOE 2011a; DOE 2011b). The impacts of these changes were determined by comparing repository performance calculated in the PC3R PA, which included the two proposed design changes, against the baseline PABC-2009, which included the current repository layout and the current Option D PCS design (Clayton et al. 2010).

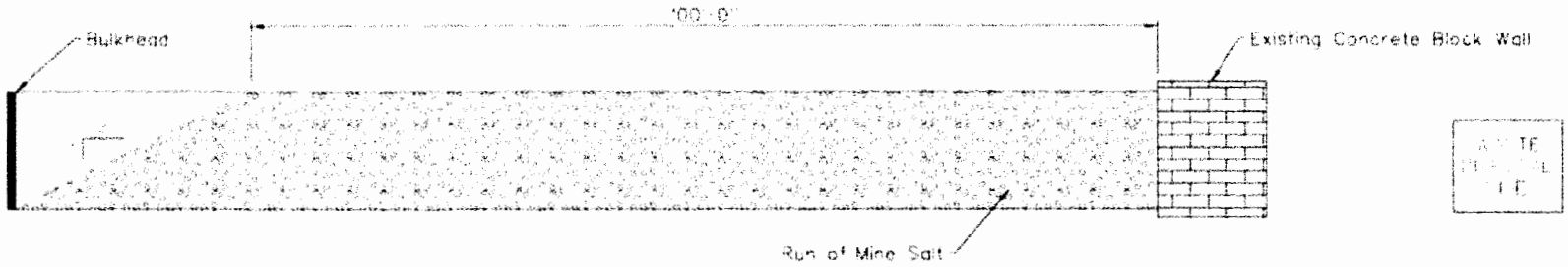
In order to isolate and assess the impacts of the proposed PCS redesign, the Agency requested that DOE prepare a PA that only addressed the proposed PCS redesign. As a result, DOE presented an overview of their proposed approach, called the PCS-2012 PA, to the Agency at a Technical Exchange Meeting in April 2012 (Air Docket A-98-49, Item II-B2-81). The PCS-2012 PA is identical to the PABC-2009 PA with the exception that the modeled panel closure system represents the proposed ROM salt PCS. All other parameters, conditions, material properties, waste inventory, and modeling scenarios are the same as those used in the PABC-2009 PA.

DOE's current PCS design PCS-2012 PA consists of a minimum of 30.5 meters (100 feet) of ROM salt placed within the panel access drift with a steel bulkhead positioned at each end. Alternatively, for waste Panels 1, 2, and 5 where explosion walls have already been constructed, the proposed PCS design consists of the explosion wall on the waste panel end, emplacement of 30.5 meters (100 feet) of ROM salt against the explosion wall, and a standard steel ventilation bulkhead on the outer end (Camphouse et al. 2012a). No concrete monoliths have yet been constructed and the proposed design does not include additional explosion walls. For long-term performance, neither the explosion walls nor the steel bulkheads are assumed to last and do not enter into the performance assessment modeling (Camphouse 2012c). The proposed modified designs are illustrated in Figures 2-3 and 2-4. The Agency's review of the PCS-2012 PA is described in Section 3.0.



From DOE 2013

Figure 2-3. Typical ROM Salt Panel Closure for Drifts without Explosion Walls



From DOE 2013

Figure 2-4. Typical ROM Salt Panel Closure for Drifts with Explosion Walls

3.0 2012 DOE PLANNED CHANGE REQUEST FOR PCS DESIGN

Section 3.0 addresses DOE's analysis of its Planned Change Request (PCR) for modifying the PCS from the approved Option D design to the ROM salt design described in Section 2. Section 3.0 describes DOE's rationale for the proposed design change, the materials and components of the proposed design, the development of DOE's PCS-2012 PA, the results of that PA, and the Agency's evaluation of those results.

DOE documented its request to change the PCS design in a PCR submitted to EPA in September 2011 (DOE 2011b). The Agency's evaluation of DOE's proposed modeling approach of the ROM salt for PCS-2012 PA is presented in Sections 3.4.2.1 and 3.4.2.2. The Agency's evaluation of DOE's proposed modeling of the PCS DRZ is presented in Section 3.4.3. Additional details are presented in Appendix A: Parameter QA.

3.1 RATIONALE FOR ROM SALT DESIGN

The most challenging aspect of implementing the Option D design is constructing the SMC monoliths. SMC is a salt saturated concrete developed for use in the WIPP Shaft Seals. During a series of test pours, DOE determined that SMC as formulated would not be able to meet the specification requirements for the Option D monoliths (DOE 2011b). DOE has, with the approval of EPA and NMED, emplaced temporary closures in various filled panels while gathering information for a revised final closure design. That effort led to the currently proposed ROM salt PCS design. DOE has described its ROM salt design as being simpler, easier and faster to construct, is less disruptive to facility operations, increases the use of natural materials, and is less expensive than the current Option D concrete monolith design, while also meeting the same operational performance requirements as the Option D concrete monolith (DOE 2011b).

3.2 ROM SALT DESIGN MATERIALS AND COMPONENTS

As described in Section 2.0, the ROM salt PCS design consists of two steel bulkheads (or one steel bulkhead and one concrete block explosion wall, if an explosion wall was previously constructed in the panel), and a minimum of 30.5 meters (100 feet) of ROM salt between the two bulkheads. Each bulkhead would consist of a steel frame covered with sheet metal. The bulkheads are designed to limit air flow through closed waste panels during WIPP's operational period and have no post-closure design function. After repository closure, DOE concludes that the bulkheads would corrode and be crushed by halite creep, and would therefore have a negligible effect on repository performance (Camphouse 2012c).

The waste disposal panels and associated access and ventilation drifts in the WIPP underground facility are excavated using a drum-type continuous miner that shreds the intact halite into centimeter size or smaller chunks that can be scooped and hauled like gravel. The ROM designation means that the salt used for the PCS is mined from the WIPP underground facility without grading or processing. The ROM salt material obtained from WIPP mining operations is planned to be delivered by haul truck or load haul dump units to the panel closure area and emplaced as-is, in a loose state or possibly compacted in lifts. Water may also be added to facilitate compaction. The final closure material would be pushed into place to the degree

practicable to minimize the gap between the salt and roof or sidewalls of the drift (Zimmerly et al. 2012). In addition to its ease of handling, the ROM salt is a noncombustible, natural material that is chemically compatible with the repository environment.

DOE believes that the long-term properties of ROM salt are also advantageous during the post-closure period due to its creep characteristics when under compressive stress. DOE's JAS3D numerical modeling indicates that following emplacement, an air gap will form between the drift roof and top of the ROM salt because the initial rate of compaction of the ROM salt from its own weight exceeds the rate of drift creep closure. Two years after salt emplacement, the air gap is predicted to reach a maximum of 19 inches and then begin to close due to inward creep of the drift roof. Modeling results indicate that the air gap closure would be complete after approximately 23 years. In addition to the roof collapse and gradual closing of the air gap, the permeability of the ROM salt will also decrease as the salt consolidates under its own weight (DOE 2013). After the air gap closes, air flow resistance would be predominately due to the consolidated ROM salt and surrounding disturbed rock zone (DRZ) rather than the steel bulkheads (DOE 2013). Although DOE's modeling estimate of 23 years for air gap closure is approximate, the air gaps are expected to have closed in all panel closures by 100 years after repository closure when the period of institutional control of the WIPP site is assumed to end.

After the air gap closes, the ROM salt will be compressed by creeping halite in the drift roof, and to a lesser extent in the drift walls and floor. Although the period of time for this process is uncertain, after about 100 years the compression of the ROM salt is expected to significantly reduce its porosity and permeability. This reduction in porosity of the ROM salt creates a backpressure which would result in greater resistance to further compaction. As the backpressure increases the fractures and fissures in the surrounding DRZ would begin to close. This process has been called "healing" the DRZ because it eventually returns the DRZ to a state that approaches the very low porosity and permeability of intact halite. This healing process is expected to be essentially complete within approximately 200 years (see discussion in Section 3.4.2.1). Therefore, in addition to its pre-closure attributes of low cost and ease of handling, DOE concludes that the ROM salt and surrounding DRZ of the ROM salt PCS design would also have the post-closure attribute of a very low permeability for most of the 10,000-year regulatory period.

3.3 ANALYSIS OF FEATURES, EVENTS, AND PROCESSES

DOE demonstrated the effects of the proposed ROM salt PCS design on long-term repository performance by conducting a PA called the PCS-2012 PA. The first step in preparing a new PA is to identify and evaluate the features, events, and processes (called FEPs) associated with the proposed design changes that could affect repository performance. The focus of the FEP review is to identify new FEPs or changes to existing FEPs that may need to be included in the new PA as a result of changes that have occurred in repository design or conceptual models since the previous PA. The identified FEPs are screened for inclusion or exclusion in the new PA. FEPs may be screened in if they are potentially significant to repository performance, and such FEPs may already be included in the PA models. FEPs may be screened out if their probability of occurrence is low; if they have no, low, or beneficial consequences on repository performance; or if they are excluded on a regulatory basis. This process produces a comprehensive list of FEPs

that are considered potentially relevant to WIPP performance. This list is called the FEPs baseline.

The following screening classifications are used in WIPP FEP analyses:

- DP Screened in for disturbed performance scenarios
- UP Screened in for undisturbed performance scenarios
- SO-C Screened out based on no, low, or beneficial consequence
- SO-P Screened out based on a very low probability of occurrence
- SO-R Screened out based on a regulatory directive

The FEP review for the PCS-2012 PA was conducted by Sandia National Laboratories (SNL) and is documented in Kirkes (2011). For the PCS-2012 PA, the baseline for comparison is the PABC-2009 PA, which has been reviewed and accepted by EPA. The principal changes in the PCS-2012 PA that potentially affect long-term repository performance are a revised design for the waste panel closures consisting of ROM crushed salt (a new repository feature), the modeling of time-dependent consolidation of the ROM salt panel closures due to halite creep (a new process), and the modeling of time-dependent consolidation of the disturbed rock zones (DRZ) around the redesigned panel closures (a revised modeling approach).

3.3.1 SNL's Identification of Potentially Relevant FEPs

SNL's summary report for the PCS-2012 PA uses the FEP review described in Kirkes (2011), which documents the FEP review for the PC3R PA (Camphouse et al. 2012a) and which SNL concluded was applicable for the PCS-2012 PA since the PCS design had not changed. SNL's reviews of potential impacts on the current FEP baseline were guided by SNL Specific Procedure SP 9-4, *Performing FEPs Baseline Impact Assessments for Planned and Unplanned Changes* (Kirkes 2009). The Agency focused its review on those FEPs related to the ROM salt PCS.

SNL's screening review began by identifying all FEPs in the current baseline that may be impacted by the PC3R planned changes. The FEPs identified through this process and related to the proposed ROM salt PCS are presented in Table 3-1. These FEPs include the geometric effects of the proposed panel closure redesign, the physical characteristics of the new panel closure material, consolidation of the ROM salt PCS and the surrounding DRZ, and stress-induced salt creep rates.

SNL's next step was to identify any FEPs associated with the PCS design changes that are not included in the current FEP baseline. This step was accomplished by reviewing the more extensive FEP list prepared in 1995 for the Draft Compliance Certification Application (DCCA). Twelve additional FEPs relevant to the role of the PCS as a seal were identified and are listed in Table 3-2 (Kirkes 2011).

Table 3-1. FEPs Identified by SNL-Related to the Panel Closure Modification

Related FEPs	Screening Classifications	Relationship to Proposed Change
W1 Disposal Geometry	[1]UP	The repository layout must be adequately represented in the BRAGFLO grid
W109 Panel Closure Geometry	UP	Proposed PCS geometry differs from the current PA baseline.
W110 Panel Closure Physical Properties	UP	Proposed PCS material properties differ from the current PA baseline.
W111 Panel Closure Chemical Composition	[2]SO-C (Beneficial)	Proposed PCS chemical composition differs from current PA baseline.
W112 Radiological effects on Panel Closures	SO-C	Proposed PCS material properties differ from current PA baseline.
W18 Disturbed Rock Zone (DRZ)	UP	Proposed repository layout may affect the behavior of the surrounding DRZ
W20 Salt Creep	UP	Proposed repository layout may alter current salt creep expectations
W73 Concrete Hydration	SO-C	Proposed PCS material properties differ from current PA baseline.
W113 Consolidation of Panel Closures	UP	Proposed PCS material properties differ from current PA baseline.
W114 Mechanical Degradation of Panel Closures	UP	Proposed PCS material properties differ from current PA baseline.
W115 Chemical Degradation of Panel Closures	UP	Proposed PCS chemical properties differ from current PA baseline.

[1]UP: Screened in, undisturbed performance scenario
[2]SO-C: Screened out, low or beneficial consequence
Source: Kirkes 2011, Table 1

Table 3-2. DCCA FEPs Excluded from the CCA that Relate to Panel Closures

DCCA FEP Name	Reason for Exclusion from the CCA
Boundary Conditions – Seals	Considered a "modeling issue," not a FEP
Correlation – Seals	Considered a "modeling issue," not a FEP
Groundwater flow: initial conditions - Seals	Considered a "modeling issue," not a FEP
Time dependence – Seals	Considered a "modeling issue," not a FEP
Advection/dispersion: hazardous constituents – Seals	Issues not regulated by 40 CFR 191
Diffusion: hazardous constituents – Seals	Issues not regulated by 40 CFR 191
Dissolution, speciation, sorption, precipitation: hazardous constituents – Seals	Issues not regulated by 40 CFR 191
Buffer additives – Seals	Applies to alternative repository design
Design modifications – Seals	Applies to alternative repository design
Faulty seal emplacement – Seals	Applies to alternative repository design
Inadequate seal or compaction: voidage – Seals	Applies to alternative repository design
Seal material deficiencies	Applies to alternative repository design

Source: Kirkes 2011

SNL's FEP review next evaluated if any FEPs listed in Table 3-2 should be included in the present baseline FEPs list. SNL determined that none of these additional FEPs warranted inclusion. Exclusion of four DCCA FEPs, because they are modeling issues, still holds. SNL concluded that the boundary conditions, correlations, initial conditions, and time dependence are necessary elements of models and should not be part of the FEP list. SNL also determined that

the three "hazardous constituent" FEPs should continue to be excluded, because they are not part of the constituents regulated by 40 CFR Part 191.

One FEP listed in Table 3-2, Design modification – Seals, was determined to be better handled by parameter and model changes, and should not be considered as part of the baseline FEP lists (Kirkes 2011). Four final seal-related FEPs—buffer additives, faulty seal emplacement, inadequate seal or compaction, and material deficiencies—are all related to negligence or poor construction practices. SNL concluded that these are generally not considered FEPs, because they are more closely related to WIPP site operational practices and should be excluded from the baseline FEP list.

SNL's final FEP review step, as required by SP 9-4, Section 2.4.4, was to review the screening arguments and decisions associated with the FEPs listed in Table 3-1 and determine whether they remain valid. If the proposed PCS design changes did not invalidate, change, or render incomplete the existing screening arguments or decisions for the identified FEPs, then the current PA framework was considered suitable to account for the changes.

SNL determined that three FEPs listed in Table 3-1; W73 Concrete Hydration, W111 Panel Closure Chemical Composition, and W112 Radiological Effects on Panel Closures, would continue to be screened out because of expected low consequence, as was done in the CRA-2009 FEPs review. Significant quantities of concrete are omitted from the panel closure redesign; therefore, less thermal rise was expected (W73). Including radionuclide sorption and sequestration in the ROM salt would have a beneficial effect on performance, and so the process is screened out (W111). Because of the low levels of radioactivity in WIPP waste, SNL expected that no radiological effects will be seen on the panel closure material (W112). SNL determined that these three FEPs can continue to be screened out, due to their continued low consequences to WIPP performance.

The remaining FEPs listed in Table 3-1 have previously been screened in and are therefore currently incorporated in WIPP PA. SNL made the following determinations regarding these FEPs. FEPs associated with salt creep and changes in the stress field will remain unaffected because of the PCS design changes and any effect is already included in the WIPP models. Panel closure-related FEPs continue to be included in the WIPP PA, and changes due to the proposed panel closure modification are captured by modeling implementation changes, such as grid alterations and parameter changes (Kirkes 2011).

Kirkes (2011) concludes that no screening decision conflicts or impacts were identified as a result of SNL's review, and therefore the current FEP baseline and PA framework are suitable to account for the changes in the PC3R (and, by extension, the PCS-2012) impact assessment.

3.3.2 EPA Review of SNL's FEP Assessment

The Agency agrees that for screened-in FEPs, the details of conceptual and numerical implementation and parameterization can be considered modeling issues, and can be documented and justified in analysis plans and reports. The Agency's reviews of DOE's approach to parameterizing and modeling the screened-in FEPs are presented elsewhere in this TSD. SNL's

analyses of the FEPs in Table 3-1 that were screened in are summarized in Kirkes (2011). The Agency accepts the reasons presented by Kirkes for screening in those FEPs.

Screened-out FEPs generally require more comprehensive justification as part of a FEP review than screened-in FEPs. This is because the treatment of screened-in FEPs can be documented and justified in subsequent analysis plans and analysis reports, while screened-out FEPs are not considered further. Depending on the issue of concern, adequate justification for screening out FEPs can range from reasoned arguments to detailed technical analyses. Three FEPs listed in Table 3-1 that are potentially relevant to the proposed PCS design change were screened out, all on the basis of past screening conclusions and reasoned arguments of continuing low or beneficial consequence (Kirkes 2011). The Agency accepts the reasons given by SNL for screening out these FEPs.

The Agency also agrees that the FEPs derived from the DCCA and listed in Table 3-2 do not need to be added to the current FEP baseline, in part for the reasons given by SNL (Kirkes 2011) and in part because some of those FEPs are redundant to FEPs already in the baseline.

During its review, the Agency identified two additional, potentially relevant FEPs that are aspects of FEPs that are in the current FEP baseline. These additional FEPs are described below. The Agency concludes that although the two FEPs are potentially relevant but were not considered in SNL's FEP review, neither is expected to have a significant impact on repository performance and their omission does not affect compliance.

3.3.2.1 Impact of Repository Gas Pressure on Reconsolidation of ROM Salt PCS

FEPs W25 *Disruption Due to Gas Effects* and W26 *Pressurization* are potentially relevant to the proposed PCS design change, because high gas pressures could delay the consolidation of the ROM salt, thereby maintaining a higher permeability in the PCS for a longer period of time. Hansen and Thompson (2002) note that if gas generation occurs and gas penetrates the ROM salt, pore pressures may build up, leading to a slowing or stopping of consolidation. However, in response to this Agency concern, in the April and February 2012 technical exchange meetings, documented in the Agency's Air Docket A-98-49, Item II-B2-81, DOE Response to Technical Question 1.3c, and Air Docket A-98-49, Item II-B2-80, DOE adequately demonstrated that significant gas pressure buildup is rare during early time when the porosity and permeability of the ROM salt would be relatively high, and would therefore have little impact on the average releases that are of regulatory concern.

3.3.2.2 Impact of Lateral Halite Movement at the Unconstrained Ends of ROM Salt PCS during Creep Closure

As creep closure progresses, the ends of the emplaced ROM salt will be unconstrained and extruded laterally. This movement and lack of constraint is likely to result in a higher porosity and permeability at the ends of the ROM salt fill than in the center where greater confinement is provided. This would limit the effectiveness of the end regions as panel closures and is an aspect of FEPs W20 *Salt Creep* and W114 *Mechanical Degradation of Panel Closures* that was not considered in SNL's FEP review. In response to this Agency concern, SNL presented the results of a numerical model of panel closure consolidation in the April 2012 technical exchange

meeting, documented in the Agency's AIR Docket A-98-49, Item II-B2-81, DOE Response to Technical Question 1.3e, that adequately demonstrated that such end effects would have little impact on PCS performance.

3.3.3 Adequacy of SNL's FEP Review

The Agency concludes that SNL's FEP baseline review successfully identified the principal modeling changes that were necessary to achieve the purpose of the PCS-2012 PA. Although the additional FEPs identified by the Agency are potentially relevant, DOE has provided additional information to screen out these FEPs.

3.4 DEVELOPMENT OF PCS-2012 PERFORMANCE ASSESSMENT

The PCS-2012 PA was built upon DOE's earlier representations of a ROM salt PCS described above in Section 2.0. The Agency's panel ROM salt design and modeling concerns were discussed in Technical Exchange Meetings between EPA and DOE, and in subsequent correspondence (Air Docket A-98-49; Item II-B2-81, DOE Response to Technical Question 1.3c, and Air Docket A-98-49; Item II-B2-80). The first of these meetings was held in Dallas, Texas, in February 2012, and the second was held in Albuquerque, New Mexico, in April 2012. The Agency's preliminary concerns related to the ROM salt design and the modeling approach proposed by DOE for the PCS-2012 PA are summarized in the following subsections.

3.4.1 ROM Salt PCS Design

The basic components of the currently proposed design were introduced as part of the aforementioned PC3R PA. The Agency's review of the ROM salt PCS design in that PA raised initial concerns that were also relevant to DOE's final design as modeled in the PCS-2012 PA.

3.4.1.1 Elimination of Explosion Walls from PCS Design

Justification for eliminating explosion walls from the ROM salt PCS design was provided by DOE in the PCR submitted to EPA in September 2011 (DOE 2011b). This appendix describes the generation mechanisms of hydrogen and methane, the two flammable gases of most concern in filled waste panels. The appendix also describes hydrogen and methane monitoring results in the waste rooms of Panels 3 and 4, and presents a worst-case analysis of hydrogen buildup in Panel 3. DOE concluded that explosion walls are not necessary because measured levels of hydrogen and methane were well below the lower explosive limit.

3.4.1.2 Elimination of Steel Bulkheads and Explosion Walls from Post-closure Modeling

For long-term performance, neither the explosion walls nor the steel bulkheads are assumed to last and do not enter into the performance assessment modeling (Camphouse 2012c). DOE explains that as a result of the loading caused by inward creep of the surrounding halite explosion walls will not be significant structures after the initial 100 year time period due to the brittle, non-plastic behavior of concrete (Camphouse 2012c). Similarly, the PCS steel bulkheads are only designed to control the pressures of ventilation air and would not be sufficiently strong to impede drift creep closure.

In view of the brittle nature of the concrete blocks, the high stresses that will eventually be imposed by creep closure, and the presence of explosion walls in only three of the 10 WIPP waste panels, the Agency agrees that explosion walls do not need to be explicitly modeled in the PCS-2012 PA. Furthermore, the Agency agrees that the bulkheads will corrode in the post-closure environment, be crushed during drift creep closure, and have no impact on post-closure repository performance.

3.4.1.3 ROM Salt Emplacement Method

The method used by DOE for emplacing the ROM salt can affect its initial porosity and permeability. Mechanical compaction and higher moisture content reduce the initial porosity and permeability of the salt.

At the time the PCS-2012 PA was performed, the method of emplacing the ROM salt was uncertain. DOE had initiated tests of three different emplacement scenarios that were as yet incomplete. Scenario 1 consisted of 1% (by weight) of water added to the ROM salt and compaction of the salt. Scenario 2 consisted of compaction of the ROM salt with no additional water. Scenario 3 consisted of the ROM salt simply being placed and pushed up tight against the roof and walls without compacting or adding water (Zimmerly et al. 2012). Uncertainty regarding the ROM salt emplacement method and initial density increases the uncertainty in estimating its permeability during the first 100 years. The Agency believes this was adequately addressed by DOE assigning wide ranges to the ROM salt porosity and permeability values in the PCS-2012 PA.

3.4.2 ROM Salt Modeling

3.4.2.1 Porosity and Permeability of the ROM Salt during Consolidation

Initial information on the porosity and permeability of the ROM salt during the consolidation process was provided by DOE in Attachment B of the PCR (DOE 2011b). This attachment consisted of a 2002 memorandum describing changes in porosity and permeability with time of the ROM salt during drift creep closure (Hansen and Thompson 2002). Hansen and Thompson estimated an initial permeability of the loosely placed ROM salt of 10^{-11} m^2 and a porosity of about 33%. Following emplacement, salt consolidation and later drift closure from halite creep would compress the ROM salt and reduce both its permeability and porosity. Based on the data of Hurtado et al. (1997), Hansen and Thompson expected the ROM salt permeability to be 10^{-15} m^2 or lower when its porosity reached 10%, and about 10^{-19} m^2 when the porosity reached 5%. As consolidation proceeds, the material will attain sufficient density so that its response would assume the constitutive response of intact salt (Hansen and Thompson 2002). Hansen and Thompson do not expect significant back pressure from the consolidating salt until the porosity drops to about 10% and permeability lower than 10^{-15} m^2 is achieved (Hansen and Thompson 2002). Based on the measured, unimpeded closure rates of WIPP drifts and considering the delaying effects of back pressure buildup, Hansen and Thompson believed that porosity on the order of 10% may be achieved within 40 to 60 years following ROM salt emplacement (Hansen and Thompson 2002).

DOE initially proposed to model the consolidation of the ROM salt in the PCS-2012 PA using two time periods: a time period (T1) extending from 0 to 100 years, and a time period (T2) extending from 100 to 10,000 years. To better model the consolidation process, the Agency recommended that DOE model three time periods instead of two and use ranges of permeability values that more accurately reflect intermediate consolidation states.

The expected conditions during the three time periods are as follows:

T1: ROM salt healing, but producing no backstress. DRZ static or expanding.
T2: ROM salt placing backstress on DRZ. Both are in process of healing.
T3: Forces balanced and healing generally complete.

DOE responded to the Agency's recommendations by incorporating three time periods in the PCS-2012 PA: time period T1 extends from zero to 100 years as before; time period T2 extends from 100 to 200 years, and time period T3 extends from 200 years to 10,000 years. DOE treated ROM salt porosity as an uncertain, sampled parameter and determined the permeability for time periods T2 and T3 using a correlation between permeability and porosity based on laboratory data from Hurtado et al. (1997). DOE proposed to sample the new T2 porosity from 2.5% to 7.5% using a uniform distribution. This range retained the same average porosity of 5% that DOE believes could be achieved by 100 years. DOE proposed to sample the T3 porosity from 0.1% to 5.19%, again using a uniform distribution. Although this range and distribution are the same as used for intact halite in WIPP PA, the T3 porosity value was independently sampled in the PCS-2012 PA. Assigning the same range and distribution assumes that the ROM salt PCS will fully compact and have properties consistent with those of intact halite during time period T3.

Because there is also uncertainty in the permeability that is correlated with a given sampled porosity, DOE proposed to use only the permeability values from Hurtado's data set that were measured with brine (not gas) as a permeant and sample permeability from a normal distribution centered on a linear least squares fit to a plot of Hurtado's porosity vs. log permeability data. This approach resulted in an overall permeability range of -20.8 log (m^2) or 1.58×10^{-21} m^2 to -16.3 log (m^2) or 5.01×10^{-17} m^2 during time period T2, and an overall range of -21.4 log (m^2) or 3.98×10^{-22} m^2 to -16.8 log (m^2) or 1.58×10^{-17} m^2 during time period T3.

The Agency agreed that incorporating three time periods better represents the ROM salt reconsolidation process. The Agency also agreed that using only Hurtado's brine data set for correlating permeability to porosity during time periods T2 and T3 is appropriate because the data represented the porosity range expected after 100 years based on DOE's proposed ROM salt emplacement methods. Correlating those data with the porosity ranges was also deemed appropriate for the halite by the Agency because brine is expected to accumulate in the repository in later time and, as previously mentioned, the permeability of consolidating ROM salt is reduced by the presence of moisture.

In recognition of the uncertainty in the rate of salt consolidation and the correlation between porosity and permeability, the DOE proposed to change the porosity and permeability of the ROM salt during time period T1 from a constant to values sampled over a range. DOE proposed sampling the porosity from a uniform distribution over the range of 6.6% to 18.7% and

independently sampling the log permeability from a uniform distribution ranging from 10^{-12} to 10^{-21} m^2 (Camphouse et al. 2012b; as amended by Patterson 2012). Sampling for the three time periods is conditioned so that the ROM salt permeability monotonically decreases with time. The T1 ranges are selected based on the porosity and permeability of the ROM salt expected by DOE at 50 years after emplacement, which is the midpoint of time period T1. The porosity range uses JAS3D modeling predictions at 50 years for initial emplacement porosities ranging from 20% to 35%, depending on whether the ROM salt was compacted upon emplacement. The permeability range is based in part on laboratory measurements of the permeability of crushed salt with porosities within the T1 range of 6.6% to 18.7% (Camphouse et al. 2012b). A more detailed discussion of the porosity and permeability values for the ROM salt is presented in Appendix A.

3.4.2.2 ROM Salt Two-Phase Flow Properties

Two-phase brine and gas flow is expected to occur within the WIPP repository during the regulatory time frame and is simulated for all materials in WIPP PA except the anhydrites using a modified Brooks-Corey model (Camphouse et al. 2012b). The parameters describing two-phase flow in the ROM salt are summarized in Table 3-3 and are further discussed in Camphouse (2012d). EPA conducted a sensitivity study of the two-phase flow properties and determined that they did not appreciably affect performance assessment results. The results of this additional study are presented in Section 4.0 of this TSD.

Table 3-3. Two-Phase Flow Properties for the ROM Salt

Property Name in PCS-2012 PA	Parameter Description
RELP_MOD	Relative permeability model number for the ROM salt
CAP_MOD	Capillary pressure model number for the ROM salt
PCT_A	Threshold capillary pressure linear parameter for the ROM salt
PCT_EXP	Threshold capillary pressure exponential parameter for the ROM salt
KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the ROM salt
PC-MAX	Maximum allowable capillary pressure for the ROM salt
PO_MIN	Minimum allowable brine pressure for the ROM salt
PORE_DIS	Brooks-Corey pore distribution parameter for the ROM salt
SAT_IBRN	Initial brine saturation of the ROM salt at the beginning of time period T1
SAT_RBRN	Residual brine saturation of the ROM salt
SAT_RGAS	Residual gas saturation of the ROM salt

Property RELP_MOD. Relative permeability Model 4, a modified Brooks-Corey model, was used for the ROM salt. The Agency believes that the modified Brooks-Corey model adequately describes two-phase flow in the ROM salt and is appropriate and consistent with the use of this model in the baseline PABC-2009.

Property CAP_MOD. Capillary pressure Models 1 and 2 both relate to the Brooks-Corey relative permeability model but Model 1 is typically used by SNL when the capillary pressure function is turned off, and Model 2 is typically used when that function is turned on. Although the database approved by the Agency for the PCS-2012 PA specified use of capillary pressure Model 2, Model 1 was used instead because it avoided numerical problems with the BRAGFLO code when using Model 2. In response to an Agency request, SNL determined that the numerical

problems resulted from assigning an initial brine saturation that was less than the residual brine saturation, as more fully described below. Because capillary pressure would actually exist in the ROM salt, at the Agency's request the problem with BRAGFLO was corrected and the PCS-2012 PA was rerun by the Agency using Model 2.

Property PCT_A. As applied to the ROM salt, threshold capillary pressure is the minimum pressure that repository gas must attain before it can overcome capillary pressure and create a continuous flowpath for gas in a partially saturated medium. Threshold capillary pressure for the Brooks-Corey model is calculated as:

$$P_t = a\,k^{-b}$$

where a is called the linear parameter, designated in WIPP PA as the property PCT_A, k is the permeability of the material in the X-direction, and b is the exponential parameter, designated in WIPP PA as the property PCT_EXP. Positive values for PCT_A activate the capillary pressure model, while zero values deactivate it. The PCS-2012 PA database approved by the Agency included a value of 0.56 for PCT_A because, as described above, capillary pressure would actually exist in the ROM salt and the Agency wanted to determine its effect on releases. However, SNL set PCT_A for the ROM salt to zero in the PCS-2012 PA to deactivate the capillary pressure model and avoid numerical problems with BRAGFLO. As described above, the problem with BRAGFLO was corrected and the PCS-2012 PA was rerun using a value of 0.56 for PCT_A.

Property PCT_EXP. PCT_EXP is the exponential parameter in the aforementioned threshold capillary pressure equation. SNL typically sets PCT_EXP to zero when PCT_A is set to zero. A value of -0.346 was accepted by the Agency for this property as part of an activated capillary pressure model in the PCS-2012 PA. SNL subsequently reset the value of PCT_EXP to zero because of numerical problems with BRAGFLO. As described above, the problem with BRAGFLO was corrected and the PCS-2012 PA was rerun using a value of -0.346 for PCT_EXP.

Property KPT. KPT is a flag for using either constant or varying permeability in the threshold pressure equation presented above. When KPT is set to 0.0, the permeability is not varied as a function of time but changes when the material changes. The Agency accepted a value of 0.0 for this parameter because the threshold capillary pressure would be appropriately recalculated for the new ROM salt PCS materials during T1, T2, and T3.

Property PC_MAX. PC_MAX is the maximum capillary pressure allowed when using capillary pressure Model 2. The Agency notes that capillary pressure can become very large at low brine saturations, and it is appropriate to limit the maximum value of this parameter to avoid numerical problems with BRAGFLO. The Agency has reviewed the value of this parameter and found it to be reasonable and appropriate for use in the PCS-2012 PA.

Property PO_MIN. PO_MIN is the minimum allowable capillary pressure. It is only used in capillary pressure Model 3, which was not used in PCS-2012 or in PABC-2009. The value of this parameter, therefore, has no impact on the PA results.

Property POR_DIS. POR_DIS is a pore distribution index that is required for the Brooks-Corey two-phase flow model used in WIPP PA. The Agency has reviewed the assigned value for this parameter and found it to be reasonable given the range of values for pore size distributions for 'consolidated rock' reported in Hurtado et al. (1997).

Property SAT_IBRN. As applied here, SAT_IBRN is the initial brine saturation of the ROM salt at the beginning of time period T1. A value lower than the residual brine saturation (described below) was used in the PCS-2012 PA because of the drying that was expected to occur in ROM salt that would be stockpiled prior to use as a panel closure material. Although the Agency considers the drying process to be realistic, the residual brine saturation is defined as the lowest possible brine saturation in the Brooks-Corey model, which does not consider drying effects. It was therefore not surprising that assigning even lower brine saturation as an initial condition caused numerical problems. As described above, the numerical problems were resolved when the PCS-2012 PA was rerun using an artificially higher value for SAT_IBRN. The Agency accepts the use of a higher value because the moisture content of the ROM salt is expected to increase upon repository closure when mine ventilation ceases.

Property SAT_RBRN. As applied here, SAT_RBRN is the residual brine saturation of the ROM salt. The residual brine saturation is the saturation at which brine flow ceases because a continuous flow path for brine through the medium no longer exists. Ignoring evaporation and chemical effects, the residual saturation is therefore the lowest brine saturation that can be attained in an initially saturated medium. In previous PAs, the range of the distribution for this parameter went to zero, which the Agency considers to be unrealistic for a porous medium. However, the end members of a distribution are rarely sampled and allowing this range to extend to zero was not expected to significantly impact repository performance. The Agency agreed to retain this distribution for the PCS-2012 PA to simplify comparison of results.

Property SAT_RGAS. As applied here, SAT_RGAS is the residual gas saturation of the ROM salt. Parallel with residual brine saturation, the residual gas saturation is the saturation at which gas flow ceases because a continuous flow path for gas through the medium no longer exists. In previous PAs, the range of the distribution for this parameter went to zero, which the Agency considers to be unrealistic for a porous medium. However, the end members of a distribution are rarely sampled and allowing this range to extend to zero was not expected to significantly impact repository performance. The Agency agreed to retain this distribution for the PCS-2012 PA to simplify comparison of results.

3.4.2.3 Bulk Compressibility of the ROM Salt during Consolidation

Bulk compressibility is used in BRAGFLO to calculate pore volume compressibility, which is part of the hydraulic diffusivity term used in calculating transient fluid flow in a compressible porous medium. Pore volume compressibility is equal to the bulk rock compressibility divided by the porosity. Bulk rock compressibility is also used to determine resistance to crushing (also called the back pressure) provided by a material under a confining stress. However, bulk compressibility is not used in this manner for the panel closures in the PCS-2012 PA because the process of creep closure around the waste panel seals is not explicitly modeled.

The same constant value of 8.0×10^{-11} Pa^{-1} was proposed by DOE for this parameter for all three time periods in the PCS-2012 PA. The proposed value was originally used for the compacted, crushed salt materials in the WIPP shaft seal. Although the Agency considers its value to be a reasonable estimate for compacted salt, the initial compressibility of the salt will be higher if it is emplaced without compaction. However, the Agency believes that the proposed value of this parameter is acceptable for all three time periods because the ROM salt may be compacted upon emplacement.

3.4.3 PCS DRZ Modeling

DOE proposed to model the PCS DRZ using characteristics of the modeling approaches that had previously been used for the Option D design and for the DRZ around the waste panels. This approach helped to facilitate comparison with the results of the baseline PABC-2009 PA and was approved by the Agency for the PCS-2012 PA. The Agency's review of the model changes proposed by DOE focused on the short- and long-term porosity and permeability, and the two-phase flow properties of the PCS DRZ. An overview of the Agency's primary conclusions is presented in the following subsections. Additional details are presented in Appendix A: Parameter QA. A summary tabulation of the Agency's modeling concerns is presented in Section A.4.

3.4.3.1 Porosity and Permeability of the PCS DRZ during Healing

The PCS DRZ is the disturbed rock zone that forms around the ROM salt fill material as a result of stress relief within the halite due to drift excavation. The stress gradients cause open fracturing near the drift walls and dilation from micro-fracturing of the halite farther from the drift walls. As described above in Section 3.2, healing of the PCS DRZ occurs as a result of drift creep closure and begins when the ROM salt begins to resist further compaction and applies a backpressure that starts to close fractures in the surrounding DRZ. This process eventually returns the DRZ to a state that approaches the very low porosity and permeability of intact halite.

DOE expects healing of the PCS DRZ to be essentially complete within approximately 200 years (Camphouse et al. 2012b). DOE chose to represent the PCS DRZ healing process in the PCS-2012 PA by combining time periods T1 and T2, such that one set of parameters (given the material name DRZ_1) represents the disturbed PCS DRZ during time periods T1 and T2, while a second set of parameters (given the material name DRZ_PCS) represents the nearly healed PCS DRZ during time period T3. The material DRZ_1 has the same material properties as the DRZ around a waste panel. Therefore, for the first 200 years the properties of the PCS DRZ are identical to those of the waste panel DRZ.

DOE proposed not to vary the porosity of the PCS DRZ with time in the PCS-2012 PA, and also proposed to use the same sampled porosity value as for the DRZ around the waste panels. This same approach was also used for the porosity of the DRZ around the Option D monolith in the PABC-2009 PA. The DRZ porosity was sampled from a cumulative distribution over the range of 0.39% to 5.48%, with a median value of 1.29% (Camphouse et al. 2012b). Although the initial DRZ porosity would be expected to be larger than the final porosity due to healing effects, EPA

accepts the range and distribution for the PCS DRZ porosity used in PCS-2012, since they were also used in PABC-2009 and therefore facilitate a comparison of results.

For time periods T1 and T2, DOE proposed to use the same sampled permeability value for the PCS DRZ as for the DRZ around the waste panels. The log permeability was therefore proposed to be sampled from a uniform distribution ranging from a minimum of -19.4 log (m^2) or 3.98×10^{-20} m^2 to a maximum of -12.5 log (m^2) or 3.16×10^{-13} m^2. The mode of the distribution was -16.0 log (m^2) or 1×10^{-16} m^2 (Camphouse et al. 2012b). For time period T3, DOE proposed to use the same permeability range and distribution as for the healed DRZ around an Option D concrete monolith. DOE therefore proposed to independently sample the log permeability from a triangular distribution ranging from a minimum of -20.699 log (m^2) or 2×10^{-21} m^2 to a maximum of -17.0 log (m^2) or 1×10^{-17} m^2. The mode of the distribution was -18.7496 log (m^2) or 1.78×10^{-19} m^2 (Camphouse et al. 2012b). The rationale for this distribution was that it would be slightly higher than the permeability range for intact halite (10^{-24} to 10^{-21} m^2) and it would be the same as the permeability range for the Option D concrete monolith, such that flow between the DRZ and the monolith would be equally probable and the concrete monolith seal 'system' would act as a single unit (Stein 2002).

The Agency was concerned that DOE's approach of independently sampling PCS DRZ permeability for the initial T1, T2 and final T3 time periods could lead to the fully healed T3 permeability being greater than the T1 and T2 permeability because the two ranges overlap. The ROM salt and surrounding DRZ can have relatively independent porosity and permeability until the ROM salt is sufficiently consolidated and begins to apply a backstress on the surrounding DRZ. The Agency agrees with the geomechanical processes that will 'heal' the DRZ as described by Camphouse et al. (2012b): "As ROM salt reaches higher fractional densities during consolidation, backstress will be imposed on the surrounding rock mass leading to eventual healing of the disturbed rock zone (DRZ)." The high end of the T3 permeability range for healed DRZ (1×10^{-17} m^2), however, is nearly the same as the mode of the T1 distribution for the ROM salt (1×10^{-16} m^2) and the low end of the T3 permeability range for healed DRZ (2.14×10^{-21} m^2) is three orders of magnitude higher than the low end of the permeability range for intact halite (1×10^{-24} m^2). The Agency's interpretation of the data is that the permeability of a healed DRZ could be closer to the permeability of intact halite.

In the PABC-2009, DOE recognized that "the permeability of the salt immediately above and below the rigid concrete monolith component of Option D will approach the intrinsic permeability of the undisturbed Salado halite," but assigned the permeability values to the DRZ_PCS identical to those for the material CONC_PCS. DOE acknowledged that this parameterization was based "not directly on experimental data (although the general range of the distribution agrees with experimental observations of healed salt" but instead "ensures that any fluid flow is equally probable through or around the Option D panel closures, and represents the range of uncertainty that exists in the performance of the panel closure system" (DOE 2009).

The Agency agreed with the PCS DRZ values used in PCS-2012 to maintain consistency with PABC-2009 and simplify a comparison of results. EPA, however, investigated the effect on potential repository releases if the permeability of the DRZ were to approach that of intact halite

200 years following repository closure. This evaluation and its results are described in Section 4.0.

3.4.3.2 PCS DRZ Two-Phase Flow Properties

The two-phase flow characteristics of the PCS DRZ are expected to be different from those of the ROM salt because of the effects of open fractures in the DRZ that would not be present in the ROM salt. The open fractures would allow gas to enter the PCS DRZ at very low capillary pressures that could drop to essentially zero if the fracture apertures are wide enough to not be bridged by capillary action. This difference occurs only when open fractures exist, and therefore applies only to the PCS DRZ during the initial time periods T1 and T2. As the fractures close and the DRZ is healed, capillary effects will be present. The properties describing two-phase flow in the PCS DRZ and their conceptual application to the three time periods are summarized in Table 3-4. The two-phase flow parameters used for the PCS DRZ in the PCS-2012 PA are summarized in Camphouse et al. (2012b). The basic functions of these properties are the same as described for the ROM salt in Table 3-4. As described below and in Section 4.0, the Agency evaluated an alternative set of two-phase flow parameter values from those used in the PCS-2012 PA as part of its analysis correlating DRZ permeability with the permeability of intact halite. The results of that analysis showed that the repository continued to meet the containment requirements of 40 CFR Part 191.13 under these alternative assumptions.

Table 3-4. Two-Phase Flow Properties for the PCS DRZ

Property Name in PCS-2012 PA	Parameter Description	Conceptual Relevance to Time Periods T1 and T2	Conceptual Relevance to Time Period T3
RELP_MOD	Relative permeability model number for the PCS DRZ	Modified Brooks-Corey model applies	Modified Brooks-Corey model applies
CAP_MOD	Capillary pressure model number for the PCS DRZ	Capillary pressure could go to zero, consistent with a fractured medium	Capillary pressure would not be zero
PCT_A	Threshold capillary pressure linear parameter for the PCS DRZ	Could be zero, consistent with a zero capillary pressure	Would not be zero
PCT_EXP	Threshold capillary pressure exponential parameter for the PCS DRZ	Could be zero, consistent with a zero capillary pressure	Would not be zero
KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the PCS DRZ	A zero value applies	A zero value applies
PC-MAX	Maximum allowable capillary pressure for the PCS DRZ	Would not be used when capillary pressure is zero	Would be used and would not be zero
PO_MIN	Minimum allowable brine pressure for the PCS DRZ	Would not be used	Would not be used
PORE_DIS	Brooks-Corey pore distribution parameter for the PCS DRZ	Would be used	Would be used
SAT_IBRN	Initial brine saturation of the PCS DRZ at time -5 years	Would be set to a value >SAT_RBRN at time -5 years	Would be calculated based on saturation at end of time period T1 and T2

Table 3-4. Two-Phase Flow Properties for the PCS DRZ

Property Name in PCS-2012 PA	Parameter Description	Conceptual Relevance to Time Periods T1 and T2	Conceptual Relevance to Time Period T3
SAT_RBRN	Residual brine saturation of the PCS DRZ	Could go to zero, consistent with a fractured medium	Would not be zero
SAT_RGAS	Residual gas saturation of the PCS DRZ	Could go to zero, consistent with a fractured medium	Would not be zero

Property RELP_MOD. Relative permeability Model 4, a modified Brooks-Corey model, was used by DOE for the PCS DRZ in all three time periods. The Agency believes that the modified Brooks-Corey model adequately describes two-phase flow in the PCS DRZ and is appropriate and consistent with the use of this model in the baseline PABC-2009.

Property CAP_MOD. DOE's use of capillary pressure Model 1 for time periods T1 and T2 is consistent with its use in the PABC-2009 PA and is also theoretically appropriate. Model 1 is used when the capillary pressure is set to zero, which is appropriate for a fractured PCS DRZ in early times. DOE's use of capillary pressure Model 1 for time period T3 is also consistent with its use in the PABC-2009 PA. A zero value would not be appropriate if all fractures were closed in a healed DRZ. The Agency accepts the use of Model 1 in both early and late time periods in the PCS-2012 PA because its continued use facilitates comparison of results. The Agency has performed a sensitivity study that evaluates the impacts of DOE's parameter values for the PCS DRZ on repository performance, including the two-phase flow parameters. The results of this study are presented in Section 4.0.

Property PCT_A. DOE's assignment of a zero value to PCT_A for time periods T1 and T2 is consistent with its use in the PABC-2009 PA and is also conceptually appropriate. A zero value for this property deactivates the capillary pressure model, which is appropriate for a fractured PCS DRZ in early times. DOE's assignment of a zero value to PCT_A for time period T3 is also consistent with its use in the PABC-2009 PA. A zero value would not be appropriate if all fractures were closed in a healed DRZ. The Agency accepted use of a constant zero value for PCT_A in the PABC-2009 PA to resolve numerical problems in BRAGFLO and because its use was judged to have an insignificant effect on repository performance. The Agency accepts the use of zero values for PCT_A in both early and late time periods in the PCS-2012 PA because its continued use facilitates comparison of results.

Property PCT_EXP. As with Property PCT_A, DOE's assignment of a zero value for PCT_EXP for time periods T1 and T2 is consistent with its use in the PABC-2009 PA and is also conceptually appropriate because capillary pressures can drop to zero in open fractures. DOE's assignment of a zero value for PCT_EXP for time period T3 is also consistent with its use in the PABC-2009 PA. A zero value would not be appropriate if all fractures were closed in a healed DRZ. The Agency accepted use of a constant zero value for PCT_EXP in the PABC-2009 PA to resolve numerical problems in BRAGFLO and because its use was judged to have an insignificant effect on repository performance. As with Property PCT_A, the Agency accepts the

use of zero values for PCT_EXP in both early and late time periods in the PCS-2012 PA because its continued use facilitates comparison of results.

Property KPT. DOE's assignment of a zero value for KPT is accepted by the Agency because the threshold capillary pressure would be appropriately recalculated for the healed PCS DRZ during time period T3 because it is a new material.

Property PC_MAX. DOE has adopted the same value of PC_MAX for the PCS DRZ as for the ROM salt. The Agency has reviewed the value of this parameter and found it to be reasonable and appropriate for use in the PCS-2012 PA. This parameter is not used in capillary pressure Model 1 and the results were therefore insensitive to its value. As described above, the Agency considers Model 1 to be appropriate for the PCS DRZ in time periods T1and T2 but not appropriate for time period T3. The Agency accepted the use of Model 1 for the entire regulatory time frame in the baseline PABC-2009 PA and also accepts its use in the PCS-2012 PA because it is consistent with its use in the baseline PABC-2009 PA and facilitates a comparison of results. The effect of DOE's selection of two-phase flow parameters is included in an EPA sensitivity study presented in Section 4.0.

Property PO_MIN. As described above, PO_MIN is only used in capillary pressure Model 3, which was not used in PCS-2012 or in PABC-2009. The value of this parameter, therefore, has no impact on the PA results.

Property POR_DIS. POR_DIS is a pore distribution index that is required for the Brooks-Corey two-phase flow model used in WIPP PA. The Agency has reviewed the assigned value for this parameter and found it to be reasonable given the range of values for pore size distributions for 'consolidated rock' reported in Hurtado et al. (1997).

Property SAT_IBRN. The initial brine saturation of the PCS DRZ was set to 1.0 at time period -5 years in both the PABC-2009 and the PCS-2012 PAs. It is not a new property for the DRZ and is included here for completeness. Initial conditions are set for many parameters in WIPP PA at 5 years before repository closure so that the models can calculate what the value would be at time zero.

Property SAT_RBRN. SAT_RBRN was assigned a constant value of zero for the PCS DRZ for all three time periods. Although as described above, the Agency considers a value of zero to be reasonable for a fractured medium and therefore reasonable for the T1 and T2 time periods, it is also not appropriate for times within period T3 when the open fractures have closed. At later times, however, most of the DRZ porosity will be filled with brine and therefore brine flow will not be significantly affected by the zero residual brine saturation.

Use of a zero value for this parameter is also appropriate for the DRZ around a waste panel where gas pressure fluctuations are expected to disrupt the DRZ and retard fracture closure. This constant zero value was retained when the PCS DRZ was separately identified for modeling the Option D PCS because it was judged to have an insignificant effect on repository performance. The Agency accepts the use of zero values in the PCS-2012 PA because they are consistent with

their use in the baseline PABC-2009 PA, are unlikely to significantly affect the results, and facilitate a comparison of results.

Property SAT_RGAS. As with SAT_RBRN, SAT_RGAS was assigned the same constant value of zero for the PCS DRZ for all three time periods. The Agency's response is also the same. Although as described above, the Agency considers a value of zero to be reasonable for a fractured medium and therefore reasonable for the T1 and T2 time periods, it is not appropriate for times within period T3 when the open fractures have closed. At later times, however, gas generation will have dropped off significantly and most of the porosity within the DRZ will be filled with brine thereby reducing the sensitivity to residual gas saturation.

Use of a zero value for this parameter is appropriate for the DRZ around a waste panel where gas pressure fluctuations are expected to disrupt the DRZ and retard fracture closure. This constant zero value was retained when the PCS DRZ was separately identified for modeling the Option D PCS because it was judged to have an insignificant effect on repository performance. The Agency accepts the use of zero values in the PCS-2012 PA because they are consistent with their use in the baseline PABC-2009 PA, are unlikely to significantly affect the results, and facilitate a comparison of results.

3.4.3.3 Bulk Compressibility of the PCS DRZ during Healing

In BRAFLO, the porosity is calculated as a function of the bulk compressibility and prevailing pressure. For the PCS-2012 PA, DOE proposed a constant value of 7.41×10^{-10} Pa^{-1} for bulk compressibility for all three time periods. Although the compressibility of the PCS DRZ should be higher during early times when the fractures are open and lower during later times as the fractures close the DRZ porosity is sampled from a distribution that would, in effect, cover a range of expected bulk compressibilities. DOE's also used the proposed value in the PABC-2009 PA. Therefore, the Agency accepted DOE's constant value for the PCS-2012 PA.

3.4.4 Development of the PCS-2012 PA Numerical Model

The PCS-2012 PA was developed by SNL to be as similar as possible to the baseline PABC-2009 PA. This was done to facilitate a comparison between the results of the two PAs that would help identify the effects of the proposed modified PCS design on repository releases. Only those aspects of the PABC-2009 calculations that were potentially impacted by the panel closure redesign were updated for the PCS-2012 PA. For example, the PCS-2012 PA used the same waste inventory information, drilling rate and plugging pattern parameters, and radionuclide solubility parameters as were used in the PABC-2009 PA (Camphouse et al. 2012a). The same set of six intrusion scenarios was also used to calculate brine and gas flow. These scenarios are summarized in Table 3-5. An E1 intrusion assumes the borehole passes through a waste-filled panel and into a pressurized brine reservoir beneath the repository in the Castile Formation. An E2 intrusion assumes that the borehole passes through the repository and the Castile Formation but does not encounter a brine reservoir. E1 and E2 borehole intrusions are illustrated in Figure 3-1.

Table 3-5. BRAGFLO Salado Flow 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 and E1 intrusion at 2,000 years

From Camphouse et al. 2012a; BF = BRAGFLO

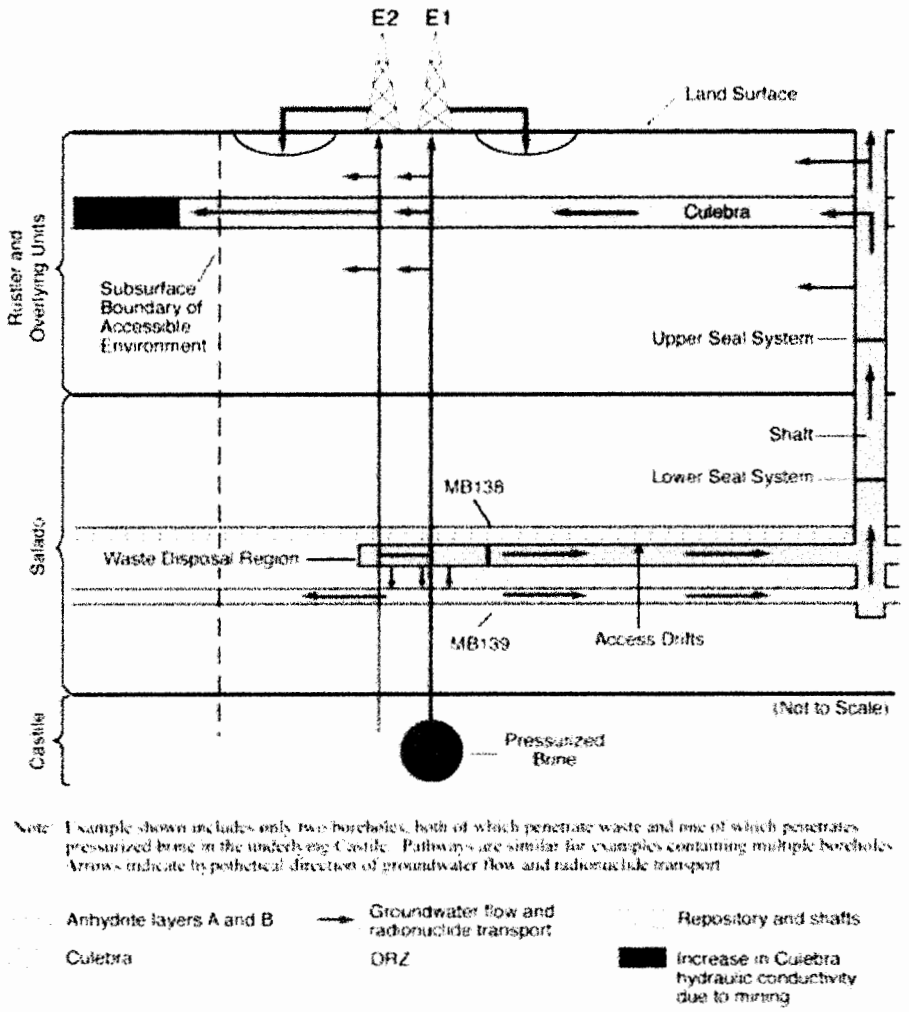


Figure 3-1. Illustration of E1 and E2 Borehole Intrusions

Most computational changes for the PCS-2012 PA were made to the BRAGFLO Salado Flow Model to accommodate the revised geometry, time periods, and material properties associated with the modified PCS design. The revised geometry was accommodated by changes to the baseline PABC-2009 BRAGFLO grid. The baseline grid with an E1 intrusion is shown in

Figure 3-2. This two-dimensional grid includes the Option D concrete monolith, which was to be "keyed in" to the DRZ and extend vertically from Anhydrite AB above to anhydrite Marker Bed 139 below, cutting off the lower and part of the upper DRZ around the monolith. The grid dimensions on the figure are in meters.

The revised grid for the PCS-2012 PA is illustrated in four figures with the same cell dimensions but different material properties: Figure 3-3 shows the grid for time period T1 (0 to 100 years); Figure 3-4 shows the grid for time period T2 (100 to 200 years), Figure 3-5 shows the grid for time period T3 (200 years to 10,000 years), and Figure 3-6 shows the T3 grid with activated intrusion borehole material properties.

As shown in Figure 3-3, during time period T1 the ROM salt is given the material name PCS_T1 and the surrounding PCS DRZ is given the same properties as the DRZ around the waste panel and around the rest of the WIPP underground facility. Segments of Anhydrite AB and anhydrite Marker Bed 139 remain in place within the PCS DRZ for two reasons. First, SNL does not expect the marker beds to be as significantly disrupted around a panel closure as they would be around a waste panel. Additionally, and as explained by Camphouse (2012c), the presence of the marker beds within the PCS DRZ help the two-dimensional model capture the impacts of brine and gas that could bypass the panel closure by flowing through the interbed layers out of plane of the model. Institutional control of the WIPP site is assumed to remain in force during time period T1 and no borehole intrusions of the waste are expected.

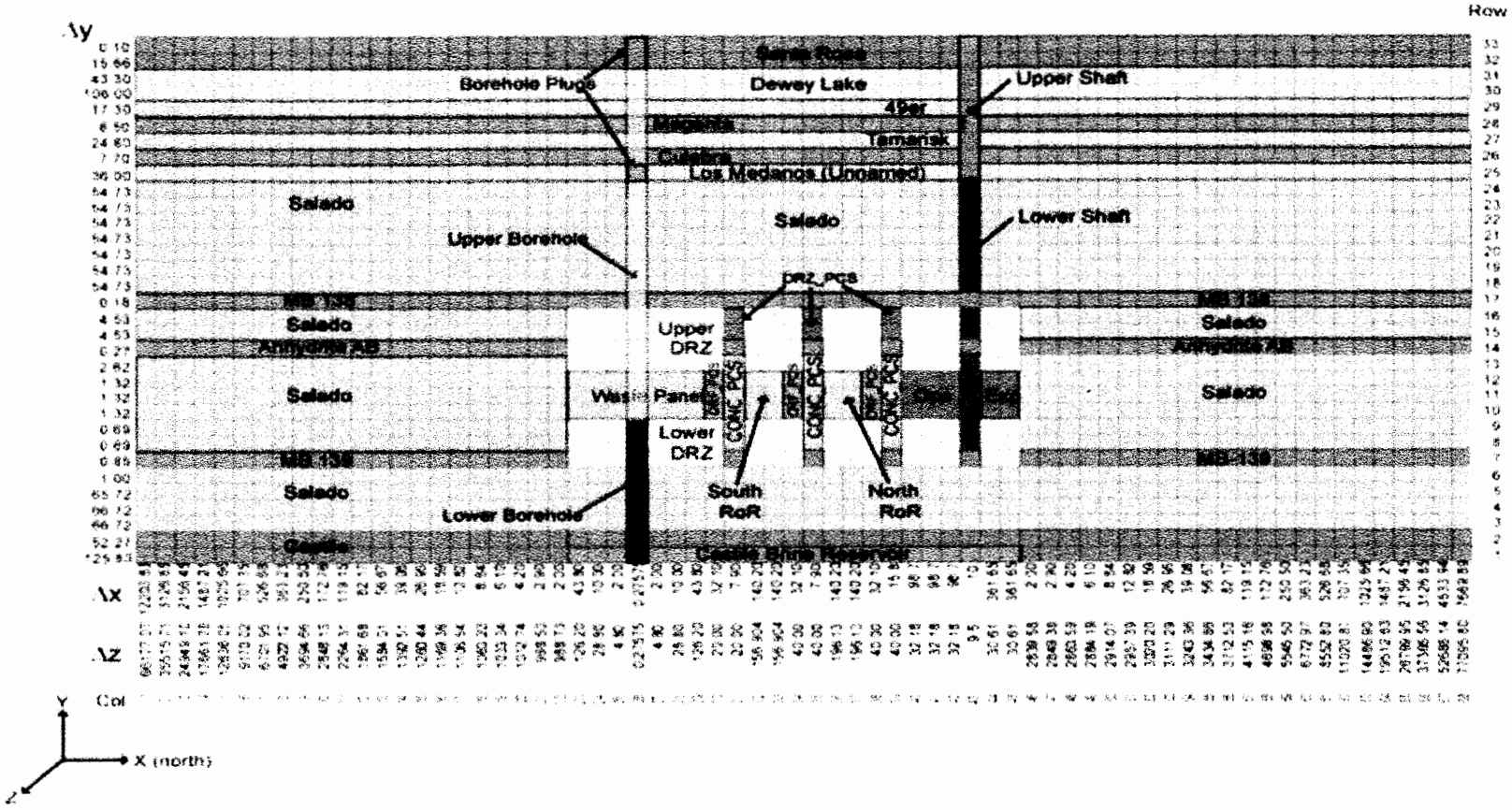
The material properties during time period T2, shown in Figure 3-4, are the same as during T1 except for the ROM salt, which has the new material name PCS_T2 and new material properties. Institutional control is expected to end after 100 years and borehole intrusions could occur during T2. Although the first E1 or E2 borehole intrusion is modeled as occurring at 350 years, for purposes of calculating direct brine releases (DBRs) or spallings releases the first borehole intrusion (which could be either an E1 or E2) is modeled as occurring at 100 years after repository closure. Repository conditions at intermediate times are linearly interpolated between the specific modeling dates.

As shown in Figure 3-5, during time period T3 the material properties change for both the ROM salt and the PCS DRZ. The ROM salt has the new material name PCS_T3 and new material properties. The surrounding DRZ has the new material name DRZ_PCS and new material properties that are different from those around a waste panel. Although borehole intrusions could occur during T3, they are not shown in the figure.

Figure 3-6 shows the BRAGFLO grid with T3 properties and an intrusion borehole penetrating the representative waste panel. The figure shows an E1 intrusion where the borehole penetrates a Castile brine reservoir beneath the repository. If an E2 intrusion is modeled, the material properties in the zone marked "lower borehole" are changed to represent the lower DRZ, Salado, and Castile properties unaffected by a borehole.

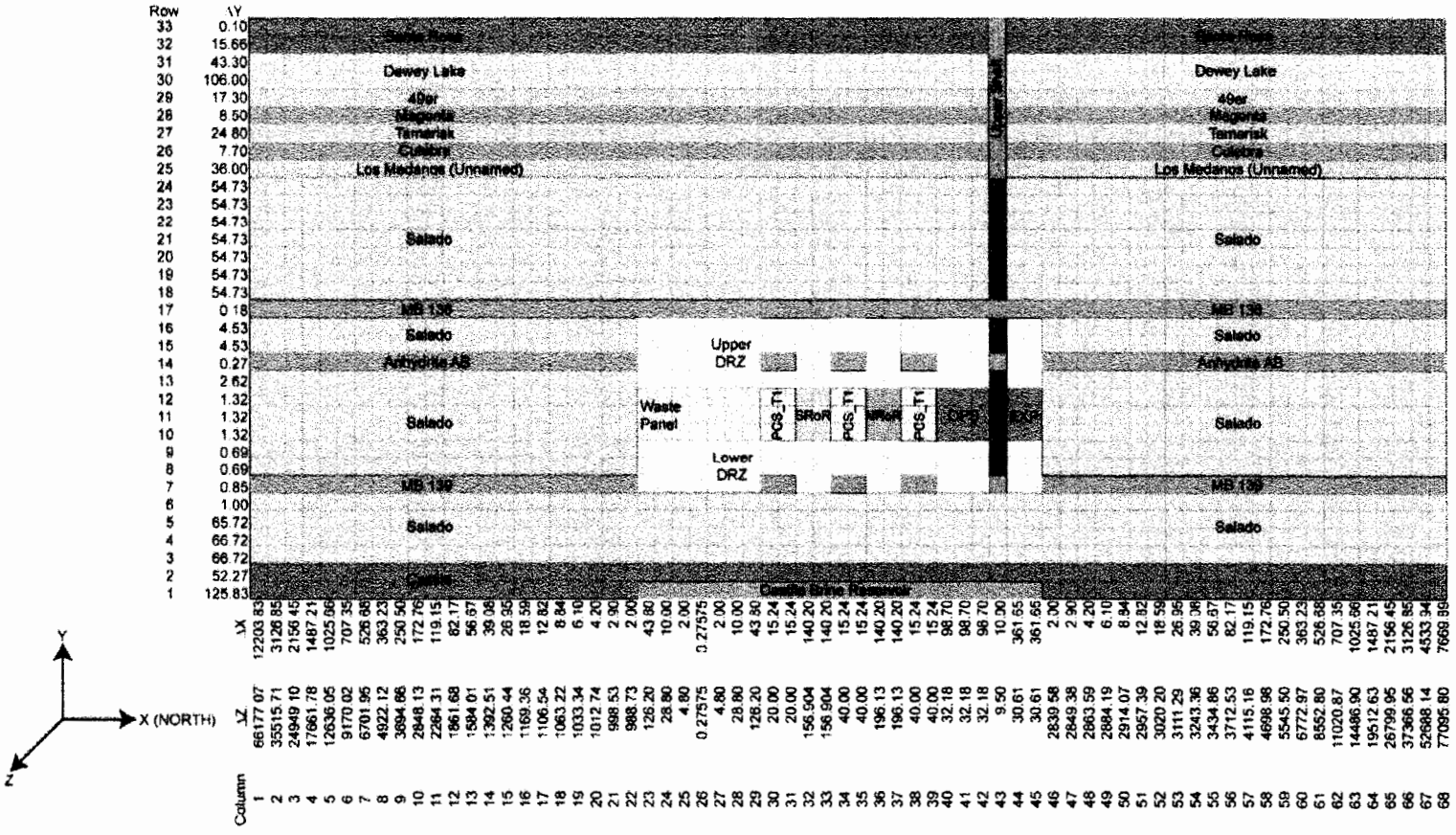
Results obtained in the six scenarios from BRAGFLO are used to initialize flow and material properties in subsequent codes in the PA computational suite. These include the calculation of direct brine releases and spallings releases. As discussed later in Section 3.5.5, implementation

of the ROM salt PCS design has a negligible impact on potential releases from the Culebra. As a result, the PCS-2012 PA calculated CCDFs of individual vectors for total normalized releases using Culebra release results calculated in the PABC-2009. The PCS-2012 PA calculated CCDFs of individual vectors for total normalized releases, cuttings and cavings releases, spallings releases, and DBRs. Although the use of the ROM salt PCS design had no impact on cuttings and cavings releases, new cuttings and cavings release volumes were calculated in the PCS-2012 PA as a by-product of the spallings calculation. Mean CCDFs for each release pathway were calculated by replicate and across all replicates. The 95% confidence limit on the mean across all replicates was also calculated.



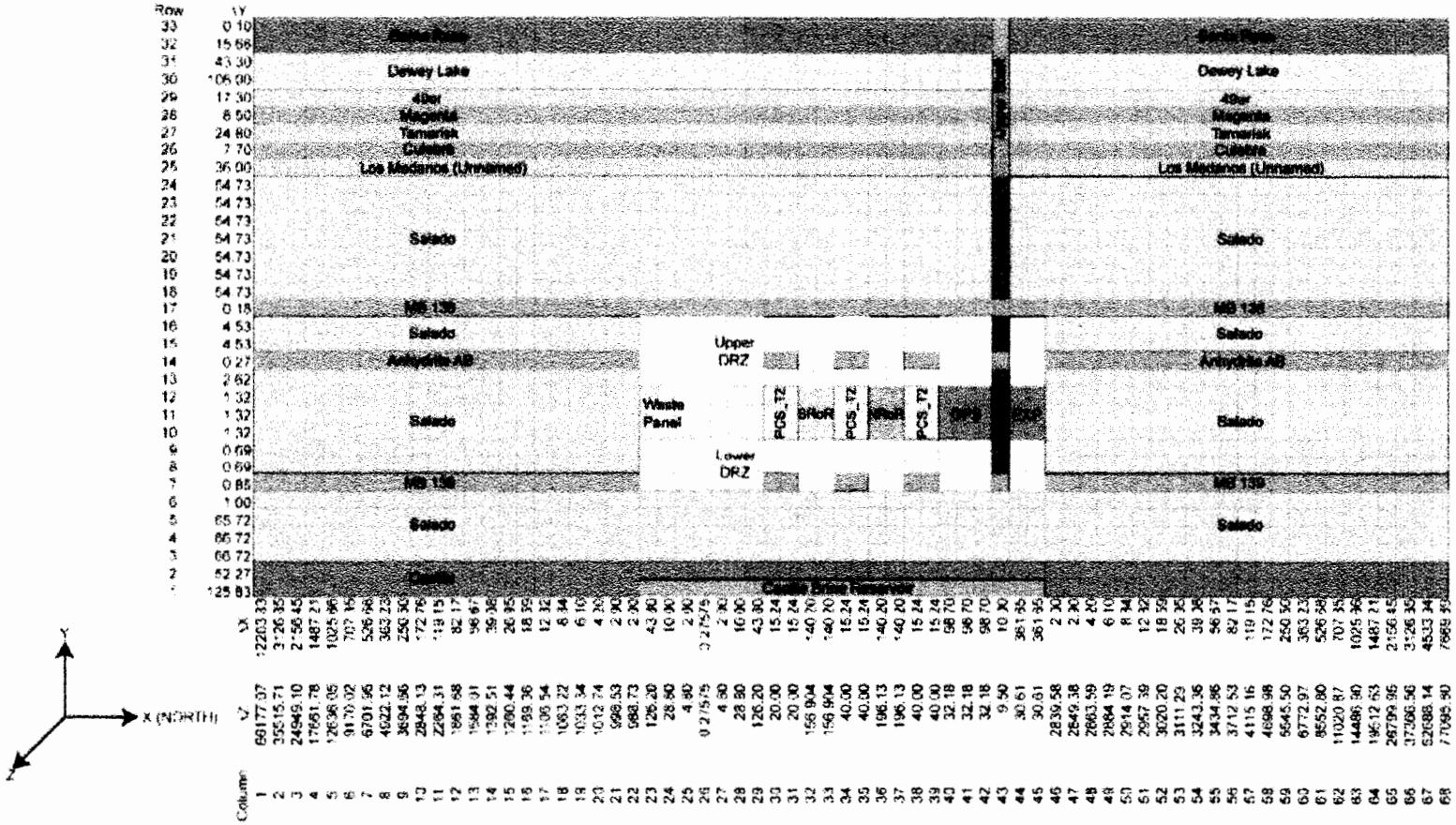
From Camphouse 2012c

Figure 3-2. PABC-2009 BRAGFLO Grid and Material Map



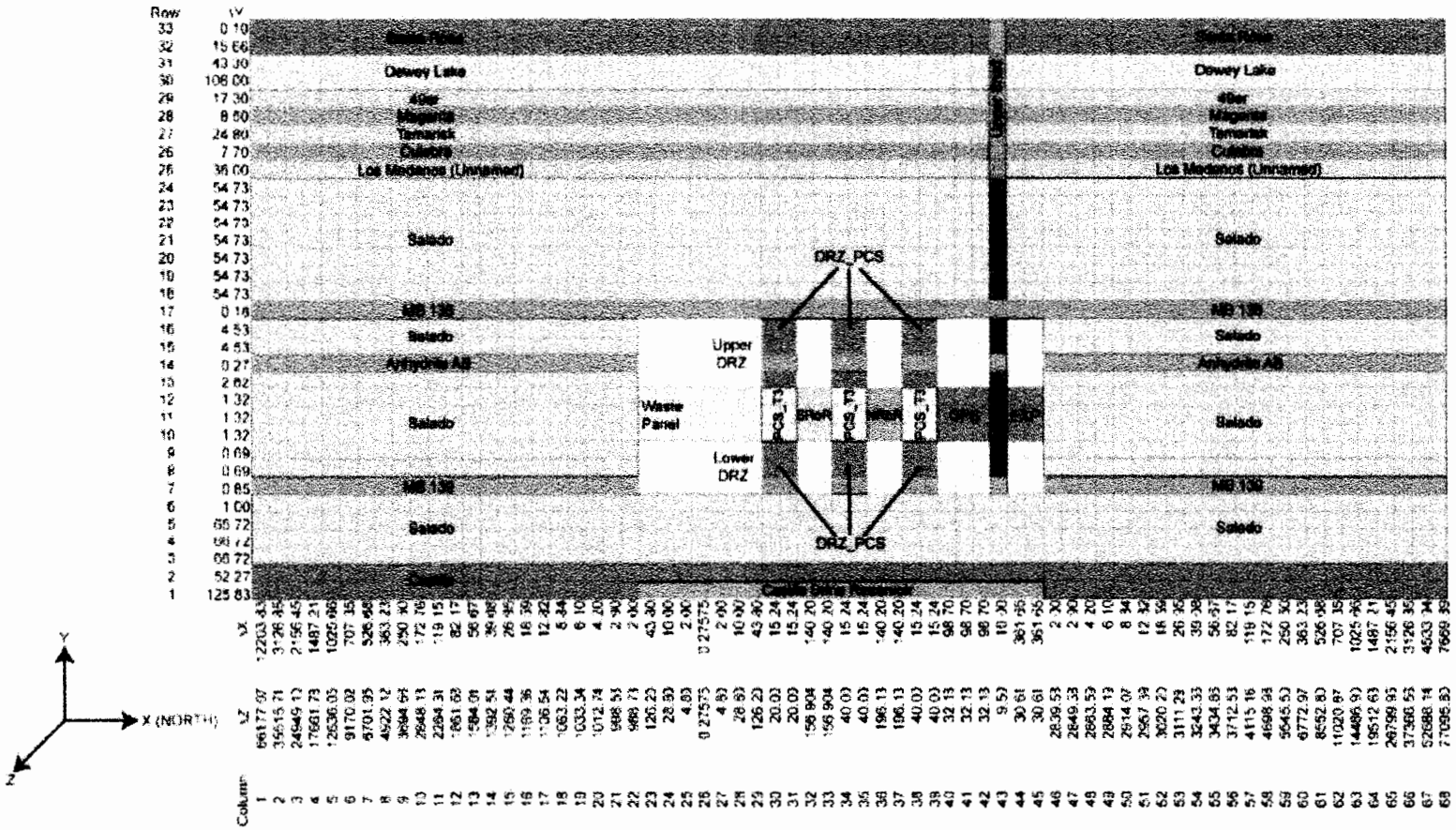
From Camphouse 2012c

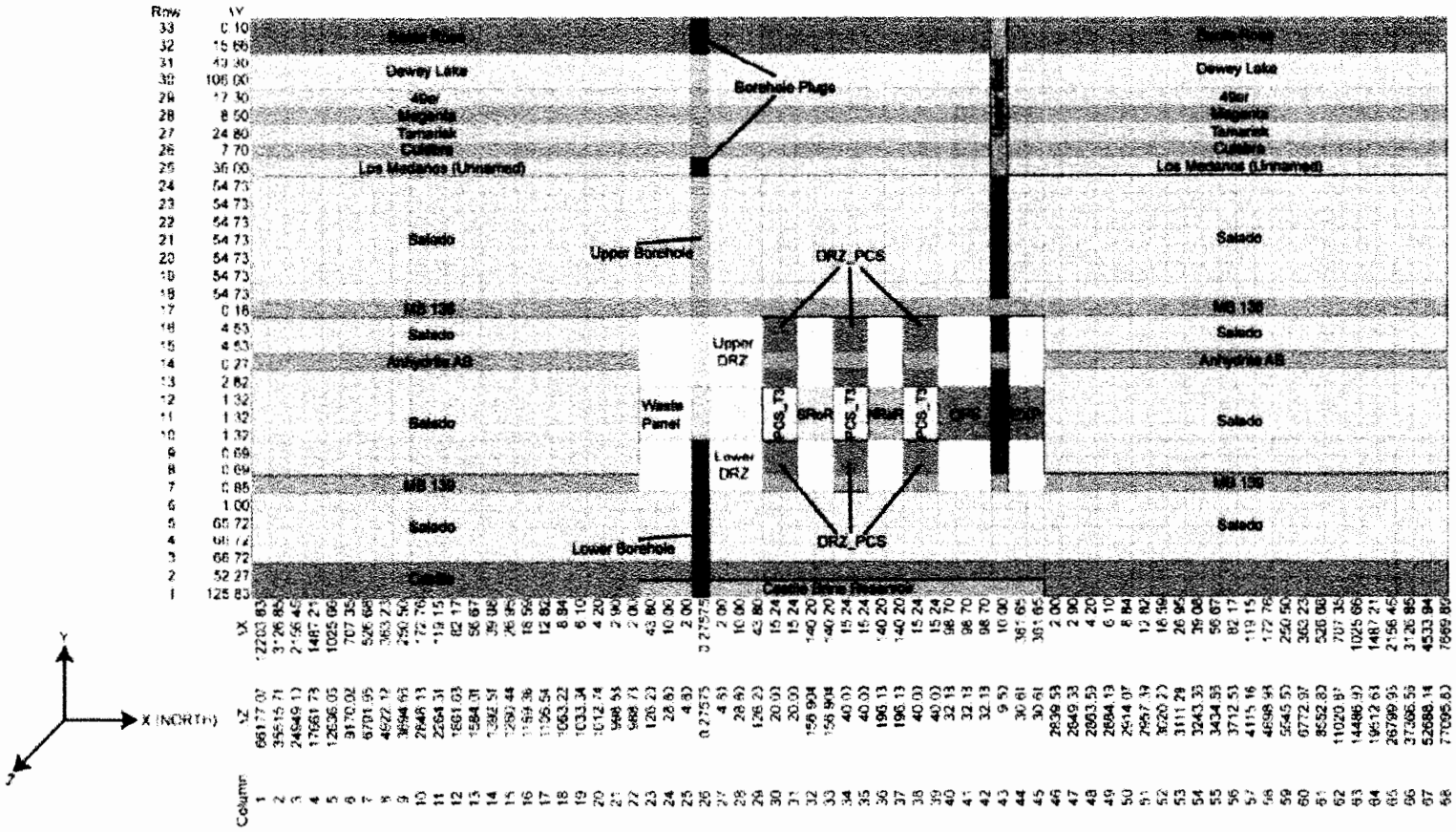
Figure 3-3. PCS-2012 BRAGFLO Grid and Material Map, Years 1 to 100



From Camphouse 2012c

Figure 3-4. PCS-2012 BRAGFLO Grid and Material Map, Years 100 to 200


Dewey Lake
Los Medanos (Unnamed)
Salado
DRZ_PCS
Upper DRZ
Waste Panel
Lower DRZ
Salado
Salado
Salado



From Camphouse 2012c

Figure 3-6. PCS-2012 BRAGFLO Grid and Material Map for an E1 Intrusion

3.5 PCS-2012 PA RESULTS AND ANALYSIS

The principal contributions to total repository releases are from cuttings and cavings releases, DBRs and spallings releases, Culebra releases contribute little to the total. All of these types of releases result from the assumed inadvertent penetration of repository waste by an oil or gas exploratory borehole. Releases by lateral transport through anhydrite interbeds or through vertical transport *via* sealed repository shafts do not involve intrusion boreholes but are negligible compared with those involving intrusion boreholes.

Cuttings releases consist of solid repository waste cut by a drill bit and carried to the ground surface by the circulating drilling mud. Cavings consist of solid repository waste eroded from the borehole wall by circulating drilling mud. Cuttings and cavings releases are calculated together. They are the largest contributors to total releases at high probabilities because they occur with every borehole intrusion. Direct Brine Releases (DBRs) are releases of radionuclides dissolved in pressurized repository brine that flows up an intrusion borehole to the surface. DBRs occur only under specific conditions of repository pressure and brine saturation, and are the greatest contributors to releases at lower probabilities. Spallings releases consist of solid repository waste entrained in pressurized gas that escapes into an intrusion borehole. Releases of dissolved radionuclides can also occur up an abandoned intrusion borehole and into the overlying Culebra dolomite horizon where they can be transported laterally by moving groundwater to the accessible environment. Spallings and Culebra releases are small compared with cuttings, cavings, and DBRs. DBR, spallings, and Culebra releases are driven by a buildup of repository gas pressure from waste degradation. Comparisons between the PCS-2012 PA and the PABC-2009 PA of total releases and releases from each of the contributing mechanisms are presented in the following subsections.

The PA methodology accommodates both uncertainty in the occurrence of future events (aleatory uncertainty) and uncertainty in the true value of a material property (epistemic uncertainty). Aleatory uncertainty is accounted for in PA by the generation of random sequences of future events. Epistemic uncertainty is accounted for by sampling the values of uncertain parameters from assigned distributions. One set of sampled parameter values is called a vector. In the PCS-2012 PA, the PA models were executed for three replicates of 100 vectors each, constituting 300 sets of sampled parameter values. Each vector, containing a different set of sampled parameter values, is executed 10,000 times for 10,000 possible sequences of future events. The normalized repository releases for each of these 10,000 sequences of future events are ranked and plotted, as required by EPA, in the form of a complementary cumulative distribution function (CCDF) that provides the probability of the release being greater than a particular value. PA results are presented as a distribution of 100 CCDFs of normalized releases for each of the three replicates (EPA 1996).

The primary effect of the proposed panel closure design modifications on repository releases was determined by SNL to result from the changes in pressure and brine saturation in the waste panels (Camphouse et al. 2012a). Direct brine and spallings releases are particularly sensitive to those parameters and those parameters in turn are sensitive to the permeability of the panel closures and surrounding DRZ which control fluid flow between the waste panels and the non-waste areas of the WIPP underground facility.

As compared with the Option D PCS design, generally higher ROM salt PCS permeability in the first 200 years and lower permeability after 200 years resulted in less isolation of individual waste panels in early times and greater isolation in later times. The lower permeability tended to trap early-time brine inflows into the waste panels resulting in generally higher brine saturations and gas pressures in the undisturbed repository after 200 years when borehole penetrations more commonly occur. The generally increased brine saturations and gas pressures encountered by borehole penetrations of the repository resulted in increases in overall mean DBR and spallings releases. Those increases in turn resulted in increases in the overall mean total repository releases which, however, remained within regulatory limits. Cuttings and cavings are important contributors to total releases but are not affected by waste panel pressure and brine saturation. As previously mentioned, releases through the Culebra remained essentially unchanged from those calculated using the Option D design.

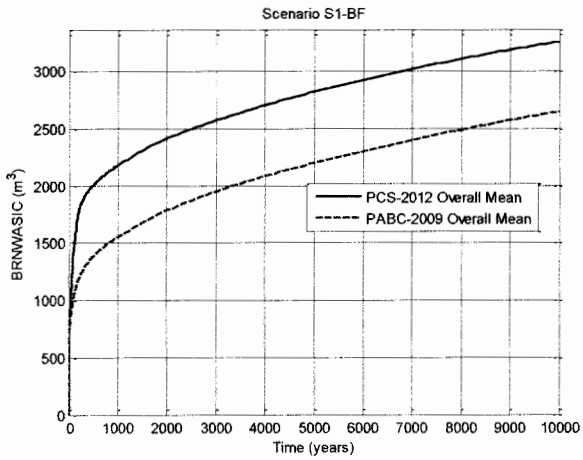
3.5.1 Results Compared with PABC 2009 PA

The important parameters of waste panel pressure and brine saturation are calculated by the BRAGFLO Salado Flow Model. Illustrations of results are plotted on the following pages using BRAGFLO output variables.

During BRAGFLO calculations, aleatory uncertainty is addressed by defining a set of six scenarios for which brine and gas flow are calculated for each of the 300 generated vectors. The six scenarios used in the PCS-2012 PA are described in Section 3.4.4 (see Table 3-5) and are unchanged from those used for the PABC-2009. Results are discussed in terms of overall means, which are obtained by forming the average of the 300 realizations calculated for a given quantity and scenario. Undisturbed results were presented by SNL for Scenario S1-BF. Intruded results were presented for Scenarios S2-BF and S4-BF, as these are representative of the intrusion types considered in Scenarios S3-BF and S5-BF, with the only differences being the timing of drilling intrusions. Results from scenario S6-BF were also briefly discussed (Camphouse et al. 2012a).

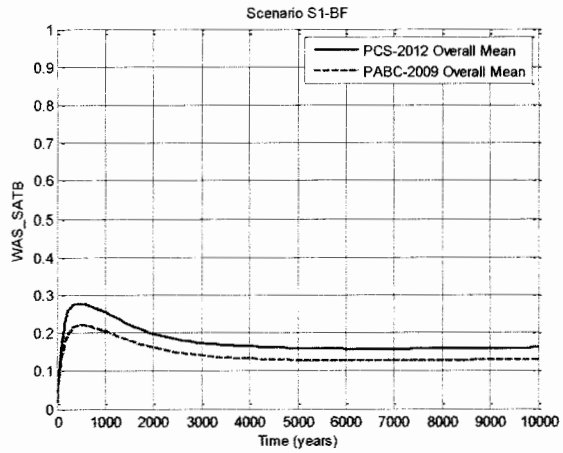
3.5.1.1 Results for an Undisturbed Repository (Scenario S1-BF)

During the first 200 years after emplacement the permeability of the ROM salt panel closure material and surrounding DRZ are higher than the permeability of the Option D concrete monolith and its surrounding DRZ. As a result, greater flows of both brine and gas occur between the waste panels and the non-waste parts of the WIPP underground facility. Figure 3-7 compares the overall mean of cumulative brine flow into the waste panel between the PCS-2012 and the PABC-2009 PAs for a repository with no borehole intrusions. The greater brine flow in the PCS-2012 PA is clearly evident in the figure. Most of this increase occurs in the first 200 years when the permeability of the ROM salt and DRZ are relatively high. After 200 years the ROM salt and DRZ are compressed by creep closure and the ROM salt assumes its long-term properties with the DRZ healed above and below it (Camphouse et al. 2012a). At 200 years, the difference between the cumulative brine flows obtained in the two analyses is roughly 600 m^3, and this difference remains fairly constant for the remainder of the regulatory period. The increase of brine flow into the waste panel results in a corresponding increase in the waste panel brine saturation, as shown in Figure 3-8. Again, most of the increase occurs in the first 200 years.



From Camphouse et al. 2012a

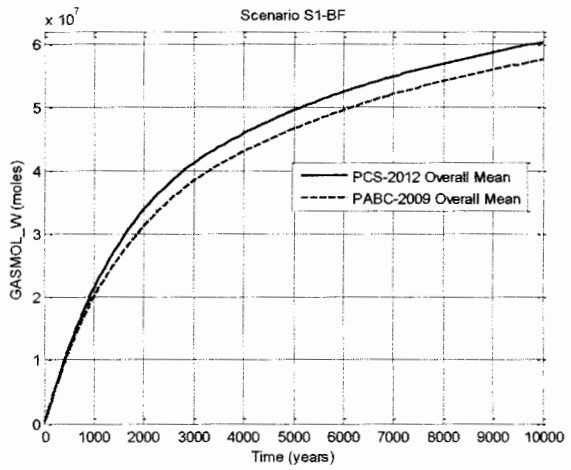
Figure 3-7. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenario S1-BF



From Camphouse et al. 2012a

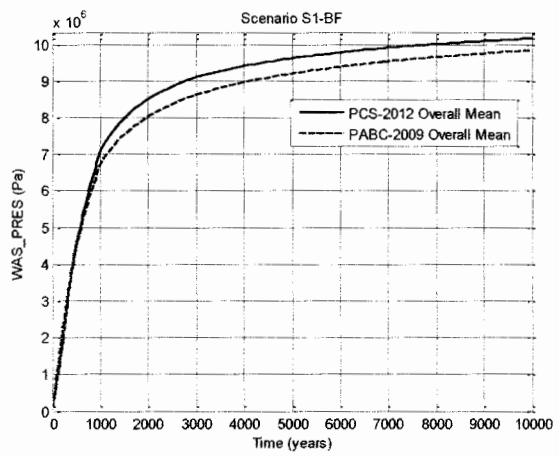
Figure 3-8. Overall Means of Waste Panel Brine Saturation (WAS_SATB), Scenario S1-BF

Gas is expected to be generated in the waste panels due to the corrosion of metals, primarily iron, and to microbial activity. Both of these processes require the presence of moisture in the form of brine. Increases in the availability of brine therefore increase gas generation, as seen in Figure 3-9. The increase in gas generation translates to a long-term increase in the waste panel mean pressure, as shown in Figure 3-10.



From Camphouse et al. 2012a

Figure 3-9. Overall Means of Waste Panel Gas Generation (GASMOL_W), Scenario S1-BF



From Camphouse et al. 2012a

Figure 3-10. Overall Means of Waste Panel Pressure (WAS_PRES), Scenario S1-BF

The greater brine saturations and gas pressures in the waste panels would tend to increase DBRs, spallings, and possibly also Culebra releases, but only if a waste panel is penetrated by an intrusion borehole. As previously mentioned, in the undisturbed repository scenario the only release pathways are through sealed shafts or laterally through anhydrite interbeds. Based on past PA results, lateral flow through anhydrite interbeds to the accessible environment is negligible. Cumulative mean flow up the shafts amounts to only 6 or 7 m^3 in 10,000 years and is also negligible (Camphouse et al. 2012a).

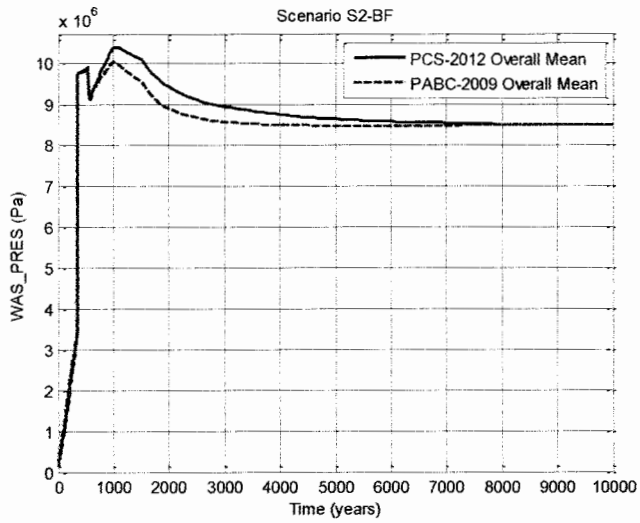
3.5.1.2 Results for an E1 Intrusion at 350 Years (Scenario S2-BF)

An E1 intrusion is the result of a borehole that penetrates a waste panel and also penetrates a brine reservoir in the underlying Castile Formation. Such boreholes create a pathway for waste to reach the ground surface or the Culebra dolomite, and also release potentially large volumes of

pressurized Castile brine into the waste panel, increasing waste panel pressure and brine saturation, and impacting other waste panel conditions.

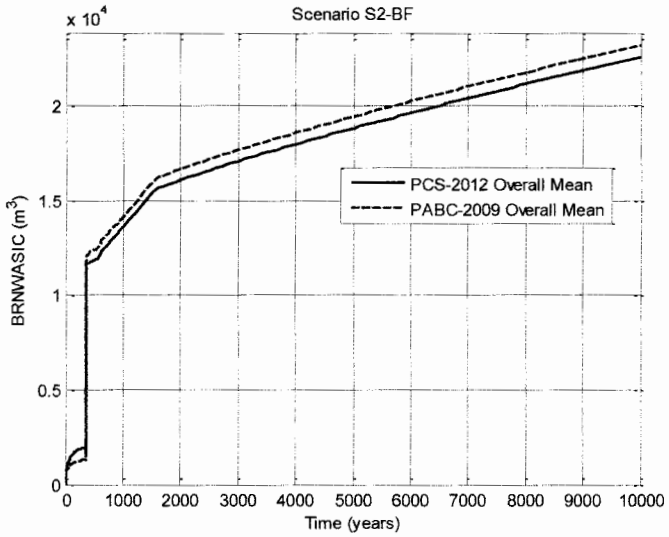
The overall means of waste panel pressure obtained in the PCS-2012 PA and the PABC-2009 PA for scenario S2-BF are plotted in Figure 3-11. As seen in that figure, the mean waste panel pressure increases rapidly to nearly 10 MPa when the brine reservoir is hit at 350 years, drops slightly and then climbs again reaching a slightly higher peak at about 1,000 years. This second pressure peak is due to increased waste degradation rates resulting from increased saturation with Castile brine. The excess pressure subsequently dissipates over the next approximately 5,000 years when it levels off at about 8.5 MPa. As seen in the figure, the second pressure peak is slightly higher in the PCS-2012 PA than in the PABC-2009 PA. This higher second peak is due to a generally lower long-term permeability of the consolidated ROM salt than the Option D concrete monolith that does not allow the excess pressure in the waste panel to dissipate as quickly.

The generally higher waste panel pressure following the E1 intrusion slightly retards the inflow of Salado brine to the waste panel, as shown in Figure 3-12. The reduction of brine inflow to the waste panel translates to a reduction in waste panel brine saturation, as shown in Figure 3-13, but the cumulative mean gas generation was nearly identical between the two PAs, as shown in Figure 3-14. The cumulative mean volume of brine flowing up the sealed intrusion borehole was also nearly identical, as shown in Figure 3-15, and amounted to nearly 9,000 m^3 in 10,000 years.



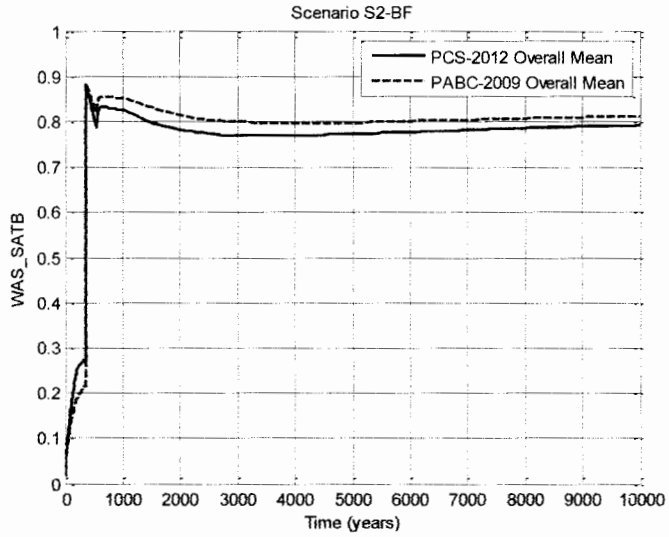
From Camphouse et al. 2012a

Figure 3-11. Overall Means of Waste Panel Pressure (WAS_PRES), Scenario S2-BF



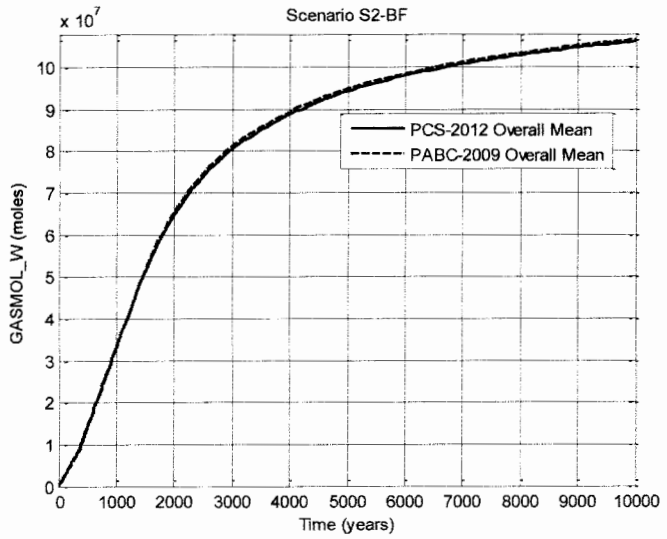
From Camphouse et al. 2012a

Figure 3-12. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenario S2-BF



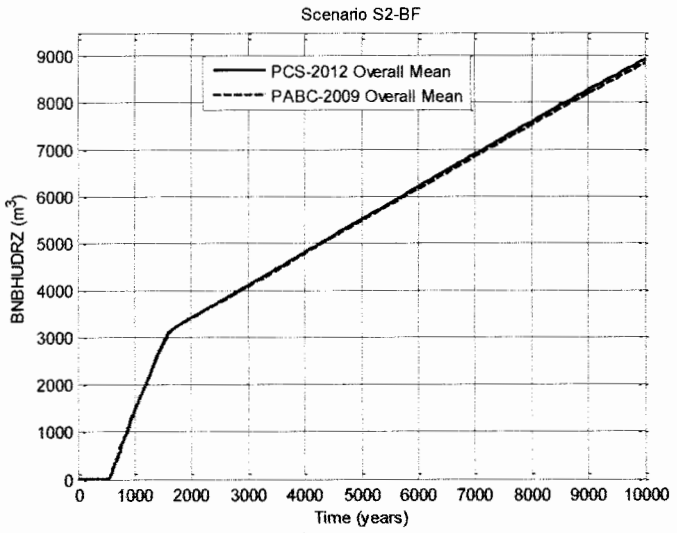
From Camphouse et al. 2012a

Figure 3-13. Overall Means of Waste Panel Brine Saturation (WAS_SATB), Scenario S2-BF



From Camphouse et al. 2012a

Figure 3-14. Overall Means of Waste Panel Gas Generation (GASMOL_W), Scenario S2-BF



From Camphouse et al. 2012a

Figure 3-15. Overall Means of Brine Flow up the Borehole (BNBHUDRZ), Scenario S2-BF

3.5.1.3 Results for an E2 Intrusion at 350 Years (Scenario S4-BF)

An E2 intrusion is the result of a borehole that penetrates a waste panel but does not penetrate a brine reservoir in the underlying Castile Formation. An E2 intrusion typically has little effect on waste panel conditions at the time of intrusion because the borehole is assumed to be immediately plugged with low permeability concrete near the ground surface. The concrete plugs are modeled as failing 200 years after the intrusion, and the entire borehole is given properties equivalent to those of sand. The result is a depressurization of the intruded waste panel beginning

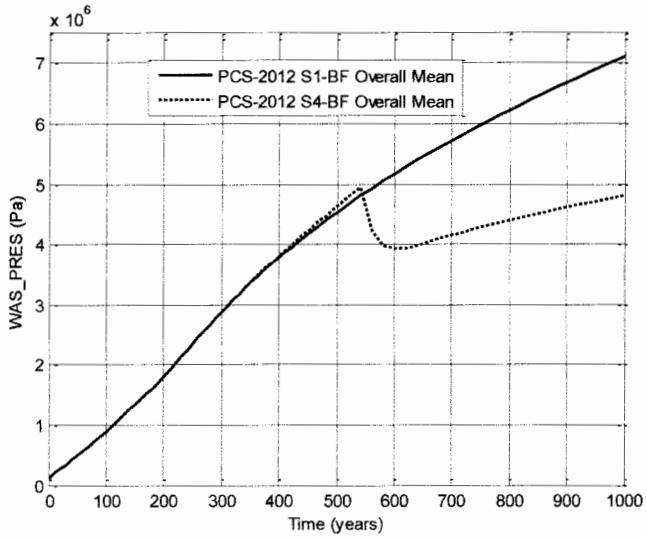
200 years after the intrusion. This depressurization is illustrated in Figure 3-16, where the effects on mean waste panel pressure of an E2 intrusion at 350 years are compared with mean waste panel pressure if no intrusion had occurred.

The overall means of waste panel pressure obtained for an E2 intrusion at 350 years in the PCS-2012 PA and in the PABC-2009 PA are shown in Figure 3-17. As discussed above and shown in Figure 3-10 for the undisturbed scenario, at the time of an E2 borehole intrusion the mean waste panel pressure obtained in the PCS-2012 PA is slightly greater than in the PABC-2009 PA. Consequently, the mean waste panel pressure is also greater 200 years after the intrusion when the borehole plugs fail. This pressure difference is augmented by an increase in gas generation rates (discussed below) and continues into later times. The result is a slightly higher mean pressure following an E2 intrusion in the PCS-2012 PA when compared to the PABC-2009 PA.

The impact of the E2 intrusion on cumulative waste panel brine inflow can be clearly seen in Figure 3-18. As discussed above, higher waste panel pressures can reduce brine inflow, while lower waste panel pressures can allow increased brine inflow. The significant increase in brine inflow at 550 years shown in Figure 3-18 is a direct result of the significant pressure drop (due to the change in borehole plug permeability) at 550 years shown in Figure 3-16. As would be expected, waste panel brine saturation also significantly increases at 550 years, commensurate with the increase in brine inflow (Camphouse et al. 2012a).

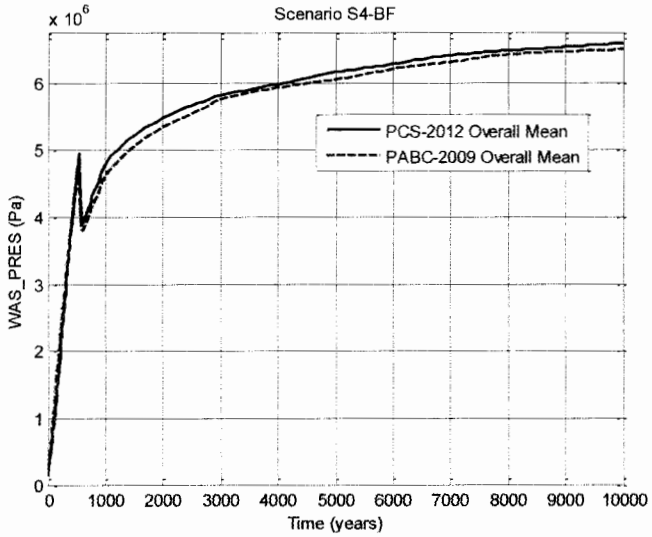
The overall means of cumulative waste panel brine inflow are compared for the PCS-2012 PA and the PABC-2009 PA in Figure 3-19. As is evident in that figure, the mean waste panel cumulative brine inflow is greater in the PCS-2012 PA. This increase is due to the increased waste panel brine inflow that occurs in the first 200 years for undisturbed conditions, shown in Figure 3-7. After the borehole plugs fail at 550 years, a similar increase in brine inflow occurs in both PAs corresponding to similar decreases in waste panel pressure. As would be expected, the increased brine inflow in the PCS-2012 PA is accompanied by an increase in brine saturation, as shown in Figure 3-20.

As in the undisturbed case, the increase in mean waste panel brine saturation results in an increase in mean waste panel gas generation. Comparative gas generation results for the PCS-2012 PA and the PABC-2009 PA are shown in Figure 3-21. The increase in gas generation rates and the accompanying increase in waste panel pressure results in an increase in brine flow up the sealed borehole, as shown in Figure 3-22.



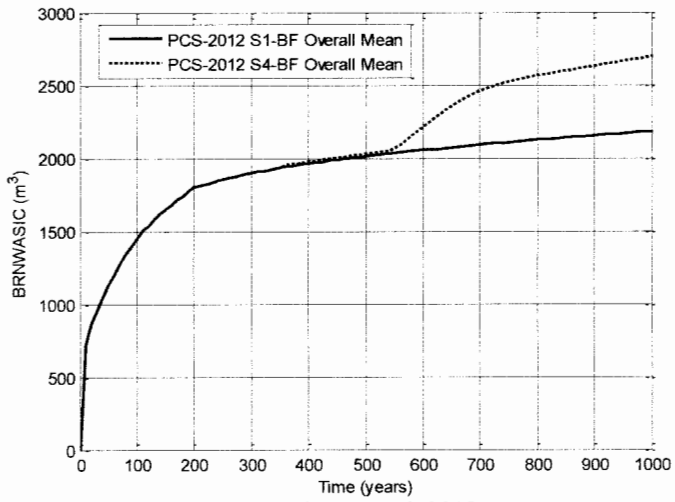
From Camphouse et al. 2012a

Figure 3-16. Overall Means of Waste Panel Pressure (WAS_PRES), Scenarios S1-BF and S4-BF for Years 0 to 1,000



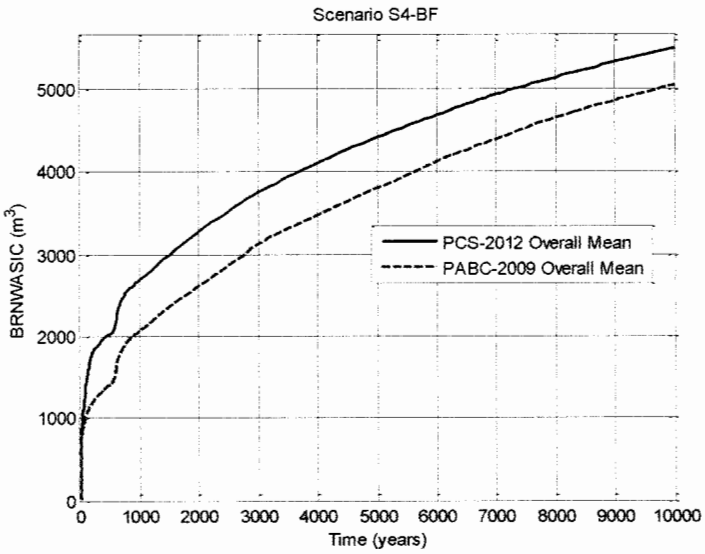
From Camphouse et al. 2012a

Figure 3-17. Overall Means of Waste Panel Pressure (WAS_PRES), Scenario S4-BF



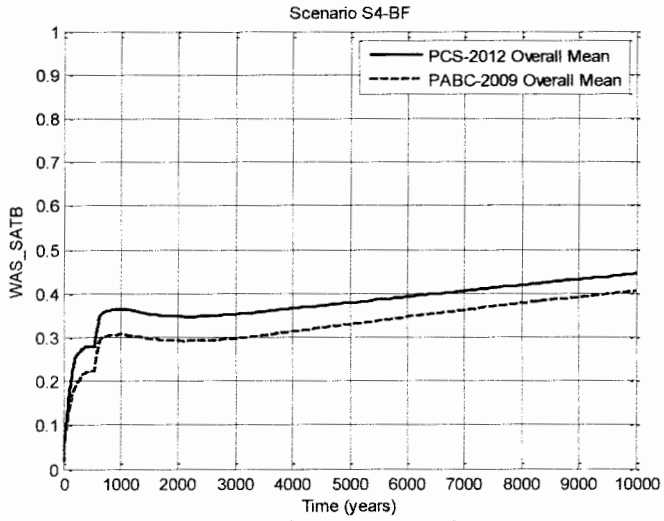
From Camphouse et al. 2012a

Figure 3-18. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenarios S1-BF and S4-BF for Years 0 to 1,000



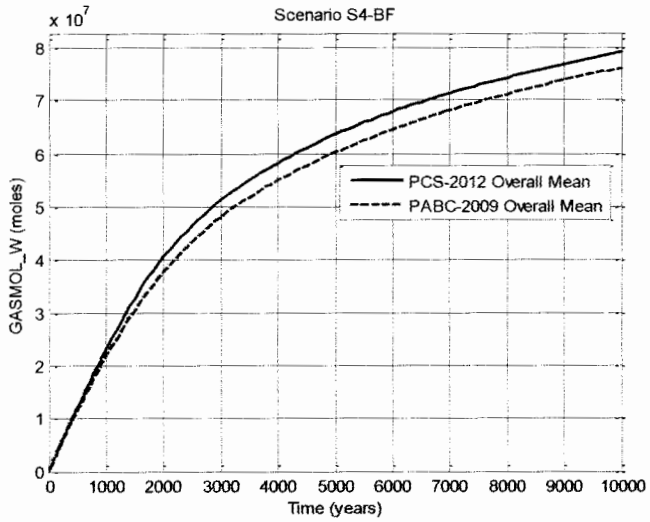
From Camphouse et al. 2012a

Figure 3-19. Overall Means of Cumulative Brine Inflow to the Waste Panel (BRNWASIC), Scenario S4-BF



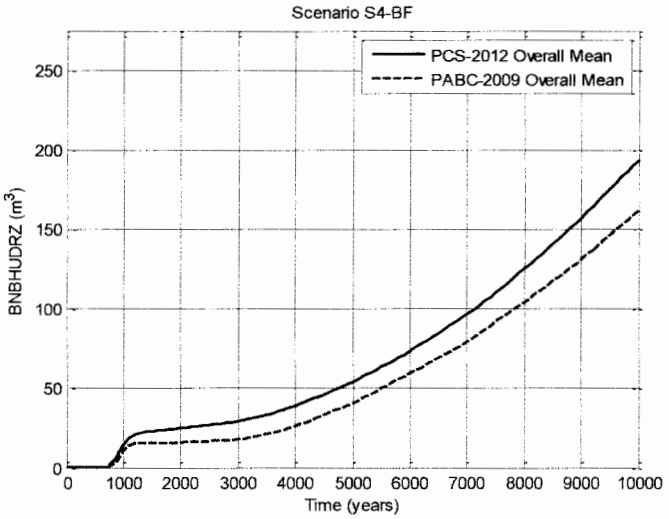
From Camphouse et al. 2012a

Figure 3-20. Overall Means of Waste Panel Brine Saturation (WAS_SATB), Scenario S4-BF



From Camphouse et al. 2012a

Figure 3-21. Overall Means of Waste Panel Gas Generation (GASMOL_W), Scenario S4-BF



From Camphouse et al. 2012a

Figure 3-22. Overall Means of Brine Flow up the Borehole (BNBHUDRZ), Scenario S4-BF

3.5.1.4 Results for an E2 Intrusion at 1000 Years Followed by an E1 Intrusion at 2000 Years (Scenario S6-BF)

This BRAGFLO scenario models an E2 intrusion occurring at 1000 years, followed by an E1 intrusion into the same panel at 2000 years. The effects of these two intrusions are qualitatively similar to those of individual E1 and E2 intrusions discussed in Sections 3.5.1.2 and 3.5.1.3 above. However, brine flows up the intrusion borehole calculated in this scenario are used in PA code PANEL to determine the radionuclide source term to the Culebra (Camphouse et al. 2012a). Releases to the Culebra are discussed in Section 3.5.5 below.

3.5.2 Cuttings and Cavings Releases

Cuttings and cavings releases and direct brine releases (DBRs) were the two primary sources contributing to total releases in the PABC-2009 PA, and continue to be so in the PCS-2012 PA. Cuttings and cavings releases are not impacted by the change in panel closure design, and so remain unchanged from those calculated in the PABC-2009 PA (Camphouse et al. 2012a).

3.5.3 Direct Brine Releases

Direct Brine Releases (DBRs) are calculated using the BRAGFLO DBR version of the BRAGFLO code in WIPP PA. These two uses of BRAGFLO require different computational grids. Results obtained from the BRAGFLO Salado Flow Model brine and gas flow calculations are mapped to the DBR grid to provide initial conditions for borehole intrusions in the DBR calculations. The mapped results include gas pressure, brine saturation, and other repository conditions. The BRAGFLO DBR Model is then used to calculate brine flow up the intruding borehole as a function of the gas pressure, brine saturation, and other properties of the intersected waste panel at the time of intrusion.

Five intrusion scenarios are considered in the DBR calculations, and are listed in Table 3-6. The types of intrusions considered in the DBR calculation and the times at which they occur are shown in the table. Repository conditions corresponding to other times are interpolated from the conditions calculated at the times shown in the table. The scenarios, intrusion locations, and timings used for the PCS- 2012 PA are the same as those used for the PABC-2009 PA.

Table 3-6. Intrusion Scenarios Used in Calculating Direct Brine Releases

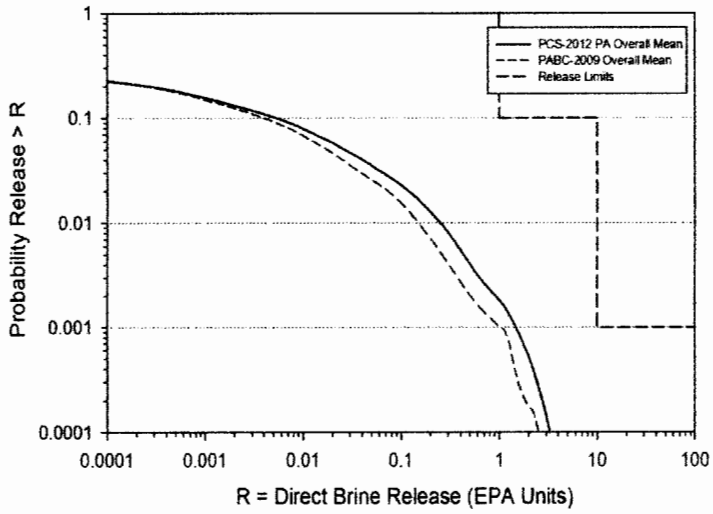
Scenario	First Intrusion Time (year and type)	Intrusion Times in Subsequent Years (year)
S1-DBR	None	100, 350, 1000, 3000, 5000, 10000
S2-DBR	350, E1	550, 750, 2000, 4000, 10000
S3-DBR	1000, E1	1200, 1400, 3000, 5000, 10000
S4-DBR	350, E2	550, 750, 2000, 4000, 10000
S5-DBR	1000, E2	1200, 1400, 3000, 5000, 10000

From Camphouse et al. 2012a; DBR = Direct Brine Release

Maximum DBR volumes consistently increased from PABC-2009 to the PCS-2012 PA. The largest increases were observed in Scenarios S4-DBR and S5-DBR, which are associated with E2 intrusions. As previously discussed, E2 intrusion scenarios in the PCS-2012 PA yielded waste panel pressures at the time of intrusion that were higher, on average, than in the PABC-2009 PA and the pressures remained higher for the duration of the 10,000 year regulatory period. Similarly, the mean waste panel brine saturation was higher at the time of intrusion in the PCS-2012 PA, resulting in higher long-term waste panel brine saturations. Because DBR volumes are strongly dependent on waste panel pressure and brine saturation at the time of intrusion, increases in these two quantities led to the increased maximum DBR volumes observed in the two E2 intrusion scenarios. The higher pressures and brine saturations also led to a higher overall number of non-zero direct brine releases (Camphouse et al. 2012a).

A more moderate increase in maximum DBR volumes was observed for E1 intrusions. SNL concludes that this is because the generally lower long-term permeability of the ROM salt as compared to Option D PCS results in increased waste panel gas pressures which tend to inhibit brine flows from an intruded Castile brine reservoir into the waste panel. Because a combination of increased pressure and increased brine saturation are needed for a direct brine release to the ground surface, the reduced brine saturation resulted in only a relatively slight 8% to 10% increase in the maximum DBR volumes for E1 intrusions (Camphouse et al. 2012a).

Although the increase in the number of non-zero DBR volumes was relatively small (about 6%) and the increase in average release volume was also small (about 10%), the maximum release volume more than doubled for E2 intrusions, resulting in a noticeable increase in overall mean DBRs (Camphouse et al. 2012a). Single realization results such as this occur due to rare combinations of pressure and saturation that are highly favorable to generating extreme events. A comparison of overall mean DBRs between the PCS-2012 PA and the PABC-2009 PA is shown in Figure 3-23.



From Camphouse et al. 2012a

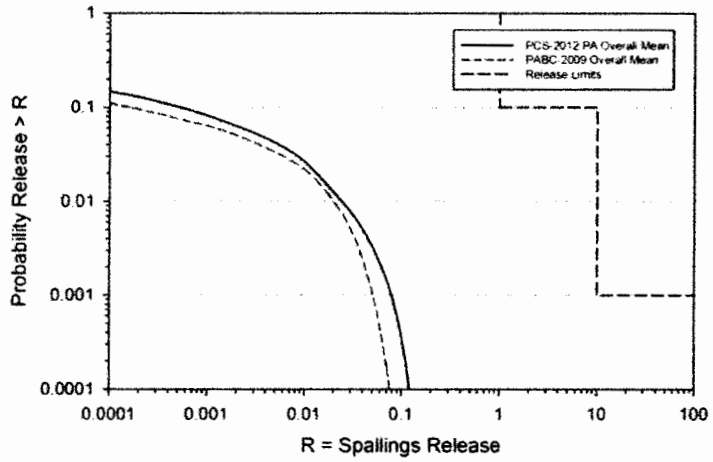
Figure 3-23. PCS-2012 PA and PABC-2009 Overall Mean CCDFs for Normalized Direct Brine Releases

3.5.4 Spallings Releases

Increases in repository pressures seen in the PCS-2012 PA BRAGFLO results have increased spallings releases. The volume of solid waste material released to the ground surface as spallings is calculated at four values of repository pressure (10, 12, 14, and 14.8 MPa). The code CUTTINGS_S is then used to linearly interpolate between these DRSPALL volumes to determine releases at the pressures calculated by BRAGFLO.

DRSPALL volumes used in the PABC-2009 were also used in the PCS-2012 PA. The intrusion scenarios and times used in the calculation of spallings volumes are the same as those presented in Table 3-6 for the calculation of DBRs, and intermediate results are interpolated in the same manner as for DBRs.

The PCS-2012 PA results show increases in the maximum spallings volumes across all three replicates. Replicate 1 showed very similar average nonzero spallings volumes in both the PCS-2012 and the PABC-2009 PA calculations. However, in Replicates 2 and 3 the average nonzero spallings volumes were higher for the PCS-2012 PA calculations compared to PABC-2009, with the most significant volume increases occurring in Scenarios S2-DBR, S3-DBR, and S5-DBR. Considering the total from all scenarios across all three replicates, the general trend shows a slightly higher average nonzero spallings volume, a larger maximum volume, and a larger percentage of vectors with spallings (Kicker 2012). The increases in spallings volumes and in the number of vectors that result in nonzero spallings volume translate to an increase in spallings releases, because both analyses use the same waste inventory (Camphouse et al. 2012a). A comparison of overall mean spallings releases between the PCS-2012 and the PABC-2009 PAs is shown in Figure 3-24. As can be seen in the figure, releases are noticeably larger in the PCS-2012 PA than in the PABC-2009 PA.

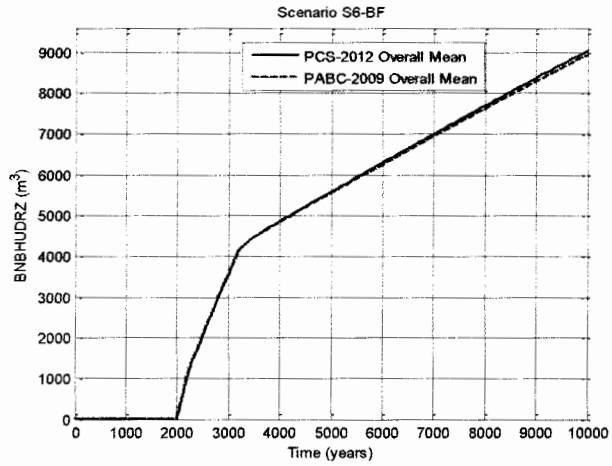


From Camphouse et al. 2012a

Figure 3-24. PCS-2012 PA and PABC-2009 Overall Mean CCDFs for Normalized Spallings Releases

3.5.5 Culebra Releases

As discussed in Section 3.5.1.3, brine flows up the intrusion borehole to the Culebra dolomite are calculated in scenario S6-BF (an E2 intrusion at 1000 years followed by an E1 intrusion at 2000 years). These results are used in PA code PANEL to determine the radionuclide source term to the Culebra. Mean brine flows up the intrusion borehole determined in the PCS-2012 and PABC-2009 PAs are shown in Figure 3-25. As shown in that figure, the mean flows are essentially the same. Based on this result and because the radionuclide source terms and Culebra flow conditions were unchanged, SNL concluded that releases from the Culebra would be essentially the same in both PAs. SNL therefore used the results obtained from the PABC-2009 PA in the PCS-2012 PA (Camphouse et al. 2012a). The Agency agrees with SNL's logic and concurs with this decision.



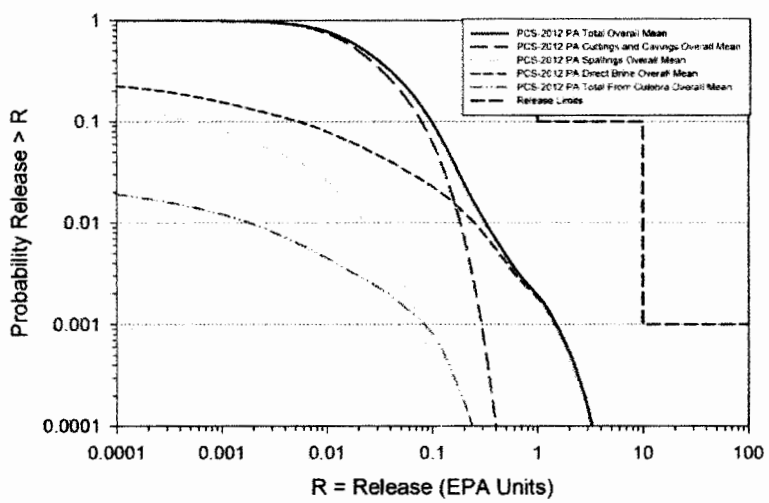
From Camphouse et al. 2012a

Figure 3-25. Overall Means of Brine Flow up the Borehole (BNBHUDRZ), Scenario S6-BF

3.5.6 Total Releases

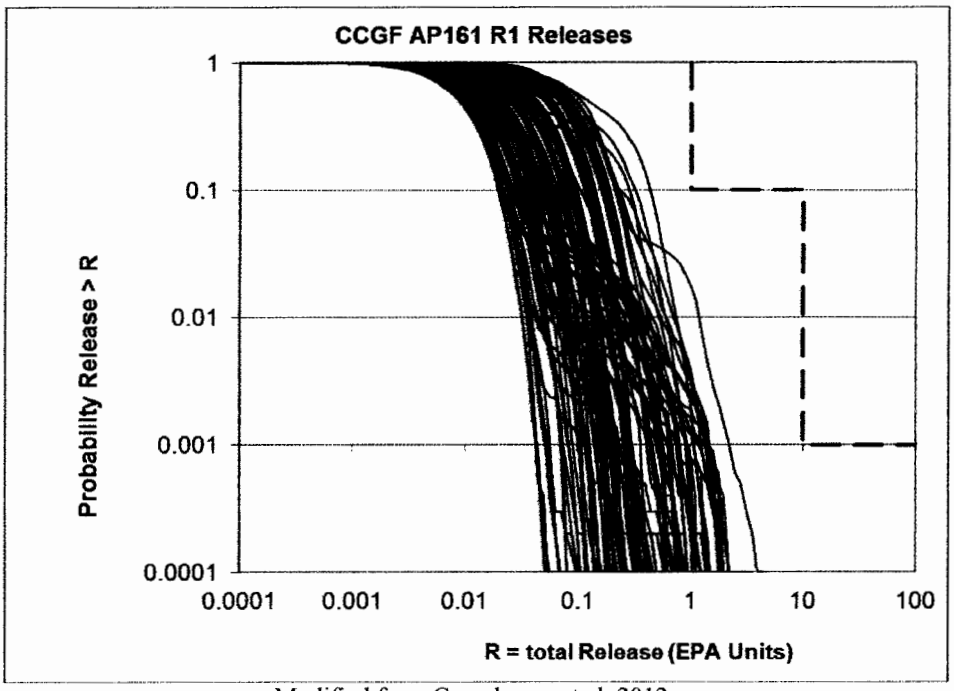
Total normalized releases are calculated as the sum of the releases from the individual pathways. Overall mean releases for the PCS-2012 PA from the four primary contributing pathways—cuttings and cavings, DBRs, spallings, and Culebra pathways—are shown along with total releases in Figure 3-26. As can be seen from the figure, cuttings and cavings releases dominate at higher probabilities and DBRs dominate at lower probabilities. Releases from spallings and Culebra pathways are approximately an order of magnitude lower than cuttings and cavings at high probabilities and are also an order of magnitude lower than DBRs at low probabilities. Spallings and Culebra releases therefore have only a small effect on total releases.

Total normalized releases for the PCS-2012 PA are shown by replicate and vector in Figures 3-27 through 3-29. Out of the 300 vectors in the PA, one vector in Replicate 2 exceeded the regulatory limit. The exceedance was at a high probability and was due to unusually high cuttings and cavings releases in that vector; however, as previously mentioned, cuttings and cavings releases in the PCS-2012 PA were unchanged from those in the PABC-2009 PA and this exceedance was unrelated to the proposed PCS design modification. The EPA limits apply not to single vectors but to the mean releases and to a demonstration that there is at least a 95% level of statistical confidence that the mean release meets the Agency's containment requirements (EPA 1996). The overall mean and 95% confidence limits are shown for the PCS-2012 PA in Figure 3-30. As shown in the figure, the mean release and upper 95% confidence limit on the mean did not exceed the Agency's release limits.



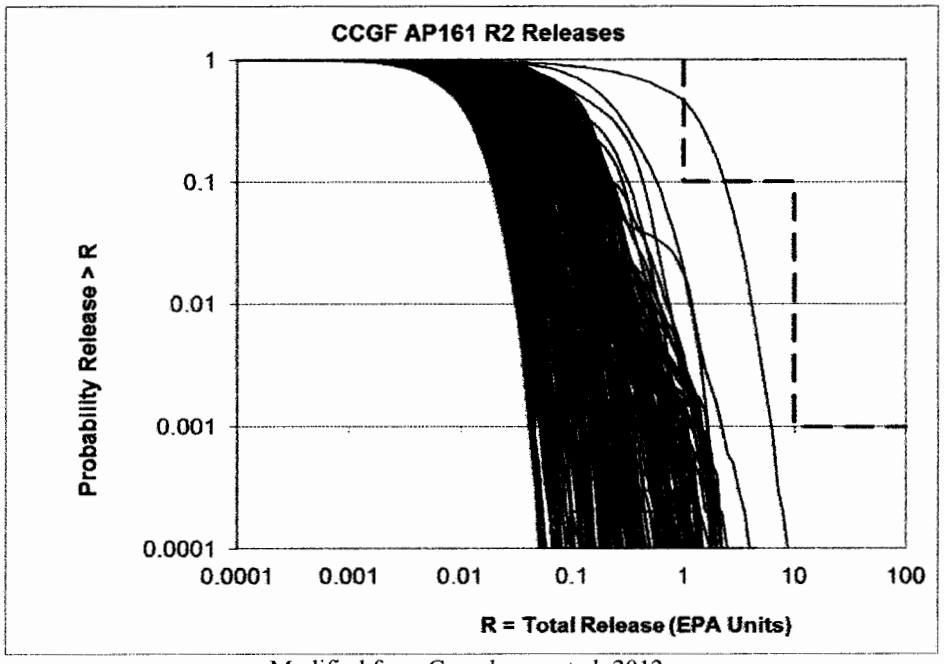
From Camphouse et al. 2012a

Figure 3-26. PCS-2012 PA Primary Components Contributing to Total Normalized Releases



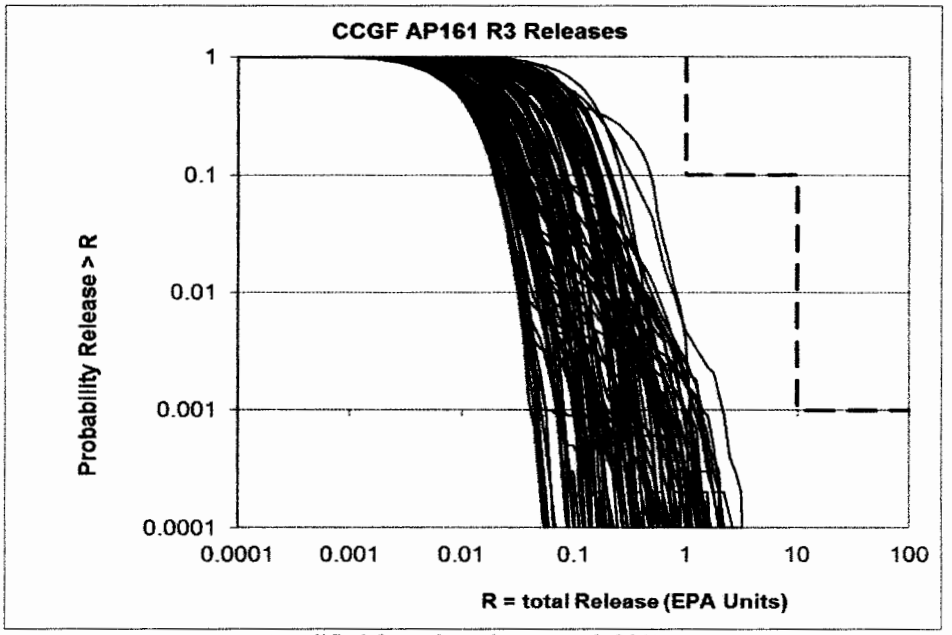
Modified from Camphouse et al. 2012a

Figure 3-27. PCS-2012 PA Replicate 1 Total Normalized Releases



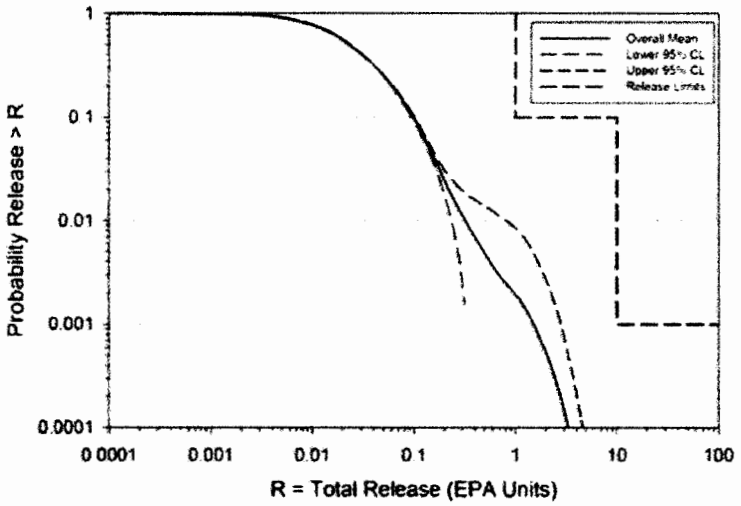
Modified from Camphouse et al. 2012a

Figure 3-28. PCS-2012 PA Replicate 2 Total Normalized Releases



Modified from Camphouse et al. 2012a

Figure 3-29. PCS-2012 PA Replicate 3 Total Normalized Releases

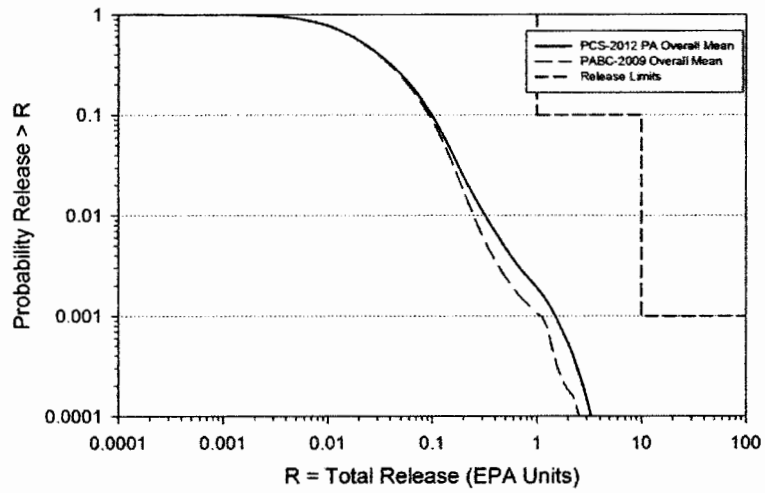


From Camphouse et al. 2012a

Figure 3-30. PCS-2012 PA Confidence Limits on Overall Mean for Total Normalized Releases

Comparisons of overall mean total releases between the PCS-2012 and the PABC-2009 PAs are shown in Figure 3-31 and Table 3-7. As can be seen in the figure, mean total releases in the PCS-2012 PA did not noticeably increase at a probability of 0.1 but did increase at a probability of 0.001. This increase is primarily due to increases in DBRs, but the overall mean for the PCS-2012 PA remains below the Agency's regulatory limits at both points of compliance. Table 3-7 provides total release statistics at probabilities of 0.1 and 0.001 for the two PAs, and also provides the Agency's regulatory limits at those probabilities for comparison. As can be seen

from the table, total releases were higher in the PCS-2012 PA than in the baseline PABC-2009 PA but remained below the regulatory limits for the mean total release as well as the 90th percentile and upper 95 % confidence limit of the mean. Because the mean total repository releases continued to remain below their regulatory limits in the PCS-2012 PA, DOE concluded that if the Option D panel closure is replaced with the ROM salt PCS design, the WIPP repository would remain in compliance with the containment requirements of 40 CFR Part 191 (Camphouse et al. 2012a).



From Camphouse et al. 2012a

Figure 3-31. PCS-2012 PA and PABC-2009 Overall Mean CCDFs for Total Normalized Releases

Table 3-7. Total Normalized Release Statistics for the PCS-2012 and PABC-2009 PAs

Probability	Analysis	Mean Total Release	90th Percentile	Lower 95% Confidence Limit	Upper 95% Confidence Limit	EPA Release Limit
0.1	PCS-2012 PA	0.10	0.17	0.10	0.10	1
	PABC-2009 PA	0.09	0.16	0.09	0.10	1
0.001	PCS-2012 PA	1.51	1.00	0.33	2.81	10
	PABC-2009 PA	1.10	1.00	0.37	1.77	10

From Camphouse et al. 2012a; Values in EPA units.

3.6 SNL PARAMETER SENSITIVITY ANALYSIS

SNL performs a parameter sensitivity analysis following completion of each PA to identify the physical properties with uncertain values that most strongly influence the variability in PA results. The sensitivity analysis for the PCS-2012 PA was documented by Kirchner (2012) and is the source of the information presented in this section. Physical properties that are potentially important to repository performance and have uncertain values, such as the permeability of the ROM salt 100 years after repository closure, are sampled in WIPP PA. Such parameters are assumed to have specific values but those values are uncertain because of a lack of knowledge.

Additional uncertainty arises because of a lack of knowledge about the occurrence of future events, such as the timing and location of a drilling intrusion. This type of uncertainty is not addressed in this sensitivity analysis. This sensitivity analysis attempts to resolve the question of which sampled physical properties contribute the most to the variability (uncertainty) observed in the PCS-2012 PA results.

The code STEPWISE Version 2.21 was used by SNL to determine the relative importance of the sampled parameters in the PCS-2012 PA. Sampled parameter values and corresponding release data calculated by the PA codes are input into STEPWISE, which then relates the releases with the parameter values through stepwise linear multivariate regression analyses. The results for the PCS-2012 PA are compared with those from the baseline PABC-2009 PA to determine whether the PCS design changed the relative importance of the sampled parameters.

One of the assumptions of the statistical model used in STEPWISE is that the dependent (output) variable (the repository release) shows a linear response to the independent (input) variables (the sampled parameters). The coefficient of determination (R^2) serves as a measure of the degree to which a given parameter or set of parameters contribute to output variability. The single parameter with the highest R^2 value is most strongly correlated with output variability and is therefore the greatest contributor to that variability. This parameter is followed in ranked order by other parameters that, when included, cumulatively improve the correlation and therefore sequentially contribute to the variability. The cumulative R^2 value represents the proportion of total variation explained by the fitted regression using the listed variables, starting with the greatest contributor to the variance. SNL concludes that the results are usually well suited for ranking the importance of the contributions of the input variables to the response of the output variable (Kirchner 2012).

Most of the regression models produced by STEPWISE do not include all of the variable parameters, even after ranking the data. This indicates that the uncertainties in many of the parameters have statistically insignificant effects on the releases. This is not to say that these non-significant parameters have no influence on the releases. Their exclusion from the tabulated results reflects the inability of this statistical technique to rank their importance with an acceptable degree of confidence. SNL notes that correlations that explain only a few percent of the variation can occur due to random sampling and may be spurious (Kirchner 2012).

For an input variable to be retained, its Standard Rank Regression Coefficient (SRRC) must be statistically distinguishable from zero. The regression coefficient is a measure of the linear contribution of an input to the prediction of the output variable. Negative regression coefficients indicate an inverse relationship between the input and output variables, where a decrease in an input variable results in an increase in an output variable. Both the cumulative R^2 value and the SRRC value are presented in the tabulated results of SNL's sensitivity analysis and are reproduced in this Agency review.

3.6.1 Parameter Regression Results

SNL's sensitivity study results for mean total releases in PCS-2012 and PABC-2009 Replicate 1 are presented in Table 3-8. As described in Section 3.5, cuttings and cavings, direct brine, and

spallings releases account for the majority of the total releases estimated in both the PCS-2012 and the PABC-2009 PAs. Also in both PAs, the variable parameter BOREHOLE:TAUFAIL was the greatest single contributor to the uncertainty in mean total releases. This parameter is the shear strength of degraded waste and is used in calculating cavings releases. There is little consistency in the ranking of the other variable parameters identified as less significant contributors to the variability in total releases. These other parameters contribute less than an additional 14 % to that variability.

Table 3-8. Stepwise Ranked Regression Results for Mean Total Releases, PCS-2012 and PABC-2009 Replicate 1

Step	PCS-2012 Replicate 1			PABC-2009 Replicate 1		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.69	-0.83	BOREHOLE:TAUFAIL	0.76	-0.88
2	CASTILER:PRESSURE	0.71	0.16	SOLMOD3:SOLVAR	0.79	0.17
3	DRZ_1:PRMX_LOG	0.74	0.17	CELLULS:FBETA	0.81	-0.14
4	SOLMOD3:SOLVAR	0.76	0.14	CASTILER:PRESSURE	0.83	0.12
5	S_HALITE:POROSITY	0.78	0.13	GLOBAL:PBRINE	0.85	0.13
6	PCS_T1:SAT_IBRN	0.79	-0.12	SHFTU:SAT_RGAS	0.85	-0.10
7	GLOBAL:TRANSIDX	0.80	0.12	GLOBAL:TRANSIDX	0.86	0.09
8	CULEBRA:MINP_FAC	0.81	0.09	BOREHOLE:DOMEGA	0.87	0.08
9	S_MB139:RELP_MOD	0.82	-0.10			
10	S_MB139:SAT_RBRN	0.83	-0.09			

From Kirchner 2012

Only two parameters identified in the analysis for PCS-2012 Replicate 1 are related to the proposed PCS design change: DRZ_1:PRMX_LOG, the log permeability of the PCS DRZ during time periods T1 and T2, and PCS_T1:SAT_IBRN, the initial brine saturation of the ROM salt. Parameter DRZ_1:PRMX_LOG contributed about 3% to the variability in total releases and is the third most significant parameter in the list. The initial brine saturation contributed only about 1%, which is not considered significant and may be spurious.

Ranked regression results for mean total releases in PCS-2012 Replicates 2 and 3 are presented in Table 3-9. Again, the parameter BOREHOLE:TAUFAIL was the greatest single contributor to the uncertainty in total releases for both replicates. Two parameters identified in the analysis of Replicate 2 are related to the proposed PCS design change: PCS_T1:POROSITY, the ROM salt porosity during T1; and PCS_T1:PORE_DIS, the ROM salt pore distribution parameter during T1. Only one parameter identified in the analysis of Replicate 3 is related to the proposed PCS design change: DRZ_1:PRMX_LOG, the permeability of the PCS DRZ during time periods T1 and T2. Each of these parameters contributed only about 1% to the variability in total mean releases. The Agency notes that parameter DRZ_1:PRMX_LOG was also identified in the analysis for Replicate 1.

Table 3-9. Stepwise Ranked Regression Results for Mean Total Releases, PCS-2012 Replicates 2 and 3

Step	PCS-2012 Replicate 2			PCS-2012 Replicate 3		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.71	-0.84	BOREHOLE:TAUFAIL	0.74	-0.85
2	CASTILER:PRESSURE	0.75	0.22	S_HALITE:POROSITY	0.77	0.18
3	CULEBRA:MINP_FAC	0.77	-0.14	CASTILER:PRESSURE	0.80	0.15
4	S_HALITE:POROSITY	0.79	0.12	SOLMOD3:SOLVAR	0.81	0.12
5	SOLMOD3:SOLVAR	0.80	0.12	BOREHOLE:DOMEGA	0.82	0.12
6	SPALLMOD:REPIPERM	0.81	-0.10	GLOBAL:PBRINE	0.83	0.10
7	PCS_T1:POROSITY	0.82	-0.10	GLOBAL:PBRINE	0.84	0.09
8	PCS_T1:PORE_DIS	0.83	-0.09	DRZ_1:PRMX_LOG	0.85	0.09
9	CASTILER:PRMX_LOG	0.84	0.09	GLOBAL:TRANSIDX	0.86	0.08
10				STEEL:CORRMCO2	0.86	-0.08

From Kirchner 2012

3.6.2 Sensitivity of Cuttings and Cavings Releases

Ranked regression results for mean cuttings and cavings releases in PCS-2012 and PABC-2009 Replicate 1 are presented in Table 3-10. Cuttings and cavings are the greatest source of releases at higher probabilities because they are removed to the ground surface in every borehole intrusion. The parameter BOREHOLE:TAUFAIL remained the greatest single contributor to the uncertainty in cuttings and cavings releases and accounted for nearly all the uncertainty in those releases. As is evident in the table, the results of the regression analysis for PCS-2012 and PABC-2009 Replicate 1 are identical. The only parameter related to the proposed PCS design change that was identified in the PCS-2012 Replicate 1 analysis was DRZ_PCS:PRMX_LOG, the permeability of the DRZ surrounding the ROM salt backfill during time period T3. This parameter accounted for less than 1% of the uncertainty in cuttings and cavings releases and is considered by SNL to have had an insignificant effect (Kirchner 2012). This same parameter was identified in the PABC-2009 Replicate 1 analysis but it represented the DRZ surrounding the Option D concrete monolith in that PA. As discussed in Section 3.4.3, the same permeability range and distribution was used for this parameter in both PAs.

Ranked regression results for mean cuttings and cavings releases in PCS-2012 Replicates 2 and 3 are presented in Table 3-11. The only parameter related to the proposed PCS design change that was identified in these analyses was PCS_T2:POR2PERM, the distribution used to calculate permeability from sampled porosity values during time period T2. This parameter only appeared in the analysis of Replicate 2. It accounted for less than 1% of the uncertainty in cuttings and cavings releases and is considered by SNL to have had an insignificant effect. No parameters related to the proposed PCS design change were identified in Replicate 3. The parameter SHFTL_T1:PRMX_LOG in Replicate 2 applies to the lower shaft and not to the revised PCS design.

Table 3-10. Stepwise Ranked Regression Results for Mean Cuttings and Cavings Releases, PCS-2012 and PABC-2009 Replicate 1

Step	PCS-2012 Replicate 1			PABC-2009 Replicate 1		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.98	-0.99	BOREHOLE:TAUFAIL	0.98	-0.99
2	BOREHOLE:DOMEGA	1.00	0.11	BOREHOLE:DOMEGA	1.00	0.11
3	SHFTL_T1:PRMX_LOG	1.00	0.02	SHFTL_T1:PRMX_LOG	1.00	0.02
4	(Composite):OXSTAT	1.00	-0.02	(Composite):OXSTAT	1.00	-0.02
5	CULEBRA:HMBLKLT	1.00	0.02	CULEBRA:HMBLKLT	1.00	0.02
6	DRZ_PCS:PRMX_LOG	1.00	0.01	DRZ_PCS:PRMX_LOG	1.00	0.01

From Kirchner 2012

Table 3-11. Stepwise Ranked Regression Results for Mean Cuttings and Cavings Releases, PCS-2012 Replicates 2 and 3

Step	PCS-2012 Replicate 2			PCS-2012 Replicate 3		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	BOREHOLE:TAUFAIL	0.98	-0.99	BOREHOLE:TAUFAIL	0.98	-0.99
2	BOREHOLE:DOMEGA	0.99	0.11	BOREHOLE:DOMEGA	0.99	0.12
3	SHFTL_T1:PRMX_LOG	0.99	0.02	(Composite):OXSTAT	0.99	0.02
4	PCS_T2:POR2PERM	0.99	0.02	SOLMOD3:SOLVAR	1.00	-0.02
5	STEEL:CORRMCO2	1.00	0.02			
6	GLOBAL:TRANSIDX	1.00	0.01			

From Kirchner 2012

3.6.3 Sensitivity of Direct Brine Releases

Ranked regression results for mean direct brine releases (DBRs) in PCS-2012 and PABC-2009 Replicate 1 are presented in Table 3-12. DBRs are the greatest source of releases at lower probabilities because they occur only under specific, relatively rare combinations of waste panel pressure and brine saturation. As evidenced from the sensitivity study results, variability in DBRs is influenced by many parameters and no single parameter dominates. The only parameter related to the proposed PCS design change that was identified in the PCS-2012 Replicate 1 analysis was DRZ_1:PRMX_LOG, the log permeability of the DRZ surrounding the ROM salt during time periods T1 and T2. This parameter accounted for about 2% of the variability in DBRs and was expected because a higher PCS DRZ permeability in early time allows more brine to flow into the waste panels. The resulting increase in brine saturation increases the likelihood of a DBR.

Ranked regression results for mean DBRs in PCS-2012 Replicates 2 and 3 are presented in Table 3-13. Two parameters related to the proposed PCS design change were identified in both replicates: DRZ_PCS:PRMX_LOG, the log permeability of the PCS DRZ during time period T3, and DRZ_1:PRMX_LOG, the log permeability of the PCS DRZ during time periods T1 and T2. The first of these, DRZ_PCS:PRMX_LOG, accounted for 5% of the variability in DBRs in each replicate. The second, DRZ_1:PRMX_LOG, accounted for 2% of the variability in DBRs in each replicate. A third parameter, PCS_T3:POROSITY, the porosity of the ROM salt in time period T3, was only identified in Replicate 3 and accounted for about 1% of the variability in DBRs. Although the contribution of PCS_T3:POROSITY on the variability in DBRs is not significant,

the contributions of DRZ_PCS:PRMX_LOG and DRZ_1:PRMX_LOG are potentially significant because of their higher magnitudes and/or frequencies of occurrence. Both had positive regression coefficients, indicating that increases in PCS DRZ permeability are correlated with increasing DBRs.

Table 3-12. Stepwise Ranked Regression Results for Mean Direct Brine Releases, PCS-2012 and PABC-2009 Replicate 1

Step	PCS-2012 Replicate 1			PABC-2009 Replicate 1		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	CASTILER:PRESSURE	0.15	0.40	SOLMOD3:SOLVAR	0.19	0.42
2	SOLMOD3:SOLVAR	0.28	0.36	CASTILER:PRESSURE	0.35	0.40
3	STEEL:CORRMCO2	0.40	-0.33	GLOBAL:PBRINE	0.45	0.33
4	GLOBAL:PBRINE	0.47	0.26	STEEL:CORRMCO2	0.55	-0.30
5	S_HALITE:POROSITY	0.50	0.17	S_MB139:RELP_MOD	0.58	-0.18
6	S_MB139:RELP_MOD	0.53	-0.19	WAS_AREA:BIOGENFC	0.60	0.15
7	WAS_AREA:SAT_WICK	0.56	-0.15	S_HALITE:POROSITY	0.63	0.15
8	DRZ_1:PRMX_LOG	0.58	0.15	CONC_PCS:SAT_RGAS	0.65	-0.14
9	SOLMOD4:SOLVAR	0.60	0.16	S_MB139:PRMX_LOG	0.67	0.14
10	SHFTU:SAT_RBRN	0.62	0.14	WAS_AREA:SAT_WICK	0.69	-0.14
11	BOREHOLE:DOMEGA	0.64	-0.14			
12	WAS_AREA:BIOGENFC	0.66	0.13			
13	WAS_AREA:SAT_RBRN	0.67	-0.13			

From Kirchner 2012

Table 3-13. Stepwise Ranked Regression Results for Mean Direct Brine Releases, PCS-2012 Replicates 2 and 3

Step	PCS-2012 Replicate 2			PCS-2012 Replicate 3		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	SOLMOD3:SOLVAR	0.16	0.43	CASTILER:PRESSURE	0.20	0.41
2	CASTILER:PRESSURE	0.31	0.31	SOLMOD3:SOLVAR	0.38	0.42
3	STEEL:CORRMCO2	0.44	-0.38	STEEL:CORRMCO2	0.48	-0.32
4	GLOBAL:PBRINE	0.52	0.29	GLOBAL:PBRINE	0.56	0.28
5	WAS_AREA:SAT_WICK	0.57	-0.22	CULEBRA:MINP_FAC	0.60	0.22
6	DRZ_PCS:PRMX_LOG	0.62	0.22	DRZ_PCS:PRMX_LOG	0.65	0.20
7	WAS_AREA:SAT_RBRN	0.65	-0.18	WAS_AREA:SAT_RBRN	0.68	-0.18
8	S_MB139:PRMX_LOG	0.67	0.17	DRZ_1:PRMX_LOG	0.70	0.17
9	WAS_AREA:PROBDEG	0.70	-0.17	CASTILER:COMP_RCK	0.72	-0.16
10	DRZ_1:PRMX_LOG	0.72	0.14	SPALLMOD:REPIPOR	0.74	0.13
11	SHFTU:PRMX_LOG	0.74	0.16	WAS_AREA:SAT_WICK	0.75	-0.12
12	BH_SAND:PRMX_LOG	0.76	-0.14	PCS_T3:POROSITY	0.76	0.11
13	S_HALITE:POROSITY	0.78	0.14	SPALLMOD:TENSLSTR	0.78	0.11
14	CULEBRA:APOROS	0.80	0.12	GLOBAL:CLIMTIDX	0.79	0.10
15	SPALLMOD:REPIPOR	0.81	0.11	S_HALITE:POROSITY	0.80	0.10

From Kirchner 2012

3.6.4 Sensitivity of Spallings Releases

Ranked regression results for mean spallings releases in PCS-2012 and PABC-2009 Replicate 1 are presented in Table 3-14. Spallings releases are smaller than DBRs and cuttings and cavings releases, and have only a small effect on total repository releases. As evidenced from the

sensitivity study results, variability in spallings releases is influenced by many parameters and no single parameter dominates. The only parameter related to the proposed PCS design change that was identified in the PCS-2012 Replicate 1 analysis was DRZ_PCS:PRMX_LOG, the log permeability of the DRZ surrounding the ROM salt during time period T3. This parameter accounted for about 4% of the variability in spallings releases in that replicate. This same parameter was identified in the PABC-2009 Replicate 1 analysis but it represented the DRZ surrounding the Option D concrete monolith in that PA. As discussed in Section 3.4.3, the same permeability range and distribution was used for this parameter in both PAs.

Table 3-14. Stepwise Ranked Regression Results for Mean Spallings Releases, PCS-2012 and PABC-2009 Replicate 1

Step	PCS-2012 Replicate 1			PABC-2009 Replicate 1		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.13	0.37	S_HALITE:POROSITY	0.14	0.34
2	SPALLMOD:PARTDIAM	0.21	-0.29	SPALLMOD:PARTDIAM	0.22	-0.28
3	DRZ_PCS:PRMX_LOG	0.25	-0.21	CULEBRA:DPOROS	0.26	-0.23
4	SPALLMOD:REPIPOR	0.29	-0.20	CASTILER:PRESSURE	0.30	0.19
5	BH_SAND:PRMX_LOG	0.32	-0.18	SHFTL_T2:PRMX_LOG	0.33	-0.18
6				WAS_AREA:PROBDEG	0.36	0.17
7				DRZ_PCS:PRMX_LOG	0.39	-0.18
8				S_MB139:PRMX_LOG	0.42	0.16

From Kirchner 2012

Ranked regression results for mean spallings releases in PCS-2012 Replicates 2 and 3 are presented in Table 3-15. The parameter DRZ_PCS:PRMX_LOG, the log permeability of the PCS DRZ in time period T3, is the only parameter related to the proposed PCS design change and was identified in both replicates. This parameter accounted for 3% of the variability in spallings releases in Replicate 2 and 7% of the variability in Replicate 3. The regression coefficients for these parameters were negative, indicating that an increase in the value of DRZ_PCS:PRMX_LOG results in a decrease in spallings releases. This relationship was expected because higher PCS DRZ permeability reduces the gas pressures and brine saturations that drive spallings releases.

Table 3-15. Stepwise Ranked Regression Results for Mean Spallings Releases, PCS-2012 Replicates 2 and 3

Step	PCS-2012 Replicate 2			PCS-2012 Replicate 3		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	S_HALITE:POROSITY	0.15	0.37	S_HALITE:POROSITY	0.17	0.41
2	BH_SAND:PRMX_LOG	0.22	-0.28	SPALLMOD:PARTDIAM	0.27	-0.28
3	CASTILER:PRESSURE	0.29	0.27	DRZ_PCS:PRMX_LOG	0.34	-0.26
4	SPALLMOD:PARTDIAM	0.34	-0.23	WAS_AREA:SAT_RGAS	0.37	-0.18
5	WAS_AREA:GRATMICI	0.37	0.18	SPALLMOD:TENSLSTR	0.40	-0.18
6	SHFTL_T1:PRMX_LOG	0.40	0.16	STEEL:CORRMCO2	0.43	0.16
7	DRZ_PCS:PRMX_LOG	0.43	-0.16	BH_SAND:PRMX_LOG	0.46	-0.16

From Kirchner 2012

3.6.5 Sensitivity of Culebra Releases

Ranked regression results for mean Culebra releases in PCS-2012 and PABC-2009 Replicate 1 are presented in Table 3-16. Culebra releases are smallest of all releases evaluated in SNL's sensitivity study except at very low probabilities and contribute little to total repository releases (Kirchner 2012). As with DBR and spallings releases, variability in Culebra releases is influenced by many parameters and no single parameter dominates. Nearly all parameters influencing the variability of Culebra releases in the PABC-2009 PA also influenced variability in the PCS-2012 PA.

Table 3-16. Stepwise Ranked Regression Results for Mean Culebra Releases, PCS-2012 and PABC-2009 Replicate 1

Step	PCS-2012 Replicate 1			PABC-2009 Replicate 1		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	BH_SAND:PRMX_LOG	0.46	0.63	BH_SAND:PRMX_LOG	0.46	0.63
2	(Composite):MKD_U	0.58	-0.32	(Composite):MKD_U	0.58	-0.36
3	PCS_T2:POR2PERM	0.62	-0.20	DRZ_PCS:PRMX_LOG	0.61	0.17
4	DRZ_PCS:PRMX_LOG	0.65	0.17	SOLMOD4:SOLVAR	0.63	-0.17
5	CULEBRA:HMBLKLT	0.67	0.15	CULEBRA:HMBLKLT	0.65	0.16
6	SOLMOD4:SOLVAR	0.70	-0.16	CULEBRA:APOROS	0.67	-0.14
7	CULEBRA:APOROS	0.71	-0.13	(Composite):MKD_PU	0.69	-0.14
8	STEEL:CORRMCO2	0.73	-0.12	STEEL:CORRMCO2	0.71	-0.13
9	GLOBAL:TRANSIDX	0.74	0.11			

From Kirchner 2012

Two parameters related to the proposed PCS design change were identified in the PCS-2012 Replicate 1 analysis: PCS_T2:POR2PERM, the distribution used to calculate permeability from sampled porosity values during time period T2, and DRZ_PCS:PRMX_LOG, the log permeability of the DRZ surrounding the ROM salt during time period T3. The parameter PCS_T2:POR2PERM accounted for about 4% of the variability in Culebra releases, and the parameter DRZ_PCS:PRMX_LOG accounted for about 3% of the variability. The parameter DRZ_PCS:PRMX_LOG also accounted for about 3% of the variability in the PABC-2009 Replicate 1 analysis but it represented the DRZ surrounding the Option D concrete monolith in that PA. As discussed in Section 3.4.3, the same permeability range and distribution was used for this parameter in both PAs.

Ranked regression results for mean Culebra releases in PCS-2012 Replicates 2 and 3 are presented in Table 3-17. Three parameters related to the proposed PCS design change were identified in the PCS-2012 Replicate 3 analysis: PCS_T1:PORE_DIS, the pore distribution parameter for the ROM salt during time period T1, DRZ_PCS:PRMX_LOG, the log permeability of the DRZ surrounding the ROM salt during time period T3, and PCS_T1:PRMX_LOG, the log permeability of the ROM salt during time period T1. Parameters PCS_T1:PORE_DIS and DRZ_PCS:PRMX_LOG each accounted for about 2% of the variability in Culebra releases, and PCS_T1:PRMX_LOG accounted for about 1% of the variability.
No parameters related to the proposed PCS design change were identified in the PCS-2012 Replicate 2 analysis. The regression coefficients for these parameters were positive, indicating that increases in their values results in increases in Culebra releases.

Table 3-17. Stepwise Ranked Regression Results for Mean Culebra Releases, PCS-2012 Replicates 2 and 3

Step	PCS-2012 Replicate 2			PCS-2012 Replicate 3		
	Variable	R^2	SRRC	Variable	R^2	SRRC
1	BH_SAND:PRMX_LOG	0.55	0.71	BH_SAND:PRMX_LOG	0.41	0.62
2	GLOBAL:OXSTAT	0.67	0.22	(Composite):MKD_U	0.55	-0.31
3	CULEBRA:MINP_FAC	0.70	-0.16	CULEBRA:APOROS	0.59	-0.21
4	(Composite):MKD_U	0.73	-0.21	WAS_AREA:SAT_WICK	0.62	-0.15
5	CONC_PLG:PRMX_LOG	0.74	-0.12	GLOBAL:CLIMTIDX	0.64	0.18
6	STEEL:CORRMCO2	0.75	-0.11	STEEL:CORRMCO2	0.67	-0.17
7	CULEBRA:HMBLKLT	0.77	0.11	CASTILER:PRESSURE	0.69	0.14
8	AM+3:MKD_AM	0.78	-0.12	PCS_T1:PORE_DIS	0.71	0.14
9	CASTILER:PRESSURE	0.79	0.11	DRZ_PCS:PRMX_LOG	0.73	0.12
10	PHUMOX3:PHUMCIM	0.80	0.11	PCS_T1:PRMX_LOG	0.74	0.12
11	WAS_AREA:SAT_RGAS	0.81	-0.10	S_HALITE:COMP_RCK	0.75	0.11
12	CULEBRA:APOROS	0.82	-0.10	CASTILER:PRMX_LOG	0.76	0.11
13				S_MB139:SAT_RBRN	0.77	-0.11

From Kirchner 2012

3.6.6 Summary of Sensitivity Results

A summary of the contributions of the parameters related to the proposed PCS design change to the variability in PCS-2012 PA releases is presented in Table 3-18. Eight parameters were identified in SNL's sensitivity study as contributing to the mean values of total releases, cuttings and cavings releases, DBRs, spallings releases, or Culebra releases. Of these eight parameters, only two were identified in more than two replicates. Those parameters were the log permeability of the PCS DRZ during the three time periods. The remaining six parameters only appeared sporadically and all, with the exception of PCS_T2:POR2PERM which appeared at a 4% level in Culebra Replicate 1, were at levels of 2% or less. The Agency considers that correlations to parameters that appear only sporadically, have little direct logical relationship with the type of release, or have weak correlations of 2% or less, are likely be spurious.

Table 3-18. Summary of Contributions to Variability for Parameters Related to the Proposed PCS Design Change

Variable Parameter	Total Mean Releases			Mean Cuttings and Cavings Releases			Mean Direct Brine Releases			Mean Spallings Releases			Mean Culebra Releases		
	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
DRZ_1:PRMX_LOG	3%	--	1%	--	--	--	2%	2%	2%	--	--	--	--	--	--
DRZ_PCS:PRMX_LOG	--	--	--	<1%	--	--	--	5%	5%	4%	3%	7%	3%	--	2%
PCS_T2:POR2PERM	--	--	--	--	<1%	--	--	--	--	--	--	--	4%	--	--
PCS_T1:SAT_IBRN	1%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
PCS_T1:POROSITY	--	1%	--	--	--	--	--	--	--	--	--	--	--	--	--
PCS_T1:PORE_DIS	--	1%	--	--	--	--	--	--	--	--	--	--	--	--	2%
PCS_T3:POROSITY	--	--	--	--	--	--	--	--	1%	--	--	--	--	--	--
PCS_T1:PRMX_LOG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1%

Note: R1, R2, and R3 are replicates of the PCS-2012 PA.

The strongest correlations to the log permeability of the PCS DRZ were for DBRs. DRZ_1:PRMX_LOG was weakly correlated to mean DBRs at a 2% level in all three replicates, and DRZ_PCS:PRMX_LOG was more strongly correlated at a 5% level in Replicates 2 and 3, but not in Replicate 1. DRZ_1:PRMX_LOG was also weakly correlated with mean total releases in Replicates 1 and 3, and DRZ_PCS:PRMX_LOG was also more strongly correlated with all three replicates of mean spallings releases and with two replicates of mean Culebra releases. These correlations would be expected because the permeability of the PCS DRZ largely controls brine and gas flow into and out of a waste panel. Very weak to no correlations were found between the PCS DRZ permeability and cuttings and cavings releases, which is also expected because these releases are independent of brine and gas flow.

In summary, the Agency concludes that correlations of 1% or less are probably spurious. Correlations of 2% to 3% are weak and may also be spurious unless accompanied by a logical pattern of incidence in more than one realization. Higher correlations are stronger, particularly when accompanied by a logical pattern of incidence. The strongest and most frequent correlations involved the influence of DRZ_PCS:PRMX_LOG on DBRs, spallings, and Culebra releases. The significance of the influence of parameter DRZ_PCS:PRMX_LOG on the results of the PCS-2012 PA was further explored in an EPA sensitivity study of the relationship between the value of that parameter and the permeability of intact halite, and is documented in Section 4.1.

3.7 EPA ASSESSMENT OF DOE'S ANALYSIS

The Agency concludes that the results of the PCS-2012 PA indicate that the containment requirements of 40 CFR Part 191 continue to be met with the ROM salt PCS design.

To avoid numerical problems with the BRAGFLO code, DOE adjusted several two-phase flow parameters for the ROM salt: CAP_MOD, PCT_A, and PCT_EXP. These parameters determine the presence or absence of capillary effects and are described in Section 3.4.2.2. At the Agency's request, the source of the numerical problems was identified and corrected by SNL, and Replicate 1 of the PCS-2012 PA was rerun by the Agency using more realistic two-phase flow parameters. The results of this sensitivity analysis are described in Section 4.2 of this TSD.

The results of the PCS-2012 PA also clarified that the time-dependent permeability of the panel closures has a noticeable effect on repository performance at lower probabilities by changing the gas pressures and brine saturations within the waste panels. The results also clarified that the panel closures should be viewed as a system that includes both the closure itself and the surrounding DRZ. In particular, the DRZ surrounding the ROM salt plays a significant role in the effective permeability of this system because its cross-section area for brine and gas flow is large compared to that of the ROM salt. As described in Section 3.4.3.1, a sensitivity analysis was performed by the Agency to determine the effects on releases of correlating the permeability of the healed DRZ to the permeability of intact halite. The results of this sensitivity analysis are described in Section 4.1 of this TSD.

4.0 EPA SENSITIVITY ANALYSIS

The Agency conducted two sensitivity studies to further evaluate DOE's results. One study investigated the impact on calculated releases if the DRZ surrounding the PCS healed to a lower permeability than the one used in the CRA-09 and PCS-2012 PAs. The other investigated the impact of activating the capillary pressure model within the panel closure material. The results of these sensitivity studies are described in the following section.

4.1 SENSITIVITY TO DRZ PERMEABILITY

The Agency concurs with DOE's expectation that the backstress imposed on the DRZ by the ROM salt panel closure due to salt creep will result in PCS DRZ properties approaching those of intact halite after approximately 200 years (T3 in the PCS-2012 PA). A more fully healed DRZ will acquire properties that resemble a consolidated material rather than the fractured material modeled during time periods T1 and T2. This section presents results of a sensitivity study performed by the Agency to evaluate the impact on the PCS-2012 PA releases if a lower permeability is assigned to the PCS DRZ.

4.1.1 Conceptualization of DRZ Healing

The PCS-2012 PA was designed to compare the ROM salt panel closure system with Option D panel closure. The only parameter values modified for the PCS-2012 PA were those used for the panel closures, such as density, permeability, porosity and compressibility. In the PCS-2012 PA, no modifications were made to the coupling between the responses of the adjacent DRZ relative to the changing properties of the ROM salt panel closure system. The Agency believed additional calculations needed to be performed to understand whether coupling the properties of the healed PCS DRZ to those of the pre-damaged halite would affect the PCS-2012 PA results for the following reasons.

There is a major difference between the response of the ROM salt PCS and the Option D PCS due the creep closure. For the ROM salt PCS, the permeability and porosity will become progressively lower, while density will increase as it consolidates and responds to creep closure. For the Option D design, the material properties were assumed not to be impacted by creep closure. Additionally, for the Option D PCS because the DRZ above and below was to be largely mined out to the anhydrite layers (~1.3 meters in the lower DRZ to the Marker Bed 139, and ~2.6 meters up to Marker Bed AB in the upper DRZ), there would be minimal DRZ halite remaining. Therefore, the properties of the DRZ were modeled as a constant. The DRZ flow properties were not correlated to that of intact halite, but rather to the Option D concrete. In contrast, for the ROM salt PCS, the DRZ halite will not be mined and therefore its behavior over time relative to the ROM salt needs to be considered by assigning parameter values representative of healed DRZ in the T3 time period.

Due to creep closure and consolidation, DOE expects the density, porosity and permeability of ROM salt to approach that of nearly intact halite within approximately 200 to 300 years. Creep closure is also expected to impose backstress from the ROM salt to the adjacent DRZ around 300 years. In the PCS-2012 PA, the DRZ properties do not change as a function of backstress

created by the ROM salt. Additionally, the permeability of the PCS DRZ was based on the 2009 PABC DRZ properties which were similar to those of the anhydrite layers. The Agency believes the response of the compressive stresses of the ROM salt panel closure imposed on the PCS DRZ between 200 and 300 years will result in a nearly healed PCS DRZ with properties similar to that of the intact halite. A brief overview of DRZ formation and its response to stress follows.

Due to repository drift excavation, a DRZ is formed as lithostatic compressive stresses are reduced. This produces dilatant strain on the *in-situ* halite that can eventually produce fractures which are generally parallel to the drift and perpendicular to the minimum principal stress. Dilatancy linearly increases during deformation and ceases when compressive stresses commence. Numerous laboratory and field tests, some of which are described below, indicate that dilatant damage in salt is reversible through crack closure and healing under compressive stress. Salt creep will impose compressive stresses that will close any gaps between the mine roof and the ROM salt. Eventually, these compressive stresses applied to the DRZ will approach lithostatic pressure, which is approximately 14.9 MPa. DOE expects these compressive stresses will heal the fractures (Hansen 2003). Studies suggest that the healing time for the DRZ will be within several hundred years after repository closure. The healed DRZ will eventually be similar to that of *in-situ* halite.

Pfeifle and Hurtado (1998) performed salt healing experiments on stress induced fractures by applying compressive pressures of 1, 5, 10 and 15 MPa to the fractures. Fractures healed within a few years when compressive pressures were between 10 and 15 MPa. The authors concluded that is would take between 200 and 300 years to heal the fractures at compressive pressures below 10 MPa.

DOE's JAS -3D numerical calculations predicted that the salt creep will create compressive pressure on the ROM salt and DRZ of at least 12 MPa by 200 years (Herrick 2012). Based on the 1998 healing experiments and JAS-3D calculations, the Agency finds it reasonable to assume that a compressive pressure of at least 10 MPa would heal the fractures in the DRZ within 200 to 300 years.

Experiments performed by IT Corporation (1987) support the assumption that fractures will heal at pressures similar to lithostatic. IT Corporation conducted permeability tests on salt cores with both longitudinal-tension and saw tooth fractures at stepped confining pressures between ~3.5 MPa to 20 MPa. All tests indicated a strong correlation between permeability and confining pressures regardless of the degree of fracturing. Compression tests on fractured samples, at pressures similar to the WIPP confining pressure (~13.78 – 17.23 MPa), were run from 3 to 163 hours and steady declines in permeability and porosity were seen as a function of pressure and time. When the fractured cores were placed under a pressure of 20 MPa for 8 days, the permeability decreased to within the same order of magnitude or less of the intact permeability. Cores with tensile induced fractures had lower end-point permeability than saw tooth fractures. The authors speculated the tensile fracture cores healed more readily because the fractured surfaces of each half had similar paired geometries. Because the fractures in the DRZ are similar to tensile induced fractures, the results from the IT experiments support a healed DRZ to have properties similar to those of intact halite at the confining pressures above ~13.78 MPa which is within the range of repository confining pressures of ~14.9 MPa.

Another line of evidence indicating that fracture healing occurs relatively quickly are those performed to measure regained tensile strength along a fractured zone. These experiments indicated fracture healing was due to grain boundaries bonding along a fracture face under compressive pressure. This bonding along the fracture face would presumably result in permeability similar to the pre-fractured value due to grain-boundary bonding. Fracture tensile strength "healing" tests were conducted by Costin and Wawersik (1980) under confining pressures ranging from 10 to 35 MPa and temperatures between 22° to 100° C. The experiments lasted between 4 to 8 days. The majority of specimens healed to within 70%–80% of original strength. Brodsky (1990) tested fracture healing and microstructure hardening of induced damaged salt cores at pressures of 5, 10 and 15 MPa. Fractures healed more quickly and effectively for those cores where fracture geometries were maintained undisturbed and conformed to the geometry created during fracture formation. Brodsky concluded that fracture closure and complete healing will occur if compressive pressures persist for an extended period of time and inferred the time for fracture closure would be within a few tens of years.

DOE and EPA agree that the porosity and density of the ROM salt are correlated and affected by creep closure. For the ROM salt, as porosity is reduced and density increases, the backstress from the progressively denser ROM salt will place the DRZ under greater compressive stresses. Hansen et al. (1993) report little to no backstress is produced during the consolidation of crushed salt until fractional densities approach 0.90. Hansen and Thompson (2002) indicate that as the porosity of the ROM salt is further reduced to a value of 0.05 (a density of 0.95), healing of the DRZ will begin to occur. If ROM salt is emplaced in the access drifts, then full reconsolidation of the adjoining DRZ will occur after the ROM salt panel closure is itself fully reconsolidated and stress equilibrium is achieved.

The healing studies described above were performed on relatively pure halite. In addition to halite, however, the DRZ also consists of thin layers of clay, and anhydrite, which may inhibit fracture healing due to grain boundary bonding. Therefore, for the Agency's sensitivity study the permeability of the PCS DRZ is set at one order of magnitude higher than the permeability of intact halite.

4.1.2 Parameters Modified for the DRZ Adjacent to the ROM Salt

During the 200 to 10,000 year time period (T3 in the PCS-2012 PA) the ROM salt panel closures will have relatively high densities, and coupled with creep closure, will produce compressive backstress that nearly heal the adjoining DRZ. Laboratory experiments predict a nearly healed DRZ will have a permeability more like that of intact halite than uncompacted ROM salt. The Agency decided to test the impact on potential releases that a lower PCS DRZ permeability, than assumed in the PCS-2012 PA, may have on overall releases.

The range of sampled permeabilities for Salado halite and the adjacent DRZ_PCS during the T3 time period, and the derived ROM salt T3 permeability (derived from the sampled porosity and POR2PERM parameter) are given in Table 4-1. These values show the range for the DRZ_PCS permeability is more like that of the ROM salt rather than of a nearly healed halite.

Table 4-1. Log Permeability Ranges for ROM Salt and the Adjacent DRZ from 200 to 10,000 Years, and for Intact Salado Halite

Log Permeability (log m^3)	Mean	Median	Minimum	Maximum
Derive ROM PCS -	-19.36	-19.34	-20.94	-17.53
DRZ_PCS	-18.82	-18.81	-20.48	-17.2
S_Halite PRMX_LOG	-22.50	-22.505	-23.97	-21.01

Given laboratory and experimental results the Agency believes the properties of the DRZ adjacent to the ROM salt should be reflective of the following:

1. The permeability of the reconsolidated PCS DRZ should be somewhat greater than the permeability of undisturbed, intact halite because it is assumed that healing of the fractures in the DRZ may not be complete and therefore the material may not completely return to its original state.

2. After 200 years the DRZ is assumed to reconsolidate and heal with few remaining fractures.

3. During time period T3 residual brine and gas saturations in the PCS DRZ are set to values reflective of porous media.

4. Capillary pressure in the PCS DRZ will vary during the three time periods. Because the PCS DRZ will initially be fractured, threshold capillary pressures can approach zero. Therefore, not invoking a threshold capillary pressure is appropriate for the first few hundred years. An activated capillary pressure model, however, is appropriate when the PCS DRZ heals and behaves as a porous medium.

To investigate whether a PCS DRZ permeability that approaches fully healed intact salt after 200 years affects potential repository releases, the Agency performed a sensitivity study which is discussed in the next few subsections.

4.1.3 Modified Parameter Values for Sensitivity Study

To investigate the sensitivity on potential releases to the DRZ permeability and two-phase flow parameters, the input files used for the PCS-2013 PA were modified by lowering the PCS DRZ permeability to a value one order of magnitude greater than that of intact halite, assigning porous media two phase flow parameters to the nearly healed DRZ, and setting the two-phase flow parameters for the ROM salt to those established by EPA and DOE for the PCS-2013 PA. Additional details of EPA's sensitivity study are provided below and in Table 4-2.

1. The disturbed salt material of the PCS DRZ is treated as a fractured medium during time periods T1 and T2. After 200 years, the DRZ is assumed to reconsolidate and nearly heal with few remaining fractures and is treated as a porous medium during time period T3. The permeability of the PCS DRZ at time period T3 is set at one order of magnitude higher than the statistically sampled permeability of intact halite. This approach assigns the same uncertainty to the PCS DRZ as to intact halite.

2. During the T3 time period the PCS DRZ is assigned a nonzero value for residual brine and gas saturations (SAT_RBRN and SAT_RGAS) reflective of porous media.

3. Capillary pressure models for the PCS DRZ differs during the time periods
   a. Capillary pressure model (CAP_MOD) = 1 is appropriate for the PCS DRZ during time periods T1 and T2. The capillary pressure model is not activated when the capillary pressure may approach zero and is appropriate for the PCS DRZ during time period T1 when open fractures may exist, and still persist through the T2 time period.
   b. Capillary pressure model (CAP_MOD) = 2 is appropriate for the DRZ_PCS during time period T3. The CAP_MOD 2 switch activates nonzero capillary pressures when values of PCT_A and PCT_EXP are nonzero. An activated capillary pressure model is appropriate for porous media.

4. In BRAGFLO, the initial brine saturation SAT_IBRN must be greater than the residual brine saturation SAT_RBRN to avoid numerical issues. Therefore, SAT_IBRN for the DRZ_PCS was set at 0.9999 at T = -5 years and was calculated by the model for later time periods.

5. The two-phase flow parameter values assigned to the ROM salt were also modified to those established by the Agency and DOE. The healed DRZ during the T3 time period is treated as a porous media. And, as such, it is appropriate to invoke the Brookes-Corey two phase model in a healed DRZ where capillary threshold pressure is a function of permeability. Threshold pressure in the Brookes-Corey two-phase model is calculated with the following equation:

$$P_t = a\,k^{-b}$$

The same values for the linear parameter 'a', PCT_A, and the exponent '-b', PCT_EXP, given in the above equation that are used in the ROM Salt PCS are adopted for the healed DRZ. These values are discussed in detail in Section 3.4.2.2.

Table 4-2. Parameter Values Modified for the DRZ Sensitivity Study

Property	T1	T2	T3	T1 + T2	T3
	PCS			DRZ_PCS	
CAP_MOD	2	2	2	1	2
KPT	0	0	0	0	0
PC_MAX	1E9	1E9	1E9	1E9	1E9
PCT_A	0.56	0.56	0.56	0	0.56
PCT_EXP	-0.346	-0.346	-0.346	0	-0.346
SAT_IBRN	Due to BRAGFLO numerical issues, SAT_IBRN must be greater than SAT_RBRN in BRAGFLO. Therefore, SAT_IBRN for the DRZ_PCS is set at 1.0 at T = -5 years and is calculated by the model for later time periods.				
SAT_RBRN	0.1	0.1	0.1	0	0.1
SAT_RGAS	0.05	0.05	0.05	0	0.05
POROSITY	Unchanged			Unchanged	
PERMEABILITY	Unchanged			Unchanged	10*k for intact halite
POR2PERM	Unchanged			n/a	

4.1.4 Results of DRZ Sensitivity Analysis

The mean and the 90th percentile releases from the pooled results for all three replicates of the DRZ and PCS- 2012 sensitivity analyses are presented in Table 4-3. A graphical comparison of the mean releases against the EPA release limits is shown in Figure 4-1.

Table 4-3. Total Normalized Release Statistics for the DRZ Test and PCS-2012 PA

PCS-2012 PA and DRZ Test EPA Release Limit Probabilities - Pooled Across All Replicates				
Probability	**Analysis**	**Mean Releases in EPA Units**	**90th Percentile Releases**	**EPA Release Limit**
Total				
0.1	PCS 2012 PA	0.098	0.17	1
	DRZ Test	0.1005	0.165	1
0.001	PCS 2012 PA	1.512	1.0	10
	DRZ Test	1.198	0.891	10
Spallings				
0.1	PCS 2012 PA	0.00053	0.002	1
	DRZ Test	0.0029	0.008	1
0.001	PCS-2012 PA	0.078	0.01	10
	DRZ Test	0.115	.019	10
DBR				
0.1	PCS 2012 PA	0.0054	0.032	1
	DRZ Test	0.0041	0.028	1
0.001	PCS-2012 PA	1.49	0.9	10
	DRZ Test	1.15	0.79	10
Cuttings and Cavings				
0.1	PCS 2012 PA	0.0795	0.14	1
	DRZ Test	0.0796	0.14	1
0.001	PCS-2012 PA	0.296	0.32	10
	DRZ Test	0.295	0.32	10

As indicated by total releases presented in Table 4-3, changing the DRZ properties causes the total mean releases to slightly increase at the 0.1 probability and decrease at the 0.001 probability level from those of the PCS-2012 PA. The probability versus releases (in EPA Units) for the primary release mechanisms spallings, direct brine and cuttings and cavings are depicted in Figures 4-2 through 4-4, respectively. Of all the release mechanisms, spallings releases are affected the most by changing the DRZ properties.

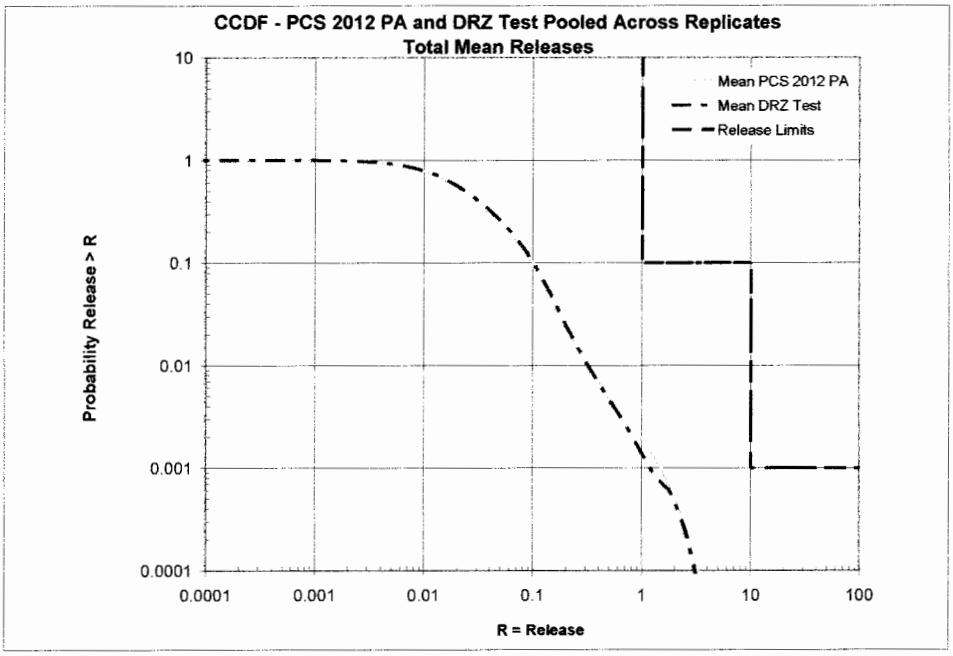


Figure 4-1. PCS 2012 PA and DRZ Test, Mean Total Normalized Releases

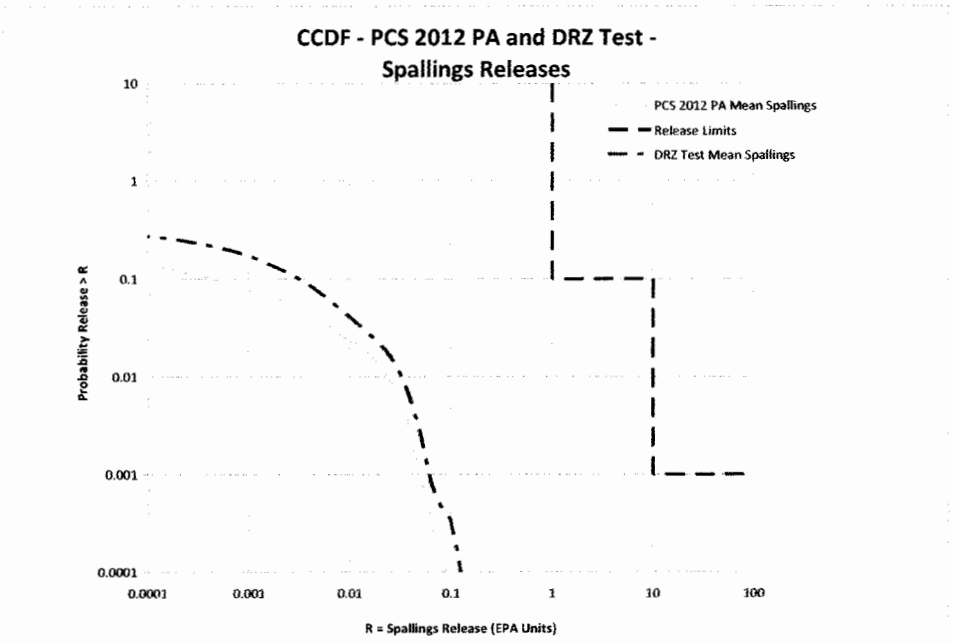


Figure 4-2. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Spallings Releases

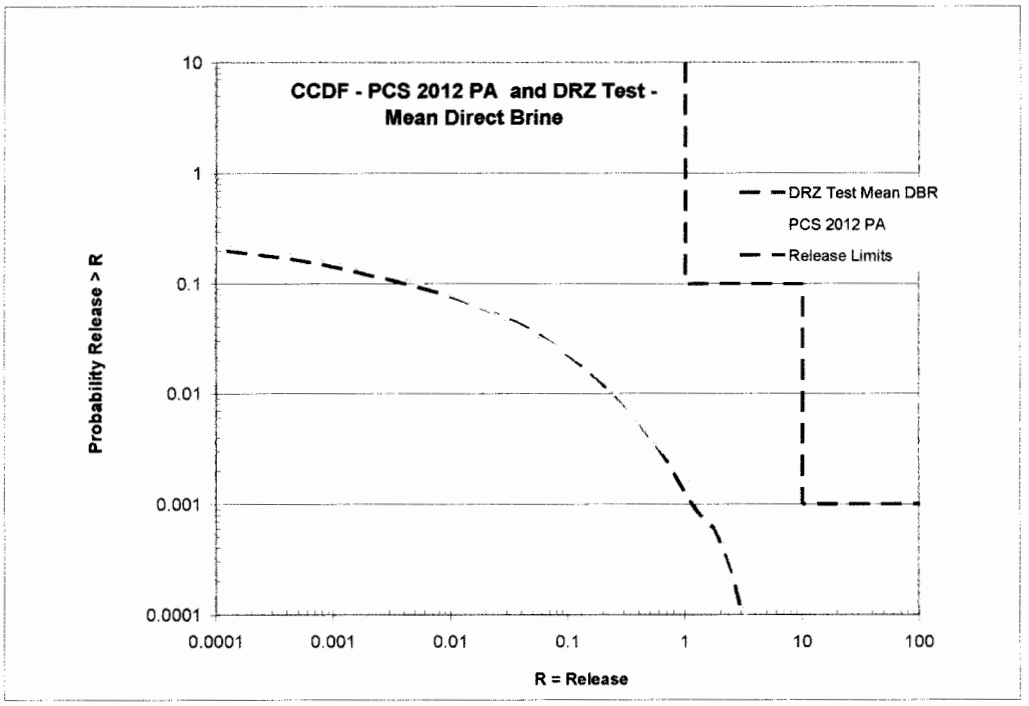


Figure 4-3. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Direct Brine Releases

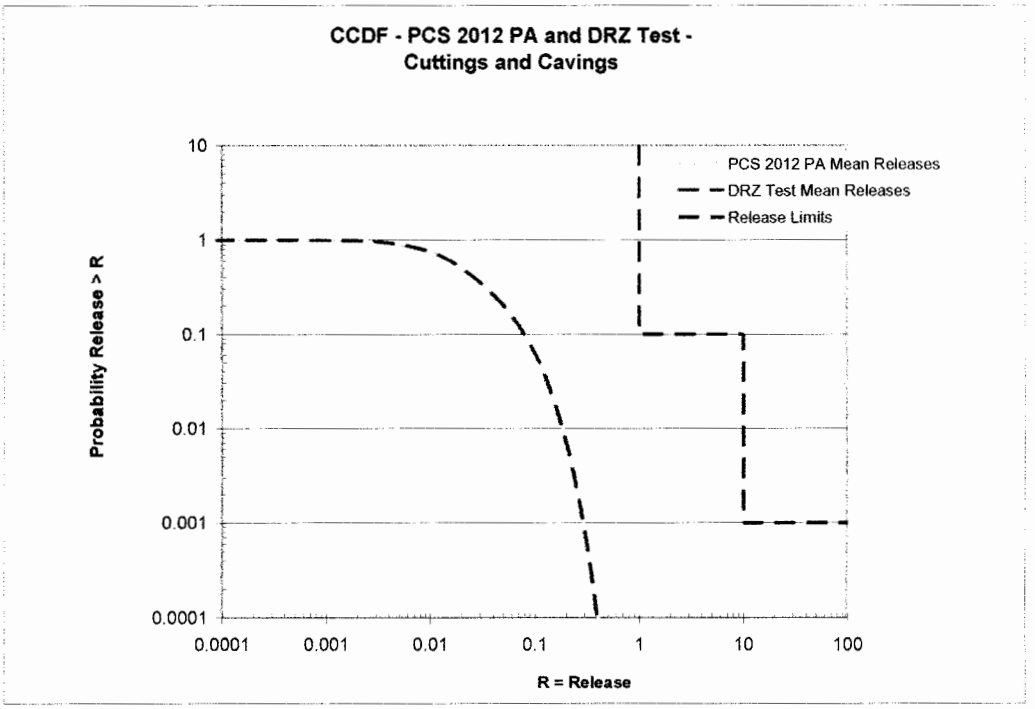


Figure 4-4. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Cuttings and Cavings Releases

The Agency investigated the BRAGFLO output variables to understand why the spallings releases increased, and found that their increase was primarily due to an increase in waste room pressures. Additionally, experiment and operations room pressures in the DRZ test cases were lower than those observed in the PCS 2012 runs. Collectively, these pressure differences suggest that gas generated in the waste rooms tends to stay in the waste region. Gas is impeded from migrating up-dip into the operations or experimental rooms that would otherwise provide additional gas storage volume and would reduce waste room pressure. These higher waste room pressures observed in the DRZ test cases subsequently result in greater spallings releases.

The overall mean for the DRZ Sensitivity test remains below the Agency's regulatory limits at both compliance points. The statistical results from this study also suggest the mean total repository releases would continue to remain below the EPA regulatory limits over a wide range of DRZ permeability, including those representative of a fully-healed DRZ with properties similar to intact halite.

In conclusion, the results indicate modifying the PCS 2012 PA DRZ flow parameter values, and invoking the capillary pressure model in the DRZ at the T3 time period lead to a slight increase in the total mean releases at the 0.1 probability level and decreased releases, by approximately 20%, at the 0.001 probability level. The shift in the mean total releases is mainly attributed to the increase in the spallings release pathway. However, the derived mean CCDF, a function of all release mechanisms, indicates that releases still fall well below the EPA release limit.

4.2 SENSITIVITY TO CAPILLARY PRESSURE IN THE ROM SALT

The representation of two-phase flow within the panel closure system was addressed during multiple technical discussions between EPA and DOE. In Camphouse et al. (2012b), DOE identifies the relative permeability and capillary pressure models intended to represent the flow of brine and gas within the panel closure system, including both the ROM salt, where the capillary pressure model was activated, and the adjoining DRZ (DRZ_PCS), where the capillary pressure model was not activated. The specific parameters, most adopted from the original salt shaft seal model (Hurtado et al. 1997) are fully described above in Section 3.4.3.2.

In an email and memorandum dated June 15, 2012, Sandia staff indicated that in the event that the BRAGFLO code failed to converge, the threshold pressure linear parameter PCT_A (originally set to 0.56 Pa) and the threshold pressure exponential parameter PCT_EXP (set at -0.346, dimensionless) for the ROM salt would both be changed to 0.0, disabling the capillary pressure model in the ROM salt. This practice has been used in past PAs, and effectively allows brine and gas to flow without needing to overcome a threshold capillary pressure.

In the PCS-2012 calculations, BRAGFLO failed to converge for many vectors when the capillary pressure model was implemented. Section 3.2.1 of the PCS-2012 BRAGFLO report (Camphouse 2012c) discusses the issue:

"As a result, values of CAP_MOD = 1, PCT_A = 0.0 Pa, and PCT_EXP = 0.0 are prescribed to materials PCS_T1, PCS_T2, and PCS_T3 in the PCS-2012 PA in order to have panel closure material consistency with the surrounding DRZ and salt properties of the original shaft seal

model, as well as to prevent numerical difficulties in BRAGFLO. These values correspond to capillary pressure modeling being disabled for these materials…"

Upon receipt of the BRAGFLO report, EPA questioned what the impacts of the parameter change would be. The Agency asked SNL staff to further investigate both the numerical problem, and the potential for the capillary pressure model to impact performance. During a trip by EPA staff to the SNL office in Carlsbad (October 2, 2012) to review the documentation of the PCS-2012 PA, SNL analysts presented their findings. The failure of the model to converge was a function of the interaction between the capillary pressure model, the initial brine saturation (SAT_IBRN), and the residual brine saturation (SAT_RBRN). The two-phase flow numerical model defines a minimum brine saturation below which brine cannot flow as the residual brine saturation. At the same time, however, an initial brine saturation (SAT_IBRN) was independently sampled from a range (0.041–0.16) that extended below some sampled values of the residual brine saturation. Numerical problems with the code were encountered for vectors where the initial brine saturation was sampled at a lower value than the sampled residual brine saturation. Sandia staff presented several test cases showing the interactions between the parameters.

In order to test the potential impact of the enabled capillary pressure model on repository performance, EPA elected to execute Replicate 1 of the PCS-2012 with the model enabled for the ROM salt, as originally intended. BRAGFLO convergence was accomplished by modifying the initial conditions so that the panel closure materials are initially fully saturated with brine. BRAGFLO converged for all replicates without loosening the convergence criteria. Results are shown in Figures 4-5 through 4-7.

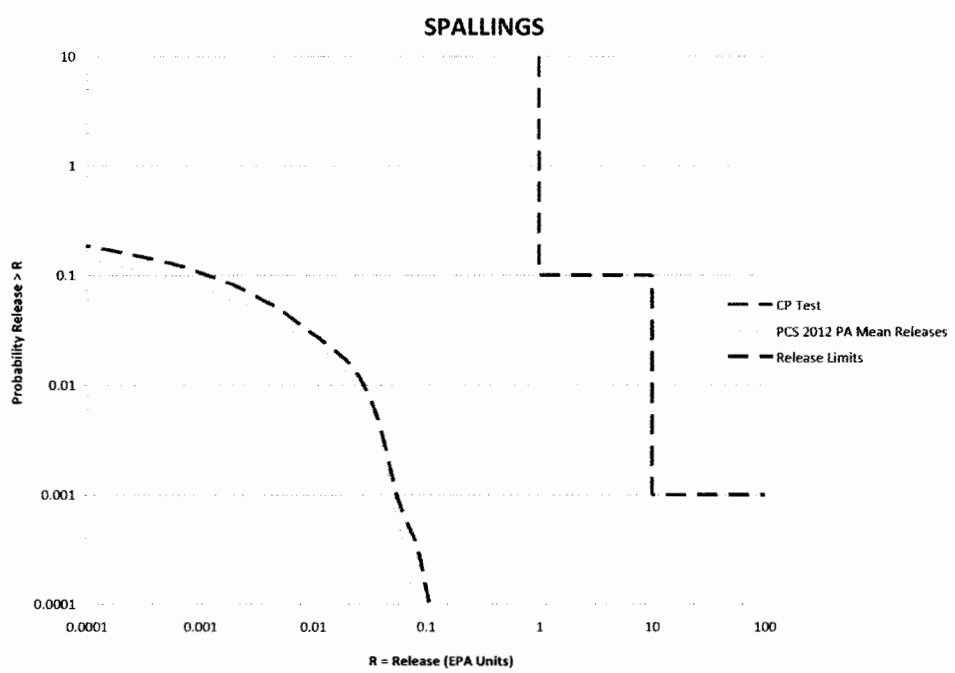


Figure 4-5. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized SPALLINGS Releases

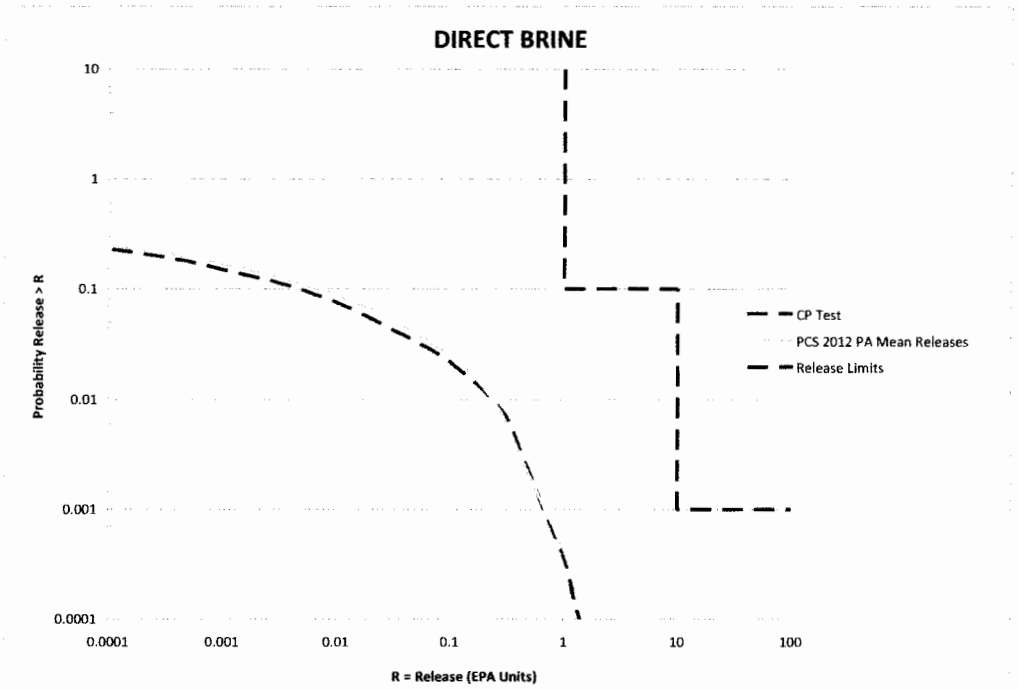


Figure 4-6. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Normalized Direct Brine Releases

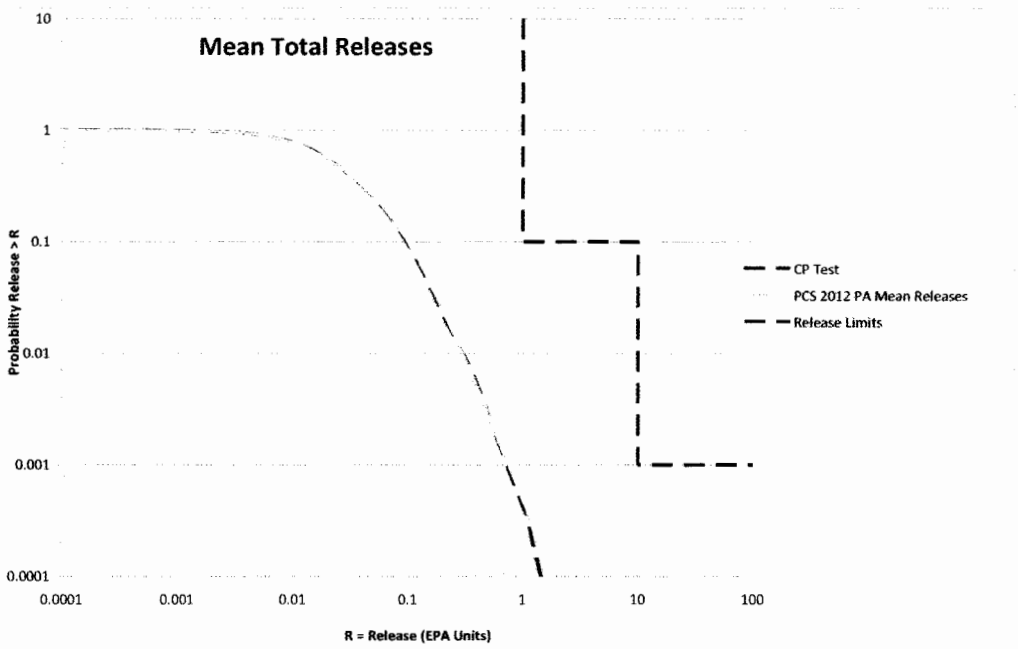


Figure 4-7. DRZ Sensitivity Test and PCS-2012 PA Overall Mean CCDFs for Total Normalized Releases

The capillary pressure model does not impact releases due to cuttings or cavings since those releases are simply calculated based upon the drill-bit diameter, and in the case of the PCS-2012 PA, releases to the Culebra were not recalculated. Applying the capillary pressure model to the ROM salt could affect spallings and DBR releases. At the 0.1 probability compliance point, mean total releases due to spallings were slightly increased, and mean total direct brine releases were slightly decreased for EPA Replicate 1, when capillary pressure effects were included. The contributions of different release mechanisms are the same at a probability of 0.001. The total mean predicted releases are indistinguishable between the PCS-2012 Replicate 1 and EPA's study.

Based upon the insensitivity to total releases, the Agency concludes that inactivating the capillary pressure model for the ROM salt to achieve model convergence does not affect the results of the PCS-2012 performance assessment.

5.0 EPA QUALITY ASSURANCE REVIEW

Section 5.1 describes the Agency's review of the parameter changes made since PABC-2009 to the parameters used in the PAPDB. A detailed discussion of the Agency's parameter review is presented in Appendix A. Section 5.2 discusses SNL's migration of the Performance Assessment Parameter Database (PAPDB, Version 1.0) used in the WIPP compliance calculations from the Microsoft SQL Server on a Windows Server to the PAPDB (Version 2.00) on the MySQL Server on Solaris. The results of EPA's more detailed review are provided in Appendix B.

5.1 PARAMETER CHANGES

SNL has made 78 parameter changes since PABC-2009 to the approximately 1,700 parameters in the PAPDB. Most of the changes involved the assignment of existing parameter names and values to newly defined materials for the three time periods used to model consolidation of both the ROM salt and the surrounding disturbed rock zone (DRZ) above and below the ROM salt. All ROM salt materials for the third time period were new because three different time periods had not previously been used in WIPP PA. Three data errors were identified by the Agency in the PCS-2012 PAPDB. These involved an erroneous value for the mean of a distribution, an erroneous designation of a distribution type (loguniform instead of uniform), and the transposition of the mean and median values of a distribution. However, none of these errors adversely affected PCS-2012 results. EPA has brought these errors to DOE's attention and has received assurances that they will be corrected.

A review of primary and secondary supporting documents was conducted for all parameter changes and all documents were quickly retrieved from the WIPP Records Center. Although the parameter values were generally correct, many of the supporting documents were not found to adequately justify those parameter values as used in the PCS-2012 analysis, and many had transparency weaknesses because the cited source documents were prepared for other analyses and the associated metadata described those analyses rather than the PCS-2012 PA. For example, the designated supporting document may have described a parameter that was used in an earlier analysis for a time period extending from zero to 200 years, but was used in the PCS-2012 PA for a time period extending from zero to 100 years. Transparency issues generally become problems for those trying to understand an analysis they are not already familiar with. DOE's approach was to explain the differences in the supporting documentation, however EPA believes that the database should be consistent with the supporting documentation. The justification weaknesses were resolved in part by the Agency's independent review of the technical basis for many of the parameter values, and in part because of the need to leave some existing parameter values unchanged to minimize differences between the PCS-2012 and the baseline PABC-2009, so that the differences in performance results could be readily attributable to the principal effects of changing the PCS design. However, modeling the progressive consolidation of ROM salt in a waste panel access drift and the subsequent consolidation of the surrounding DRZ involves processes and parameters that are new to WIPP PA.

A database interface evaluation was performed for all new parameters and the correct parameter values were retrieved from the PAPDB with the exception of one instance where the distribution identified for the parameter in the PAPDB was not properly sampled. However, this error did not

affect the PCS-2012 PA results because the returned value was the desired value. The Agency has brought this error to DOE's attention and has received assurances that it will be corrected. Procedures for developing, documenting, controlling, and changing parameters, and for entering those parameters into the PAPDB, were also reviewed. The Agency found all procedural changes to be consistent with earlier versions and found all revisions to be appropriate.

In summary, during this review the Agency discovered several parameter transparency, implementation and quality assurance control issues. The number of these parameter deficiencies was far more than have been raised by the Agency in previous PA reviews. The Agency believes that the Department should have identified and corrected these parameter issues as part of their routine technical and quality assurance program reviews. This is particularly significant because relatively few parameter changes were required for DOE's PCS-2012 analyses. As demonstrated by additional EPA analyses, however, EPA concluded shortcomings associated with the parameters did not affect the overall PCS-2012 PA results.

5.2 DATABASE MIGRATION

In 2011, SNL migrated the PAPDB (Version 1.0) used in the WIPP compliance calculations from the Microsoft SQL Server on a Windows Server to the PAPDB (Version 2.00) on the MySQL Server on Solaris. The purpose of the migration was to facilitate the access to the parameter data from the PA codes on Solaris, Linux and VMS. In addition, the design of the database was also modified to improve its ease of use. A detailed discussion of the Agency's review of the (PAPDP) migration, design modifications and testing activities performed by SNL is presented in Appendix A. A summary of those activities and findings are presented below.

SNL defines a parameter as any value or distribution of values used directly or indirectly as input to a PA. The PAPDB contains the parameters used in WIPP PAs, the names of documents related to those parameters, the names of the codes that use the parameters, and a log of the parameters that were exported to the various codes during analyses. In the PAPDP a parameter may be represented by a single value or assigned a distribution which represents epistemic uncertainty. The values of parameters can change through time as new information becomes available. The database contains the different versions of the parameter identified by a version number and also by the analysis where the parameter was first defined and the effective date for its use. Specific versions of a parameter can be associated with one or more analyses. The purpose of the database is to securely store the parameter data used in the PA analyses, to allow access to that data directly from the applications that need those data, and to log the usage of the data. In addition, the PAPDB is designed to access the data from a user interface to facilitate querying the database to document the parameter values used in the various analyses

The primary objectives of the Agency's review of the PAPDP migration activities were to assess the accuracy of the database migration to the new platform and to assess the transcription accuracy, documentation, and traceability of changes to the parameter values, distributions and metadata. The PAPDB parameter database and associated metadata are maintained in Carlsbad, New Mexico, by SNL. Hard copies of documentation supporting the parameters and their values are maintained in SNL's WIPP Records Center in Carlsbad. The supporting documents are

tracked by SNL's Electronic Record Management System (ERMS), through which a unique identifying number is assigned to each document.

The Agency has reviewed the PAPDP life-cycle documentation that SNL has developed to assess whether the PAPDP migration to a new platform meet the requirements specified in §194.22 and §194.23. In addition to the life-cycle documentation, the Agency reviewed several migration reports (Kirchner 2012).

The PAPDB Version 2.00 was shown to meet the requirements listed in the Verification Validation Plan (VVP). Data could be successfully obtained from the database or inserted into the database from a FORTRAN application and permission to write into the database was properly controlled using group membership on Solaris.

6.0 SUMMARY AND CONCLUSIONS

The EPA has reviewed the PCS-2012 PA submitted by DOE in support of the Planned Change Request (PCR) to modify the Panel Closure System (PCS) from the Option D design, as specified in Condition 1 of 40 CFR 194, to a design primarily consisting of run of mine (ROM) salt. The PCS-2012 PA was developed by DOE to isolate the effects of the proposed ROMPCS design change on WIPP repository performance by maintaining the structure of the calculations as similar as possible to that used in the current regulatory baseline PABC-2009. This approach facilitated a comparison between the results of the two PAs and helped isolate the effects of the proposed PCS design change on repository releases.

The Agency reviewed DOE's ROM salt design and method of emplacement and its treatment of the hydrologic properties of salt during reconsolidation. The primary uncertainties are the rate of change and values of porosity and permeability of the ROM salt with time. DOE adopted a wide range of values for these parameters. The Agency accepts the values adopted for porosity and permeability in the PCS-2012 PA and agrees that they adequately capture the range of uncertainty.

The Agency reviewed DOE's FEP analysis associated with the proposed ROM salt panel closure design and concludes that SNL's FEP baseline review adequately indentified the principal modeling changes that were necessary to achieve the purpose of the PCS-2012 PA. The Agency accepts the computational changes adopted in the PCS-2012 PA made to the BRAGFLO Salado Flow Model in order to accommodate the revised geometry, time periods, and material properties associated with the modified PCS design.

The Agency agrees with DOE's conceptualization of long-term "healing" of the disturbed rock zone adjacent to the ROMPC and accepts the values DOE adopted for the PCS DRZ to maintain reasonable consistency with PABC-2009. The DRZ surrounding the PCS plays a significant role in the effective permeability of the system because its cross-section area for brine and gas flow is large compared to that of the ROM salt. The Agency performed a subsequent study of the sensitivity of PCS-2012 PA results to an alternative parameterization of the healed DRZ. The Agency's study indicated that lowering the permeability of the healed PCS DRZ and invoking the capillary pressure did not result in a significant change in total predicted releases.

The results of the PCS-2012 PA indicate that the time-dependent permeability of the panel closures has a noticeable effect on repository performance by changing the gas pressures and brine saturations within the waste panels. Slightly higher repository gas pressures and higher brine saturations, resulting in slightly higher spallings and DBR releases. However, overall releases were well below the EPA limits. DOE concluded the primary effect of the proposed panel closure design modifications on repository releases were the changes in pressure and brine saturation in the waste panels (Camphouse et al. 2012a). This is because direct brine, spallings, and Culebra releases are sensitive to those parameters and those parameters in turn are sensitive to the permeability of the panel closures and surrounding DRZ which controls fluid flow between the waste panels and the non-waste areas of the WIPP underground facility. The Agency agrees with this conclusion.

With a review of the information presented by DOE and its own analyses, EPA is satisfied that the revised PCS-2012 PA provides an adequate performance measure for the ROMPCS, and has been adequately implemented. The Agency has a reasonable expectation that the WIPP still complies with the containment requirements of 40 CFR Part 191.13 with ROM salt as the primary material in the PCS.

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APPENDIX A

QUALITY ASSURANCE REVIEW OF THE PCS-2012 PA PARAMETER DATABASE

TABLE OF CONTENTS

Abbreviations and Acronyms iv
Executive Summary v
1.0 Introduction 1
2.0 Approach 3
3.0 Review of Parameter Database Migration 5
4.0 Review of Parameters used in PCS-2012 that have Changed Since PABC-2009 7
4.1 Errors Identified in Parameter Data Entries 7
4.2 Transparency Concerns Identified in Parameter Data Entries 8
4.3 Review of Supporting Documentation 10
4.3.1 Use of Default Values 27
4.3.2 ROM Salt Porosity and Permeability Values 27
4.3.3 PCS DRZ Porosity and Permeability Values 30
4.3.4 Two-Phase Flow Parameters 31
4.4 Review of PAPDB Database-to-Code Interface for PCS-2012 34
5.0 Parameter Data Entry Process Review 43
6.0 Computing Hardware 44
7.0 Conclusions 45
References 46

LIST OF TABLES

Table 1. Parameters Used in the PCS-2012 PA that have Changed since PABC-2009 11
Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009 14
Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009.....36
Table 4. WIPP PA Alpha Cluster Nodes Used in PCS-2012.....44

ABBREVIATIONS AND ACRONYMS

CCA	Compliance Certification Application
CFR	*Code of Federal Regulations*
DOE or the Department	U.S. Department of Energy
DRZ	Disturbed Rock Zone
EPA or the Agency	U.S. Environmental Protection Agency
ERMS	Electronic Record Management System
HP	Hewlett Packard
PA	Performance Assessment
PABC-2009	2009 WIPP Performance Assessment Baseline Calculation
PAPDB	Performance Assessment Parameter Database
PAVT	Performance Assessment Verification Test
PC3R	Panel Closure Redesign and Repository Reconfiguration Analysis
PCS	Panel Closure System
PDE	Parameter Data Entry
QA	Quality Assurance
ROM	Run-of-Mine
SAN	Storage Area Network
SNL	Sandia National Laboratories
T1	First Time Period (0 to 100 years)
T2	Second Time Period (100 to 200 years)
T3	Third Time Period (200 to 10,000 years)
TBM	Technical Baseline Migration
TSD	Technical Support Document
VBA	Virtual Basic for Applications
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

This appendix documents a quality assurance review of the changes made by DOE/SNL to the WIPP Performance Assessment Database (PAPDB) for the PCS-2012 PA. Of the approximately 1,700 parameters in the PAPDB, 78 changes were made since PABC-2009. Most of the changes involved the assignment of existing parameter names and values to newly defined materials for the three time periods used to model consolidation of both the ROM salt and the disturbed rock zone (PCS DRZ) above and below the salt. All ROM salt materials for the third time period were new because three different time periods had not previously been used in WIPP PA. Three data errors were identified by the Agency in the PCS-2012 PAPDB. These involved an erroneous value for the mean of a distribution, an erroneous designation of a distribution type (loguniform instead of uniform), and transposition of the mean and median values of a distribution. However, none of these errors adversely affected PCS-2012 results. EPA has brought these errors to DOE's attention and has received assurances that they will be corrected.

A review of primary and secondary supporting documents was conducted for all parameter changes and all documents were quickly retrieved from the WIPP Records Center. Although the parameter values were generally correct, many of the supporting documents were not found to adequately justify those parameter values as used in the PCS-2012 analysis, and many had transparency weaknesses because the cited source documents were prepared for other analyses and the associated metadata described those analyses rather than the PCS-2012 PA. For example, the designated supporting document may have described a parameter that was used in an earlier analysis for a time period extending from zero to 200 years, but was used in the PCS-2012 PA for a time period extending from zero to 100 years. Transparency issues generally become problems for those trying to understand an analysis they are not already familiar with. DOE's approach was to explain the differences in the supporting documentation, however EPA believes that the database should be consistent with the supporting documentation. The justification weaknesses were resolved in part by the Agency's independent review of the technical basis for many of the parameter values, and in part because of the need to leave some existing parameter values unchanged to minimize differences between the PCS-2012 and the baseline PABC-2009, so that the differences in performance results could be readily attributable to the principal effects of changing the PCS design. However, modeling the progressive consolidation of ROM salt in a waste panel access drift and the subsequent consolidation of the surrounding DRZ involves processes and parameters that are new to WIPP PA. If the alternative PCS design proposed by DOE is implemented, the Agency will thoroughly evaluate all associated parameter values for continued relevance for use in future PAs.

A database interface evaluation was performed for all new parameters and the correct parameter values were retrieved from the PAPDB with the exception of one instance where the distribution identified for the parameter in the PAPDB was not properly sampled. However, this error did not affect the PCS-2012 PA results because the returned value was the desired value. The Agency has brought this error to DOE's attention and has received assurances that it will be corrected.

Procedures for developing, documenting, controlling, and changing parameters, and for entering those parameters into the PAPDB, were also reviewed. The Agency found all procedural changes to be consistent with earlier versions and found all revisions to be appropriate.

In summary, many more concerns were raised by this review than were raised in previous PA parameter reviews. However, as documented in this report, the problems identified by the Agency concern details of the PCS-2012 parameters that did not affect the overall PA results.

1.0 INTRODUCTION

The panel closure system (PCS) at the Waste Isolation Pilot Plant (WIPP) consists of barriers constructed in access drifts to filled waste panels that close the panels to further access, and reduce brine and gas transfer between the filled panels and the rest of the repository. The U.S. Department of Energy (the Department or DOE) has proposed to change the PCS design from the current "Option D" design, consisting of a concrete monolith and an explosion wall, to a design nominally consisting of 100 feet of run-of-mine (ROM) crushed salt fill between two ventilation bulkheads. Where explosion walls already exist, only one ventilation bulkhead would be constructed on the outboard side of the ROM salt. The purpose of these bulkheads is to restrict air flows and personnel access to filled waste panels. DOE expects the ROM salt panel closure to be easier and less expensive to construct than the Option D design. In addition, the proposed design eliminates the need for an explosion wall, which has been found to be unnecessary because of low volatile gas concentrations in the waste panels (Nelson 2011). The two alternative PCS designs are more fully described in Camphouse et al. (2012a). Changing the panel closure design would require a new rulemaking by the U.S Environmental Protection Agency (the Agency or EPA), because one of the conditions in the 1998 Agency rulemaking that certified WIPP to receive transuranic waste mandated use of the Option D design.

The short-term purpose of the PCS is to minimize the impact of filled waste panels on the rest of the WIPP repository for worker protection during the repository's operational period. After the operational period ends and the repository is closed, DOE expects that increasing pressure from the surrounding bedded salt as it creeps into the filled access drifts will consolidate the ROM salt and eventually return it to the near undisturbed, in situ conditions of very low permeability and porosity. Over the long term, DOE expects the decreasing permeability will increasingly isolate each waste panel by reducing the exchange of brine and gas with the rest of the repository.

Sandia National Laboratories (SNL), DOE's science advisor, designed the PCS-2012 performance assessment (PA) to compare the long-term performance of the WIPP repository with the proposed ROM salt PCS against the long-term performance with the original Option D PCS. This was achieved by revising the parameter values in the PABC-2009 PA, which is the current regulatory baseline, to reflect the proposed use of crushed salt instead of concrete, and to simulate the progressive consolidation of the crushed salt during creep closure. The changes primarily affect the BRAGFLO Salado Flow PA model. Only those changes that directly relate to the panel closure materials and their consolidation were made (Camphouse et al. 2012a). The ventilation bulkheads were not simulated in the PCS-2012 PA because SNL does not consider them to have long-term functionality (Camphouse et al. 2012a). The only change in the BRAGFLO model grid was to better simulate the ROM salt panel closure, which is about 10 m shorter than the Option D concrete monolith (Camphouse et al. 2012a). DOE evaluated the effect of the proposed ROM salt PCS on long-term repository performance by comparing the results of the PCS-2012 PA against those of the PABC-2009 PA.

This appendix describes the Agency's review of the Performance Assessment Parameter Database (PAPDB), parameter traceability, adequacy of parameter documentation, and changes to the performance assessment (PA) parameters used to support DOE's PCS-2012 PA. The results of this review document the Agency's evaluation of DOE's compliance with the

requirements of 40 CFR 194.23(c)(4). The PAPDB is a computerized database that contains the values of parameters used in PA calculations. The PAPDB also records a history of parameter value changes for different PA runs. It identifies metadata, such as parameter names, units, and distribution characteristics, and it identifies supporting documentation. Following completion of the PABC-2009 PA, SNL migrated the PAPDB to a new version and platform to improve its ease of use and to facilitate access of the parameter data by the PA codes.

2.0 APPROACH

This review was conducted by Agency and contractor personnel. The scope of the review included the following:

- Verification and documentation of the PAPDB migration to a new platform
- Verification and documentation of changes made to the PAPDB for the PCS-2012 PA
- Reviewing procedural documentation supporting database changes
- Reviewing and evaluating supporting metadata for new and changed parameter values
- Checking the ability of PA codes to accurately access input parameters from the new database

The primary objectives of the Agency's review were to assess the accuracy of the database migration to the new platform and to assess the transcription accuracy, documentation, and traceability of changes to the parameter values and metadata that were made for the PCS-2012 PA. Parameter values and modeling approaches for the PCS-2012 PA were proposed by DOE in February 2012. Several concerns were raised by the Agency during its evaluation of DOE's proposal and a final modeling approach was agreed upon in June 2012. The Agency's review of the adequacy of DOE's implementation of the modeling approach was initiated in October 2012 with an on-site review of the PAPDB and its PA code interfaces. The PAPDB parameter database and associated metadata are maintained in Carlsbad, New Mexico, by SNL. Hard and electronic copies of documentation supporting the parameters and their values are maintained in SNL's WIPP Records Center in Carlsbad. The supporting documents are tracked by SNL's Electronic Record Management System (ERMS), through which a unique identifying number is assigned to each document.

The parameter changes from PABC-2009 to PCS-2012 consisted of 48 new parameters for the ROM salt and 30 new parameters for the disturbed rock zone (DRZ) above and below the ROM salt. This zone is herein identified as the PCS DRZ. The following activities were conducted in reviewing these parameter changes and the aforementioned database migration during the Agency review team's October 2012 visit to Carlsbad:

- Reviewed the structure of the new PAPDB and the steps taken by SNL to confirm an accurate migration of the PABC-2009 parameter values and associated metadata into the new database.
- Reviewed the accuracy of data entry into the PAPDB by visually comparing the online PAPDB values with the values on the Parameter Data Entry (PDE) forms for every new parameter. Parameter units, distribution type, statistics, names, and references were also reviewed.

- Checked PDE forms of all new and changed parameters for completeness, signatures, and references to supporting documentation.
- Reviewed supporting documentation identified on the PDE forms for every new parameter to confirm accuracy of parameter values on the PDE forms and to evaluate the traceability of the parameter changes.
- Reviewed the ability of the current PA codes to accurately access every new input parameter from the database.

Follow-up activities were subsequently conducted by e-mail, telephone, and a return visit to Carlsbad in November 2012. SNL provided clarifications, copies of applicable data entry and handling quality assurance procedures, and copies of additional documentation as requested to address issues that developed as the review of the database changes proceeded.

3.0 REVIEW OF PARAMETER DATABASE MIGRATION

Following completion of PABC-2009, SNL developed new database software, called PAPDB Version 2.00, to replace the previous PAPDB Version 1.00, and migrated the parameter values and associated metadata from Version 1.00 to Version 2.00. The database structure was modified to make it easier to use and to facilitate parameter data access from the PA codes on Solaris, Linux, and VMS platforms. The new database resides on a MySQL Server and is physically located on an Intel-based server running Solaris 11 (Kirchner and Long 2012). The database migration process is more fully described by Kirchner (2011).

A primary improvement in the new database is the ability to accurately retrieve parameter values used in earlier PAs. PAPDB Version 2.00 is designed to default to the parameter value most recently entered into the database, and to automatically log in the analysis that used the parameter value. However, if desired, an earlier value can be returned by specifying an earlier analysis. A similar functionality was provided in PAPDB Version 1.00, but did not work properly. In addition, distributed parameters are now assigned a default value for use when the distribution is not to be sampled. For example, when assigning three-dimensional, isotropic permeability values to a material, only the value of PRMX_LOG is randomly sampled using the PRELHS code. The constant default values for PRMY_LOG and PRMZ_LOG are taken from the database as placeholders and are subsequently reassigned the same value as PRMX_LOG in the BRAGFLO ALGEBRA file.

The methodology for retrieving parameter values from the database remains essentially unchanged. The MATSET code retrieves the default value for every parameter in the analysis. Parameter values that are to be sampled are identified in the input files to the PRELHS code, which supplies that information to the LHS code. The LHS code then retrieves 100 sample values per replicate from the database and supplies them to the post LHS code. If a parameter has been retrieved by LHS, the POSTLHS code replaces the default parameter value retrieved by MATSET with the parameter value retrieved by LHS. In a subsequent step, the remaining default values retrieved by MATSET for distributed parameters are replaced by the desired value in the ALGEBRA1 file, as described in the example above. For constant parameters, the default value is the constant value and remains unchanged. Although the default values for distributed parameters are typically the means or medians of the distributions, any value can be used as the default value.

The PAPDB Version 2.00 database tables are constructed to store the data residing in PAPDB Version 1.00. An Access database, ParamTransfer.mdb, was used to transfer the data from PAPDB Version 1.00 to PAPDB Version 2.00. Most of the transfers were done using queries to extract the data from the PAPDB Version 1.00 and append it to tables in PAPDB Version 2.00. The transfers were checked for completeness using a series of queries and, for the parameter value data, two VBA (Visual Basic for Applications) routines. The queries were designed to compare the PAPDB Version 2.00 values with the corresponding values in PAPDB Version 1.00 and to show only records in the PAPDB Version 1.00 that were not matched in the PAPDB Version 2.00. Thus, the desired outcome was an empty data set.

Verification of the transfer process involved a transfer of the data followed by the deletion of selected records from the various tables and execution of the various queries to show that the missing records were detected. Following the verification of the procedures, the data were transferred once again and the same queries run to verify that no records were dropped during the transfer. It was also necessary to generate a report that showed the records whose value string could not be matched due to differences in formatting. The records shown in that report were compared and verified to be equivalent.

In addition to the records transferred from PAPDB Version 1.00, two sets of records were developed that were missing from the original database. The design of PAPDB Version 1.00 did not allow for multiple analyses being run under a single Analysis Plan (AP), as was done for AP-132. It appears to have kept only the records from the most recent retrieval of parameters. Furthermore, the retrieval of parameters by MATSET for use in NUTS seems to never have been recorded. To capture these usages of parameters, a series of queries were run to insert the missing records.

The data were transferred following verification of the transfer procedures. SNL verified an accurate data transfer by reviewing the comparison reports, as documented by Kirchner and Long (2012). Problems found in initial data transfers were corrected and in the final transfer, all of the comparison tests were successful except one, where the data did not exactly match due to formatting differences. Those test results were reviewed manually and the values of the two data sets were found to be equivalent.

The transfer process was reviewed by the Agency and detailed documentation of that review is presented in Appendix A.

4.0 REVIEW OF PARAMETERS USED IN PCS-2012 THAT HAVE CHANGED SINCE PABC-2009

This review evaluated 78 new parameters out of approximately 1,700 parameters currently in the PAPDB. All changes to the PABC-2009 parameter database involve new parameters, because the use of ROM salt panel closures is new to WIPP PA. Three time periods with varying material properties were introduced in PCS-2012 to represent time-dependent consolidation of the ROM salt panel closure material and the related time-dependent healing of the DRZ above and below the PCS. Time period T1 extends from repository closure (at time zero) to 100 years, time period T2 extends from 100 to 200 years, and time period T3 extends from 200 years to the end of the regulatory time frame at 10,000 years. Time-dependent changes were not needed for the properties of the Anhydrite AB layer modeled within the DRZ above the ROM salt, because anhydrite does not exhibit the creep characteristics of halite and would be little affected by the proposed change to ROM salt as the panel closure material.

The parameters representing the ROM salt PCS were separately entered in the PAPDB for each of the three time periods, as reflected in the material names. The parameters representing the DRZ above and below the ROM salt were assigned pre-existing material names DRZ_1 and DRZ_PCS. These material names were originally developed by SNL for a 2006 analysis of a ROM salt PCS, called AP-129, which was never formally reviewed by the Agency. Material DRZ_1 is used in PCS-2012 to represent the properties of the PCS DRZ during time periods T1 and T2, and material DRZ_PCS is used in PCS-2012 to represent the properties of the PCS DRZ during time period T3.

The new parameters are identified in Table 1. This table presents the parameter names (consisting of a material name and a property name), the distribution type, the parameter values used in the PCS-2012 analysis, the analysis where the parameter value was first used, the parameter units, and the PA code(s) using the parameter. The Parameter Data Entry (PDE) form provides the source information for parameter values and associated metadata to be entered into the PAPDB.

4.1 ERRORS IDENTIFIED IN PARAMETER DATA ENTRIES

The parameter values and metadata entered into the PAPDB were visually compared with those on the PDE forms and the following data entry errors were identified. As noted below, none of these errors resulted in impacts to the PCS-2012 PA:

- Parameters PCS_T1:PRMY_LOG and PCS_T1:PRMZ_LOG were identified on PDE form PDE 2012a and entered in the PAPDB as having loguniform distributions, whereas they should have been identified as having uniform distributions. Parameter PCS_T1:PRMX_LOG was properly identified and sampled from a uniform distribution. No impact to the PCS-2012 PA resulted from this error, because constant default values were taken from the PAPDB for PCS_T1:PRMY_LOG and PCS_T1:PRMZ_LOG, and later set equal to the sampled value of PCS_T1:PRMX_LOG in the BRAGFO ALGEBRA1 file. The correct distributions for these parameters are given in Table 1.

- The mean of the uniform distribution for parameter PCS_T3:POROSITY was identified in the source document Camphouse (2012), on PDE form PDE 2012b, and in the PAPDB as 0.05, whereas it should have been entered as 0.0265. Again, no impact to the PCS-2012 PA resulted from this error, because the mean is not used in LHS when developing a sampling scheme for a uniform distribution. The correct mean value for this parameter is given in Table 1.
- The mean and median values of the cumulative distribution for PCS_T3:SAT_RBRN are reversed on PDE form PDE 2012b and in the PAPDB. The mean should be 0.25 and the median should be 0.2, consistent with the means and medians for the parallel parameters PCS_T1:SAT_RBRN and PCS_T2:SAT_RBRN. Again, no impact to the PCS-2012 PA resulted from this error, because the constant default value was taken from the PAPDB for PCS_T3:SAT_RBRN and later set equal to the sampled value of PCS_T1:SAT_RBRN in the BRAGFLO ALGEBRA1 file. The correct mean and median values for this parameter are given in Table 1.

4.2 TRANSPARENCY CONCERNS IDENTIFIED IN PARAMETER DATA ENTRIES

The Agency's transparency review of parameter data entries focused on the clarity and completeness of the PDE forms. All PDE forms were found to have properly entered and dated signatures of the individuals responsible for Concurrence, Data Entry, and QA Reviewer/Checker. The traceability concerns identified by the Agency most commonly resulted from the use of source documents that were prepared for analyses other than the PCS-2012 PA. Although the parameter names and values were the same in these earlier documents and resulted in no errors for the PCS-2012 PA, the metadata referred to different applications of the parameter, which would be misleading to someone not familiar with the PCS-2012 PA. The Agency's findings for each new parameter are presented in Table 2. Several of the more common transparency concerns are summarized below:

- The parameter values to be entered into the PAPDB are commonly identified in the PDE forms by attaching one or more pages from source documents containing tables of parameter values and indicating on those tables which parameter values are relevant to the specific PDE form. The Agency has noted a transparency concern regarding this practice, as exemplified by PDE form PDE 2012a. The parameter values to be entered are currently indicated by arrows in the margins pointing at the row in the table containing the relevant parameter and value, whereas in the past, those rows containing parameters and values not relevant to the particular PDE were lined out and those that were relevant were circled. The current process can be made more transparent by explaining the significance of the arrows in the PDE form and lining out the non-relevant parameters, or by reverting to the previous practice of circling the relevant parameters and lining out the rest.

- The sources of the parameter values to be entered into the PAPDB are sometimes identified on tables attached to the PDE forms that were taken from source documents. This practice can be misleading, because although the source of the attached table can be inferred to be the source document identified on the PDE form, the "sources" of the

parameter values identified on the table are second tier documents only identified in the reference list of the document from which the table was taken, and are not given on the PDE form or its attachments. An example is again PDE form PDE 2012a, where the "source" of the parameter value is identified on the attached table as, for example, "Patterson Page 13" or "This memo." A clarifying note should be added that "This memo" does not refer to this PDE form or its attachments, but to Camphouse (2012), and that the citation to "Patterson" can be found in the reference list for the primary source document Camphouse (2012), which is identified on the PDE form.

- Two parameters, PCS_T3:PORE_DIS and PCS_T3:SAT_RBRN, are assigned cumulative distributions and have documented mean values in the PAPDB. However, PDE form PDE 2012b for these properties does not show mean values for these distributions and therefore could not have been the source for them. Data entry information for the T1 and T2 versions of these parameters (for example, PDE form PDE 2006c for PCS_T1:PORE_DIS) was documented on an earlier version of the PDE form that prompts entry of mean values and does document those values.

- Those parameters on Table 1 referenced to a First Use analysis of AP-129 are documented in PDE forms prepared in 2006 for SNL's Redesigned Panel Closure System Analysis. Because that analysis used the same material names PCS_T1 and PCS_T2, and the same parameter types and values as in the current PCS-2012 PA, the PAPDB entries for AP-129 were used without modification for PCS-2012. A transparency concern arose in the metadata, however, because the parameter descriptions have changed since the AP-129 analysis. In the PCS-2012 analysis, time period T1 extends from zero to 100 years, while in the AP-129 analysis, time period T1 is described in the PDE form as extending from zero to 200 years. Also, in the PCS-2012 analysis, time period T2 extends from 100 to 200 years, while in the AP-129 analysis, time period T2 is described in the PDE form as extending from 200 to 10,000 years. Examples are provided in PDE forms PDE 2006a and PDE 2006b for parameters PCS_T1:COMP_RCK and PCS_T2:COMP_RCK. To avoid confusion, new PDE forms with new parameter descriptions should have been developed for the PCS-2012 analysis. SNL's practice of explaining these differences in parameter descriptions in the source documents is not adequate, because the database and the source documents should be consistent.

- The DRZ_1 parameters on Table 1 referenced to a First Use analysis of CCA and TBM are documented in PDE forms prepared in 1996 for the CCA and in 2002 for the TBM. Because those analyses used the same material name DRZ_1 and the same parameter types and values as in the current PCS-2012 PA, the PAPDB entries for those parameters were used without modification for PCS-2012. A transparency concern arose in the metadata, because the parameter descriptions have changed since the CCA and TBM analyses. In the CCA and TBM, material DRZ_1 is described as "Disturbed Rock Zone: 0 to 1000 yrs" (for example, see PDE Form SNL 1997 for DRZ-1:RELP_MOD, dating to the 1996 CCA database). In the PCS-2012 PA, material DRZ_1 is applied to the properties of the DRZ above and below the PCS during the time period from zero to 200 years. The current definition is not the same as that originally adopted for the CCA and TBM. To avoid confusion, new PDE forms with new parameter descriptions should

have been developed for the PCS-2012 analysis for parameter descriptions dating back to the CCA and TBM.

4.3 REVIEW OF SUPPORTING DOCUMENTATION

Table 2 summarizes an assessment of the adequacy of supporting documentation for justifying the parameter changes. Table 2 provides the parameter name (material and property names), a description of the parameter type, ERMS numbers for the PDE form and principal supporting document(s), the effective date of the change, and comments that summarize the basis for the change.[1]

As previously mentioned, several concerns were raised by the Agency during its evaluation of the parameter values proposed by DOE for the PCS-2012 PA, and a final agreement was reached in June 2012. This agreement was based upon the modeling approach and parameter values described in a May 2012 memo by Camphouse et al. (2012a) and upon a proposal by DOE to lower the minimum permeability value of the ROM salt during time period T1 from -18.7 $\log(m^2)$, as proposed by Camphouse et al. (2012a), to -21.0 $\log(m^2)$. The development of permeability values for the time-dependent consolidation of the crushed salt and the surrounding DRZ is further described below. As also described below, the Agency approved keeping several parameter values the same as in the baseline PABC-2009 PA to facilitate a direct comparison of results. However, when approving the PCS-2012 modeling approach and parameter values, the Agency noted that the PCS-2012 PA was designed and parameterized to facilitate a comparison of results, and that the appropriateness of continuing to use the same modeling approach and parameter values would be re-evaluated for the 2014 recertification PA.

[1] Parameter Data Entry (PDE) forms are identified by ERMS number in this report and are not included in the reference list.

Table 1. Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Distribution Type	Parameter Value Used in PCS-2012 PA					First Use	Parameter Units	Used in Code
			Mean	Other	Minimum	Maximum	Default			
PCS_T1	CAP_MOD	Constant	1	- -	1	1	1	PC3R	None	BRAGFLO
PCS_T2	CAP_MOD	Constant	1	- -	1	1	1	PC3R	None	BRAGFLO
PCS_T3	CAP_MOD	Constant	1	- -	1	1	1	AP 161	None	BRAGFLO
PCS_T1	COMP_RCK	Constant	8.0E-11	- -	8.0E-11	8.0E-11	8.0E-11	AP 129	Pa^{-1}	BRAGFLO
PCS_T2	COMP_RCK	Constant	8.0E-11	- -	8.0E-11	8.0E-11	8.0E-11	AP 129	Pa^{-1}	BRAGFLO
PCS_T3	COMP_RCK	Constant	8.0E-11	- -	8.0E-11	8.0E-11	8.0E-11	AP 161	Pa^{-1}	BRAGFLO
PCS_T1	KPT	Constant	0.0	- -	0.0	0.0	0.0	AP 129	None	BRAGFLO
PCS_T2	KPT	Constant	0.0	- -	0.0	0.0	0.0	AP 129	None	BRAGFLO
PCS_T3	KPT	Constant	0.0	- -	0.0	0.0	0.0	AP 161	None	BRAGFLO
PCS_T1	PC-MAX	Constant	1E08	- -	1E08	1E08	1E08	AP 129	Pa	BRAGFLO
PCS_T2	PC-MAX	Constant	1E08	- -	1E08	1E08	1E08	AP 129	Pa	BRAGFLO
PCS_T3	PC-MAX	Constant	1E08	- -	1E08	1E08	1E08	AP 161	Pa	BRAGFLO
PCS_T1	PCT_A	Constant	0.0	- -	0.0	0.0	0.0	PC3R	Pa	BRAGFLO
PCS_T2	PCT_A	Constant	0.0	- -	0.0	- -	0.0	PC3R	Pa	BRAGFLO
PCS_T3	PCT_A	Constant	0.0	- -	0.0	- -	0.0	AP 161	Pa	BRAGFLO
PCS_T1	PCT_EXP	Constant	0.0	- -	0.0	- -	0.0	PC3R	None	BRAGFLO
PCS_T2	PCT_EXP	Constant	0.0	- -	0.0	- -	0.0	PC3R	None	BRAGFLO
PCS_T3	PCT_EXP	Constant	0.0	- -	0.0	- -	0.0	AP 161	None	BRAGFLO
PCS_T1	PO_MIN	Constant	1.01325 E05	- -	1.01325 E05	1.01325 E05	1.01325 E05	AP 129	Pa	BRAGFLO
PCS_T2	PO_MIN	Constant	1.01325 E05	- -	1.01325 E05	1.01325 E05	1.01325 E05	AP 129	Pa	BRAGFLO
PCS_T3	PO_MIN	Constant	1.01325 E05	- -	1.01325 E05	1.01325 E05	1.01325 E05	AP 161	Pa	BRAGFLO
PCS_T1	PORE_DIS	Cumulative	2.52	Median 0.94	0.11	8.1	0.94	AP 129	None	PRELHS BRAGFLO
PCS_T2	PORE_DIS	Cumulative	2.52	Median 0.94	0.11	8.1	0.94	AP 129	None	BRAGFLO
PCS_T3	PORE_DIS	Cumulative	2.52	Median 0.94	0.11	8.1	0.94	AP 161	None	BRAGFLO
PCS_T1	POROSITY	Uniform	0.1265	- -	0.066	0.187	0.1265	AP 161	None	PRELHS BRAGFLO
PCS_T2	POROSITY	Uniform	0.05	- -	0.025	0.075	0.05	AP 161	None	PRELHS BRAGFLO
PCS_T3	POROSITY	Uniform	0.0265	- -	0.001	0.0519	0.0265	AP 161	None	PRELHS BRAGFLO
PCS_T1	PRMX_LOG	Uniform	-16.5	- -	-21	-12	-16.5	AP 161	$\log(m^2)$	PRELHS BRAGFLO
PCS_T1	PRMY_LOG	Uniform	-16.5	- -	-21	-12	-16.5	AP 161	$\log(m^2)$	BRAGFLO
PCS_T1	PRMZ_LOG	Uniform	-16.5	- -	-21	-12	-16.5	AP 161	$\log(m^2)$	BRAGFLO

Table 1. Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Distribution Type	Parameter Value Used in PCS-2012 PA					First Use	Parameter Units	Used in Code
			Mean	Other	Minimum	Maximum	Default			
PCS_T2	POR2PERM	Normal	0.0	Std Dev 0.86	-1.72	+1.72	0.0	AP 161	None	PRELHS BRAGFLO
PCS_T2	PRMX_LOG	Constant	-18.6	- -	-18.6	-18.6	-18.6	AP 161	$\log(m^2)$	BRAGFLO
PCS_T2	PRMY_LOG	Constant	-18.6	- -	-18.6	-18.6	-18.6	AP 161	$\log(m^2)$	BRAGFLO
PCS_T2	PRMZ_LOG	Constant	-18.6	- -	-18.6	-18.6	-18.6	AP 161	$\log(m^2)$	BRAGFLO
PCS_T3	POR2PERM	Normal	0.0	Std Dev 0.86	-1.72	+1.72	0.0	AP 161	None	BRAGFLO
PCS_T3	PRMX_LOG	Constant	-19.1	- -	-19.1	-19.1	-19.1	AP 161	$\log(m^2)$	BRAGFLO
PCS_T3	PRMY_LOG	Constant	-19.1	- -	-19.1	-19.1	-19.1	AP 161	$\log(m^2)$	BRAGFLO
PCS_T3	PRMZ_LOG	Constant	-19.1	- -	-19.1	-19.1	-19.1	AP 161	$\log(m^2)$	BRAGFLO
PCS_T1	RELP_MOD	Constant	4	- -	4	4	4	AP 129	None	BRAGFLO
PCS_T2	RELP_MOD	Constant	4	- -	4	4	4	AP 129	None	BRAGFLO
PCS_T3	RELP_MOD	Constant	4	- -	4	4	4	AP 129	None	BRAGFLO
PCS_T1	SAT_IBRN	Uniform	0.1	- -	0.04	0.16	0.1	AP 161	None	PRELHS BRAGFLO
PCS_T1	SAT_RBRN	Cumulative	0.25	Median 0.2	0.0	0.6	0.2	AP 129	None	PRELHS BRAGFLO
PCS_T2	SAT_RBRN	Cumulative	0.25	Median 0.2	0.0	0.6	0.2	AP 129	None	BRAGFLO
PCS_T3	SAT_RBRN	Cumulative	0.25	Median 0.2	0.0	0.6	0.2	AP 161	None	BRAGFLO
PCS_T1	SAT_RGAS	Uniform	0.2	- -	0.0	0.4	0.2	AP 129	None	PRELHS BRAGFLO
PCS_T2	SAT_RGAS	Uniform	0.2	- -	0.0	0.4	0.2	AP 129	None	BRAGFLO
PCS_T3	SAT_RGAS	Uniform	0.2	- -	0.0	0.4	0.2	AP 161	None	BRAGFLO
DRZ_1	CAP_MOD	Constant	1	- -	1	1	1	CCA	None	BRAGFLO
DRZ_PCS	CAP_MOD	Constant	1	- -	1	1	1	TBM	None	BRAGFLO
DRZ_1	COMP_RCK	Constant	7.41E-10	- -	7.41E-10	7.41E-10	7.41E-10	CCA	Pa^{-1}	BRAGFLO
DRZ_PCS	COMP_RCK	Constant	7.41E-10	- -	7.41E-10	7.41E-10	7.41E-10	TBM	Pa^{-1}	BRAGFLO
DRZ_1	KPT	Constant	0.0	- -	0.0	0.0	0.0	CCA	None	BRAGFLO
DRZ_PCS	KPT	Constant	0.0	- -	0.0	0.0	0.0	TBM	None	BRAGFLO
DRZ_1	PC_MAX	Constant	1E08	- -	1E08	1E08	1E08	CCA	Pa	BRAGFLO
DRZ_PCS	PC_MAX	Constant	1E08	- -	1E08	1E08	1E08	TBM	Pa	BRAGFLO
DRZ_1	PCT_A	Constant	0.0	- -	0.0	0.0	0.0	CCA	Pa	BRAGFLO
DRZ_PCS	PCT_A	Constant	0.0	- -	0.0	0.0	0.0	TBM	Pa	BRAGFLO
DRZ_1	PCT_EXP	Constant	0.0	- -	0.0	0.0	0.0	CCA	None	BRAGFLO
DRZ_PCS	PCT_EXP	Constant	0.0	- -	0.0	0.0	0.0	TBM	None	BRAGFLO
DRZ_1	PRMX_LOG	Uniform	-16.0	- -	-19.4	-12.5	-16.0	CCA	$\log(m^2)$	PRELHS BRAGFLO

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Material Name	Property Name	Distribution Type	Parameter Value Used in PCS-2012 PA					First Use	Parameter Units	Used in Code
			Mean	Other	Minimum	Maximum	Default			
DRZ_1	PRMY_LOG	Uniform	-16.0	- -	-19.4	-12.5	-16.0	CCA	$\log(m^2)$	BRAGFLO
DRZ_1	PRMZ_LOG	Uniform	-16.0	- -	-19.4	-12.5	-16.0	CCA	$\log(m^2)$	BRAGFLO
DRZ_PCS	PRMX_LOG	Triangular	-18.8160	Mode -18.7496	-20.699	-17.0	-18.7496	TBM	$\log(m^2)$	PRELHS BRAGFLO
DRZ_PCS	PRMY_LOG	Triangular	-18.8160	Mode -18.7496	-20.699	-17.0	-18.7496	TBM	$\log(m^2)$	BRAGFLO
DRZ_PCS	PRMZ_LOG	Triangular	-18.8160	Mode -18.7496	-20.699	-17.0	-18.7496	TBM	$\log(m^2)$	BRAGFLO
DRZ_1	PO_MIN	Constant	1.01325 E05	- -	1.01325 E05	1.01325 E05	1.01325 E05	CCA	Pa	BRAGFLO
DRZ_PCS	PO_MIN	Constant	1.01325 E05	- -	1.01325 E05	1.01325 E05	1.01325 E05	TBM	Pa	BRAGFLO
DRZ_1	PORE_DIS	Constant	0.7	- -	0.7	0.7	0.7	CCA	None	BRAGFLO
DRZ_PCS	PORE_DIS	Constant	0.7	- -	0.7	0.7	0.7	TBM	None	BRAGFLO
DRZ_1	POROSITY	Cumulative	0.0211	Median 0.0129	0.0039	0.0548	0.0129	AP-132	None	PRELHS BRAGFLO
DRZ_PCS	POROSITY	Cumulative	0.0211	Median 0.0129	0.0039	0.0548	0.0129	AP-132	None	BRAGFLO
DRZ_1	RELP_MOD	Delta	4	Median 4	1	4	0	CCA	None	BRAGFLO
DRZ_PCS	RELP_MOD	Delta	4	Median 4	1	4	0	TBM	None	BRAGFLO
DRZ_1	SAT_RBRN	Constant	0.0	- -	0.0	0.0	0.0	CCA	None	BRAGFLO
DRZ_PCS	SAT_RBRN	Constant	0.0	- -	0.0	0.0	0.0	TBM	None	BRAGFLO
DRZ_1	SAT_RGAS	Constant	0.0	- -	0.0	0.0	0.0	CCA	None	BRAGFLO
DRZ_PCS	SAT_RGAS	Constant	0.0	- -	0.0	0.0	0.0	TBM	None	BRAGFLO

Notes to Table 1

First Use Analyses:

- CCA: Compliance Certification Analysis, 1996
- TBM: Technical Baseline Migration Analysis, 2002
- AP-129: Redesigned Panel Closure System Analysis, 2006
- AP-132: 2009 Compliance Recertification Analysis, 2007
- PC3R: Panel Closure Redesign and Repository Reconfiguration Analysis (AP-151), 2010
- AP-161: PCS-2012 PA Analysis, 2012

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
PCS_T1	CAP_MOD	Capillary pressure model number for the ROM Salt during time period T1	544680	554623	12/20/2010	ERMS 554623 states that capillary pressure Model 1 was selected for the ROM salt during time period T1 to agree with the model selected for the DRZ above and below the ROM salt. ERMS 557721 (not cited in the PAPDB as a source for this parameter) adds that Model 1 is also used to avoid numerical difficulties in BRAGFLO. Model 1 is typically used when the threshold capillary pressure is set to zero, which deactivates the capillary pressure model. However, the parameter values accepted by EPA in ERMS 557396 included a value of 2 for the capillary pressure model, which would have activated that model. The EPA subsequently performed an analysis, which showed that an activated capillary pressure model made no significant difference in repository performance. See text discussion of two-phase flow parameters for additional information.
PCS_T2	CAP_MOD	Capillary pressure model number for the ROM Salt during time period T2	554681	554623	12/20/2010	The comment for PCS_T1:CAP_MOD also applies to PCS_T2:CAP_MOD
PCS_T3	CAP_MOD	Capillary pressure model number for the ROM Salt during time period T3	557951	557721	7/17/2012	ERMS 557721 states that capillary pressure Model 1 was selected for the ROM salt during time period T3 to agree with the model selected for the DRZ around the ROM salt and that Model 1 is also used to avoid numerical difficulties in BRAGFLO. Model 1 is typically used when the threshold capillary pressure is set to zero, which deactivates the capillary pressure model. However, as stated above, the parameter values accepted by EPA in ERMS 557396 included a value of 2 for the capillary pressure model, which would have activated that model. The EPA subsequently performed an analysis, which showed that an activated capillary pressure model for the ROM salt and surrounding DRZ made no significant difference in repository performance. See text discussion of two-phase flow parameters for additional information.
PCS_T1	COMP_RCK	Bulk compressibility of the ROM Salt during time period T1	543322	542894	3/27/2006	ERMS 542894 states that the value of this parameter was used for the crushed salt materials in the original shaft seal, that it is considered a reasonable estimate for reconsolidated salt, and that "the initial compressibility of the salt will be higher since it will be emplaced without compaction." EPA has reviewed this parameter value and concurs that it is appropriate for reconsolidated salt. EPA believes that the use of this parameter for time periods T1 and T2, when the ROM salt likely has not fully reconsolidated, is acceptable because the ROM salt may be compacted upon emplacement.
PCS_T2	COMP_RCK	Bulk compressibility of the ROM Salt during time period T2	543322	542894	3/27/2006	The comment for PCS_T1:COMP_RCK also applies to PCS_T2:COMP_RCK.
PCS_T3	COMP_RCK	Bulk compressibility of the ROM Salt during time period T3	557951	557721	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that it was used for the crushed salt materials in the original shaft seal, but provides no further justification or references. EPA has reviewed this parameter value and concurs that it is appropriate for the reconsolidated salt that would be present during time period T3.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
PCS_T1	KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the ROM Salt during time period T1	543323	542894	3/27/2006	ERMS 542894 states that all WIPP PA materials use the same value of 0.0 for KPT and that this parameter is specific to the capillary pressure model used in WIPP PA. This parameter is a flag for using constant or varying permeability in the threshold pressure calculation and was originally set to 0.0, because varying permeability was not used in the CCA calculations. EPA understands that when KPT is set to zero, the threshold capillary pressure is recalculated for each new material and would therefore be appropriately recalculated for the new ROM salt materials during T1, T2, and T3. EPA therefore accepts a value of 0.0 for KPT. See text discussion of two-phase flow parameters for additional information.
PCS_T2	KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the ROM Salt during time period T2	543338	542894	3/27/2006	The comment for PCS_T1:KPT also applies to PCS_T2:KPT.
PCS_T3	KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that all WIPP PA materials use the same values for KPT, but provides no further justification as to why this is appropriate for the ROM salt, which is a new material in WIPP PA. Despite the weakness in DOE's justification, EPA understands that when KPT is set to zero, the threshold capillary pressure is recalculated for each new material, and would therefore be appropriately recalculated for the new ROM salt materials during T3. EPA therefore accepts a value of 0.0 for KPT. See text discussion of two-phase flow parameters for additional information.
PCS_T1	PC_MAX	Maximum allowable capillary pressure for the ROM Salt during time period T1	543324	542946 542894	3/27/2006	ERMS 542946 states that the values of PC_MAX and PO_MIN were reversed in ERMS 542894 and corrects that error. ERMS 542894 states that all WIPP PA materials use the same value for PC_MAX, but provides no justification for that value, nor does it refer to documents that do provide justification. However, EPA has reviewed the value of this parameter and found it to be reasonable. EPA also notes that capillary pressure can become very large at low brine saturations, and it is appropriate to limit the maximum value of this parameter to avoid numerical problems with BRAGFLO. EPA therefore concludes that the current value of this parameter is appropriate for PCS-2012. See text discussion of two-phase flow parameters for additional information.
PCS_T2	PC_MAX	Maximum allowable capillary pressure for the ROM Salt during time period T2	543339	542946 542894	3/27/2006	The comment for PCS_T1:PC_MAX also applies to PCS_T2:PC_MAX.
PCS_T3	PC-MAX	Maximum allowable capillary pressure for the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that all WIPP PA materials use the same value for PC_MAX, but provides no justification for that value, nor does it refer to documents that do provide justification. In addition to the above comments for PC_MAX during T1 and T2, EPA notes that this parameter is not used when CAP_MOD is set to 1.0, as it was in PCS-2012, and is therefore acceptable. However, EPA expected CAP_MOD to be set to 2.0 for the ROM salt. See text discussion of two-phase flow parameters for additional information.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
PCS_T1	PCT_A	Threshold capillary pressure linear parameter for the ROM Salt during time period T1	554680	554623	12/20/2010	ERMS 554623 states that PCT_A was set to 0.0 for the PCS during time period T1 to agree with the model selected for the DRZ around the ROM salt. ERMS 557721 (not cited in the PAPDB as a source for this parameter) adds that PCT_A was also set to 0.0 to avoid numerical difficulties in BRAGFLO. Setting PCT_A to zero sets the threshold capillary pressure to zero and deactivates the capillary pressure model. The parameter values accepted by EPA in ERMS 557396 included a value of 0.56 for PCT_A, which would have activated the capillary pressure model. The EPA subsequently performed an analysis which showed that an activated capillary pressure model made no significant difference in repository performance. See text discussion of two-phase flow parameters for additional information.
PCS_T2	PCT_A	Threshold capillary pressure linear parameter for the ROM Salt during time period T2	554681	554623	12/20/2010	The comment for PCS_T1:PCT_A also applies to PCS_T2:PCT_A.
PCS_T3	PCT_A	Threshold capillary pressure linear parameter for the ROM Salt during time period T3	557951	557721	7/17/2012	ERMS 557721 states that the value of PCS_T3:PCT_A was set to 0.0 in order to have consistency between the ROM salt and the surrounding DRZ, that a value of 0.0 was also used for the crushed salt component of the original shaft seal model, and that a value of 0.0 avoids numerical difficulties in BRAGFLO. EPA notes that setting PCT_A to zero is consistent with the selection of capillary pressure Model 1 and with capillary pressure modeling practice in the baseline PABC-2009. However, as stated above, the parameter values accepted by EPA in ERMS 557396 included a value of 0.56 for PCT_A, which would have activated the capillary pressure model. The EPA subsequently performed an analysis which showed that an activated capillary pressure model made no significant difference in repository performance. See text discussion of two-phase flow parameters for additional information.
PCS_T1	PCT_EXP	Threshold capillary pressure exponential parameter for the ROM Salt during time period T1	554680	554623 557721	12/20/2010	ERMS 554623 states that PCT_EXP was set to 0.0 for the ROM salt during time period T1 to agree with the model selected for the DRZ around the ROM salt, which deactivates capillary pressure. PCT_EXP is typically set to zero when PCT_A is set to zero. The parameter values accepted by EPA in ERMS 557396 included a value of 0.56 for PCT_A and a value of -0.346 for PCT_EXP, which would have activated the capillary pressure model. The EPA subsequently performed an analysis which showed that an activated capillary pressure model made no significant difference in repository performance. See text discussion of two-phase flow parameters for additional information.
PCS_T2	PCT_EXP	Threshold capillary pressure exponential parameter for the ROM Salt during time period T2	554681	554623 557721	12/20/2010	The comment for PCS_T1:PCT_EXP also applies to PCS_T2:PCT_EXP.
PCS_T3	PCT_EXP	Threshold capillary pressure exponential parameter for the ROM Salt during time period T3	557951	557721	7/17/2012	ERMS 557721 states that the value of PCS_T3:PCT_EXP was set to 0.0 in order to have consistency between the ROM salt and the surrounding DRZ, and that a value of 0.0 was also used for the crushed salt component of the original shaft seal model. EPA notes that setting PCT_EXP to zero is consistent with the selection of capillary pressure Model 1 and with capillary pressure modeling practice in the baseline PABC-2009. However, the parameter values accepted by EPA in ERMS 557396 included

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Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
						values for PCT_A and PCT_EXP that would have activated the capillary pressure model. The EPA subsequently performed an analysis which showed that an activated capillary pressure model made no significant difference in repository performance. See text discussion of two-phase flow parameters for additional information.
PCS_T1	PO_MIN	Minimum allowable brine pressure for the ROM Salt during time period T1	543327	542894 542946	3/27/2006	ERMS 542946 states that the values of PC_MAX and PO_MIN were reversed in ERMS 542894 and corrects that error. ERMS 542894 states that all WIPP PA materials use the same value for PO_MIN, but provides no justification for that value, nor does it refer to documents that do provide justification. EPA notes that this parameter is only used for capillary pressure Model 3, which was not used in PCS-2012 or in PABC-2009. The value of this parameter, therefore, has no impact on the PA results.
PCS_T2	PO_MIN	Minimum allowable brine pressure for the ROM Salt during time period T2	543342	542894 542946	3/27/2006	The comment for PCS_T1:PO_MIN also applies to PCS_T2:PO_MIN.
PCS_T3	PO_MIN	Minimum allowable brine pressure for the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that all WIPP PA materials use the same value for PO_MIN, but provides no justification for that value, nor does it refer to documents that do provide justification. EPA notes that this parameter is only used when CAP_MOD is set to 3.0. Because only capillary pressure Models 1 or 2 have been contemplated for PCS-2012, this parameter was not used.
PCS_T1	PORE_DIS	Brooks-Corey pore distribution parameter for the ROM Salt during time period T1	543328	542894	3/27/2006	ERMS 542894 states that all WIPP salt-related parameters for the original shaft seal model use relative permeability Model 4, a modified Brooks-Corey model, which requires this property. EPA has reviewed the range and distribution for this parameter and found them to be reasonable.
PCS_T2	PORE_DIS	Brooks-Corey pore distribution parameter for the ROM Salt during time period T2	543343	542894	3/27/2006	The comment for PCS_T1: PORE_DIS also applies to PCS_T2: PORE_DIS.
PCS_T3	PORE_DIS	Brooks-Corey pore distribution parameter for the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that the crushed salt materials for the original shaft seal model use the same values and distributions for PORE_DIS as used in PCS-2012 and in PABC-2009. EPA has reviewed the range and distribution for this parameter and found them to be reasonable.
PCS_T1	POROSITY	Porosity of the ROM Salt during time period T1	557949	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that, depending on the method of emplacement, the initial porosity of the ROM salt will vary between 20% and 35%. The range of PCS porosity for T1 was determined at the T1 midpoint time of 50 years, when the ROM salt porosity predicted by JAS3D modeling is a low of 6.6% for an initial porosity of 20% and a high of 18.7% for an initial porosity of 35%. EPA acknowledges that considerable uncertainty is associated with the rate of ROM salt consolidation in a panel closure and accepts this range and the underlying uniform distribution as providing adequate estimates of ROM salt porosities for PCS-2012 during time period T1. Also see text discussion of ROM salt porosity and permeability.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
PCS_T2	POROSITY	Porosity of the ROM Salt during time period T2	557950	557721 557396	7/23/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that the range of ROM salt porosity values for T2 is based on JAS3D modeling results, on consideration of 0.05 as the expected value, and on maintaining a range that is similar to the range for intact halite. EPA acknowledges that considerable uncertainty is associated with the rate of ROM salt consolidation in a panel closure and accepts this range and the underlying uniform distribution as providing adequate estimates of ROM salt porosities for PCS-2012 during time period T2. Also see text discussion of ROM salt porosity and permeability.
PCS_T3	POROSITY	Porosity of the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that the ROM salt T3 porosity is assumed to be equal to the porosity for intact halite and is therefore the same as the porosity range for intact halite in WIPP PA. EPA agrees that the porosity of the ROM salt will, over time, approach that of intact halite and agrees that, based on modeling and analog studies, the ROM salt T3 porosity range and underlying uniform distribution provide adequate estimates appropriate for the PCS-2012 PA. Also see text discussion of ROM salt porosity and permeability.
PCS_T1	PRMX_LOG	Permeability of the ROM Salt in the X-direction during time period T1	557949	557721	7/17/2012	The cited source ERMS 557721 refers to ERMS 557396 as the source of the original range, -18.7 to -12 log(m^2), for this parameter. ERMS 557396 states that this permeability range corresponds to laboratory data for the porosity range of 0.066 to 0.187 assigned to the parameter PCS_T1:POROSITY. ERMS 557721 refers to a 2012 DOE response to EPA questions (ERMS 557865) as the source of a revised lower value of the sampled range for this parameter, -21 log(m^2). However, this revised lower value was based on laboratory data that was reviewed by DOE in ERMS 557396 and rejected when developing the original range. See text section on ROM salt porosity and permeability for additional discussion of this inconsistency. EPA accepts the assumption that the ROM salt material is isotropic, with the same permeabilities in the X-, Y-, and Z-directions.
PCS_T1	PRMY_LOG	Permeability of the ROM Salt in the Y-direction during time period T1	557949	557721	7/17/2012	The comment for PCS_T1:PRMX_LOG also applies to PCS_T1:PRMY_LOG.
PCS_T1	PRMZ_LOG	Permeability of the ROM Salt in the Z-direction during time period T1	557949	557721	7/17/2012	The comment for PCS_T1:PRMX_LOG also applies to PCS_T1:PRMZ_LOG.
PCS_T2	POR2PERM	Distribution used to calculate permeability from porosity values during time period T2	557950	557721 537396	7/23/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 adequately describes the sampling process and the derivation of the ROM salt permeability as a function of porosity, but unfortunately does not mention the property POR2PERM. POR2PERM is, in fact, the same as the parameter alpha in ERMS 557396 Equation 2. Except for this lapse in transparency, EPA believes that POR2PERM (or alpha) was adequately described and justified, and provides an appropriate mechanism for incorporating uncertainty into a correlation of permeability and porosity. See the text discussion of PCS porosity and permeability for additional information.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
PCS_T2	PRMX_LOG	Permeability of the ROM Salt in the X-direction during time period T2	557950	557721	7/23/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. The constant PCS_T2: PRMX_LOG default value is identified as the average of the minimum and maximum values described for T2 in ERMS 557396, Table 5. The default value is retrieved from the database and then set equal to the ROM salt permeability calculated for time period T2 based on the T2 porosity and POR2PERM value. This same permeability value is assigned to the X-, Y-, and Z-directions. The Agency accepts this process for determining permeability values and considers the assumption of isotropic permeability to be reasonable. See the text discussion of ROM salt porosity and permeability for additional information.
PCS_T2	PRMY_LOG	Permeability of the ROM Salt in the Y-direction during time period T2	557950	557721	7/23/2012	The comment for PCS_T2: PRMX_LOG also applies to PCS_T2: PRMY_LOG.
PCS_T2	PRMZ_LOG	Permeability of the ROM Salt in the Z-direction during time period T2	557950	557721	7/23/2012	The comment for PCS_T2: PRMX_LOG also applies to PCS_T2: PRMZ_LOG.
PCS_T3	POR2PERM	Distribution used to calculate permeability from sampled porosity values during time period T3	557951	557721 557396	7/17/2012	The comment for PCS_T2:POR2PERM also applies to PCS_T3:POR2PERM.
PCS_T3	PRMX_LOG	Permeability of the ROM Salt in the X-direction during time period T3	557951	557721	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. The constant PCS_T3: PRMX_LOG default value is identified as the average of the minimum and maximum values described for T3 in ERMS 557396, Table 5. The default value is retrieved from the database and then set equal to the ROM salt permeability calculated for time period T3 based on the T3 porosity and POR2PERM value. This is the same process as used for calculating the PCS_T2: PRMX_LOG value. The same T3 permeability value is assigned to the X-, Y-, and Z-directions. The Agency accepts this process for determining permeability values and considers the assumption of isotropic permeability to be reasonable. See the text discussion of ROM salt porosity and permeability for additional information.
PCS_T3	PRMY_LOG	Permeability of the ROM Salt in the Y-direction during time period T3	557951	557721	7/17/2012	The comment for PCS_T3: PRMX_LOG also applies to PCS_T3: PRMY_LOG.
PCS_T3	PRMZ_LOG	Permeability of the ROM Salt in the Z-direction during time period T3	557951	557721	7/17/2012	The comment for PCS_T3: PRMX_LOG also applies to PCS_T3: PRMZ_LOG.
PCS_T1	RELP_MOD	Relative permeability model number for the ROM Salt during time period T1	543333	542894	3/27/2006	ERMS 542894 states that all WIPP salt-related parameters for the original shaft seal model use relative permeability Model 4, a modified Brooks-Corey model. EPA has reviewed this model and found it to be appropriate for the ROM salt .
PCS_T2	RELP_MOD	Relative permeability model number for the ROM Salt during time period T2	543348	542894	3/27/2006	The comment for PCS_T1:RELP_MOD also applies to PCS_T2:RELP_MOD.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
PCS_T3	RELP_MOD	Relative permeability model number for the ROM Salt during time period T2	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that the two-phase flow model for the ROM salt PCS uses the modified Brooks-Corey model, which corresponds to relative permeability Model 4. EPA believes that the choice of Model 4 for the ROM salt PCS is appropriate and consistent with the use of Model 4 in the baseline PABC-2009.
PCS_T1	SAT_IBRN	Initial brine saturation of the ROM Salt at the beginning of time period T1	557949	557721	7/17/2012	ERMS 557721 states that a range of initial brine saturations of the ROM salt was used in the PCS-2012 PA to account for uncertainty in the method to be used in emplacing the ROM salt. The low end of the range is based on loose emplacement with no added moisture. The high end of the range assumes the salt is compacted to 20% porosity with 1% by weight added moisture. The density of brine was assumed to be 1220 kg/m^3 and the density of halite was assumed to be 2140 kg/m^3. The Agency accepts this range; however, see text discussion of two-phase flow parameters.
PCS_T1	SAT_RBRN	Residual brine saturation of the ROM Salt during time period T1	543334	542894	3/27/2006	ERMS 542894 states that all WIPP salt-related parameters for the original shaft seal model use the same probability distribution and values to model residual brine saturation, and that this distribution is also appropriate for the ROM salt materials, but provides no further justification or references. Because this distribution was also used in PABC-2009, EPA considers it appropriate to retain it for PCS-2012 to simplify comparison of results. However, see text discussion of two-phase flow parameters.
PCS_T2	SAT_RBRN	Residual brine saturation of the ROM Salt during time period T2	543349	542894	3/27/2006	The comment for PCS_T1:SAT_RBRN also applies to PCS_T2:SAT_RBRN.
PCS_T3	SAT_RBRN	Residual brine saturation of the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that the residual brine saturation for the ROM salt uses the same values and distribution as for the crushed salt component of the shaft seals, and were defined for the CCA based on a literature review and on professional judgment. A reference is provided to the original CCA justification documentation. EPA accepts these values and distribution as appropriate for comparative purposes in PCS-2012. However, see text discussion of two-phase parameters for additional information.
PCS_T1	SAT_RGAS	Residual gas saturation of the ROM Salt during time period T1	543335	542894	3/27/2006	ERMS 542894 states that all WIPP salt-related parameters for the original shaft seal model use the same probability distribution and values to model residual gas saturation, and that this distribution is also appropriate for the ROM salt materials, but provides no further justification or references. Because this distribution was also used in PABC-2009, EPA considers it appropriate to retain it for PCS-2012 to simplify comparison of results. However, see text discussion of two-phase flow parameters.
PCS_T2	SAT_RGAS	Residual gas saturation of the ROM Salt during time period T2	543350	542894	3/27/2006	The comment for PCS_T1:SAT_RGAS also applies to PCS_T2:SAT_RGAS.
PCS_T3	SAT_RGAS	Residual gas saturation of the ROM Salt during time period T3	557951	557721 557396	7/17/2012	ERMS 557721 refers to ERMS 557396 as the source of this parameter. ERMS 557396 states that the residual gas saturation for the ROM salt uses the same values and distribution as for the crushed salt component of the shaft seals, and were defined for the CCA based on a literature review and on professional judgment. A reference is provided to the original CCA justification documentation. EPA accepts these values and distribution appropriate for comparative purposes in PCS-2012. However, see text discussion of two-phase parameters for additional information.

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Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
DRZ_1	CAP_MOD	Capillary pressure model number for the PCS DRZ during time periods T1 and T2	545696	545496	3/01/2007	EPA found no mention of parameter DRZ_1:CAP_MOD in the cited source document ERMS 545496. Despite this lack of traceability, EPA concludes that the choice of Model 1 for the capillary pressure model is appropriate, because it is consistent with SNL practice of selecting Model 1 when the threshold capillary pressure is set to zero. See text discussion of two-phase flow parameters.
DRZ_PCS	CAP_MOD	Capillary pressure model number for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. Despite the redefinition of the time frame for this material to 0 to 200 years in PCS-2012, EPA accepts the choice of Model 1 for the capillary pressure model as appropriate, because it is consistent with SNL's practice of selecting Model 1 when the threshold capillary pressure is set to zero. See text discussion of two-phase flow parameters.
DRZ_1	COMP_RCK	Bulk compressibility of the PCS DRZ during time periods T1 and T2	232871	232288	2/12/1996	ERMS 232288 identifies the value of this parameter that was used in PCS-2012 and in PABC-2009 as the bulk compressibility of the DRZ around a waste panel for times greater than zero. Although the conceptual model of the DRZ around a waste panel is described and this compressibility value is asserted to be consistent with the conceptual model, no specific technical justification of this parameter value is presented, either for its original application to the DRZ around a waste panel or to its current application to the DRZ around a ROM salt panel closure. However, EPA accepts this compressibility value to minimize differences between PCS-2012 and the baseline PABC-2009, and simplify comparison of results.
DRZ_PCS	COMP_RCK	Bulk compressibility of the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. Despite the redefinition of the time frame for this material in PCS-2012, EPA has reviewed and accepts the assigned value as representative of the bulk compressibility of nearly intact halite.
DRZ_1	KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the PCS DRZ during time periods T1 and T2	232870	235271	4/09/1996	ERMS 235271 describes this parameter as a flag for using either constant or varying permeability in the threshold pressure calculation, and states that the value should be set to 0.0 because varying permeability will not be used in the CCA calculations. EPA notes that at the time this justification was prepared, material DRZ_1 was defined as representing the waste panel DRZ from time zero to 10,000 years. However, EPA accepts setting KPT to zero for PCS-2012, because it is understood that the threshold capillary pressure is recalculated by BRAGFLO for each new material, and would therefore provide a threshold pressure relevant to the permeability of material DRZ_1 for time periods T1 and T2. See text discussion of two-phase flow parameters for additional information.
DRZ_PCS	KPT	Flag for selecting the permeability used in calculating threshold capillary pressure for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. Despite the redefinition of the time frame for this material in PCS-2012, EPA accepts setting KPT to zero for PCS-2012, because it is understood that the threshold capillary pressure is

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Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
						recalculated by BRAGFLO for each new material, and would therefore provide a threshold pressure relevant to the permeability of material DRZ_PCS for time period T3. See text discussion of two-phase flow parameters for additional information.
DRZ_1	PC_MAX	Maximum allowable capillary pressure for the PCS DRZ during time periods T1 and T2	232899	238568	2/05/1996	The cited source ERMS 238568 identifies this parameter as one of many "legacy parameters" and states that there are numerous sources for these parameters, but that the majority of parameter values can be considered as the choice of the PA analyst. A specific source for this parameter was not provided. Because PC_MAX represents a specific cutoff pressure in capillary pressure calculations, EPA considers that its magnitude should have been specifically justified. However, EPA has reviewed the value of this parameter and found it to be reasonable.
DRZ_PCS	PC_MAX	Maximum allowable capillary pressure for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. Despite the redefinition of the time frame for this material in PCS-2012, EPA has reviewed the value of this parameter and found it to be reasonable.
DRZ_1	PCT_A	Threshold capillary pressure linear parameter for the PCS DRZ during time periods T1 and T2	236559	232288	2/22/1996	The assigned value of zero for PCT_A in PCS-2012 sets the threshold capillary pressure of the DRZ to zero during time periods T1 and T2. The material DRZ_1 originally represented the DRZ around a waste panel, which was conceptually considered to not heal and retain open vertical fractures throughout the regulatory time frame because of the effect of gas pressurization. ERMS 232288 correctly states that a zero threshold capillary pressure is reasonable for a fractured material. EPA therefore considers a value of zero for PCT_A to be appropriate for material DRZ_1 as used in PCS-2012, because it represents a fractured halite that has not fully healed. EPA also accepts a value of zero for this parameter to facilitate a comparison of results because it was used in both PCS-2012 and PABC-2009. See text discussion of two-phase flow parameters for additional information.
DRZ_PCS	PCT_A	Threshold capillary pressure linear parameter for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. Despite the redefinition of the time frame for this material in PCS-2012, EPA accepts a value of zero for PCT_A to facilitate a comparison of results because it was used in both PCS-2012 and PABC-2009. However, a value of zero may not be fully appropriate for the PCS DRZ, because it represents a healed rather than a fractured material. See text discussion of two-phase flow parameters for additional information.
DRZ_1	PCT_EXP	Threshold capillary pressure exponential parameter for the PCS DRZ during time periods T1 and T2	236560	232288	2/22/1996	The assigned value of zero in ERMS 232288 for PCT_EXP is consistent with the assigned value of zero for PCT_A, which sets the threshold capillary pressure to zero. The comment for DRZ_1:PCT_A therefore also applies to DRZ_1:PCT_EXP. EPA accepts a value of zero for this parameter to facilitate comparison of results, because it was used in both PCS-2012 and PABC-2009. See text discussion of two-phase flow parameters for additional information.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
DRZ_ PCS	PCT_EXP	Threshold capillary pressure exponential parameter for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. EPA accepts a value of zero for DRZ_PCS:PCT_EXP for reasons stated above for DRZ_1:PCT_EXP. See text discussion of two-phase flow parameters for additional information.
DRZ_ 1	PRMX_LOG	X-direction permeability of the PCS DRZ during time periods T1 and T2	522016	519513	2/14/2002	The range and distribution of permeabilities assigned to DRZ_1 is the same as those assigned to the DRZ around the waste panels in the PAVT and in subsequent analyses. ERMS 519513 traces the origin of this range and distribution to EPA-mandated values for the PAVT and provides a brief summary of their justification. ERMS 519513 also presents additional data that support this range. EPA accepts this range and distribution as applicable to T1 and T2 because, like the DRZ around a waste panel, the PCS DRZ may not be fully healed during these time periods. EPA also accepts the assumption of an isotropic permeability for this material.
DRZ_ 1	PRMY_LOG	Y-direction permeability of the PCS DRZ during time periods T1 and T2	522016	519513	2/14/2002	The comment for DRZ_1:PRMX_LOG also applies to DRZ_1:PRMY_LOG.
DRZ_ 1	PRMZ_LOG	Z-direction permeability of the PCS DRZ during time periods T1 and T2	522016	519513	2/14/2002	The comment for DRZ_1:PRMX_LOG also applies to DRZ_1:PRMZ_LOG.
DRZ_ PCS	PRMX_LOG	X-direction permeability of the PCS DRZ during time period T3	520524 555599	520524	2/14/2002 5/24/2011	ERMS 520524 refers to AP-086 (ERMS 520612) for a detailed description and justification of material DRZ_PCS. This material was originally defined as the healed DRZ above the Option D concrete monolith. ERMS 520612 states that the DRZ above the monolith would heal quickly and would likely have slightly higher permeability than intact halite because it is relatively thin and may have small-scale heterogeneities, such as thin clay seams, that would increase its permeability. The permeability range for intact halite is -24 to -21 log(m^2). Material DRZ_PCS was given the same permeability range as the Option D concrete monolith, because it met the criterion of being slightly higher than for intact halite, and so that the DRZ and concrete monolith would act as a composite system. EPA agrees that healing of the DRZ around the ROM salt would likely be essentially complete by time period T3, and the use of this permeability range for PCS-2012 is therefore acceptable for purposes of comparison with PABC-2009. EPA also accepts the assumption of an isotropic permeability for this material. However, the healing and consequent permeability reduction of the PCS DRZ is linked with the healing of the ROM salt . See text discussion of DRZ porosity and permeability.
DRZ_ PCS	PRMY_LOG	Y-direction permeability of the PCS DRZ during time period T3	520524 555599	520524	2/14/2002 5/24/2011	The comment for DRZ_PCS:PRMX_LOG also applies to DRZ_PCS:PRMY_LOG.
DRZ_ PCS	PRMZ_LOG	Z-direction permeability of the PCS DRZ during time period T3	520524 555599	520524	2/14/2002 5/24/2011	The comment for DRZ_PCS:PRMX_LOG also applies to DRZ_PCS:PRMZ_LOG.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
DRZ_1	PO_MIN	Minimum allowable brine pressure for the PCS DRZ during time periods T1 and T2	232903	236051	2/22/1996	The cited source document ERMS 236051 identifies only the value of this parameter used in PCS-2012. It does not justify that value, nor does it refer to a document that does provide justification. However, EPA understands that this parameter is used only in capillary pressure Model 3, which was not used in either PCS-2012 or in PABC-2009. EPA therefore considers this parameter value to be acceptable despite the lack of justification.
DRZ_PCS	PO_MIN	Minimum allowable brine pressure for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. EPA understands that this parameter is used only in capillary pressure Model 3, which was not used in either PCS-2012 or in PABC-2009. EPA therefore considers this parameter value to be acceptable despite the lack of justification.
DRZ_1	PORE_DIS	Brooks-Corey pore distribution parameter for the PCS DRZ during time periods T1 and T2	232901	232288	2/12/1996	ERMS 232288 identifies the assigned constant value of 0.7 for this parameter as the median for Salado halite; however, for the ROM salt PCS, this parameter is sampled from a cumulative distribution with a median value of 0.94. EPA accepts a constant value of 0.7 for this parameter to facilitate comparison of results because it was used in both PCS-2012 and PABC-2009. However, the difference in median values and the use of a constant value for the PCS DRZ versus a distributed value for the ROM salt PCS should be justified.
DRZ_PCS	PORE_DIS	Brooks-Corey pore distribution parameter for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. Despite the redefinition of the time frame for this material in PCS-2012, EPA accepts a constant value of 0.7 for this parameter for the reasons given above for DRZ_1:PORE_DIS.
DRZ_1	POROSITY	Porosity of the PCS DRZ during time periods T1 and T2	545795	545755	4/10/2007	ERMS 545755 corrects an error in the maximum value of parameter S_HALITE:POROSITY and also lists the porosity range and distribution used for DRZ_1:POROSITY, but provides no justification for those parameters, nor does it refer to a document that does provide justification. However, ERMS 557396 states that the initial porosity of the PCS DRZ is set equal to the porosity of the DRZ around the waste panels. EPA accepts this approach as reasonable despite a lack of justification in the cited source document.
DRZ_PCS	POROSITY	Porosity of the PCS DRZ during time period T3	545795	545755	4/10/2007	ERMS 545755 corrects an error in the maximum value of parameter S_HALITE:POROSITY and also lists the porosity range and distribution used for DRZ_PCS:POROSITY, but provides no justification for those parameters, nor does it refer to a document that does provide justification. However, ERMS 557396 states that the long-term value of DRZ_PCS:POROSITY is the same as the porosity of the DRZ around the Option D panel closure (which is also the same as the initial DRZ_1 porosity around the panel closures). Although the long-term DRZ porosity would be expected to be smaller than the initial porosity due to consolidation effects, EPA accepts the range and distribution for the DRZ_PCS porosity used in PCS-2012, because they were also used in PABC-2009 and therefore facilitate a comparison of results.

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
DRZ_1	RELP_MOD	Relative permeability model number for the PCS DRZ during time periods T1 and T2	232910	232288	2/13/1996	ERMS 232288 identifies the two-phase flow model as "Brooks/Corey (same as Halite)." EPA considers it appropriate to use the same model for DRZ_1 as for the intact halite. However, this parameter is shown in the cited PDE form and the PAPDB as distributed using a Delta function with a probability of 0.33 for a value of 1 (which selects Permeability Model 1, a modified van Genuchten-Parker model) and a probability of 0.67 for a value of 4 (which selects Permeability Model 4, a modified Brooks-Corey model). Despite specifying a distributed value in the database, this distribution was not sampled and a value of 4 was returned for every vector. Although EPA accepts this result because Model 4 is the desired Brooks-Corey model, the inconsistencies between the database, the justification, and the actual sampling practice are not acceptable. See text discussion of Table 3 for more information.
DRZ_PCS	RELP_MOD	Relative permeability model number for the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Although this parameter is shown in the PDE form and the PAPDB as distributed using a Delta function with a probability of 0.33 for a value of 1 (which selects Permeability Model 1) and a probability of 0.67 for a value of 4 (which selects Permeability Model 4), a value of 4 was returned for every vector. Although EPA accepts this result because Model 4 is the desired Brooks-Corey model, the inconsistency between the database and the actual sampling practice is not acceptable. See text discussion of Table 3 for more information.
DRZ_1	SAT_RBRN	Residual brine saturation of the PCS DRZ during time periods T1 and T2	232912	238568	12/05/1996	The cited source ERMS 238568 identifies this parameter as one of many "legacy parameters" and states that there are numerous sources for those parameters, but the majority can be considered as the choice of the PA analyst. A specific source for this parameter was not provided. Because SAT_RBRN represents a cutoff saturation below which brine cannot flow, EPA considers that its magnitude should have been specifically justified. EPA accepts the assigned constant value of zero for this parameter to facilitate comparison of results, because it was used in both PCS-2012 and PABC-2009. However, EPA notes that while a value of zero may be appropriate for a fractured medium and may therefore be justified for a fractured DRZ during time periods T1 and T2, it may not be appropriate for consolidated materials. In addition, SAT_RBRN is treated as a constant for the DRZ_PCS while it was sampled over a range from zero to 0.6 for the ROM salt material. The lack of consistent treatment and the appropriateness of a zero value should be justified. EPA accepts the value of DRZ_1:SAT_RBRN used in PCS-2012 despite a lack of justification, because it was also used in PABC-2009 and facilitates comparison of results. Also see text discussion of two-phase flow parameters.
DRZ_PCS	SAT_RBRN	Residual brine saturation of the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. In considering the redefinition of the time frame for this material in PCS-2012, EPA notes that while a value of zero may be appropriate for a fractured medium, it may not be appropriate for a consolidated and healed DRZ, such as is conceptually assumed for the DRZ_PCS during T3. In addition, SAT_RBRN is treated as a constant for the DRZ_PCS while it was sampled over a range from zero to 0.6 for the ROM salt

Table 2. Justification Check for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Parameter Type	Parameter Data Entry ERMS No.	Supporting Document ERMS No.	Effective Date	Comments
						material. The lack of consistent treatment and the appropriateness of a zero value should be justified. EPA accepts the value of DRZ_PCS:SAT_RBRN used in PCS-2012 despite a lack of justification, because it was also used in PABC-2009 and facilitates comparison of results. Also see text discussion of two-phase flow parameters
DRZ_ 1	SAT_RGAS	Residual gas saturation of the PCS DRZ during time periods T1 and T2	232913	238568	12/05/1996	The cited source ERMS 238568 identifies this parameter as one of many "legacy parameters" and states that there are numerous sources for those parameters, but the majority can be considered as the choice of the PA analyst. A specific source for this parameter was not provided. Because SAT_RGAS represents a specific cutoff saturation below which gas cannot flow, EPA considers that its magnitude should have been specifically justified. EPA accepts the assigned constant value of zero for this parameter to facilitate comparison of results because it was used in both PCS-2012 and PABC-2009. However, EPA notes that a value of zero may not be appropriate for consolidated materials, and that SAT_RGAS was sampled over a range from zero to 0.4 for the ROM salt material. The lack of consistent treatment and appropriateness of a zero value should be justified. Also see text discussion of two-phase flow parameters.
DRZ_ PCS	SAT_RGAS	Residual gas saturation of the PCS DRZ during time period T3	520524	520524	2/14/2002	ERMS 520524 states that, except for permeabilities, the property values assigned to the DRZ_PCS are the same as those used for the PAVT material DRZ_1, but does not refer to documents that justify those values. Material DRZ_1 was defined for the PAVT and most subsequent analyses as the DRZ from 0 to 10,000 years. In considering the redefinition of the time frame for this material in PCS-2012, EPA notes that while a value of zero may be appropriate for a fractured medium, it may not be appropriate for a consolidated and healed DRZ, such as is conceptually assumed for the DRZ_PCS during T3. In addition, SAT_RGAS is treated as a constant for the DRZ_PCS while it was sampled over a range from zero to 0.4 for the ROM salt material. The lack of consistent treatment and the appropriateness of a zero value should be justified. EPA accepts the value of DRZ_PCS:SAT_RGAS used in PCS-2012 despite a lack of justification, because it was also used in PABC-2009 and facilitates comparison of results. Also see text discussion of two-phase flow parameters.

References for Supporting Documents:
ERMS 232288: Vaughn 1996a
ERMS 232910: SNL 1997
ERMS 235271: Vaughn 1996b
ERMS 236051: Vaughn 1996c
ERMS 238568: Tierney and Vaughn 1996
ERMS 519513: Wall 2001
ERMS 520524: Stein 2002a
ERMS 520612: Stein 2002b
ERMS 542894: Vugrin et al. 2006
ERMS 542946: Vugrin 2006
ERMS 543322: PDE 2006a
ERMS 543328: PDE 2006c
ERMS 545496: Vugrin and Nemer 2007
ERMS 545755: Ismail 2007
ERMS 554623: Camphouse 2010
ERMS 557396: Camphouse et al. 2012a
ERMS 557721: Camphouse 2012
ERMS 557865: Patterson 2012
ERMS 557949: PDE 2012a
ERMS 557951: PDE 2012b

4.3.1 Use of Default Values

As previously noted, distributed parameters are now assigned a default value in the PAPDB for use when the distribution is not to be sampled (Kirchner 2011). Seven parameters were sampled for the ROM salt materials and three parameters were sampled for the PCS DRZ materials. The sampled parameters are shown in Table 1. When a sampled parameter value is applied without change for all three time periods in the PCS-2012 analysis, the sampling occurs during the first time period where the parameter is used. The default value, shown in Table 1, is retrieved from the database for subsequent time periods and is later set equal to the original sampled value in the BRAGFLO ALGEBRA1 file. This same process is used for directional permeabilities in isotropic media. The X-direction permeability PRMX_LOG is sampled, default values are retrieved from the database for PRMY_LOG and PRMZ_LOG, and are later set equal to the PRMX_LOG value in the BRAGFLO ALGEBRA1 file.

The foregoing sampling process is applied to four of the six sampled ROM salt properties (PORE_DIS; POR2PERM; SAT_RBRN, and SAT_RGAS) and is also applied to all sampled PCS DRZ properties (PRMX, Y, Z_LOG; POROSITY; and RELP_MOD). The ROM salt property POR2PERM applies only to time periods T2 and T3. The ROM salt property POROSITY is separately sampled from uniform distributions for the three time periods T1, T2, and T3. The initial brine saturation of the ROM salt, SAT_IBRN, is sampled from a uniform distribution. The sampled value is applied at time zero and replaces the brine saturation calculated during the 5 year preclosure time period. The ROM salt permeability is directly sampled for T1. For T2 and T3, default values are taken from the database and the permeabilities used in the PCS-2012 analysis are calculated as a function of the randomly selected values of POR2PERM and POROSITY. This process is further explained below.

4.3.2 ROM Salt Porosity and Permeability Values

The porosity of the ROM salt is sampled from a uniform distribution for time period T1. For time period T2, the ROM salt porosity is sampled from a different uniform distribution and is compared to the porosity value sampled for T1. If the T2 value is greater than the T1 value, a new T2 value is calculated that is less than or equal to the T1 value. Similarly, for time period T3, the ROM salt porosity is sampled from a third uniform distribution and is compared to the porosity value determined for T2. If the T3 value is greater than the T2 value, a new T3 value is calculated that is less than or equal to the T2 value. This approach is appropriate because the porosity of the ROM salt should be monotonically decreasing during creep closure. The porosity ranges for the three time periods are shown in Table 1.

The log permeability of the ROM salt is sampled from a uniform distribution for time period T1, independent of the sampled porosity value for T1. The log permeability for the ROM salt is then determined for time period T2 as a function of the T2 porosity and the sampled value of a parameter called PCS_T2:POR2PERM that is used to correlate permeability with porosity. SNL developed a correlation between porosity (expressed as fractional salt density) and log permeability based on laboratory brine permeability studies by Brodsky (1994). Development of this correlation is described by Camphouse et al. (2012a). This correlation showed that the permeability of moist, crushed salt consolidating under an external applied stress tends to

decrease as the porosity decreases. Such a correlation is logical and would be generally expected. Consolidation data for moist crushed salt is also appropriate, as compared with data for dry crushed salt, because moist conditions are expected in the post-closure repository. A least squares linear fit to the data served to identify the expected value of log permeability as a function of porosity, and at a given porosity the distribution of test results around this expected value was shown to be reasonably well approximated by a normal distribution. This normal distribution was standardized by taking the expected value as the mean, assigning the mean a default value of zero, and sampling over two standard deviations from the mean. The sampled value of PCS_T2:POR2PERM is the deviation from the mean of this normal distribution of log permeability values.

Knowing the value of PCS_T2:POROSITY, an algorithm in the BRAGFLO ALGEBRA1 file calculates the actual value of the mean permeability corresponding to that porosity and replaces the default value of zero with the actual value. Knowing the value PCS_T2:POR2PERM, the algorithm also uses the deviation from that mean to calculate the value of PCS_T2:PRMX_LOG. Because the ROM salt is assumed to be isotropic, this same log permeability is assigned to PCS_T2:PRMY_LOG and PCS_T2:PRMZ_LOG. The PAPDB contains only constant default values of PCS_T2:PRMX_LOG, PCS_T2:PRMY_LOG, and PCS_T2:PRMZ_LOG as placeholders. These default values are the means of the overall ranges of log permeability values corresponding to the range of porosities applicable to time period T2 and are the same for all three directional permeabilities. These default values are replaced by the calculated values once the actual log permeabilities are determined.

A separate calculation is then made to compare the T2 permeability with the T1 permeability. If the T2 permeability is greater than the sampled T1 permeability, the T2 permeability is set equal to the T1 permeability. This approach is appropriate, because the permeability of the ROM salt should be monotonically decreasing during creep closure.

A similar process is used to determine the T3 permeability, however for this time period, the value of POR2PERM is assumed to be the same as for time period T2. This is accomplished by retrieving a constant default value of 0.0 from the PAPDB for parameter PCS_T3:POR2PERM and replacing that default value with the sampled value of PCS_T2:POR2PERM in the BRAGFLO ALGEBRA1 file. This approach maintains the same deviation from the mean for the permeability distribution during time periods T2 and T3 and is appropriate, because if an above normal permeability is sampled for T2, for example, it is reasonable that the permeability for T3 would also likely be above normal.

Knowing the value of PCS_T3:POROSITY, an algorithm in the BRAGFLO ALGEBRA1 file calculates the actual value of the mean and replaces the default mean value of zero with the actual value. Knowing that the value of PCS_T3:POR2PERM is the same as the value of PCS_T2:POR2PERM, this algorithm also uses the deviation from that mean to calculate the value of PCS_T3:PRMX_LOG. Because the ROM salt is assumed to be isotropic, this same log permeability is assigned to the Y- and Z-directional permeabilities during time period T3. Again, the PAPDB contains only constant default values of PCS_T3:PRMX_LOG, PCS_T3:PRMY_LOG, and PCS_T3:PRMZ_LOG as placeholders. These default values are the means of the overall range of log permeability values corresponding to the range of porosities

applicable to time period T3 and are replaced by the calculated values once the actual log permeabilities are determined. The T3 permeabilities calculated in this manner will generally be different from the T2 permeabilities because of the differences in porosity values.

A separate calculation is then made to compare the T3 permeability with the T2 permeability. If the T3 permeability is greater than the T2 permeability, the T3 permeability is set equal to the T2 permeability. This approach is appropriate, because the permeability of the ROM salt should be monotonically decreasing during creep closure.

The ROM salt log permeability used in the PCS-2012 PA for time period T1 ranges over nine orders of magnitude, from a low of -21 log(m^2) (1×10^{-21} m^2) to a high of -12 log(m^2) (1×10^{-12} m^2). The default value of -16.5 for PCS_T1:PRMY_LOG, and PCS_T1:PRMZ_LOG is the mean of this range. This range was developed by SNL based on laboratory data for consolidated crushed salt at or near the minimum (0.066) and maximum (0.187) porosities in the range sampled for time period T1.

The ROM salt log permeability for time period T2 ranges from -20.8 log(m^2) (1.44×10^{-21} m^2) to -16.3 log(m^2) (4.55×10^{-17} m^2), however only the mean constant default value of -18.6 log(m^2) is entered into the PAPDB for all three T2 directional permeabilities. The ROM salt log permeability for time period T3 ranges from -21.4 log(m^2) (4.46×10^{-22} m^2) to -16.8 log(m^2) (1.47×10^{-17} m^2), however only the mean constant default value of -19.1 log(m^2) is entered into the PAPDB for all three T3 directional permeabilities. These permeability ranges are not provided in the PAPDB, but are documented in Camphouse et al. (2012a).

Following completion of the PCS-2012 PA calculations, an error in calculating the permeability of the ROM salt materials for time periods T2 and T3 was discovered in the BRAGFLO ALGEBRA1 file. The permeability is calculated using the equation

$$k = 10^{-21.187(1-\Phi)+1.5353+\alpha}$$

where k is the calculated permeability, Φ is the sampled porosity value, and α is the sampled POR2PERM value from a normal distribution with a mean of 0, a standard deviation of 0.86, and truncated at ±2 standard deviations. Upon closer inspection, The Agency found that the leading-term constant of -21.187 in this equation was incorrectly transcribed to the ALGEBRA1 input file as
-21.87 for both materials PCS_T2 and PCS_T3. This error led to calculated permeabilities for materials PCS_T2 and PCS_T3 that were lower than the minimum values listed above for some vectors. However, as described in Camphouse et al. (2012b), this transcription error was found to have a negligible impact on the PCS-2012 PA results. SNL reran Replicate 1 of the PCS-2012 PA with the corrected equation and the resulting releases were virtually identical with those of the original analysis.

As previously described, the original range of T1 log permeabilities was from -18.7 to -12.0 log(m^2), and the low end was later extended from -18.7 to -21.0 log(m^2) based on the minimum value from Test 3 of Case et al. (1987), as corrected for the Klinkenberg effect (Patterson 2012). Case et al.'s Test 3 was for moist WIPP salt with 20 mm maximum grain size.

These same test results were considered by Camphouse et al. (2012a), but were not used when developing the original T1 permeability range "...because the maximum grain size for Test 3, 20 mm, is somewhat smaller than the measured maximum grain size for WIPP salt, 38 mm." (Camphouse et al. 2012a). Generally, permeability would be expected to drop more rapidly when consolidating a finer-grained material than when consolidating a coarser-grained material. However, Patterson notes a disagreement on the magnitude of this effect in laboratory test results and concludes that, "The impact of grain size on permeability measurements for moistened cores of crushed salt is ambiguous at this time" (Patterson 2012).

In light of the apparent disagreement within DOE over whether to include the Case et al. Test 3 results in the range of ROM salt permeabilities for T1, the Agency performed an independent evaluation of the appropriateness of the T1 permeability range for the purpose of the PCS-2012 PA. The Agency observes that the range of permeabilities used in the PCS-2012 PA for time period T1 is larger than the ranges for the subsequent time periods, suggesting a greater uncertainty during T1. This uncertainty arises in part from uncertainty in the rate at which the ROM salt is compressed during creep closure, and also in part from uncertainty in the method that will be used by DOE to emplace the ROM salt. The Agency also notes that the minimum permeability of -21.0 $\log(m^2)$ during T1 is less than the minimum permeability during T2 for the entire range of T2 porosities, and is also less than the minimum permeability during T3 for most T3 porosities. These comparisons indicate an inconsistency with the aforementioned conceptual model of monotonically decreasing permeability over time, as well as an inconsistency between the permeability data sets used by DOE.

The adjustments SNL has made to the sampled/calculated values of porosity and permeability to assure physically reasonable monotonic decreases in the values of these parameters with time has also contributed to some permeabilities falling below the originally agreed-upon two standard deviation range for T2 and T3. Although the Agency believes that the minimum ROM salt permeability of -21.0 $\log(m^2)$ during time period T1 may be unrealistically low for coarse WIPP ROM salt in an initial time period of 100 years, the Agency understands that the T2 and T3 data sets from Brodsky (1994) are relatively sparse, and that a high degree of uncertainty is associated with the consolidation of an ROM salt panel closure during T1. The Agency accepts the use of the applied permeability range for T1 because of the uncertainty involved, and because a log permeability of -21.0 $\log(m^2)$ is several orders of magnitude higher than the lowest permeability of -24.0 $\log(m^2)$ used for intact WIPP halite, indicating that complete healing of the ROM salt has not yet occurred. However, if the Agency approves DOE's proposal to modify the PCS design and if the uncertainty in the T1 permeability range is reduced, for example when the initial conditions of the ROM salt are better understood once the method of salt emplacement is determined by DOE or if additional relevant data become available, the Agency may re-evaluate the appropriateness of the T1 ROM salt permeability range for use in future PAs.

4.3.3 PCS DRZ Porosity and Permeability Values

As indicated in Tables 1 and 2, the porosity values for the DRZ above and below the ROM salt were not adequately justified and were modeled as unchanging during all three time periods. The permeability data were better supported and did generally reflect a decrease over time, as would be expected with a consolidating material. However, the permeability ranges for material DRZ_1

(early time) overlap with those for material DRZ_PCS (late time), which may result in an unrealistic permeability increase in late time because the distributions are sampled independently. Additionally, the PCS DRZ permeability is independent of the ROM salt permeability, even though the conceptual model described by Camphouse et al. (2012a) states, "As ROM salt reaches higher fractional densities during consolidation, back stress will be imposed on the surrounding rock mass leading to eventual healing of the disturbed rock zone (DRZ)." The Agency agrees that healing of the PCS DRZ cannot occur until sufficient back stress is generated by the ROM salt and such back stress cannot be generated until the ROM salt is sufficiently consolidated to significantly reduce its porosity and permeability. It is apparent that the decrease in permeability of the PCS DRZ is correlated with the decrease in permeability of the ROM salt. Although the Agency agreed with the PCS DRZ values used in PCS-2012 to maintain consistency with PABC-2009 and simplify comparison of results, the appropriateness of conditioning for monotonic decreases in porosity and permeability over time, and for correlating decreases in PCS DRZ porosity and permeability with decreases in ROM salt porosity and permeability, may be evaluated by the Agency for the 2014 recertification PA.

4.3.4 Two-Phase Flow Parameters

Relative permeability Model 4 is a Brooks-Corey model that was modified by SNL to use a residual gas saturation in calculating the effective saturation for the relative permeability of the non-wetting (gas) phase. Model 4 was used to model two-phase flow in the PCS-2012 PA for both the ROM salt and the surrounding PCS DRZ. Inputs for this model specific to two-phase flow include a capillary pressure model CAP_MOD, a pore distribution PORE_DIS, an initial brine saturation SAT_IBRN, a residual brine saturation SAT_RBRN, and a residual gas saturation SAT_RGAS. Capillary pressure Models 1 and 2 are generally used in WIPP PA. Model 1 is similar to Model 2, except that Model 2 invokes a maximum value for the capillary pressure, while Model 1 has no maximum and is typically used when the threshold capillary pressure is set to zero, which deactivates the model. Inputs for the capillary pressure models include a maximum allowable capillary pressure PC_MAX (for Model 2) and a threshold capillary pressure P_t. If the threshold capillary pressure is set to zero, the material is modeled in BRAGFLO as having no (zero) capillary pressure. A minimum allowable capillary pressure PO_MIN must also be specified in the database, but is only used in capillary pressure Model 3, which was not used in either PCS-2012 or PABC-2009.

Threshold capillary pressure is the pressure required for a gas to overcome capillary forces and enter a brine-saturated salt. Threshold capillary pressure for the Brooks-Corey model is calculated as

$$P_t = a\,k^{-b}$$

where a is called the linear parameter, designated in WIPP PA as the property PCT_A, k is the permeability of the material in the X-direction, and b is the exponential parameter, designated in WIPP PA as the property PCT_EXP. Both a and b are constants in WIPP PA. Inputs for the threshold capillary pressure model are, therefore, PCT_A, PCT_EXP, the permeability k, and a flag called KPT that determines whether k is constant (KPT = 0.0) or whether k changes with time (KPT = 1.0) during the analysis. According to Chris Camphouse (SNL's BRAGFLO

administrator), k is automatically reset to the current X-direction permeability each time the material changes. Therefore, even if KPT is set to zero, the threshold capillary pressure is recalculated for the ROM salt for each time period T1, T2, and T3, because PCS_T1, PCS_T2, and PCS_T3 each represent a different material in BRAGFLO.

Two-phase flow parameters for unconsolidated salt were first developed in WIPP PA for modeling the DRZ around the waste panels and for modeling the salt component of the original shaft seal. The waste panel DRZ was considered to retain open fractures and relatively high permeabilities (compared to intact halite) for the entire regulatory time frame because of the disruptive effects of gas pressurization from waste decomposition. The salt component of the original shaft seal was to be emplaced as a porous material using ROM WIPP salt, also with a relatively high permeability. The open fractures and pores of the waste panel DRZ were considered to result in an essentially zero threshold capillary pressure, a zero residual brine saturation, and a zero residual gas saturation. Capillary pressures are not modeled in a material if the threshold capillary pressure is zero. In addition, KPT was set to zero, because permeabilities remained constant during a given realization.

Zero values continued to be assigned to these DRZ parameters until the DOE proposed a modified panel closure design that used ROM salt, whose consolidation was to be specifically modeled over three time periods in the PCS-2012 PA. The agreed upon parameterization for that PA included a nonzero threshold capillary pressure for the ROM salt, a residual brine saturation that was sampled over a range from 0.0 to 0.6, and a residual gas saturation that was sampled over a range from 0.0 to 0.4. The effect of nonzero values for these parameters is to add restrictions to the flow of brine and gas in the salt. Low values approaching zero for threshold capillary pressure, residual brine saturation, and residual gas saturation may be appropriate for materials that have open fractures, but nonzero values would be expected for consolidated materials. Capillary pressure Model 2 is typically used when the threshold capillary pressure is nonzero, and that model was specified in the agreed-upon parameterization. Zero values for these parameters were used for the PCS DRZ to maintain consistency with the baseline PABC-2009 and simplify comparison of the effects of different panel closure designs.

As previously stated, capillary pressure Model 1 is typically used in WIPP PA when the threshold capillary pressure is zero. When performing the PCS-2012 PA, DOE found that a nonzero threshold capillary pressure for the ROM salt caused numerical difficulties in BRAGFLO and resolved this problem by setting the threshold capillary pressure for the ROM salt to zero. Because this change was not consistent with the parameterization that the Agency had previously agreed upon and the effect of a nonzero threshold capillary pressure could not be determined from the PCS-2012 results, the Agency requested DOE to correct the numerical difficulties in BRAGFLO and rerun the PCS-2012 PA with nonzero threshold capillary pressures in the ROM salt.

SNL found that the aforementioned numerical difficulties arose when the threshold capillary pressure was nonzero and the initial brine saturation was less than the residual brine saturation. In capillary pressure Model 2, BRAGFLO computes the brine saturation at which the capillary pressure equals the maximum allowable capillary pressure, PCMAX. Because capillary pressure increases as brine saturation decreases, this calculated value is the minimum allowable brine

saturation for the particular material. If the initial brine saturation is less than this minimum value, the capillary pressure is set to the PCMAX value of 1×10^8 Pa (Nemer 2007b). In previous analyses, the initial brine saturation was set to 1.0 (a fully saturated condition) at time -5 years for the DRZ and intact halite in the vicinity of a waste panel, and at time zero, the brine saturation was the saturation calculated by BRAGFLO after 5 years of drainage into the waste panel. However, for the ROM salt, the initial brine saturation SAT_IBRN was reset to a much drier condition at time zero that was representative of the expected range of brine saturations for granular ROM salt. Because this initial saturation was less than the minimum value, the capillary pressure was increased to 1×10^8 Pa at time zero. Because gas pressure equals brine pressure plus capillary pressure, BRAGFLO also increased gas pressure at time zero by 1×10^8 Pa over the brine pressure to maintain equilibrium conditions. Because the gas pressure in adjacent materials at time zero was still low, this sudden increase created an unrealistically high gas pressure gradient that resulted in numerical difficulties in BRAGFLO. Numerical difficulties can also arise as the brine saturation drops and approaches the residual brine saturation because capillary pressures are increasing rapidly at these low saturations. In addition to the lack of a physical reason why the gas pressure in the repository should suddenly increase to a high value at time zero, as discussed below, brine saturations below the residual brine saturation represent a non-physical condition in BRAGFLO.

In previous analyses, the aforementioned numerical difficulties in BRAGFLO were resolved by reverting to capillary pressure Model 1 and setting the threshold capillary pressure to zero. This set the capillary pressure to zero and made the gas pressure equal to the brine pressure, thereby eliminating large gas pressure gradients between adjacent materials. A nonzero threshold capillary pressure can be specified in Model 1, but unlike Model 2, no maximum value for capillary pressure is provided in Model 1. Because there is no maximum capillary pressure in Model 1, if the brine saturation is below the residual brine saturation, the capillary pressure is arbitrarily set to zero (Nemer 2007b). This default, coupled with a zero capillary pressure for higher brine saturations, set capillary pressure in Model 1 to zero for any brine saturation. Eliminating capillary pressure altogether eliminated large gas pressure gradients and allowed BRAGFLO to converge more readily.

The initial brine saturation for the ROM salt was determined to range from 0.04 to 0.16, assuming a granular material that had dried and was partially rewetted, whereas the residual brine saturation was sampled over a range from 0.0 to 0.6, resulting in many vectors with sampled residual brine saturations greater than the initial brine saturations. Although the range of initial brine saturations is physically reasonable, they can only be reached by assuming an evaporative or chemically based moisture removal process that is not modeled in BRAGFLO. Under the humid conditions modeled in BRAGFLO, such a drying process could not happen, because it would require brine flow in salt to occur below the lower limit that such flow could occur, as defined by the residual brine saturation. This numerical problem can be resolved by setting the initial brine saturation above the residual brine saturation. It was temporarily resolved by SNL by increasing the initial brine saturation of the ROM salt to 1.0. The Agency considers the assumption of higher brine saturations to be appropriate, because humid conditions are expected to develop in the repository soon after closure.

SNL reran the corrected BRAGFLO code with an initial brine saturation of the ROM salt at time zero reset to 1.0 and nonzero threshold capillary pressures in the ROM salt for all three time periods. The initial brine saturation in the PCS DRZ did not need to be changed, because it was set to 1.0 at time -5 years and not reset at time zero. The results showed that including threshold capillary pressures in the ROM salt made no significant difference in the mean repository releases. Because SNL's BRAGFLO runs were not reviewed for quality assurance purposes, the WIPP PA codes were reviewed and rerun by the Agency with the same results. The Agency therefore concludes that DOE's deviation from the agreed-upon parameterization in PCS-2012 is acceptable.

As described above, the Agency accepted retention in the PCS-2012 PA of several parameter values from the PABC-2009 PA to simplify comparison of results by focusing only on parameter value changes that were potentially significant and resulted directly from the proposed changes in PCS design. However, when agreeing with the parameter values for the PCS-2012 PA in June 2012, the Agency noted that although the multi-phase flow and other parameters in BRAGFLO could remain as they have been in past PAs, they may be re-evaluated for appropriateness in the 2014 recertification PA.

4.4 REVIEW OF PAPDB DATABASE-TO-CODE INTERFACE FOR PCS-2012

Accurate access by the WIPP PA codes of PAPDB parameter values was evaluated by visually comparing code input files with PAPDB database values. The PA code input files were accessed by SNL staff member Jennifer Long in the SNL Carlsbad office. The input files were observed and compared with PAPDB values by the Agency review team. This review was conducted for all parameters used in PCS-2012 that have changed since CRA-2009. The results of this review are shown in Table 3.

Table 3 presents the parameter name (material and property), the code that used the parameter, the names of the input file and library that were accessed, the parameter value in PAPDB, the parameter value returned from the PAPDB, and comments providing additional details. In every case, the code using the parameter was BRAGFLO. BRAGFLO Version 6.0 (Nemer 2007a) was used in both PCS-2012 and in CRA-2009. For all constant parameters, the value returned was the same as the PAPDB value. For all distributed parameters, the value returned was within the range of the parameter distribution. For distributed parameters, two or more values were generally returned, representing samples for specific replicates and vectors randomly selected by the Agency reviewer. In all but one case, the correct values were returned.

The single exception was the sampled value for DRZ_1:RELP_MOD. This parameter identifies the relative permeability model to be used for material DRZ_1. This parameter is entered into the PAPDB as a sampled value from a Delta function with a probability of 0.33 for a value of 1 (which selects relative permeability Model 1, a modified van Genuchten-Parker model) and a probability of 0.67 for a value of 4 (which selects relative permeability Model 4, a modified Brooks-Corey model). However, three different vectors were checked from three replicates, and in each case a value of 4 was returned. The sampled results were further checked and a value of 4 was returned for every vector in every replicate. Although this indicates a problem with the PRELHS sampling algorithm, the Agency concludes that it has no impact on the PCS-2012

results, because relative permeability Model 4 is the desired model for the modified Brooks-Corey model used in PCS-2012 and PABC-2009. This problem did not exist for the parameter DRZ_PCS:RELP_MOD, because the default value of zero was returned and later set equal to the sampled value for DRZ_1:RELP_MOD in the BRAGFLO ALGEBRA1 file. This problem also did not exist for the ROM salt, because the value of RELP_MOD for that material is entered in the PAPDB as a constant equal to 4 for all three time periods. The Agency informed Chris Camphouse (SNL) of this error. He confirmed the error and said it would also have been present in PABC-2009 and will be corrected by changing this parameter to a constant value.

The methodology used to establish a value for DRZ_1:POROSITY is complex and warrants a brief explanation. The porosity of the DRZ around the PCS is the same as the porosity of the DRZ around a waste panel. The value of this parameter is derived from a sampled porosity value for intact halite which, once determined, remains unchanged throughout the regulatory time frame. Most such parameters are sampled for the first time period (usually the zero to 200-year time period of DRZ_1 for the DRZ PCS) and a default value is taken from the database for later time periods (in this case, the 200 to 10,000-year time period for material DRZ_PCS) that is subsequently set equal to the sampled value for the earlier time period in the BRAGFLO ALGEBRA1 file. However, for DRZ_1:POROSITY, the default value rather than a sampled value is taken from the database and is then set equal to the value for parameter DRZ_0:POROSITY in the BRAGFLO ALGEBRA1 file. DRZ_0:POROSITY is the porosity assigned to the DRZ for the time period -5 years to time zero. This time period is used to establish initial conditions in the DRZ at time zero for BRAGFLO parameters, such as initial brine saturation. The value of DRZ_0:POROSITY is equal to the sampled porosity value for intact halite, S_HALITE:POROSITY, plus a constant value of 0.0029 (parameter DRZ_0:ADDPOR). This correlation assures that the porosity of the DRZ is always greater than the porosity of intact halite. Although the distributions for DRZ_0:POROSITY, DRZ_1:POROSITY, DRZ PCS:POROSITY, and S_HALITE:POROSITY are correct in the PAPDB, only the distribution for S_HALITE:POROSITY is actually sampled. This parameter was handled the same way in the PCS-2012 PA as it was in the PABC-2009.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
PCS_T1	CAP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1	1	The correct value was returned.
PCS_T2	CAP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1	1	The correct value was returned.
PCS_T3	CAP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1	1	The correct value was returned.
PCS_T1	COMP_RCK	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	8.0E-11	8.0E-11	The correct value was returned.
PCS_T2	COMP_RCK	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	8.0E-11	8.0E-11	The correct value was returned.
PCS_T3	COMP_RCK	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	8.0E-11	8.0E-11	The correct value was returned.
PCS_T1	KPT	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T2	KPT	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T3	KPT	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T1	PC-MAX	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.0E08	1.0E08	The correct value was returned.
PCS_T2	PC-MAX	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.0E08	1.0E08	The correct value was returned.
PCS_T3	PC-MAX	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.0E08	1.0E08	The correct value was returned.
PCS_T1	PCT_A	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T2	PCT_A	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T3	PCT_A	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T1	PCT_EXP	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T2	PCT_EXP	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T3	PCT_EXP	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
PCS_T1	PO_MIN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.01325E05	1.01325E05	The correct value was returned.
PCS_T2	PO_MIN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.01325E05	1.01325E05	The correct value was returned.
PCS_T3	PO_MIN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.01325E05	1.01325E05	The correct value was returned.
PCS_T1	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.11 to 8.1	0.5301	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.11 to 8.1.
PCS_T1	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.11 to 8.1	7.108	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.11 to 8.1.
PCS_T2	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.11 to 8.1	0.940	Value from R2 V31. The default value was correctly returned.
PCS_T2	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.11 to 8.1	0.940	Value from R1 V57. The default value was correctly returned.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
PCS_T2	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.11 to 8.1	0.940	Value from R3 V42. The default value was correctly returned.
PCS_T3	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.11 to 8.1	0.940	Value from R2 V31. The default value was correctly returned.
PCS_T3	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.11 to 8.1	0.940	Value from R1 V57. The default value was correctly returned.
PCS_T3	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.11 to 8.1	0.940	Value from R3 V42. The default value was correctly returned.
PCS_T1	POROSITY	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.066 to 0.187	0.09049	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.066 to 0.187.
PCS_T1	POROSITY	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.066 to 0.187	0.07102	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.066 to 0.187.
PCS_T2	POROSITY	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.025 to 0.075	0.06855	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.025 to 0.075.
PCS_T2	POROSITY	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.025 to 0.075	0.02965	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.025 to 0.075.
PCS_T2	POROSITY	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.025 to 0.075	0.02683	Value from R3 V42. Sampled value correctly lies within the sampled range of 0.025 to 0.075.
PCS_T3	POROSITY	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.001 to 0.0519	0.03087	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.001 to 0.0519.
PCS_T3	POROSITY	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.001 to 0.0519	0.01855	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.001 to 0.0519.
PCS_T3	POROSITY	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.001 to 0.0519	0.01705	Value from R3 V42. Sampled value correctly lies within the sampled range of 0.001 to 0.0519.
PCS_T1	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-21 to -12	-14.24	Value from R2 V31. Sampled value correctly lies within the sampled range of -21 to -12.
PCS_T1	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-21 to -12	-18.04	Value from R1 V57. Sampled value correctly lies within the sampled range of -21 to -12.
PCS_T1	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-16.5	-16.5	Value from R2 V31. The default value was correctly returned.
PCS_T1	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-16.5	-16.5	Value from R1 V57. The default value was correctly returned.
PCS_T1	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-16.5	-16.5	Value from R2 V31. The default value was correctly returned.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
PCS_T1	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-16.5	-16.5	Value from R1 V57. The default value was correctly returned.
PCS_T2	POR2PERM	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-1.72 to +1.72	0.8755	Value from R2 V31. Sampled value correctly lies within the sampled range of -1.72 to +1.72.
PCS_T2	POR2PERM	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-1.72 to +1.72	-1.092	Value from R1 V57. Sampled value correctly lies within the sampled range of -1.72 to +1.72.
PCS_T2	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-18.6	-18.6	Value from R2 V31. The default value was correctly returned. See text discussion.
PCS_T2	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-18.6	-18.6	Value from R1 V57. The default value was correctly returned.
PCS_T2	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-18.6	-18.6	Value from R2 V31. The default value was correctly returned.
PCS_T2	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-18.6	-18.6	Value from R1 V57. The default value was correctly returned.
PCS_T2	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-18.6	-18.6	Value from R2 V31. The default value was correctly returned.
PCS_T2	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-18.6	-18.6	Value from R1 V57. The default value was correctly returned.
PCS_T3	POR2PERM	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-1.72 to +1.72	0	Value from R2 V31. The default value was correctly returned. See text discussion.
PCS_T3	POR2PERM	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-1.72 to +1.72	0	Value from R1 V57. The default value was correctly returned.
PCS_T3	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-19.1	-19.1	Value from R2 V31. The default value was correctly returned. See text discussion.
PCS_T3	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-19.1	-19.1	Value from R1 V57. The default value was correctly returned.
PCS_T3	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-19.1	-19.1	Value from R2 V31. The default value was correctly returned.
PCS_T3	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-19.1	-19.1	Value from R1 V57. The default value was correctly returned.
PCS_T3	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-19.1	-19.1	Value from R2 V31. The default value was correctly returned.
PCS_T3	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-19.1	-19.1	Value from R1 V57. The default value was correctly returned.
PCS_T1	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	4	4	The correct value was returned.
PCS_T2	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	4	4	The correct value was returned.
PCS_T3	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	4	4	The correct value was returned.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
PCS_T1	SAT_IBRN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.04 to 0.16	0.1335	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.04 to 0.16.
PCS_T1	SAT_IBRN	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.04 to 0.16	0.1337	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.04 to 0.16.
PCS_T1	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0 to 0.6	0.1561	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.0 to 0.6.
PCS_T1	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0 to 0.6	0.5511	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.0 to 0.6.
PCS_T2	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0 to 0.6	0.2	Value from R2 V31. The default value was correctly returned.
PCS_T2	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0 to 0.6	0.2	Value from R1 V57. The default value was correctly returned.
PCS_T2	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.0 to 0.6	0.2	Value from R3 V42. The default value was correctly returned.
PCS_T3	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0 to 0.6	0.2	Value from R2 V31. The default value was correctly returned.
PCS_T3	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0 to 0.6	0.2	Value from R1 V57. The default value was correctly returned.
PCS_T3	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.0 to 0.6	0.2	Value from R3 V42. The default value was correctly returned.
PCS_T1	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0 to 0.4	0.105	Value from R2 V31. Sampled value correctly lies within the sampled range of 0.0 to 0.4.
PCS_T1	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0 to 0.4	0.07844	Value from R1 V57. Sampled value correctly lies within the sampled range of 0.0 to 0.4.
PCS_T2	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0 to 0.4	0.2	Value from R2 V31. The default value was correctly returned.
PCS_T2	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0 to 0.4	0.2	Value from R1 V57. The default value was correctly returned.
PCS_T2	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.0 to 0.4	0.2	Value from R3 V42. The default value was correctly returned.
PCS_T3	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0 to 0.4	0.2	Value from R2 V31. The default value was correctly returned.
PCS_T3	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0 to 0.4	0.2	Value from R1 V57. The default value was correctly returned.
PCS_T3	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.0 to 0.4	0.2	Value from R3 V42. The default value was correctly returned.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
DRZ_1	CAP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1	1	The correct value was returned.
DRZ_PCS	CAP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1	1	The correct value was returned.
DRZ_1	COMP_RCK	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	7.41E-10	7.41E-10	The correct value was returned.
DRZ_PCS	COMP_RCK	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	7.41E-10	7.41E-10	The correct value was returned.
DRZ_1	KPT	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_PCS	KPT	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_1	PC_MAX	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.0E08	1.0E08	The correct value was returned.
DRZ_PCS	PC_MAX	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.0E08	1.0E08	The correct value was returned.
DRZ_1	PCT_A	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_PCS	PCT_A	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_1	PCT_EXP	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_PCS	PCT_EXP	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_1	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-19.4 to -12.5	-13.05	Value from R2 V31. Sampled value correctly lies within the sampled range of -19.4 to -12.5.
DRZ_1	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-19.4 to -12.5	-16.37	Value from R1 V57. Sampled value correctly lies within the sampled range of -19.4 to -12.5.
DRZ_1	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	-19.4 to -12.5	-14.48	Value from R3 V42. Sampled value correctly lies within the sampled range of -19.4 to -12.5.
DRZ_1	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-16.0	-16.0	Value from R2 V31. The default value was correctly returned.
DRZ_1	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-16.0	-16.0	Value from R1 V57. The default value was correctly returned.
DRZ_1	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-16.0	-16.0	Value from R2 V31. The default value was correctly returned.
DRZ_1	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-16.0	-16.0	Value from R1 V57. The default value was correctly returned.
DRZ_PCS	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-20.699 to -17.0	-18.4	Value from R2 V31. Sampled value correctly lies within the sampled range of -20.699 to -17.0.
DRZ_PCS	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-20.699 to -17.0	-17.79	Value from R1 V57. Sampled value correctly lies within the sampled range of -20.699 to -17.0.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
DRZ_ PCS	PRMX_LOG	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	-20.699 to -17.0	-19.53	Value from R3 V42. Sampled value correctly lies within the sampled range of -20.699 to -17.0.
DRZ_ PCS	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-18.7496	-18.7496	Value from R2 V31. The default value was correctly returned.
DRZ_ PCS	PRMY_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-18.7496	-18.7496	Value from R1 V57. The default value was correctly returned.
DRZ_ PCS	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	-18.7496	-18.7496	Value from R2 V31. The default value was correctly returned.
DRZ_ PCS	PRMZ_LOG	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	-18.7496	-18.7496	Value from R1 V57. The default value was correctly returned.
DRZ_ 1	PO_MIN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.01325E05	1.01325E05	The correct value was returned.
DRZ_ PCS	PO_MIN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1.01325E05	1.01325E05	The correct value was returned.
DRZ_ 1	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.7	0.7	The correct value was returned.
DRZ_ PCS	PORE_DIS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.7	0.7	The correct value was returned.
DRZ_ 1	POROSITY	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0039 to 0.0548	0.0129	Value from R2 V31. The default value was correctly returned. See text discussion.
DRZ_ 1	POROSITY	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0039 to 0.0548	0.0129	Value from R1 V57. The default value was correctly returned. See text discussion.
DRZ_ 1	POROSITY	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.0039 to 0.0548	0.0129	Value from R3 V42. The default value was correctly returned. See text discussion.
DRZ_ PCS	POROSITY	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0039 to 0.0548	0.0129	Value from R2 V31. The default value was correctly returned.
DRZ_ PCS	POROSITY	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	0.0039 to 0.0548	0.0129	Value from R1 V57. The default value was correctly returned.
DRZ_ PCS	POROSITY	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	0.0039 to 0.0548	0.0129	Value from R3 V42. The default value was correctly returned.
DRZ_ 1	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1 or 4	4	Value from R2 V31. A value of 4 was returned in every sample whereas it should have only been returned an average of 67% of time. See text discussion.
DRZ_ 1	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	1 or 4	4	Value from R1 V57. Same comment as for R2 V31.
DRZ_ 1	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	1 or 4	4	Value from R3 V42. Same comment as for R2 V31.
DRZ_ PCS	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	1 or 4	0	Value from R2 V31. The default value was correctly returned.

Table 3. Database-Code Interface Test Results for Parameters Used in the PCS-2012 PA that have Changed since PABC-2009

Material Name	Property Name	Code	File Name	Library	PAPDB Value	Value Returned	Comments
DRZ_ PCS	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R1_V057.CDB	LIBAP161_BF	1 or 4	0	Value from R1 V57. The default value was correctly returned.
DRZ_ PCS	RELP_MOD	BRAGFLO	LHS3_BF_AP161_R3_V042.CDB	LIBAP161_BF	1 or 4	0	Value from R3 V42. The default value was correctly returned.
DRZ_ 1	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_ PCS	SAT_RBRN	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_ 1	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.
DRZ_ PCS	SAT_RGAS	BRAGFLO	LHS3_BF_AP161_R2_V031.CDB	LIBAP161_BF	0.0	0.0	The correct value was returned.

5.0 PARAMETER DATA ENTRY PROCESS REVIEW

Parameter data entry process and control were evaluated by reviewing the PDE forms used as the basis for data entry into the PAPDB, in accordance with SNL Procedure NP 9-2 Rev 01, *Parameters*. This procedure was most recently updated in August 2006 and is the same procedure that was reviewed by the Agency for PABC-2009. This procedure prescribes the processes for developing, documenting, controlling, and changing parameters used in compliance-level and programmatic PA calculations performed by SNL in support of the WIPP. Parameter values are required to be developed and documented in accordance with approved, procedurally driven planning documents. NP 9-2 Rev 01 provides detailed instructions for entering or changing a parameter value in the PAPDB. Responsibilities for checking and approval are clearly defined and appropriate. No concerns regarding this procedure were identified.

EPA also reviewed Activity Specific Procedure SP 9-5 Rev 01, *Parameter Data Entry,* for PABC-2009. This procedure has since been recalled, because data entry in PAPDB Version 2.00 is accomplished directly by responding to prompts in the database input files. The master input file is called *Parameter Database Data Entry*. It presents a series of options for various tasks: identifying a new code; identifying new documents; defining new analyses; entering new parameters; and setting up a new analysis. Under the *New Parameter* button, for example, choices are given for adding a new material, adding a new property, adding a new parameter, adding parameter attributes, and adding parameter documentation. Under *Add New Parameter*, for example, the material name, property name, units, and reference type (such as reference constant) are entered. The Agency reviewed the data entry options and found them to be complete. Entries made through this system are manually checked for accuracy against the PDE forms and signed off. Additionally, the Agency found no problems related to the functioning of the PAPDB Version 2.00 in its database – code interface review. The new database appears to be working well and provides an enhancement over PAPDB Version 1.00.

Each PDE form for the 78 parameters that are new or have been changed since PABC-2009 was inspected by the Agency for completeness to confirm that all appropriate blanks were filled in and the necessary signatures were provided. Accuracy of the data entry process was checked by visually comparing the information on the form with the information shown in the online PAPDB. Although several errors were found in the documentation used to create the PDE forms, in none of the cases were errors found in the entered parameter values when compared to the forms.

A review of the PDE forms supporting the parameter changes between PABC-2009 and PCS-2012 determined that they were completely and correctly filled out. Handwritten changes were found on several forms correcting the associated metadata. These hand entries were dated and initialed by the originator of the form or by another responsible individual and were, therefore, acceptable.

6.0 COMPUTING HARDWARE

Run control for BRAGFLO is documented in Camphouse et al. (2012b). The calculations that were affected by the changes from PABC-2009 were updated, while the results from previous PAs were used for the calculations that were relatively unaffected by the changes. For PCS-2012 calculations, the codes were executed on the WIPP PA Alpha Cluster consisting of 8 Hewlett Packard (HP) AlphaServer nodes configured to share the same disk array using Storage Area Network (SAN) technology for efficient disk utilization and data storage and management. This allows for highly distributed processing while providing for integrated data access. The WIPP PA Alpha Cluster runs the Open VMS operating system (Version 8.2). The node name and hardware description for the nodes used are provided in Table 4.

Table 4. WIPP PA Alpha Cluster Nodes Used in PCS-2012

Node	Hardware Type	Number of CPUs	CPU	Operating System
TBB	HP AlphaServer ES47	4	Alpha EV7	Open VMS 8.2
TRS	HP AlphaServer ES47	4	Alpha EV7	Open VMS 8.2
GNR	HP AlphaServer ES47	4	Alpha EV7	Open VMS 8.2
MC5	HP AlphaServer ES47	4	Alpha EV7	Open VMS 8.2
CCR	HP AlphaServer ES45 Model 2	4	Alpha EV68	Open VMS 8.2
TDN	HP AlphaServer ES45 Model 2	4	Alpha EV68	Open VMS 8.2
BTO	HP AlphaServer ES45 Model 2	4	Alpha EV68	Open VMS 8.2
CSN	HP AlphaServer ES45 Model 2	4	Alpha EV68	Open VMS 8.2

Brine and gas flow in and around the repository and in overlying formations are calculated using the BRAGFLO suite of codes (PREBRAG, BRAGFLO, and POSTBRAG) in conjunction with several utility codes. Sampling of the uncertain parameters used by the various process model codes is performed with the PRELHS and LHS codes. PRELHS reads information about the ranges and distributions of the uncertain parameters from the PAPDB and formats this information for LHS. The LHS code implements the sampling algorithms. LHS is executed once per replicate. Each of the three replicates includes six scenarios designed to cover a range of drilling intrusion types and times. For each replicate/scenario combination, calculations are performed for 100 vectors of uncertain model input parameters. Additional run control information is provided by Camphouse et al. (2012b).

7.0 CONCLUSIONS

Although a number of database problems were identified in this review, none had a significant effect on the results of the PCS-2012 analysis. Of the approximately 1,700 parameters in the PAPDB, 78 changes were made since PABC-2009. Most of the changes involved the assignment of existing parameter names and values to newly defined materials used in the ROM salt PCS and newly defined time periods applied to the PCS DRZ. All PCS_T3 materials were new, because three different time periods had not previously been used in WIPP PA. Three data errors were identified in the PAPDB. All resulted from errors in source data tables and none resulted from transcription errors in preparing parameter data entry forms or in entering values into the PAPDB. However, none of these errors adversely affected PCS-2012 results.

A check of primary and secondary supporting documents was made for all parameter changes, and all documents were quickly retrieved from the WIPP Records Center. Many of the supporting documents were not found to adequately justify the parameter values used in the PCS-2012 analysis, and many had transparency weaknesses, because the cited source documents were prepared for other analyses and the associated metadata described those analyses rather than the PCS-2012 PA.

A database interface evaluation was performed for all new parameters and the correct parameter values were retrieved from the PAPDB in all but one case, where the parameter was not sampled from the distribution described in the database. This error had no effect on the PCS-2012 PA results.

Procedures for developing, documenting, controlling, and changing parameters, and for entering those parameters into the PAPDB, were also reviewed. The Agency found all procedural changes to be consistent with earlier versions and found all revisions to be appropriate.

In summary, many more concerns were raised by this review than were raised in previous PA parameter reviews. However, as documented in this report, the Agency's concerns address details of the PCS-2012 PA database that did not affect the overall results.

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APPENDIX B

REVIEW OF WIPP PERFORMANCE ASSESSMENT COMPUTERIZED DATABASE (PAPDB) MIGRATION

TABLE OF CONTENTS

Executive Summary ii

1.0 Introduction 1

2.0 General Approach 3

3.0 Review of the PAPDB Migration 4

- 3.1 Rationale for Database Migration and Update 4
- 3.2 Migration Objectives 5
- 3.3 Approach 5
- 3.4 Software 5
- 3.5 Acceptance Criteria 6
- 3.6 Testing Methodology 6
  - 3.6.1 Migration from SQL to MySQL Server 6
  - 3.6.2 Code Functionality 6
  - 3.6.3 Test Cases 8
  - 3.6.4 Execution of Tests 9
- 3.7 Test Results 9

4.0 Summary and Conclusions 11

5.0 References 12

EXECUTIVE SUMMARY

The ability of the DOE WIPP facility to continue to meet the certification requirements of the EPA is demonstrated in part through the use of a series of performance assessment (PA) computer codes. DOE must demonstrate on an ongoing basis that PA computer software is in compliance with regulations outlined in Section §194.23 – Models and Computer Codes and in ASME NQA-2a-1990 addenda, part 2.7. Since the Agency's certification of the DOE WIPP Compliance Certification Application (CCA), DOE has added computer hardware and upgraded the computer software. In order to maintain compliance with Sections §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7, DOE is required to conduct testing on the computer codes to ensure that they still function properly on new hardware and software.

This appendix describes the results of the U.S. Environmental Protection Agency's (EPA or the Agency) review of Performance Assessment Parameter Database (PAPDB) migration, design modifications and testing activities performed by Sandia National Laboratories (SNL) in support of their ongoing Performance Assessment (PA) activities at the Waste Isolation Pilot Plant (WIPP).

In 2011, SNL migrated the PAPDB (Version 1.0) used in the WIPP compliance calculations from the Microsoft SQL Server on a Windows Server to the PAPDB (Version 2.00) on the MySQL Server on Solaris. The purpose of the migration is to facilitate access to the parameter data from the PA codes on Solaris, Linux and VMS. In addition, the design of the database was also modified to improve its ease of use.

SNL defines a parameter as any value or distribution of values used directly or indirectly as input to a PA. The PAPDB contains the parameters used in WIPP PAs, the names of documents related to those parameters, the names of the codes that use the parameters, and a log of the parameters that were exported to the various codes during analyses. In the PAPDB a parameter may be represented by a single value or assigned a distribution which represents epistemic uncertainty. The values of parameters can change through time as new information becomes available. The database contains the different versions of the parameter(s) which are identified by a version number, by the analysis where the parameter was first defined, and by the effective date for its first use. Specific versions of a parameter can be associated with one or more analyses. The purpose of the database is to securely store the parameter data used in the PA analyses, to allow access to that data directly from the applications that need those data, and to log the usage of the data. In addition, the PAPDB is designed to access the data from a user interface to facilitate querying the database to document the parameter values used in the various analyses

The primary objectives of the Agency's review of the PAPDB database migration to the new platform are to assess the transcription accuracy, documentation, and traceability of changes to the parameter values, distributions and metadata. The PAPDB parameter database and associated metadata are maintained in Carlsbad, New Mexico, by SNL. Hard copies of documentation supporting the parameters and their values are maintained in SNL's WIPP Records Center in Carlsbad. The supporting documents are tracked by SNL's Electronic Record Management System (ERMS), through which a unique identifying number is assigned to each document.

The Agency has reviewed the PAPDB life-cycle documentation (e.g., Requirements Document, Design Document, Verification and Validation Plan) to determine whether the PAPDB migration to a new platform meets the requirements specified in §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7. In addition to the life-cycle documentation, the Agency reviewed several migration reports to further evaluate the migration testing procedures and results (Kirchner and Long 2012; Kirchner 2011).

Based upon these reviews, the Agency found that the PAPDB verification tests adequately test all the functional requirements necessary for PAPDB Version 2.00 to effectively support PA, and that PAPDB Version 2.00 has successfully passed the tests. Furthermore, the Agency determined that SNL has developed documentation that is consistent with life-cycle and testing requirements outlined in §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7. The Agency therefore concludes that PAPDB Version 2.00 is in compliance with §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7 and that PAPDB Version 2.00 is approved for WIPP PA use in PA calculations.

1.0 INTRODUCTION

This appendix describes the results of the U.S. Environmental Protection Agency's (EPA or the Agency) review of Performance Assessment Parameter Database (PAPDB) migration, design modifications and testing activities performed by Sandia National Laboratories (SNL) in support of their ongoing Performance Assessment (PA) activities at the Waste Isolation Pilot Plant (WIPP).

In 2011, SNL developed new database software, called PAPDB Version 2.00, to replace the previous PAPDB Version 1.00, and migrated the parameter values and associated metadata from Version 1.00 to Version 2.00. The database structure was modified to make it easier to use and to facilitate parameter data access from the PA codes on Solaris, Linux, and VMS platforms. The new database resides on a MySQL Server and is physically located on an Intel-based server running Solaris 11 (Kirchner and Long 2012). The database migration process is more fully described by Kirchner (2011).

A primary improvement in the new database is the ability to accurately retrieve parameter values used in earlier PAs. PAPDB Version 2.00 is designed to default to the parameter value most recently entered into the database, and to automatically log in the analysis that used the parameter value. However, a previous value can also be returned by specifying an earlier analysis. A similar functionality was provided in PAPDB Version 1.00, but did not work properly (Kirchner 2011). In addition, distributed parameters are now assigned a default value when the distribution is not to be sampled. For example, when assigning three-dimensional, isotropic permeability values to a material, only the value of PRMX_LOG is randomly sampled using the PRELHS code. The constant default values for PRMY_LOG and PRMZ_LOG are taken from the database as placeholders and are subsequently reassigned the same value as PRMX_LOG in the BRAGFLO ALGEBRA file.

The methodology for retrieving parameter values from the database remains essentially unchanged. The MATSET code retrieves the default value for every parameter in the analysis. Parameter values that are to be sampled are identified in the input files to the PRELHS code, which supplies that information to the LHS code. The LHS code then retrieves 100 sample values per replicate from the database and supplies them to the post LHS code. If a parameter has been retrieved by LHS, the POSTLHS code replaces the default parameter value retrieved by MATSET with the parameter value retrieved by LHS. In a subsequent step, the remaining default values retrieved by MATSET for distributed parameters are replaced by the desired value in the ALGEBRA1 file, as described in the example above. For constant parameters, the default value is the constant value and remains unchanged. Although the default values for distributed parameters are typically the means or medians of the distributions, any value can be used as the default value.

The PAPDB Version 2.00 database tables are constructed to store the data residing in PAPDB Version 1.00. An Access database, ParamTransfer.mdb, was used to transfer the data from PAPDB Version 1.00 to PAPDB Version 2.00. Most of the transfers were done using queries to extract the data from the PAPDB Version 1.00 and append it to tables in the PAPDB Version

2.00. The transfers were checked for completeness using a series of queries and, for the parameter value data, two VBA (Visual Basic for Applications) routines. The queries were designed to compare the PAPDB Version 2.00 values with the corresponding values in PAPDB Version 1.00 and to show only records in the PAPDB Version 1.00 that were not matched in the PAPDB Version 2.00. Thus, the desired outcome was an empty data set.

Verification of the transfer process involved a transfer of the data followed by the deletion of selected records from the various tables and execution of the various queries to show that the missing records were detected. Following the verification of the procedures, the data were transferred once again and the same queries run to verify that no records were dropped during the transfer. It was also necessary to generate a report that showed the records whose value string could not be matched due to differences in formatting. The records shown in that report were compared and verified to be equivalent.

In addition to the records transferred from PAPDB Version 1.00, two sets of records were developed that were missing from the original database. The design of the PAPDB Version 1.00 did not allow for multiple analyses being run under a single AP, as was done for AP-132. It appears to have kept only the records from the most recent retrieval of parameters. Furthermore, the retrieval of parameters by MATSET for use in NUTS seems to never have been recorded. To capture these usages of parameters, a series of queries were run to insert the missing records.

The data were transferred following verification of the transfer procedures. SNL and the Agency verified an accurate data transfer by reviewing the comparison reports, as documented by Kirchner and Long (2012). Problems found by SNL in initial data transfers were corrected and in the final transfer, all of the comparison tests were successful except one, where the data did not exactly match due to formatting differences. Those test results were reviewed manually and SNL concluded that the values of the two data sets were found to be equivalent. The Agency agrees with this assessment.

The remaining sections present the approach that the Agency followed to determine whether PAPDB Version 2.00 is in compliance with §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7.

2.0 GENERAL APPROACH

To demonstrate that computer software is in compliance with disposal regulations outlined in §194.22, SNL established a life-cycle management process for software used to support their PA activities. Their qualification approach for the software follows the life-cycle phases outlined in ASME NQA-2a-1990 addenda, part 2.7, as follows:

- Planning
- Requirements
- Design
- Implementation
- Validation
- Installation and Checkout
- Maintenance
- Retirement

SNL implements the life-cycle phases using an iterative or sequential approach and each phase is supported with relevant documentation (e.g., Design Document, Verification Plan, and Implementation Document).

The Agency's review of the adequacy of SNL's implementation and testing of the database migration was initiated in October 2012 with an on-site review of the PAPDB and its PA code interfaces. SNL maintains the parameter database and associated metadata in Carlsbad, New Mexico. Hard copies of documentation supporting the parameters and their values are retained in SNL's WIPP Records Center in Carlsbad. SNL tracks the supporting documents by an Electronic Record Management System (ERMS) in which a unique identifying number is assigned to each document.

The primary objectives of the Agency's review of the database migration to the new platform were to assess the adequacy of the documentation, traceability of the modifications and reliability of the testing. The scope of the review was primarily focused upon reviewing the following documentation for PAPDB (Version 2):

- Analysis Plan (Kirchner 2011)
- Software Quality Assurance Plan (Kirchner 2011a)
- Requirements Document (Kirchner 2011b)
- Verification Validation Plan (Kirchner 2011c)
- Design Document (Kirchner 2012)
- Validation Document (Kirchner 2012a)
- Installation and Checkout (Kirchner 2012b)
- Migration Report (Kirchner and Long 2012)

The transcription accuracy of the migration and the traceability of changes to the parameter values and metadata that were made for the PCS-2012 PA were also evaluated (Appendix A).

3.0 REVIEW OF THE PAPDB MIGRATION

3.1 RATIONALE FOR DATABASE MIGRATION AND UPDATE

In 2011, the Parameter Database (PAPDB Version 1.0) was revised to Version 2.0 and migrated from the Microsoft SQL on a Windows Server to the MySQL software running Solaris 11. Prior to being migrated to MySQL, the parameter database (PAPDB) was physically located on an Intel-based server also running Solaris 11, tgw.sandia.gov. SNL migrated the database to facilitate access to the parameter data from the PA codes located on Solaris, Linux and VMS.

The primary function of PAPDB is to supply parameter values for use in PA and PAPDB contains data values, associated codes, references for relevant documents, usage and additional information documenting the parameters used in PA. These data are exported to the other PA codes via routines in the SDBREAD_LIB. In PAPDB Version 1.00 the numeric data was encoded for a parameter, such as the mean, median and standard deviation, into an XML-formatted string. This was done to facilitate the display of the data *via* a web browser, which was the original goal for the database. SNL, however, notes that this design complicates the interface to the PA codes since the desired values must be unpacked from the XML string and converted from text to numeric data.

To alleviate the complicated design, SNL redesigned PAPDB Version 1.00 into Version 2.00 which has no stored procedures or queries. In Version 2.00, the business rules that had been implemented as stored procedures in Version 1.00 have either been eliminated through the redesign of the database or have been implemented in the revision of SDBREAD_LIB. For example, the logging of parameter export by analysis and code is now the responsibility of SDBREAD_LIB rather than implemented as a stored procedure. Thus, the PAPDB Version 2.00 provides storage for the data but has no inherent functionality.

The specifications for the PAPDB Version 1.00 state that the parameter values obtained via SDBREAD_LIB should default to the most recent version unless an earlier version is specified (PAPDB Version 1.00 Requirements Document). SDBREAD_LIB contains the routines that are the interface between the performance assessment (PA) codes and the database. However, SNL notes that this functionality appears to be flawed since the ability to specify earlier versions does not seem to work properly (Kirchner 2011). Special analyses run by SNL to support PA over the last few years often require new parameter values, with subsequent return to the parameters of the last PA baseline calculation. Thus, the typical approach that SNL has followed has been to 1) enter the new values of some parameters for the PA, 2) run the PA, and 3) restore the values from the last baseline calculation by re-entering them. This process is unproductive because it requires a number of changes to the database, adds redundant data to the database, and increases the chance of making an error when restoring baseline values. Furthermore, SNL describes a problem that arises in the 'AnalysisID' field of the PAPDB (Version 1)(Kirchner 2011). This field reflects the analysis when parameters are first defined, but in some cases those parameters were not used in that analysis, e.g. the lower limit of the distribution assigned to BOREHOLE:TAUFAIL was redefined in AP-131 (Kirkes and Herrick 2006) and entered into the database but the PA for AP-131 did not use those new values. In this case, the code that used

BOREHOLE:TAUFAIL, PRELHS, was not run and instead the LHS sampled values from a previous analysis were used in the AP-131 PA. As noted by SNL, no record was entered into the 'AnalysisRetrievalHistory' and thus the PAPDB Version 1 database could not be used to determine which version of the parameter was really used in the PA.

3.2 MIGRATION OBJECTIVES

SNL designed the MySQL version of the PAPDB (PAPBD Version 2.00) to store numeric values associated with parameters in a numeric field that allow the codes to specify a specific version of a parameter value to be returned by specifying an analysis.

To allow a determination of which version of the parameter was used in the PA SNL added a new table to map from an analysis name to a version for each parameter used in an analysis. In addition, parameters assigned distributions are assigned a 'value' property in the PAPDB Version 2.00 that are used as the default value when the distribution is not to be sampled. In PAPDB Version 1.00 the median is used as the default value for most distributions and the mode for triangular distributions. SNL notes that this has the consequence that the value assigned to the median has not always been the true median of the distribution. SNL also indicates that this situation has no impact on the distribution sampled by LHS because for the majority of the distributions, excluding the triangular, cumulative and Student's distributions, it is only the maximum and minimum values that are used to specify the distributions. SNL added the default values in the PAPDB Version 2.00 to remedy this issue.

3.3 APPROACH

The PAPDB Version 2.00 database tables are constructed to store the data residing in the PAPDB Version 1.00. SNL, however, simplified the structure of the database by eliminating the many 'index' tables, such as the table dbo_Material which lists the material name along with a numeric index associated with the material name. The number of tables was reduced from 41 to 14 for inclusion in PAPDB Version 2. A number of the tables in PAPDB Version 1 were meant for functions that were never implemented. Other tables stored values that were always the same, or which were never used in the parameters viewer or to retrieve values for the codes. SNL did not transfer these tables to PAPDB Version 2. In some cases, SNL combined two or more tables into one.

3.4 SOFTWARE

SNL used an Access database, ParamTransfer.mdb, to transfer the data from PAPDB Version 1 to PAPDB Version 2.00. Most of the transfers were done using queries to extract the data from the PAPDB Version 1.00 and append it to tables in the PAPDB Version 2.00. SNL notes that there is some order dependency on transferring the data and therefore, SNL created a VBA (Visual Basic for Applications) routine to execute the transfers in the proper order. This routine also deletes the current contents of each PAPDB Version 2.00 table before appending the data. The transfer of the data from 'dbo ParameterRecord' requires additional processing in VBA code to parse the XML 'value' field and extract the numeric data from the string. A series of queries are used in

the transfer of data from tables in PAPDB Version 1 to equivalent tables in PAPDB Version 2. There are two tables that are not populated from the PAPDB Version 1.00: the 'DatabaseVersion' table, used to store the current version number of the database, and the Attributes table, which lists the names of the attributes that might be assigned to a parameter, such as the mean, median or constant value. SNL expects that the Attributes table will be used in the future to facilitate entering new parameter values or for displaying results.

3.5 ACCEPTANCE CRITERIA

SNL checked the transfers among the tables for completeness using a series of queries and, for the parameter value data, two VBA routines. SNL designed the queries to compare the PAPDB Version 2.00 values to the corresponding values in the PAPDB Version 1.00 and to show only records in the PAPDB Version 1.00 that are not matched in the PAPDB Version 2.00. Thus, if the tables transferred correctly the result would be an empty set. SNL notes that the comparison of numeric values back to the values stored in the XML strings of 'dbo_parameterRecord' is problematic because the numeric values were stored using several different formats, e.g. 1, 1.0, 1.00, 1.0e+00, etc. There were three formats that were used most frequently and VBA code was used to generate three XML strings from the PAPDB Version 2.00 data for each record of the dbo_parameterRecord using these formats. Therefore, SNL concludes that the comparison in this case succeeds if any of the three generated XML strings exactly matches the original XML string. The Agency agrees with this assessment. SNL generated a report to display the strings that could not be matched in this way. A visual examination of this report by the Agency found that the XML strings are equivalent.

3.6 TESTING METHODOLOGY

3.6.1 Migration from SQL to MySQL Server

SNL completed two major tasks in the transfer process, 1) verification that the transfer procedures transfer the data, and 2) performing the transfer. The verification process actually involved a transfer of the data, followed by the deletion of some records from the various tables and execution of the various queries to show that the missing records are detected. Following the verification of the procedures the data are transferred once again and the same queries run to verify that no records were dropped during the transfer. It is also necessary to generate a report that shows the records in dbo_parameterRecords whose XML value string could not be matched are due to differences in immaterial factors (e.g., formatting, run dates).

3.6.2 Code Functionality

The Verification and Validation Plan/Validation Report (VVP) for the PAPDB (Kirchner 2011a) describes how the functional requirements (Table 3.1) described in the Requirements Document (Kirchner 2011b) will be tested, and the Agency found that it is in conformance with WIPP QA NP 19-1 Revision 12, Software Requirements. The Validation Document (VD) describes the success of the verification and validation tests. SNL used the utility program Test_ParamDB (Appendix 1 of Kirchner 2011a) to verify that the parameter data can be extracted from the PAPDB Version 2.00 using a FORTRAN application linked to a set of C routines. Similar

routines were implemented in SDBREAD_LIB. The PAPDB database was tested by SNL using the following environment:

Database Server OS: Solaris 11
Database Software: MySQL 5.1.37
Database Name: ParamDB

The Solaris operating system was upgraded to Version 11 following the publication of the VVP. The version of MySQL was changed because Version 5.1.37 was provided with the installation of the operation system from Oracle. The FORTRAN code used by SNL to test the database was run on the Solaris platform. The application of service packs (whether to the OS or to the database software) or patches have no impact on the test cases.

While individual tests can be run and visual inspection can be applied to verifying the results, the test framework provided by SNL has been developed to allow for inspection of the results of the tests by viewing an output file produced by running all of the tests. There are three general types of testing that have been performed: getting the database version, retrieving parameter data, and logging production retrievals.

Each major 'functional area' being verified is done through a conceptual grouping of test cases into a 'test'. Each 'test' is a grouping of one or more test cases that all support the verification of a function supplied by the software. Each of the test cases for a particular test help support the testing of a major software function.

All tests have the same acceptance criterion: the expected output and the returned output must be identical in all relevant details. Differences in dates of log records, for example, are expected to be different. Neither spaces nor word case in output values are considered to be significant (relevant). Any discrepancy that cannot be explained results in a test failure.

Table 3.6. Software Requirements for the PAPDB Version 2 and Implementation Methods

Functional Requirements		Implementation Method	Verification
F1	The database must allow the user to retrieve the version number of the database. [PAPDB, Version 2.00 software must provide the version number of the database.]	The table DatabaseVersion contains the current version number of the database.	Version is retrieved and displayed using Test_ParamDB utility.
F2	The database must be able to receive all relevant data from the PAPDB 1.00 [Documentation of the successful transfer of all relevant data is described in the report documenting the transfer under AP-158, (Kirchner 2011)]	The tables described in Table 1 of Kirchner (2012a) contain fields to store all relevant data.	This requirement is verified by the procedures described in AP-158 (Kirchner 2011)
F3	The database must provide the transfer of parameter data from the PAPDB to the codes or user interfaces that request them. [Numeric values for the parameters are stored in double precision fields. These data must be transferred, within the limits of floating point data, from the database to the applications requesting them.]	MySQL provides the mysqlclient library for accessing data. The data are passed as strings and must be converted to the appropriate type, double in the case of numerical values, using the standard conversion function 'atof()'. SDBREAD LIB contains the code for accessing the PAPDB data for use by the PA codes.	Verification is done with the Test_ParamDB utility.

Table 3.6. Software Requirements for the PAPDB Version 2 and Implementation Methods

Functional Requirements		Implementation Method	Verification
F4	The database must allow storage and retrieval of data by material, property, analysis and analysis revision, and code. [The goal is to be able to retrieve parameter values used by a code in an analysis. Queries which do not properly specify the retrieval of a parameter should fail to return a record set.]	The specified keys are used, as appropriate, in the tables listed in Table 1 of Kirchner (2012a).	Verification of retrieval is done with the Test ParamDB utility.
F5	The database must allow for logging of retrievals by analysis, analysis revision, and code. [Logging should occur only for the execution of 'official' PAs, i.e. those conducted under the WIPP QA program and defined by an analysis plan. Access should be granted for unofficial use but no logging performed. Control of logging will be managed by the interface routines like those in SDBREAD_L1B (Gilkey 2012)	The table Analysis Retrieval History is designed to record the export of data from the PAPDB. The control of the logging resides with the code interface, typically SDBREAD LIB. It is equivalent to the table dbo_Analysis Retrieval History in the PAPDB Version 1.00 except that it also records the revision number of the analysis.	Verification of logging is done with the Test ParamDB utility.
Attributes – Security		**Design/Implementation Method**	
A1	The database software must control write access to the data tables using passwords. The database is defined as a MySQL schema. [User accounts in the database and the account used to access the database through code must be assigned passwords. Read-only access should be provided by default and write rights should be granted only to those users authorized to make changes or additions to the database. The database server computer is protected using passwords as required by Sandia National Laboratories.	lySQL controls access to data using user passwords and the delegation of rights to the users. The PAPDB database administrator has exclusive permission to create users and to assign privileges to the users.	Verification of control via MySQL user privileges is done with Test ParamDB.

3.6.3 Test Cases

SNL designed nine (9) test cases in which all or some of the following are specified: material, property, analysis, analysis revision number, code, and code version. The version number of the database is output for every test. The test displays the version number of the database, the attributes assigned to the parameter for a specific analysis and analysis revision, discrete values assigned to that version's parameter's distribution, the documents associated with the parameter, and the analyses where the various versions of the parameter are first defined. These data correspond to the information displayed in the parameter viewer application used with Version 1.00 of the database. The test cases are:

- Test Case 1- Display the information for a parameter having no defined distribution
- Test Case 2- Display the information for a model parameter having a distribution with standard statistical parameters (e.g., a distribution other than a Student, Delta or Cumulative).
- Test Case 3- Display the information for a parameter having two sets of values within one analysis
- Test Case 4- Display the information for a parameter having a Student distribution

- Test Case 5- Display the information for a parameter having a Delta distribution
- Test Case 6- Display the information for a parameter having a Cumulative Distribution
- Test Case 7- Display that nothing is returned for a parameter having a non-existent material:property
- Test Case 8- Show that logging a record identical to one existing in Analysis Retrieval History updates the timestamp.
- Test Case 9- Show that a user not having insertion and deletion privileges cannot delete or insert a record into the Analysis Retrieval History table

3.6.4 Execution of Tests

SNL conducted the tests using the FORTRAN code Test_ParamDB and the scripts RunTests.csh and RunTest9.csh. The source code, executable file, makefile (build script), a copy of the database as a sqldump file, the Test_ParamDB.out file and the test scripts were stored in the CVS repository $CVSLIB/Databases/ParamDB. Several of these output files were reviewed by the Agency during the onsite review in October 2012.

The output of each test was stored in the file Test_ParamDB.out. This file becomes the expected output for future regression tests. The test outputs were verified by SNL by inspecting database tables using the WIPP Parameter Viewer (a web application) to determine if the correct results were returned. The Agency verified a subset of these test results with the WIPP Parameter Viewer and all of the hardcopy output. Although the VVP stated that the Version 1.00 PAPDB would be used for verification, SNL used Version 2.00 because: 1) the design of the Parameter Viewer for the Version 1.00 database was found to omit some documents associated with the parameters, and 2) the complete transfer of data from the Version 1.00 to the Version 2.00 database was verified and documented in Kirchner (2012).

3.7 TEST RESULTS

While individual tests can be run and visual inspection can be applied to verifying the results, the test framework provided has been developed to allow for inspection of the results of the tests by viewing an output file produced by running all of the tests. The results of the tests were compared to the data stored in the database and, for sample values for some distributions, viewing the data from the Distribution Data table using the Parameter Transfer database described in Kirchner (2012).

Failure in the transfer of data from the PAPDB Version 1.00 would result in missing records in one or more of the PAPDB Version 2.00 tables or having data in corresponding records that do not match. Potentially missing or erroneous records are identified using a series of 'Check' queries. SNL verified that these Check queries functioned correctly by 1) transferring the data, and 2) deleting one or more records and modifying values in the remaining records from each of the tables listed in Table 6 and 3 in Kirchner (2012a). Since the record set of the Check queries were all empty the transfer was determined by the Agency to be successful and was is indicated

in the Check Transfer form documenting that PAPDB Version 2.00 meets the requirements listed in the VVP.

4.0 SUMMARY AND CONCLUSIONS

The primary objectives of the Agency's review of the PAPDB database migration to the new platform are to assess the transcription accuracy, documentation, and traceability of changes to the parameter values, distributions and metadata. The PAPDB parameter database and associated metadata are maintained in Carlsbad, New Mexico, by SNL. Hard copies of documentation supporting the parameters and their values are maintained in SNL's WIPP Records Center in Carlsbad. The supporting documents are tracked by SNL's Electronic Record Management System (ERMS), through which a unique identifying number is assigned to each document.

The Agency's review of the adequacy of SNL's implementation and testing of the database migration was initiated in October 2012 with an on-site review of the PAPDB and its PA code interfaces. The Agency has reviewed the PAPDB life-cycle documentation (e.g., Requirements Document, Design Document, Verification and Validation Plan) to determine whether the PAPDB migration to a new platform meet the requirements specified in §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7. In addition to the life-cycle documentation, the Agency reviewed several migration reports to further evaluate the migration testing procedures and results (Kirchner and Long 2012; Kirchner 2011).

Based upon these reviews, the Agency found that the PADB verification tests adequately test all the functional requirements necessary for PAPDB Version 2.00 to effectively support PA, and that PAPDB Version 2.00 has successfully passed the tests. Furthermore, the Agency determined that SNL has developed documentation that is consistent with life-cycle and testing requirements outlined in §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7. The Agency therefore concludes that PAPDB Version 2.00 is in compliance with §194.22, §194.23 and ASME NQA-2a-1990 addenda, part 2.7 and that PAPDB Version 2.00 is approved for WIPP PA use in PA calculations.

5.0 REFERENCES

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