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Waste Isolation Pilot Plant

Analysis Package for Salado Flow Modeling Done in the AP-161 (PCS-2012) Performance Assessment

Revision 0

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1 EXECUTIVE SUMMARY

Waste panel closures comprise a repository feature that has been represented in WIPP PA since the original Compliance Certification Application (CCA) of 1996. The 1998 rulemaking that certified WIPP to receive transuranic waste placed conditions on the panel closure design to be implemented in the repository. The mandated design consists of a concrete block wall, an open drift section, and a concrete monolith, and was termed the "Option D" panel closure. Following the selection of the Option D design in 1998, the engineering of the panel closure has been re-assessed, and a revised design has been established that is simpler, cheaper, and easier to construct. The revised panel closure design, termed the Run-of-Mine Panel Closure System (ROMPCS), is comprised of 100 feet of ROM salt with barriers at each end. The PCS-2012 PA quantifies WIPP repository performance impacts associated with the replacement of the currently approved Option D panel closure design with the ROMPCS. Impacts are assessed via a direct comparison of results obtained in the PABC-2009 (where Option D was used) to those calculated in the PCS-2012 PA with the ROMPCS.

For undisturbed conditions, implementation of the ROMPCS yields higher long-term waste panel pressure (on average) than was seen in the PABC-2009. The increase in mean waste panel pressure is accompanied by an increase in the average waste panel brine saturation for the ROMPCS results. The ROMPCS design allows more brine inflow to the waste panel during the first 200 years when compared to Option D results. This increased brine inflow, combined with the tightness of the ROMPCS after 200 years, results in increased waste panel gas generation (on average) and a subsequent increase to waste panel mean pressure.

The lower long-term permeability range of the ROMPCS as compared to Option D yields a period of increased waste panel pressurization following an E1 intrusion. The increased waste panel mean pressure slightly inhibits brine flow into the panel after the intrusion, with a corresponding slight decrease to the mean waste panel brine saturation as compared to PABC-2009 E1 intrusion results.

For E2 intrusion scenarios, the PCS-2012 PA mean waste panel pressure is higher than that seen in the PABC-2009 at the time of intrusion, and it remains higher for the duration of the 10,000 year regulatory period. Similarly, the mean waste panel brine saturation is higher at the time of intrusion in the PCS-2012 PA, resulting in higher long-term waste panel brine saturations for E2 intrusion scenarios.

Brine flows up the borehole that are used to calculate the radionuclide source term in WIPP PA are negligibly impacted by the replacement of Option D with the ROMPCS.

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2 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, has been developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations (CFR), Part 191. The DOE demonstrates compliance with the containment requirements according to the Certification Criteria in Title 40 CFR Part 194 by means of performance assessment (PA) calculations performed by Sandia National Laboratories (SNL). WIPP PA calculations estimate the probability and consequence of potential radionuclide releases from the repository to the accessible environment for a regulatory period of 10,000 years after facility closure. The models used in PA are maintained and updated with new information as part of an ongoing process. Improved information regarding important WIPP features, events, and processes typically results in refinements and modifications to PA models and the parameters used in them. Planned changes to the repository and/or the components therein also result in updates to WIPP PA models. WIPP PA models are used to support the repository recertification process that occurs at five-year intervals following the receipt of the first waste shipment at the site in 1999.

Waste panel closures comprise a repository feature that has been represented in WIPP PA since the original Compliance Certification Application (CCA) of 1996. Panel closures are included in WIPP PA models principally because they are a part of the disposal system, not because they play a substantive role in inhibiting the release of radionuclides to the outside environment. The DOE stated in the CCA (DOE 1996) that *"The panel closure system was not designed or intended to support long-term repository performance."* The 1998 rulemaking that certified WIPP to receive transuranic waste placed conditions on the panel closure design to be implemented in the repository. The mandated design consists of a concrete block wall, an open drift section, and a concrete monolith, and was termed the "Option D" panel closure. Following the selection of the Option D design in 1998, the engineering of the panel closure has been re-assessed, and a revised design has been established that is simpler, cheaper, and easier to construct. The revised panel closure design, termed the Run-of-Mine Panel Closure System (ROMPCS), is comprised of 100 feet of ROM salt with barriers at each end. The ROM salt is generated from ongoing mining operations at the WIPP and may be compacted and/or moistened as it is emplaced in a panel entry. The barriers consist of ventilation bulkheads, similar to those currently used in the panels as room closures.

The DOE has submitted a planned change request (PCR) to the EPA requesting that the EPA modify Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194 (EPA, 1998) for the WIPP. The PCR submitted to EPA requests that Condition 1 be changed, and that the ROMPCS design be approved for use in all panels (DOE, 2011). In support of this rulemaking change, a performance assessment has been completed that incorporates the ROMPCS design into the current PA baseline established by the 2009 Performance Assessment Baseline Calculation (PABC-2009) (Clayton et al., 2010). The name given to this new panel closure PA is PCS-2012, and the plan for its execution is detailed in AP-161 (Camphouse 2012a). PCS-2012 PA results are compared to those obtained in the PABC-2009 as a means to quantify

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potential impacts due to the panel closure redesign. This analysis package consists of the Salado flow modeling component of the PCS-2012 PA.

3 CONCEPTUAL APPROACH FOR PCS-2012 PA

The conceptual models implemented in the BRAGFLO simulations for the PCS-2012 PA are unchanged from those used in the PABC-2009. The computational grid, particularly the material map used by BRAGFLO, is changed for the PCS-2012 PA in order to incorporate the ROMPCS into the calculations. These changes are discussed below. Gas generation rates and the creep closure model have not changed from the PABC-2009 to the PCS-2012 PA. Consequently, the same porosity surface is used in this calculation as was used in the PABC-2009.

3.1 Repository Representation in BRAGFLO

The goal of the PCS-2012 PA is to quantify regulatory compliance impacts resulting from the replacement of the Option D panel closure with the ROMPCS. For the sake of reference, a schematic of the Option D panel closure is given in Figure 3-1. As seen in that figure, the Option D panel closure is 40 meters long and consists of three components, namely a concrete explosion wall, an open drift section, and a concrete monolith. This panel closure has been implemented in PA analyses done in support of WIPP re-certification since the CRA-2004 PA (Stein & Zelinski 2003). The PABC-2009 is the current regulatory baseline. The BRAGFLO grid and material map used in the PABC-2009 also represented the Option D closure, and is shown in Figure 3-2. Note that a minor error has been corrected in the material map schematic shown in Figure 3-2. That figure depicts an E1 intrusion into the repository. The BRAGFLO schematic included with the PABC-2009 Salado flow analysis package (Nemer 2010) depicts the lower borehole extending only to the bottom horizon of the lower DRZ. In actuality, the lower borehole extends to the floor of the intruded waste panel. The PABC-2009 BRAGFLO grid and material map shown in Figure 3-2 has been modified so that it represents the correct extent of the lower borehole in an E1 intrusion.

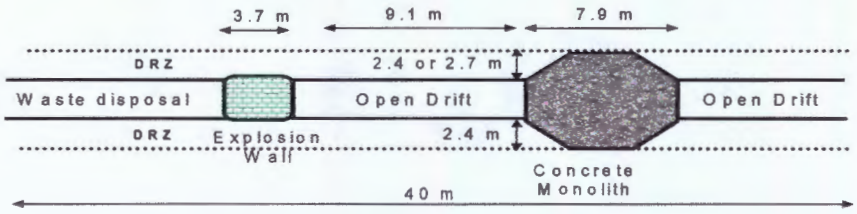

Figure 3-1: A Schematic of the "Option D" Panel Closure

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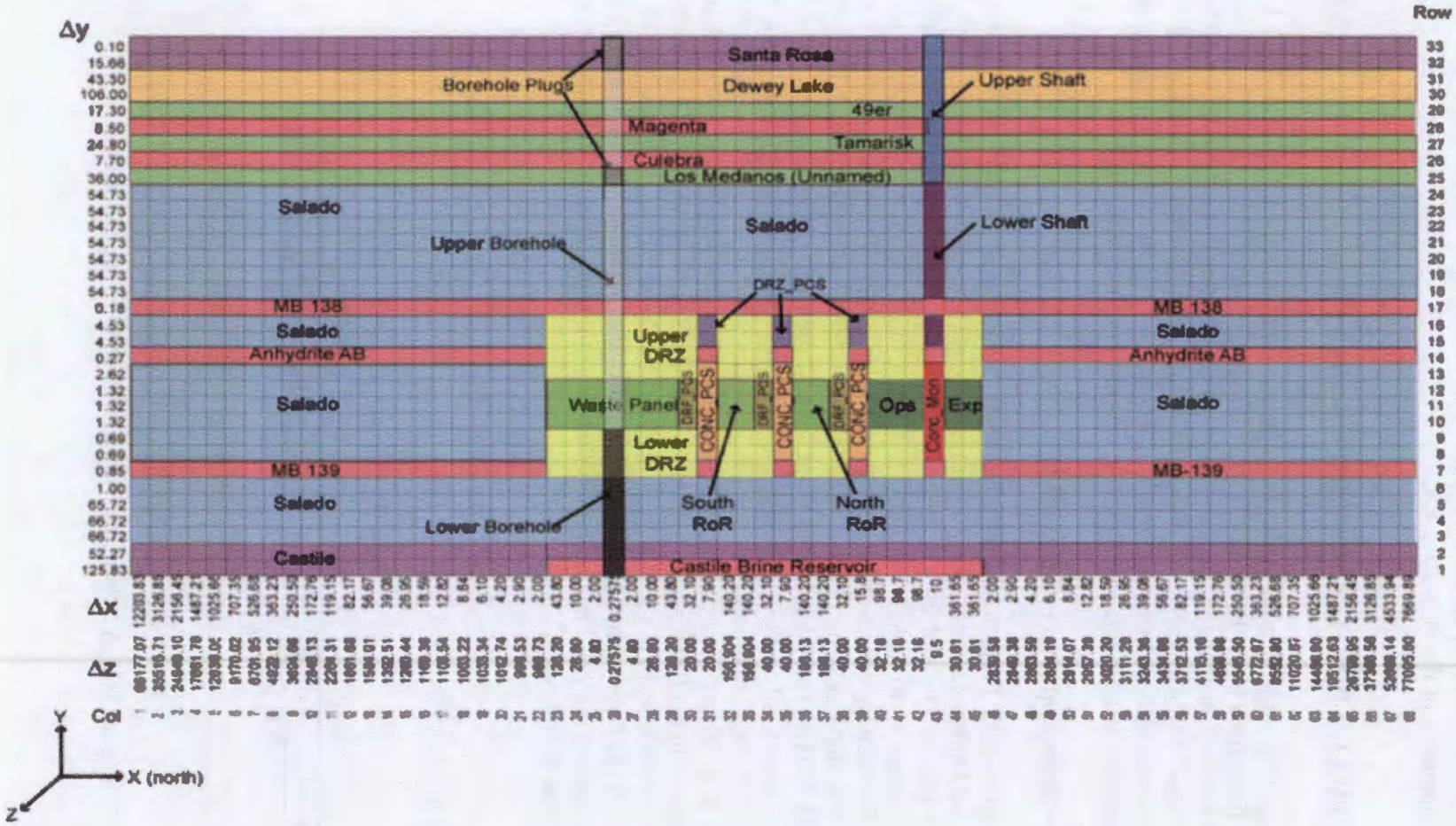

Figure 3-2: PABC-2009 BRAGFLO Grid and Material Map (Δx, Δy, and Δz dimensions in meters).

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Several aspects of the Option D implementation in BRAGFLO are worth noting. First, the concrete monolith portion of the panel closure is "keyed in" to the lower and upper DRZ. The monolith portion of the panel closure is represented by material CONC_PCS, and this material extends above and below the upper and lower horizons of repository waste panels, extending into the surrounding DRZ.

The permeability in the x-direction prescribed for material CONC_PCS in the PABC-2009 varies between a minimum value of 2.0×10^{-21} m^2 and a maximum of 1.0×10^{-17} m^2. The value assigned for each particular vector is obtained through parameter sampling over this range. The impact of the Option D panel closure on the overlaying DRZ in the PABC-2009 is also of note. The Option D panel closure was modeled as having an immediate healing effect on the DRZ above it in the PABC-2009. This healed portion of DRZ is represented by material DRZ_PCS, and its spatial extent can be seen in Figure 3-2. The permeability range assigned to material DRZ_PCS is equal to that prescribed to material CONC_PCS in the x-direction.

Segments of interbed material were included in the PABC-2009 representation of the Option D panel closure. As seen in Figure 3-2, segments of the Anhydrite AB layer are located between materials CONC_PCS and DRZ_PCS. Likewise, segments of the MB-139 layer can be found between material CONC_PCS and the underlaying Salado halite. The reasoning for including these interbed segments is provided in the BRAGFLO analysis performed in support of CRA-2004 (Stein & Zelinski 2003). Essentially, they are included to capture the impacts of brine and gas effectively bypassing the panel closure by flowing through the interbed layers.

Now that the most salient features of the Option D implementation in BRAGFLO have been discussed, attention is given to the implementation of the ROMPCS in the PCS-2012 PA. The ROMPCS is comprised of 100 feet of run-of-mine (ROM) salt with barriers at each end, and is illustrated in Figure 3-3. The ROM salt is generated from ongoing mining operations at the WIPP and may be compacted and/or moistened as it is emplaced in a panel entry. The barriers consist of ventilation bulkheads, similar to those currently used in the panels as room closures. The ventilation bulkheads are designed to restrict air flows and prevent personnel access into waste-filled areas during the operational phase. In Panels 1, 2, and 5, where explosion walls fabricated from concrete blocks have already been emplaced in the panel entries, an explosion wall is the inner barrier and a ventilation bulkhead will be the outer barrier, as shown in Figure 3-3(b). Explosion walls are inspected on a regular basis, and their anticipated condition is also assessed through numerical modeling (e.g. RockSol, 2006). Installed explosion walls show surface spalling or slabbing of the concrete blocks as a result of the loading caused by inward creep of the salt. Numerical stress analysis of the concrete explosion wall has demonstrated that the free faces and the rib contacts will be in a condition of plastic yield with an unyielded core by 7 years after emplacement (Rocksol, 2006, Figures 7 and 10). No long term stress analyses have been carried out; however, it is expected that the spalling and yield will be progressive, and that the walls will not be significant structures after the initial 100 year time period, due to the brittle, non-plastic behavior of concrete. The ventilation bulkheads and explosion walls are therefore expected to have no significant impact on long-term performance of the panel closures and are therefore not included in the PCS-2012 PA representation of the ROMPCS. Consequently, the ROMPCS is modeled as consisting of 100 feet of ROM salt in the PCS-2012 PA.

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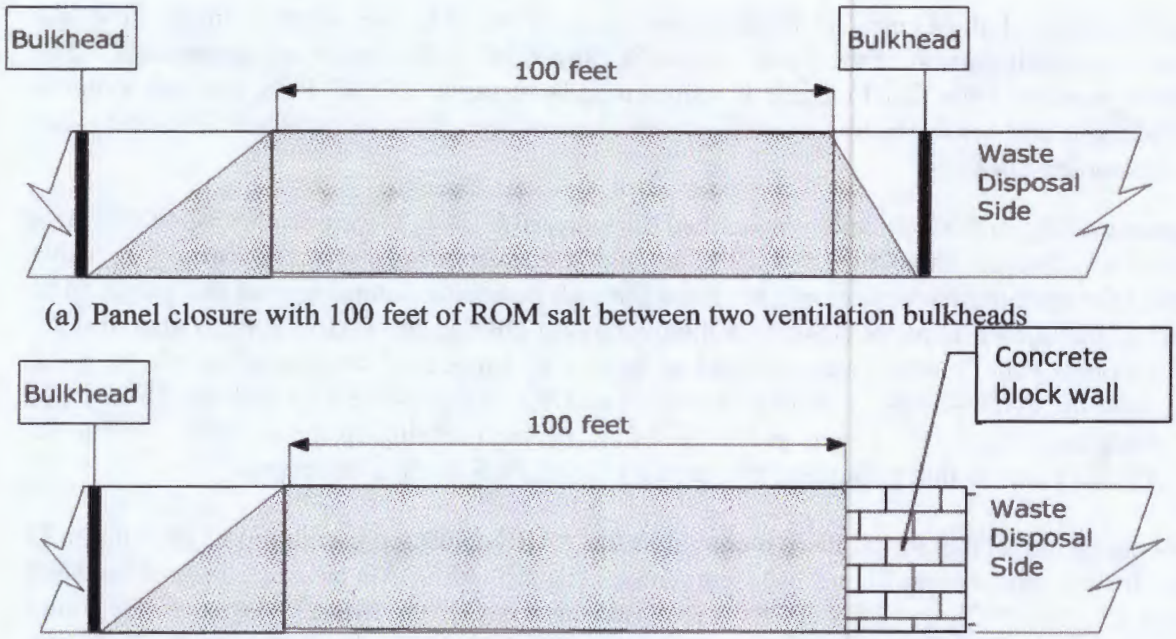

(a) Panel closure with 100 feet of ROM salt between two ventilation bulkheads

(b) Panel closure with 100 feet of ROM salt between a ventilation bulkhead & explosion wall

Figure 3-3: Schematic Diagram of the ROMPCS

The ROMPCS properties are based on three time periods: from 0 to 100 years, from 100 years to 200 years, and from 200 years to 10,000 years. Three time periods are appropriate because the process to consolidate the ROM salt occurs over a primary time scale of approximately 100 years, while the process to heal fractures in the DRZ surrounding the PCS occurs over a longer time scale of approximately 200 years. The ROM salt is therefore represented by three materials, denoted as PCS_T1 for the first 100 years, PCS_T2 from 100 to 200 years, and PCS_T3 for 200 to 10,000 years. Analyses and calculations have shown (Camphouse et al 2012a) that the time-dependent back stress imposed on the DRZ by the re-consolidated ROM salt panel closure does not become appreciable until roughly 200 years after emplacement of the ROM salt in the drift. As a result, it is reasonable and appropriate to maintain the same properties for the DRZ above and below the ROMPCS for the first 200 years after closure as are specified to the DRZ surrounding the disposal rooms. After 200 years, the DRZ above and below the ROMPCS is modeled as having healed, and this sub-region of the DRZ is represented by material DRZ_PCS. Material DRZ_PCS has the same property values in the PCS-2012 PA as were assigned to it in the PABC-2009.

The 200-year delay of DRZ healing in the PCS-2012 PA is an important distinction between the panel closure representations used in the PABC-2009 and the PCS-2012 PA. As noted above, the Option D panel closure was modeled in the PABC-2009 (and prior analyses) as having an immediate healing effect on the DRZ above it, with material DRZ_PCS being in place at t = 0. In contrast, the ROMPCS in the PCS-2012 PA is modeled as having no healing effect on the DRZ until 200 years after panel closure emplacement. For the first 200 years, the DRZ above and below the ROMPCS is indistinguishable from the DRZ above and below the waste panels.

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The DRZ overall (PA parameter DRZ_1) has a permeability range varying from a minimum value of 3.98 x 10^{-20} m^2 to a maximum of 3.16 x 10^{-13} m^2 in the x, y, and z directions. As a result, there is a path of increased permeability (on average) above and below panel closures in the PCS-2012 PA for the first 200 years as compared to the PABC-2009. An expected consequence of this increased permeability is an increase in brine and gas flow through the DRZ and around the panel closure for the first 200 years. In effect, the panel closures in the PCS-2012 PA are "looser" than those implemented in the PABC-2009 for the first 200 years due to the higher permeability (on average) of the DRZ material above and below them.

The temporal evolution of the ROMPCS in BRAGFLO for the PCS-2012 PA is illustrated in Figure 3-4 to Figure 3-6. As seen in Figure 3-4 and Figure 3-5, the only change in the BRAGFLO grid and material map for time periods 0 to 100 years and 100 to 200 years is the material used to represent the panel closure. Material PCS_T1 is used to represent the ROMPCS for years 0 to 100 while material PCS_T2 represents the panel closure for years 100 to 200. As discussed above, the ROMPCS is modeled as having no impact on the DRZ above and below the closure for the first 200 years after emplacement. For the first 200 years, the DRZ material above and below the closure in the BRAGFLO material map is the same as the material above and below other repository regions. After 200 years, the material used to represent the ROMPCS changes to PCS_T3, and the regions of healed DRZ above and below the closure is modeled by material DRZ_PCS, as shown in Figure 3-6. The repository representation shown in Figure 3-6 is used for times between 200 years and the time of intrusion. The BRAGFLO grid and element maps corresponding to particular intrusion types are shown in Figure 3-7 and Figure 3-8.

The Option D panel closure implemented in the PABC-2009 is 40 meters long, while the ROMPCS implemented in the PCS-2012 PA is 100 feet (30.48 meters) long. Consequently, the panel closure length is reduced to a value of 30.48 meters in the PCS-2012 PA, with panel closures represented by two elements in the x-direction, each 15.24 meters long.

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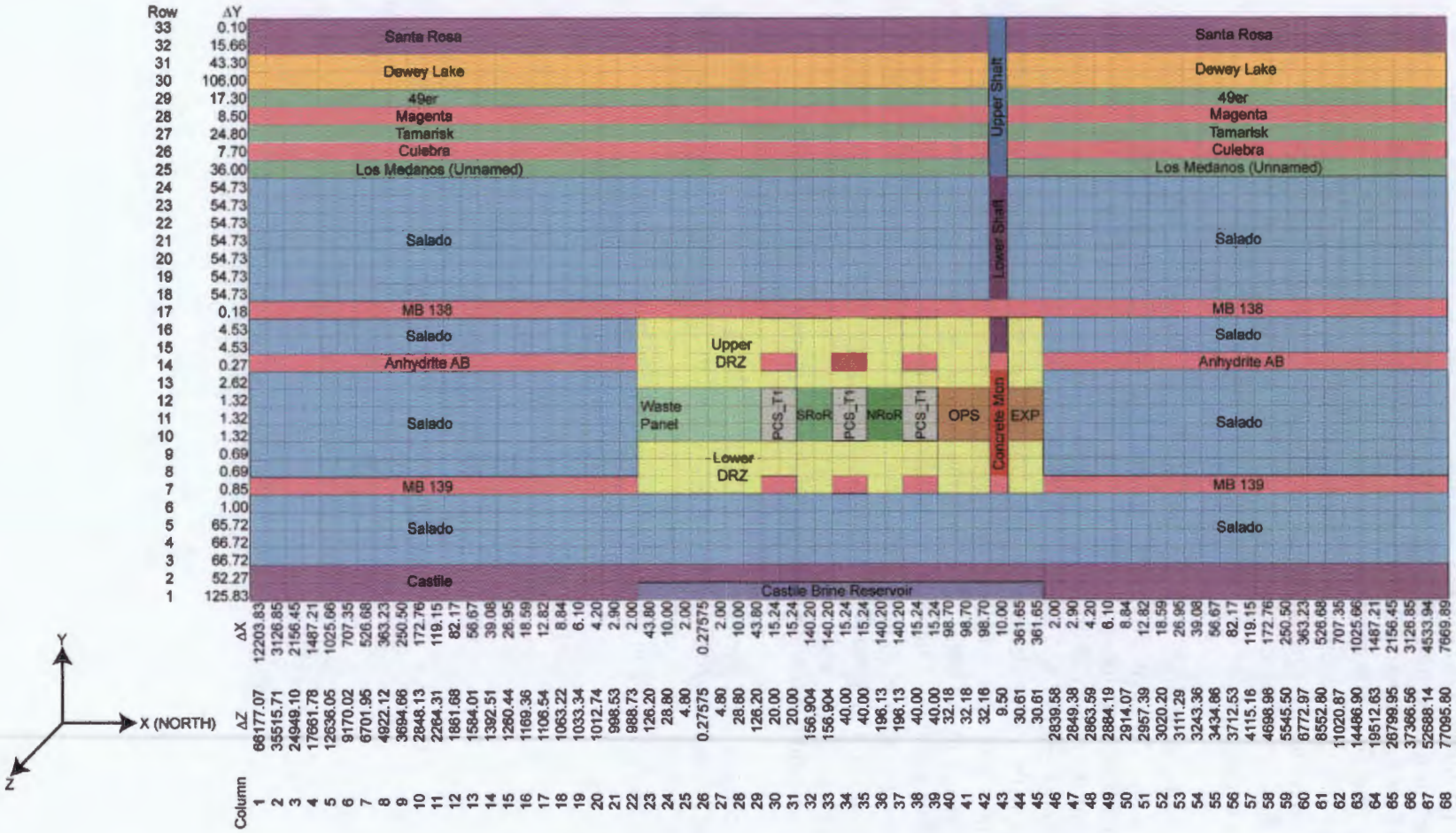

Figure 3-4: PCS-2012 BRAGFLO Grid and Material Map, Years 0 to 100

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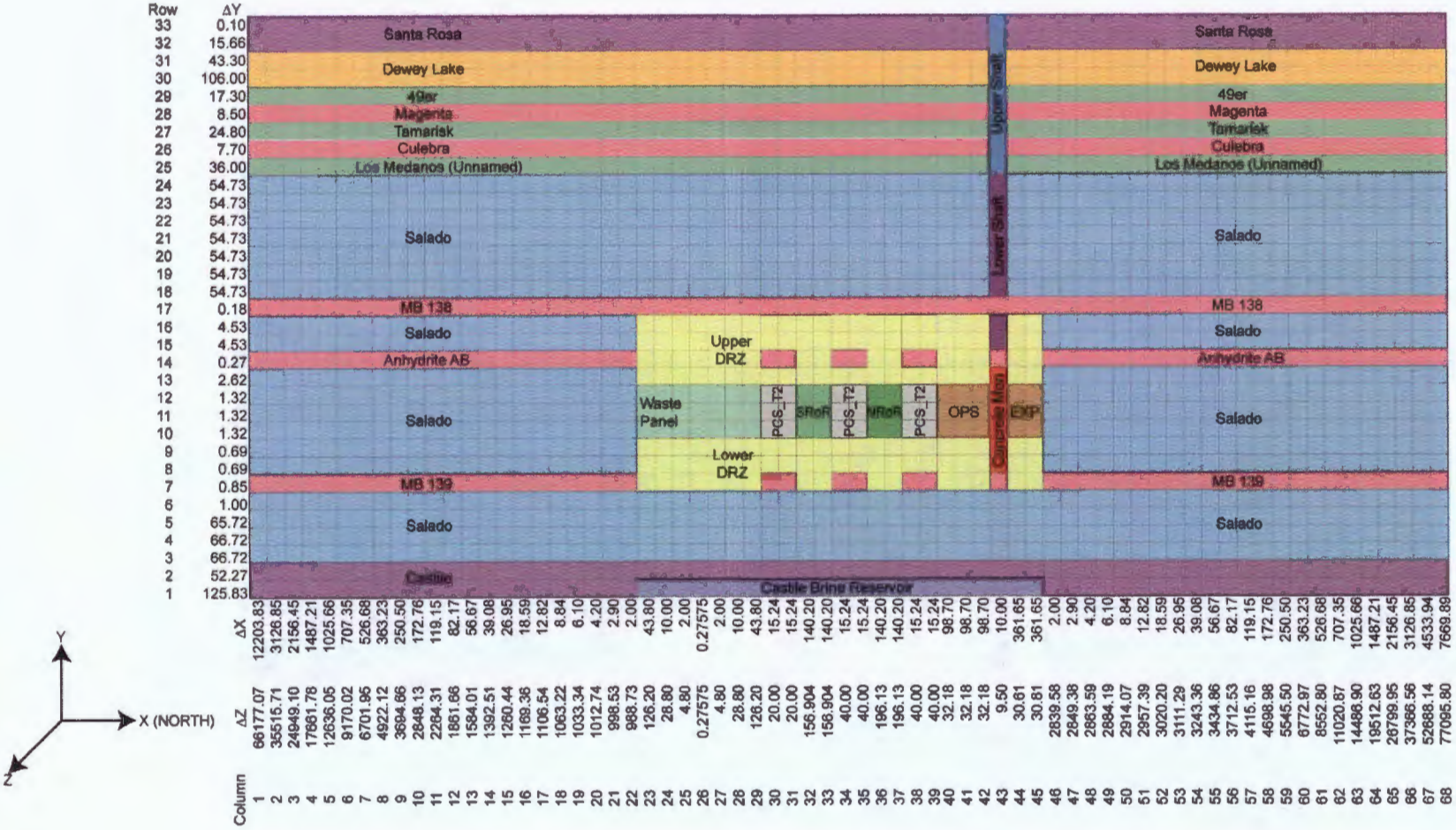

Figure 3-5: PCS-2012 BRAGFLO Grid and Material Map, Years 100 to 200

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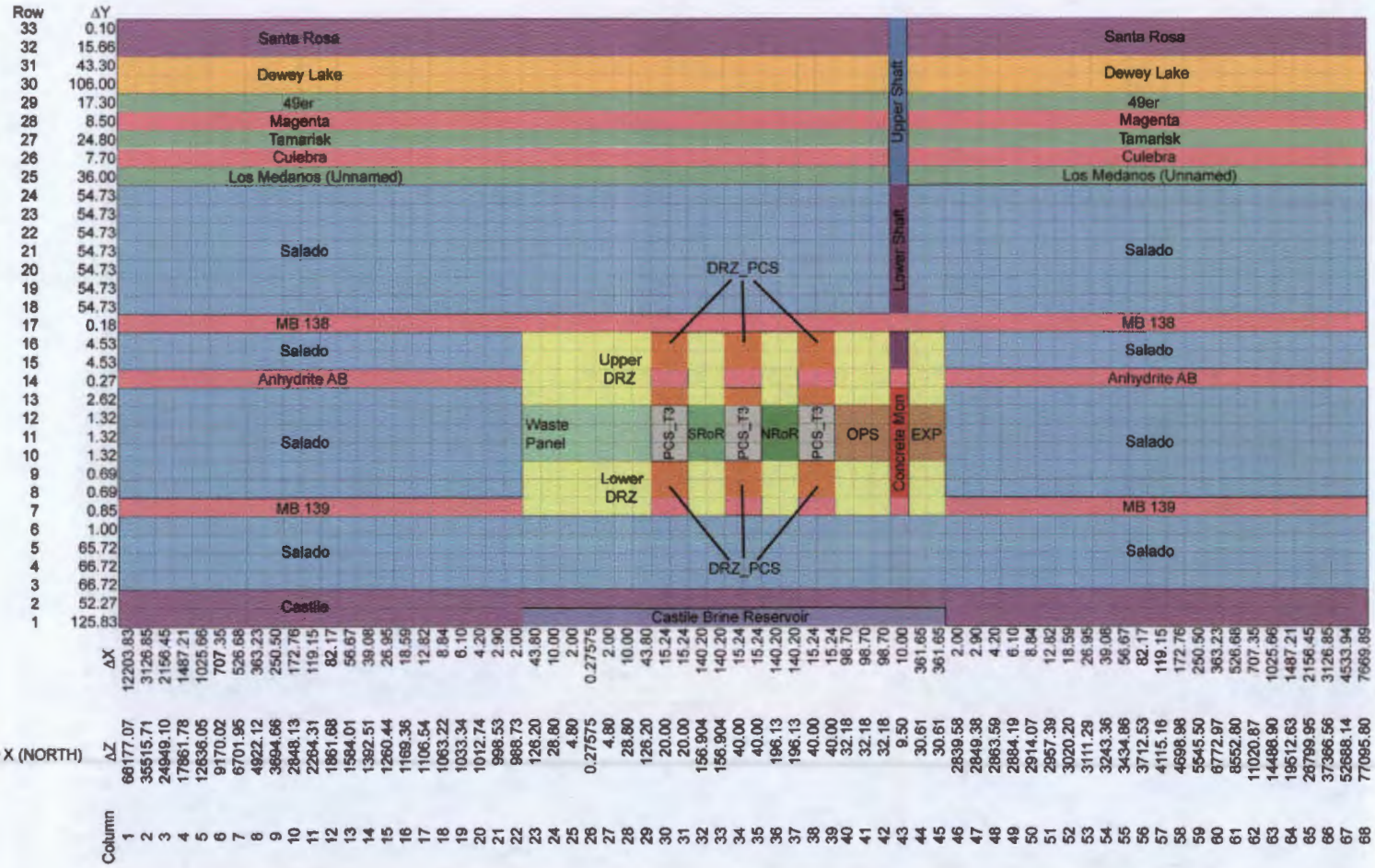

Figure 3-6: PCS-2012 BRAGFLO Grid and Material Map, Years 200 to Time of Intrusion

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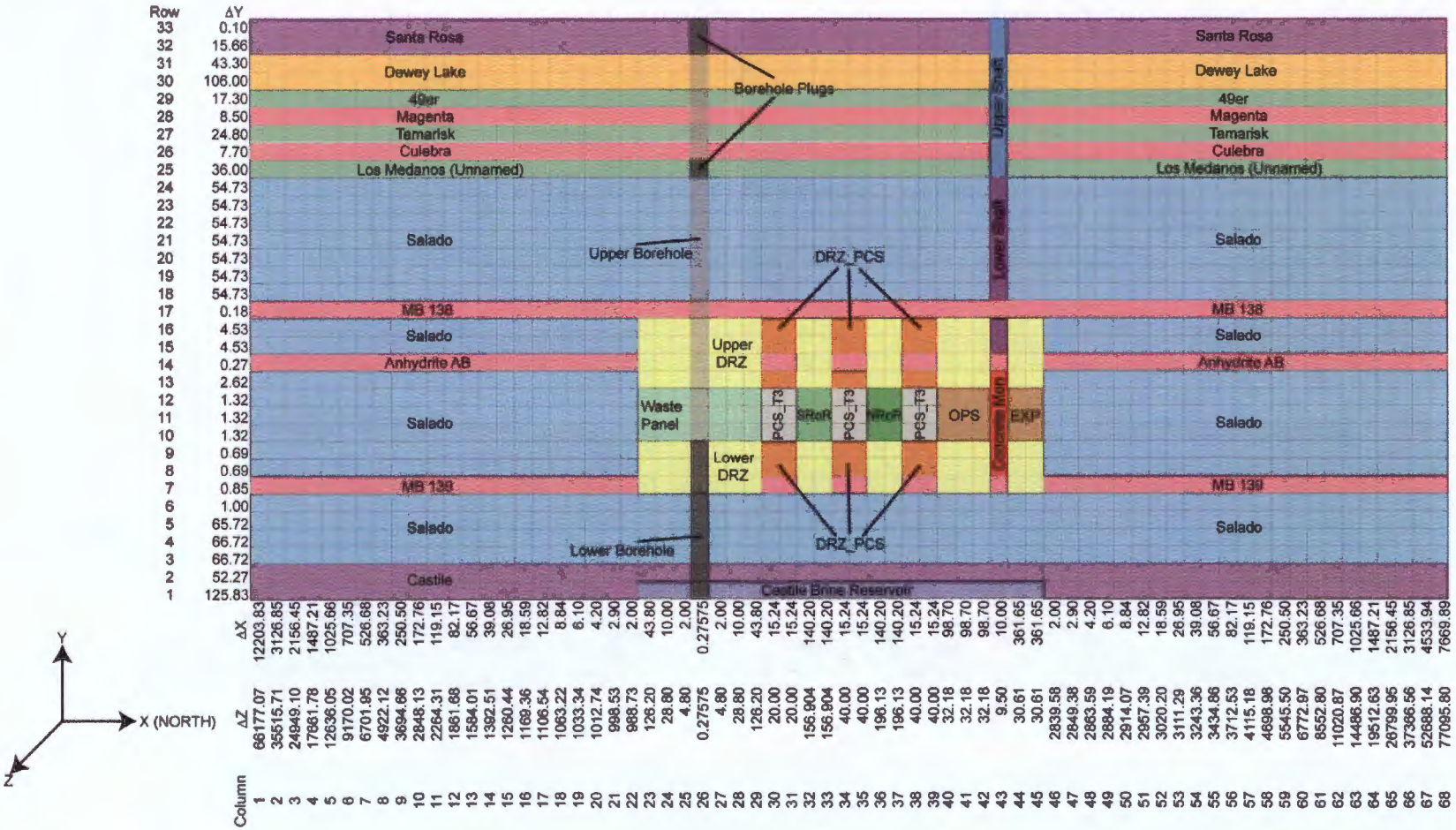

Figure 3-7: PCS-2012 BRAGFLO Grid and Material Map for an E1 Intrusion

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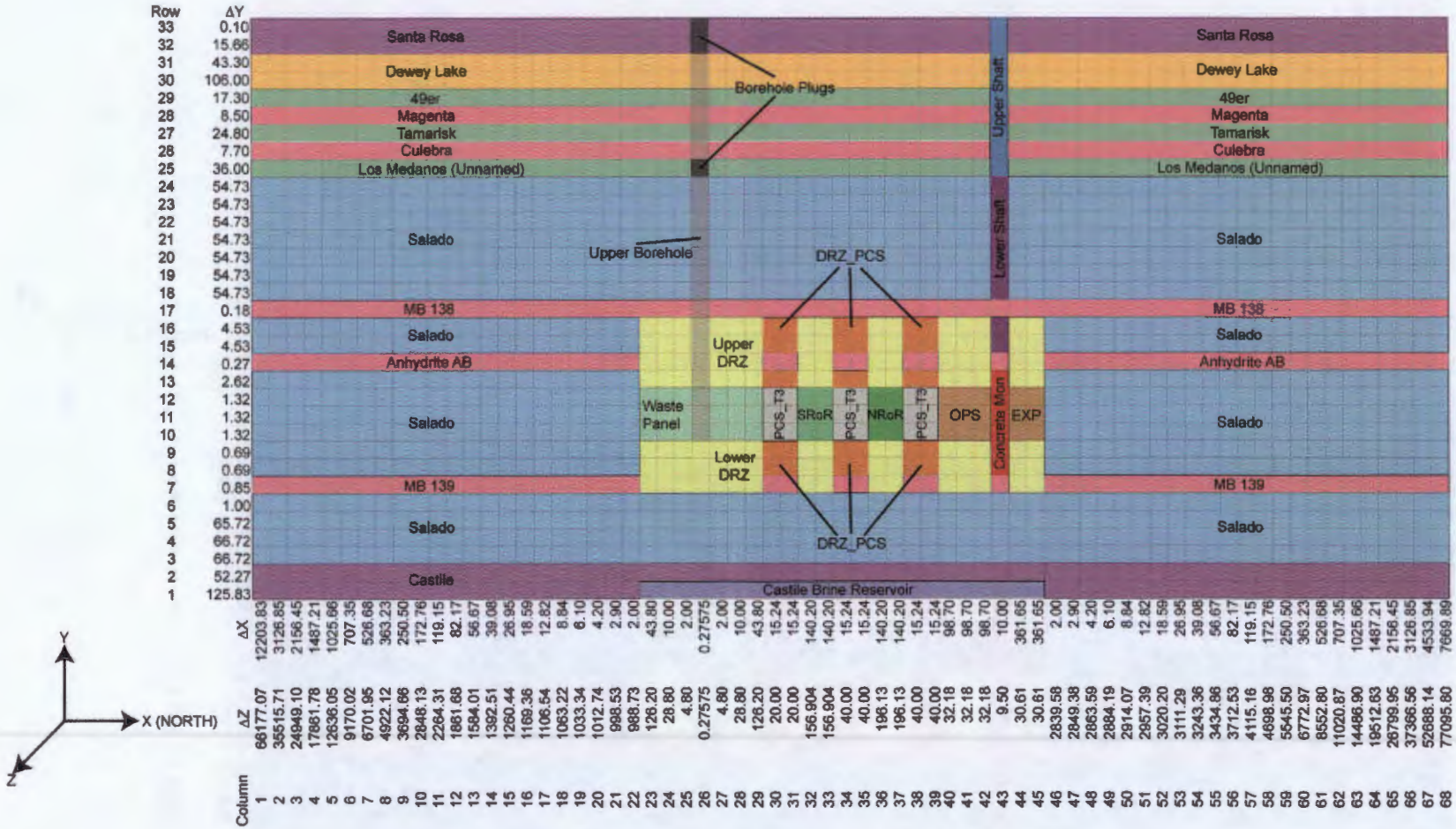

Figure 3-8: PCS-2012 BRAGFLO Grid and Material Map for an E2 Intrusion

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3.2 Panel Closure Parameterization

Numerous parameters were specified for the Option D panel closure in the PABC-2009. Of note are those prescribed for the porosity and permeability of the Option D concrete monolith (PA material CONC_PCS) as well as the DRZ overall (PA material DRZ_1) and the region of healed DRZ above the panel closure (PA material DRZ_PCS). These parameters are listed in Table 1.

Table 1: Option D Panel Closure Parameters Used in the PABC-2009

Material	Property	Distribution	Statistics
CONC_PCS	Porosity	Constant	0.05
	PRMX (m^2)	Triangular	Min = 2.0×10^{-21}
	PRMY (m^2)		Mean = 1.53×10^{-19}
	PRMZ (m^2)		Max = 1.0×10^{-17}
DRZ_1	Porosity	Cumulative	Min = 0.0039
			Mean = 0.0211
			Max = 0.0548
	PRMX (m^2)	Uniform	Min = 3.98×10^{-20}
	PRMY (m^2)		Mean = 1.0×10^{-16}
	PRMZ (m^2)		Max = 3.16×10^{-13}
DRZ_PCS	Porosity	Cumulative	Min = 0.0039
			Mean = 0.0211
			Max = 0.0548
	PRMX (m^2)	Triangular	Min = 2.0×10^{-21}
	PRMY (m^2)		Mean = 1.53×10^{-19}
	PRMZ (m^2)		Max = 1.0×10^{-17}

The full set of ROMPCS parameter values that are used in the PCS-2012 PA were developed in Camphouse et al (2012a), Patterson (2012), and Camphouse (2012b), with a discussion of BRAGFLO two-phase flow parameters given in Camphouse (2012c). As developed in Camphouse et al (2012a), permeability and porosity values are obtained through sampling for ROMPCS material PCS_T1. However, only porosity is sampled for materials PCS_T2 and PCS_T3. Sampled porosity values are then used to calculate permeability values for these materials according to the algorithm developed on page 15 of Camphouse et al (2012a). The algorithm used to calculate permeability from a sampled porosity value depends on an additional sampled parameter, quantity α in the algorithm developed in Camphouse et al (2012a). The name given to this additional parameter in the PCS-2012 PA is POR2PERM. Porosity and permeability ranges used for materials PCS_T1, PCS_T2, and PCS_T3 are shown in Table 2. As can be seen in that table, there is overlap in the porosity ranges specified for PCS_T1 and PCS_T2. This overlap could potentially result in an increase in panel closure porosity during the transition from PCS_T1 to PCS_T2 at 100 years, a non-physical result. To prevent this possibility, the porosity for PCS_T2 is conditionally sampled in the PCS-2012 PA such that PCS_T2:POROSITY $\leq$ PCS_T1:POROSITY (Camphouse 2012b). There is also overlap in the

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porosity ranges specified for PCS_T2 and PCS_T3. To prevent physically unrealistic increases in porosity during the transition from PCS_T2 to PCS_T3 at 200 years, the porosity for PCS_T3 is conditionally sampled so that PCS_T3:POROSITY ≤ PCS_T2:POROSITY. Similar constraints are placed on the calculated permeability values for PCS_T2 and PCS_T3. As can be seen in Table 2, a low sampled permeability value for PCS_T1 could be followed by a higher calculated permeability value for PCS_T2, dependent on the sampled PCS_T2 porosity and POR2PERM values. An instantaneous increase in panel closure permeability after 100 years of creep closure is an unrealistic occurrence. To prevent this non-physical result, the calculated permeability value for PCS_T2 is constrained in the PCS-2012 PA such that PCS_T2:PRMX ≤ PCS_T1:PRMX. The same is true for the calculated permeabilities in the y and z directions. A similar constraint is placed on the calculated permeability for PCS_T3 in order to prevent non-physical instantaneous increases in panel closure permeability at 200 years. The constraint placed on the calculated permeability for PCS_T3 is that PCS_T3:PRMX ≤ PCS_T2:PRMX, and likewise in the x and y directions.

Table 2: ROMPCS Parameters Used in the PCS-2012 PA

Material	Property	Distribution	Statistics
PCS_T1	Porosity	Uniform	Min = 0.066
			Mean = 0.1265
			Max = 0.187
	PRMX (m^2)	Uniform	Min = 1.0×10^{-21}
	PRMY (m^2)		Mean = 3.16×10^{-17}
	PRMZ (m^2)		Max = 1.0×10^{-12}
PCS_T2	Porosity	Uniform	Min = 0.025
			Mean = 0.05
			Max = 0.075
	POR2PERM	Normal	Min = -1.72
			Mean = 0.0
			Max = 1.72
	PRMX (m^2)	N/A – Permeability is calculated using the sampled Porosity and POR2PERM values	Min = 1.44×10^{-21}
	PRMY (m^2)		
	PRMZ (m^2)		Max = 4.55×10^{-17}
PCS_T3	Porosity	Uniform	Min = 0.001
			Mean = 0.05
			Max = 0.0519
	POR2PERM	Normal	Min = -1.72
			Mean = 0.0
			Max = 1.72
	PRMX (m^2)	N/A – Permeability is calculated using the sampled Porosity and POR2PERM values	Min = 4.46×10^{-22}
	PRMY (m^2)		
	PRMZ (m^2)		Max = 1.47×10^{-17}

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Distributions and statistics specified for materials DRZ_1 and DRZ_PCS are equal in the PABC-2009 and the PCS-2012 PA. Useful insight can be obtained by examining the Option D parameters in Table 1 and those developed for the ROMPCS in Table 2. For the first 100 years, the minimum permeability value allowed for ROMPCS material PCS_T1 is 1.0 x 10^{-21} m^2, comparable to the minimum value of 2.0 x 10^{-21} m^2 specified for the Option D concrete monolith. However, the maximum permeability value allowed for PCS_T1 is 1.0 x 10^{-12} m^2, which is significantly greater than the maximum value of 1.0 x 10^{-17} m^2 allowed for the Option D monolith. Moreover, the permeability range for material PCS_T1 is comparable to the permeability range specified to the DRZ overall (material DRZ_1 in Table 1). The DRZ above and below the ROMPCS does not heal until 200 years after emplacement, while the DRZ above the Option D panel closure is modeled as healing immediately by material DRZ_PCS. Consequently, one would expect the larger permeabilities associated with PCS_T1 and DRZ_1 to potentially result in increased brine and gas flow through the ROMPCS and the DRZ above and below it for the first 100 years when compared to the Option D panel closure.

At 100 years, the ROMPCS material transitions from PCS_T1 to PCS_T2. As seen in Table 1 and Table 2, the range of calculated permeabilities for PCS_T2 is quite comparable to the permeability range assigned to the Option D concrete monolith. However, the DRZ above and below the ROMPCS remains unhealed from 100 to 200 years, providing a pathway of increased permeability above and below the panel closure as compared to Option D. As a result, one would expect the larger permeabilities (on average) above and below material PCS_T2 to potentially result in brine and gas flows through the upper and lower DRZ, effectively bypassing the ROMPCS.

At 200 years, the ROMPCS material transitions from PCS_T2 to PCS_T3 with the DRZ region above and below PCS_T3 represented as healed by material DRZ_PCS. Under this configuration, the range of calculated permeabilities for PCS_T3 is comparable to the permeability range assigned to the Option D monolith, with the minimum value calculated for PCS_T3 being roughly an order of magnitude less than the minimum CONC_PCS permeability value. As material DRZ_PCS represents regions of healed DRZ for both the ROMPCS and the Option D closure, the final ROMPCS configuration comprises a panel closure that is slightly "tighter" (on average) than the Option D case.

3.2.1 Capillary Pressure Parameters

Two-phase flow parameters for PCS_T1, PCS_T2, and PCS_T3 are given in Camphouse et al (2012a). Tables 7 and 8 of that document assign values of CAP_MOD = 2, PCT_A = 0.56 Pa, and PCT_EXP = -0.346 for materials PCS_T1, PCS_T2, and PCS_T3. These particular material parameters are associated with capillary pressure modeling in BRAGFLO. The values listed in Camphouse et al (2012a) were obtained from the parameter developments undertaken in the 2006 PCS PA (Vugrin et al 2006), which also investigated regulatory compliance impacts of a panel closure redesign having a ROM salt component. Values of CAP_MOD = 2, PCT_A = 0.56 Pa, and PCT_EXP = -0.346 were initially planned in the 2006 PCS PA, but were subsequently changed to values of 1, 0.0 Pa, and 0.0, respectively. This change was made to maintain consistency with the corresponding properties of the salt materials used in the original

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shaft seal model (Vugrin and Dunagan 2006). These values (CAP_MOD = 1, PCT_A = 0.0 Pa, and PCT_EXP = 0.0) were also used for materials DRZ_1, DRZ_PCS, and the Option D material CONC_PCS in the PABC-2009. The PCS-2012 PA representation of the ROMPCS typically results in instantaneous changes in panel closure permeability at 100 and 200 years. Instantaneous changes in permeability, due to material changes in a grid region, cause difficulty in numerically satisfying the convergence criterion for the capillary pressure constraint equation used in BRAGFLO (Camphouse 2012c). Values of CAP_MOD = 2, PCT_A = 0.56 Pa, and PCT_EXP = -0.346 have not been used in BRAGFLO panel closure modeling since before 2002 as these values cause BRAGFLO numerical difficulties.

As discussed in Camphouse (2012c), values of CAP_MOD = 2, PCT_A = 0.56 Pa, and PCT_EXP = -0.346 for materials PCS_T1, PCS_T2, and PCS_T3 were expected to cause BRAGFLO numerical difficulties in the PCS-2012 PA. For the sake of brevity in what follows, denote these parameter values as Case 1. Denote values of CAP_MOD = 1, PCT_A = 0.0 Pa, and PCT_EXP = 0.0 for materials PCS_T1, PCS_T2, and PCS_T3 as Case 2. During the BRAGFLO testing phase of the PCS-2012 PA, sidebar calculations were performed to determine the computational feasibility of these two parameter cases. The results of these sidebar calculations are now briefly discussed.

Using the PCS-2012 PA BRAGFLO grid and material map, the first 20 vectors of replicate 1 were simulated using the parameter values of Case 1. The same was also done using the parameter values of Case 2. Every vector corresponding to Case 2 resulted in a 10,000-year BRAGFLO solution using default convergence criteria. On the other hand, 35% of vectors corresponding to Case 1 did not result in a 10,000-year BRAGFLO solution with default convergence criteria. Moreover, *every* vector corresponding to Case 1 required significantly more iterations in obtaining a BRAGFLO numerical solution. For most Case 1 vectors, several thousand additional iterations were required for vectors resulting in a 10,000-year BRAGFLO solution as compared to Case 2. For Case 1 vectors that did not yield 10,000-year solutions under default criteria, the maximum number of iterations allowed (20,000) were used with BRAGFLO exiting prior to the 10,000 year mark. The impact to computational time was substantial. For some Case 1 vectors, the time necessary to obtain a BRAGFLO solution increased by roughly a factor of 110 when compared to Case 2. For these reasons, it was determined that the parameters corresponding to Case 1 are not computationally feasible. 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 (Camphouse 2012c).

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4 SALADO FLOW MODELING METHODOLOGY

The BRAGFLO software calculates the flow of brine and gas in the vicinity of the WIPP repository over a 10,000-year regulatory compliance period. The results of these calculations are used by other software to calculate potential radionuclide releases to the accessible environment. Some of the specific processes included in the BRAGFLO calculations include:

- Brine and gas flow.
- Pressure generation as a function of time and space.
- Creep closure of the waste filled regions within the repository.
- Physical changes (e.g. permeability and porosity) in the modeling domain over time.
- Cumulative brine flow into and out of the repository and its subregions.

There is significant uncertainty associated with characterizing the physical properties of geologic materials that influence these processes. WIPP PA addresses these uncertainties in two ways. Properties such as permeability and porosity are usually measured indirectly and vary significantly depending upon location. The uncertainty in particular physical property values is called subjective (epistemic) uncertainty. Subjective uncertainty can, in theory, be reduced by further study of the system. Subjective uncertainty is addressed within Salado flow modeling by the use of probability distributions for subjectively uncertain parameters. Multiple flow realizations are performed in which the values of uncertain parameters are sampled from their respective distributions. For subjectively uncertain, spatially distributed quantities, e.g. the permeability of the DRZ, one sampled value is used to specify a particular parameter value over its entire spatial extent in a single realization. To reduce the number of realizations required and to ensure that low probability (and possibly high consequence) combinations are represented, Latin Hypercube Sampling (LHS) is used to create the realizations. For the WIPP PA, the LHS software (Vugrin 2005) is used to create a "replicate" of 100 distinct parameter sets ("vectors") that are sampled from the full range of parameter uncertainty. To ensure that the Latin Hypercube replicates are representative, a total of three replicates are run for a total of 300 separate vectors.

Another type of uncertainty encountered in WIPP PA is that of stochastic (aleatory) uncertainty associated with incomplete knowledge of future events. Unlike subjective uncertainty, stochastic uncertainty cannot be reduced by further study. WIPP PA addresses stochastic uncertainty by employing a Monte Carlo sampling technique on random futures. In this context, a future is defined as one possible sequence of events. During BRAGFLO calculations, stochastic uncertainty is addressed by defining a set of six scenarios for which brine and gas flow is calculated for each of the vectors generated by the LHS software. The total number of BRAGFLO simulations that have to be run for a WIPP PA calculation is 300 vectors times 6 scenarios equaling 1,800 BRAGFLO simulations.

The six scenarios used in the PCS-2012 PA are unchanged from those used for the 1996 CCA and the PABC-2009. No changes to BRAGFLO scenarios are needed to address the differences in the ROMPCS and the Option D panel closure.

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Results obtained in the six scenarios from BRAGFLO are used to initialize flow and material properties in subsequent codes in the PA computational suite, e.g. in the calculation of direct brine releases. The intrusion types specified in PA code calculations subsequent to BRAGFLO are the same as those implemented in BRAGFLO. The intrusion times, however, are not always equal. To avoid confusion resulting from the use of identical scenario notation for scenarios with unequal intrusion times in the various PA codes, the scenarios in BRAGFLO are denoted as S1-BF to S6-BF. The scenarios include one undisturbed scenario (S1-BF), four scenarios that include a single inadvertent future drilling intrusion into the repository during the 10,000 year regulatory period (S2-BF to S5-BF), and one scenario investigating the effect of two intrusions into a single waste panel (S6-BF). Two types of intrusions, denoted as E1 and E2, are considered. An E1 intrusion assumes the borehole passes through a waste-filled panel and into a pressurized brine pocket that may exist under the repository in the Castile formation. An E2 intrusion assumes that the borehole passes through the repository but does not encounter a brine pocket. Scenarios S2-BF and S3-BF model the effect of an E1 intrusion occurring at 350 years and 1000 years, respectively, after the repository is closed. Scenarios S4-BF and S5-BF model the effect of an E2 intrusion at 350 and 1000 years. Scenario S6-BF models an E2 intrusion occurring at 1000 years, followed by an E1 intrusion into the same panel at 2000 years. BRAGFLO results obtained in Scenario S6-BF are used to calculate transport releases to the Culebra. Transport releases from the Culebra obtained in the PABC-2009 are also used in the PCS-2012 PA. Results from BRAGFLO scenario S6-BF are briefly discussed in this report to justify the appropriateness of PABC-2009 Culebra transport calculations for the PCS-2012 PA. Table 3 summarizes the six scenarios used in this analysis.

Table 3: BRAGFLO Modeling Scenarios

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

4.1 Initial Conditions

BRAGFLO simulation of the six scenarios listed above requires the assignment of initial conditions including brine pressure, brine saturation, and concentrations of iron and biodegradable material. These initial conditions are provided to BRAGFLO through various pre-processing steps during which values are extracted or sampled from the WIPP PA Performance Assessment Parameter Database.

At the beginning of each BRAGFLO run (scenario-vector combination), the model simulates a short period of time representing disposal operations. This portion of the run is called the initialization period and lasts for 5 years (from t = -5 to 0 years), corresponding to the time a typical waste panel is expected to be open during disposal operations. All grid blocks require initial pressure and saturation at the beginning of the run (t = -5 years). At the beginning of the regulatory period (0 to 10,000 years), BRAGFLO resets initial conditions within the excavated regions and in the shaft.

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The initial conditions specified for BRAGFLO modeling are listed below:

- Brine pressure in all non-excavated regions is equal to lithostatic pressure. This pressure is sampled at a single location and assumed hydrostatic at all other locations.
- Pressure within excavated regions is set to one atmosphere (1.01325×10^5 Pa) at t = -5 years.
- At t = 0 years, pressure in the excavated waste regions is increased to 1.28039×10^5 Pa in order to account for the pressure increase (0.26714×10^5 Pa) associated with microbial gas produced at short times (see Subsection 4.2.1 of Nemer et al. 2005).
- Brine saturation within the non-excavated regions is set to 1.0.
- Brine saturation within the excavated regions is set to a value of 0 at t = -5 years.
- Brine saturation in the excavated regions at t = 0 is prescribed the following values:
    - 0.015 for the excavated waste regions, which was chosen to be conservative with respect to the WIPP Waste Acceptance Criteria which allows waste to come to WIPP with no more than 1 % liquids by volume (see Subsection 3.4.1 of DOE 2007).
    - 0.0 for the operations and experimental areas
    - 0.9999999 for the concrete portion of the shaft.
    - For each vector, the initial brine saturation of ROMPCS material PCS_T1 is assigned a sampled value obtained from a uniform distribution with a minimum of 0.04 and a maximum of 0.16 (Camphouse 2012b).

During the initialization period brine tends to flow into the excavated areas and the shaft, resulting in decreased pressure and saturation in the rock immediately adjacent to the excavations. At time t = 0 the pressure and saturation in all the excavations is reset to initial conditions for the materials used to represent these regions for the regulatory period. This practice is intended to capture the effect of evaporation of brine inflow during the operational period and the transport of this brine up the shaft ventilation system, as well as the depressurization of the surrounding rock formations due to excavation.

4.2 Boundary Conditions

The boundary conditions assigned for the BRAGFLO calculations in the PCS-2012 PA are the same as those for the PABC-2009.

- Constant pressure at the north and south ends of the Culebra and Magenta dolomites.
- Constant pressure (1.01325×10^5 Pa) and saturation (0.08363) conditions at the land surface boundary of the grid, except at the shaft cell on the land surface boundary (Vaughn 1996). The saturation in this cell is set along with the rest of the shaft to the initial saturation prescribed in the WIPP parameter database (SAT_IBRN) for each of the respective shaft materials.
- No-flow conditions at all other grid boundaries.

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5 RUN CONTROL

Run control, including code versions used and descriptions of code sequencing used to obtain BRAGFLO results in the PCS-2012 PA, is documented in Camphouse et al (2012b). PCS-2012 PA results obtained in the BRAGFLO post-processing step have file names ALG2_BF_AP161_Rr_Ss_Vvvv.CDB, where r (the replicate number) equals 1,2, or 3, s (the scenario number) equals 1,2,3,4,5, or 6, and vvv (the vector number) is between 001 and 100. These files are located in CMS library LIBAP161_BFRrSs under class AP161-0. PABC-2009 results obtained in the BRAGFLO post-processing step have file names ALG2_BF_PABC09_Rr_Ss_Vvvv.CDB, and are located in CMS library LIBPABC09_BFRrSs under class PABC09-0.

6 RESULTS

Computed results are now presented for the PCS-2012 PA and compared with those obtained in the PABC-2009. In the following sections, results are presented in terms of volume-averaged quantities such as volume-averaged pressure. Volume-averaged pressure is given by forming the product of grid block pressure and grid block volume for each grid block in the region of concern, summing this product up over all grid blocks in the region, and dividing by the bulk volume of the region. All other volume-averaged quantities are computed in the same manner. Cumulative flow volumes are also presented. Cumulative flow into a region is defined as the time-dependent flow into a region integrated over time. In the results that follow, the routine calculation of means and generation of plots were done with Matlab version R2008a, a Commercial off-the Shelf (COTS) software package. As discussed previously, Scenario S1-BF represents undisturbed repository conditions. Scenarios S2-BF through S6-BF capture consequences of drilling intrusions into the repository. The impact on repository performance following an intrusion through the repository and into a pressurized brine pocket in the Castile (an E1 event) are considered in Scenarios S2-BF and S3-BF. Drilling intrusions that do not encounter pressurized Castile brine (an E2 event) are considered in scenarios S4-BF and S5-BF. Transport releases to the Culebra are captured in Scenario S6-BF. Scenario S6-BF is used for determining the radionuclide source term to the Culebra in the PA code PANEL, and results of this BRAGFLO scenario are briefly discussed. The particular mechanics of each scenario are shown below. Note that the ROMPCS implemented in the PCS-2012 PA, as well as materials used to represent the shaft, attain their long-term permeability values at 200 years, well before the occurrence of any of the waste panel intrusions in scenarios S2-BF to S6-BF.

<u>Scenario S1-BF</u> (Undisturbed Conditions)

0 years: ROMPCS represented by material PCS_T1 with no healing of the DRZ above and below the panel closure.

100 years: ROMPCS material transitions from PCS_T1 to PCS_T2 with no healing of the DRZ above and below the panel closure.

200 years: ROMPCS material transitions from PCS_T2 to PCS_T3 with healed regions of DRZ above and below the panel closure represented by material DRZ_PCS. Lower shaft material properties are changed.

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Scenario S2-BF (E1 intrusion at 350 years)

0 years: ROMPCS represented by material PCS_T1 with no healing of the DRZ above and below the panel closure.

100 years: ROMPCS material transitions from PCS_T1 to PCS_T2 with no healing of the DRZ above and below the panel closure.

200 years: ROMPCS material transitions from PCS_T2 to PCS_T3 with healed regions of DRZ above and below the panel closure represented by material DRZ_PCS. Lower shaft material properties are changed.

350 years: Borehole intrusion through the Waste Panel and into a hypothetical pressurized brine reservoir in the underlying Castile Formation, with the borehole represented by material BH_OPEN. Concrete borehole plugs, represented by material CONC_PLG, immediately emplaced in the borehole below the Culebra and at the surface.

550 years: Borehole plugs fail, and the entire borehole is modeled as having properties equivalent to sand. The borehole, bottom to top, is represented by material BH_SAND.

1550 years: The permeability of the borehole between the repository and the Castile brine reservoir decreases due to creep closure of the salt. The lower borehole is represented by material BH_CREEP as a result.

Scenario S3-BF (E1 intrusion at 1000 years)

0 years: ROMPCS represented by material PCS_T1 with no healing of the DRZ above and below the panel closure.

100 years: ROMPCS material transitions from PCS_T1 to PCS_T2 with no healing of the DRZ above and below the panel closure.

200 years: ROMPCS material transitions from PCS_T2 to PCS_T3 with healed regions of DRZ above and below the panel closure represented by material DRZ_PCS. Lower shaft material properties are changed.

1000 years: Borehole intrusion through the Waste Panel and into a hypothetical pressurized brine reservoir in the underlying Castile Formation, with the borehole represented by material BH_OPEN. Concrete borehole plugs, represented by material CONC_PLG, immediately emplaced in the borehole below the Culebra and at the surface.

1200 years: Borehole plugs fail, and the entire borehole is modeled as having properties equivalent to sand. The borehole, bottom to top, is represented by material BH_SAND.

2200 years: The permeability of the borehole between the repository and the Castile brine reservoir decreases due to creep closure of the salt. The lower borehole is represented by material BH_CREEP as a result.

Scenario S4-BF (E2 intrusion at 350 years)

0 years: ROMPCS represented by material PCS_T1 with no healing of the DRZ above and below the panel closure.

100 years: ROMPCS material transitions from PCS_T1 to PCS_T2 with no healing of the DRZ above and below the panel closure.

200 years: ROMPCS material transitions from PCS_T2 to PCS_T3 with healed regions of DRZ above and below the panel closure represented by material DRZ_PCS. Lower shaft material properties are changed.

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350 years: Borehole intrusion terminating at the floor of the Waste Panel, with the borehole represented by material BH_OPEN. Concrete borehole plugs, represented by material CONC_PLG, immediately emplaced in the borehole below the Culebra and at the surface.

550 years: Borehole plugs fail, and the entire borehole is modeled as having properties equivalent to sand. The borehole, bottom to top, is represented by material BH_SAND.

Scenario S5-BF (E2 intrusion at 1000 years)

0 years: ROMPCS represented by material PCS_T1 with no healing of the DRZ above and below the panel closure.

100 years: ROMPCS material transitions from PCS_T1 to PCS_T2 with no healing of the DRZ above and below the panel closure.

200 years: ROMPCS material transitions from PCS_T2 to PCS_T3 with healed regions of DRZ above and below the panel closure represented by material DRZ_PCS. Lower shaft material properties are changed.

1000 years: Borehole intrusion terminating at the floor of the Waste Panel, with the borehole represented by material BH_OPEN. Concrete borehole plugs, represented by material CONC_PLG, immediately emplaced in the borehole below the Culebra and at the surface.

1200 years: Borehole plugs fail, and the entire borehole is modeled as having properties equivalent to sand. The borehole, bottom to top, is represented by material BH_SAND.

Scenario S6-BF (E2 intrusion at 1000 years, E1 intrusion at 2000 years)

0 years: ROMPCS represented by material PCS_T1 with no healing of the DRZ above and below the panel closure.

100 years: ROMPCS material transitions from PCS_T1 to PCS_T2 with no healing of the DRZ above and below the panel closure.

200 years: ROMPCS material transitions from PCS_T2 to PCS_T3 with healed regions of DRZ above and below the panel closure represented by material DRZ_PCS. Lower shaft material properties are changed.

1000 years: Borehole intrusion terminating at the floor of the Waste Panel, with the borehole represented by material BH_OPEN. Concrete borehole plugs, represented by material CONC_PLG, immediately emplaced in the borehole below the Culebra and at the surface.

1200 years: Borehole plugs fail, and the entire borehole is modeled as having properties equivalent to sand. The borehole, bottom to top, is represented by material BH_SAND.

2000 years: A second borehole intrusion connects the waste panel to a hypothetical pressurized brine reservoir in the underlying Castile Formation. The lower borehole is represented by material BH_OPEN.

2200 years: The lower borehole is modeled as having properties equivalent to sand, and is represented by material BH_SAND.

3200 years: The permeability of the borehole between the repository and the Castile brine reservoir decreases due to creep closure of the salt. The lower borehole is represented by material BH_CREEP as a result.

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

Results are now presented for undisturbed scenario S1-BF. For the sake of brevity in what follows, waste area results are discussed in terms of the waste panel. Trends discussed for the waste panel also apply to other repository waste areas.

A horsetail plot of cumulative brine flow into the waste panel, denoted by quantity BRNWASIC, is given in Figure 6-3. The horsetail plot shown in Figure 6-3 is assembled using all 300 scenario S1-BF vectors. Replicate means of BRNWASIC, as well as the overall BRNWASIC mean calculated over all 300 vectors, are shown in Figure 6-4. As seen in that figure, there is close agreement between the three replicate means, as well as the overall mean, of cumulative brine inflow to the waste panel.

The PCS-2012 PA overall mean of cumulative brine flow into the waste panel is compared to the PABC-2009 overall mean of the same quantity in Figure 6-5. As seen in that figure, there is an increase in the mean cumulative brine flow into the waste panel in the PCS-2012 PA as compared to the PABC-2009. As discussed in Section 3.2, the permeability range assigned to the ROMPCS during the first 100 years is comparable to the permeability range of the DRZ overall. The Option D concrete monolith, however, is much less permeable than the DRZ (on average). Moreover, the DRZ above the Option D panel closure heals immediately and is assigned the same permeability range prescribed to the concrete monolith. As the DRZ remains unhealed for the first 200 years in the ROMPCS model, there is a path of increased permeability through and around the ROMPCS for the first 100 years as compared to the Option D closure. The result is an increase in cumulative brine flow toward the waste panel during that time period. For 100 to 200 years, the permeability range prescribed to the ROMPCS is comparable to the range assigned to the Option D concrete monolith. The DRZ above and below the ROMPCS remains unhealed during this time period, however. The result is a path of increased permeability (on average) above and below the ROMPCS as compared to the Option D case, with a corresponding increase in cumulative brine flow into the waste panel. After 200 years, the DRZ above and below the ROMPCS is modeled as having healed by material DRZ_PCS, resulting in a final ROMPCS configuration that is slightly "tighter" on average than the Option D case. Consequently, the majority of the increase in quantity BRNWASIC for the PCS-2012 PA occurs during the first 200 years. The increase during the first 200 years is readily apparent in Figure 6-6, where the time scale used to plot BRNWASIC overall means is restricted to the first 1,000 years. As seen in that figure, the difference in the overall means obtained in the two analyses increases steadily until 200 years. At 200 years, the ROMPCS assumes its long-term properties with the DRZ healed above and below it. At 200 years in the PCS-2012 PA BRNWASIC overall mean in Figure 6-6, the rate of increase decreases sharply. At 200 years, the difference between the BRNWASIC overall means obtained in the two analyses is roughly 600 m^3, and this difference between the overall means remains fairly constant for the remainder of the regulatory period.

The impact of panel closure material and the DRZ around it is made more evident by examining the cumulative volume of brine flowing out of a panel closure plane and toward the waste panel. The name given for this quantity is BNWPSPCS (brine toward the waste panel, south from the panel closure system). The schematics shown in Figure 6-1 and Figure 6-2 illustrate how this

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quantity is calculated. In both of those figures, the southernmost panel closure plane is illustrated by a red vertical line. For both the PCS-2012 PA and the PABC-2009, this line intersects the waste panel/panel closure interface, and extends from the intact halite below the repository to the intact halite above it. Quantity BNWPSPCS is a cumulative tally of southward brine flow between the regions of intact halite below and above the repository and toward the region of intact halite immediately south of the repository. In the schematics shown in Figure 6-1 and Figure 6-2, brine flows used to calculate BNWPSPCS are right-to-left across the panel closure planes denoted by the red vertical lines. Note that Figure 6-1 shows the representation of the ROMPCS for the first 100 years. The ROMPCS southernmost panel closure plane is defined at the same location as in Figure 6-1 for years 100 to 200 and years 200 to 10,000.

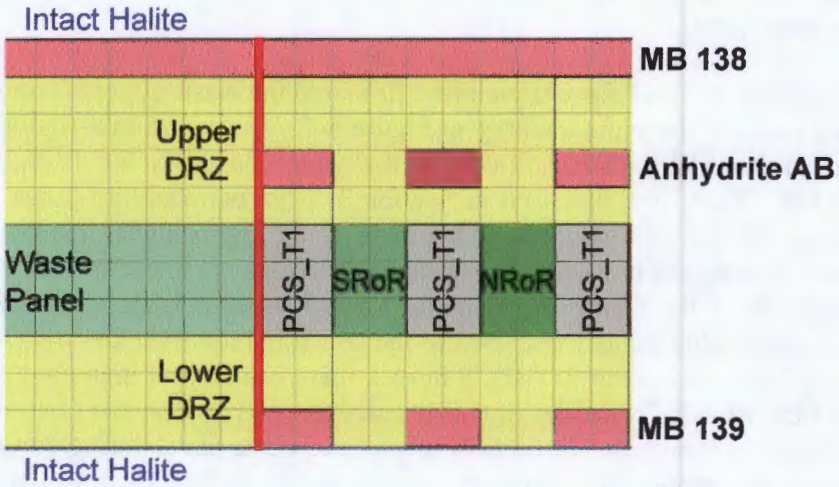

Figure 6-1: PCS-2012 PA Definition of Cumulative Flow toward the Waste Panel, across the Southernmost Panel Closure Plane

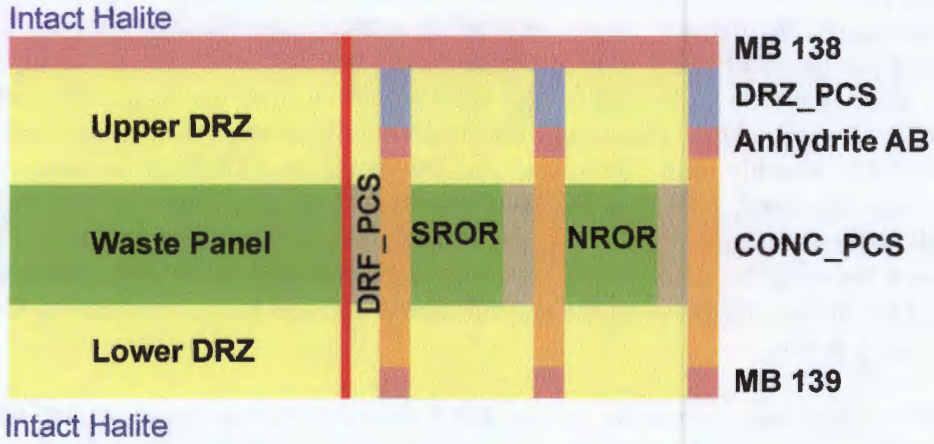

Figure 6-2: PABC-2009 Definition of Cumulative Flow toward the Waste Panel, across the Southernmost Panel Closure Plane

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Figure 6-7 shows the overall means of quantity BNWPSPCS for both the PCS-2012 PA and the PABC-2009. As seen in that figure, there is an increase in the BNWPSPCS overall mean in the PCS-2012 PA as compared to the PABC-2009. This increase is attributed to the increased permeability of the ROMPCS, and the DRZ above and below it, for the first 200 years as compared to Option D. Figure 6-8 shows overall means of quantity BNWPSPCS with the time scale restricted to the first 1,000 years. As seen in that figure, the rate of increase in the overall mean of BNWPSPCS for the PCS-2012 PA decreases slightly at 100 years. At 100 years, The ROMPCS model transitions from material PCS_T1 to PCS_T2. The reduction in the permeability range for material PCS_T2 has a slight reducing effect on the rate of increase of BNWPSPCS. At 200 years, the ROMPCS material transitions from PCS_T2 to PCS_T3 with the DRZ above and below the panel closure modeled as healed by material DRZ_PCS. In Figure 6-8, there is a sharp change in slope in the PCS-2012 PA BNWPSPCS overall mean at 200 years. Brine flow southward out of the southernmost panel closure plane is effectively stopped by the ROMPCS and healed DRZ, resulting in no increase to the BNWPSPCS overall mean for a period of time after 200 years. The difference between the BNWPSPCS overall means seen in the PCS-2012 PA and the PABC-2009 is roughly 550 m^3 after 200 years. This volume of brine corresponds very closely to the difference seen in the cumulative brine flow into the waste panel (Figure 6-6) after 200 years, indicating that the increase of cumulative brine flow into the waste panel is primarily due to the increase of brine flow through and around the ROMPCS for the first 200 years as compared to Option D.

The increase of brine flow into the waste panel results in a corresponding increase in the waste panel brine saturation, denoted by quantity WAS_SATB. A horsetail plot of waste panel brine saturation calculated in the PCS-2012 PA is shown Figure 6-9. The horsetail plot shown in that figure is assembled using all 300 realizations of waste panel brine saturation. The three individual replicate means, as well as the overall mean, of WAS_SATB are shown in Figure 6-10. As seen in that figure, there is very close agreement among the PCS-2012 PA replicate means as well as the overall mean.

The overall means for WAS_SATB obtained in the PCS-2012 PA and the PABC-2009 are plotted together in Figure 6-11. As seen in that figure, there is an increase in the mean for WAS_SATB in the PCS-2012 PA as compared to the PABC-2009. The increase in brine inflow to the waste panel during the first 200 years translates to an increase in the waste panel brine saturation. The impact of the ROMPCS temporal evolution on the waste panel brine saturation is more clearly seen in Figure 6-12. In that figure, overall means of WAS_SATB obtained in the two analyses are plotted together with the time scale restricted to the first 1,000 years. As seen in that figure, the overall mean for WAS_SATB obtained in the PCS-2012 PA increases at a higher rate than the mean calculated in the PABC-2009 for the first 200 years. At 200 years, the ROMPCS and the DRZ above and below it assume their long-term properties. At 200 years in Figure 6-12, the rate of increase in the WAS_SATB mean curve obtained in the PCS-2021 PA decreases sharply. Beyond 200 years, the WAS_SATB overall means obtained in the two analyses are qualitatively very similar with differences seen in the magnitude of the respective curves primarily due to increases seen in the PCS-2012 PA during the first 200 years.

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Increases in waste panel brine inflow and brine saturation potentially impact waste panel gas generation, denoted by quantity GASMOL_W. The horsetail plot of waste panel gas generation (in moles), assembled over all 300 vectors, for the PCS-2012 PA is shown in Figure 6-13. The three individual replicate means, as well as the overall mean, are shown in Figure 6-14. As seen in that figure, there is close agreement between the replicate and overall means for GASMOL_W. Overall means of waste panel gas generation obtained in the PCS-2012 PA and the PABC-2009 are plotted together in Figure 6-15. As seen in that figure, the overall mean for gas generated in the waste panel increased in the PCS-2012 PA. The increases seen in the mean waste panel brine inflow and mean waste panel brine saturation in the PCS-2012 PA result in a corresponding increase in waste panel gas generation.

The temporal evolution of the ROMPCS and the changes to waste panel gas generation seen in the PCS-2012 PA impact the waste panel pressure, denoted by quantity WAS_PRES. The horsetail plot for WAS_PRES, assembled over all 300 vectors, is shown in Figure 6-16. The three WAS_PRES replicate means, as well as the overall mean, are shown together in Figure 6-17. As seen in that figure, there is very close agreement between the replicate means and the overall mean of waste panel pressure.

Overall means of waste panel pressure obtained in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-18. As seen in that figure, there is a long-term increase in the mean waste panel pressure obtained in the PCS-2012 PA as compared to the PABC-2009. The increase in waste panel gas generation seen in the PCS-2012 PA results in a long-term increase in the waste panel mean pressure. The combined impacts of the ROMPCS temporal evolution and increased waste panel gas generation are more closely seen in Figure 6-19. In that figure, the overall means of waste panel pressure obtained in the PCS-2012 PA and the PABC-2009 are plotted together with the time scale restricted to the first 1,000 years. As seen in that figure, the PCS-2012 PA mean waste panel pressure is lower than that obtained in the PABC-2009 at early times. The higher permeability (on average) of the ROMPCS for the first 100 years, and the DRZ above and below it for the first 200 years, allows for increased release of pressure from the waste panel as compared to Option D. After the ROMPCS assumes its long-term properties at 200 years, with the DRZ modeled as healed above and below it, the PCS-2012 PA mean waste panel pressure curve steadily increases, eventually becoming greater than the PABC-2009 mean waste panel pressure curve. The combination of a "tighter" panel closure after 200 years and increased gas generation in the waste panel translates to an eventual increase in the PCS-2012 PA mean waste panel pressure.

The release of pressure from repository waste areas at early times to other repository regions can be clearly seen in Figure 6-20 and Figure 6-21. As seen in Figure 6-20, the mean pressure in the operations area, denoted by quantity OPS_PRES, is greater in the PCS-2012 PA at early times when compared to the PABC-2009. The same is also true for the mean pressure in the experimental area (Figure 6-21). After the ROMPCS and the DRZ above and below it assume their long-term properties at 200 years, the rate of pressure release from repository waste areas into the operations and experimental regions decreases. The "tighter" characteristics of the ROMPCS after 200 years results in less pressure being released to the experimental and operations regions as compared to Option D. The result is an eventual decrease in the mean pressure in these regions when compared to PABC-2009 results.

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As seen in the BRAGFLO schematics of Figure 3-2 and Figure 3-4 to Figure 3-8, the base of the repository shaft is modeled in WIPP PA as being directly between the operations and experimental regions. Consequently, the pressure in these two regions impacts the volume of brine moved up the shaft toward the ground surface. The horsetail plot of the volume of brine flowing up the shaft, denoted by quantity BNSHUDRZ, is shown in Figure 6-22. The three BNSHUDRZ replicate means obtained in the PCS-2012 PA, and the overall mean obtained for this quantity, are plotted together in Figure 6-23. As seen in that figure, there is good agreement between the means obtained for brine flow up the shaft in the PCS-2012 PA. The overall means of brine flow up the shaft obtained in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-24. As seen in that figure, the trends for brine flow up the shaft correspond closely to pressure trends in the operations and experimental areas. At early times, an increase is seen in the mean volume of brine flow up the shaft in the PCS-2012 PA. Eventually, however, the mean brine flow up the shaft is reduced in the PCS-2012 PA results, primarily due to the reductions in the mean pressure seen in the operations and experimental areas after the ROMPCS and surrounding DRZ assume their long-term properties.

Summary statistics for scenario S1-BF are shown in Table 4.

Table 4: Summary Statistics for Scenario S1-BF

Quantity (units)	Mean Value		Maximum Value	
	PABC-2009	PCS-2012 PA	PABC-2009	PCS-2012 PA
BRNWASIC ($x10^3$ m^3)	1.78	2.38	12.46	16.67
WAS_SATB (none)	0.16	0.20	0.99	0.99
GASMOL_W ($x10^6$ moles)	29.09	30.84	148.40	149.00
WAS_PRES (MPa)	6.52	6.77	16.19	16.29
BNSHUDRZ (m^3)	2.74	2.46	34.76	32.11

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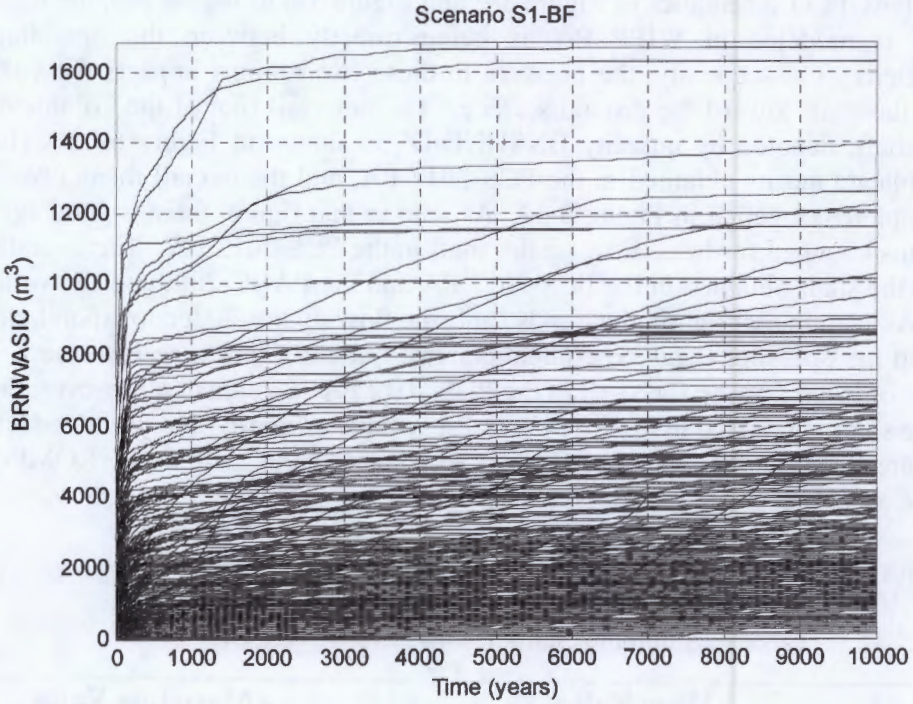

Figure 6-3: Horsetail Plot of Cumulative Brine Inflow to the Waste Panel, Scenario S1-BF.

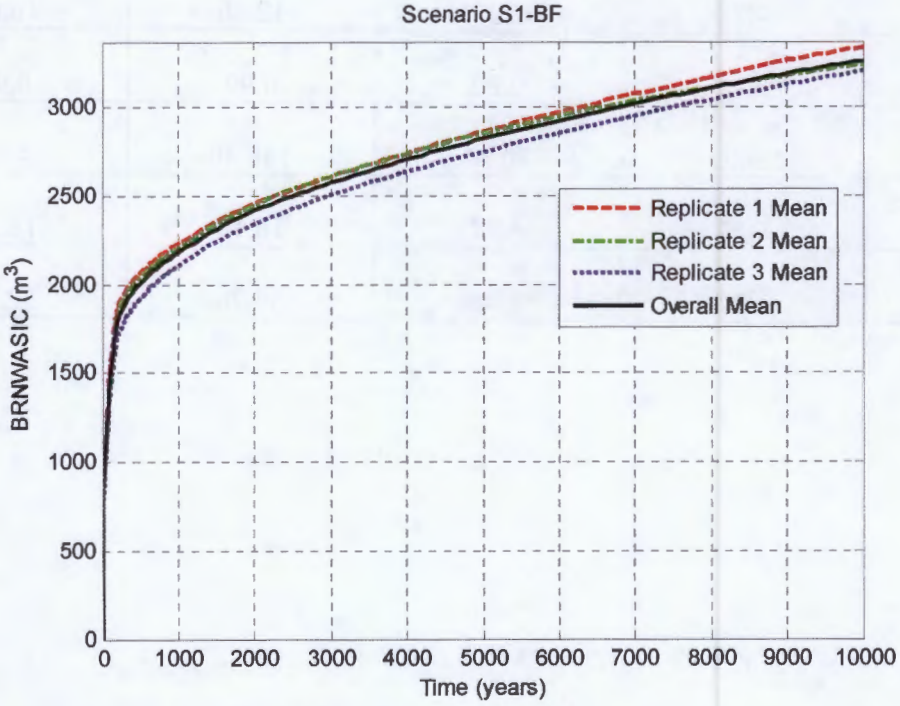

Figure 6-4: Means of Cumulative Brine Inflow to the Waste Panel, Scenario S1-BF.

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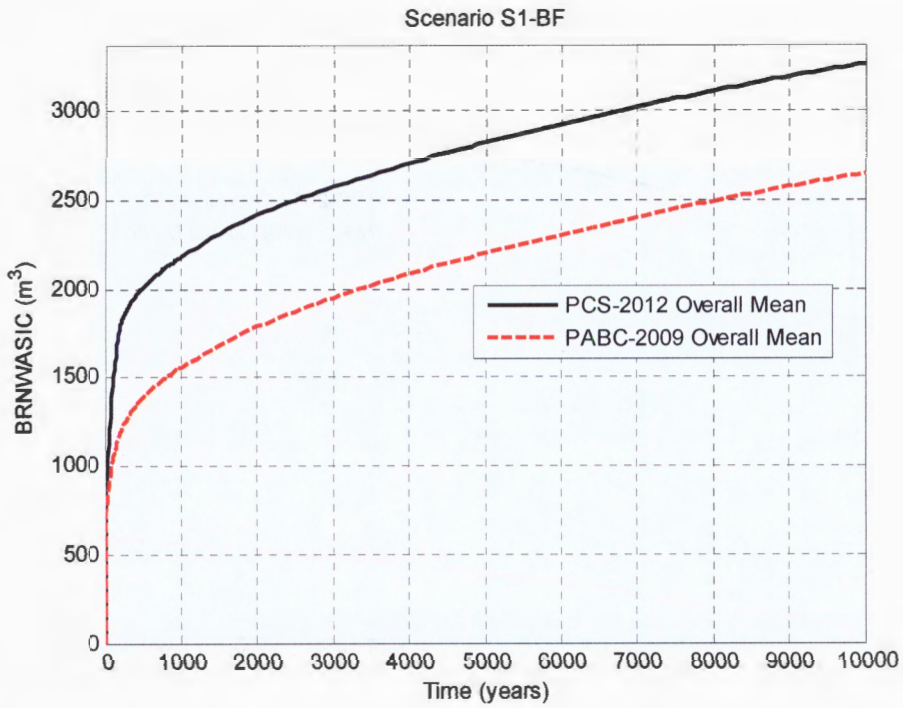

Figure 6-5: Overall Means of Cumulative Brine Inflow to the Waste Panel, Scenario S1-BF.

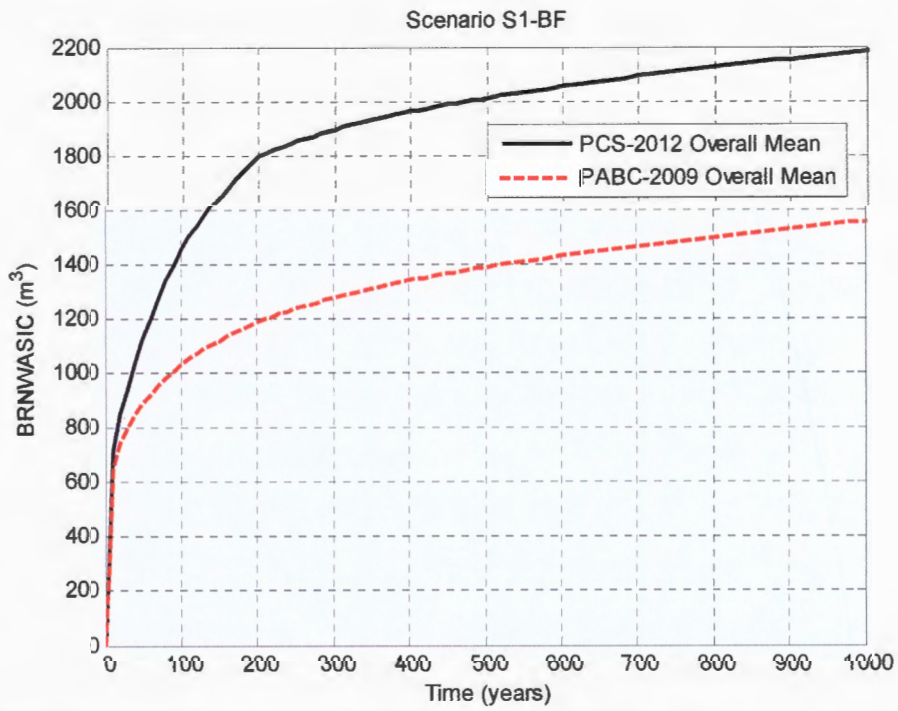

Figure 6-6: Overall Means of Cumulative Brine Inflow to the Waste Panel, Scenario S1-BF and Years 0 to 1,000.

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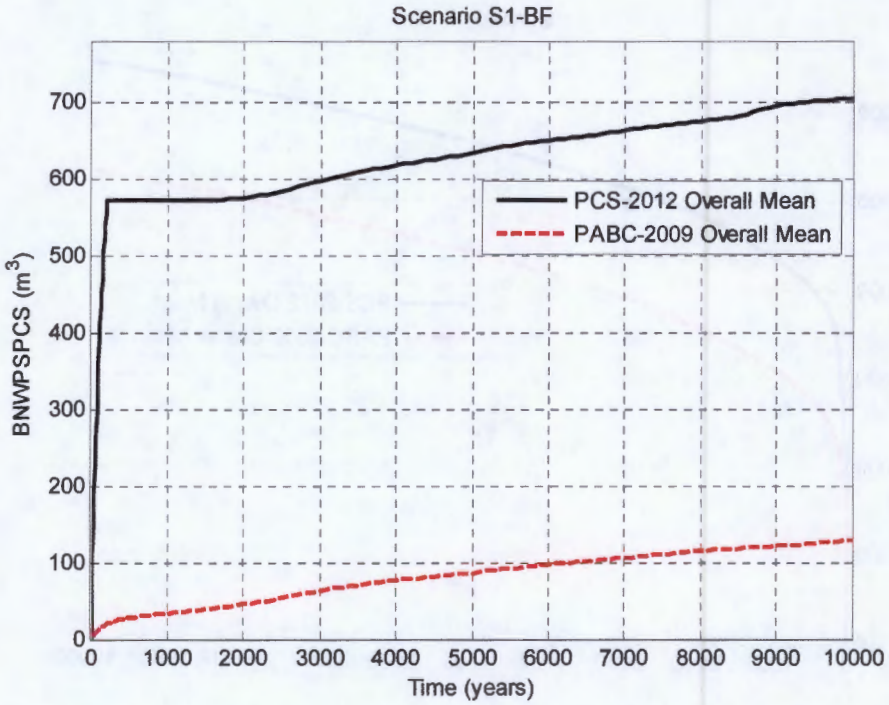

Figure 6-7: Overall Means of Cumulative Brine Flow Southward from the Panel Closure Plane and toward the Waste Panel, Scenario S1-BF

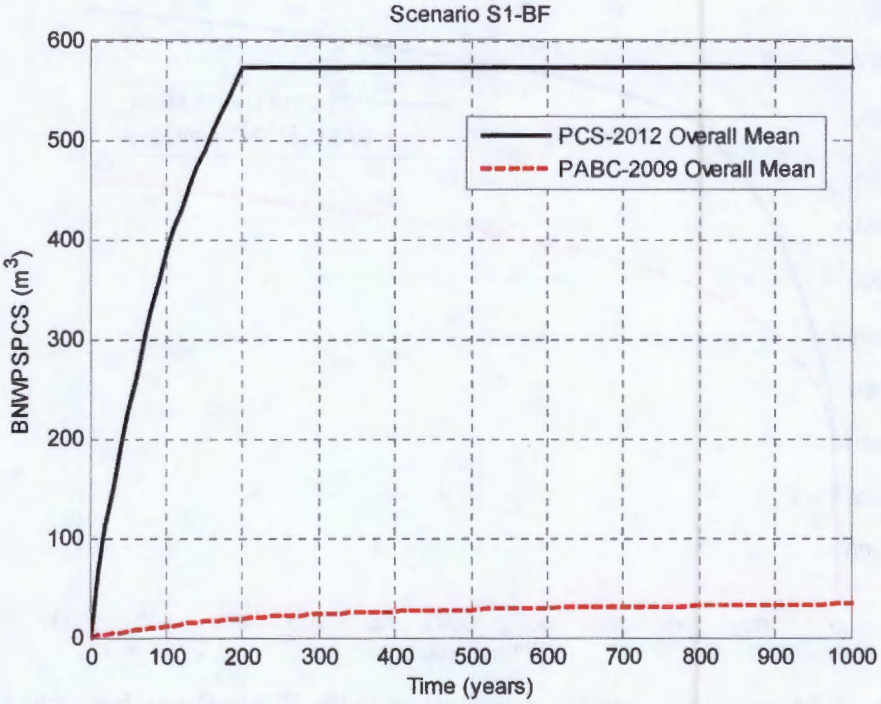

Figure 6-8: Overall Means of Cumulative Brine Flow Southward from the Panel Closure Plane and toward the Waste Panel, Scenario S1-BF and Years 0 to 1,000.

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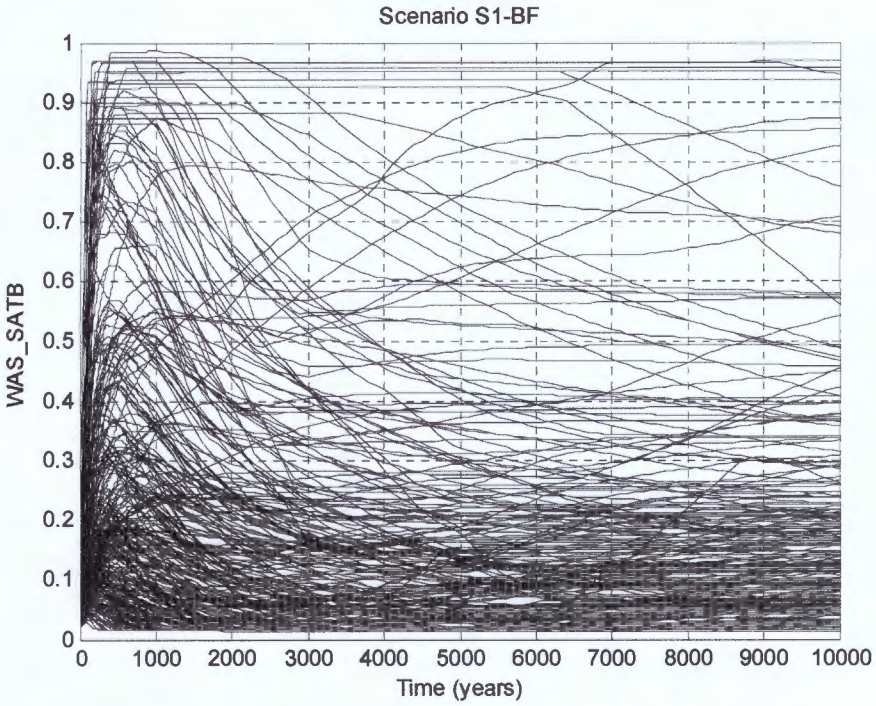

Figure 6-9: Horsetail Plot of Waste Panel Brine Saturation, Scenario S1-BF.

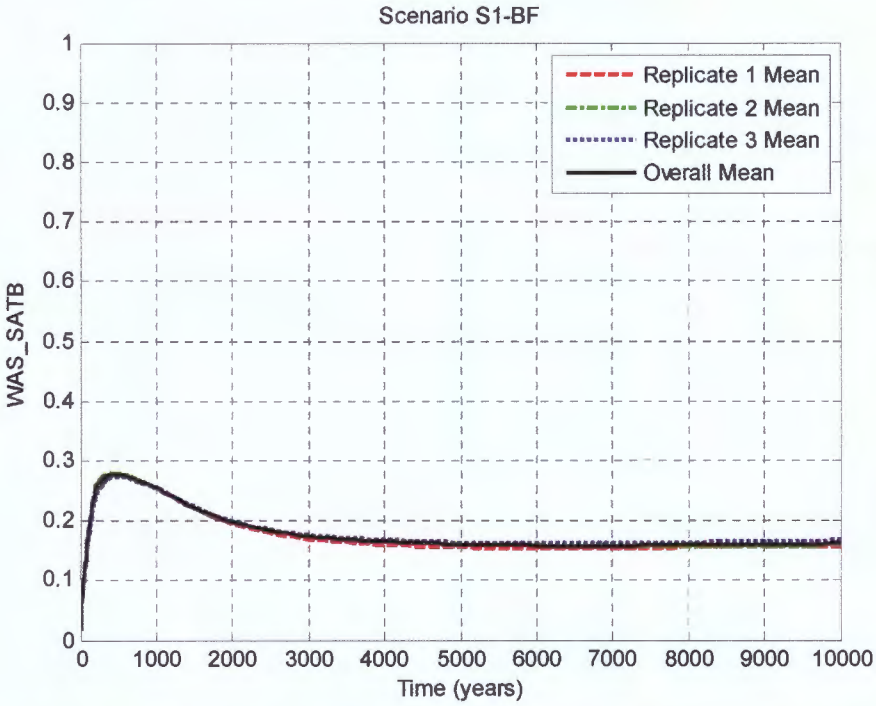

Figure 6-10: Means of Waste Panel Brine Saturation, Scenario S1-BF.

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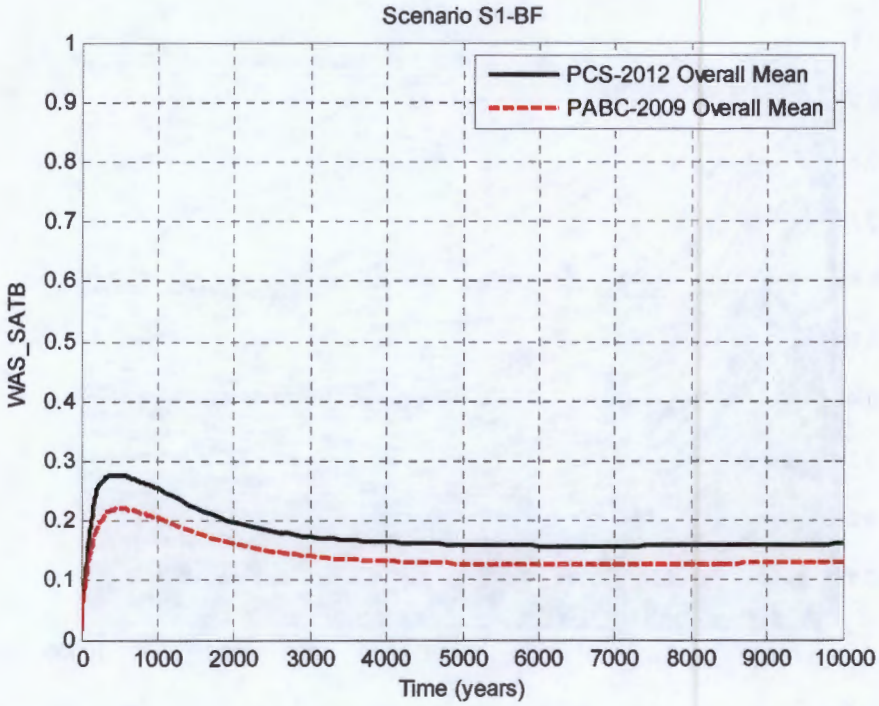

Figure 6-11: Overall Means of Waste Panel Brine Saturation, Scenario S1-BF.

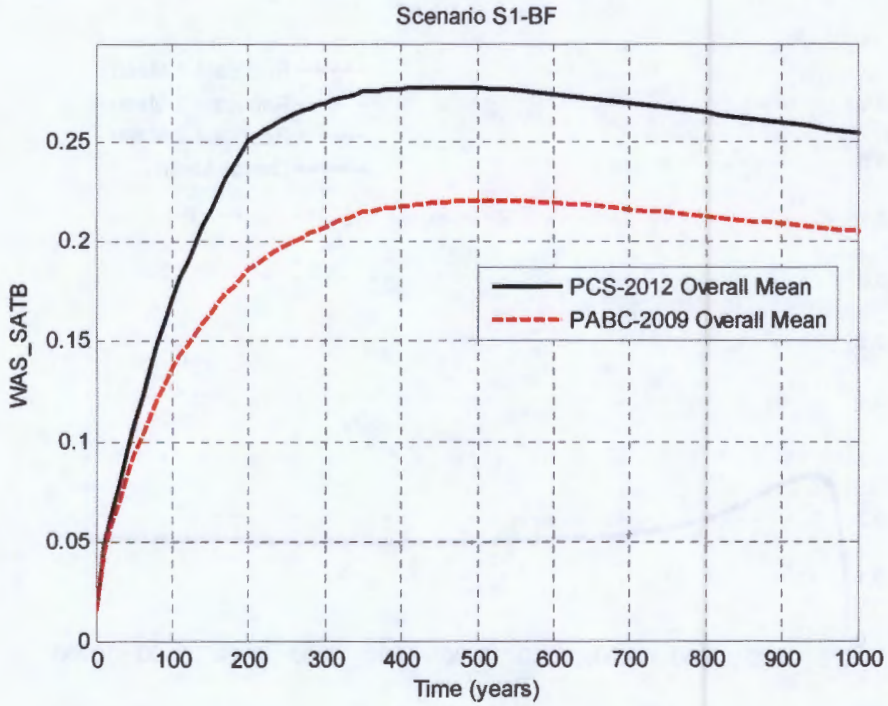

Figure 6-12: Overall Means of Waste Panel Brine Saturation, Scenario S1-BF and Years 0 to 1,000.

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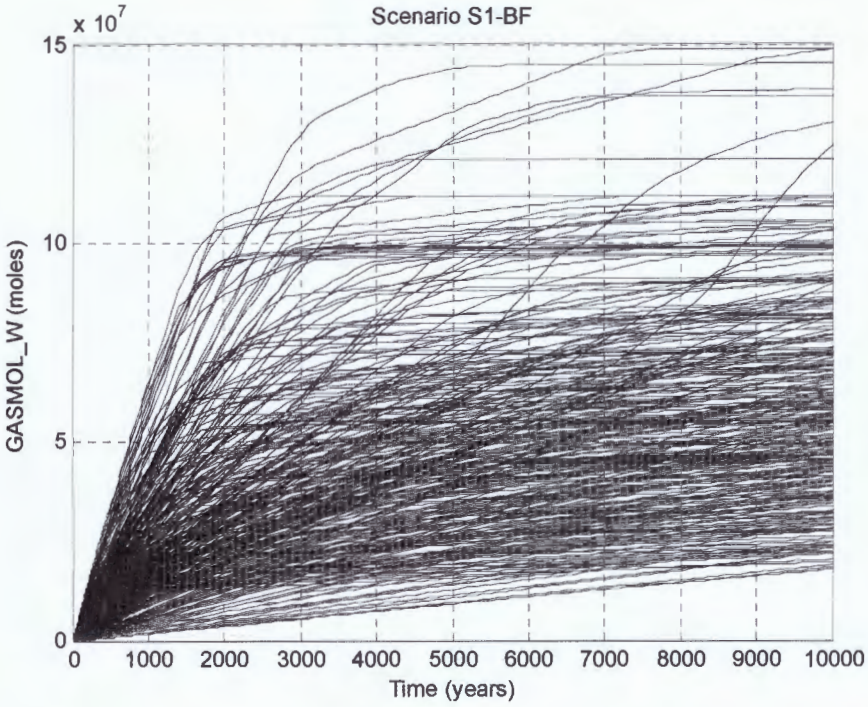

Figure 6-13: Horsetail Plot of Waste Panel Gas Generation (in moles), Scenario S1-BF.

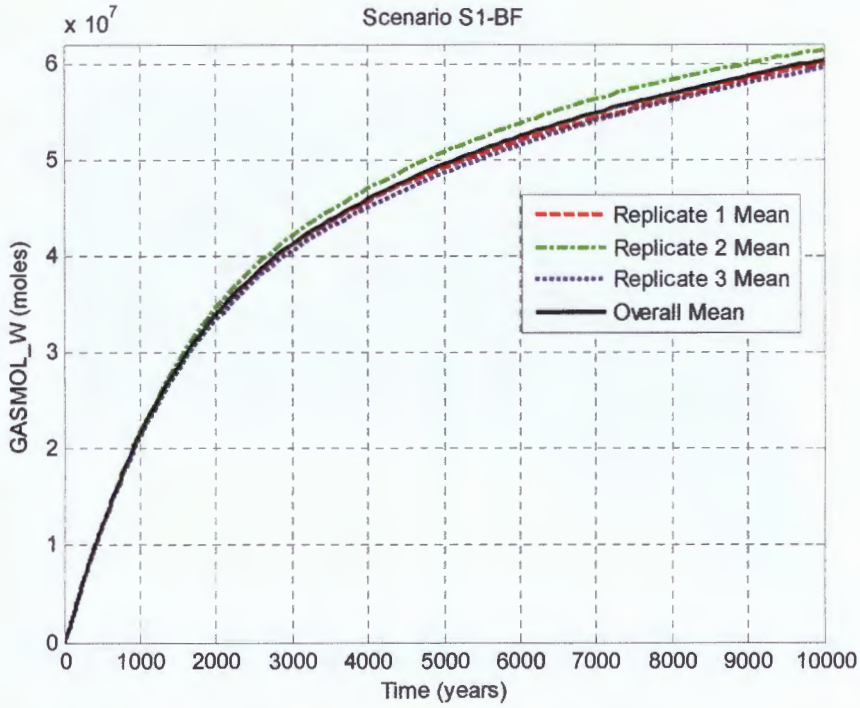

Figure 6-14: Means of Waste Panel Gas Generation (in moles), Scenario S1-BF.

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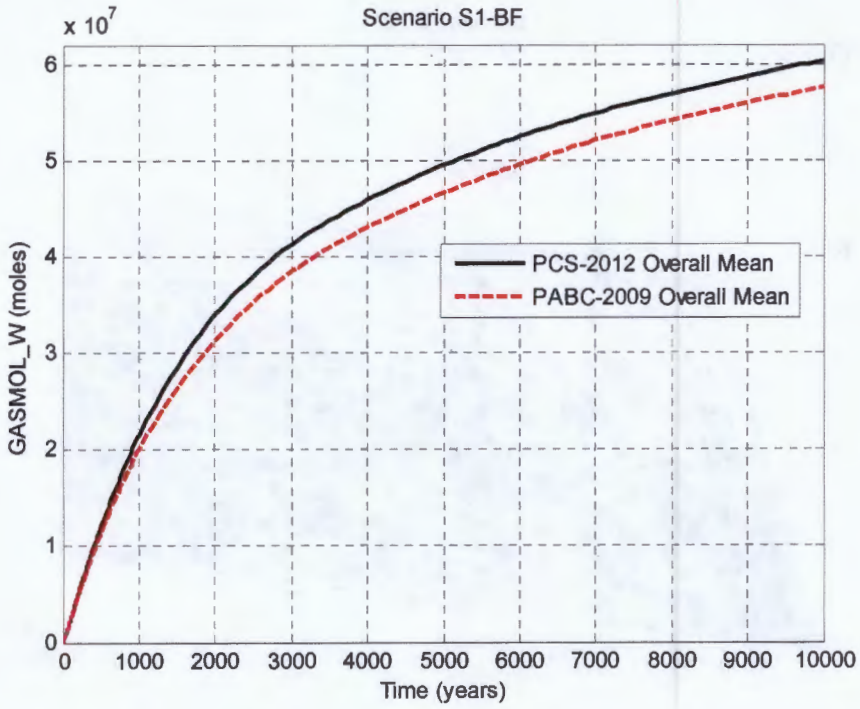

Figure 6-15: Overall Means of Waste Panel Gas Generation (in moles), Scenario S1-BF.

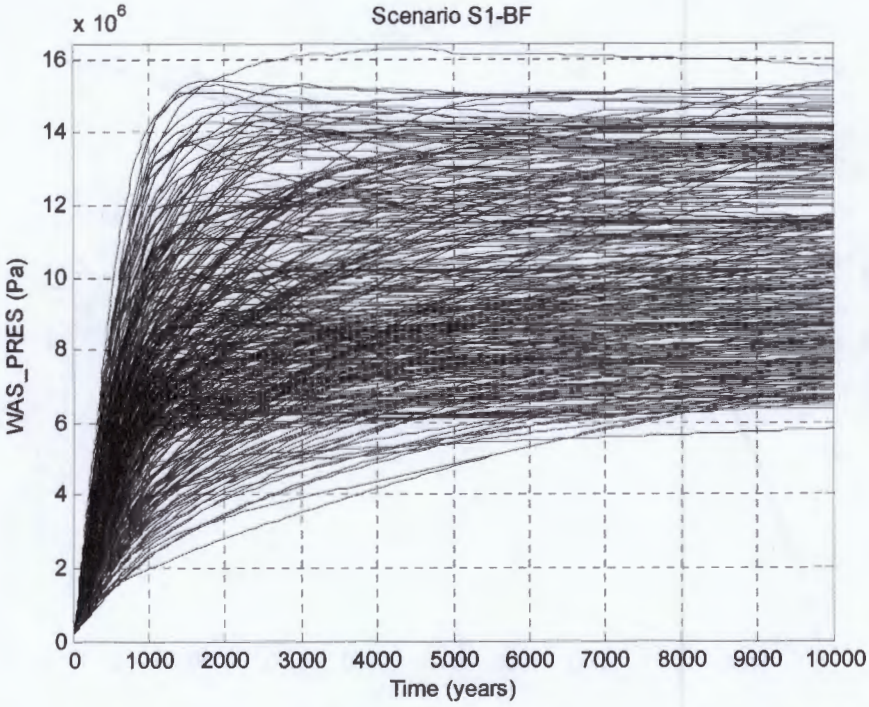

Figure 6-16: Horsetail Plot of Waste Panel Pressure, Scenario S1-BF.

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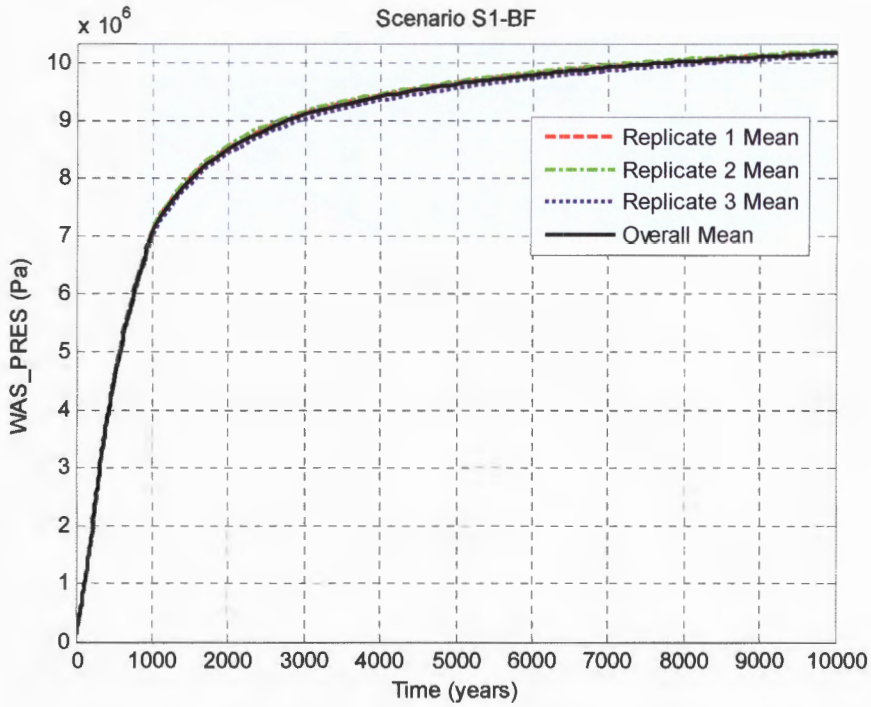

Figure 6-17: Means of Waste Panel Pressure, Scenario S1-BF.

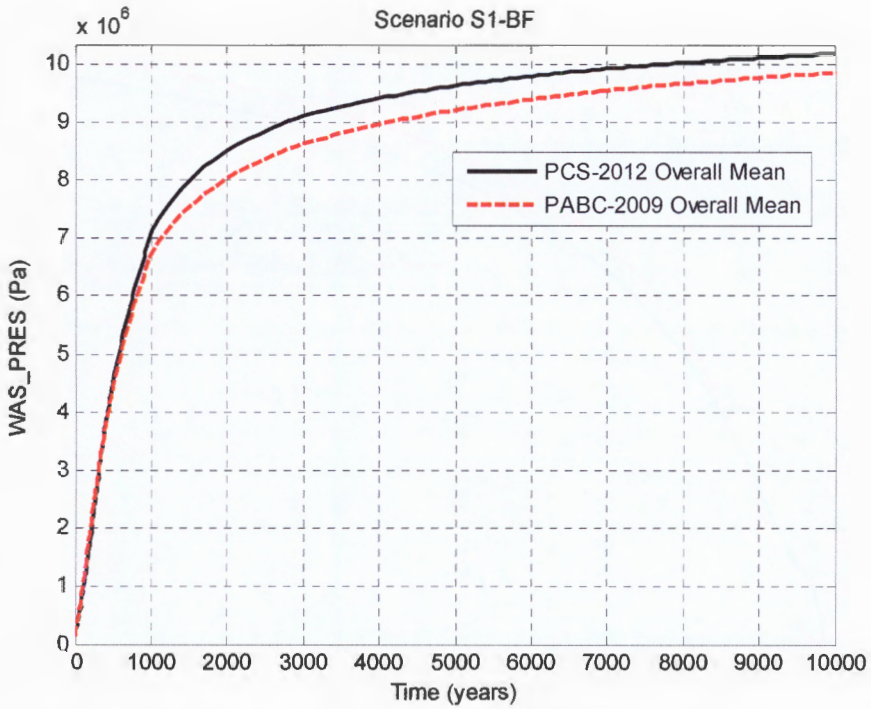

Figure 6-18: Overall Means of Waste Panel Pressure, Scenario S1-BF.

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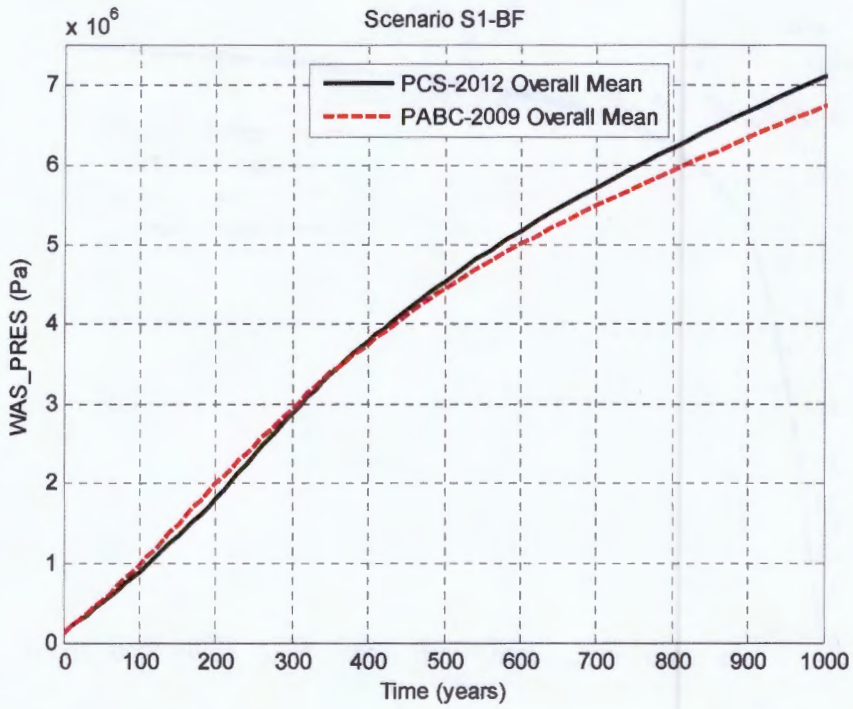

Figure 6-19: Overall Means of Waste Panel Pressure, Scenario S1-BF and Years 0 to 1,000.

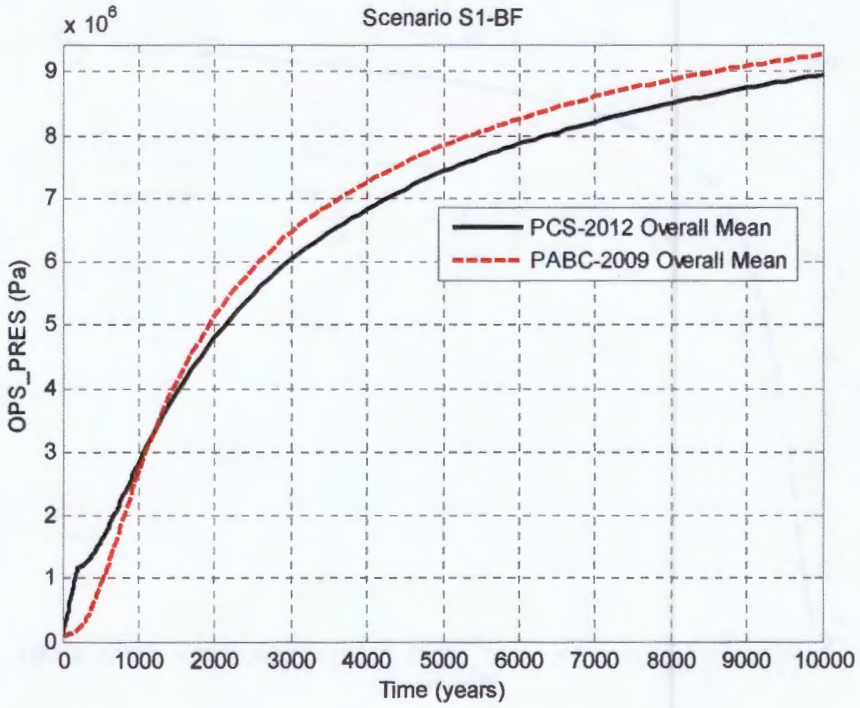

Figure 6-20: Overall Means of Pressure in the Operations Region, Scenario S1-BF.

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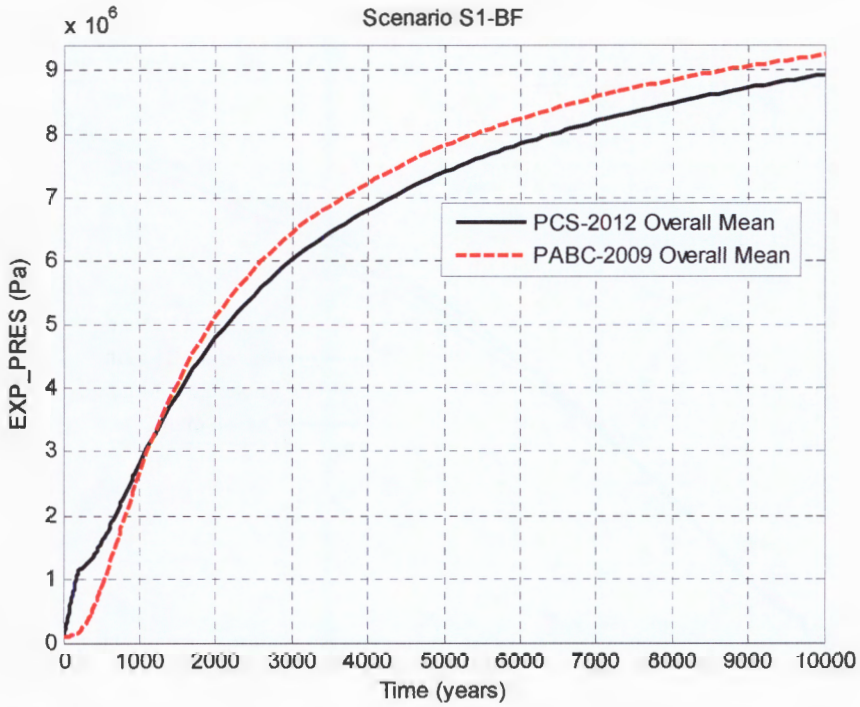

Figure 6-21: Overall Means of Pressure in the Experimental Region, Scenario S1-BF.

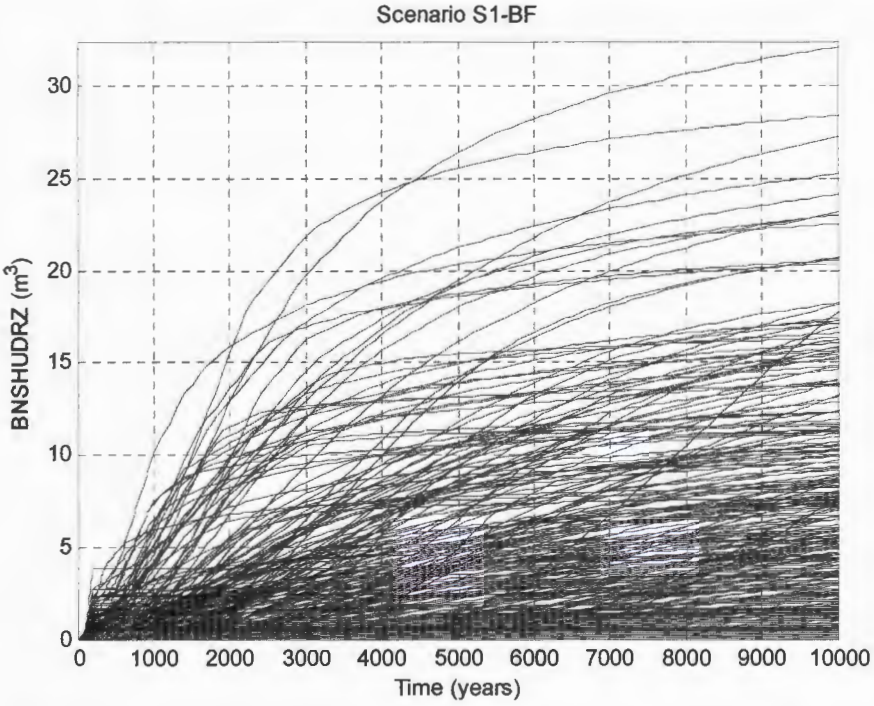

Figure 6-22: Horsetail Plot of Brine Flow up the Shaft, Scenario S1-BF.

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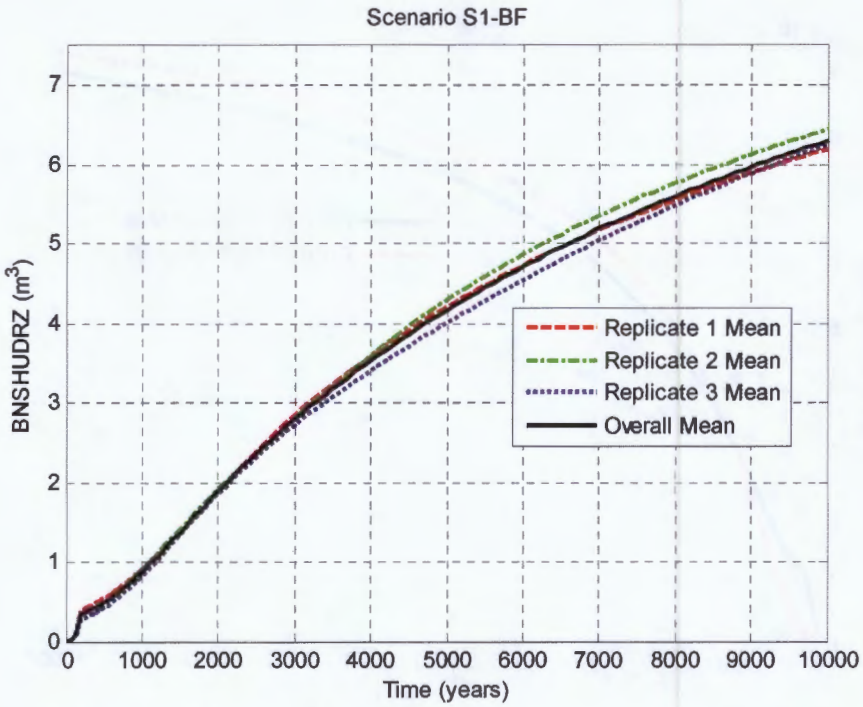

Figure 6-23: Means of Brine Flow up the Shaft, Scenario S1-BF.

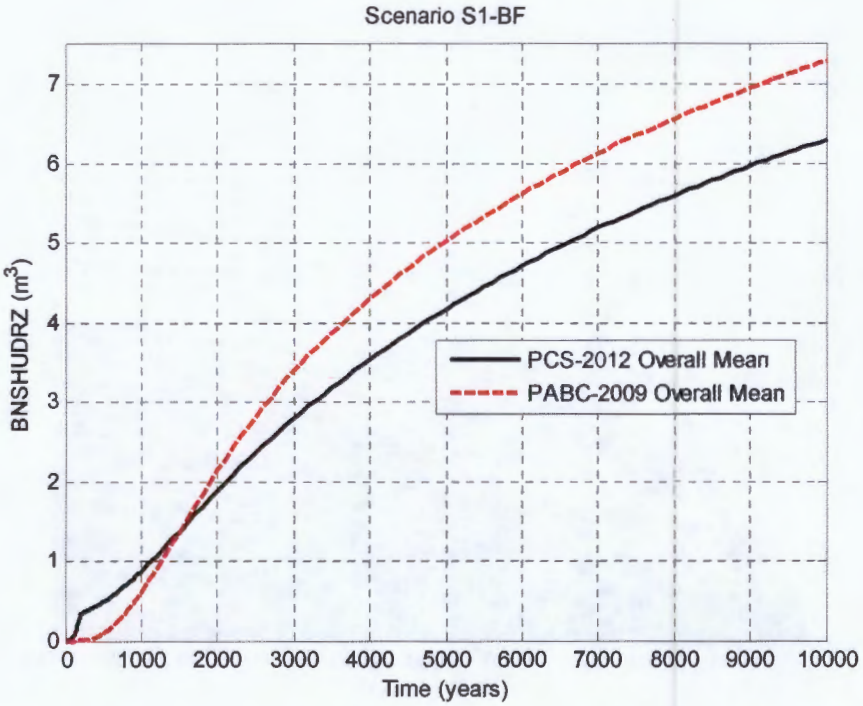

Figure 6-24: Overall Means of Brine Flow up the Shaft, Scenario S1-BF.

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

Results are now presented for disturbance scenario S2-BF. Results presented for this scenario are representative of those calculated for E1 intrusion scenarios (scenarios S2-BF and S3-BF), with the only difference being the time of the intrusion. In the results that follow, PCS-2012 PA trends discussed for scenario S2-BF also apply to scenario S3-BF.

The fundamental characteristic of an E1 intrusion is the creation of a connected pathway between the repository waste panel and a region of pressurized brine in the Castile. Castile brine moves upward into the waste panel immediately after the intrusion, increasing waste panel pressure, brine saturation, and impacting other waste panel quantities.

A horsetail plot of waste panel pressure obtained for scenario S2-BF in the PCS-2012 PA is shown in Figure 6-25. The three replicate means, as well as the overall mean, of waste panel pressure for this scenario are shown in Figure 6-26. As seen in that figure, there is good agreement among the means of waste panel pressure obtained in the PCS-2012 PA.

The overall means of waste panel pressure obtained in the PCS-2012 PA and the PABC-2009 for scenario S2-BF are plotted together in Figure 6-27. As seen in that figure, the mean waste panel pressure calculated in the PCS-2012 PA is greater than that found in the PABC-2009 for a period of time after the intrusion. As discussed previously, the long-term permeability range of the ROMPCS is lower than that prescribed to the Option D design in the PABC-2009. This reduction results in less long-term brine and gas flow through the ROMPCS, away from the waste panel, as compared to Option D. Following the E1 intrusion at 350 years, the "tighter" ROMPCS design results in a period of increased waste panel pressurization as compared to the PABC-2009 results.

An increase in waste panel pressure potentially impacts the volume of cumulative brine inflow to the waste panel. The horsetail plot of quantity BRNWASIC for PCS-2012 PA scenario S2-BF is shown in Figure 6-28. The three replicate means, as well as the overall mean, are shown in Figure 6-29. As seen in that figure, there is fairly close agreement between the means obtained for cumulative waste panel brine inflow. The overall means of BRNWASIC obtained in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-30. As seen in that figure, the increased permeability range of the ROMPCS at early times results in greater brine inflow to the waste panel before the ROMPCS attains its long-term properties at 200 years. Following the intrusion time of 350 years, an increase in mean waste panel pressure occurs in the PCS-2012 PA results. This pressure increase slightly inhibits brine flow into the waste panel, resulting in a reduction in cumulative waste panel brine inflow as compared to the PABC-2009 results.

The reduction of brine flowing into the waste panel in the PCS-2012 PA impacts the waste panel brine saturation. The horsetail plot of waste panel brine saturation obtained in PCS-2012 PA scenario S2-BF is shown in Figure 6-31. The three replicate means, and the overall mean, of WAS_SATB are shown together in Figure 6-32. As seen in that figure, there is very close agreement between the replicate means and the overall mean of waste panel brine saturation. The overall means of quantity WAS_SATB obtained in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-33. As is evident in that figure, the mean waste panel brine

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saturation obtained in the PCS-2012 PA is reduced slightly from that calculated in the PABC-2009 after the intrusion at 350 years. The reduction of brine inflow to the waste panel translates to a reduction in waste panel brine saturation.

A horsetail plot of waste panel gas generation (in moles) is given in Figure 6-34. The three replicate means, and the overall mean, for quantity GASMOL_W are shown together in Figure 6-35. As seen in that figure, there is very good agreement among the scenario S2-BF means obtained for waste panel gas generation in the PCS-2012 PA. The overall means of waste panel gas generation obtained in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-36. The overall means obtained for quantity GASMOL_W obtained in the two analyses are nearly identical, with a very slight reduction seen in the PCS-2012 PA mean. This slight reduction in gas generation is most likely due to the reduction in waste panel brine inflow and brine saturation seen in the PCS-2012 PA results.

The volume of brine flow up the intrusion borehole is denoted by quantity BNBHUDRZ. The horsetail plot of quantity BNBHUDRZ is shown in Figure 6-37. The three replicate means, and the overall mean for quantity BNBHUDRZ, are shown together in Figure 6-38. As seen in that figure, there is variability among the PCS-2012 PA means obtained for quantity BNBHUDRZ. The means obtained in the PCS-2012 PA are almost identical to those obtained in the PABC-2009, however, as is evident by comparing Figure 6-38 and Figure 6-39. Overall means of BNBHUDRZ obtained in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-40. The overall means obtained in the two analyses are almost identical, with a very slight increase seen in the PCS-2012 PA result.

Summary statistics for scenario S2-BF are shown in Table 5.

Table 5: Summary Statistics for Scenario S2-BF

Quantity (units)	Mean Value		Maximum Value	
	PABC-2009	PCS-2012 PA	PABC-2009	PCS-2012 PA
BRNWASIC ($x10^3$ m^3)	14.03	13.68	182.15	182.08
WAS_SATB (none)	0.68	0.67	0.99	0.99
GASMOL_W ($x10^6$ moles)	54.75	54.57	149.00	149.00
WAS_PRES (MPa)	7.39	7.50	15.63	16.40
BNBHUDRZ ($x10^3$ m^3)	3.25	3.28	166.84	169.54

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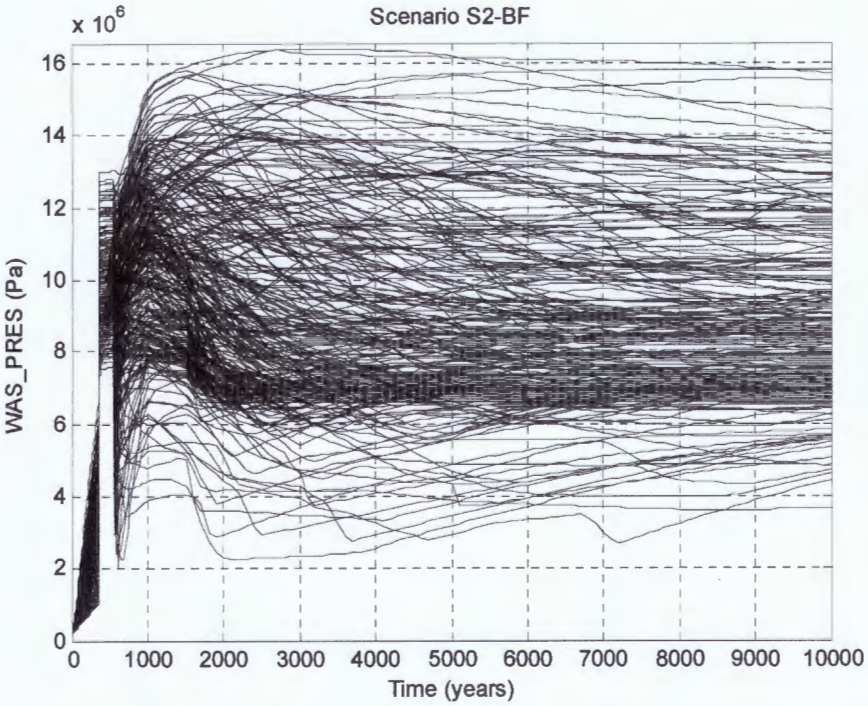

Figure 6-25: Horsetail Plot of Waste Panel Pressure, Scenario S2-BF.

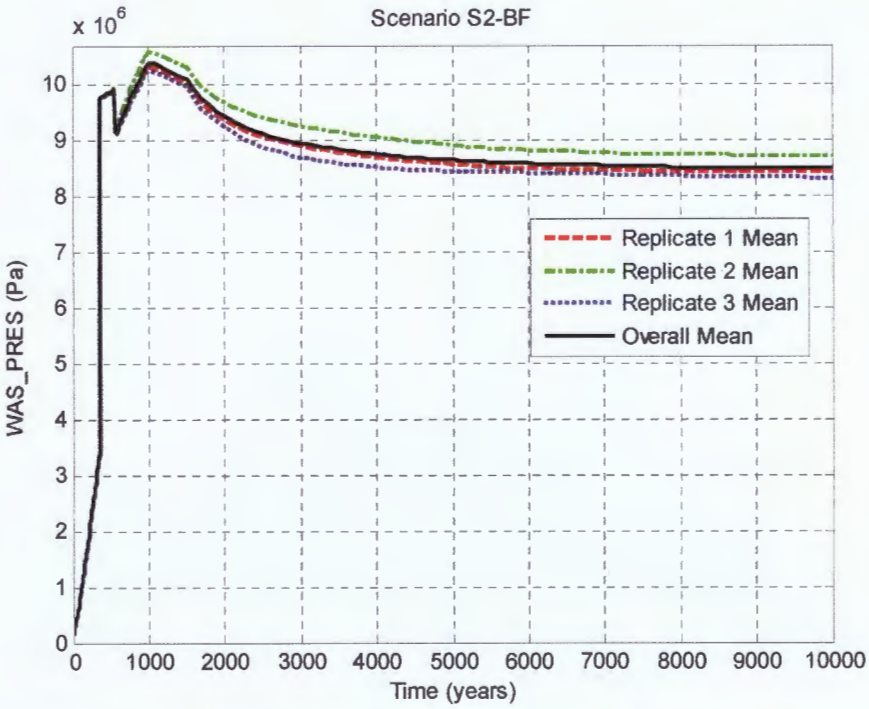

Figure 6-26: Means of Waste Panel Pressure, Scenario S2-BF.

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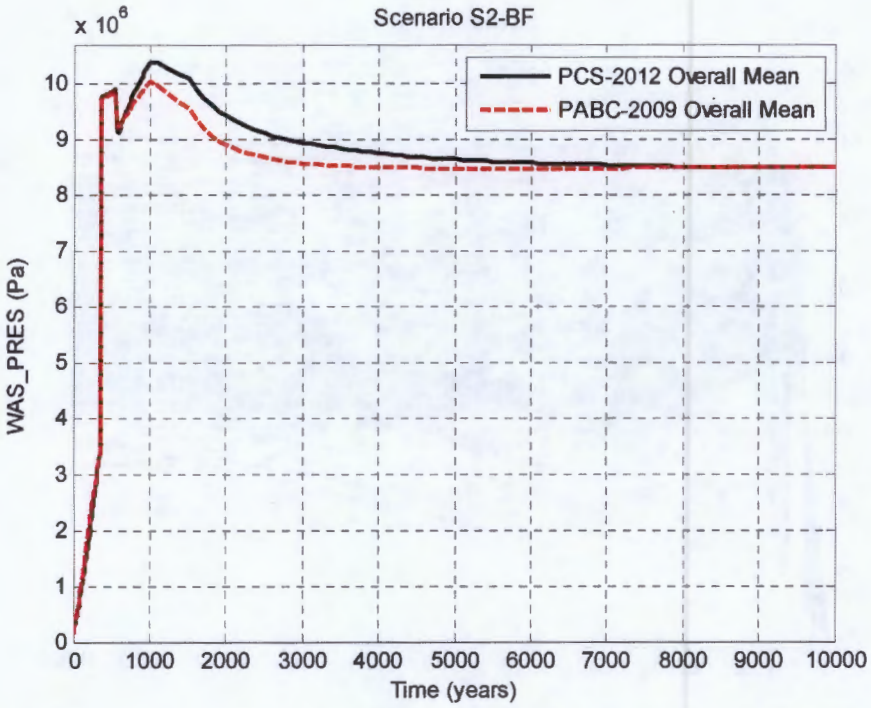

Figure 6-27: Overall Means of Waste Panel Pressure, Scenario S2-BF.

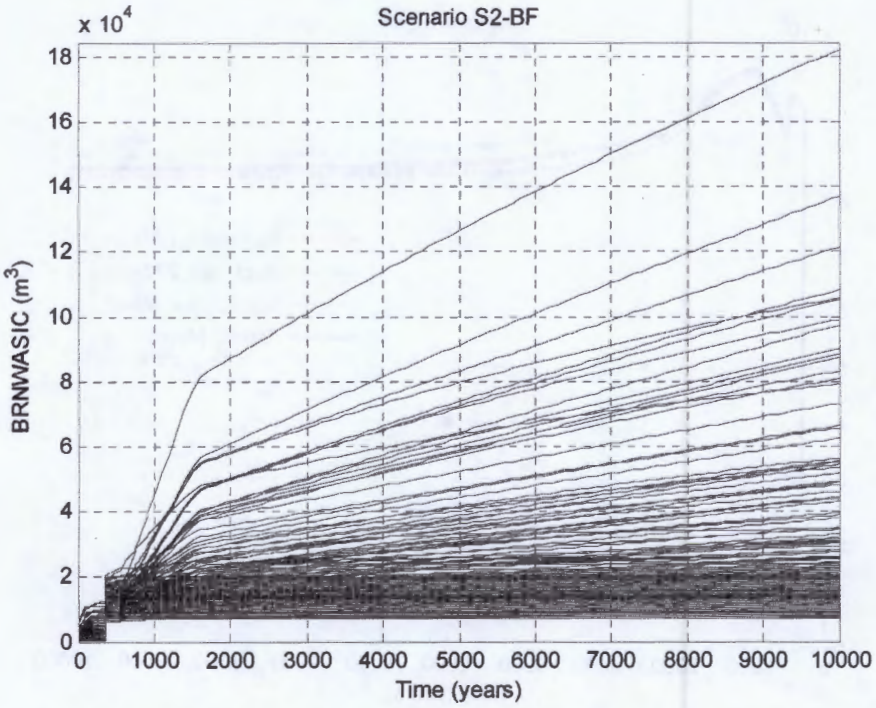

Figure 6-28: Horsetail Plot of Cumulative Brine Inflow to the Waste Panel, Scenario S2-BF.

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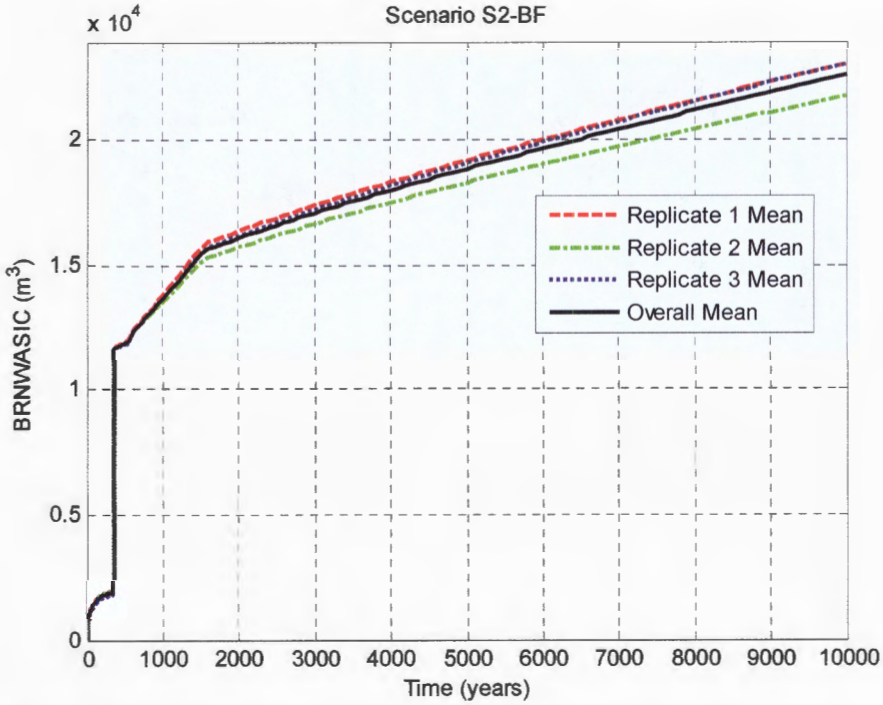

Figure 6-29: Means of Cumulative Brine Inflow to the Waste Panel, Scenario S2-BF.

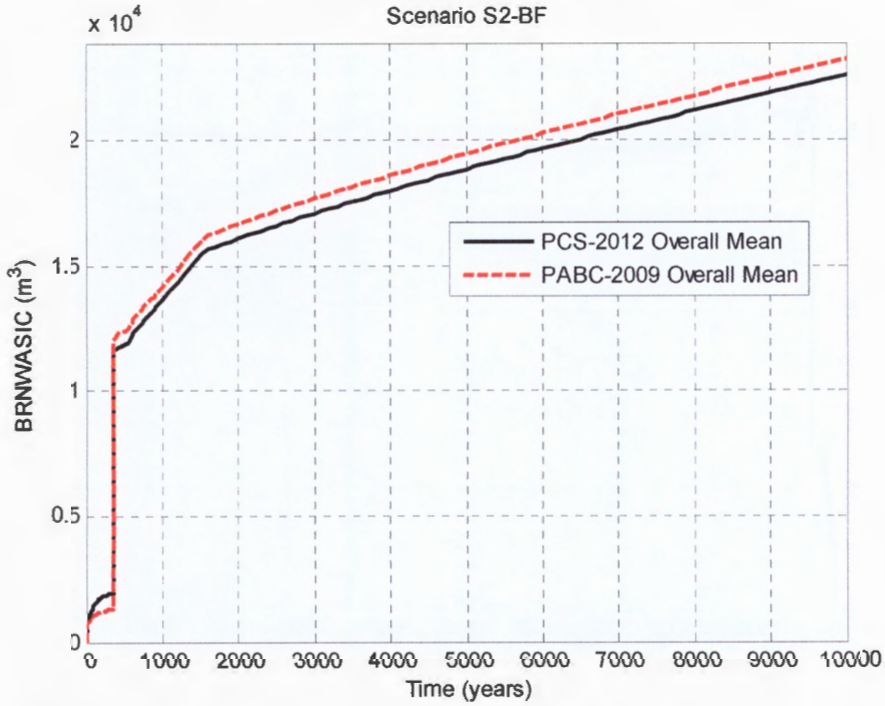

Figure 6-30: Overall Means of Cumulative Brine Inflow to the Waste Panel, Scenario S2-BF.

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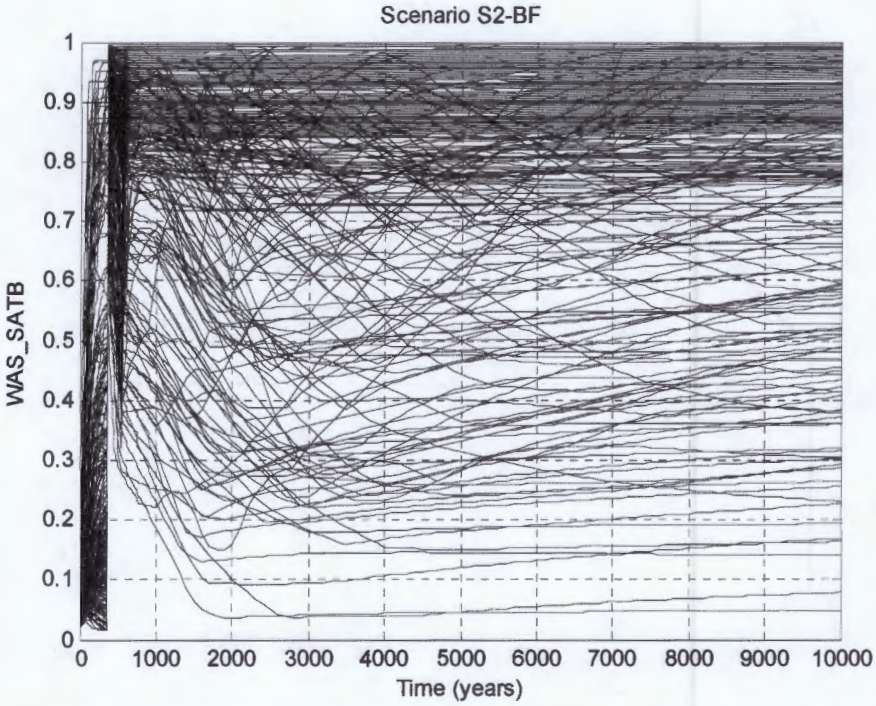

Figure 6-31: Horsetail Plot of Waste Panel Brine Saturation, Scenario S2-BF.

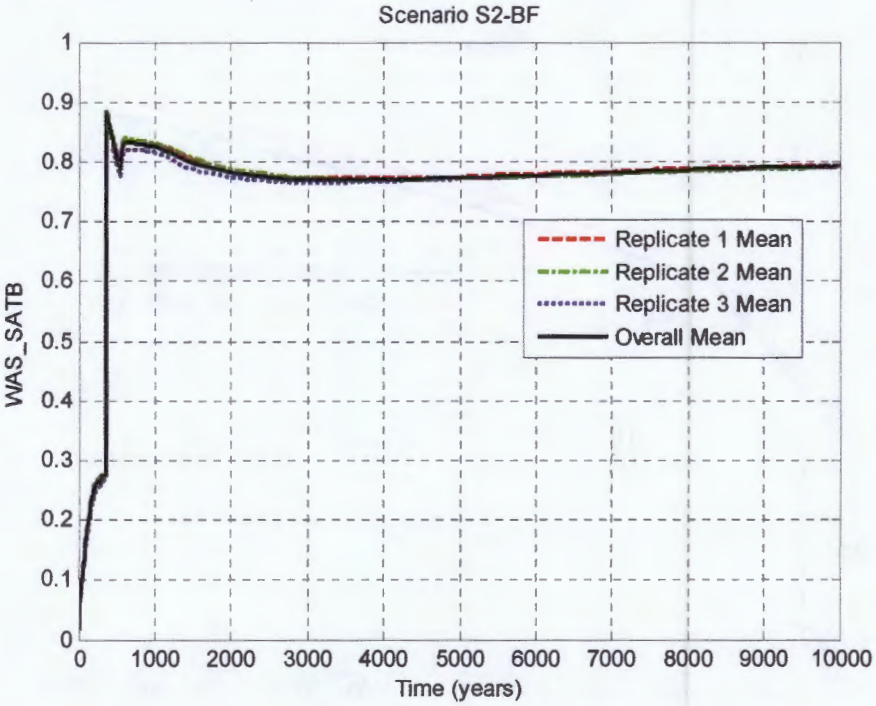

Figure 6-32: Means of Waste Panel Brine Saturation, Scenario S2-BF.

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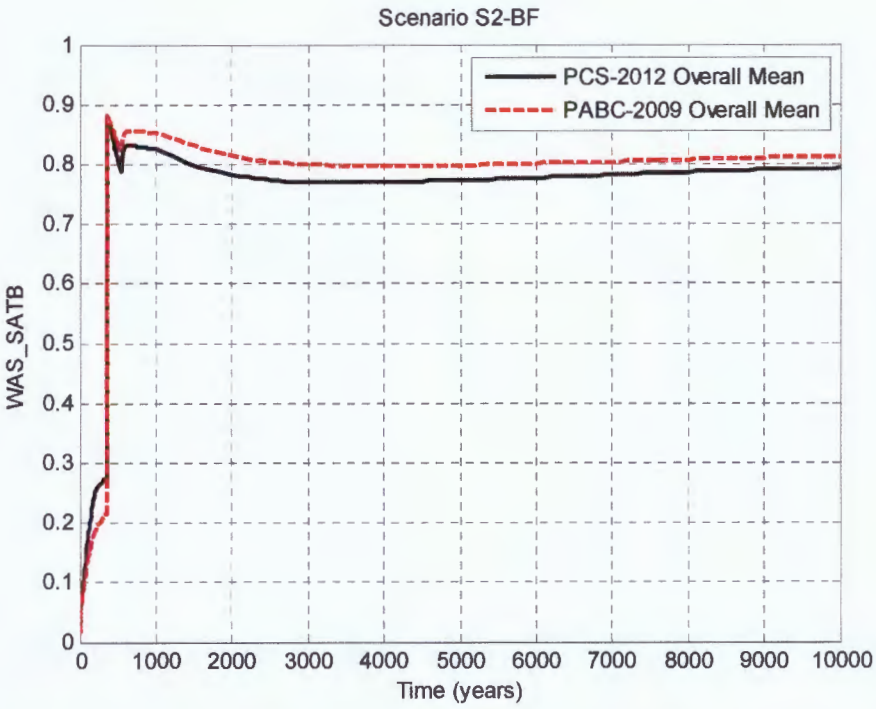

Figure 6-33: Overall Means of Waste Panel Brine Saturation, Scenario S2-BF.

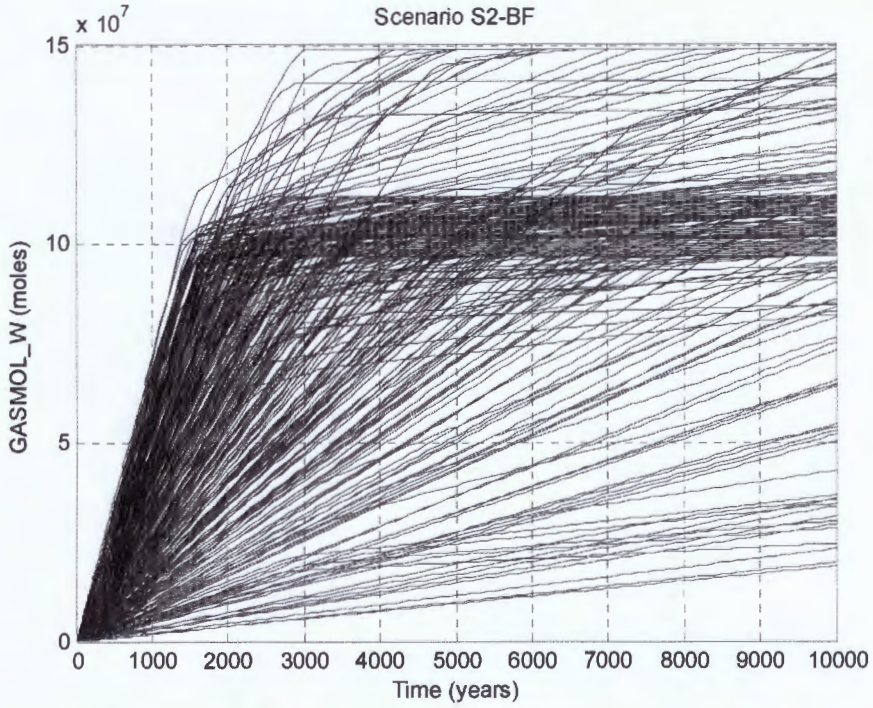

Figure 6-34: Horsetail Plot of Waste Panel Gas Generation (in moles), Scenario S2-BF.

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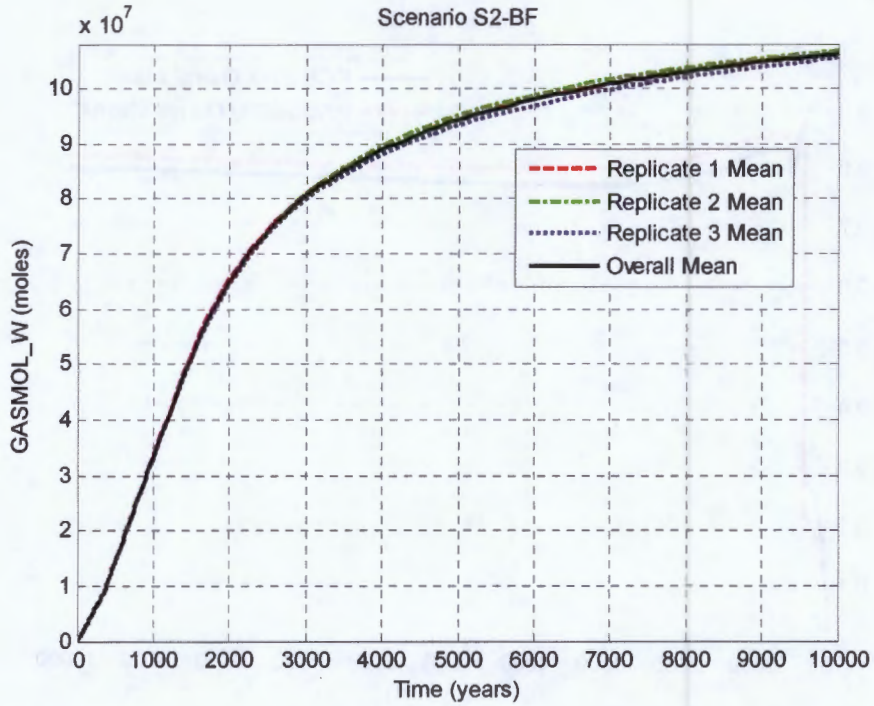

Figure 6-35: Means of Waste Panel Gas Generation (in moles), Scenario S2-BF.

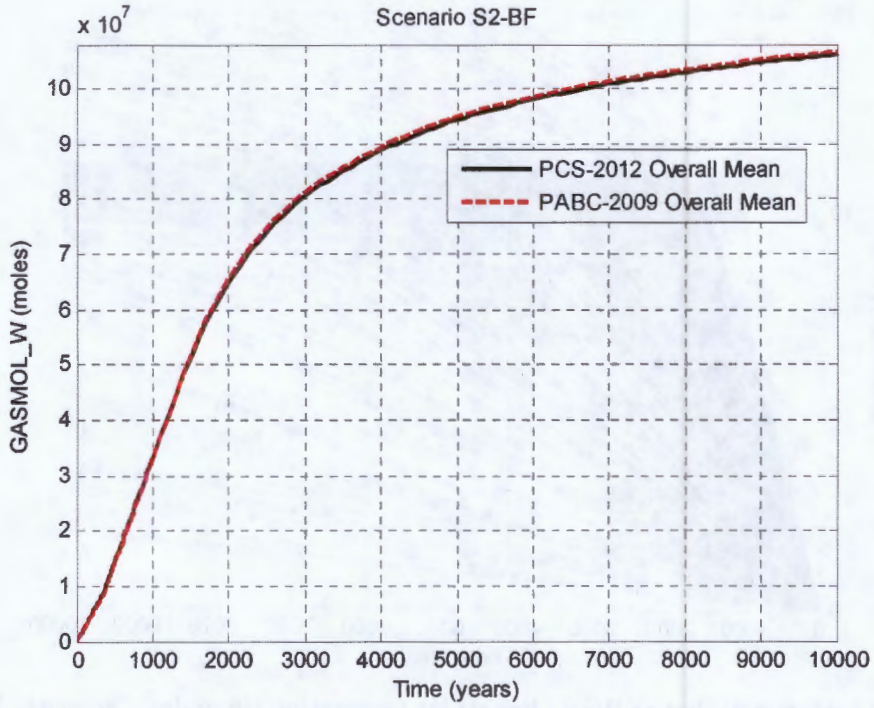

Figure 6-36: Overall Means of Waste Panel Gas Generation (in moles), Scenario S2-BF.

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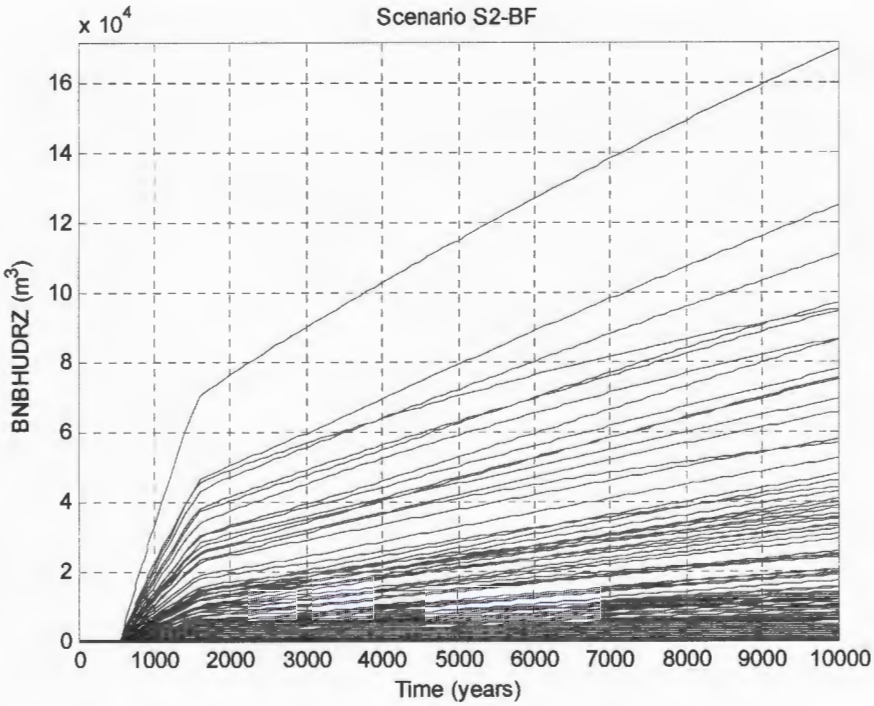

Figure 6-37: Horsetail Plot of Brine Flow up the Borehole, Scenario S2-BF.

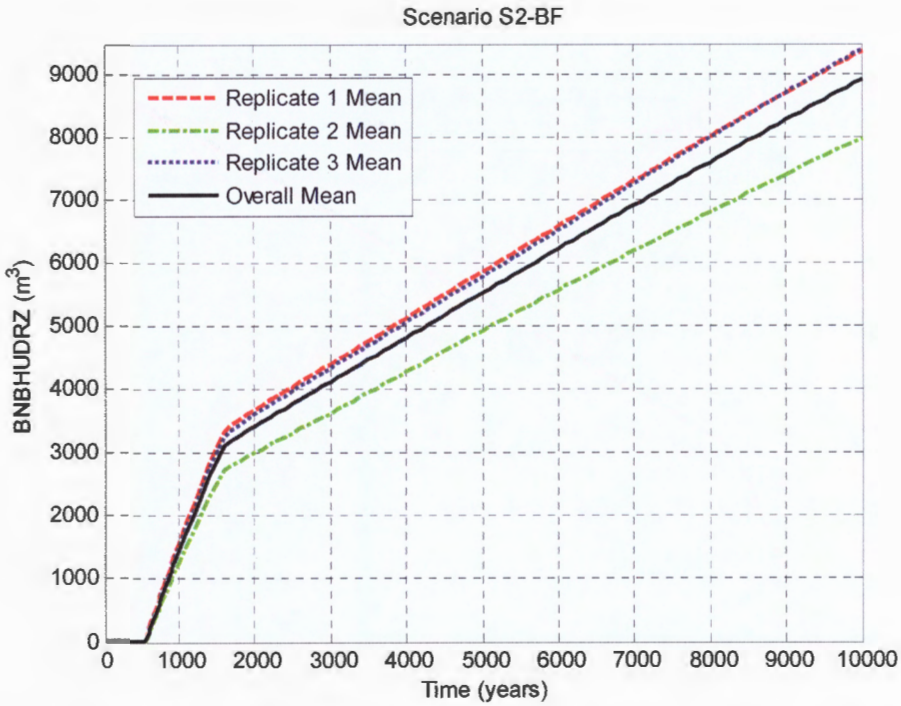

Figure 6-38: Means of Brine Flow up the Borehole, Scenario S2-BF.

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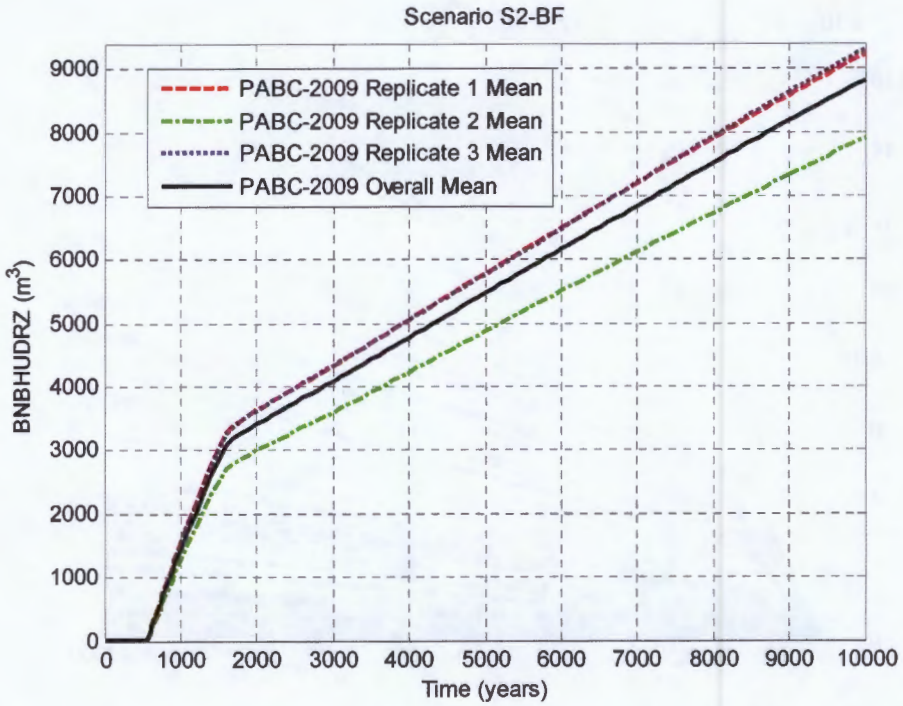

Figure 6-39: Means of Brine Flow up the Borehole, Scenario S2-BF for the PABC-2009.

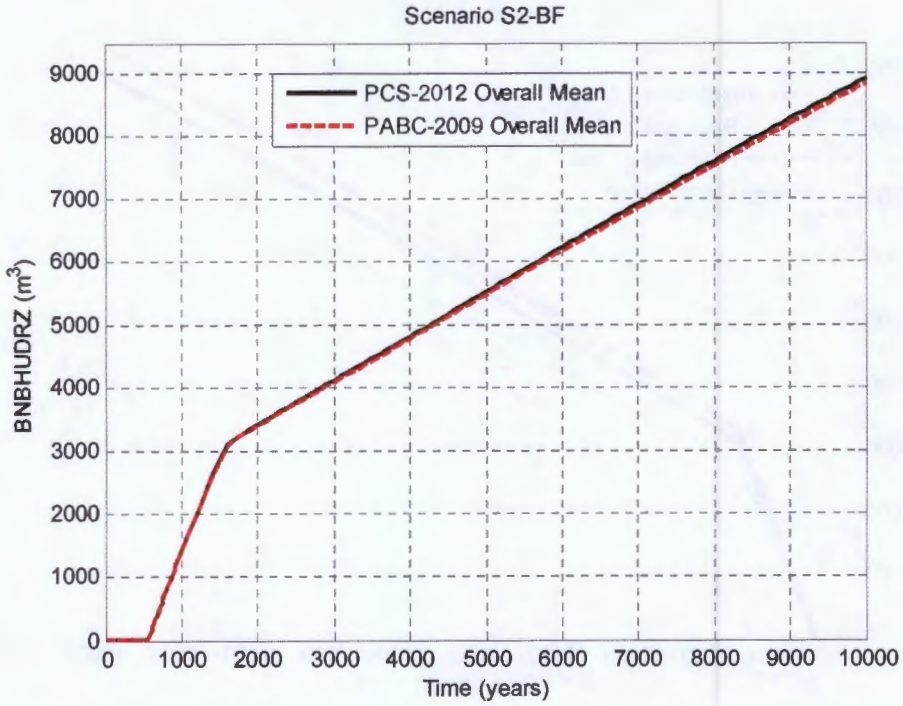

Figure 6-40: Overall Means of Brine Flow up the Borehole, Scenario S2-BF.

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

Results are now presented for disturbance scenario S4-BF. Results presented for this scenario are representative of those calculated for E2 intrusion scenarios (scenarios S4-BF and S5-BF), with the only difference being the time of the intrusion. In the results that follow, PCS-2012 PA trends discussed for scenario S4-BF also apply to scenario S5-BF.

As seen in the previous section, an E1 intrusion scenario results in an immediate influx of pressurized Castile brine to the waste panel, resulting in an increase is waste panel pressure when compared to undisturbed conditions. An E2 intrusion typically has the opposite effect. For the E2 intrusion scenario, no connected pathway is created between pressurized Castile brine and the repository waste panel. Following the intrusion, concrete plugs are immediately emplaced in the borehole near the ground surface. Consequently, an E2 intrusion does not typically have a significant impact on waste panel quantities *at the time of intrusion.* 200 years after the time of intrusion, concrete plugs emplaced in the borehole are modeled as failing, with the entire borehole assuming properties equivalent to sand. The result is a depressurization of the waste panel, beginning 200 years after the intrusion. Whereas an E1 intrusion typically results in an immediate increase in waste panel pressure, an E2 intrusion typically results in a *reduction* in waste panel pressure 200 years after the intrusion as compared to undisturbed conditions.

A horsetail plot of waste panel pressure obtained in the PCS-2012 PA scenario S4-BF is shown in Figure 6-41. The three replicate means, and the overall mean, for quantity WAS_PRES are shown together in Figure 6-42. As seen in that figure, there is close agreement among the replicate means and the overall mean obtained for waste panel pressure in the PCS-2012 PA. The impact of the E2 intrusion on waste panel pressure is more closely seen in Figure 6-43. In that figure, PCS-2012 PA overall means of waste panel pressure obtained in scenarios S1-BF and S4-BF are plotted together with the time scale restricted to the first 1,000 years. As seen in that figure, no noticeable impact is seen in the mean waste panel pressure when the E2 intrusion occurs at 350 years. For the period of 350 years to 550 years, there is a slight increase in the mean pressure for scenario S4-BF as compared to undisturbed results. The borehole plugs fail at 550 years, creating a pathway for waste panel pressure release through the borehole and toward the ground surface. Consequently, the mean waste panel pressure for scenario S4-BF is reduced sharply at 550 years when compared to undisturbed results.

The overall means of waste panel pressure obtained for scenario S4-BF in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-44. As seen in that figure, the mean waste panel pressure obtained in the PCS-2012 PA is slightly greater than the PABC-2009 result. As already discussed, the PCS-2012 PA mean waste panel pressure is greater than that seen in the PABC-2009 for undisturbed conditions (Figure 6-18). Consequently, at the time of the E2 intrusion, the mean waste panel pressure is greater in the PCS-2012 PA, and is also greater 200 years later when the borehole plugs fail. The result is a slightly higher mean pressure in the PCS-2012 PA scenario S4-BF result when compared to the PABC-2009.

A horsetail plot of cumulative waste panel brine inflow for PCS-2012 PA scenario S4-BF is shown in Figure 6-45. The three replicate means, and the overall mean, for quantity

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BRNWASIC are shown together in Figure 6-46. As seen in that figure, there is close agreement among the PCS-2012 PA means for quantity BRNWASIC.

The impact of the E2 intrusion on cumulative waste panel brine inflow can be clearly seen in Figure 6-47. At the intrusion time of 350 years until the borehole plugs fail at 550 years, there is only a very slight increase in quantity BRNWASIC as compared to undisturbed conditions. After the borehole plugs fail, a decrease in the waste panel pressure occurs. This pressure reduction yields in an increase in brine flow into the waste panel at 550 years compared to the undisturbed case.

The overall mean for quantity BRNWASIC in the PCS-2012 PA and the PABC-2009 are plotted together in Figure 6-48. As evident in that figure, an increase to the mean waste panel cumulative brine inflow is seen in the PCS-2012 PA results. This increase is due to the increased waste panel brine inflow seen for undisturbed conditions (Figure 6-5). As discussed above, very little impact is seen in the mean curve for quantity BRNWASIC as compared to undisturbed conditions, until the borehole plugs fail at 550 years. The PCS-2012 PA mean waste panel brine inflow curve is already greater than that obtained in the PABC-2009 when the borehole plugs fail at 550 years. The increase in brine inflow seen after the borehole plugs fail results in a PCS-2012 PA mean waste panel brine inflow curve that remains greater than that seen in the PABC-2009.

The change to cumulative waste panel brine inflow seen in the PCS-2012 PA impacts the waste panel brine saturation. A horsetail plot of the PCS-2012 PA waste panel brine saturation is shown in Figure 6-49. The three replicate means, and the overall mean, obtained for quantity WAS_SATB are plotted together in Figure 6-50. As seen in that figure, there is good agreement between the means obtained in the PCS-2012 PA for the waste panel brine saturation. The impact of the E2 intrusion on quantity WAS_SATB is similar to that seen for cumulative brine flow into the waste panel. As seen in Figure 6-51, the mean waste panel brine saturation is changed very little as compared to undisturbed conditions for the time period of 350 to 550 years. After the borehole plugs fail at 550 years, an increase of brine inflow to the waste panel translates to a corresponding increase in brine saturation. The result is a PCS-2012 PA mean waste brine saturation curve that is greater than that seen in the PABC-2009 results (Figure 6-52). The increase in the mean cumulative brine inflow to the waste panel seen in the PCS-2012 PA translates to an increase in the mean waste panel brine saturation.

The increase in waste panel brine saturation impacts gas generation in the waste panel. A horsetail plot of PCS-2012 PA waste panel gas generation (in moles) is shown in Figure 6-53. The three replicate means, and the overall mean, for quantity GASMOL_W are plotted together in Figure 6-54. The impact of the E2 intrusion on waste panel gas generation can be seen in Figure 6-55. Between the intrusion time of 350 years to the time of borehole plug failure at 550 years, the mean waste panel gas generation curve is increased very slightly compared to undisturbed conditions. After the borehole plugs fail, the increase to waste panel brine saturation results in a corresponding increase to waste panel gas generation. More brine flows into the waste panel (on average) in PCS-2012 PA scenario S4-BF as compared to the PABC-2009, resulting in an overall mean for quantity GASMOL_W is the PCS-2012 PA that is greater than that seen in the PABC-2009 (Figure 6-56).

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The volume of brine flowing up the borehole toward the ground surface is denoted by quantity BNBHUDRZ. A horsetail plot of this quantity for the PCS-2012 PA scenario S4-BF is given in Figure 6-57. The three replicate means, and the overall mean, for BNBHUDRZ are plotted together in Figure 6-58. As seen in that figure, some variability exists among the means of brine flow up the borehole obtained in the PCS-2012 PA. This variability is not substantially different than that seen in the PABC-2009, as is evident by comparing Figure 6-58 and Figure 6-59. The increase in the mean waste panel pressure seen in the PCS-2012 PA yields a slight long-term increase in the means of quantity BNBHUDRZ. The overall mean of this quantity is greater in the PCS-2012 PA, as shown in Figure 6-60.

Summary statistics for scenario S4-BF are shown in Table 6.

Table 6: Summary Statistics for Scenario S4-BF

Quantity (units)	Mean Value		Maximum Value	
	PABC-2009	PCS-2012 PA	PABC-2009	PCS-2012 PA
BRNWASIC ($x10^3$ m^3)	2.73	3.29	23.81	19.39
WAS_SATB (none)	0.28	0.33	0.99	0.99
GASMOL_W ($x10^6$ moles)	36.40	38.35	149.00	149.00
WAS_PRES (MPa)	4.64	4.70	14.92	15.21
BNBHUDRZ (m^3)	34.76	43.76	4876.89	5287.28

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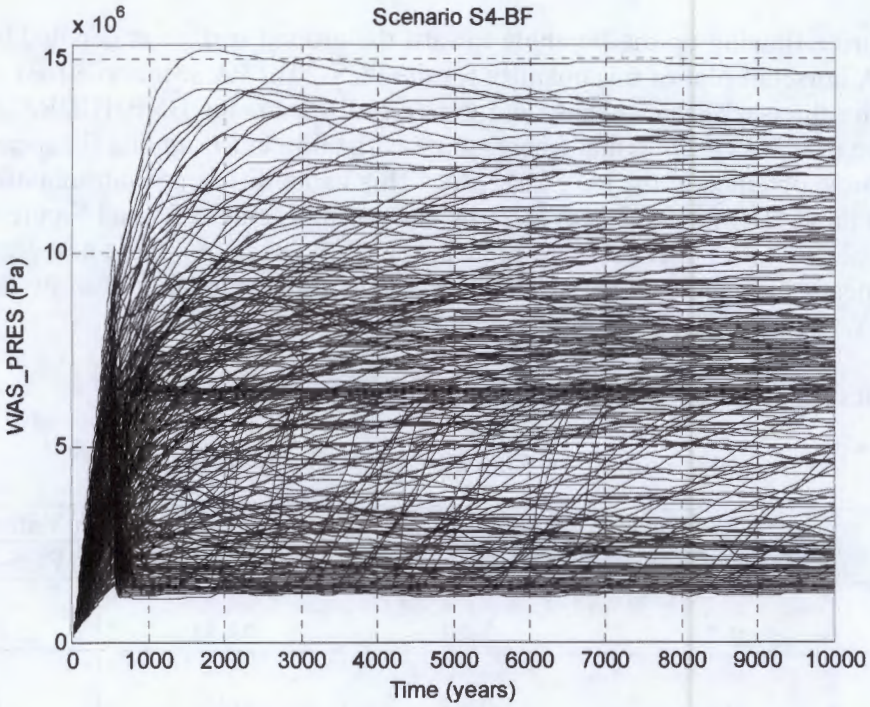

Figure 6-41: Horsetail Plot of Waste Panel Pressure, Scenario S4-BF.

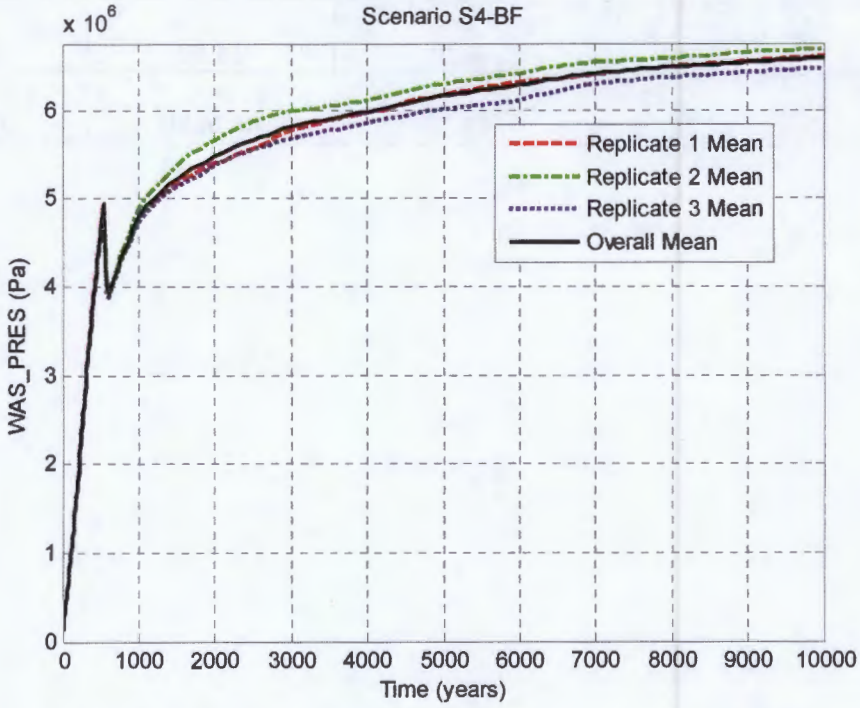

Figure 6-42: Means of Waste Panel Pressure, Scenario S4-BF.

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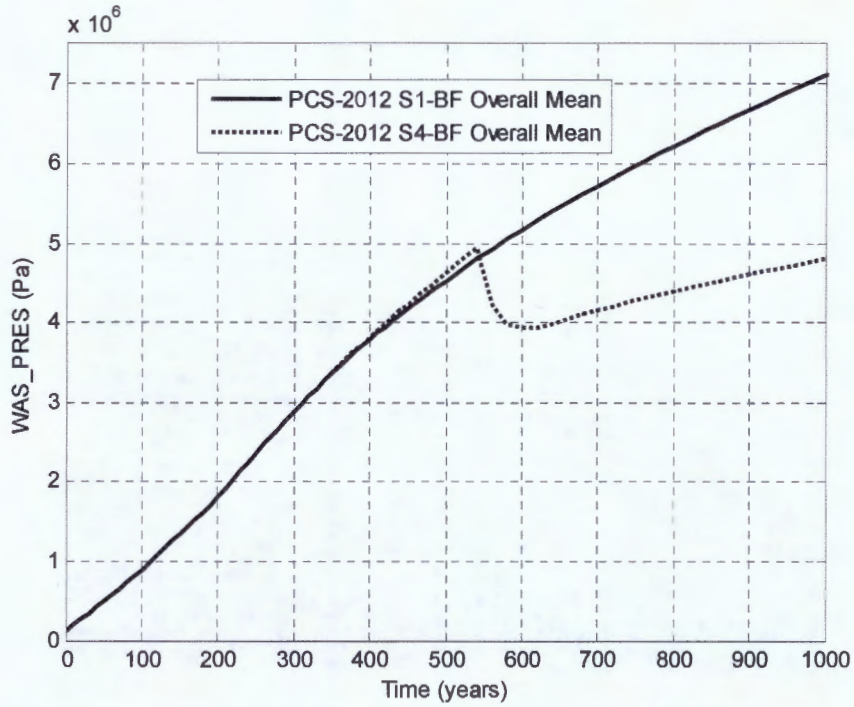

Figure 6-43: Overall Means of Waste Panel Pressure, Scenarios S1-BF and S4-BF for Years 0 to 1,000.

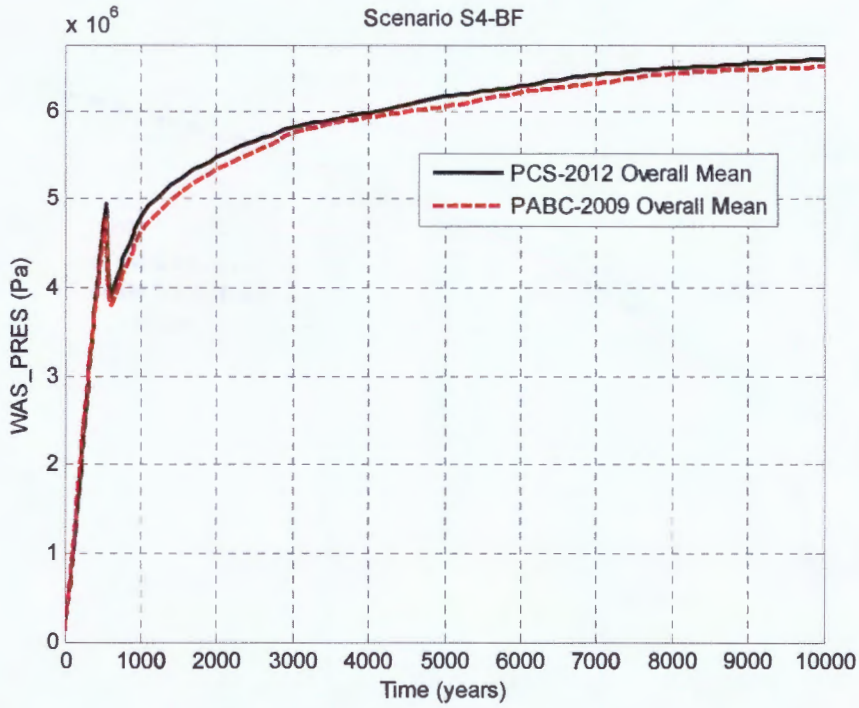

Figure 6-44: Overall Means of Waste Panel Pressure, Scenario S4-BF.

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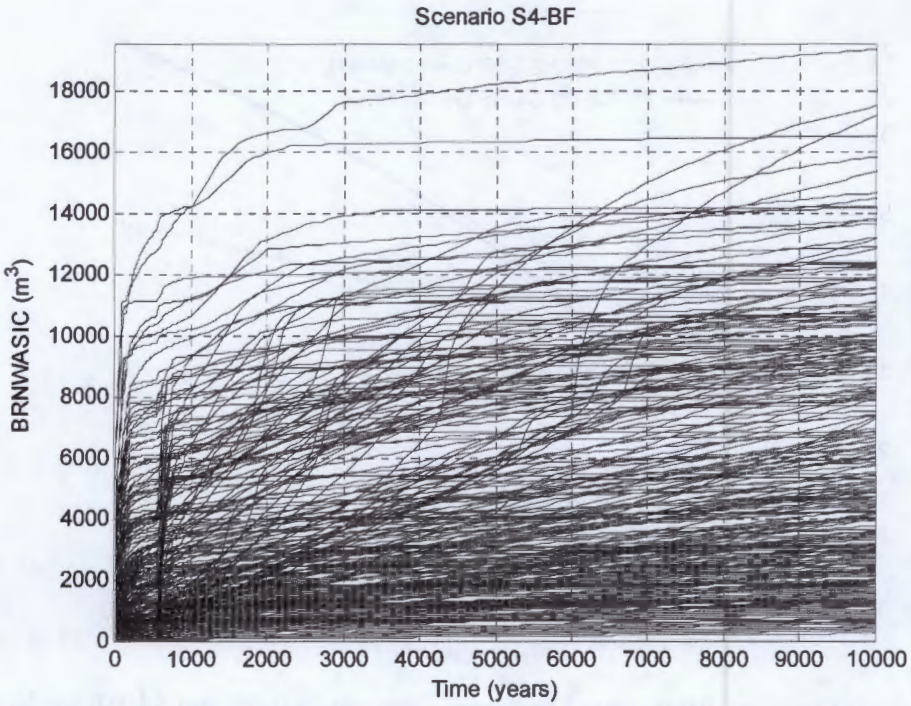

Figure 6-45: Horsetail Plot of Cumulative Brine Inflow to the Waste Panel, Scenario S4-BF.

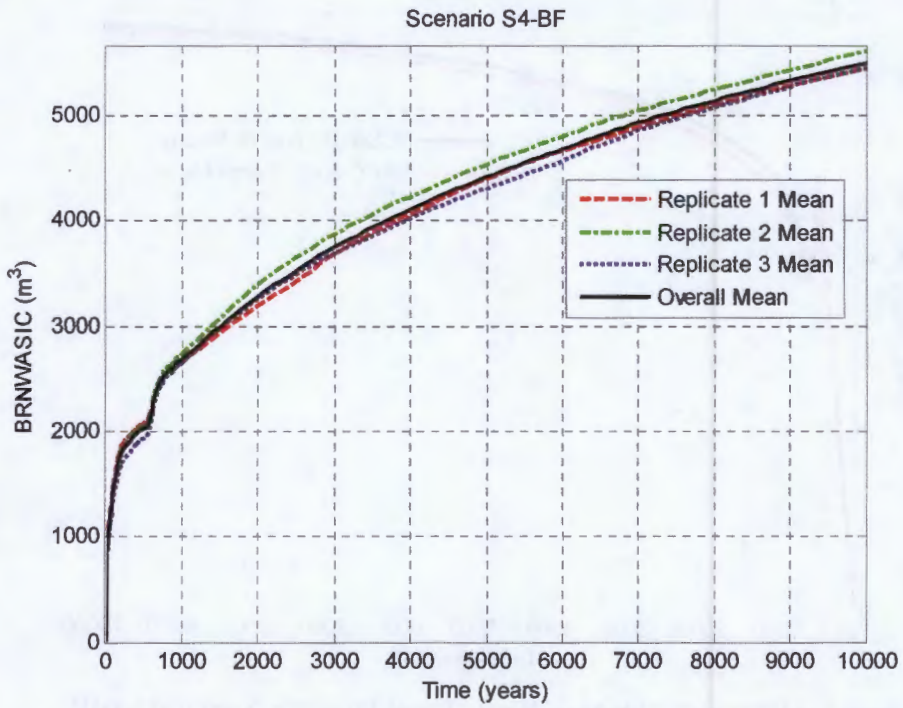

Figure 6-46: Means of Cumulative Brine Inflow to the Waste Panel, Scenario S4-BF.

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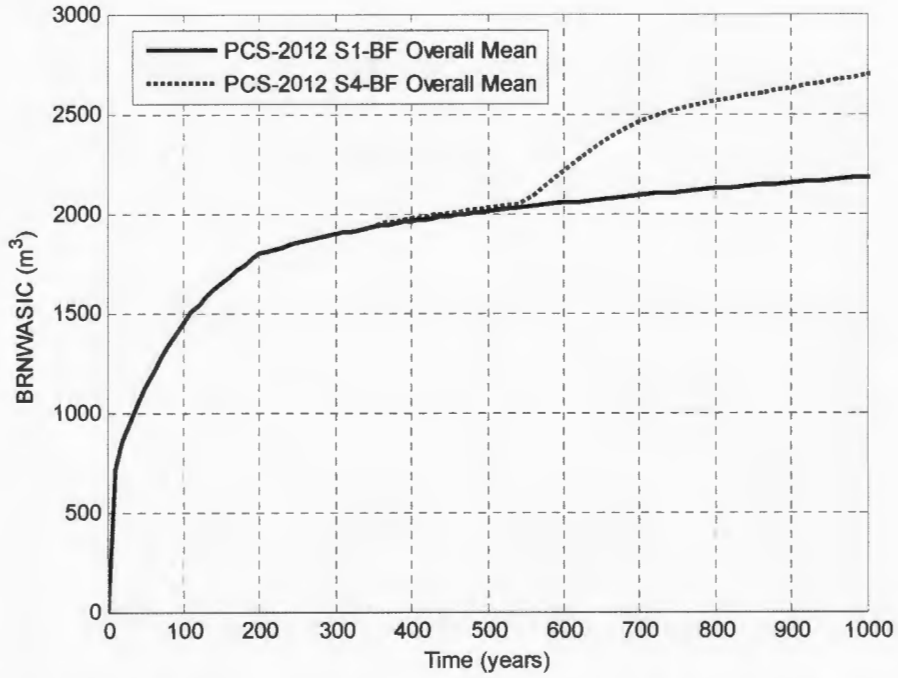

Figure 6-47: Overall Means of Cumulative Brine Inflow to the Waste Panel, Scenarios S1-BF and S4-BF for Years 0 to 1,000.

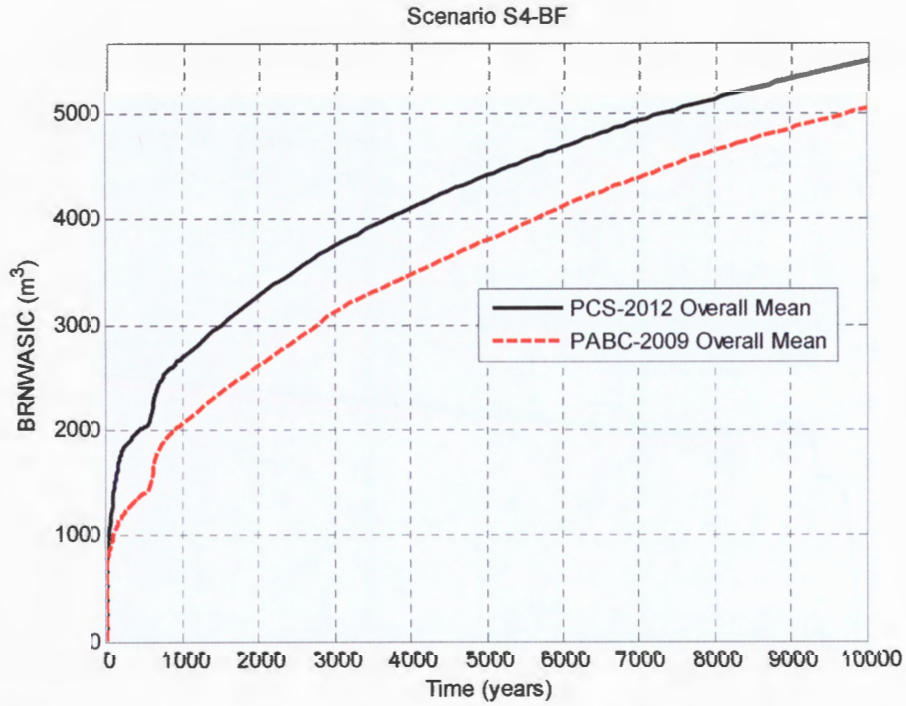

Figure 6-48: Overall Means of Cumulative Brine Inflow to the Waste Panel, Scenario S4-BF.

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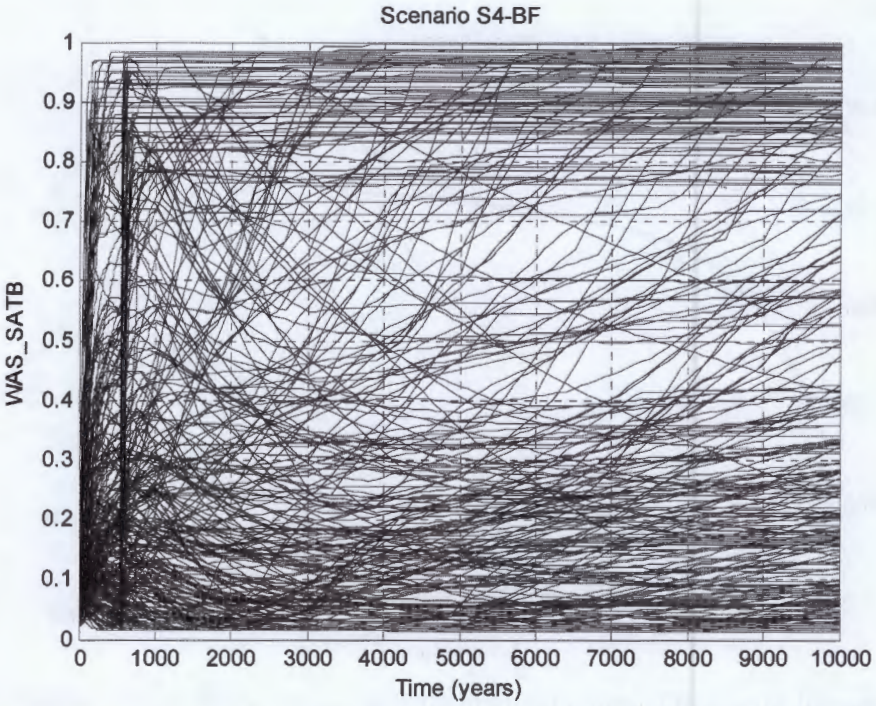

Figure 6-49: Horsetail Plot of Waste Panel Brine Saturation, Scenario S4-BF.

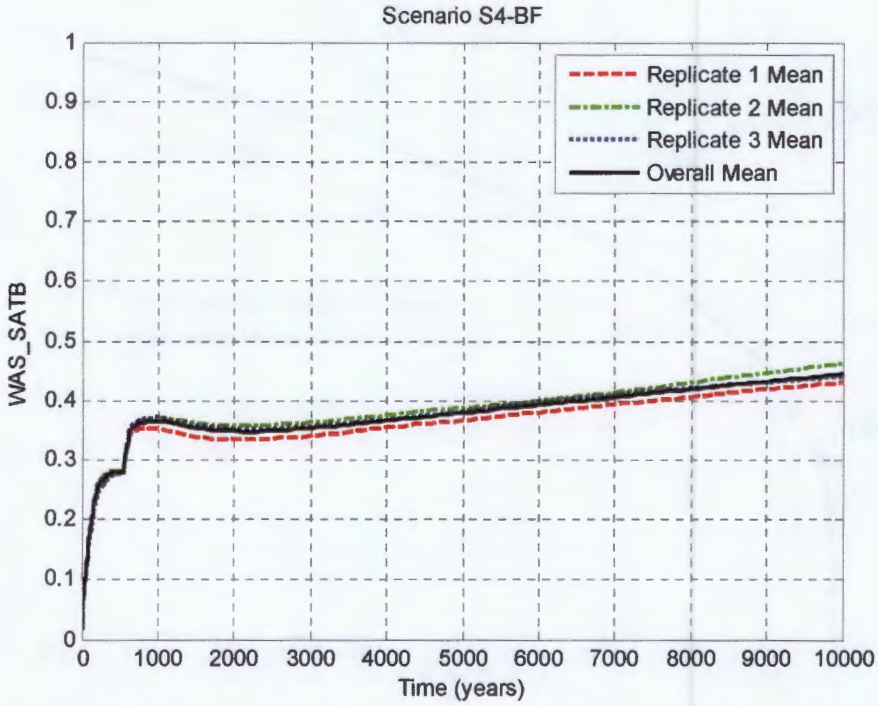

Figure 6-50: Means of Waste Panel Brine Saturation, Scenario S4-BF.

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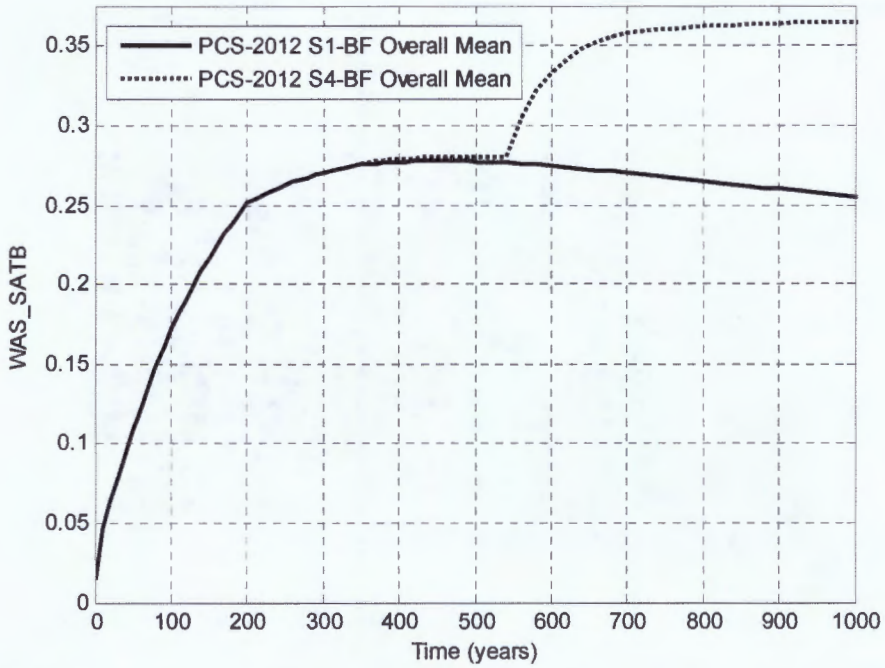

Figure 6-51: Overall Means of Waste Panel Brine Saturation, Scenarios S1-BF and S4-BF for Years 0 to 1,000.

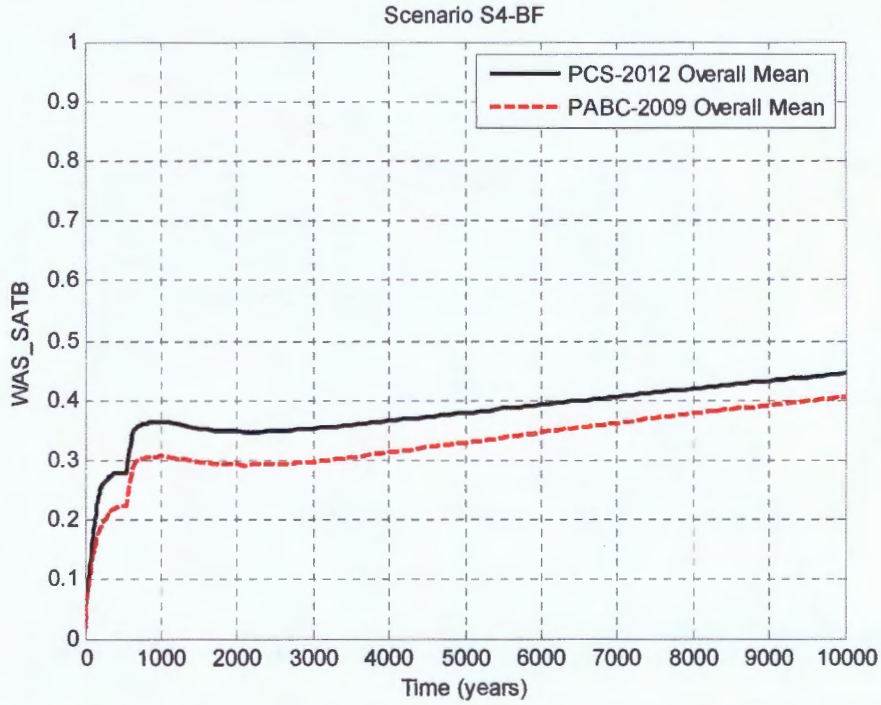

Figure 6-52: Overall Means of Waste Panel Brine Saturation, Scenario S4-BF.

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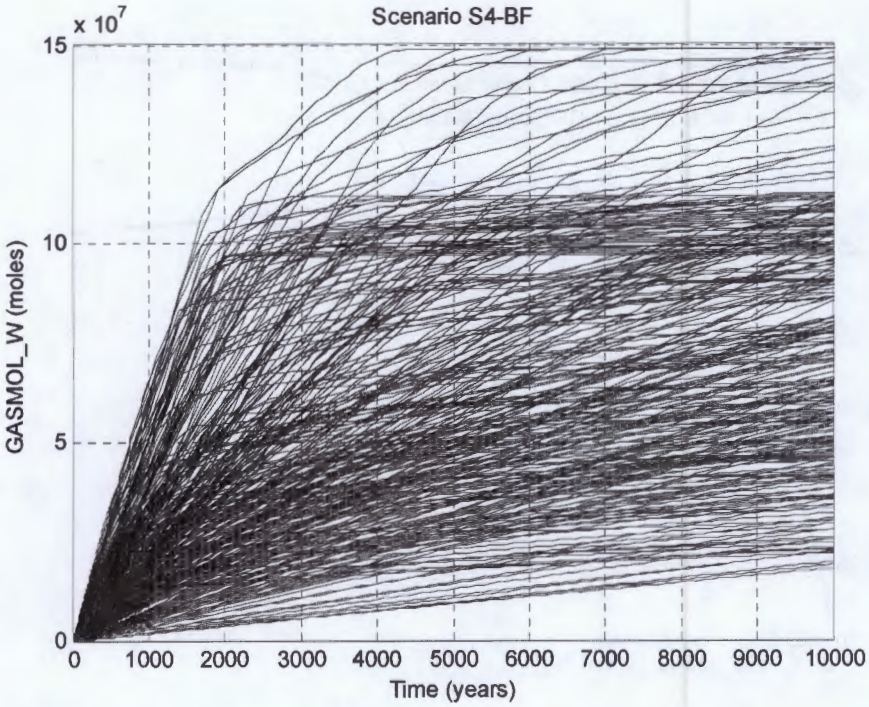

Figure 6-53: Horsetail Plot of Waste Panel Gas Generation (in moles), Scenario S4-BF.

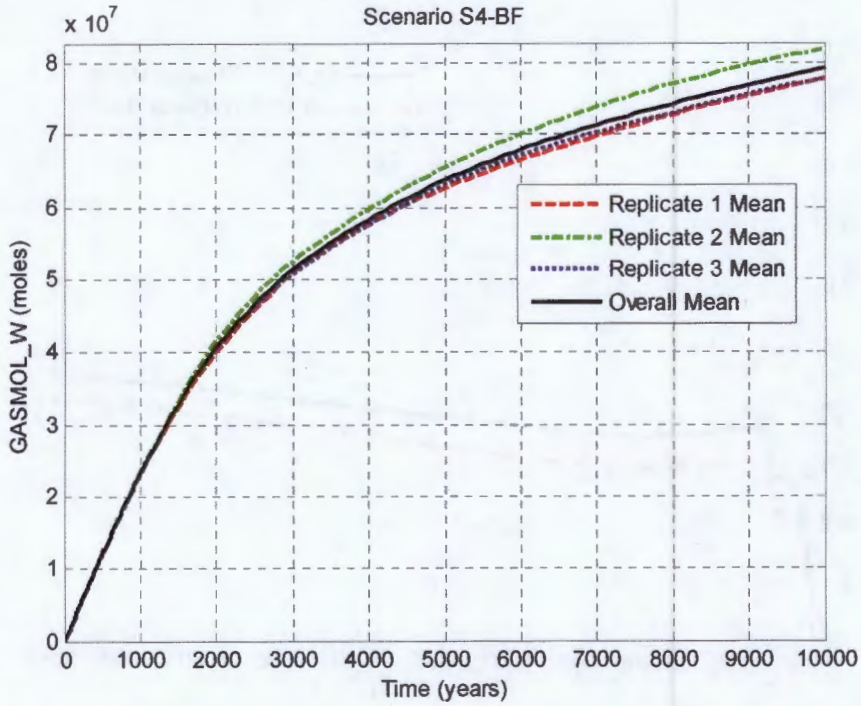

Figure 6-54: Means of Waste Panel Gas Generation (in moles), Scenario S4-BF.

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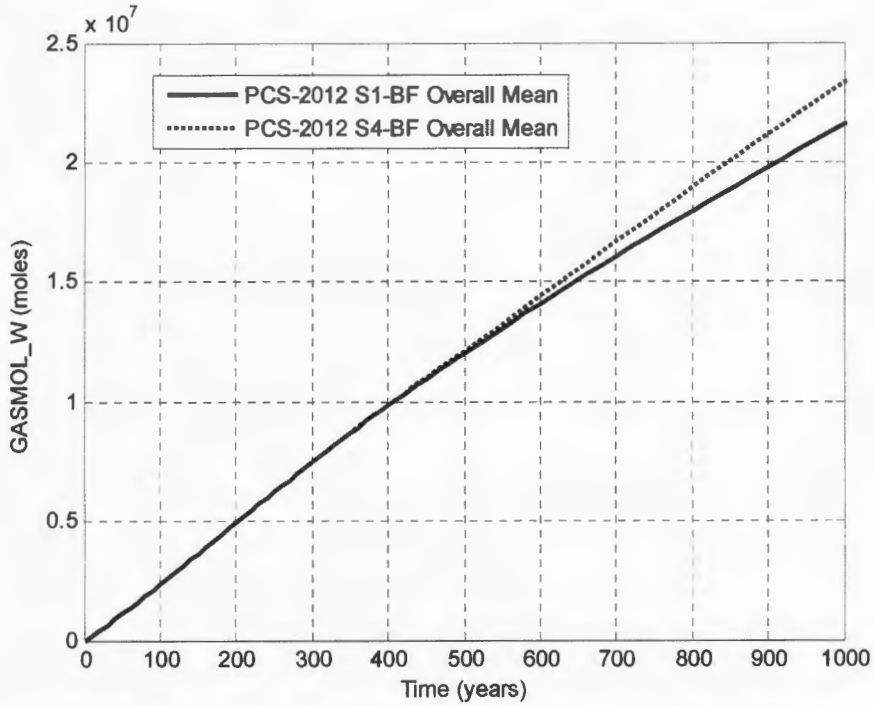

Figure 6-55: Overall Means of Waste Panel Gas Generation (in moles), Scenarios S1-BF and S4-BF for Years 0 to 1,000.

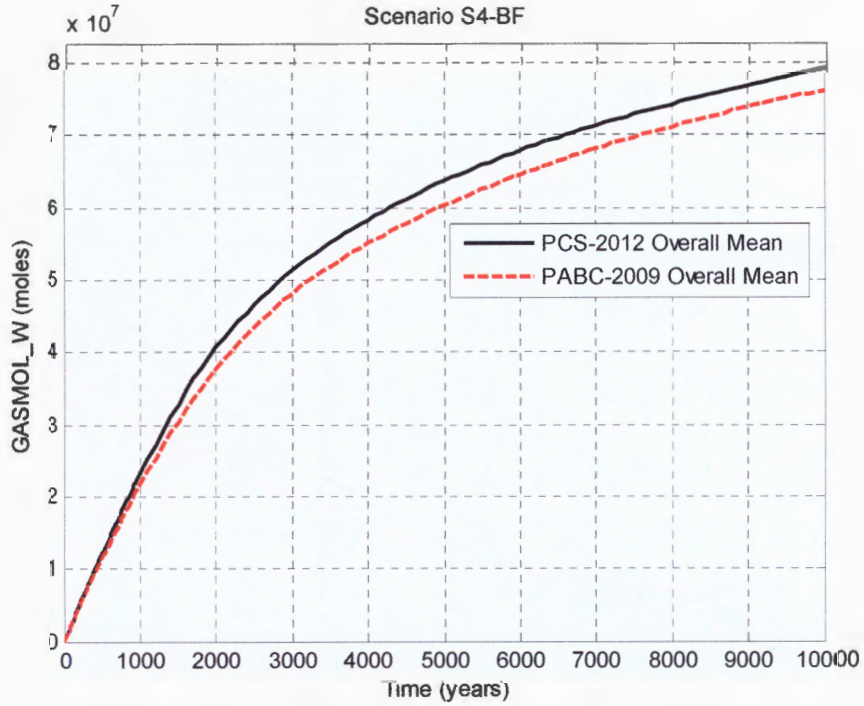

Figure 6-56: Overall Means of Waste Panel Gas Generation (in moles), Scenario S4-BF.

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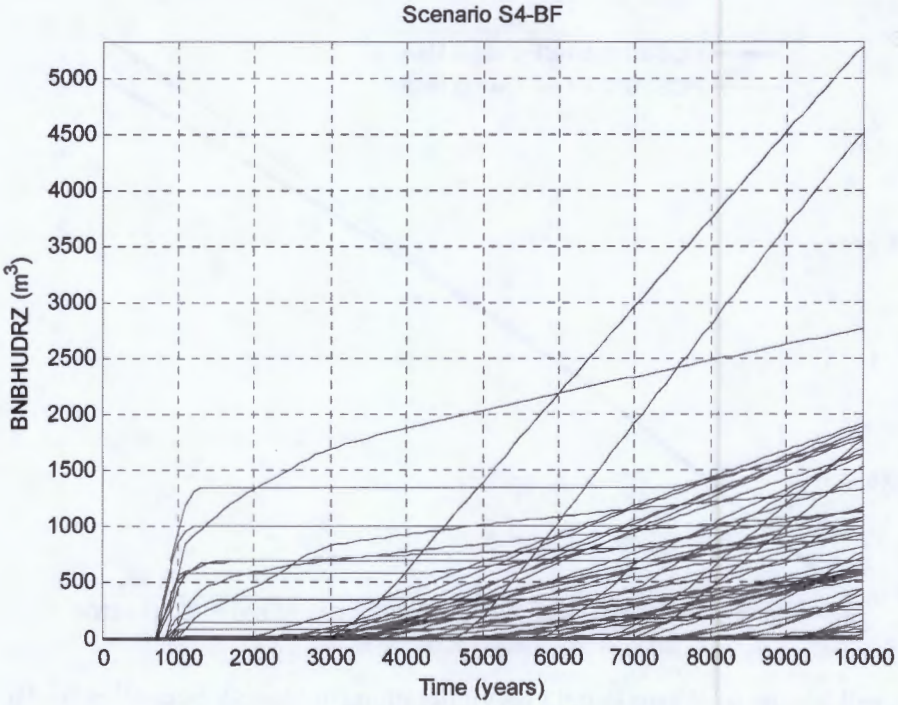

Figure 6-57: Horsetail Plot of Brine Flow up the Borehole, Scenario S4-BF.

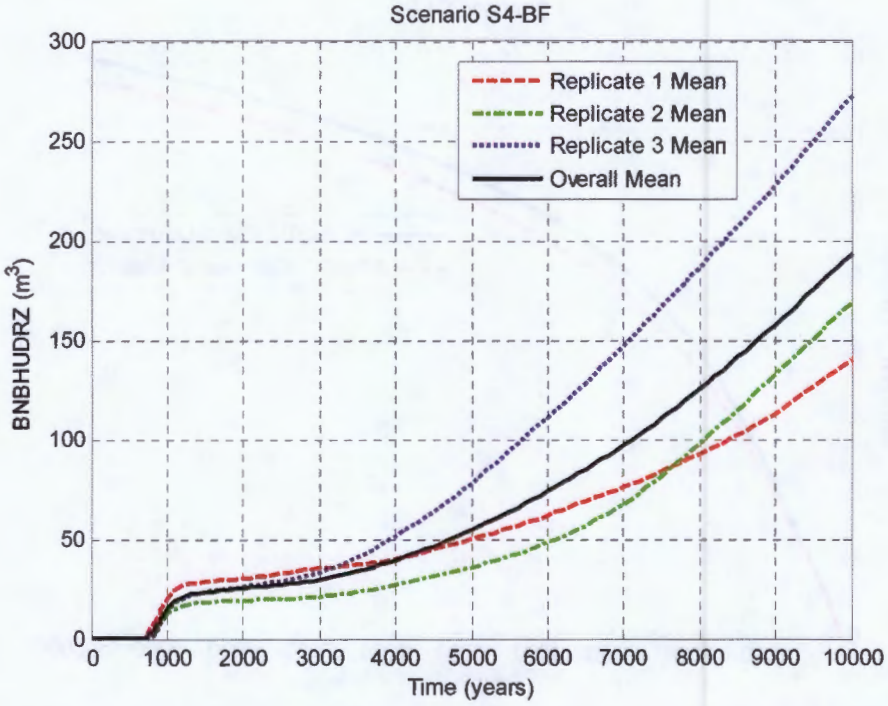

Figure 6-58: Means of Brine Flow up the Borehole, Scenario S4-BF.

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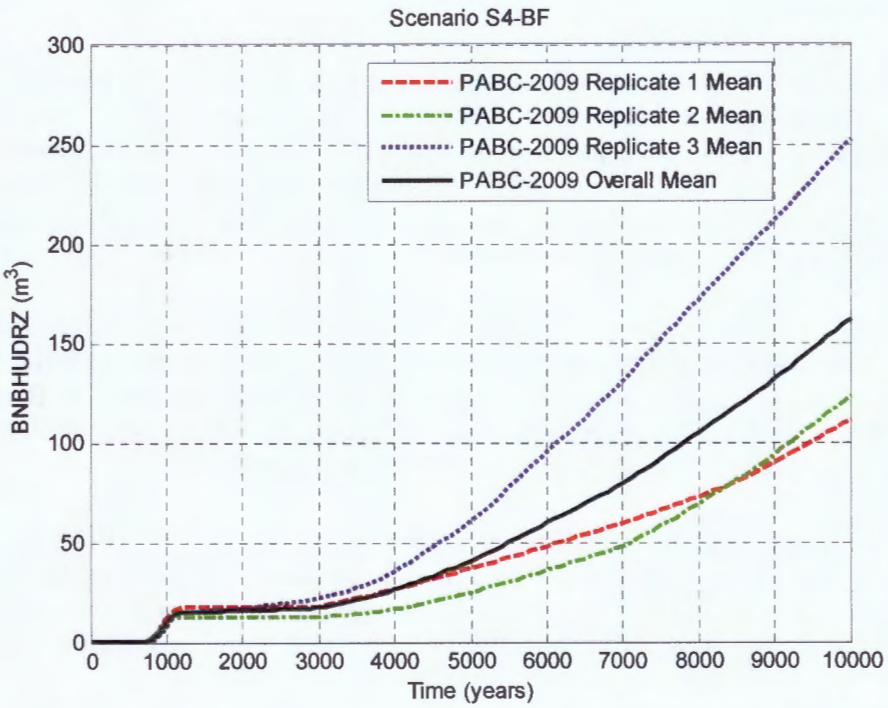

Figure 6-59: Means of Brine Flow up the Borehole, Scenario S4-BF for the PABC-2009.

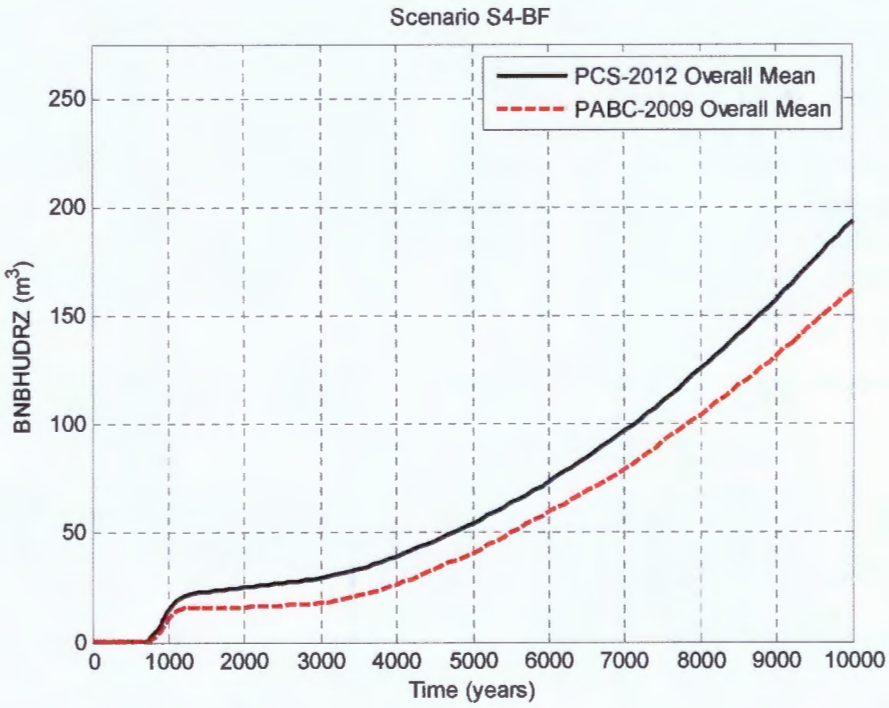

Figure 6-60: Overall Means of Brine Flow up the Borehole, Scenario S4-BF.

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

BRAGFLO scenario S6-BF models an E2 intrusion occurring at 1000 years, followed by an E1 intrusion into the same panel at 2000 years. Calculated brine flows up the intrusion borehole obtained in scenario S6-BF are used in PA code PANEL to determine the radionuclide source term to the Culebra. Transport releases from the Culebra obtained in the PABC-2009 are used in the PCS-2012 PA. Results from BRAGFLO scenario S6-BF are now briefly discussed to justify the appropriateness of PABC-2009 Culebra transport calculations for the PCS-2012 PA.

The volume of brine flowing up the borehole toward the ground surface is denoted by quantity BNBHUDRZ. A horsetail plot of this quantity for the PCS-2012 PA scenario S6-BF is given in Figure 6-61. For the sake of comparison, the horsetail plot obtained for quantity BNBHUDRZ obtained in the PABC-2009 calculations is shown in Figure 6-62. The horsetail plots obtained for this quantity in the PABC-2009 and the PCS-2012 PA are very similar.

The three replicate means, and the overall mean, obtained for quantity BNBHUDRZ in scenario S6-BF are plotted together in Figure 6-63. The analogous curves obtained in the PABC-2009 calculations are shown in Figure 6-64. As seen by comparing the results shown in Figure 6-63 and Figure 6-64, the means obtained for quantity BNBHUDRZ in the two analyses are virtually identical.

The overall means obtained for quantity BNBHUDRZ in the PCS-2012 PA and the PABC-2009 are shown together in Figure 6-65. As seen in that figure, there is very close agreement between the overall means obtained in the two analyses. The replacement of the Option D panel closure with the ROMPCS design has a negligible impact on brine flow up the intrusion borehole in BRAGFLO scenario S6-BF. Actinide solubilities, the repository waste inventory, and Culebra transmissivity fields are unchanged from the PABC-2009 to the PCS-2012 PA. As the brine flows up the intrusion borehole obtained in the two analyses are virtually identical in scenario S6-BF, the radionuclide source term to the Culebra is virtually unchanged by the ROMPCS design as compared to Option D results. Consequently, transport releases from the Culebra are also virtually unchanged. Incorporating PABC-2009 Culebra transport results into the PCS-2012 PA is reasonable and appropriate.

Summary statistics for quantity BNBHUDRZ obtained in scenario S6-BF are shown in Table 7.

Table 7: Summary Statistics for Scenario S6-BF

Quantity (units)	Mean Value		Maximum Value	
	PABC-2009	PCS-2012 PA	PABC-2009	PCS-2012 PA
BNBHUDRZ ($x10^3$ m^3)	2.92	2.94	169.03	169.30

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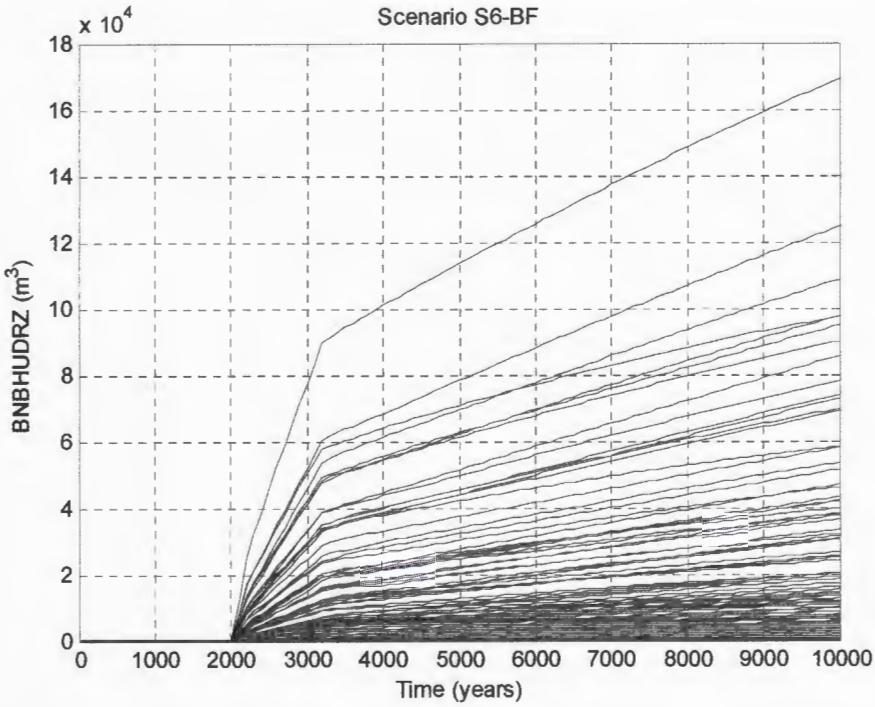

Figure 6-61: PCS-2012 PA Horsetail Plot of Brine Flow up the Borehole, Scenario S6-BF.

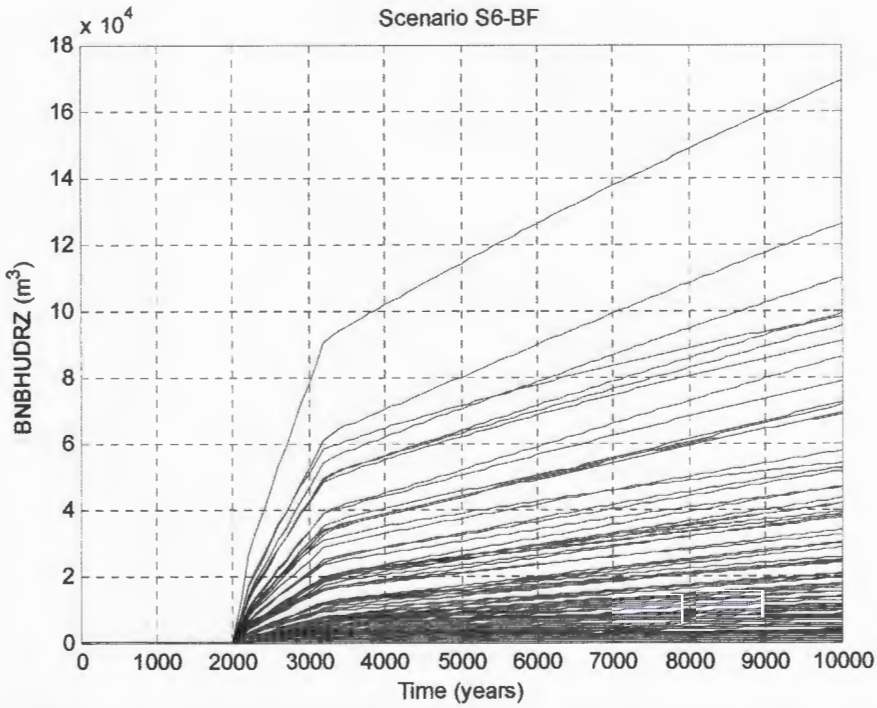

Figure 6-62: PABC-2009 Horsetail Plot of Brine Flow up the Borehole, Scenario S6-BF.

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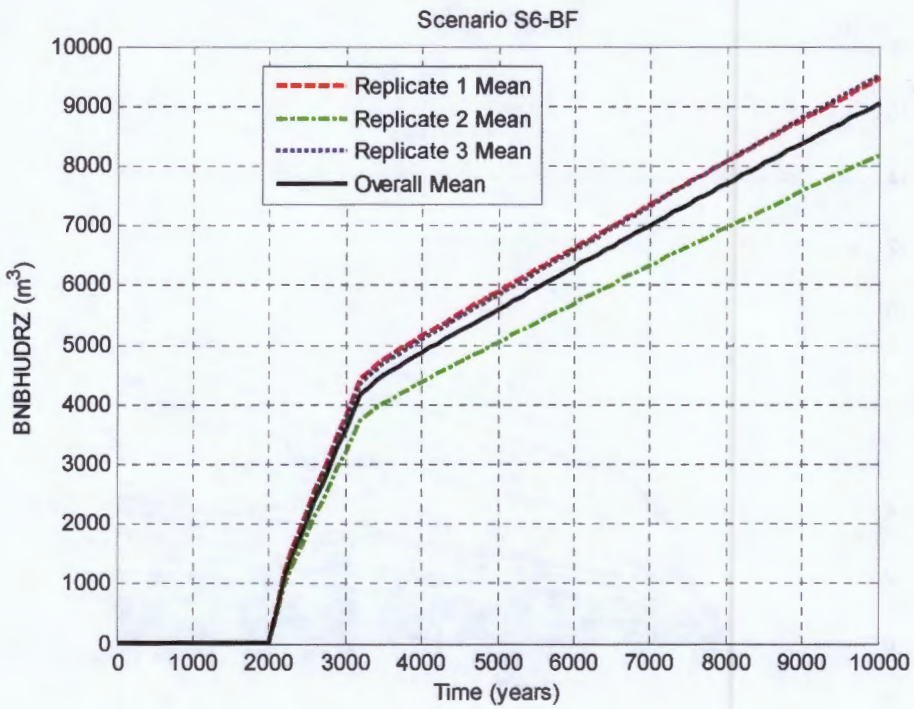

Figure 6-63: PCS-2012 PA Means of Brine Flow up the Borehole, Scenario S6-BF.

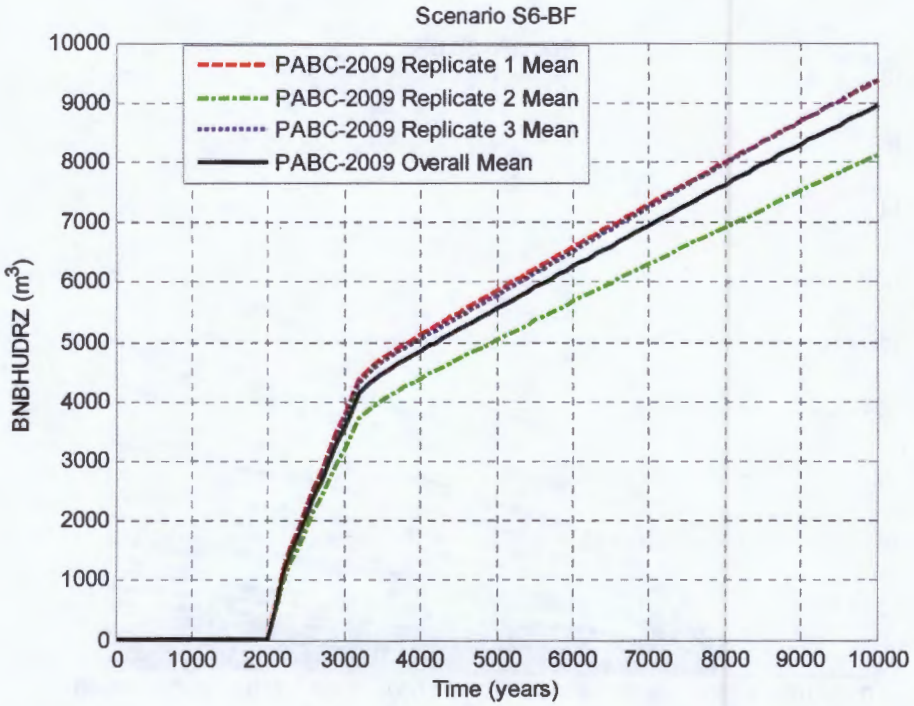

Figure 6-64: PABC-2009 Means of Brine Flow up the Borehole, Scenario S6-BF.

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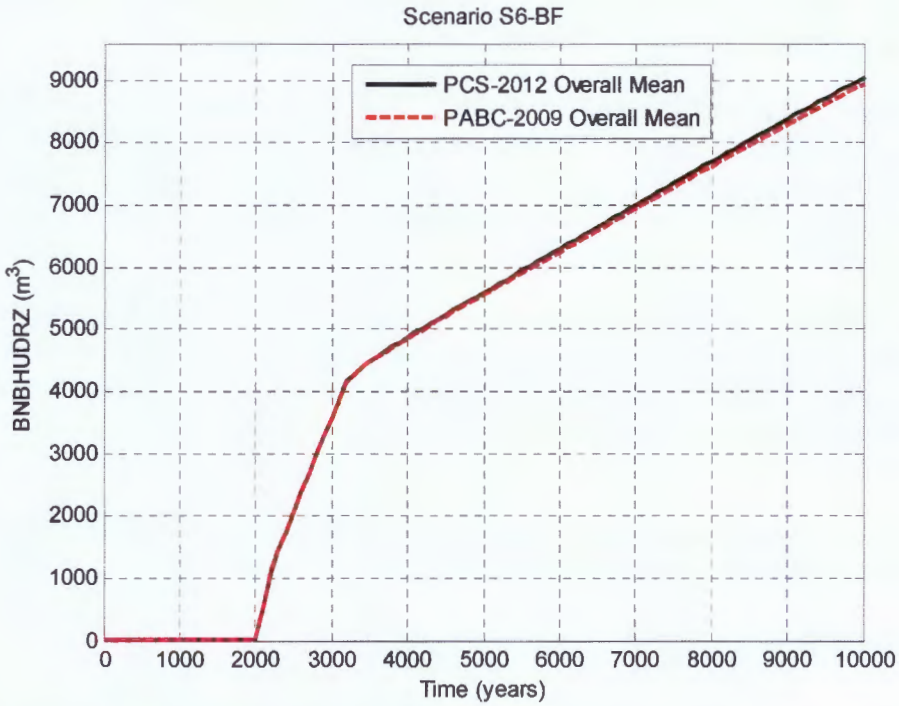

Figure 6-65: Overall Means of Brine Flow up the Borehole, Scenario S6-BF.

7 SUMMARY

Waste panel closures comprise a repository feature that has been represented in WIPP PA since the original Compliance Certification Application (CCA) of 1996. The 1998 rulemaking that certified WIPP to receive transuranic waste placed conditions on the panel closure design to be implemented in the repository. The mandated design consists of a concrete block wall, an open drift section, and a concrete monolith, and was termed the "Option D" panel closure. Following the selection of the Option D design in 1998, the engineering of the panel closure has been re-assessed, and a revised design has been established that is simpler, cheaper, and easier to construct. The revised panel closure design, termed the Run-of-Mine Panel Closure System (ROMPCS), is comprised of 100 feet of ROM salt with barriers at each end. The PCS-2012 PA quantifies WIPP repository performance impacts associated with the replacement of the currently approved Option D panel closure design with the ROMPCS. Impacts are assessed via a direct comparison of results obtained in the PABC-2009 (where Option D was used) to those calculated in the PCS-2012 PA with the ROMPCS.

For undisturbed conditions, implementation of the ROMPCS yields higher long-term waste panel pressure (on average) than was seen in the PABC-2009. The increase in mean waste panel pressure is accompanied by an increase in the average waste panel brine saturation for the ROMPCS results. The ROMPCS design allows more brine inflow to the waste panel during the first 200 years when compared to Option D results. This increased brine inflow, combined with

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the tightness of the ROMPCS after 200 years, results in increased waste panel gas generation (on average) and a subsequent increase to waste panel mean pressure.

The lower long-term permeability range of the ROMPCS as compared to Option D yields a period of increased waste panel pressurization following an E1 intrusion. The increased waste panel mean pressure slightly inhibits brine flow into the panel after the intrusion, with a corresponding slight decrease to the mean waste panel brine saturation as compared to PABC-2009 E1 intrusion results.

For E2 intrusion scenarios, the PCS-2012 PA mean waste panel pressure is higher than that seen in the PABC-2009 at the time of intrusion, and it remains higher for the duration of the 10,000 year regulatory period. Similarly, the mean waste panel brine saturation is higher at the time of intrusion in the PCS-2012 PA, resulting in higher long-term waste panel brine saturations for E2 intrusion scenarios.

Brine flows up the borehole that are used to calculate the radionuclide source term in WIPP PA are negligibly impacted by the replacement of Option D with the ROMPCS.

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