Mr. Frank Marcinowski
Office of Radiation and Indoor Air
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington D.C., 20460

Dear Mr. Marcinowski:

The Carlsbad Field Office (CBFO) of the Department of Energy (DOE) requests your approval of a proposed change to the EPA 40 CFR Part 194 Certification of the Waste Isolation Pilot Plant (WIPP) with regard to the design of the Panel Closures. Specifically, CBFO requests that the Environmental Protection Agency (EPA) modify Condition 1 of the WIPP Certification decision by agreeing that the New Mexico Environment Department (NMED) is responsible for final review and approval of the design and construction of the panel closure system at WIPP. At the same time, the CBFO recognizes that EPA's review and approval of the impact analyses relating to the 194 Certification Final Rule on Panel Closures is still required, and that EPA must be satisfied that any design change will not adversely affect the long-term performance of the repository.

As you know, the purpose of the panel closure system in the WIPP facility is to control volatile organic compound (VOC) emissions during the operating life of the facility. The panel closure must also protect the health and safety of workers as required by the Mine Safety and Health Administration and by the DOE. There are no long-term design requirements or performance specifications for these closures, beyond the necessity to demonstrate that any design change does not have an adverse affect on long-term performance. The analyses that accompany this letter demonstrate that the long-term performance of the repository is not sensitive to the closure design, within a broad range of likely closure permeability values.

The CBFO believes it is therefore reasonable that the NMED be responsible for final review and approval of panel closure design and construction. The CBFO requests that the EPA modify Condition 1 of the Final Rule to recognize this responsibility. We suggest that such a change might include the following:

- That the Department will implement a panel closure system as approved by the NMED
- That the Department will demonstrate, by an appropriate impact assessment, that the panel closure system proposed to NMED does not adversely affect the long-term performance of the repository
The currently approved panel closure design ("Option D") specified in Condition 1 involves installation of a concrete block "explosion wall", removal of the DRZ along a section of the panel access drift, and emplacement of a concrete monolith composed of Salado Mass Concrete (SMC) in that section of access drift. After three years of experience with WIPP as an operational facility, we have re-evaluated a number of its engineering and construction aspects. This effort included detailed planning to install Option D closures in Panel 1 and a parallel analysis of alternative closure designs. As a result of this re-evaluation, we believe a redesign of the panel closure system is warranted. The redesigned panel closure (called the WIPP panel closure (WPC)) will be much simpler and significantly less expensive to build, will reduce the risk of accidents and industrial injury to construction workers, will provide for re-use of mined salt, and will reduce the potential for disruption of waste emplacement activities. All of these benefits will accrue without influencing the short- or long-term performance of the repository.

The proposed change in Condition 1 requires that the EPA be fully cognizant of the CBFO's Permit modification request to the NMED for panel closures. To this end, the details of the redesign and its performance are included in the attachments to the enclosed Notification of Proposed Change. Attachment A of the Notification, Design Report for a Revised Panel Closure System at the Waste Isolation Pilot Plant, provides a description of the proposed design and demonstrates its adequacy to meet and exceed requirements of the Resource Conservation and Recovery Act (RCRA) during the operational period. This design report has been certified by a Professional Engineer registered in New Mexico. Attachment A is being transmitted to the NMED as part of a Permit Modification Request to change the Closure Plan contained in the Hazardous Waste Facility Permit (HWFP).

Attachment B, Effective Permeability of the Redesigned Panel Closure System, provides estimates of the permeability of the WPC as a function of time. Specifically, it demonstrates that the new closures will have a permeability between $10^{-15}$ m$^2$ and $10^{-19}$ m$^2$ throughout the regulatory period. This range is significant because it is consistent with the range of panel closure permeability evaluated in Attachment C.

Attachment C, Panel Closure Impact Assessment Documentation, evaluates the impacts of panel closures on the long-term performance of the repository. This analysis report is prepared pursuant to 40 CFR Part 191, Subparts B and C, and 40 CFR Part 194. The report demonstrates that impacts to the predicted long-term performance of the repository associated with the installation of the WPC are negligible compared to the currently prescribed Option D design.

The HWFP issued by the NMED specifies panel closure requirements that comply with the requirements of the New Mexico hazardous waste regulations during the operational period of the repository. The analyses in Attachments B and C demonstrate that the long-term performance of the repository is not sensitive to the closure design, within a broad range of closure permeability. Because the panel
closure specifications cover only the operational period and because long-term performance is insensitive to this design, CBFO believes that the NMED, which regulates hazardous waste disposal in New Mexico, should have responsibility for final approval of the panel closure system design. CBFO therefore requests that EPA modify Condition 1 of the WIPP Certification decision to acknowledge that the NMED is responsible for regulating the design and construction of the panel closure system at WIPP, provided that the Department demonstrates that there are no long-term impacts on performance.

The EPA will continue to be involved as regards the long-term performance of panel closures even if Condition 1 is modified. The CBFO must demonstrate to the EPA that any future panel closure redesign will have a long-term permeability within a range that is acceptable to the EPA, e.g., the range evaluated in Attachments B and C to this Notification. If this is not the case, a full performance assessment would be required for a new range of closure permeabilities.

We appreciate your timely consideration of this request. Should you require further information, please contact Mr. Daryl Mercer at (505) 234-7452.

Sincerely,

[Signature]
Dr. Inés R. Triay
Manager

Enclosure

cc: w/enclosure
L. Smith, EM-23
B. Forinash, EPA-ORIA
C. Byrum, EPA-ORIA
S. Ghose, EPA-ORIA
N. Stone, EPA-Region VI
S. Zappe, NMED
M. Silva, EEG

cc: w/o enclosure
J. Bearzi, NMED
C. Zvonar, CBFO
B. Lilly, CBFO
J. Pigg, CBFO
J. Lee, WTS
P. Shoemaker, SNL
NOTIFICATION OF PROPOSED CHANGE TO THE
EPA 40 CFR PART 194 CERTIFICATION OF
THE WASTE ISOLATION PILOT PLANT
FOR
PANEL CLOSURE SYSTEM DESIGN
OCTOBER 7, 2002
Notification of Proposed Change to the

EPA 40 CFR Part 194 Certification of

the Waste Isolation Pilot Plant

for

Panel Closure System Design

October 7, 2002
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ATTACHMENT A:  *Design Report for a Revised Panel Closure System at the Waste Isolation Pilot Plant, Revision 1*

ATTACHMENT B:  *Effective Permeability of the Redesigned Panel Closure System*

ATTACHMENT C:  Panel Closure Impact Assessment Documentation

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# Acronyms

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<td>Carlsbad Field Office</td>
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<tr>
<td>CCA</td>
<td>Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant (DOE 1996)</td>
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<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
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<tr>
<td>DOE</td>
<td>U.S. Department of Energy</td>
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<tr>
<td>DRZ</td>
<td>Disturbed Rock Zone</td>
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<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
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<td>HWFP</td>
<td>Hazardous Waste Facility Permit</td>
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<td>NMED</td>
<td>New Mexico Environmental Department</td>
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<td>PA</td>
<td>Performance Assessment</td>
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<td>PAVT</td>
<td>Performance Assessment Verification Test</td>
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<td>PCS</td>
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<tr>
<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
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<td>SMC</td>
<td>Salado Mass Concrete</td>
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<tr>
<td>VOC</td>
<td>Volatile Organic Compound</td>
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<td>WIPP</td>
<td>Waste Isolation Pilot Plant</td>
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<td>WIPP Panel Closure</td>
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Glossary of Terms


Certification. Any action taken by the Administrator of the U.S. Environmental Protection Agency under Section 8(d) of the Waste Isolation Pilot Plant Land Withdrawal Act.

Run of mine salt. Salt produced from mining operations in the WIPP underground without undergoing any additional treatment.
Executive Summary

The U.S. Department of Energy (DOE) Carlsbad Field Office (CBFO) requests that the U.S. Environmental Protection Agency (EPA) modify Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194. Based on the information in this notification, CBFO believes EPA may defer decisions regarding the design of panel closures at the Waste Isolation Pilot Plant (WIPP) to the New Mexico Environment Department (NMED), provided that the CBFO demonstrates that any panel closure system will not adversely impact long-term releases from the repository. CBFO is making this proposal based on the following:

- NMED has responsibility for regulating closure of hazardous waste disposal units in accordance with the New Mexico Hazardous Waste Act and the WIPP Hazardous Waste Facility Permit.

- The primary purpose of the panel closure system (PCS) is to control volatile organic compound (VOC) emissions during the operational life of the facility.

- There are no long-term design requirements or performance specifications for the PCS, beyond the necessity to demonstrate that any design change does not have an adverse effect on long-term performance.

- The analyses provided with this notification demonstrate that long-term releases are insensitive to a broad range of panel closure permeability.

In parallel with this request to the EPA, the CBFO is also proposing a new, less complex design, the WIPP Panel Closure (WPC), to the NMED. Adopting the WPC does not adversely affect compliance with the disposal standards in 40 CFR Part 191, Subparts B and C, but does alter the PCS prescribed in Condition 1. Condition 1 requires the installation of a specific panel closure system [Option D with Salado Mass Concrete (SMC)], which consists of construction of an explosion isolation wall, followed by removal of the majority of the disturbed rock zone in the area of the closure and emplacement of a large Salado Mass Concrete barrier. The proposed WPC would consist of installing a concrete block explosion isolation wall and run of mine salt backfill.

The CBFO is proposing the WPC design for the following reasons:

1. The WPC is less complex, resulting in a closure that is simpler, easier and faster to construct. This, in turn, reduces the risk to workers during the installation activities and enhances constructibility.

2. The WPC design provides greater flexibility in scheduling construction activities and materials staging, and therefore reduces impacts on other repository operations.

3. The WPC can be constructed in the underground environment using common construction practices, and requires no special equipment.
4. The cost of implementing the WPC design is considerably less than the cost of installation of an Option D closure. It is estimated that a savings of well over $1.3 million for each PCS (2002 dollars) and cumulatively, over $10 million dollars for all the PCSs would result from implementing the WPC over the operating life of the WIPP repository.

An analysis of the WPC design is being submitted to the NMED as part of a Permit Modification Request to approve this design in lieu of the currently approved Option D closure. The CBFO has determined that the WPC will meet the environmental performance standards for a miscellaneous unit imposed by the Hazardous Waste Facility Permit. In meeting these standards, the proposed WPC will control the release of VOCs during waste operations (nominally 35 years). The WPC will also continue to perform its required functions under the conditions of a postulated methane explosion and will not adversely impact the long-term performance of the repository.

To conclude that there were no adverse impacts on long-term repository performance, the CBFO represented the Option D closure in the Performance Assessment Verification Test (PAVT) model. The results of this effort, combined with the earlier PAVT modeling, established a range of permeabilities, between $10^{-15}$ m$^2$ and $10^{-19}$ m$^2$, for panel closure configurations that would have negligible impacts on long-term repository performance. Since the permeability of the proposed WPC will lie within this range, it follows that the long-term performance of the WPC will be essentially the same as the performance of the Option D panel closure.
1.0 Introduction

The U.S. Department of Energy (DOE) Carlsbad Field Office (CBFO) requests that the U.S. Environmental Protection Agency (EPA) modify Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194.

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

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

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

The Option D closure (see Figure 1) consists of installation of a concrete block explosion isolation wall, removal of the majority of the disturbed rock zone (DRZ) in the area of the closure, and emplacement of a large Salado mass concrete (SMC) monolith. This closure would be installed in each panel of the repository after waste emplacement in that panel is completed.

Based on the information in this notification, CBFO believes EPA may defer decisions regarding the design of panel closures at WIPP to the New Mexico Environment Department (NMED), provided that the CBFO demonstrates to the EPA that any proposed panel closure system will not adversely impact long-term releases from the repository. As a result, the CBFO is proposing that EPA modify Condition 1 to reflect this position. The CBFO is making this proposal based on the following:

• NMED has responsibility for regulating closure of hazardous waste disposal units in accordance with the New Mexico Hazardous Waste Act and the WIPP Hazardous Waste Facility Permit (HWFP).

• The purpose of the panel closure system (PCS) is to control volatile organic compound (VOC) emissions during the operational life of the facility.

• There are no long-term design requirements or performance specifications for the PCS beyond the necessity to demonstrate that any design change does not have an adverse effect on long-term performance.

• The analyses provided with this notification demonstrate that long-term repository releases are unchanged over a broad range of panel closure permeabilities.
The proposed change in Condition 1 requires the EPA to be fully cognizant of the CBFO’s Permit modification request to the NMED. In addition, the EPA allowed the DOE to revisit the design of the PCS. Specifically, in the preamble to the Final Certification Rulemaking (EPA 1998), the EPA stated:

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

To these ends, the details of the proposed WPC design and its performance are discussed in this Notification.

The proposed WPC design was developed as part of CBFO’s ongoing review of all engineering aspects of the repository. During this review, the CBFO has determined that the performance requirements for the panel closures can be achieved more easily and more effectively by modifying the design from that required by the EPA in Condition 1, and by the NMED in the HWFP. Section 2.0 of this notification provides a description of the nature and scope of the proposed change to the design of the closure system. Section 3.0 describes how the redesigned PCS information differs from the information on panel closure designs presented in the Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant (DOE 1996) (CCA). Section 4.0 summarizes the DOE’s regulatory assessment of the proposed change to Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant’s Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule (EPA 1998) (40 CFR Part 194).

In addition, three attachments are included with this notification. Attachment A, Design Report for a Revised Panel Closure System at the Waste Isolation Pilot Plant (Revision 1), provides detailed design and engineering specifications for the construction of the WPC in the WIPP repository. Attachment B, Effective Permeability of the Redesigned Panel Closure, describes the expected behavior of the WPC in the context of the modeling results. Attachment C, Panel Closure Impact Assessment Documentation, provides the results of Performance Assessment Verification Test (PAVT) modeling for two panel closure designs that represent the reasonably expected range of panel closure properties.
2.0 Nature and Scope

2.1 Nature of the Proposed Modification

The nature of the proposed change is a modification to Condition 1 of the Final Certification Rulemaking for 40 CFR 194. This modification would defer decisions regarding the design of panel closures to the New Mexico Environment Department (NMED) as long as the EPA concurs that panel closure system design changes have no adverse impacts to long-term releases from the repository.

This change will result in the clarification and simplification of the regulatory framework for reviewing and approving the design and construction of these systems. The CBFO recognizes that EPA's review and approval of the impact analyses relating to the Final Certification Rulemaking is required and that the EPA must be satisfied that any design change will not adversely affect the long-term performance of the repository.

2.2 Scope of the Proposed Design Change

The original PCS presented in the CCA presented four specific panel closure options, A through D, with specific criteria for selecting among them. Condition 1 of EPA's Final Certification Rulemaking (EPA 1998) mandated that the DOE install the Option D closure design and substituted SMC for the ordinary Portland cement concrete originally specified in the design option. SMC is a salt-saturated concrete evaluated in the CCA for use in the WIPP shaft seal design.

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

The WPC, shown in Figure 2, consists of two components: an enlarged concrete block explosion isolation wall and run of mine salt backfill. The concrete block wall, facing the last waste emplaced in the panel, consists of a 30-foot wall of mortared concrete blocks. Surface treatment around the wall would include removal of loose material to create a clean and regular surface for the construction of the block wall. The wall would be mortared tight to the ribs and back to provide a complete seal against the in-situ salt surface. The run of mine salt is pushed against the explosion isolation wall until the entire drift is filled over a minimum distance of 100 feet. Attachment A to this notification provides an engineering design report for the WPC, and includes a larger version of Figure 2.
2.3 Rationale for the Proposed Modification

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

- NMED has responsibility for regulating closure of hazardous waste disposal units in accordance with the New Mexico Hazardous Waste Act and the WIPP HWFP.

- The purpose of the PCS is to control VOC emissions during the operational life of the facility.

- There are no long-term design requirements or performance specifications for the PCS beyond the necessity to demonstrate that any design change does not have an adverse effect on long-term performance.

- The analyses provided with this notification demonstrate that long-term releases are insensitive to a broad range of panel closure permeabilities.

The design of the WPC also reduces risk of injury to construction workers, enhances constructibility, reduces construction cost, and reduces the impacts on on-going repository operations.
Figure 1. Option D Panel Closure System
Figure 2. Proposed WIPP Panel Closure
3.0 Information Different from the CCA

This section summarizes changes in information presented in the CCA resulting from the proposed panel closure redesign. The differences in panel closure design and the related impacts have been identified through a systematic examination of the certification baseline, as modified through March 15, 2002 (EPA 2002). Specifically, the following chapters and appendices of the CCA are relevant to the panel closure design:

1. Chapter 3
2. Appendix PCS
3. Chapter 7
4. Chapter 9
5. Appendix PEER
6. Appendix EBS

CCA Chapter 3 provides the facility description and technical information about the engineered systems at WIPP that are important to meeting the disposal standards of 40 CFR Part 191, Subparts B and C. Chapter 3 includes a description of the PCS and its ability to provide for protection of workers, human health and the environment during operations.

CCA Appendix PCS contains the detailed design of the PCS. This appendix describes the design evaluations and identifies four specific options capable of ensuring that ventilation air will not circulate through a closed panel, thereby limiting the flow of VOCs from a closed panel to the operational areas of the repository.

CCA Chapter 7, Chapter 9, and Appendices PEER and EBS discuss the incorporation of multiple natural and engineered barriers, including plugs, seals, and backfill, into the repository. In its Compliance Application Review Document 44, Engineered Barriers (EPA 1997), the EPA indicated that it did not evaluate panel closures as engineered barriers, but rather that it considered the closures as features of the disposal system design and evaluated them in that context. Since the EPA does not consider the PCS an engineered barrier, the CCA is not affected in this regard. This viewpoint is confirmed by the results in Attachments B and C, which demonstrate that the long-term releases from the repository are essentially the same over a broad range of permeabilities represented by different PCS designs, regardless of which PCS is emplaced.

3.1 CCA Presentation of the PCS

CCA Chapter 3 and Appendix PCS establish the purpose of installing panel closures. The introduction to the facility description in Chapter 3 states,

*The DOE will close each panel of waste with a panel closure system to provide for operational protection of workers, the public, and the environment from emplaced waste.*
In addition, Section 3.3.2 states:

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

Attachment A documents that the proposed WPC will meet the requirements for RCRA partial closure. The WPC is designed to protect the workers, human health and the environment from VOCs associated with emplaced waste during the operational period. Attachment A, (Section 7, Table 7.1) of this notification summarizes the design basis for the WPC and demonstrates compliance with the design basis.

CCA Appendix PCS presents four options for panel closure design. The EPA reviewed the four PCS options and required that Option D, constructed with SMC, be implemented for all panel closures. In making the decision in the Final Certification Rulemaking (EPA 1998), the EPA proposed that the intended purpose of the PCS is to “prevent the existing disturbed rock zone (DRZ) in the panel access drifts (tunnels) from increasing in permeability after panel closure...” In this regard, Attachments B and C demonstrate that the design of the panel closure system has negligible impacts to long-term performance of the repository within a broad range of panel closure and DRZ permeabilities.

### 3.2 Evaluation of the WPC

To demonstrate compliance with 40 CFR Part 191, Subparts B and C, the CBFO used the PAVT model with an appropriate panel closure permeability to represent an Option D closure. The results of this modeling, combined with the earlier PAVT modeling used for the EPA certification decision, established the long-term performance of the repository within a broad range of permeabilities for panel closure configurations. Modeling completed with the Option D design represents a low permeability closure, and the original PAVT results represented a high permeability closure. The permeability for the WPC is estimated to fall between the permeabilities used for the original PAVT calculations and for the Option D design.

The following table summarizes the various PCS designs and their representation in PA.

<table>
<thead>
<tr>
<th>PA Model</th>
<th>Panel Closure Permeability</th>
<th>Documentation</th>
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</thead>
<tbody>
<tr>
<td>PAVT</td>
<td>Permeability of panel closure is $10^{-15}$ m$^2$</td>
<td>PA results described in Attachment C</td>
</tr>
<tr>
<td>PAVT with Option D</td>
<td>Permeability of panel closure is $10^{-19}$ m$^2$</td>
<td>PA results described in Attachment C</td>
</tr>
<tr>
<td>PAVT with WPC</td>
<td>Permeability of closure ranges between $10^{-15}$ m$^2$ and $10^{-19}$ m$^2$, as described in Attachment B.</td>
<td>PA results will fall between those for the PAVT and for the PAVT with Option D.</td>
</tr>
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</table>
In the PAVT, the panel closure permeability was set to $10^{-15}$ m$^2$. The impact assessment documentation (Attachment C) demonstrates that the Option D closure has permeability on the order of $10^{-19}$ m$^2$. The long-term repository performance with this low permeability closure was essentially the same as for the more permeable PAVT closure, as shown in Attachment C. It is therefore expected that long-term repository performance will not be sensitive to any closure permeability falling within the range between the original PAVT closure and the Option D closure.

Based on information in the WPC design report (Attachment A) and an analysis of creep and salt consolidation data (Attachment B), the permeability of the WPC is expected to fall within the range analyzed in the impact assessment documents (Attachment C). Thus, the influence of the WPC design on long-term repository performance is expected to be negligible in comparison to the PAVT results.
4.0 Regulatory Assessment for 40 CFR Part 194

This section summarizes the regulatory impact of the WPC design change. The WPC proposed by the CBFO is different from that prescribed by 40 CFR Part 194, Appendix A, Condition 1: 194.14(b), Disposal system design, panel closure system, states:

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

However, the EPA indicated in the Final Certification Rulemaking (EPA 1998) that the CBFO may reassess the panel closure design and propose a change for EPA approval. Specifically, EPA stated:

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

The CBFO believes that a change in Condition 1 and in the panel closure design is warranted. The rationale for modifying Condition 1 is presented in Section 2.3. The rationale for the proposed design change is that the WPC is a much less complex design that is significantly less expensive and easier to construct than Option D. As a result, the WPC will:

1. Reduce risk of accident and injury to workers involved with the construction
2. Reduce impacts on repository operations during construction
3. Enhance the constructibility of the closure by using conventional construction practices that require no special equipment or requirements.

The DOE has determined that the WPC will also:

1. Fully protect human health and the environment
2. Meet the closure performance requirements imposed by the HWFP
3. Perform satisfactorily under the conditions of a postulated methane explosion
4. Have negligible impacts to the long-term performance of the repository

The Final Certification Rulemaking (EPA 1998) requires installation of the Option D panel closure with SMC. The performance assessments documented in Attachment C examine PCS permeabilities of $10^{15}$ m$^2$ for the original PAVT and $10^{19}$ m$^2$ for the Option D closure. The repository performance, in terms of the complementary cumulative distribution function for
normalized release, is essentially unchanged for these two extremes. The WPC will be within this range of permeabilities, as shown in Attachment B. It follows that the proposed change to Condition 1 and the associated change to the PCS design will not impact the long-term performance of the repository.
References


ATTACHMENT A

Design Report for a Revised Panel Closure System
at the Waste Isolation Pilot Plant, Revision 1
DESIGN REPORT FOR A
REVISED PANEL CLOSURE SYSTEM
AT THE WASTE ISOLATION PILOT PLANT

Revision 1
October 2002

Any comments or questions regarding this report should be
directed to the U.S. Department of Energy
Carlsbad Field Office
P.O. Box 3090
Carlsbad, New Mexico 88221

Or to Westinghouse TRU Solutions, LLC
P.O. Box 2078
Carlsbad, New Mexico 88221

This report was prepared for Westinghouse TRU Solutions, LLC by
RockSol Consulting Group, Inc., under Purchase Order Number 3164.
Certification

I certify under penalty of law that this document was prepared under my supervision for Westinghouse TRU Solutions, LLC, under the RockSol Consulting Group, Inc., Quality Assurance Program. This quality assurance program is designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete.

ORIGINAL SIGNED BY:

Saeid Saeb, Ph.D., P.E.
New Mexico
Certification No. 11777
Expires December 31, 2003
Executive Summary

Scope. RockSol Consulting Group, Inc., under contract to Westinghouse TRU Solutions, prepared a detailed design for a panel closure system for the Waste Isolation Pilot Plant (WIPP). Preparation of this detailed design of an operational-phase panel closure system is required to support the WIPP Hazardous Waste Facility Permit (HWFP). This report describes the detailed design for a panel closure system specific to the WIPP site. The recommended WIPP Panel Closure system (WPC) will adequately isolate the waste disposal panels from the active workings of the repository for the required design life of 35 years.

Purpose. This report provides detailed design and engineering specifications for the construction of the WPC. The WPC design will ensure a nominal operational life of 35 years. The design provides assurance that the mass release rate limits specified in the WIPP HWFP for the migration of volatile organic compounds (VOCs) will be met as specified in the relevant sections of the HWFP (e.g. Attachment N), for simplicity the point of compliance is referred to hereafter as E-300 drift. The WPC will be located in the air-intake and air-exhaust drifts (Figure ES-1-1). The system components are designed to maintain their intended functional requirements under loads generated from salt creep and a postulated methane explosion. The proposed design complies with regulatory requirements promulgated by Mine Safety and Health Administration (MSHA). The design uses common construction practices according to existing standards.

Background. The engineering design considered expected subsurface conditions at the location of the WPC. The geology is predominantly halite with inter-beded anhydrite at the repository horizon. During the operational period, the WPC will be subject to creep from the surrounding host rock. The salt strata at the repository horizon are known to contain only trace amounts of brine.

The HWFP provides information in Module IV on Geologic Repository Disposal. The VOCs of concern in Table IV.F.2.c of the HWFP include carbon tetrachloride, chlorobenzene, chloroform, 1,1-dichloroethene, 1,2-dichloroethane, methylene chloride, 1,1,2,2-tetrachloroethane, toluene, and 1,1,1-trichloroethane.

The primary intent of the WPC is to ensure that VOC releases are less than the regulatory limits specified in the HWFP. The E-300 drift mass release rate limit equals the E-300 drift concentration limit as specified in Table IV.F.2.c of the HWFP times the minimum ventilation rate of 260,000 ft³/min (7,362 m³/min) required by the HWFP. This value establishes the current design mass release rate limits for flow of VOCs of concern from the waste disposal areas.
Figure ES-1-1 Typical Panel Layout with Drift Cross Sections
While no specific requirements exist for closing disposal areas under MSHA regulations, the intent of these regulations is to safely isolate abandoned areas from active workings using barricades of "substantial construction." A previous analysis (DOE, 1996a) examined the issue of methane gas generation from transuranic waste and the potential consequences of a postulated methane explosion in closed waste disposal areas.

To demonstrate compliance with the E-300 drift mass release rate limits for the individual VOCs of concern, two air-flow models were evaluated: (1) unrestricted flow and (2) restricted flow through the panel closure system. The unrestricted air-flow model is defined as a model in which the gas pressure that develops is at, or very near, atmospheric pressure such that no back pressure exists in the disposal areas. The restricted air-flow model is defined as a model in which a back pressure develops in a closed waste disposal panel due to the restriction of flow through the panel closure system and the surrounding disturbed rock zone. The analyses were based on an assumed approximate gas generation rate of 0.1 moles per drum per year due to microbial degradation, the expected volumetric closure rate due to salt creep, the expected headspace concentration for a series of nine VOCs of concern, and the expected air ventilation rate at the E-300 drift. The analyses showed that in both air-flow models the release rate of each VOC at the E-300 drift is significantly below the permit limit. In the restricted case the release is further reduced.

**Alternate Designs.** Various concepts were developed for evaluation. These concepts intentionally covered a broad range. A design review committee was convened and was requested to rank the various alternatives. The design review committee carefully discussed all the alternatives, evaluated their potential performance, and recommended several of the concepts for further consideration. After further engineering evaluation and assessment, the explosion isolation wall with run of mine salt backfill was selected as the preferred alternative for the WPC. This alternative satisfies all performance specifications, is simple to construct, has a low impact on waste receipt, and is cost effective.

**WIPP Panel Closure System.** The WPC has two components: a 30-foot (9.1-meter) concrete block wall and a run of mine salt backfill. Figure ES-1-2 illustrates these design components. The construction methods and materials to be used to implement the design have been proven in previous mining and construction projects. No other special requirements for engineered components beyond the normal requirements for fire suppression and methane explosion or deflagration containment exist for the WPC during the operational period.
Figure ES-1-2 Explosion Isolation Wall in Combination with the Run of Mine Salt Backfill
**Design Evaluation.** The evaluation of this design was performed to investigate several key design issues. This design evaluation can be divided into two components: (1) the operational requirements of the system, and (2) the structural and material requirements of the system.

The conclusions reached from the evaluation addressing the operational requirements for the WPC design are as follows:

- The mass flow rate for different VOCs through the WPC (including flow through the disturbed rock zone [DRZ], the explosion isolation wall, and the run of mine salt backfill) were demonstrated to be at least two orders of magnitude below the limits specified in Table IV.F.2.c of the WIPP HWFP.

- The Monte Carlo Simulation Method was used to assess the uncertainty of VOCs headspace concentrations, gas generation rate, and panel volume closure rate on the mass flow rate of carbon tetrachloride. The time required to reach the steady-state mass flow rate of VOCs depends on the intrinsic permeability of the flow components. In some realizations in which the mass flow rate rises rapidly to the steady-state mass flow rate, the flow is essentially unrestricted. In most cases, however, the WPC offers some resistance to flow and mass flow rates develop more slowly. In all cases, the explosion isolation wall with the run of mine salt backfill complies with the mass flow rate limit at the E-300 drift. The maximum mass flow rate through WPC calculated by this analysis was more than an order of magnitude below the mass flow rate limits specified in Table IV.F.2.c of the WIPP HWFP.

- The dimensions selected for the passive design components of the WPC are conservative, and thus ensure that these components will not require routine maintenance during the operational life of 35 years.

The conclusions reached from the design evaluation addressing the structural and material requirements of the WPC are as follows:

- Thermal cracking due to heat of hydration effects does not apply to concrete blocks.

- The salt strata at the repository horizon are known to contain only trace amounts of brine that will not degrade the main concrete block wall over the nominal operational life of 35 years.

- Detailed axisymmetric FLAC models were developed to assess the state of stress in the
concrete block wall and surrounding rock due to creep closure of the salt. The length selected for the explosion isolation wall provides for a substantial margin of safety against structural failure.

- Stress analysis showed that the wall will withstand the forces of both creep closure and the postulated methane explosion. Further, at the likely time of a postulated explosion, the development of confining stress on the block wall would prevent fracturing around the block wall.

**Design Components.** Figure ES-1-2 illustrates the design components developed to satisfy the requirements for the WPC. The main barrier consists of a 30-foot (9.1-meter) long concrete block wall with construction joints. The concrete block wall design complies with MSHA requirements as it is made of incombustible materials of substantial construction. Surface treatment around the explosion isolation wall includes the removal of loose material to create a clean and regular surface for the construction of the block wall. The backfill consists of run of mine salt with a minimum length of 100 ft (30.5 m). Run of mine salt is a natural selection for backfill that is compatible with the environment.

The performance of the WPC design was evaluated against the performance specifications established for the panel closure system. The WPC design complies with all aspects of the performance specifications established for the panel closure system.
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List of Acronyms

atm atmosphere
CFR Code of Federal Regulations
cm centimeter(s)
CQC Contractor Quality Control
CQCP Contractor Quality Control Plan
DOE Department of Energy
DRZ Disturbed Rock Zone
ft foot (feet)
FLAC Fast Lagrangian Analysis of Continua
g gram(s)
HASP Health and Safety Plan
HWFP Hazardous Waste Facility Permit
K Kelvin
kg kilogram(s)
m meter(s)
mg milligram(s)
min minute(s)
MPa Mega Pascal(s)
MSHA Mine Safety and Health Administration
PCS Panel Closure System
ppm part(s) per million
psi pound(s) per square inch
QA/QC Quality Assurance/Quality Control
RCRA Resource Conservation and Recovery Act
s second(s)
SNL Sandia National Laboratories
TRU Transuranic
VOC(s) Volatile Organic Compound(s)
WIPP Waste Isolation Pilot Plant
WPC WIPP Panel Closure system
yr year(s)
1.0 Introduction

The Waste Isolation Pilot Plant (WIPP), a U.S. Department of Energy (DOE) facility located near Carlsbad, New Mexico, was established for the safe disposal of defense-generated transuranic (TRU) waste. The WIPP repository is approximately 2,150 feet (ft) (655 meters [m]) below the surface, in the Salado Formation.

One important aspect of repository operations at the WIPP is the activity associated with closure of waste disposal panels. Each panel consists of air-intake and air-exhaust drifts, panel-access drifts, and seven rooms (Figure 1-1). After completion of waste disposal activities in a panel, it will be closed at the same time that waste disposal may be occurring in the other panel(s). The closure of individual panels during the operational period will be accomplished in accordance with project-specific health, safety, and environmental performance criteria.

The WIPP Panel Closure system (WPC) design is an explosion isolation wall with run of mine salt backfill. The original Panel Closure System (PCS) design was contained in DOE (1996a) and Appendix PCS of the WIPP Compliance Certification Application (CCA) (DOE, 1996b). A large portion of the design information contained in that appendix is applicable to the WPC design. This includes the application of the restricted and unrestricted flow models, heat transfer analyses, and analyses associated with the methane gas explosion. Throughout this document, the CCA appendix is referred to as Appendix PCS.

1.1 Scope

This report provides analyses of the WPC design for effectiveness of the explosion isolation wall as a gas barrier; the structural adequacy of the explosion isolation wall; and the design description of the WPC for a nominal operational period of 35 years. The WPC design provides assurance that the limit for the migration of volatile organic compounds (VOCs) will be met as specified in the relevant sections of the HWFP (e.g. Attachment N), for simplicity the point of compliance is referred to hereafter as the E-300 drift. The WPC will be located in the air-intake and air-exhaust drifts to each panel (Figure 1-1). The WPC design maintains its intended functional requirements under loads generated from salt creep and a postulated methane explosion. The design complies with regulatory requirements promulgated by Mine Safety and Health Administration (MSHA).
Figure 1-1 Typical Panel Layout with Drift Cross Sections
1.2 Regulatory Requirements

1.2.1 Hazardous Waste Regulations

The Closure Plan in the WIPP HWFP was prepared in accordance with the requirements of 20.4.1.500 New Mexico Administrative Code (incorporating 40 Code of Federal Regulations §264 Subparts G, I, and X). The WPC complies with the relevant portions of those requirements.

1.2.2 Mine Safety and Health Administration

Under 30 CFR 57 “barriers and stopping” must be constructed of noncombustible materials appropriate for the specific mine category and must be of "substantial construction." Substantial construction implies construction of such strength, material, and workmanship that the barrier could withstand air blasts, methane detonation or deflagration, blasting shock, and ground movement expected in the mining environment. The WPC complies with the relevant portions of those regulations.

1.3 Report Organization

This report presents evaluations of the WPC. Chapter 2 presents the description of the design. Chapter 3 presents the design evaluations addressing the gas barrier effectiveness of the explosion isolation wall and the structural adequacy of the explosion isolation wall. Chapter 4 presents the design calculations. Chapters 5 and 6 present the technical specifications, and drawings respectively. Chapter 7 presents the conclusions to the report.
2.0 Design Descriptions

This chapter describes how the concept for the WPC was developed and describes the explosion isolation wall and run of mine salt backfill components of the WPC.

2.1 WPC Performance Specifications

Original design criteria were presented in Table 7-1 of DOE (1996a) and were revised in Attachment I of the HWFP as issued. These criteria were reviewed for continued applicability and only one of the performance specifications was modified, as italicized in the following list. The WPC performance specifications are:

- The panel closure system design shall limit VOC migration from a closed panel consistent with the limits found in Table IV.F.2.c of the HWFP.

- The panel closure system shall consider potential flow of VOCs through the disturbed rock zone (DRZ) in addition to flow through closure components.

- The panel closure system shall perform its intended functions under loads generated by creep closure of the tunnels.

- The panel closure system shall perform its intended function under the conditions of a postulated methane explosion.

- The nominal operational life of the closure system is thirty-five (35) years.

- The panel closure system for each individual panel shall not require routine maintenance during its operational life.

- The panel closure system shall address the most severe ground conditions expected in the waste disposal area.

- The design class of the panel closure system shall be IIIb (which means that it is to be built to generally accepted national design and construction standards).

- The design and construction shall follow conventional mining practices.

- Structural analysis shall use data acquired from the WIPP underground.

- Materials shall be compatible with their emplacement environment and function.
• Treatment of surfaces in the closure areas shall be considered in the design.

• Thermal cracking of concrete shall be addressed.

• During construction, a Quality Assurance/Quality Control (QA/QC) program shall be established to verify material properties and construction practices.

• Construction of the panel closure system shall consider shaft and underground access and services for materials handling.

Various concepts were developed for evaluation. These concepts intentionally covered a broad range. For each of these concepts, the estimated conductance was calculated and a preliminary construction cost was estimated. These were intended only as aids to facilitate ranking during the selection process.

A design review committee was convened and was requested to rank the various alternatives. The design review committee carefully discussed all the alternatives, evaluated their potential performance, and recommended several of the concepts for further consideration. After further engineering evaluation and assessment, the explosion isolation wall with run of mine salt backfill was selected as the preferred alternative for the WPC. This alternative satisfies all performance specifications, is simple to construct, has a low impact on waste receipt, and is cost effective.

2.2 Design Concept

The selected design for WPC is a combination of a mortared concrete block wall and a run of mine salt backfill. Figure 2-1 illustrates these design components. The construction methods and materials used to implement the design are well proven in previous mining and construction projects. This configuration satisfies the E-300 drift mass flow rate limits for the flow of VOCs of concern out of the panel. The selected design will resist the temperature transients and methane explosion pressure as discussed in Sections 3.2.2 through 3.2.4.

2.3 Design Components

The following subsections present system and components design features.
Figure 2-1 Explosion Isolation Wall in Combination with the Run of Mine Salt Backfill
2.3.1 Explosion Isolation Wall

The explosion isolation wall consists of a 30-foot (9.1-meter) long, mortared, solid block wall as shown in Figure 2-2. Detailed structural analyses have been performed (Section 3.2.4) to assess the development of stresses within the block wall. These analyses showed that a 30-foot (9.1-meter) long concrete block wall reduces the relative proportion of the compressive abutment zones near the ends of the wall to an acceptable level. Five construction joints were introduced to mitigate the axial tensile stresses, which develop in the wall due to salt creep. The construction joints also eliminate the effects of potential differential displacements along the axis of the wall. Since the construction joints are normal to the direction of VOCs flow out of the closed panel they have minimal impact on flow conductance of the wall.

The blocks of the wall are 8x8x16 inches and have a minimum unconfined compressive strength equal to 5000 psi (34.5 MPa). The specifications include materials testing to verify material properties and construction practices.

The concrete block wall design complies with MSHA requirements. It is made of incombustible materials and is of substantial construction. The block wall can also resist forces of a postulated methane explosion under creep load from the surrounding rocksalt as discussed in Section 3.2.4. The surrounding salt surfaces will be prepared to create a smooth, clean surface for the placement of bricks and mortar.

The explosion isolation wall with the run of mine salt backfill separates the active ventilated underground workings from the closed panels. The restricted flow analysis presented subsequently (Section 3.1.1) shows an adequate design margin for meeting VOC release limits.

2.3.2 Backfill

The backfill consists of run of mine salt with a minimum length of 100 ft (30.5 m). Run of mine salt is a natural material for backfill that is completely compatible with the environment. In the absence of the block wall, run of mine salt backfill provides protection against a methane explosion. An analysis was conducted to assess the effect of methane gas explosion on the backfill. In this analysis, the explosion isolation wall was ignored and the run of mine salt backfill alone resisted the impact loading from the postulated methane explosion. The analysis showed that the backfill will absorb the explosion impact due to deflagration.
Figure 2-2 Explosion Isolation Wall
3.0 Design Evaluations

This chapter presents the evaluations that support the design of the WPC: (1) analyses addressing the operational requirements, and (2) analyses addressing the material and structural requirements. The first group includes air-flow analyses, an advection analysis, and an uncertainty analysis of air-flow. The second group includes material compatibility evaluation, heat generation, explosion evaluation, stress analysis and fracture-propagation evaluation.

3.1 Analyses Addressing Operational Requirements

To evaluate the effectiveness of the WPC, air-flow analyses were performed to examine the flow of VOCs through the WPC. The following sections address the air-flow analyses, the advection analysis, and air-flow uncertainty analysis. These analyses support the WPC design for both the overall protection of human health and the environment, and compliance at the E-300 drift as required by HWFP.

3.1.1 Air-Flow Analyses

The purpose of the air-flow analyses is to evaluate the flow of VOCs through the WPC. The effective intrinsic permeability of the WPC is evaluated and used as input to the air-flow model (DOE, 1996a) to assess VOC(s) flow performance.

In this study, two air-flow models are considered: (1) unrestricted flow, and (2) restricted flow through the panel closure system. The unrestricted air-flow model is defined as a model in which the gas pressure that develops is at, or very near, atmospheric pressure such that no back pressure exists in the disposal areas. The restricted air-flow model is defined as a model in which a back pressure develops in a closed waste disposal panel due to the restriction of flow through the panel closure system and the surrounding disturbed rock zone. The analyses are based on an assumed gas generation rate of 8,650 moles per panel per year (0.1 moles per drum per year [DOE, 1996a] for 86,500 drums per panel [HWFP]) due to microbial degradation, an average volumetric closure rate of 31,430 ft$^3$ (890 m$^3$) per year due to salt creep (Appendix B), the expected headspace concentration for nine VOCs (Appendix A), and the minimum mine ventilation rate of 260,000 ft$^3$/min (7,362 m$^3$/min) required by HWFP at E-300 drift.

3.1.1.1 Evaluation Procedure

In the restricted flow model, the gases in the waste-emplacement area are in part compressed in the void space within a panel and in part flow into the main return air. The restricted flow model
is based on the following assumptions:

- Gases (including VOCs) within the void space will obey the Ideal Gas Law. The gases will be generated at a rate of 0.1 moles per drum per year (DOE, 1996a) and will be stored by an increase in gas pressure. The rate of pressure buildup will be so gradual that it occurs at constant temperature.

- Volumetric reduction due to creep will reduce the void space at a rate of 31,430 ft³ (890 m³) per year (Appendix B) and will result in pressurization.

- Flow of gas out of the panel will obey Darcy's Law under quasi steady-state conditions. Under quasi steady-state conditions, the air pressure within the WPC will change so gradually that the compressive storage of the air within the void space of the WPC could be neglected.

- Rates of gas generation, air outflow, and change in compressive storage will balance.

- Hydrodynamic dispersion through the barrier will be neglected.

- Analysis will consider the superposition of flow rates from individual panels according to the operating schedule for a nominal operational life of 35 years.

The air-flow under these assumptions follows a nonlinear system of two first-order ordinary differential equations. The model is characterized by molar gas generation and reduction in void volume that together result in an increase in air pressure.

The problem can be solved using the system of nonlinear ordinary differential equations as derived in Appendix A:

$$\frac{dp}{dt} = R \cdot T \cdot \left( g_r - \frac{p}{RT} \cdot C \cdot \frac{p - p_{atm}}{\gamma} \right) \cdot \frac{V}{V^2} - n \cdot \frac{dV}{dt}$$  \hspace{1cm} (Equation 3-1)

$$\frac{dn}{dt} = -g_r + \frac{p}{RT} \cdot C \cdot \frac{p - p_{atm}}{\gamma}$$  \hspace{1cm} (Equation 3-2)

where
\( dt \) = Change in time (years)

\( R \) = Universal gas constant (atm \cdot m^3/(mole \cdot K))

\( T \) = Absolute temperature (K)

\( n \) = Moles of gas in the panel

\( p \) = Pressure (atm)

\( p_{atm} \) = Atmospheric pressure (atm)

\( C \) = Conductance (m^2/s) of the panel closure system = \( K_s \cdot \frac{A}{L} \)

\( K_s \) = Effective air conductivity of the panel closure system (m/s)

\( A \) = Cross sectional area of the panel closure system (m^2)

\( L \) = Flow path length of the panel closure system (m)

\( \gamma \) = Air density (kg/(m^2 \cdot s^2))

\( g_r \) = Gas generation rate (moles/yr)

\( V \) = Volume of the panel void space (m^3)

\( \frac{dV}{dt} \) = Panel volumetric closure rate (m^3/yr)

\( \frac{dp}{dt} \) = Panel pressure rate (atm/yr)

\( \frac{dn}{dt} \) = Panel molar storage rate (mole/yr).

The above relationships are subject to the following initial conditions: (1) the pressure in the panel will be atmospheric; and (2) the moles of gas in the panel equal the moles of gas occupying the initial panel void volume at the temperature of the repository at the time of panel closure.
The effective air conductivity of the panel closure system \( (K_s) \) can be expressed in terms of the effective intrinsic permeability of the panel closure system \( (k_s) \) and the fluid properties of air as (Freeze and Cherry, 1979):

\[
K_s = \frac{k_s \cdot \rho \cdot g}{\mu}
\]

(Equation 3-3)

where

\[
\begin{align*}
\rho &= \text{Air mass density (kg/m}^3) \\
g &= \text{Acceleration due to gravity (m/s}^2) \\
\mu &= \text{Absolute air viscosity (kg/(m \cdot s))}
\end{align*}
\]

The effective intrinsic permeability of the WPC \( (k_s) \) can be evaluated by considering the intrinsic permeabilities of the various flow components over their respective areas, as presented in Table 3-1.

Permeability measurements in salt were summarized in the original design report (DOE, 1996a). These data show a zone of increased permeability \( (10^{-15} \text{ to } 10^{-20} \text{ ft}^2 [10^{-19} \text{ m}^2 \text{ to } 10^{-21} \text{ m}^2]) \) 3 to 42 ft (1 to 14 m) from the excavation surface. Based on these observations, the calculations assumed that the cross-sectional area for flow through the DRZ and the WPC will equal nine times the air-intake and air-exhaust drift area or that the DRZ extends out three radii from the center (DOE, 1996a).

As shown in Table 3-1, a distinction is made between “dilated salt”, and “fractured salt”. Dilated salt exhibits a higher permeability than intact salt due to relief of the lithostatic stresses, and this corresponds to the increased permeability zone observed by Case and Kelsall (1986). The more conservative value of \( 10^{-19} \text{ m}^2 \) is used here for the intrinsic permeability of dilated salt. The fractured salt refers to the highly fractured zone in the immediate vicinity of the openings.

The intrinsic permeability of the concrete block wall was estimated from the intrinsic permeabilities of the concrete blocks and the interface zone between the mortar and concrete blocks that is tributary to each block. A parallel system was used to calculate the intrinsic permeability of the concrete block wall from the intrinsic permeabilities of its flow components (concrete blocks and interface). It is assumed that the intrinsic permeability of mortar is the same as that of concrete block. For the concrete blocks an intrinsic permeability of \( k_c = 1.0 \times 10^{-19} \text{ m}^2 \).
(PCA, 2002) was used with a flow area of $A_c = 8 \times 16 \text{ in}^2 = 128 \text{ in}^2 = 0.083 \text{ m}^2$. Further, the intrinsic permeability of the interface zone surrounding the concrete blocks was estimated using an interface zone aperture of 11 micron (Fernandez et al., 1994). For a smoothwall aperture of $b$, the interface zone intrinsic permeability is equal to $b^2/12$ (Fernandez et al., 1994). For an aperture of $b = 11 \times 10^{-6} \text{ m}$, the interface zone intrinsic permeability of $k_i = 1 \times 10^{-11} \text{ m}^2$ is obtained. The area of the interface zone surrounding each concrete block is $A_i = 2(16 \text{ in} + 8 \text{ in}) b = 1.34 \times 10^{-5} \text{ m}^2$.

The intrinsic permeability of the concrete block wall can be calculated using Equation A-14 of Appendix A as follows:

$$k_{wall} = \frac{k_c \cdot A_c + k_i \cdot A_i}{A_c + A_i}$$  \hspace{1cm} \text{(Equation 3-4)}

This results in an intrinsic permeability of $1.64 \times 10^{-15} \text{ m}^2$ for the concrete block wall which is rounded to $2 \times 10^{-15} \text{ m}^2$.

The run of mine salt backfill is placed in a loose state in the air-intake and air-exhaust drifts of each panel. Case et al. (1987) reports on an experiment on WIPP crushed salt that measured the relationship of hydraulic conductivities to porosity when subjected to confining pressure. The test results showed that the intrinsic permeability might equal 0.01 darcy ($10^{-14} \text{ m}^2$) at 15 percent porosity. For high porosities from 35 to 40 percent, the test results showed that the intrinsic permeability might equal $10^2$ darcy ($10^{-10} \text{ m}^2$). In the current analysis, an intrinsic permeability of 10 darcy ($10^{-11} \text{ m}^2$) was used. This is a reasonable value for the expected range of porosities.

### Table 3-1 Intrinsic Permeability of Flow Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Intrinsic Permeability</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{ft}^2$</td>
<td>$\text{m}^2$</td>
</tr>
<tr>
<td>Dilated salt</td>
<td>$1 \times 10^{-18}$</td>
<td>$1 \times 10^{-19}$</td>
</tr>
<tr>
<td>Fractured salt</td>
<td>$1 \times 10^{-14}$</td>
<td>$1 \times 10^{-15}$</td>
</tr>
<tr>
<td>Clay seams</td>
<td>$1 \times 10^{-16}$</td>
<td>$1 \times 10^{-17}$</td>
</tr>
<tr>
<td>Marker Bed 139</td>
<td>$1 \times 10^{-15}$</td>
<td>$1 \times 10^{-16}$</td>
</tr>
<tr>
<td>Interface zone</td>
<td>$1 \times 10^{-10}$</td>
<td>$1 \times 10^{-11}$</td>
</tr>
<tr>
<td>Concrete block wall</td>
<td>$2 \times 10^{-14}$</td>
<td>$2 \times 10^{-15}$</td>
</tr>
<tr>
<td>Run of mine salt</td>
<td>$1 \times 10^{-10}$</td>
<td>$1 \times 10^{-11}$</td>
</tr>
</tbody>
</table>
Finally, for the clay seams, Marker Bed 139, and the interface zone between the concrete block wall and the surrounding rocksalt, the values from the previous design (DOE, 1996a) were used.

To calculate the void space volume of the panel (V), the analysis assumed that the volume of the waste is equal to the total waste capacity of a panel (600,000 ft³ [16,990 m³]) (DOE, 1994) times the assumed average solid volume of the waste drums (23 percent) (IT, 1994). The analysis uses a solid waste volume equal to 138,000 ft³ (3,908 m³) for the panel and this volume remains constant during the operational life of the panel.

The waste-emplacement capacity of a panel includes the seven rooms and the panel access drifts from Room 1 to Room 7. Field data from geotechnical engineering measurements were used to determine creep closure rates for 35 years as presented in Appendix B.

A model for unrestricted flow of VOCs was also developed to predict the mass flow rates of VOCs (Appendix A). The results of unrestricted flow analysis are used for comparison with the restricted flow case.

3.1.1.2 Modeling Results

The HWFP provides information in Module IV on Geologic Repository Disposal. Table IV.F.2.c of this module presents the E-300 drift concentration limits for VOCs of concern. These limits are shown on appropriate figures. The VOCs of concern in Table IV.F.2.c of the HWFP include carbon tetrachloride, chlorobenzene, chloroform, 1,1-dichloroethene, 1,2-dichloroethane, methylene chloride, 1,1,2,2-tetrachloroethane, toluene, and 1,1,1-trichloroethane.

The E-300 drift mass release rate limit equals the E-300 drift concentration limit as specified in Table IV.F.2.c of the HWFP times the minimum mine ventilation rate of 260,000 ft³/min (7,362 m³/min) required by HWFP. This value establishes the current design mass release rate limits for flow of VOCs of concern from the waste disposal areas.

Comparisons are made of the expected mass release rate of VOCs of concern to the E-300 drift mass release rate limits. The calculation of the expected mass flow uses the product of (1) an estimate of the actual headspace concentrations for each of the VOCs of concern, and (2) an estimate of the actual gas flow rate from the restricted flow model as presented previously.
The sources of information for the actual VOCs headspace concentrations (Appendix A) include Table A-2 of DOE (1996a), and the WIPP Waste Information System Headspace Gas Concentration Report (2002). The maximum values for actual mass concentrations from the two sources of information are used in the present analysis.

Figure 3-1 shows the expected pressure buildup in a single panel after closure. The pressure within the panel builds up gradually due to the large compressibility of the panel void space relative to the air-flow rate out of the panel. The restricted air-flow rate also builds up gradually to a steady-state flow rate.

Figure 3-2 presents the expected mass release rates for the VOCs of concern versus time for comparison to the E-300 drift mass release limits for the repository. In these analyses, the current panel closure schedule (Westinghouse, 2002) is considered, and the expected mass release rates from individual panels as they are closed are superimposed in time. The analyses show that in every case, the expected mass release rate from the repository is much lower than E-300 drift mass release rate limit for the VOCs of concern.

3.1.1.3 Conclusions

The air-flow model (DOE, 1996a) was used to predict the expected mass flow rate for VOCs of concern through a panel closure system consisting of a concrete block wall with run of mine salt backfill. The analysis suggests that VOC flow over the operational period will be at least two orders of magnitude below the HWFP limits established at the E-300 drift (Figure 3-2).

3.1.2 Advection Evaluation

The purpose of the advection evaluation is to assess contaminant transport time through various media. As panel pressure develops with time, gases will travel through the panel closure system. The restricted air-flow model considered that the VOC concentration front will instantaneously develop in the active underground workings and the gases would then flow by advection. The more detailed analysis presented below considers the flow distribution in different components.

3.1.2.1 Evaluation Procedure

The relative significance of each of the air-flow zones can be evaluated by studying flow conductance. The flow conductance through a parallel system is calculated as follows (Freeze and Cherry, 1979):
Figure 3-1 Pressure Buildup with Time for a Single Panel
Figure 3-2 Migration Rates versus E-300 Drift Limit Values for the VOCs of Concern
Figure 3-2 (continued) Migration Rates versus E-300 Drift Limit Values for the VOCs of Concern
\[ C = \sum \frac{K_i \cdot A_i}{L_i} \]  

(Equation 3-5)

where

\begin{align*}
C & \quad = \text{Flow conductance of the system (m}^2/\text{s)} \\
K_i & \quad = \text{Air conductivity of the } i^{th} \text{ component (m/s)} \\
A_i & \quad = \text{Cross sectional area of the } i^{th} \text{ component (m}^2) \\
L_i & \quad = \text{Length of the } i^{th} \text{ component (m)}
\end{align*}

The conductance through the WPC will depend on the air conductivity and cross-sectional area of the flow components. Table 3-2 summarizes these values for each component. Since the conductance of run of mine salt is at least four orders of magnitude higher than that of any other component, the breakthrough of VOCs through run of mine salt occurs very rapidly. Therefore, in the advection analysis the effect of run of mine salt is neglected. The calculations show that flow through the block wall and fractured salt will dominate the conductance.

In Table 3-2, the flow area of the interface zone between the 14 ft x 21 ft concrete block wall and surrounding rocksalt is based on an interface zone aperture of \( b = 11 \times 10^{-6} \text{ m} \) (Fernandez et al., 1994). This results in an interface flow area of \( A_i = 2(14 \text{ ft} + 21 \text{ ft}) \cdot b = 2.34 \times 10^{-4} \text{ m}^2 \). For a smoothwall aperture of \( b \), the interface zone intrinsic permeability is equal to \( b^2/12 \) (Fernandez et al., 1994). For an aperture of \( b = 11 \times 10^{-6} \text{ m} \), the interface zone intrinsic permeability of \( k_i = 1 \times 10^{-11} \text{ m}^2 \) is obtained. The interface zone air conductivity can be calculated from Equation 3-3. Using the air density of \( \gamma = \rho \cdot g = 0.0735 \text{ lbf/ft}^3 \) (11.55 kg/(m}^2 \cdot \text{s}^2) and air viscosity of \( \mu = 3.85 \times 10^{-7} \text{ lbf s/ft}^2 \) (1.84 \times 10^{-5} \text{ kg/(m} \cdot \text{s}) (Lindeburg, 1986), the interface zone air conductivity is obtained equal to \( 6.26 \times 10^{-6} \text{ m/s} \).

The breakthrough of VOCs through the WPC under the assumption of advection will occur when the VOC front has traversed its length. The average linear velocity equals the Darcy flux divided by the effective porosity for the various flow components. The average linear velocity, neglecting compressibility effects of the gas, is given by (Freeze and Cherry, 1979):

\[ V(p(t))_{avg_i} = \frac{K_i \cdot (p(t) - p_{atm})}{n_e \cdot L \cdot \gamma} \]  

(Equation 3-6)
where

\[ V(p(t))_{avg_i} = \text{Average linear velocity for the } i^{th} \text{ component (m/s)} \]

\[ K_i = \text{Air conductivity of the } i^{th} \text{ component (m/s)} \]

\[ p(t) = \text{Panel internal pressure as a function of time (atm)} \]

\[ p_{atm} = \text{Atmospheric pressure (atm)} \]

\[ L = \text{Length of the barrier (m)} \]

\[ \gamma = \text{Air density (kg/(m}^2 \cdot \text{s}^2)) \]

\[ n_e = \text{Effective porosity} \]

The following assumptions were made in this advection model:

- The air-flow velocity will be constant along the panel closure system.
- The gases (including VOCs) within the void space will obey the Ideal Gas Law.

### Table 3-2 Air Conductance Through System Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Effective Porosity</th>
<th>Air Conductivity (m/s)</th>
<th>Approximate Cross-Sectional Area (m²)</th>
<th>Conductance per Unit Length (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilated salt¹</td>
<td>0.001</td>
<td>6.26x10⁻¹⁴</td>
<td>170</td>
<td>1.0x10⁻¹¹</td>
</tr>
<tr>
<td>Fractured salt¹</td>
<td>0.040</td>
<td>6.26x10⁻¹⁰</td>
<td>16</td>
<td>1.0x10⁻⁸</td>
</tr>
<tr>
<td>Clay seams¹</td>
<td>0.400</td>
<td>6.26x10⁻⁷</td>
<td>0.09</td>
<td>5.6x10⁻¹³</td>
</tr>
<tr>
<td>Marker Bed 139¹</td>
<td>0.040</td>
<td>6.26x10⁻¹¹</td>
<td>11</td>
<td>6.9x10⁻¹⁰</td>
</tr>
<tr>
<td>Interface²</td>
<td>1.000</td>
<td>6.26x10⁴</td>
<td>2.34x10⁻⁴</td>
<td>1.5x10⁹</td>
</tr>
<tr>
<td>Concrete block wall²</td>
<td>0.200</td>
<td>1.25x10⁻⁸</td>
<td>27</td>
<td>3.4x10⁻⁸</td>
</tr>
<tr>
<td>Run of mine salt³</td>
<td>0.440</td>
<td>6.26x10⁻⁶</td>
<td>27</td>
<td>1.7x10⁻⁴</td>
</tr>
</tbody>
</table>

¹ DOE, 1996a
² Calculated
³ Case et al., 1987
- The flow of air out of the panel will obey Darcy's law under quasi steady-state conditions. Under quasi steady-state conditions, the air pressure within the panel closure system will change so gradually that the compressive storage of air within the void space of the panel closure system will be neglected.

- The two-phase flow and interactions between air and brine will be neglected, although the re-saturation of salt would tend to reduce the flow of VOCs through the panel closure system.

The air-flow average linear velocity as a function of time was calculated for each component of the WPC using the maximum pressure determined from the air-flow model (DOE, 1996a). The breakthrough time for advective transport was then determined for each of the WPC components (fractured salt, MB 139, clay seams, and the explosion isolation wall).

### 3.1.2.2 Modeling Results

In the model presented for air-flow, the pressure varies as a function of time for flow through the WPC. This will result in a change in the average linear velocity as a function of time that was calculated for each of the various components (fractured salt, MB 139, clay seams, and the explosion isolation wall).

Breakthrough times for a WPC due to advection were computed and are shown in Figure 3-3. The advection analysis suggests that for fractured salt and the mortared block wall, average linear velocities will be high due to high permeability, and low porosity, and that VOC breakthrough may occur within one to several years.

Previous analysis (DOE, 1996a) evaluated the effects of hydrodynamic dispersion on VOC transport through the WPC, using a one-dimensional dispersion model (Freeze and Cherry, 1979). This analysis showed that since breakthrough due to advection occurs rapidly through the dominant flow paths within several years, the effects of hydrodynamic dispersion are negligible. The analysis presented in this report also shows a similar rapid breakthrough through fractured salt in one to several years, as was the case in the previous analysis.
Figure 3-3 Breakthrough Time for VOCs through Several Media
3.1.2.3 Conclusion

The restricted air-flow analysis of Section 3.1.1 showed that the mass flow rates of VOCs of concern will remain well below the HWFP required E-300 drift limit. The results of advection analysis suggest the appropriateness of the restricted flow model (DOE, 1996a) for the instantaneous breakthrough of VOCs. The advection analysis showed that for fractured salt and the mortared block wall, average linear velocities will be high due to high permeability, and low porosity, and that VOC breakthrough may occur within one to several years. While it may appear that this breakthrough time is short, the quantities involved are so small that, as was concluded in Section 3.1.1.3, VOC flow over the operational period will be at least two orders of magnitude below the HWFP required limit in the E-300 drift.

3.1.3 Monte Carlo Simulation of VOC Release

This section presents a Monte Carlo Simulation Analysis (Hahn and Shapiro 1967) for mass flow rate of carbon tetrachloride over 35 years of operation. Carbon tetrachloride is used as a surrogate for all VOCs of concern since it is likely to be present in the greatest concentration in a closed panel. In the Monte Carlo Simulation Method, uncertain input parameters are represented by separate probability distribution functions. Each of the uncertain input parameters is sampled to develop multiple realizations. It is assumed that the uncertain input parameters are independent of each other and that the covariance between the input parameters can be neglected. A deterministic function or model is then used to evaluate the output parameter (in this case, the mass flow rate of carbon tetrachloride) for each set of realization of input parameters.

In an analysis of the flow of VOCs from a panel, a number of uncertain input parameters can be identified. For example, the concentration of VOCs can vary within and between panels, so the actual headspace concentration can be considered as uncertain input for calculation purposes. The migration of VOCs depends on the panel volumetric closure rate and the molar gas generation rate, both of which are uncertain parameters. Finally, in the case of restricted flow, the intrinsic permeabilities of the WPC (for both closure components and the surrounding disturbed rock zone) also are a source of uncertainty.

In the current Monte Carlo Simulation, only the restricted flow of VOCs is considered. A schematic representation of the Monte Carlo Simulation for restricted flow analysis is shown in Figure 3-4. Each of the uncertain inputs is discussed in the following sections:

Headspace concentration: The VOC inventory perhaps represents the most significant source of uncertainty. WIPP receives waste from multiple facilities with multiple waste streams. Both the
Figure 3-4 Monte Carlo Simulation of Restricted Air-Flow Analysis
unrestricted and restricted flow models assume that the headspace concentrations serve as a constant source of VOCs. This assumption is conservative because most containers only have trace quantities of VOCs, either trapped in the headspace or on the surfaces of the various waste components. It is likely that only a small number of waste containers have a significantly greater source of VOCs such as a solvent-soaked rag. Only this small number of waste containers have a realistic likelihood of maintaining a constant headspace VOC concentration as gas generation proceeds.

The current project baseline uses a headspace concentration of 3625.77 mg/m$^3$ for carbon tetrachloride (DOE, 1996a). To account for the uncertainty, it is assumed that the headspace concentration for carbon tetrachloride ranges from 0 to 7250 mg/m$^3$ with a uniform distribution.

**Gas generation rate:** The next uncertain parameter is the gas generation rate. The current project baseline uses a gas generation rate of 0.1 moles per drum per year. In the current uncertainty analysis it is assumed that the gas generation rate ranges from 0 to 0.2 moles per drum per year with a uniform distribution. The uniform distribution provides an estimate of variance that is higher than that for a normal distribution. It is therefore conservative to assume that the molar gas generation rate is uniformly distributed.

**Volumetric closure rate:** Another uncertain parameter is the volumetric closure rate. In the original design the panel closure rate was based upon data from Panel 1. Since that time, Panel 2 has been excavated, and data are available for assigning the uncertainty. The air-flow analysis presented in Section 3.1.1 used an average volumetric closure rate of 890 m$^3$ (31,430 ft$^3$) per year (Appendix B). For the purpose of uncertainty analysis, it is assumed that the volumetric closure rate is uniformly distributed between 600 (21,200) to 1200 m$^3$ (42,400 ft$^3$) per year.

**Intrinsic permeabilities:** The remaining uncertain parameters are the intrinsic permeabilities of the various flow components. Log uniform distributions are used in this analysis for intrinsic permeabilities of various flow components. The ranges of intrinsic permeabilities selected for the Monte Carlo Simulation Analysis are presented in Table 3-3.

The intrinsic permeability of salt in the disturbed rock zone includes the intrinsic permeability of dilated salt and fractured salt. Within the first meter of most excavations, some fractures parallel to the drift are observed from boreholes at the midheight of the rib (DOE, 1995). In this region, the permeabilities are generally greater than at any other location in the salt. Between 3 and 6 ft (1 and 2 m) into the rib, permeabilities decrease to about $10^{-19}$ m$^2$ and below; beyond 6 ft (2 m), the permeabilities rapidly decrease to the value associated with intact salt ($10^{-22}$ m$^2$). Based on
these observations, the analysis assumes that the dilated salt has a range of intrinsic permeabilities from $10^{-20}$ to $10^{-17}$ m². Also, the analysis assumes the fractured salt intrinsic permeability ranges from $10^{-17}$ to $10^{-12}$ m². Thus the combined range of the dilated salt and fractured salt values is exceptionally broad and covers the extreme range of values commonly used in various other WIPP-related assessments.

Freeze and Cherry (1979, p. 29) present a range of intrinsic permeabilities for clay, which can be used to estimate values for the clay seams. The range selected here is from $10^{-19}$ to $10^{-16}$ m².

Single-phase brine and nitrogen permeabilities were measured in the laboratory for specimens of MB 139 taken from the underground workings at the WIPP (DOE, 1995). Permeabilities to gas ranged from approximately $1.8 \times 10^{-19}$ to $2.5 \times 10^{-17}$ m², and the Klinkenberg-corrected equivalent liquid permeabilities ranged from $1.4 \times 10^{-18}$ to $1.6 \times 10^{-17}$ m². Measured permeabilities to brine ranged from $4.4 \times 10^{-20}$ to $9.7 \times 10^{-17}$ m². Based upon these values, the range of intrinsic permeability for the MB 139 is selected as from $1 \times 10^{-20}$ to $1 \times 10^{-16}$ m².

The intrinsic permeability for the interface zone between the concrete block wall and the surrounding rock salt is estimated based on a smoothwall aperture range from $b = 2$ to $b = 16$ microns (Fernandez et al., 1994). For a smoothwall aperture of $b$, the interface zone intrinsic permeability is equal to $b^2/12$ (Fernandez et al., 1994). The results range from $3.33 \times 10^{-13}$ to $2.13 \times 10^{-11}$ m² for the interface zone intrinsic permeability.

| Table 3-3 Ranges of Intrinsic Permeabilities in the Monte Carlo Simulation Analysis |
|-----------------------------------------------|-----------------|-----------------|
| Median | Lower Value (m²) | Upper Value (m²) |
| Dilated Salt | $1.00 \times 10^{-20}$ | $1.00 \times 10^{-17}$ |
| Fracture Salt | $1.00 \times 10^{-17}$ | $1.00 \times 10^{-12}$ |
| Clay Seams | $1.00 \times 10^{-19}$ | $1.00 \times 10^{-16}$ |
| Marker Bed 139 | $1.00 \times 10^{-20}$ | $1.00 \times 10^{-16}$ |
| Interface Zone | $3.33 \times 10^{-13}$ | $2.13 \times 10^{-11}$ |
| Explosion Isolation Wall | $1.00 \times 10^{-17}$ | $1.00 \times 10^{-13}$ |
| Run of Mine Salt Backfill | $1.00 \times 10^{-14}$ | $1.00 \times 10^{-10}$ |
The intrinsic permeability of the concrete block wall was estimated in Section 3.1.1.1 as $2 \times 10^{-15} \text{ m}^2$. To account for uncertainty, a range of permeability of four orders of magnitude for the explosion isolation wall was selected from $10^{-17} \text{ m}^2$ to $10^{-13} \text{ m}^2$.

The run of mine salt backfill is placed in a loose state in the air-intake and air-exhaust drifts of each panel. Case et al. (1987) reports on an experiment on WIPP crushed salt that measured the relationship of hydraulic conductivities to porosity when subjected to confining pressure. The test results showed that the intrinsic permeability might equal $0.01 \text{ darcy} \left(10^{-14} \text{ m}^2\right)$ at 15 percent porosity. For high porosities from 35 to 40 percent, the test results showed that the intrinsic permeability might equal $10^2 \text{ darcy} \left(10^{-10} \text{ m}^2\right)$. Therefore, the range of intrinsic permeability is selected from $10^{-14} \text{ m}^2$ to $10^{-10} \text{ m}^2$.

### 3.1.3.1 Evaluation Procedure

In order to combine information on assessing the mass flow rate of carbon tetrachloride from a single panel, MathConnex (MathSoft, Inc., 1999) was used. MathConnex is an environment for visually integrating and linking applications and data sources to create heterogeneous computational systems. MathConnex provides a means of connecting MathCad and EXCEL files together in a network. In the MathConnex file entitled Monte Carlo Simulation for Restricted Flow, the uncertain parameters are implemented in four MathConnex components:

- **Headspace Concentration of CCl₄** is an EXCEL file that generates a random sample for the headspace concentration of carbon tetrachloride as discussed above.

- **Volumetric Closure Rate** is an EXCEL file that generates a random sample of the panel volumetric closure rate as discussed above.

- **Gas Generation Rate** is an EXCEL file that generates a random sample of the gas generation rate as discussed above.

- **Intrinsic Permeabilities** is an EXCEL file that generates a random sample of the intrinsic permeabilities for each of the flow components as discussed above.

For a single realization of the randomly sampled parameters, the outputs from each of these components is input to the MathCad file entitled Restricted Flow Model. The restricted flow model is used to develop a time history for the mass flow rate of CCl₄ out of the panel. The output from the Restricted Flow Model is then input to an EXCEL file Monte Carlo Simulation. This file develops the time histories for multiple realizations of the input parameters.
3.1.3.2 Modeling Results

A Monte Carlo Simulation was performed for the restricted flow analysis of VOCs. The results of this simulation for 40 different realizations are presented in Figure 3-5. The figure shows the variation of mass flow rate for carbon tetrachloride during the operational life of the WPC. The mass flow rate limit for CCL4 is calculated as the mass concentration limit at E-300 drift times the minimum underground ventilation flow rate of 260,000 ft³/min (7,362 m³/min) required by HWFP.

In general, the magnitude of the unrestricted steady-state mass flow rate of CCL4 reflects the uncertainty in VOCs concentration rates, panel gas generation rate, and panel volumetric closure rate. The time required to reach the restricted steady-state VOC mass flow rate depends on the intrinsic permeability of the flow components. In some restricted realizations, the mass flow rate rises rapidly to the unrestricted steady-state mass flow rate, so the flow is essentially unrestricted. In the large majority of cases, however, the WPC offers some resistance to flow and the mass flow rates develop much more slowly. In all cases the WPC complies with the mass flow rate limit at the E-300 drift as required by HWFP.

3.2 Analyses Addressing Material and Structural Requirements

This section presents evaluations relating to the material and structural requirements for the WPC.

3.2.1 Material Compatibility Evaluation

The purpose of the material compatibility evaluations is to select suitable materials for the WPC. The materials must be chemically compatible with the host rock and brine without chemical degradation. This section presents information on brine-cement interactions at the locations of the WPC.

WIPP brines were initially studied when evidence of some minor concrete deterioration in the Waste Shaft key was noted (DOE, 1996a). The cause was geochemical alteration of the concrete shaft liner and shaft grout by the brine present at the Rustler-Salado contact. Chemical constituents detected in brine samples included both organic and inorganic compounds that probably originated from dissolution of the concrete liner and grout materials used in the shaft construction. The presence of large amounts of organics that likely originated from the chemical grout appeared to have complexed the calcium present in the brine, interfering with the inorganic chemistry of the naturally occurring brine. The brines in contact with the Waste Shaft key were
Figure 3-5 Mass Flow Rate for Carbon Tetrachloride
also found to be significantly higher in both chlorides and magnesium than the Salado Formation brine.

Several other studies investigated the effect of the high-magnesium brine interactions on various candidate barrier materials (DOE, 1996a). However, the original PCS design concluded that two extremely different service environments can be inferred between the Waste Shaft key and the underground repository horizon.

The WPC consists of concrete block wall and run of mine salt backfill. Blocks will be pre-cast in a factory setting and no organic grout compounds are used in the design. The magnesium level in the brines is much lower at the repository horizon. Further, only trace amounts of brine would contact the explosion isolation wall over the operational period due to the relative impermeability of the surrounding halite. For these reasons, significant brine-cement interactions are not anticipated and the block walls will perform their function within this time period. Run of mine salt backfill is entirely compatible with the underground environment.

3.2.2 Heat Generation

The WPC uses concrete blocks for explosion isolation wall. The concrete blocks will be pre-cast and cured in a factory setting. They will then be transported to the site and taken underground as convenient. Note that for these small blocks (8x8x16 inches), the volume to surface ratio is smaller than for large monolithic emplacements of concrete. Thus the temperature rise due to the heat of hydration can be dissipated without the development of tensile strains within the blocks before emplacement. Quality control testing of the blocks will assure strength and serviceability. Therefore cement heat generation is not an issue for the WPC.

3.2.3 Explosion Evaluations

The evaluation of the postulated methane explosion consists of evaluating the pressure and thermal effects of such an explosion on the explosion isolation wall. A methane explosion would generate an initial pressure transient that would impinge on the explosion isolation wall. Subsequently, temperature would rise in the panel as well as in the explosion isolation wall.

Two analyses are necessary to evaluate methane-explosion effects: (1) effect of explosion pressure, and (2) effect of explosion heat. After an explosion, the explosion isolation wall would be subjected to short-term dynamic loading. The design pressure can be calculated as the maximum pressure times the dynamic load factor (Biggs, 1964). The dynamic load factor will
depend on the shape of the pressure-time transient. An explosion will result in a transient pressure pulse that will rise instantaneously and then drop gradually.

The second effect requires a thermal analysis with a heat-transfer model. The results of the heat transfer model calculations (DOE, 1996a) are valid under the postulated explosion. The heat transfer model under the postulated explosion within the panel considered the heat balance between the gas and the walls of the panel for a stoichiometric mixture of methane. The rate at which the gas temperature will rise within the panel depends on (1) the number of moles of methane, (2) the specific heat capacity of the gas and the heat transfer to the salt and the walls through radiation, (3) convection along the vertical and horizontal surfaces, and (4) conduction within the salt and walls. The thermal analysis result (DOE, 1996a) showed that the elevated temperature due to explosion would propagate a maximum of 6 inches (15 cm) through the wall.

In the event of a hydrocarbon explosion either (1) deflagration will result in a rapid rise of pressure, with no transition to a detonation, or (2) a detonation wave front will propagate as a supersonic shockwave. The transition to a detonation is a function of two parameters: (1) the methane concentration at the time of the explosion, and (2) the ability for a wave front to form. In underground excavations, the latter condition typically requires a reasonably long passage through which the combustion wave travels and transforms to a detonation. The probability of occurrence of a detonation in an air-gas mixture also depends strongly upon the type of air-gas mixture. In the case of WIPP, the open passages above the waste stack will reduce in size due to creep closure so it is unlikely that a long passage with open geometry will exist. As a result the occurrence of detonation in underground excavation at WIPP is very unlikely. Therefore this analysis will only consider deflagration.

The peak explosive pressure arising from a deflagration is about eight times (DOE, 1996a) the ambient pressure at the time of explosion. The ambient pressure at the time of explosion depends on panel volume reduction rate, gas flow rate from WPC, and gas generation rate. In the current analysis the ambient pressure will reach a steady value of 1.41 atmosphere in a short time after panel closure. This results in a peak explosion pressure of 164 psi (1.14 MPa).

The dynamic load factor will depend on the natural frequency of the explosion isolation wall. The value for the dynamic load factor approaches a maximum value of 2, with increased natural frequency for a variety of exponential curves (DOE, 1996a). Based upon this loading, the block wall will be subjected to an equivalent uniform pressure of 328 psi (2.28 MPa). The result of the stress analysis is presented in the next section.
3.2.4 Stress Analysis

The purpose of the stress analysis was to evaluate the interaction of the block wall and run of mine salt backfill of the WPC with the surrounding salt. Stresses are expected to develop in the block wall component due to continued creep closure of the air-intake and air-exhaust drifts after installation of the block wall. Stresses are also expected to develop in the run of mine backfill, although at a very much slower rate than in the block wall. It is also shown that each component can individually withstand the postulated methane explosion.

3.2.4.1 Block Wall Evaluation

Detailed two-dimensional axisymmetric representations of the WPC were developed using the FLAC (Itasca, 2000) computer code. The properties used in these models are presented in Appendix C.

FLAC has been used since 1991 to model underground excavations at the WIPP. FLAC is a two-dimensional explicit finite difference code that simulates the behavior of rock and soil-like structures. The WIPP Reference Creep Law is built into the code and has been verified against the WIPP Second Benchmark Problem (Kreig, 1984). The following sections describe the geometry and boundary conditions of the models used in the FLAC analysis.

Model Development. A detailed axisymmetric model was developed to investigate the barrier under creep loading and combined creep and explosion loading. The geometry of this model is shown in Figure 3-6. There are five construction joints in this case, which are spaced evenly in the block wall. The construction joints have no cohesion (see Appendix C). The concrete is modeled as a Mohr-Coulomb material with a tension cut-off. Three cases were run with different loading and strength properties as called for by the ACI Ultimate Strength Design Method (ACI 318-02):

\[ 1.4 W \]
\[ 1.2 W + 1.6 E \]
\[ 0.9 W + 1.6 E \]

where \( W \) and \( E \) denote the dead load (far-field stress) and explosion load, respectively. All three cases used a strength reduction factor of 0.8. In addition to these three cases, a service load case
Figure 3-6 Creep Plus Explosion Model Geometry and Boundary Conditions
was run with all loading and strength properties set to their nominal values. In all cases with an explosion load, the explosive force was applied instantaneously, equilibrium was reached, and then the force was removed.

**Modeling Results.** The results from the ultimate strength design cases showed that while some compressive failure occurs near the ends of the block wall, the wall maintains a sizable intact confined core in every case, thus validating the design. Only the results from the service load case are presented here. Profiles of the stress in the block wall caused by an explosion after ten years of creep loading are shown in Figure 3-7 and Figure 3-8. The vertical (radial) loading is not significantly changed, while the axial loading is actually improved since the stress goes slightly compressive rather than tensile. Figure 3-9 and Figure 3-10 show contours of stress in the wall and in the rock during the explosion. Figure 3-11 shows the plasticity state in the wall at 35 years. This figure shows a limited tensile fracture zone near the rocksalt-concrete interface. Like the construction joints, these fractures are normal to the direction of the VOC flow through the WPC and have minimal impact on the flow conductance. Figure 3-12 shows a vertical stress profile in the block wall at 35 years, the required design life. These figures show that the block wall will perform its required function throughout the nominal operational design life.

### 3.2.4.2 Run of Mine Salt Backfill Evaluation

The run of mine salt backfill also provides a barrier to resist explosion pressure. To show the effectiveness of the salt backfill as an explosion barrier, a simple analytical model was developed. The following simplifying assumptions were made to conduct a conservative analysis.

- The run of mine backfill was subjected to all of the explosion loading.

- The explosion pressure is assumed to reach the maximum value of 1.14 MPa (Section 3-2-3) instantly and remains constant with negligible decay.

- The confining pressures on the salt backfill due to creep closure of the surrounding rocksalt are ignored.

- The geometric and material dampings are ignored.

- The only resistance mechanism is the frictional contact between backfill and rocksalt.

- Backfill material is assumed to be elastic.
Figure 3-7 Vertical (Radial) Stress Profile at Top of Block Wall During an Explosion Occurring 10 Years after Emplacement

Figure 3-8 Horizontal (Axial) Stress Profile at Top of Block Wall During an Explosion Occurring 10 Years after Emplacement
Figure 3-9 Vertical (Radial) Stress Contours in Block Wall During an Explosion Occurring 10 Years after Emplacement

Figure 3-10 Horizontal (Axial) Stress Contours in Block Wall During an Explosion Occurring 10 Years after Emplacement
Figure 3-11 Plasticity State in Block Wall at 35 Years

Figure 3-12 Vertical (Radial) Stress Profile at Top of Block Wall at 35 Years
The strain-stress relations for a general three-dimensional body can be written as (Fung, 1965):

\[
\begin{align*}
\varepsilon_x &= \frac{\sigma_x}{E} - \nu \frac{\sigma_y}{E} - \nu \frac{\sigma_z}{E} \\
\varepsilon_y &= \frac{\sigma_y}{E} - \nu \frac{\sigma_x}{E} - \nu \frac{\sigma_z}{E} \\
\varepsilon_z &= \frac{\sigma_z}{E} - \nu \frac{\sigma_x}{E} - \nu \frac{\sigma_y}{E}
\end{align*}
\]  
(Equation 3-7)

where \( \sigma_x, \sigma_y \) and \( \sigma_z \) are the normal stress components in the \( x, y \) and \( z \) directions, respectively, \( \varepsilon_x, \varepsilon_y \) and \( \varepsilon_z \) are the corresponding normal strain components, and \( E \) and \( \nu \) are the Young’s modulus and Poisson’s ratio respectively.

By taking the \( x \) axis as the longitudinal axis along the salt backfill (\( 0 < x < \infty \)) and setting \( \varepsilon_y = \varepsilon_z = 0 \), Equation 3-7 reduces to the following one-dimensional form:

\[
\varepsilon_x = \left(1 - 2\nu K_o\right) \frac{\sigma_x}{E}
\]  
(Equation 3-8)

where

\[
K_o = \frac{\nu}{1-\nu}
\]

By substituting Equation 3-8 into the one-dimensional strain-displacement relation of \( \varepsilon_x = du/dx \) and defining \( \sigma_x = -p \) one obtains:

\[
\frac{du}{dx} = -\left(1 - 2\nu K_o\right) \frac{P}{E}
\]  
(Equation 3-9)

where \( u = u(x,t) \) is the axial displacement along the \( x \) axis at time \( t \).

The applied forces on a longitudinal backfill element of length \( dx \) are shown in Figure 3-13. Equilibrium of these forces along the \( x \) axis results in:

\[
p A = \rho \frac{\partial^2 u}{\partial t^2} A \, dx + (p + dp) A + \mu K_o \, p \, Q \, dx \quad (u, x, t > 0)
\]  
(Equation 3-10)
in which:

\[ \rho = \text{mass density} \]

\[ \mu = \text{coefficient of friction} \]

\[ A = \text{cross-sectional area of backfill} \]

\[ Q = \text{perimeter of backfill in cross section} \]

\[ \rho \frac{\partial^2 u}{\partial t^2} A \, dx = \text{inertia force} \]

\[ \mu K_0 p Q \, dx = \text{friction force along the perimeter of backfill} \]

Using Equation 3-9, Equation 3-10 can be further simplified as:

\[
C^2 \frac{\partial^2 u}{\partial x^2} - \frac{\partial^2 u}{\partial t^2} + 2 \lambda C^2 \frac{\partial u}{\partial x} = 0 \quad (u, x, t > 0) \quad \text{(Equation 3-11)}
\]

where

\[
C = \sqrt{\frac{E}{\rho (1 - 2\nu K_0)}}
\]

\[
\lambda = \frac{K_0 \mu Q}{2A}
\]

Equation 3-11 is subjected to zero displacement and velocity as initial conditions. Also, from Equation 3-9, the following boundary condition is applied:

\[
\frac{\partial u}{\partial x} (0, t) = - \left(1 - 2\nu K_0\right) \frac{p(t)}{E} \quad \text{(Equation 3-12)}
\]

where \( p(t) \) is the explosion pressure at the explosion face. By ignoring the reflected wave effect from the far end of the backfill, Equation 3-11 is solved using the central finite difference method. The elastic parameters for run of mine salt \( (E = 20.1 \text{ MPa}, \nu = 0.25) \) were adopted from Callahan and DeVries (1991). A conservative value of 25 degrees similar to loose silt or silty sand (Bowls, 1982) was used for the friction angle of run of mine salt.
Figure 3-14 shows the result of the analysis. Based on this figure, the displacement of the salt at the explosion face is 13.8 inches (0.350 m) when the maximum displacement at the opposite end is about 0.4 inches (0.01 m). This verifies that the run of mine salt backfill performs as an effective explosion barrier.

3.2.5 Fracture-Propagation Evaluation

The fracture-propagation studies evaluate the potential for fracture propagation, using the results of previous analyses. The results of the thermal analysis suggest that elevated temperatures within an explosion isolation wall and salt will be a localized phenomenon. During an explosion two phenomena could affect the potential fracturing of the salt: (1) the expansion of the explosion products into existing fractures, and (2) the potential reflection of sonic waves off free surfaces around the barrier. The fractures in the roof and floor could be affected by the expansion of the gas products on the order of 164 psi (1.14 MPa), which decay rapidly with time and attenuate with distance. Around the wall, the confining stress on the order of 2,100 psi (15 MPa) will develop. Horizontal fracture propagation could occur around the barrier only if the internal gas pressure exceeds confining pressure. Because the peak internal pressure from deflagration is less than ten percent of the confining pressure, fractures would not propagate through or around the main wall.

Following an explosion, the wall would be subject to sonic waves that would impinge on the wall. As the sonic wave encounters a contrast in wall stiffness, a portion of the sonic wave would be refracted, and a portion would be reflected (Jaeger and Cook, 1972). This would result in minor tensile spalling of the isolation wall. The salt backfill causes a partial wave transmission and damping which in turn reduces the reflected tensile wave. At the time of a potential explosion, the development of confining stress relative to the explosion pressure would prevent fracturing around the block wall. The block wall can safely withstand the pressure from the postulated methane gas explosion.
Friction Force

Inertia Force

\[ p = \text{Inertia Force} \]

\[ p + dp \]

\[ dx \]

Figure 3-13  Applied Forces on a Longitudinal Element of Backfill

Figure 3-14  Dynamic Displacement versus Distance from Explosion Face
4.0 Design Calculations

All calculations were performed in accordance with the RockSol Consulting Group, Inc., Quality Assurance Program and comply with Westinghouse TRU Solutions requirements. The documentation for the codes and calculations, as well as related documents such as verification and validation tests, constitute quality records and are maintained in accordance with WIPP procedures.

The bases for all calculations are presented in Chapter 3 and Appendices A, B, and C. All software for the design calculations have been documented, verified and validated in accordance with the RockSol Consulting Group, Inc. Quality Assurance Program. This program complies with the requirements of the Westinghouse TRU Solutions QA Program.
5.0 Technical Specifications

The specifications are in the engineering file room at the WIPP and are the property of Westinghouse. These specifications are included as an attachment in Appendix D and are summarized in Table 5-1.

<table>
<thead>
<tr>
<th>Division 1 - General Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 01010</td>
</tr>
<tr>
<td>Section 01090</td>
</tr>
<tr>
<td>Section 01400</td>
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<tr>
<td>Section 01600</td>
</tr>
</tbody>
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<table>
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<tr>
<th>Division 2 - Site Work</th>
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<td>Section 02010</td>
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<tr>
<td>Section 02222</td>
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<table>
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<th>Division 3 - Masonry</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Section 03300</td>
</tr>
<tr>
<td>Section 03400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Division 4 - Salt Backfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 04100</td>
</tr>
</tbody>
</table>
6.0 Drawings

The Drawings (Appendix E) are in the engineering file room at the WIPP and are summarized in Table 6-1.

Table 6-1 WIPP Panel Closure System Drawings

<table>
<thead>
<tr>
<th>Drawing Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>110-CD001</td>
<td>Panel closure system, title sheet</td>
</tr>
<tr>
<td>110-CD002</td>
<td>Panel closure system, underground waste disposal panel</td>
</tr>
<tr>
<td>110-CD003</td>
<td>Panel closure system, construction details</td>
</tr>
</tbody>
</table>
7.0 Conclusions

This chapter presents the conclusions for the detailed design activities for the WPC. Table 7-1 shows the performance specifications for the WPC and the compliance of the design with the performance specifications. The design configuration and essential features for the WPC include an explosion isolation wall constructed of 5000 psi (34.5 MPa) unconfined compressive strength blocks that is 30 ft (9.1 m) long, and a run of mine salt backfill section that is 100 ft (30.5 m) long. Surface treatment around the explosion isolation wall includes the removal of loose material to create a clean, regular surface for construction of the block wall.

The design is presented in this report as performance specifications, a series of calculations, and engineering Drawings and Specifications. Structural analyses used to select the design length and other design features are based upon data acquired from the WIPP underground. The Drawings illustrate and describe the construction and details for the system. The Specifications cover the general requirements of the system, quality assurance and quality control, site work, masonry, and run of mine salt backfill. Information on the proposed construction method is also presented. The WPC can be built to generally-accepted national design and construction standards.

The design complies with all aspects of the design basis established for the WPC. The design can be constructed in the underground environment with no special requirements at the WIPP. To investigate several key design issues and to implement the design, design evaluations were performed. The conclusions reached from the evaluations are as follows:

- The mass flow rates for different VOCs through the WPC (including flow through the DRZ, the explosion isolation wall, and run of mine salt backfill) are substantially below the limits established in the HWFP for the E-300 drift.

- The Monte Carlo Simulation Method was used to assess the uncertainty of VOCs headspace concentrations, gas generation rates, and panel volume closure rates on the mass flow rate of carbon tetrachloride. The time required to reach the steady-state mass flow rate of carbon tetrachloride depends on the intrinsic permeability of the flow components. In some realizations the mass flow rate rises rapidly to the steady-state mass flow rate and the flow is essentially unrestricted. In most cases, however, the WPC offers resistance to flow, and mass flow rates would develop more slowly. In all cases, the explosion isolation wall with the run of mine salt backfill complies with the mass flow rate limit at the E-300 drift.

- The passive design components of the WPC do not require routine maintenance during the
nominal operational life of 35 years.

- Thermal cracking due to heat of hydration effects does not apply to concrete blocks.

- The trace amounts of brine from the salt at the repository horizon would not degrade the main concrete barrier for at least 35 years.

- Detailed axisymmetric models were developed to assess the state of stress in the block wall and surrounding rock due to creep closure of the salt. The length selected for the explosion isolation wall provides for a substantial margin of safety against structural failure due to creep loading.

- Stress analysis shows that the wall will withstand both the forces of creep and the postulated methane explosion. Further, at the time of a potential explosion, the development of confining stress would prevent fracturing around the block wall.

- The heat-transfer analysis in the previous PCS design (DOE, 1996a) showed that elevated temperatures would occur within the salt and the explosion isolation wall; however, the elevated temperatures will be isolated by the PCS. Temperature gradients will not significantly affect the stability of the wall.

- The WPC provides for flexibility over the 35-year operational life in construction scheduling and construction material transportation and therefore minimizes the effect on waste receipt.

In addition to the design requirements presented above, the design includes a QA/QC program to verify material properties and construction practices. The existing shafts and underground access can accommodate the construction of the WPC.
Table 7-1 Compliance with Performance Specifications

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Design Report Section</th>
<th>Compliance with Requirement</th>
<th>Notes on Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>The panel closure system design shall limit VOC migration from a closed panel consistent with the limits found in Table IV.F.2.c of the HWFP.</td>
<td>3.1</td>
<td>Complies</td>
<td>Gas-flow modeling shows that the VOC flow is substantially less than the E-300 drift limit specified in the HWFP.</td>
</tr>
<tr>
<td>The panel closure system shall consider potential flow of VOCs through the disturbed rock zone (DRZ) in addition to flow through closure components.</td>
<td>3.1</td>
<td>Complies</td>
<td>Restricted gas-flow model considers flow through the DRZ.</td>
</tr>
<tr>
<td>The panel closure system shall perform its intended functions under loads generated by creep closure of the tunnels.</td>
<td>3.2.4</td>
<td>Complies</td>
<td>Stress analyses and design calculations show that the WPC performs as intended under creep closure.</td>
</tr>
<tr>
<td>The panel closure system shall perform its intended function under the conditions of a postulated methane explosion.</td>
<td>3.2.3, 3.2.4, 3.2.5</td>
<td>Complies</td>
<td>The methane explosion studies, fracture propagation studies, and supporting design calculations show that the WPC performs as intended.</td>
</tr>
<tr>
<td>The nominal operational life of the closure system is thirty-five (35) years.</td>
<td>3.1, 3.2</td>
<td>Complies</td>
<td>Gas-flow modeling and stress analyses shows satisfactory performance for 35 years.</td>
</tr>
<tr>
<td>The panel closure system for each individual panel shall not require routine maintenance during its operational life.</td>
<td>2.2</td>
<td>Complies</td>
<td>Passive design components require no routine maintenance.</td>
</tr>
<tr>
<td>The panel closure system shall address the most severe ground conditions expected in the waste disposal area.</td>
<td>3.1, 3.2</td>
<td>Complies</td>
<td>Design is based upon flow and structural analyses of the most severe ground conditions.</td>
</tr>
<tr>
<td>The design class of the panel closure system shall be IIIb (which means that it is to be built to generally accepted national design and construction standards).</td>
<td>2.3</td>
<td>Complies</td>
<td>The construction sequence for the design followed conventional mining practices.</td>
</tr>
<tr>
<td>The design and construction shall follow conventional mining practices.</td>
<td>2.2, 2.3</td>
<td>Complies</td>
<td>The specifications include normal construction practices used in the underground at WIPP and according to the most current mortar and concrete block specifications.</td>
</tr>
<tr>
<td>Requirement</td>
<td>Design Report Section</td>
<td>Compliance with Requirement</td>
<td>Notes on Compliance</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Structural analysis shall use data acquired from the WIPP underground.</td>
<td>3.2.4</td>
<td>Complies</td>
<td>The structural analysis uses properties that model creep closure for stress analyses from data acquired in the WIPP Geotechnical Monitoring Program.</td>
</tr>
<tr>
<td>Materials shall be compatible with their emplacement environment and function.</td>
<td>3.2.1</td>
<td>Complies</td>
<td>The material compatibility studies showed no degradation of materials and no need for surface treatment.</td>
</tr>
<tr>
<td>Treatment of surfaces in the closure areas shall be considered in the design.</td>
<td>Appendix D</td>
<td>Complies</td>
<td>Design specifications address surface treatment.</td>
</tr>
<tr>
<td>Thermal cracking of concrete shall be addressed.</td>
<td>3.2.2</td>
<td>Complies</td>
<td>Thermal cracking due to heat of hydration effects do not apply to concrete blocks.</td>
</tr>
<tr>
<td>During construction, a Quality Assurance/Quality Control (QA/QC) program shall be established to verify material properties and construction practices.</td>
<td>Appendix D</td>
<td>Complies</td>
<td>The specifications include materials testing to verify material properties and construction practices.</td>
</tr>
<tr>
<td>Construction of the panel closure system shall consider shaft and underground access and services for materials handling.</td>
<td>Appendix D</td>
<td>Complies</td>
<td>The specifications allow construction within the capacities of underground access.</td>
</tr>
</tbody>
</table>
8.0 References

American Concrete Institute (ACI), 2002, "Building Code Requirements for Structural Concrete and Commentaries," *ACI 318-02*, American Concrete Institute, Farmington Hills, Michigan.


New Mexico Environment Department, 2000, "Adoption of 40 CFR Part 264," Title 20 (Environmental Protection) of the New Mexico Administrative Code, Chapter 4 (Hazardous Waste), Part 1 (Hazardous Waste Management), New Mexico Hazardous and Radioactive Materials Bureau, Santa Fe, New Mexico.


APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS
APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS

A.1.0 Introduction

This appendix presents the derivation of unrestricted and restricted air-flow models used to determine the performance of the panel closure system. These derivations were used in the analyses in Section 3.1 to determine gas flow from a panel. These analyses provide an estimate of the volume of gas that might flow through the panel closure systems at the Waste Isolation Pilot Plant (WIPP).

A.2.0 Model for Unrestricted Flow of VOCs

A model for the unrestricted flow of volatile organic compounds (VOCs) was developed to predict the mass flow rates of VOCs and to compare these mass flow rates with the design migration limits for VOCs. Over time, a mixture of gases containing VOCs flows from each waste container. It is assumed for the unrestricted flow model that the headspace concentrations serve as a constant source of VOCs. This assumption is conservative because most containers only have trace quantities of VOCs, either trapped in the headspace or on the surfaces of the various waste components. It is likely that only a small number of waste containers have a significantly greater source of VOCs such as a solvent-soaked rag. Only this small number of waste containers have a realistic likelihood of maintaining a constant headspace VOC concentration as gas generation proceeds.

The VOCs originating from the waste containers can migrate from the panel due to volumetric creep closure of the panel void space and to gas generation due to microbial degradation of the waste. Because flow is unrestricted, the VOCs migrate under a pressure of one atmosphere. Other assumptions in the unrestricted flow model are as follows:

- Any gases released into the mine atmosphere would be reduced in concentration by the minimum ventilation rate of 260,000 ft³/min (7,362 m³/min) required by HWFP at E-300 drift. The mass flow rate of individual VOCs from individual panels following their closure is summed to determine the mass flow rate of VOCs at E-300 drift.

- The analysis uses the schedule for closure of individual panels (Westinghouse, 2002) as illustrated in Table A-1 during the operational life of the panel closure system.
• Open panels of waste are not considered as a source contributing to the emissions of VOCs.

Considering only advection in the migration of VOCs, the mass-balance relationship is (DOE, 1996):

\[ C_p \cdot Q_p = C_{E300} \cdot Q_{E300} \]  
(Equation A-1)

where

- \( C_p \) = Headspace concentration for an individual VOC
- \( Q_p \) = Flow rate of VOCs from the panel
- \( C_{E300} \) = Concentration of VOCs at the E-300 drift
- \( Q_{E300} \) = Underground ventilation flow rate at the E-300 drift

Table A-2 presents the maximum headspace concentrations for different VOCs of concern. The total flow rate of VOCs from the panel can be obtained as follows (DOE, 1996):

\[ Q_p = Q_{gr} + Q_c \]  
(Equation A-2)

where

- \( Q_{gr} \) = Volumetric flow rate due to gas generation
- \( Q_c \) = Volumetric flow rate due to panel volumetric closure

The volumetric flow rate due to gas generation is calculated as the gas generation rate (0.1 moles per drum per year) times the number of drums within a panel times the specific volume under atmospheric pressure. The VOCs concentrations at the E-300 drift must be restricted to the limits found in Table IV.F.2.c of the HWFP, which are shown in Table A-3.
Table A-1 Schedule for Panel Closure
(After Westinghouse, 2002)

<table>
<thead>
<tr>
<th>Panel #</th>
<th>Closure time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.11</td>
</tr>
<tr>
<td>2</td>
<td>6.15</td>
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<tr>
<td>3</td>
<td>7.36</td>
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<td>4</td>
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<td>11.93</td>
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<td>6</td>
<td>14.55</td>
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<td>7</td>
<td>17.38</td>
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<tr>
<td>8</td>
<td>23.18</td>
</tr>
<tr>
<td>9</td>
<td>28.98</td>
</tr>
<tr>
<td>10</td>
<td>35.00</td>
</tr>
</tbody>
</table>

Table A-2 Maximum Headspace Concentrations for VOCs

<table>
<thead>
<tr>
<th>Compound</th>
<th>Maximum Headspace Concentration (milligrams per cubic meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Tetrachloride</td>
<td>3625.77</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>63.99</td>
</tr>
<tr>
<td>Chloroform</td>
<td>76.79</td>
</tr>
<tr>
<td>1,1-Dichloroethene</td>
<td>48.68</td>
</tr>
<tr>
<td>Methylene Chloride</td>
<td>3387.03</td>
</tr>
<tr>
<td>1,1,2,2-Tetrachloroethane</td>
<td>69.65</td>
</tr>
<tr>
<td>Toluene</td>
<td>105.51</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>1.24</td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td>145.75</td>
</tr>
</tbody>
</table>
Table A-3 VOC Concentrations of Concern
(After Table IV.F.2.c of the HWFP. This list of VOCs is the same as the list of VOCs in the previous design (DOE, 1996a) except for 1,2-dichloroethane and 1,1,1-trichloroethane.)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Drift E-300 Concentration Limit (micrograms per cubic meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Tetrachloride</td>
<td>1050</td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>1015</td>
</tr>
<tr>
<td>Chloroform</td>
<td>890</td>
</tr>
<tr>
<td>1,1-Dichloroethene</td>
<td>410</td>
</tr>
<tr>
<td>Methylene Chloride</td>
<td>6700</td>
</tr>
<tr>
<td>1,1,2,2-Tetrachloroethane</td>
<td>350</td>
</tr>
<tr>
<td>Toluene</td>
<td>715</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>175</td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td>3200</td>
</tr>
</tbody>
</table>
A.3.0 Model for Restricted Flow of VOCs

The assumptions for the restricted air-flow model are as follows:

- Gases (including VOCs) within the void space will obey the Ideal Gas Law. The gases will be generated at a rate of 0.1 moles per drum per year and will be stored by an increase in gas pressure. The rate of pressure buildup will be so gradual that it occurs at constant temperature.

- Volumetric reduction due to creep will reduce the void space at a rate of $31,430 \text{ ft}^3$ (890 m$^3$) per year (Appendix B) and will result in pressurization.

- Flow of gas out of the panel will obey Darcy's Law under quasi steady-state conditions. Under quasi steady-state conditions, the air pressure within the panel closure system will change so gradually that the compressive storage of the air within the void space of the panel closure system could be neglected.

- Rates of gas generation, air outflow, and change in compressive storage will balance.

- Hydrodynamic dispersion through the barrier will be neglected.

- Analysis will consider the superposition of flow rates from individual panels according to the operating schedule for a nominal operational life of 35 years.

After panel closure, the volume, moles of gas, and pressure change as functions of time. The Ideal Gas Law (Hiller and Herber, 1960) is written as:

$$p = \frac{n \cdot R \cdot T}{V}$$

(Equation A-3)

where

- $p =$ Pressure in the panel
- $n =$ Moles of gas in the panel
- $R =$ Universal gas constant
- $T =$ Absolute temperature
- $V =$ Volume of the panel void space
Differentiating Equation A-3 with respect to time \( t \) and using the chain rule results in:

\[
\frac{dp}{dt} = R \cdot T \cdot \frac{dn \cdot V - n \cdot \frac{dV}{dt}}{V^2}
\]  
(Equation A-4)

The rate at which gas enters the panel minus the rate that gas leaves the panel must equal the change in moles stored. Therefore, the mass-balance relationship can be written as follows (DOE, 1996):

\[
\frac{dn}{dt} = g_r - \frac{P}{R \cdot T} \cdot K_s \cdot \frac{A \cdot P - p_{atm}}{\gamma}
\]  
(Equation A-5)

where

- \( g_r \) = Panel gas generation rate
- \( p_{atm} \) = Atmospheric pressure
- \( \gamma \) = Air density
- \( K_s \) = Effective panel closure system conductivity
- \( A \) = Cross-sectional area
- \( L \) = Length of flow path

Conductance \( C \) can be defined as follows:

\[
C = K_s \cdot \frac{A}{L}
\]  
(Equation A-6)

Substituting into the ordinary differential equations, the following relations can be obtained:

\[
\frac{dp}{dt} = R \cdot T \cdot \frac{(g_r - \frac{P}{R \cdot T} \cdot C \cdot \frac{P - p_{atm}}{\gamma}) \cdot V - n \cdot \frac{dV}{dt}}{V^2}
\]  
(Equation A-7)

\[
\frac{dn}{dt} = g_r - \frac{P}{R \cdot T} \cdot C \cdot \frac{P - p_{atm}}{\gamma}
\]  
(Equation A-8)
These two first-order coupled ordinary differential equations can be solved by a simple explicit finite difference technique as follows:

\[
p_j = p_{j-1} + R \cdot T \cdot \frac{(g_r \cdot \frac{P_{j-1}}{R \cdot T} \cdot C \cdot \frac{P_{j-1} - P_{\text{atm}}}{\gamma} \cdot V - n_{j-1}}{\nu^2} \cdot \frac{dV}{dt} \cdot \Delta t \]  

(Equation A-9)

\[
n_j = n_{j-1} + (g_r \cdot \frac{P_{j-1}}{R \cdot T} \cdot C \cdot \frac{P_{j-1} - P_{\text{atm}}}{\gamma}) \cdot \Delta t \]  

(Equation A-10)

where

\[
p_j, n_j = \text{the pressure and moles of gas at the current time step}
\]

\[
p_{j-1}, n_{j-1} = \text{the pressure and moles of gas at the previous time step}
\]

The initial conditions for the ordinary differential equations include: (1) the initial pressure equals atmospheric pressure; and (2) the initial moles of gas can be determined by the Ideal Gas Law at initial volume and pressure. Further note that the volume can be approximated as a linear function of time:

\[
V(t) = \alpha \cdot t + \beta
\]

(Equation A-11)

where

\[
\alpha = \text{Slope of the volume-time relationship}
\]

\[
\beta = \text{Intercept of volume-time relationship}
\]

\[
t = \text{Time}
\]

These expressions can be substituted into the above explicit finite difference relationships, and the pressure and molar air-flow rates can be determined as functions of time.

**A4.0 Effective Intrinsic Permeability of a Parallel System**

The effective flow conductance for a parallel system consisting of \( n \) flow components can be obtained in terms of the conductances of its flow components as follows (Freeze and Cherry, 1979):

\[
\text{ conductance of a parallel system} = \frac{1}{\sum^{n} \frac{1}{\text{conductance of individual components}}}
\]
\[ C_t = \sum_{i=1}^{n} C_i \]  \hspace{1cm} \text{(Equation A-12)}

where \( C_t \) = Total flow conductance of the system
\( C_i \) = Flow conductance of the \( i^{th} \) component

Based on the definition of flow conductance (Equation A-6), Equation A-12 can be rewritten as:

\[ K_t \frac{A_t}{L} = \sum_{i=1}^{n} K_i \frac{A_i}{L} \]  \hspace{1cm} \text{(Equation A-13)}

or

\[ K_t \frac{\sum_{i=1}^{n} K_i A_i}{A_t} \]  \hspace{1cm} \text{(Equation A-14)}

where \( K_t \) = Effective conductivity of the system
\( A_i \) = Cross-sectional area of the \( i^{th} \) component
\( A_t \) = Total cross-sectional area of the system \( (\sum_{i=1}^{n} A_i) \)
\( L \) = Length of flow path

**A5.0 Effective Intrinsic Permeability of a Series System**

The effective flow conductance for a series system consisting of \( n \) flow components can be obtained in terms of the conductances of its flow components as follows (Freeze and Cherry, 1979):

\[ \frac{1}{C_t} = \sum_{i=1}^{n} \frac{1}{C_i} \]  \hspace{1cm} \text{(Equation A-15)}
where

\[ C_t = \text{Total flow conductance of the system} \]

\[ C_i = \text{Flow conductance of the } i^{th} \text{ component} \]

Based on the definition of flow conductance (Equation A-6), Equation A-15 can be rewritten as follows:

\[ \frac{L_t}{K_t \cdot A} = \sum_{i=1}^{n} \frac{L_i}{K_i \cdot A} \]  \hspace{1cm} (Equation A-16)

or

\[ K_t = \frac{L_t}{\sum_{i=1}^{n} \frac{L_i}{K_i}} \]  \hspace{1cm} (Equation A-17)

where

\[ K_t = \text{Effective conductivity of the system} \]

\[ L_i = \text{Length of flow path for } i^{th} \text{ component} \]

\[ L_t = \text{Total length of flow path } (\sum_{i=1}^{n} L_i) \]

\[ A = \text{Cross-sectional area of the flow path} \]

A6.0 References


APPENDIX B

CALCULATIONS OF PANEL VOLUME CLOSURE
APPENDIX B
CALCULATIONS OF PANEL VOLUME CLOSURE

B.1.0 Introduction

This appendix presents the closure mechanisms and supporting calculations for panel volumetric closure for the analysis of gas pressurization within a closed panel at the WIPP. The volume reduction is due to the panel volume change from viscoplastic creep closure of the walls, roof, and floor. As the walls, roof, and floor of the excavations converge, the total volume of the panel decreases. The volumetric closure of a panel is the result of several different mechanisms working simultaneously. These mechanisms include:

- Viscoplastic creep of the salt toward the excavation
- Fracturing in the roof and floor caused by the deviatoric stresses around the excavation
- Bed separation at the clay seams in the roof and the floor.

The combination of these three mechanisms causes the observed convergence rates in Panels 1 and 2. Of these mechanisms, only creep of the salt reduces the total volume of the panel and pore space in the surrounding disturbed rock zone (DRZ). Fracturing in the roof and floor and bed separation transfer the void volume within the excavation to the DRZ. This void volume within the DRZ is assumed to be interconnected with the open excavation. Therefore the total reduction in volume within the panel, based simply on room closure, overestimates the effective reduction in void volume. However, quantifying the amount of interconnected void space within the DRZ would require a much more detailed analysis. Using the total volume change calculated from the room closure measurements is therefore considered conservative.

Other assumptions made in this calculation are:

- The volumetric closure rates are constant after panel closure.
- The waste in the panel provides no significant resistance to creep closure during the initial 35 years.
- The air volume is the total volume of the excavations minus the solid volume of the waste in drums or other waste packages. The solid volume is estimated to be 3,908 m$^3$ (138,000 ft$^3$) (DOE, 1996).
• The closure rate of each room in the panels equals the closure rate at the mid-width and mid-height of the room.

• The length of each room or drift is constant. To simplify the calculations, only the width and height change with creep closure.

**B.2.0 Panel Volume Change Calculation**

The panel volume change calculation is performed in steps. First, the initial panel volume is calculated, then the room and drift closure rates are calculated, and finally the panel volumetric closure rate is determined. Because the closure rates and the closure history in Panel 2 are different than Panel 1, the volume calculations for each panel are done separately. Following is a detailed description of each part of the calculation for Panel 1 and then for Panel 2.

**B.2.1 Panel 1 Volume Change Calculation**

**B.2.1.1 Initial Panel Volume**

The initial panel volume is determined immediately after completion of excavation. The total volume is calculated by summing the individual room and drift volumes within the panel. These volumes are based on the as-built dimensions of the excavated rooms and drifts in Panel 1 (DOE, 1993). Table B-1 presents the room and drift dimensions and the calculated volume of each room and drift. The total initial volume of Panel 1 is 47,757 m$^3$ (1,686,500 ft$^3$).

The total solid volume of the waste in a filled panel is 3,908 m$^3$ (138,000 ft$^3$) (DOE, 1996). Subtracting the waste volume from the total panel volume gives the total initial void volume (43,850 m$^3$ [1,548,500 ft$^3$]) in the panel.

**B.2.1.2 Closure Rates**

Using convergence data from Panel 1 the average closure rates of the rooms and drifts are determined. Closure rates within the rooms and drifts are higher in the first five years after excavation. When Panel 2 mining began, closure rates in Panel 1 increased about 30% on average. Therefore, three distinct time periods are considered: 0 to 5 years, 6 to 13 years, and beyond 13 years. The roof-to-floor and wall-to-wall closure rates for each of the rooms and drifts are presented in Table B-2.

Because data from the east end of S1600 are not available for the Panel 2 mining period, the rates beyond five years for this area are assumed to be the same as in the west end of S1600 in the panel.
### Table B-1 Initial Room and Drift Dimensions and Volume of Panel 1

<table>
<thead>
<tr>
<th>Room or Drift</th>
<th>Initial Width (m)</th>
<th>Initial Height (m)</th>
<th>Initial Length (m)</th>
<th>Initial Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 1</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
<td>3644</td>
</tr>
<tr>
<td>Room 2</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
<td>3644</td>
</tr>
<tr>
<td>Room 3</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
<td>3644</td>
</tr>
<tr>
<td>Room 4</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
<td>3644</td>
</tr>
<tr>
<td>Room 5</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
<td>3644</td>
</tr>
<tr>
<td>Room 6</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
<td>3644</td>
</tr>
<tr>
<td>Room 7</td>
<td>10.06</td>
<td>4.27</td>
<td>91.44</td>
<td>3925</td>
</tr>
<tr>
<td>S1950: Room 1 to Room 7</td>
<td>10.06</td>
<td>4.27</td>
<td>258.5</td>
<td>11094</td>
</tr>
<tr>
<td>S1950: Access to Room 1</td>
<td>6.10</td>
<td>3.96</td>
<td>12.18</td>
<td>294</td>
</tr>
<tr>
<td>S1600: Room 1 to Room 5</td>
<td>10.06</td>
<td>3.96</td>
<td>174.7</td>
<td>6961</td>
</tr>
<tr>
<td>S1600: Room 5 to Room 7</td>
<td>10.06</td>
<td>4.27</td>
<td>79.86</td>
<td>3428</td>
</tr>
<tr>
<td>S1600: Access to Room 1</td>
<td>4.27</td>
<td>3.66</td>
<td>12.18</td>
<td>190</td>
</tr>
</tbody>
</table>

**Total Initial Panel Volume**: 47757 m³

### Table B-2 Panel 1 Room and Drift Closure Rates

<table>
<thead>
<tr>
<th>Room or Drift</th>
<th>Vertical Closure Rates</th>
<th>Horizontal Closure Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 5 Years (cm/yr)</td>
<td>6 to 13 Years (cm/yr)</td>
</tr>
<tr>
<td></td>
<td>0 to 5 Years (cm/yr)</td>
<td>6 to 13 Years (cm/yr)</td>
</tr>
<tr>
<td>Room 1</td>
<td>9.736</td>
<td>6.234</td>
</tr>
<tr>
<td>Room 3</td>
<td>9.736</td>
<td>5.493</td>
</tr>
<tr>
<td>Room 4</td>
<td>9.736</td>
<td>5.441</td>
</tr>
<tr>
<td>Room 5</td>
<td>9.736</td>
<td>5.345</td>
</tr>
<tr>
<td>Room 6</td>
<td>9.736</td>
<td>5.305</td>
</tr>
<tr>
<td>Room 7</td>
<td>9.736</td>
<td>5.687</td>
</tr>
<tr>
<td>S1950: Room 1 to Room 7</td>
<td>9.736</td>
<td>5.513</td>
</tr>
<tr>
<td>S1950: Access to Room 1</td>
<td>5.878</td>
<td>4.436</td>
</tr>
<tr>
<td>S1600: Room 5 to Room 7</td>
<td>9.736</td>
<td>5.064</td>
</tr>
<tr>
<td>S1600: Room 1 to Room 5</td>
<td>9.736</td>
<td>5.064</td>
</tr>
<tr>
<td>S1600: Access to Room 1</td>
<td>3.478</td>
<td>1.753</td>
</tr>
</tbody>
</table>

**B-3 Rev. 1 10/3/2002**
B.2.1.3 Volumetric Panel Closure Rate

Using the closure rates from Table B-2, the dimensions of the rooms and drifts in Panel 1 can be calculated at the end of each progressive year or for subsequent years using the following equations:

\[ D_t = D_0 - C_5 \]

at five years

\[ D_t = D_0 - C_5 - (t-5)C_{ssa} \]

for years six to thirteen

\[ D_t = D_0 - C_5 - 8C_{ssa} - (t-13)C_{ssa} \]

for years > thirteen

where:

\[ t \]

= Number of years since excavation

\[ D_t \]

= Magnitude of the dimension (height or width) after year \( t \)

\[ D_0 \]

= Original magnitude of the dimension

\[ C_5 \]

= Total convergence in the direction of the dimension after the first five years

\[ C_{ssa} \]

= Steady-state convergence rate of the dimension before Panel 2 mining

\[ C_{ssa} \]

= Steady-state convergence rate of the dimension after Panel 2 mining

The dimension cannot go below zero. The length is assumed to remain constant. The volume is then calculated as:

\[ V_t = H_t \cdot W_t \cdot L \]

where:

\[ V_t \]

= Volume of a section after year \( t \)

\[ H_t \]

= Height of a section after year \( t \)

\[ W_t \]

= Width of a section after year \( t \)

\[ L \]

= Length of a section (constant)

The total volume for the panel is calculated by summing the volumes of the individual sections as follows:
\[ \dot{V}_{Pt} = \sum_{i=1}^{n} (V_t)_i - V_w \]

where:

- \( V_{Pt} \) = Volume of the entire panel, less the volume of the waste, after year \( t \)
- \( n \) = Number of sections
- \( V_w \) = Volume of the solids in the waste

The volume versus time for Panel 1 is shown graphically in Figure B-1 and in tabular form in Table B-3. The average annual volume loss was found to be 790 cubic meters (27900 ft³) per year.

**B.2.2 Panel 2 Volume Change Calculation**

The calculation of volume change for Panel 2 differs slightly from that of Panel 1, primarily because only about two years' data is available to date from Panel 2. Panel 2 was subdivided slightly differently than Panel 1 due to its different instrument layout.

**B.2.2.1 Initial Panel 2 Volume**

Table B-4 presents the room and drift initial dimensions and the calculated initial volume of each room and drift. The total initial volume of Panel 2 is 46,166 m³ (1,630,300 ft³). Subtracting the waste volume from the total panel volume gives the total initial void volume (42,258 m³ [1,492,300 ft³]) in the panel.

**B.2.2.2 Panel 2 Closure Rates**

Using convergence data from Panel 2, the average closure rates of the rooms and drifts are determined. Due to the relatively short time since excavation in Panel 2, two rate periods were used: 0 to 1 years and beyond 1 year. This assumes that the rate calculated for the second year after excavation is the long-term steady-state rate. Because it usually takes about two years to reach steady-state, the values used here are likely to overestimate the long-term rates. The roof-to-floor and wall-to-wall closure rates for each of the rooms and drifts are presented in Table B-5.
Figure B-1 Panel 1 Volume versus Time
<table>
<thead>
<tr>
<th>Year</th>
<th>Volume (m³)</th>
<th>Year (cont'd)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>43849.77</td>
<td>28</td>
<td>16599.56</td>
</tr>
<tr>
<td>5</td>
<td>36744.52</td>
<td>29</td>
<td>15724.08</td>
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<tr>
<td>6</td>
<td>35980.50</td>
<td>30</td>
<td>14857.13</td>
</tr>
<tr>
<td>7</td>
<td>35220.91</td>
<td>31</td>
<td>13998.73</td>
</tr>
<tr>
<td>8</td>
<td>34465.74</td>
<td>32</td>
<td>13148.86</td>
</tr>
<tr>
<td>9</td>
<td>33715.00</td>
<td>33</td>
<td>12307.53</td>
</tr>
<tr>
<td>10</td>
<td>32968.69</td>
<td>34</td>
<td>11474.74</td>
</tr>
<tr>
<td>11</td>
<td>32226.81</td>
<td>35</td>
<td>10650.49</td>
</tr>
<tr>
<td>12</td>
<td>31489.35</td>
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<td>9834.775</td>
</tr>
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<td>13</td>
<td>30756.33</td>
<td>37</td>
<td>9027.598</td>
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<tr>
<td>14</td>
<td>29752.78</td>
<td>38</td>
<td>8228.958</td>
</tr>
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<td>28757.76</td>
<td>39</td>
<td>7438.857</td>
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<td>27771.29</td>
<td>40</td>
<td>6657.294</td>
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<tr>
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<td>26793.35</td>
<td>41</td>
<td>5884.269</td>
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<tr>
<td>18</td>
<td>25823.95</td>
<td>42</td>
<td>5166.191</td>
</tr>
<tr>
<td>19</td>
<td>24863.09</td>
<td>43</td>
<td>4642.604</td>
</tr>
<tr>
<td>20</td>
<td>23910.77</td>
<td>44</td>
<td>4124.191</td>
</tr>
<tr>
<td>21</td>
<td>22966.99</td>
<td>45</td>
<td>3610.953</td>
</tr>
<tr>
<td>22</td>
<td>22031.74</td>
<td>46</td>
<td>3102.889</td>
</tr>
<tr>
<td>23</td>
<td>21105.03</td>
<td>47</td>
<td>2599.999</td>
</tr>
<tr>
<td>24</td>
<td>20186.86</td>
<td>48</td>
<td>2102.285</td>
</tr>
<tr>
<td>25</td>
<td>19277.23</td>
<td>49</td>
<td>1609.744</td>
</tr>
<tr>
<td>26</td>
<td>18376.13</td>
<td>50</td>
<td>1122.378</td>
</tr>
<tr>
<td>27</td>
<td>17483.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room or Drift</td>
<td>Initial Width (m)</td>
<td>Initial Height (m)</td>
<td>Initial Length (m)</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Room 1</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
</tr>
<tr>
<td>Room 2</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
</tr>
<tr>
<td>Room 3</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
</tr>
<tr>
<td>Room 4</td>
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<td>Room 5</td>
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<td>3.96</td>
<td>91.44</td>
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<tr>
<td>Room 6</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
</tr>
<tr>
<td>Room 7</td>
<td>10.06</td>
<td>3.96</td>
<td>91.44</td>
</tr>
<tr>
<td>S2180: Room 1 to west rib Room 2</td>
<td>10.06</td>
<td>3.96</td>
<td>40.54</td>
</tr>
<tr>
<td>S2520: Room 1</td>
<td>10.06</td>
<td>3.96</td>
<td>40.54</td>
</tr>
<tr>
<td>S2180: Room 2 to mid Room 3/4 pillar</td>
<td>10.06</td>
<td>3.96</td>
<td>65.84</td>
</tr>
<tr>
<td>S2520: East rib of Room 1 to mid Room 2/3 pillar</td>
<td>10.06</td>
<td>3.96</td>
<td>55.78</td>
</tr>
<tr>
<td>S2520: Mid Room 2/3 pillar to mid Room 3/4 pillar</td>
<td>10.06</td>
<td>3.96</td>
<td>40.54</td>
</tr>
<tr>
<td>S2180: Mid Room 3/4 pillar to east rib Room 4</td>
<td>10.06</td>
<td>3.96</td>
<td>25.30</td>
</tr>
<tr>
<td>S2520: Mid Room 3/4 pillar mid Room 5/6 pillar</td>
<td>10.06</td>
<td>3.96</td>
<td>81.08</td>
</tr>
<tr>
<td>S2180: East rib Room 4 to mid Room 5/6 pillar</td>
<td>10.06</td>
<td>3.96</td>
<td>55.78</td>
</tr>
<tr>
<td>S2520: Mid Room 5/6 pillar to east rib Room 6</td>
<td>10.06</td>
<td>3.96</td>
<td>25.30</td>
</tr>
<tr>
<td>S2180: Mid Room 5/6 pillar to Room 7</td>
<td>10.06</td>
<td>3.96</td>
<td>65.84</td>
</tr>
<tr>
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<td>10.06</td>
<td>3.96</td>
<td>40.54</td>
</tr>
<tr>
<td>S2180: Access to west rib Room 1</td>
<td>4.27</td>
<td>3.66</td>
<td>12.18</td>
</tr>
<tr>
<td>S2520: Access to west rib Room 1</td>
<td>6.10</td>
<td>3.96</td>
<td>12.18</td>
</tr>
<tr>
<td>Total Initial Panel Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Abbreviations/Acronyms

ACI  American Concrete Institute  
ANSI  American National Standards Institute  
ASTM  American Society for Testing and Materials  
CFR  Code of Federal Regulations  
CQCP  Contractor Quality Control Plan  
DOE  U.S. Department of Energy  
DWG  Drawing  
EPA  U.S. Environmental Protection Agency  
HASP  Health And Safety Plan  
JHA  Job Hazard Analysis  
LHD  Load Haul Dump  
LLC  Limited Liability Corporation  
MSHA  U.S. Mine Safety and Health Administration  
RCRA  Resource Conservation and Recovery Act  
USACE  U.S. Army Corps of Engineers  
VOC  Volatile Organic Compound  
WIPP  Waste Isolation Pilot Plant

1.4 List of Drawings
The following Drawings are made apart of this Specification:

DWG 110-CD001  Panel closure system, title sheet  
DWG 110-CD002  Panel closure system, underground waste disposal panel configuration  
DWG 110-CD003  Panel closure system, construction details
1.5 Work by Others

Survey

All survey work to locate, control, confirm, and complete the work will be performed by Westinghouse. All survey work for record purposes will be performed by Westinghouse. The Contractor shall be responsible for developing the concrete block wall to fit the excavation.

Other

Westinghouse may elect to perform certain portions, or all, of the work. The work performed by the Westinghouse will be defined prior to the contract. Unless otherwise agreed by Westinghouse, the Contractor shall use underground equipment furnished by Westinghouse for construction of the explosion isolation walls and placement of the run of mine salt. Underground mining personnel who are qualified for the operation of such underground construction equipment may be made available to the Contractor. The use of Westinghouse equipment shall be coordinated with Westinghouse.

1.6 Contractor’s Use of Site

Site Conditions

The site is located near Carlsbad, New Mexico, as shown on the Drawings. The underground arrangements and location of the WIPP waste disposal panels are shown on the Drawings. The work is to construct the explosion isolation walls and place run of mine salt in the air-intake and air-exhaust drifts of one of the panels upon completion of the disposal phase of that panel. The waste disposal panels are located approximately 2,150 ft (655 m) below the ground surface. The Contractor shall visit the site and become familiar with the site and site conditions prior to preparing his bid proposal.

Contractor’s Use of Site

Areas at the ground surface will be designated for the Contractor’s use in assembling and storing his equipment and materials. The Contractor shall utilize only those areas designated.

Limited space within the underground area will be designated for the Contractor’s use for storage of material and setup of equipment.
Coordination of Contractor's Work

The Contractor is advised that on-going waste emplacement and excavation operations will be conducted throughout the period of construction of the panel closure system. These operations have priority over the Contractor's work. The Contractor shall coordinate his construction operations with that of the waste emplacement and mining operations. All coordination shall be through Westinghouse.

1.7 Contractor's Use of Facilities

Existing facilities at the site available for use by the Contractor are:

- Waste shaft conveyance
- Salt skip hoist
- 460 volt AC, 3 phase power
- Water (underground, at waste shaft only) (above ground, at location designated by Westinghouse)

Additional information on these facilities is presented in Section 02010.

1.8 Work Sequence

Work Sequence shall be as shown on the Drawings and as directed by Westinghouse.

1.9 Work Plan

The Contractor shall prepare a Work Plan fully describing his proposed construction operation. The work plan shall define all proposed equipment and methods. Westinghouse shall approve the Work Plan and no work shall be performed prior to approval of the Work Plan.

1.10 Health and Safety Plan (HASP)

The Contractor shall obtain, review, and agree to applicable portions of the existing WIPP Safety Manual, WP 12-1. The Contractor shall prepare a project-specific HASP taking into account all applicable sections of the WIPP Safety Manual. All personnel shall be qualified to work underground. All personnel operating heavy construction equipment shall be qualified to operate such equipment. The Contractor shall also perform a Job Hazard Analysis (JHA) in accordance with WP 12-111. Westinghouse shall approve the HASP and JHA and no work shall be performed prior to approval of the HASP and JHA.
1.11 Contractor Quality Control Plan (CQCP)

The Contractor shall prepare a CQCP identifying all personnel and procedures necessary to produce an end product, which complies with the contract requirements. The CQCP shall comply with all Westinghouse requirements, including operator training and qualification; and Section 01400, Contractor Quality Control, of this Specification. Westinghouse shall approve the CQCP and no work shall be performed prior to approval of the CQCP.

1.12 Submittals

Submittals shall be in accordance with Westinghouse Submittal Procedures and as required by the individual Specifications.

PART 2 - PRODUCTS

Not used

PART 3 - EXECUTION

Not used

End of section
SECTION 01090
REFERENCE STANDARDS
PART 1 - GENERAL

1.1 Scope
This section includes:

- Provision of Reference Standards at Site
- Acronyms used in Contract Documents for Reference Standards

1.2 Quality Assurance
For products or workmanship specified by association, trade, or Federal Standards, the Contractor shall comply with requirements of the standard, except when more rigid requirements are specified or are required by applicable codes.

Conform to reference by date of issue current on the date of the owner-contractor agreement.

The Contractor shall obtain, at his own expense, a copy of the standards referenced in the individual Specification sections and shall maintain that copy at the jobsite until completion and acceptance of the work.

Should specified Reference Standards conflict with the contract documents, the Contractor shall request clarification from Westinghouse before proceeding.

1.3 Schedule of References
Various publications referenced in other sections of the Specifications establish requirements for the work. These references are identified by document number and title. The addresses of the organizations responsible for these publications are listed below.

ACI
ACI International
P.O. Box 9094
Farmington Hills, MI 48333
Ph: 248-848-3700
NIST
National Institute of Standards and Technology
100 Bureau Drive, Stop 3460
Gaithersburg, MD 20899-3460
Ph: 301-975-6478
Fax: 301-975-8295

NRMCA
National Ready-Mixed Concrete Association
900 Spring St
Silver Spring, MD 20910
Ph: 301-587-1400
Fax: 301-585-4219

NTIS
National Technical Information Service
U.S. Department of Commerce
Springfield, VA 22161
Ph: 703-605-6000
Fax: 703-321-8547

PCA
Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60077
Ph: 847-966-6200
Fax: 847-966-8389

End of section
1.1 Scope
This section includes:

- Contractor Quality Control Plan (CQCP)
- Reference Standards
- Quality Assurance
- Tolerances
- Testing Services
- Inspection Services
- Submittals

1.2 Related Sections
- 01090 - Reference Standards
- 01600 - Material and Equipment
- 02222 - Excavation
- 03100 - Mortar
- 03300 - Unit Masonry System
- 03400 - Masonry Explosion Isolation Structure
- 04100 - Salt Backfill

1.3 Contractor Quality Control Plan (CQCP)
The Contractor shall prepare a Contractor Quality Control Plan (CQCP), as described in Part 3. No work shall be performed prior to Westinghouse approval of the CQCP.

1.4 Reference Standards
Refer to individual Specification sections for standards referenced therein, and to Section 01090, Reference Standards, for general listing.

Standards referenced in this section are as follows:

ASTM C 1077-02  Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
1.5 Quality Assurance

The Contractor shall:

- Monitor suppliers, manufacturers, products, services, site conditions, and workmanship to produce work of specified quality
- Comply with specified standards as minimum quality for the work except where more stringent tolerances, codes, or specified requirements indicate higher standards or more precise workmanship
- Perform work with qualified persons to produce required and specified quality

1.6 Tolerances

The Contractor shall:

- Monitor excavation, fabrication, and tolerances in order to produce acceptable work. The Contractor shall not permit tolerances to accumulate.

1.7 Testing Services

Unless otherwise agreed by Westinghouse, the Contractor shall employ an independent firm qualified to perform the testing services and other services specified in the individual Specification sections, and as may otherwise be required by Westinghouse. Testing and source quality control may occur on or off the project site.

The testing laboratory shall comply with applicable sections of the Reference Standards and shall be authorized to operate in the State of New Mexico.

Testing equipment shall be calibrated at reasonable intervals traceable to either the National Institute of Standards and Technology or accepted values of natural physical constants.
<table>
<thead>
<tr>
<th>Room or Drift</th>
<th>Vertical Closure Rates</th>
<th></th>
<th>Horizontal Closure Rates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 1 Years (cm/yr)</td>
<td>&gt; 1 Years (cm/yr)</td>
<td>0 to 1 Years (cm/yr)</td>
<td>&gt; 1 Years (cm/yr)</td>
</tr>
<tr>
<td>Room 1</td>
<td>17.19</td>
<td>9.375</td>
<td>12.14</td>
<td>6.246</td>
</tr>
<tr>
<td>Room 2</td>
<td>10.14</td>
<td>9.375</td>
<td>14.85</td>
<td>6.113</td>
</tr>
<tr>
<td>Room 3</td>
<td>17.51</td>
<td>8.432</td>
<td>15.39</td>
<td>5.957</td>
</tr>
<tr>
<td>Room 4</td>
<td>20.19</td>
<td>8.923</td>
<td>16.74</td>
<td>6.341</td>
</tr>
<tr>
<td>Room 5</td>
<td>18.41</td>
<td>7.855</td>
<td>14.98</td>
<td>5.495</td>
</tr>
<tr>
<td>Room 6</td>
<td>12.21</td>
<td>7.672</td>
<td>14.08</td>
<td>5.488</td>
</tr>
<tr>
<td>Room 7</td>
<td>13.10</td>
<td>8.548</td>
<td>11.33</td>
<td>5.106</td>
</tr>
<tr>
<td>S2180: Room 1 to west rib Room 2</td>
<td>19.25</td>
<td>8.723</td>
<td>6.19</td>
<td>6.323</td>
</tr>
<tr>
<td>S2520: Room 1</td>
<td>11.66</td>
<td>7.633</td>
<td>15.78</td>
<td>5.562</td>
</tr>
<tr>
<td>S2520: East rib of Room 1 to mid Room 2/3 pillar</td>
<td>25.26</td>
<td>9.458</td>
<td>15.78</td>
<td>5.562</td>
</tr>
<tr>
<td>S2520: Mid Room 2/3 pillar to Mid Room 3/4 pillar</td>
<td>22.13</td>
<td>8.806</td>
<td>15.68</td>
<td>5.797</td>
</tr>
<tr>
<td>S2180: Mid Room 3/4 pillar to east rib Room 4</td>
<td>24.30</td>
<td>10.756</td>
<td>13.91</td>
<td>6.323</td>
</tr>
<tr>
<td>S2520: Mid Room 3/4 pillar mid Room 5/6 pillar</td>
<td>20.44</td>
<td>8.406</td>
<td>15.68</td>
<td>5.797</td>
</tr>
<tr>
<td>S2180: East rib Room 4 to mid Room 5/6 pillar</td>
<td>18.10</td>
<td>9.463</td>
<td>13.91</td>
<td>6.323</td>
</tr>
<tr>
<td>S2520: Mid Room 5/6 pillar to east rib Room 6</td>
<td>12.75</td>
<td>8.189</td>
<td>10.60</td>
<td>4.666</td>
</tr>
<tr>
<td>S2180: Mid Room 5/6 pillar to Room 7</td>
<td>12.08</td>
<td>7.065</td>
<td>12.20</td>
<td>4.832</td>
</tr>
<tr>
<td>S2520: East rib Room 6 to Room 7</td>
<td>11.36</td>
<td>6.824</td>
<td>10.60</td>
<td>4.666</td>
</tr>
<tr>
<td>S2180: Access to west rib Room 1</td>
<td>6.92</td>
<td>4.266</td>
<td>7.12</td>
<td>4.358</td>
</tr>
<tr>
<td>S2520: Access to west rib Room 1</td>
<td>7.39</td>
<td>5.102</td>
<td>11.06</td>
<td>5.804</td>
</tr>
</tbody>
</table>
**B.2.2.3 Volumetric Panel Closure Rate**

Using the closure rates from Table B-4, the dimensions of the rooms and drifts in Panel 2 can be calculated at the end of each progressive year or for subsequent years using the following equations:

\[
D_t = D_0 - C_1 \quad \text{after the first year}
\]

\[
D_t = D_0 - C_1 - C_2 \quad \text{after the second year}
\]

\[
D_t = D_0 - C_1 - C_2 - (t - 2)C_{ss} \quad \text{for years > two}
\]

where:

- \( t \) = Number of years since excavation
- \( D_t \) = Magnitude of the dimension (height or width) after year \( t \)
- \( D_0 \) = Original magnitude of the dimension
- \( C_1 \) = Total convergence in the direction of the dimension after the first year
- \( C_2 \) = Total convergence in the direction of the dimension during the second year
- \( C_{ss} \) = Steady-state convergence rate of the dimension

The volume is then calculated as for Panel 1 (Section B.2.1.3). The volume versus time for Panel 2 is shown graphically in Figure B-2 and in tabular form in Table B-6. The average annual volume loss was found to be 989 m\(^3\) (34,930 ft\(^3\)) per year.

**B.2.3 Average Volumetric Panel Closure Rate**

In the current analyses, the volume closure rate is taken as the average of the volume closure rates of Panels 1 and 2 that is 890 m\(^3\) (31,430 ft\(^3\)) per year. Also, the void volume of Panel 2 (42,258 m\(^3\)) is taken as typical of all panels.

**B.3.0 References**

Figure B-2  Panel 2 Volume versus Time
Table B-6 Panel 2 Volume

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume (m³)</th>
<th>Year (cont'd)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>42,258</td>
<td>21</td>
<td>17,232</td>
</tr>
<tr>
<td>1</td>
<td>39,706</td>
<td>22</td>
<td>16,229</td>
</tr>
<tr>
<td>2</td>
<td>38,487</td>
<td>23</td>
<td>15,237</td>
</tr>
<tr>
<td>3</td>
<td>37,264</td>
<td>24</td>
<td>14,257</td>
</tr>
<tr>
<td>4</td>
<td>36,053</td>
<td>25</td>
<td>13,289</td>
</tr>
<tr>
<td>5</td>
<td>34,853</td>
<td>26</td>
<td>12,332</td>
</tr>
<tr>
<td>6</td>
<td>33,665</td>
<td>27</td>
<td>11,387</td>
</tr>
<tr>
<td>7</td>
<td>32,489</td>
<td>28</td>
<td>10,453</td>
</tr>
<tr>
<td>8</td>
<td>31,324</td>
<td>29</td>
<td>9,531</td>
</tr>
<tr>
<td>9</td>
<td>30,170</td>
<td>30</td>
<td>8,620</td>
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<td>10</td>
<td>29,029</td>
<td>31</td>
<td>7,721</td>
</tr>
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<td>27,898</td>
<td>32</td>
<td>6,834</td>
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<td>12</td>
<td>26,780</td>
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<td>5,958</td>
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</tr>
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<td>14</td>
<td>24,577</td>
<td>35</td>
<td>4,241</td>
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<tr>
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<td>23,493</td>
<td>36</td>
<td>3,409</td>
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<td>22,420</td>
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<td>21,360</td>
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<td>1,803</td>
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<td>18</td>
<td>20,310</td>
<td>39</td>
<td>1,016</td>
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<td>19</td>
<td>19,272</td>
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<td>20</td>
<td>18,246</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C

FLAC MODELING OF THE WIPP PANEL CLOSURE SYSTEM
APPENDIX C
FLAC MODELING OF THE WIPP PANEL CLOSURE SYSTEM

Numerical modeling is considered here for quantifying the interaction of block wall with the surrounding rock salt. A series of models were developed to evaluate the interaction of the panel closure system with the surrounding salt. This appendix discusses the code used and describes the material constitutive models used in the stress analysis.

All calculations were performed in accordance with the RockSol Consulting Group, Inc., Quality Assurance Program and comply with Westinghouse TRU Solutions requirements. These constitute quality records and are maintained in accordance with WIPP procedures. These records include verification and validation documents.

C.1.0 FLAC Code
FLAC software has been used for numerical modeling of the underground excavations at the Waste Isolation Pilot Plant (WIPP) since 1991. FLAC (Itasca, 2000) is a finite difference code that simulates the behavior of rock and soil-like structures. The WIPP Reference Creep Law is built into FLAC. The version of FLAC (Version 4.00) used for the panel closure system modeling has been verified against the WIPP Second Benchmark Problem (Krieg, 1984).

C.2.0 Material Constitutive Models
The material properties associated with the material constitutive models are given in Tables C-1 through C-3. These are standard properties used in a wide variety of previous WIPP geotechnical FLAC modeling. The halite properties are based on Krieg (1984). The Mohr-Coulomb model was used for block wall and its properties were calculated using Atkinson et al. (1989) and Ahmed and Drysdale (1988) and ACI 530.1-95. The block wall has a minimum compressive strength of 5000 psi (34.5 MPa) (Appendix D).

C.3.0 References

Table C-1 Halite Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk modulus (GPa)</td>
<td>20.7</td>
</tr>
<tr>
<td>Shear modulus (GPa)</td>
<td>12.4</td>
</tr>
<tr>
<td>Density (km/m³)</td>
<td>2,300</td>
</tr>
<tr>
<td>Activation energy (cal/mol)</td>
<td>12,000</td>
</tr>
<tr>
<td>A</td>
<td>4.56</td>
</tr>
<tr>
<td>B</td>
<td>127</td>
</tr>
<tr>
<td>D (Pa^n/s)</td>
<td>5.79×10⁻³⁶</td>
</tr>
<tr>
<td>n</td>
<td>4.9</td>
</tr>
<tr>
<td>Universal Gas constant (cal/(mol . K))</td>
<td>1.987</td>
</tr>
<tr>
<td>Critical strain rate (1/s)</td>
<td>5.39×10⁻⁶⁸</td>
</tr>
</tbody>
</table>

Table C-2 Concrete Material Properties

<table>
<thead>
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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk modulus (GPa)</td>
<td>11.6</td>
</tr>
<tr>
<td>Shear modulus (GPa)</td>
<td>9.0</td>
</tr>
<tr>
<td>Density (kg/m3)</td>
<td>2,300</td>
</tr>
<tr>
<td>Friction angle (degrees)</td>
<td>35</td>
</tr>
<tr>
<td>Cohesion (MPa)</td>
<td>9.1</td>
</tr>
<tr>
<td>Tension cut-off (MPa)</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Table C-3  Clay Seam, Rock/Concrete Contact, and Construction Joint Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal stiffness (Pa/m)</td>
<td>$1.0 \times 10^{12}$</td>
</tr>
<tr>
<td>Shear stiffness (Pa/m)</td>
<td>$5.0 \times 10^{10}$</td>
</tr>
<tr>
<td>Cohesion (Pa)</td>
<td>0.0</td>
</tr>
<tr>
<td>Friction (degrees)</td>
<td>30</td>
</tr>
</tbody>
</table>
APPENDIX D
TECHNICAL SPECIFICATIONS
SECTION 01010
SUMMARY OF WORK
PART 1 - GENERAL

1.1 Scope
This section includes:

- Scope of Work
- Definitions and Abbreviations
- List of Drawings
- Work by Others
- Contractor’s Use of Site
- Contractor’s Use of Facilities
- Work Sequence
- Work Plan
- Health and Safety Plan (HASP)
- Contractor Quality Control Plan (CQCP)
- Submittals

1.2 Scope of Work
The Contractor shall furnish all labor, materials, equipment and tools to construct two (2) panel closure systems. The closure system consists of an explosion isolation wall and run of mine salt backfill, one of each to be installed in the air-intake drift and the air-exhaust drift of a waste disposal panel, as shown on the Drawings and described in these Specifications. Unless otherwise agreed by Westinghouse, the Contractor shall use Westinghouse supplied equipment underground. Such use shall be coordinated with Westinghouse and may include the use of Westinghouse qualified operators.

The scope of work shall include but not necessarily be limited to the following units of work:

- Develop work plan, health and safety plan (HASP) and contractors quality control plan (CQCP)
- Prepare and submit all plans requiring approval
- Mobilize to site
- Coordinate construction with WIPP operations
• Perform the following for the air-intake entry and the air-exhaust entry:
  - Prepare the surfaces for the explosion isolation wall
  - Construct the explosion isolation wall
  - Place run of mine salt material
• Clean up construction areas in underground and above ground
• Submit all required record documents
• Demobilize from site

1.3 Definitions and Abbreviations

Definitions

Concrete masonry units—Concrete blocks used for construction of the explosion isolation wall.

Creep—Viscoplastic deformation of salt under deviatoric stress.

Explosion isolation wall—A mortared concrete block wall adjacent to the panel waste disposal area that can sustain the pressure and temperature transients of a methane explosion.

Methane explosion—A postulated deflagration caused by methane gas at an explosive level.

Partial closure—The process of rendering a part of the hazardous waste management unit in the underground repository inactive and closed according to approved facility closure plans.

Volatile Organic Compound (VOC)—Any VOC with Hazardous Waste Facility Permit emission limits.

Westinghouse—Westinghouse TRU Solutions, LLC as the construction management authority.
1.8 Inspection Services
The Contractor may employ an independent firm to perform inspection services as a supplement to the Contractor's quality control as specified in the individual Specification sections, and as may be required by Westinghouse. Inspection may occur on or off the project site.

The inspection firm shall comply with applicable sections of the Reference Standards.

1.9 Submittals
The Contractor shall submit a CQCP as described herein.

Prior to start of work, the Contractor shall submit for approval, the testing laboratory name, address, telephone number and name of responsible officer of the firm as well as a copy of the testing laboratory compliance with the reference ASTM standards and a copy of report of laboratory facilities inspection made by Materials Reference Laboratory of National Institute of Standards and Technology with memorandum of remedies of any deficiencies reported by the inspection.

The Contractor shall submit the names and qualifications of personnel proposed to perform the required inspections, along with their individual qualifications and certifications. Once approved by Westinghouse these personnel shall be available as may be required to promptly and efficiently complete the work.

**PART 2 - PRODUCTS**

Not used

**PART 3 - EXECUTION**

3.1 General
The Contractor is responsible for quality control and shall establish and maintain an effective quality control system. The quality control system shall consist of plans, procedures, and organization necessary to produce an end product which complies with the contract requirements. The system shall cover all construction operations, both on site and off site, and shall be keyed to the proposed construction sequence. The project superintendent will be held responsible for the quality of work on the job. The project superintendent in this context is the individual with the responsibility for the overall management of the project including quality and production.
3.2 Contractor Quality Control Plan

3.2.1 General
The Contractor shall supply, not later than 30 days after receipt of notice to proceed, the Contractor Quality Control Plan (CQCP) which implements the requirements of the Contract. The CQCP shall identify personnel, procedures, control, instructions, tests, records, and forms to be used. Construction shall not begin until the CQCP is approved by Westinghouse.

3.2.2 Content of the CQCP
The CQCP shall cover all construction operations, both on site and off site, including work by subcontractors, fabricators, suppliers, and purchasing agents and shall include, as a minimum, the following items:

- A description of the quality control organization, including a chart showing lines of authority and acknowledgment that the Contractor Quality Control (CQC) staff shall implement the control system for all aspects of the work specified.
- The name, qualifications (in resume format), duties, responsibilities, and authorities of each person assigned a CQC function.
- A description of CQCP responsibilities and a delegation of authority to adequately perform the functions described in the CQCP, including authority to stop work.
- Procedures for scheduling, reviewing, certifying, and managing submittals, including those of subcontractors, off site fabricators, suppliers, and purchasing agents. These procedures shall be in accordance with Westinghouse Submittal Procedures.
- Control, verification, and acceptance testing procedures as may be necessary to ensure that the work is completed to the requirements of the Drawings and Specifications.
- Procedures for tracking deficiencies from identification, through acceptable corrective action, to verification that identified deficiencies have been corrected.
- Reporting procedures, including proposed reporting formulas.

3.2.3 Acceptance of Plan
Acceptance of the Contractor's plan is conditional. Westinghouse reserves the right to require the Contractor to make changes in his CQCP and operations, including removal of personnel, if necessary, to obtain the quality specified.

3.2.4 Notification of Changes
After acceptance of the CQCP, the Contractor shall notify Westinghouse in writing of any proposed change. Proposed changes are subject to acceptance by Westinghouse.
3.3. Tests

3.3.1 Testing Procedure
The Contractor shall perform specified or required tests to verify that control measures are adequate to complete the work to contract requirements. Upon request, the Contractor shall furnish, at his own expense, duplicate samples of test specimens for testing by Westinghouse. The Contractor shall perform, as necessary, the following activities and permanently record the results:

- Verify that testing procedures comply with contract requirements.
- Verify that facilities and testing equipment are available and comply with testing standards.
- Check test instrument calibration data against certified standards.
- Verify that recording forms and test identification control number system, including all of the test documentation requirements, have been prepared.
- Record the results of all tests taken, both passing and failing. Specification paragraph reference, location where tests were taken, and the sequential control number identifying the test will be given. If approved by Westinghouse, actual test reports may be submitted later with a reference to the test number and date taken. An information copy of tests performed by an off site or commercial test facility will be provided directly to Westinghouse.

3.4 Testing Laboratory
The testing laboratory shall provide qualified personnel to perform specified sampling and testing of products in accordance with specified standards, and the requirements of Contract Documents.

Reports indicating results of tests, and compliance or noncompliance with the contract documents will be submitted in accordance with Westinghouse submittal procedures. Testing by an independent firm does not relieve the Contractor of the responsibility to perform the work to the contract requirements.

3.5 Inspection Services
The inspection firm shall provide qualified personnel to perform specified inspection of products in accordance with specified standards.
Reports indicating results of the inspection and compliance or noncompliance with the contract documents will be submitted in accordance with Westinghouse submittal procedures.

Inspection by the independent firm does not relieve the Contractor of the responsibility to perform the work to the contract requirements.

3.6 Completion Inspection

3.6.1 Pre-Final Inspection

At appropriate times and at the completion of all work, the Contractor shall conduct an inspection of the work and develop a punch list of items which do not conform to the Drawings and Specifications. The Contractor shall then notify Westinghouse that the work is ready for inspection. Westinghouse will perform this inspection to verify that the work is satisfactory and appropriately complete. A final punch list will be developed as a result of this inspection. The Contractor shall ensure that all items on this list are corrected and notify Westinghouse so that a final inspection can be scheduled. Any items noted on the final inspection shall be corrected in a timely manner. These inspections and any deficiency corrections required by this paragraph will be accomplished within the time slated for completion of the entire work.

3.6.2 Final Acceptance Inspection

The final acceptance inspection will be formally scheduled by Westinghouse based upon notice from the Contractor. This notice will be given to Westinghouse at least 14 days prior to the final acceptance inspection. The Contractor shall assure that all specific items previously identified as unacceptable, along with all remaining work performed under the contract, will be complete and acceptable by the date scheduled for the final acceptance inspection.

3.7 Documentation

The Contractor shall maintain current records providing factual evidence that required quality control activities and/or tests have been performed. These records shall include the work of subcontractors and suppliers and shall be on an acceptable form approved by Westinghouse.

3.8 Notification of Noncompliance

Westinghouse will notify the Contractor of any noncompliance with the foregoing requirements. The Contractor shall take immediate corrective action after receipt of such notice. Such notice, when delivered to the Contractor at the worksite, shall be deemed sufficient for the purpose of notification. If the Contractor fails or refuses to comply promptly, Westinghouse may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part
of the time lost due to such stop orders shall be made the subject of claim for extension of time or for excess costs or damages by the Contractor.

End of section
1.1 Scope
This section includes:

- Equipment
- Products
- Transportation and Handling
- Storage and Protection
- Substitutions

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 02010 - Mobilization and Demobilization
- 02222 - Excavation
- 03100 - Mortar
- 03300 - Unit Masonry System
- 03400 - Masonry Explosion Isolation Structure
- 04100 - Salt Backfill

1.3 Equipment
The Contractor shall specify his proposed equipment in the Work Plan. Power equipment for use underground shall be either electrical or diesel engine driven. All diesel engine equipment shall be certified for use underground at the WIPP site.

1.4 Products
The Contractor shall specify in the Work Plan, or in subsequently required submittals, the proposed products including, but not limited to, the mortar mix and its components, masonry blocks, and run of mine salt. The proposed products shall be supported by laboratory test results as required by the Specifications. All products shall be subject to approval by Westinghouse.
1.5 Transportation and Handling

The Contractor shall:

- Transport and handle products in accordance with manufacturer's instructions.
- Promptly inspect shipments to ensure that products comply with requirements, quantities are correct, and products are undamaged.
- Provide equipment and personnel to handle products by methods to prevent soiling, disfigurement, or damage.

1.6 Storage and Protection

The Contractor shall:

- Store and protect products in accordance with manufacturers' instructions.
- Store with seals and labels intact and legible.
- Store sensitive products in weather tight, climate controlled, enclosures in an environment favorable to product.
- Provide ventilation to prevent condensation and degradation of products.
- Store loose granular materials on solid flat surfaces in a well-drained area and prevent mixing with foreign matter.
- Provide equipment and personnel to store products by methods to prevent soiling, disfigurement, or damage.
- Arrange storage of products to permit access for inspection and periodically inspect to verify products are undamaged and are maintained in acceptable condition.

1.7 Substitutions

1.7.1 Equipment Substitutions

The Contractor may substitute equipment for that proposed in the Work Plan subject to Westinghouse approval.

1.7.2 Product Substitutions

The Contractor may not substitute products after the proposed products have been approved by Westinghouse unless he can demonstrate that the supplier/source of that product no longer exists in which case he shall submit alternate products with lab test results to Westinghouse for approval. In the case that product is a component in a mix, the Contractor shall perform mix testing using that component and submit laboratory test results.
PART 2 – PRODUCTS
Not used

PART 3 - EXECUTION
Not used

End of section
SECTION 02010
MOBILIZATION AND DEMOBILIZATION
PART 1 - GENERAL

1.1 Scope
This section includes:

- Mobilization of Equipment and Facilities to Site
- Contractor Use of Site
- Use of Existing Facilities
- Demobilization of Equipment and Facilities
- Site Cleanup

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment

PART 2 - PRODUCTS
Not used

PART 3 - EXECUTION

3.1 Mobilization of Equipment and Facilities to Site
Upon authorization to proceed, the Contractor shall mobilize his equipment and facilities to the jobsite. Equipment and facilities shall be as specified and as defined in the Contractor's Work Plan.

Westinghouse will provide utilities at designated locations. The Contractor shall be responsible for all hookups and tie-ins required for his operations.

The Contractor shall be responsible for providing his own office, storage, and sanitary facilities.

Areas will be designated for the Contractor's use in the underground area in the vicinity of the panel closure system installation. These areas are limited.
3.2 Contractor Use of Site

The Contractor shall use only those areas specifically designated for his use by Westinghouse. The Contractor shall limit his on-site travel to the specific routes required for performance of his work, and designated by Westinghouse.

3.3 Use of Existing Facilities

Existing facilities available for use by the Contractor are:

- Waste shaft conveyance
- Salt skip hoist
- 460 Volt AC, 3 phase power
- Water underground at waste shaft only
- Water on surface at location designated by Westinghouse

The Contractor shall arrange for use of the facilities with Westinghouse and coordinate his actions and requirements with ongoing Westinghouse operations.

Use of water in the underground will be restricted. No washout or cleanup will be permitted in the underground except as designated by Westinghouse. Above ground washout or cleanup of equipment will be allowed in the areas designated by Westinghouse.

The Contractor is cautioned to be aware of the physical dimensions of the waste conveyance and the air lock.

The Contractor shall be responsible for any damage incurred by the existing site facilities as a result of his operations. Any damage shall be reported immediately to Westinghouse and repaired at the Contractor's cost.

3.4 Demobilization of Equipment and Facilities

At completion of this work, the Contractor shall demobilize his equipment and facilities from the job site. All Contractor's equipment and materials shall be removed and all disturbed areas restored. Utilities shall be removed to their connection points unless otherwise directed by Westinghouse.

3.5 Site Cleanup

At conclusion of the work, the Contractor shall remove all trash, waste, debris, excess construction materials, and restore the affected areas to their prior condition, to the satisfaction of
Westinghouse. A final inspection will be conducted by Westinghouse and the Contractor before final payment is approved.

End of section
SECTION 02222
EXCAVATION
PART 1 - GENERAL

1.1 Scope
This section includes:

- Excavation for surface preparation and leveling of surrounding areas for explosion isolation wall
- Disposition of excavated materials
- Field measurement and survey

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment
- 03400 - Masonry Explosion Isolation Structure

1.3 Reference Documents

1.4 Field Measurements and Survey
All survey required for performance of the work will be provided by Westinghouse.

PART 2 - PRODUCTS
Not used

PART 3 - EXECUTION

3.1 Excavation for Surface Preparation and Leveling of Surrounding Areas for Explosion Isolation Wall
The Contractor shall excavate and prepare the surface around the entire perimeter of the explosion isolation walls by removing all loose material, generally squaring the excavation cross-section, and cleaning all rock surfaces. The surface preparation of the floor shall produce a surface suitable for placing the first course of block in the explosion isolation walls. Excavation may be performed by either mechanical or manual means. Use of explosives is prohibited.
3.2 Disposition of Excavated Materials

The Contractor shall dispose of all excavated materials as directed by Westinghouse.

3.3 Field Measurements and Survey

All survey required for performance of the work will be provided by Westinghouse. The Contractor shall protect all survey control points, benchmarks, etc., from damage by his operations. Westinghouse will verify that the Contractor has excavated to the required lines and grades. No block work is to be erected until approved by Westinghouse.

End of section
1.1 Scope
This section includes:

- Mortar for Explosion Isolation Wall.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 03300 - Unit Masonry System
- 03400 - Masonry Explosion Isolation Structure

1.3 References

ASTM C 91-01 Standard Specification for Masonry Cement
ASTM C 144-02 Standard Specification for Aggregate for Masonry Mortar
ASTM C 150-02 Standard Specification for Portland Cement
ASTM C 207-91 Standard Specification for Hydrated Lime for Masonry Purposes
ASTM C 270-01a Standard Specification for Mortar for Unit Masonry
ASTM C 780-02 Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
ASTM C 1142-95 Standard Specification for Extended Life Mortar for Unit Masonry
ASTM C 94-00 Standard Specification for Ready-Mixed Concrete

1.4 Submittals for Review and Approval

The Contractor shall submit the followings 30 days prior to the initiation of work at the site:

- Design mix.
- Certified laboratory tests for the proposed design mix, indicating conformance of mortar to property requirements of ASTM C 270, and test and evaluation reports to ASTM C 780.
The mix shall not be used until approved by Westinghouse.

1.5 Submittals at Completion
The Contractor shall submit certified laboratory test results for the construction testing of mortar mix.

1.6 Quality Assurance
The Contractor shall:

- Perform work in accordance with the Contractor's Quality Control Plan and referenced ASTM standards.
- Acquire cement, aggregate, and component materials from the same source throughout the work.

1.7 Delivery Storage Handling
The Contractor shall maintain packaged materials clean, dry and protected against dampness, freezing and foreign matter.

PART 2 - PRODUCTS

2.1 Mortar Mix
The Contractor shall provide mortar for explosion isolation walls, which shall conform with ASTM C 270 type M, using the property specification 3,000 psi at 28 days as the minimum requirement. The Contractor shall provide the mortar design mix to achieve the minimum compressive strength requirement for masonry structure as specified in Section 03400. Aggregate for mortar shall conform to ASTM C 144.

2.2 Water
Water used in mixing concrete shall be of potable quality, free of injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances. Water shall conform to the provisions in ASTM C 94, and in addition, shall conform to the following:

- PH not less than 6.0 or greater than 8.0
- Carbonates and/or bicarbonates of sodium and potassium: 1000 ppm maximum
- Chloride ions (Cl): 250 ppm maximum
- Sulfate ions (SO₄): 1000 ppm maximum
- Iron content: 0.3 ppm maximum
- Total solids: 2000 ppm maximum
The source of water is to be indicated and certified copies of test data from an approved laboratory confirming that the water to be used meets the above requirements shall be submitted for approval with the trial mix data.

The supply of materials as defined in the design mix shall remain the same throughout the job.

**PART 3 - EXECUTION**

**3.1 General**
The Contractor shall furnish all labor, materials, equipment, and tools to perform all operations in connection with supplying and mixing mortar for constructing the explosion isolation walls. The Contractor shall fully describe his proposed mortar mixing operation, including proposed equipment and materials in the Work Plan.

**3.2 Mortar Mixing**
Mortar shall be machine-mixed with sufficient water for a period of time not less than three minutes or more than ten minutes to achieve satisfactory workability. Maintain sand uniformly damp immediately before the mixing process. If water is lost by evaporation, retemper only within one and one half hours of mixing. Use mortar within two hours of mixing. Mortar which has hardened or stiffened due to hydration of the cement shall not be used.

**3.3 Installation**
The Contractor shall install mortar to the requirements of Section 03300 Unit Masonry System.

**3.4 Field Quality Control**
The Contractor shall provide a Quality Control Inspector to perform all sampling and testing to confirm that the mortar mix conforms to the proposed mix properties developed in the design mix.

Construction testing of mortar mix shall be in accordance with ASTM C 780 for compression strength. Four prism specimens shall be taken for each 50 ft³ of mortar or fraction thereof placed each day.

End of section
SECTION 03300
UNIT MASONRY SYSTEM
PART 1 – GENERAL

1.1 Scope
This section includes:

- Concrete Masonry Units

1.2 Related Sections

- 01010 Summary of Work
- 01400 Contractor Quality Control
- 01600 Material and Equipment
- 03100 Mortar
- 03400 Masonry Explosion Isolation Structure

1.3 References
ASTM C 55-01a  Standard Specification for Concrete Brick
ASTM C 140-02  Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units

1.4 Submittals for Revision and Approval
The Contractor shall submit for approval the following 30 days prior to initiation of the work at the site.

- Certified laboratory test results for the proposed solid masonry units.

1.5 Quality Assurance
The Contractor shall perform the work in accordance with the CQCP.

PART 2 - PRODUCTS

2.1 Concrete Masonry Units
Concrete masonry units shall be solid (no cavities or cores), load-bearing, high-strength individual units having a minimum compressive strength of 5000 psi. Concrete masonry units shall be tested in accordance with ASTM C 140. All other aspects of the concrete masonry units shall comply with ASTM C 55, Type I Moisture Controlled.
Nominal modular size shall be 8x8x16 inches, or as otherwise approved by Westinghouse.

Concrete brick shall comply with ASTM C 55, Grade N, Type I (moisture controlled) but having a minimum compressive strength of 5500 psi (Avg. 3 units) or 5000 psi for individual unit.

2.2 Mortar
Mortar shall be as specified in Section 03100 Mortar.

PART 3 - EXECUTION
Not used

End of section
SECTION 03400
MASONRY EXPLOSION ISOLATION STRUCTURE
PART 1 - GENERAL

1.1 Scope
This section includes:

- Masonry Explosion Isolation Structure

1.2 Related Sections

- 01010 Summary of Work
- 01400 Contractor Quality Control
- 01600 Material and Equipment
- 03100 Mortar
- 03300 Unit Masonry Structure

1.3 References

ASTM C 1314-02a Standard Test Method for Compressive Strength of Masonry Prism

ACI 530.1-02 Specification for Masonry Structures

1.4 Submittals for Revision and Approval

The Contractor shall submit for approval the following 30 days prior to initiation of the work at the site.

- Certified laboratory test results for compressive strength of masonry by the prism method for a set of five masonry prisms. Materials used for the construction of the prisms shall be taken from those to be used in the construction of the explosion isolation wall. The minimum compressive strengths of the tests shall exceed \( f'_{m} \) as required in 1.6.

1.5 Quality Assurance

The Contractor shall perform the work in accordance with the CQCP.
1.6 Compressive Strength of Masonry
Compressive strength of masonry in each masonry wythe shall exceed 5000 psi \( (f'_m=5000 \text{ psi}) \). The unconfined compressive strength shall be determined by prism test method in accordance with ASTM C 1314 and ACI 530.1.

PART 2 - PRODUCTS

2.1 Concrete Masonry Units
Concrete masonry units shall be as specified in Section 03300 Unit Masonry System. Concrete masonry units shall not be wetted unless otherwise approved by Westinghouse.

2.2 Mortar
Mortar shall be as specified in Section 03100 Mortar.

PART 3 - EXECUTION

3.1 General
The Contractor shall furnish all labor, material, equipment and tools to perform all operations of installing Unit Masonry Explosion Isolation Walls as shown on the Drawings.

The Contractor shall request that Westinghouse inspect and approve all surfaces before beginning any masonry work.

3.2 Installation
The Contractor shall install the explosion isolation walls using concrete masonry units as specified above. Masonry units shall be installed with 3/8-inch mortar joints with full mortar bedding and full head joints. The mortar shall be sufficiently plastic and units shall be placed with sufficient pressure to extrude mortar from the joint and produce a tight joint. Deep furrowing which produces voids shall not be used. The initial bed joint thickness shall not be less than 1/4 inch or more than 1 inch, subsequent bed joints shall be not less than 1/4 inch or more than 5/8 inch in thickness.

Masonry units shall be installed in running bond with headers every third course. Masonry units shall be mortared tight to the ribs and the back wall to provide a seal all around the explosion isolation wall. All surfaces shall be clean and free of deleterious materials.

Cut concrete blocks may be used as required to minimize the dimensional fit-up at the top or sides of the isolation walls. All interfaces between the explosion isolation wall and the rock
surfaces shall be completely mortared to provide full contact between the rock surfaces and the block wall.

Construction joints shall be left as shown on the Drawings. Construction joints shall be left open and unfilled.

3.3 Field Quality Control
The Contractor shall provide a Quality Control Inspector to inspect the installation of the Unit Masonry Explosion Isolation Walls. Inspection and testing of the mortar shall be in accordance with Section 03100 Mortar. Inspection and testing of masonry units are in accordance with Section 03300. A prism test in accordance with Part 1.6 of Section 03400 shall be performed for each 2000 ft³ of block wall.

End of section
SECTION 04100
SALT BACKFILL
PART 1 - GENERAL

1.1 Scope
This section includes:

• Salt Backfill Placement

1.2 Related Sections

• 01010 Summary of Work
• 01400 Contractor Quality Control
• 01600 Material and Equipment

1.3 Submittals for Revision and Approval
The backfill emplacement method, dust control plan and other safety related material shall be approved by Westinghouse.

1.4 Quality Assurance
The Contractor shall perform the work in accordance with the CQCP.

PART 2 - PRODUCTS

2.1 Salt Backfill Material
The salt backfill is run of mine salt and requires no grading or compaction. The salt backfill shall be free of organic material.

PART 3 - EXECUTION

3.1 General
The Contractor shall furnish all labor, material, equipment and tools to handle and place the salt backfill.

The Contractor shall use underground equipment and underground mine personnel as required in Part 1.5 Work by Others in Section 01010 Summary of Work. Westinghouse will supply run of mine salt. The Contractor shall make suitable arrangements for transporting and placing the run of mine salt.
3.2 Installation
Run of mine salt shall be transported to the panel closure area after the construction of explosion isolation wall has been completed. Salt will be pushed against the explosion isolation wall until the entire opening is filled over the length and angle of layback as shown on Drawings. The salt may be left at the angle of repose or some lower slope, but shall not be less than 1 (rise) to 2 (run). There should be no gap left between backfill and roof or sidewalls. Hand placement can be used to fill all the voids if necessary. Backfill may be emplaced in layers to facilitate the construction.

3.3 Field Quality Control
The Contractor shall provide a Quality Control Inspector to inspect the emplacement of backfill.
ATTACHMENT B

Effective Permeability of the Redesigned Panel Closure System
Introduction

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

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

Panel closure design

As noted in the introduction, and described in detail in the design report (Saeb and Case, 2002), the closure comprises a mortared, solid concrete block wall 30 ft. long, and run-of-mine salt backfill 100 ft long placed to leave no gaps against the roof and ribs (Figure 1).
The resistance to fluid flow of this closure system will be a composite of the resistance to flow of the different elements, including the wall, the crushed salt and the surrounding disturbed rock zone (DRZ). Each of these components will vary in its flow resistance over time, and each will dominate over a particular time period. Since the intent of this memorandum is to review the flow resistance of the closure itself for comparison to the range examined in the impact analysis, the effect of the DRZ is not considered here, although it will be relevant to overall performance.

During the operational period the conductivity of this closure will be dominated by the mortared cement block wall, which is estimated in the design report to have a permeability of $2 \times 10^{-15}$ m$^2$. Over time the concrete wall will gradually fracture and fail under the loads applied by the creep of the surrounding salt, and its permeability will gradually increase. However, the same creep closure which causes the concrete block wall to fail will also gradually compact the salt backfill, thus slowly decreasing its permeability and this element will come to dominate the flow performance of the closure system.

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

**Salt Consolidation**

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

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

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

<table>
<thead>
<tr>
<th>Closure Measurement Location</th>
<th>Exhaust Drift (S1600) (in/day)</th>
<th>Air Intake Drift (S1950) (in/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical (Center)</td>
<td>0.00203</td>
<td>0.00364</td>
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<tr>
<td>Vertical (S. third point)</td>
<td>0.00185</td>
<td>0.00300</td>
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<tr>
<td>Vertical (N. third point)</td>
<td>0.00196</td>
<td>0.00365</td>
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<tr>
<td>Mean Vertical</td>
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<td>0.00333</td>
</tr>
<tr>
<td>Horizontal (Upper third point)</td>
<td>0.00230</td>
<td>0.00250</td>
</tr>
<tr>
<td>Horizontal (Center)</td>
<td>0.00216</td>
<td>0.00266</td>
</tr>
<tr>
<td>Horizontal (Lower third point)</td>
<td>0.00200</td>
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</tr>
<tr>
<td>Mean Horizontal</td>
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</tbody>
</table>

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

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

**Conclusion**

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

References


Figure 1. Explosion Isolation Wall in Combination with the Run-of-Mine Salt Backfill (Saeb and Case, 2002)
Figure 2. Permeability of Consolidated Crushed Salt as a Function of Fractional Density (DOE, 1996)
NOTES:
1. Excavation date: April 1986.

Figure 3: Closure Data for the Exhaust Drift (S1600) (DOE, 2001)
CONVERGENCE POINTS
S1950 DRIFT-E407

NOTES:
1. Excavation date: May 1986.

Figure 4: Closure Data for the Air Intake Drift (S1950) (DOE, 2001)
Figure 5. Calculated Drift Closure Assuming Constant Closure Rates and no Backstress
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Figure 9. Calculated Fractional Density Versus Time for Crushed Salt Compacted in the Shaft.
ATTACHMENT C

Panel Closure Impact Assessment Documentation
ATTACHMENT C
Part 1

Analysis Report for the Panel Closure System Impact Assessment, Revision 1
Executive Summary

The Department of Energy (DOE) is proposing to modify the design of the panel closure system for the Waste Isolation Pilot Plant (WIPP). In support of that proposal, DOE tasked Sandia National Laboratories (SNL) to assess the long-term impact of alternate panel closure systems on the performance of the WIPP. In response, SNL conducted a series of calculations, using the EPA-approved WIPP performance assessment models, which characterized the potential impact on repository performance of a range of panel closure designs.

This report presents the analysis of the panel closure’s effects on repository performance. An earlier report summarized the effect of the panel closures on brine and gas flow in the repository (Hansen, 2002). In this analysis, we considered two panel closure cases: one modeled upon the mandated Option D panel closure design, and a second modeled upon the generic panel closure included in the performance assessments conducted for the Compliance Certification Application (CCA) and the Performance Assessment Verification Test (PAVT). The primary distinction between these two panel closure cases is the permeability of the panel closure material, which ranges from quite low in the case of the Option D panel closure to fairly permeable in the CCA and PAVT panel closure case.

We found that releases in the two panel closure cases were nearly identical. Cuttings, cavings and spallings from drilling intrusions account for the majority of releases; direct brine releases are smaller by roughly one order of magnitude. Hansen, 2002 showed that, in some scenarios, the pressures in the repository are somewhat higher in the Option D panel closure case than in the PAVT case. However, the increase in pressure occurs in a relatively small set of possible futures and thus does not significantly affect the spallings or direct brine releases. Thus, this analysis concludes that releases from the repository are not sensitive to the permeability of the panel closures.

To corroborate our findings, we compared the results of this analysis to the results of the Technical Baseline Migration (TBM), which modeled the Option D panel closures with greater detail (Hansen et al, 2002a). The TBM indicates larger spallings releases than does the Option D case in this impact assessment; direct brine releases are expected to be smaller in the TBM, and releases by other mechanisms are the same for both calculations. However, the difference in spallings releases between the two calculations is not greater than 10%. Even if spallings releases in this impact assessment increased by 10%, the total releases would remain below the compliance limit by nearly one order of magnitude. Thus we conclude that the releases calculated in this impact assessment are representative of results from more detailed modeling.
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Introduction

In May of 1998 the Environmental Protection Agency (EPA) issued its final rule on the certification of the Waste Isolation Pilot Plant (WIPP). EPA certified WIPP’s compliance with 40 CFR Part 194 subject to specific conditions, the first of which mandated the design of the panel closure system (PCS). As stated in the EPA ruling, “In its Compliance Certification Application (CCA), the Department of Energy (DOE) presented four options for the design of the PCS, but did not specify which one would be constructed at the WIPP. The EPA based its certification decision on the condition that DOE implement the most robust design (referred to in the CCA as “Option D”). The Agency found the Option D design to be adequate, but also determined that the use of a Salado Mass Concrete – using brine rather than fresh water – would produce concrete seal permeabilities in the repository more consistent with the values used in DOE’s performance assessment. Therefore, Condition 1 of EPA’s certification requires DOE to implement the Option D PCS at the WIPP, with Salado Mass Concrete.” (EPA, 1998a)

DOE is proposing to modify the design of the PCS. In support of that proposal, DOE tasked Sandia National Laboratories (SNL) to assess the long-term impact of alternate panel closure systems on the performance of the WIPP. In response, SNL conducted a series of calculations, using the EPA-approved WIPP performance assessment (PA) models, which characterized the potential impact on repository performance of a range of panel closure permeabilities.

This document reports the results of the performance assessment calculations. A previous report summarized the effects of the panel closures on the output of the two-phase flow performance assessment model (Hansen, 2002). The calculations are documented in Coman, 2002. In this report, we first outline the methodology we applied to this impact assessment and describe the panel closures. We present our findings of the effects on releases from the repository of the panel closures. Finally, we corroborate our conclusions by comparing this analysis with the results of the Technical Baseline Migration (TBM) calculations (Hansen et al, 2002a).
Methodology

We applied the performance assessment methodology to assess the impact on repository performance of varying the panel closure characteristics. The most significant characteristic in question is the permeability of the panel closure system. Permeability governs the flow of gas and brine through the panel closures, and may affect the amounts of brine and gas in the waste panels. The amount of gas and brine in the waste panels determines pressures and saturations, which in turn significantly affect releases from the repository.

As described in the analysis plan for the impact assessment (Hansen et al., 2002b), we investigated repository performance for two cases:

1. the PA VT case, in which the panel closures model a generic material with a fairly high permeability;
2. the Option D case, in which the panel closures are modeled after the Option D design, which has a low effective permeability.

These two cases illustrate the effects on repository performance of varying panel closure permeability.

For the PA VT case, we used the archived results of the PA VT and did not re-run the PA codes. For the low Option D case, we developed a representation of the Option D panel closures within the approved performance assessment models of the repository. To the extent possible, we used the same code versions, parameter values, and random samplings for the Option D case as were used in the PA VT, in order to isolate the effects of the different panel closure permeabilities. This document summarizes the differences between the two cases besides the panel closure permeabilities, and explains the expected effects of these differences.

The performance assessment methodology accommodates both stochastic and subjective uncertainty in its constituent models. Stochastic uncertainty describes the possible future events, such as drilling, that may affect repository performance and is treated by randomly generating sequences of future events. Subjective uncertainty describes the possible values for uncertain input parameters, such as the permeability of a material, and is treated by sampling a parameter value from an assigned distribution. One set of sampled values is termed a vector. We executed the performance assessment models for 100 vectors of parameter values. For each vector, we computed the results for each of 10,000 possible sequences of future events.

By regulation, performance assessment results are presented as a distribution of cumulative complementary distribution functions (CCDFs) of releases. Each individual CCDF summarizes the likelihood of releases in all futures for one vector of parameter values; the uncertainty in parameter values results in a distribution of CCDFs. Our analysis compares the distribution of CCDFs obtained for both panel
closure cases to determine the effect on repository performance of varying panel closure permeability.

Panel Closure Cases

In this section we describe the two panel closures, summarize the differences between the two panel closure cases, and discuss limitations on this analysis.

Properties of Option D and PAVT Panel Closures

We investigated repository performance for two cases:

1. the PAVT case where the panel closures model a generic material with a fairly high permeability;
2. the Option D case in which the panel closures are modeled after the Option D design.

The PAVT panel closure case is the same as the 1997 PAVT performance assessment. The PAVT assumed a generic panel closure material with relatively high permeability.

In the Option D case, we developed a representation of the Option D panel closures using the PAVT computational grid. To account for the detailed features of the Option D panel closure within the resolution of the PAVT grid, we calculated an effective permeability, and volume-averaged porosity and initial brine saturation for the panel closure material PAN_SEAL. We did not change any grid dimensions or any other material assignment within the grid.

PAVT Panel Closures

In the PAVT grid, panel closures are represented by two single columns of cells with width either 40 m or 80 m. These cells are assigned a single material, PAN_SEAL. The cells above and below the panel closures are assigned properties representing the disturbed rock zone (DRZ).

In the PAVT, the material PAN_SEAL was assigned a constant permeability of $1.0 \times 10^{-15}$ m$^2$ in each direction. Porosity was constant at 0.075 and the initial brine saturation of the panel closure was 0.99. The permeability of the surrounding DRZ was represented by a loguniform distribution varying between $3.16 \times 10^{-13}$ m$^2$ to $3.98 \times 10^{-20}$ m$^2$. The relatively high permeability of the panel closures maintained a relatively easy path for brine and gas to move between panels, even when DRZ permeability was low (EPA, 1998b). Figure 1 shows the panel closures in the PAVT grid.

---

1 In the PAVT performance assessment, the cells representing the northern PCS are 80 m in the X-direction, representing two sets of panel closures in series.
Figure 1. PAVT Computational Grid.

Shaft Materials

- Earthen fill
- Compacted clay
- Asphalt
- Concrete
- Compacted clay
- Concrete
- Crushed salt
- Concrete
- Compacted clay
- Lower clay
- Concrete monolith
Option D Panel Closure in the PAVT Grid

In contrast to the PAVT panel closures, the Option D panel closure design specifies two distinct components, a concrete monolith that is 7.9 m thick, and an adjacent drift containing an explosion wall that is 3.7 m thick. The concrete monolith extends into the DRZ above and below the drift. Figure 2 illustrates the Option D panel closure design.

Figure 2. Option D Panel Closure Design.

To represent the Option D panel closures with a single column of cells, we calculate the permeability, porosity and initial brine saturation for the Option D materials and assign these values to the material PAN_SEAL; the subsequent section of the report summarizes these calculations. All other properties of the material PAN_SEAL remain the same as for the PAVT calculation.

Figure 3 illustrates how we derive the properties of the material PAN_SEAL for the Option D case. We conceptually divide the interior of each of the three PAN_SEAL cells into two regions: the monolith and the drift. Properties for the monolith are taken from the material CONC_T1, used in the CCA and PAVT to represent the long-term behavior of Salado Mass Concrete (DOE, 1996a). Properties for the drift are taken from materials used to represent void space in the repository, such as in the operations and experimental areas. The properties for the monolith and the drift are appropriately combined to obtain properties for the composite material PAN_SEAL.

The concrete monolith has a fixed width of 7.9 m in the X-direction. The grid cells representing the southern panel closures are 40 m in the X-direction; hence the width of the drift material in these cells is 32.1 m. As shown in Figure 1, between the rest of the repository (RoR) and the operations area, a single column of grid cells represents two sequential panel closures with a total extent of 80 m in the X-direction. In this column of cells, there are two monoliths and two drifts, each drift being 32.1 m in width.
The material above and below the panel closures is termed DRZ_1, and represents the combination of the surrounding disturbed rock zone (DRZ) and the panel closure components above and below the drift. The presence of the concrete monolith is expected to induce back stresses in the disturbed halite above the monolith, which will cause the DRZ to "heal" over time, reducing its permeability (Stein, 2002). However, at the time of this analysis the appropriate peer review for incorporating DRZ healing into the DRZ conceptual model has not been completed. Therefore, in this analysis the DRZ above the monolith is not assumed to heal. We assign to DRZ_1 the same properties as were assigned to the DRZ surrounding the repository in the PAVT.

**Permeability of Material PAN_SEAL**

For the material PAN_SEAL, we calculate effective permeability values in the X-, Y- and Z-directions from the component materials. The effective permeability in the X-direction can be expressed as the X-length-weighted harmonic mean of the permeability of the concrete and the drift because flow in X is normal to the interface between materials. The formulation of the permeability in the X-direction is thus:

\[
k_X = \frac{k_X \Delta x_a + k_X \Delta x_b}{\Delta x_a/k_X + \Delta x_b/k_X} \tag{1}
\]

where \(k_X\) and \(k_X\) are the X components of permeability and \(\Delta x_a\) and \(\Delta x_b\) are the X-dimensions.
The effective permeability in the Y- and Z-directions parallel to their interface can be expressed as the length-weighted means of the components of permeability,

$$k_Y = \frac{k_{ya} \Delta x_a + k_{yb} \Delta x_b}{\Delta x_a + \Delta x_b}$$  \hspace{1cm} (2)

**Permeability of Panel Closure Concrete**

The EPA required the use of Salado Mass Concrete (SMC) for the Option D panel closures as a condition of their rule (EPA, 1998a). Material parameters for SMC are summarized in DOE, 1996a. The permeability of the SMC seal components was treated as a random variable defined by a log triangular distribution with a mode of $1.78 \times 10^{-19}$ m$^2$ and lower and upper limits of $2.0 \times 10^{-21}$ and $1.0 \times 10^{-17}$ m$^2$, respectively. In this analysis we used a constant value for the permeability of the concrete in the panel closures and chose the mode of SMC permeability distribution.

The CCA assumed that cementitious materials would degrade after 400 years. However, a subsequent and more detailed evaluation (Thompson and Hansen, 1996) concluded that no significant degradation is expected for the concrete members of the panel closure concrete. They showed that potential flow through the concrete closure is nearly two orders of magnitude too small to cause any significant degradation. Consequently, in this analysis we assume that the PCS concrete does not degrade over time.

**Permeability of Panel Closure Drift**

To represent the drift and explosion wall, we assigned properties equal to the neighboring regions. The two drifts for the panel closures are adjacent to two regions in the PAVT grid, referred to as the Panel and the Rest of Repository (RoR). Both of these regions are filled with the material representing the waste, termed WAS_AREA. Hence, we assume that the drift has permeability equivalent to WAS_AREA ($2.4 \times 10^{-13}$ m$^2$).

**Effective Permeability of Option D PCS**

Using the permeabilities for the concrete and drift portions of the PCS, we use Equation (1) and calculate the effective permeability of the PCS in the X-direction to be

$$\frac{1.78 \times 10^{-19} \cdot 2.4 \times 10^{-13} \cdot (7.9 + 32.1)}{7.9 \times 2.4 \times 10^{-13} + 32.1 \cdot 1.78 \times 10^{-19}} = 9.01 \times 10^{-19} \text{ m}^2$$

for the 40 m wide panel closure cells. Since the 80 m wide cells represent two sequential panel closures, the effective permeability in the X-direction is the same as for the 40 m wide cells.

In the Y- and Z-directions, we apply Equation (2) and calculate the effective permeability to be
\[
\frac{1.78 \times 10^{-19} \cdot 7.9 + 2.4 \times 10^{-13} \cdot 32.1}{7.9 + 32.1} = 1.93 \times 10^{-13} \text{ m}^2
\]

for the 40 m wide panel closure cells. Again, the 80 m wide cells have the same permeability values.

**Porosity of Material PAN\_SEAL**

The porosity of the panel closure is the pore volume divided by the total volume. For this analysis, we assign to the material PAN\_SEAL the volume-weighted average porosity for the concrete and drift components. Since all three cells for material PAN\_SEAL have a constant depth of 10 m, the volume-weighted average is the same as the length-weighted average. The porosity of the concrete was set at 0.05, the same value used for the SMC material (DOE, 1996b). In the PAVT, void space such as in the operations and experimental areas is assigned a constant porosity of 0.18. In this analysis, we use the value of 0.18 for the porosity of adjacent drift, resulting in a porosity value for PAN\_SEAL of

\[
\frac{7.9 \cdot 0.05 + 32.1 \cdot 0.18}{7.9 + 32.1} = 0.15
\]

for the 40 m wide cells; the value for the 80 m wide cells is the same.

**Initial Brine Saturation of Material PAN\_SEAL**

The initial brine saturation for PAN\_SEAL is calculated as the volume-weighted average of the initial brine saturations for the concrete and drift components. The initial brine saturation for the concrete was set at 0.99, the same value as was used for SMC in the PAVT. For the drift, the initial brine saturation was 0.015, the same value used for void space in the PAVT grid. The initial brine saturation for the material PAN\_SEAL is thus

\[
\frac{7.9 \cdot 0.99 + 32.1 \cdot 0.015}{7.9 + 32.1} = 0.21
\]

for the 40 m wide cells; the 80 m wide cells have the same value.

Table 1 summarizes the properties of the material PAN\_SEAL that differ between the two panel closure cases.

**Table 1. Panel Closure Properties.**

<table>
<thead>
<tr>
<th></th>
<th>PAVT Panel Closure</th>
<th>Option D Panel Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability (X-direction)</td>
<td>$1 \times 10^{-15} \text{ m}^2$</td>
<td>$9.01 \times 10^{-19} \text{ m}^2$</td>
</tr>
<tr>
<td>Permeability (Y-direction)</td>
<td>$1 \times 10^{-15} \text{ m}^2$</td>
<td>$1.93 \times 10^{-13} \text{ m}^2$</td>
</tr>
<tr>
<td>Permeability (Z-direction)</td>
<td>$1 \times 10^{-15} \text{ m}^2$</td>
<td>$1.93 \times 10^{-13} \text{ m}^2$</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.075</td>
<td>0.15</td>
</tr>
<tr>
<td>Initial Brine Saturation</td>
<td>0.99</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Other Differences between Panel Closure Cases

To isolate the effects of the different panel closures, we sought to eliminate any other differences between the two cases. However, the two panel closure cases differ in:

1. The fracture model in the upper DRZ.
2. The versions of the codes that were used for computation.
3. Several parameters for materials other than the panel closures.

We discuss each of these differences and their potential effects on the conclusions of this analysis.

Fracture Model

In the PAVT, the anhydrite fracture model was applied to the DRZ as part of the sensitivity analysis. This fracture model was not part of the peer-reviewed conceptual model of the DRZ for the certification. Thus, we did not apply the fracture model to the DRZ in the Option D panel closure case. The fracture model is applied in the BRAGFLO code. Analysis of BRAGFLO results showed that removing the fracture model had negligible impact on repository pressure and saturation (Hansen 2002); hence, we conclude that its removal does not affect repository releases.

Code Versions

To the degree possible, the Option D case used the same code versions as the PAVT. Coman, 2002 compares the code versions used in the Option D case and the PAVT. Since the PAVT was calculated, the parameter database has been migrated to new database software (Lechel and Tisinger, 2002). As a consequence of the new database software, several codes had to be modified to read from the new parameter database. We used these revised codes in the Option D case. After modification, each code was tested to verify that the code performed correctly after the revision (Lechel and Tisinger, 2002). Consequently the different code versions do not produce differences between the PAVT and the Option D cases. Table 2 lists the code versions that differ in the two panel closure cases.

Table 2. Code Versions that Differ Between the PAVT and the Option D Case.

<table>
<thead>
<tr>
<th>Code</th>
<th>PAVT version</th>
<th>Version used for PCS Impact Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUTTINGS S</td>
<td>5.04</td>
<td>5.04a</td>
</tr>
<tr>
<td>MATSET</td>
<td>9.00</td>
<td>9.10</td>
</tr>
<tr>
<td>NUTS</td>
<td>2.05</td>
<td>2.05a</td>
</tr>
<tr>
<td>PRELHS</td>
<td>2.10</td>
<td>2.30</td>
</tr>
</tbody>
</table>

In addition to the change in the parameter database software, since the PAVT a few errors have been identified in some codes. These errors include an incorrect value for the molecular weight of cellulose in BRAGFLO, a missing factor of $2\pi$ in BRAGFLO DBR, and an incorrect modeling of the DRZ in the BRAGFLO DBR grid. We chose not to correct these errors for the Option D calculation, to avoid introducing differences not attributable to the panel closures.
Other Parameters

For the Option D case, we used nearly the same random sampling of input parameters as was used in the PAVT, to permit vector-by-vector comparison of the results between calculations. However, some parameter distributions have been corrected since the PAVT. During the migration to the new database software, various errors in the PAVT parameter database were corrected. (Lechel and Tisinger, 2002) Table 3 summarizes the differences between the parameter set used in the two panel closure sets exclusive of the differences due to the panel closures. We judge that none of the differences listed in Table 3 have any observable effect on the output of the performance assessment models, and hence these parameter differences do not affect our conclusions about the effects of panel closures.

In addition to these corrections, the values of several other parameters have changed since the PAVT, namely, the matrix partition coefficients and some inventory parameters (Hansen and Leigh, 2002, and Sanchez, 2002). We did not include these parameter changes in the calculations for the Option D case. The matrix partition coefficients are used in the SECOTP2D code to compute transport in the Culebra. To avoid introducing differences between the two cases that are not attributable to panel closure properties, we used the PAVT SECOTP2D results to construct the CCDFs in the Option D case. The SECOTP2D code requires as input the volume brine flowing from the repository to the Culebra through a borehole, which is calculated by BRAGFLO. Comparison of the PAVT and the Option D case showed that brine flow up a borehole is similar in both cases. Hence, the application of PAVT SECOTP2D results to the Option D case does not significantly affect our conclusions.

The inventory parameters describe the amount of each radionuclide placed into the repository. These parameters are used in the codes ALGEBRA and CCDFGF to compute the time-dependent amount of radionuclides in the waste. Releases of each radionuclide are directly proportional to the inventory parameters. Subsequent to the PAVT, the inventories were corrected to account for an error in one waste site's reported inventory (Sanchez, 2002). For the Option D calculation, we used the inventory parameters prior to the correction documented in Sanchez, 2002. We chose not to include the inventory corrections in the Option D calculation in order to maintain focus on the effects of the panel closures.
Table 3. Parameter Differences between PAVT and PCS Impact Assessment.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>PAVT value</th>
<th>Present value</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPHALT - PORE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>S_ANH_AB - SAT_RBRN</td>
<td>Residual brine saturation</td>
<td>Min: 6.884e-02</td>
<td>Min: 7.7846e-03</td>
<td>Correction</td>
</tr>
<tr>
<td>S_ANH_AB - SAT_RGAS</td>
<td>Residual gas saturation</td>
<td>Value 1.20000e-01 (Student dist.)</td>
<td>Value 1.16370e-01 (Student dist.)</td>
<td>Rounding error</td>
</tr>
<tr>
<td>S_MB138 - SAT_RBRN</td>
<td>Residual brine saturation</td>
<td>Min: 7.8460e-03</td>
<td>Min: 7.7846e-03</td>
<td>Correction</td>
</tr>
<tr>
<td>S_MB138 - SAT_RGAS</td>
<td>Residual gas saturation</td>
<td>Min: 1.3980e-02</td>
<td>Min: 1.3981e-02</td>
<td>Rounding error</td>
</tr>
<tr>
<td>S_MB139 - SAT_RBRN</td>
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<td>Min: 7.8460e-03</td>
<td>Min: 7.7846e-03</td>
<td>Correction</td>
</tr>
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<td>S_MB139 - SAT_RGAS</td>
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<td>Min: 1.3980e-02</td>
<td>Min: 1.3981e-02</td>
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<tr>
<td>S_MB139 - PRESSURE</td>
<td>Brine far-field pore pressure</td>
<td>Min: 1.111e+07</td>
<td>Min: 9.380e+06</td>
<td>Correction</td>
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<tr>
<td>SALT_T1 - PORE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
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<tr>
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<tr>
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<td>Correction</td>
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<tr>
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<td>Correction</td>
</tr>
</tbody>
</table>
Analysis of Releases
In this section, we summarize the important mechanisms for releases from the repository, and compare the releases for the two panel closure cases.

Summary of Findings
We found that the two panel closure cases produced nearly identical distributions of total normalized releases. Moreover, the releases by the most significant mechanisms (spallings, cuttings and cavings, and direct brine releases) are also nearly identical. We conclude that the different panel closure properties represented in this analysis do not significantly affect repository performance.

Releases from the Repository
Releases from the WIPP fall into two principal categories:
1. Direct releases, which may occur at the time of a drilling intrusion
2. Long-term releases, which may take place throughout the regulatory period

We outline here the components of each category of releases.

Direct releases are subdivided into three components: cuttings and cavings; spallings; and direct brine releases. Cuttings refer to the material actually encountered by a drill bit as it passes through the waste. Cavings include material eroded from the walls of the waste and brought to the surface by the drilling fluid. Spallings accounts for additional material that may be brought to the surface through venting of repository gas pressure to the lower-pressure borehole. Direct brine releases are flows of brine from the repository to the surface during the few days before a borehole is assumed to be plugged.

Long-term releases include nuclide transport in groundwater through the various geologic units to the land withdrawal boundary. The most transmissive unit is the Culebra. Nuclides may be transported to the Culebra primarily by brine flow up boreholes. Other transport paths, such as through the shaft seals, or through the marker beds, have been demonstrated to be insignificant.

Comparison of Releases
Figure 4 shows the distribution of total normalized releases for all 100 vectors in the Option D calculation. The most extreme vector produced releases that remain less than the regulatory limit by at least a factor of 3. The Option D distribution of total normalized releases is very similar to that from the PAVT. Figure 5 compares the statistics for the two distributions of total normalized releases. The mean, median and quantiles are almost identical between the two distributions. We conclude that the changes to the panel closures as represented in the Option D case have no meaningful impact on total releases.
Figure 4. Distribution of CCDFs for Total Normalized Releases, Option D Case.

Total Normalized Releases
100 Observations, 10,000 Futures/Observation

--- EPA Limit

Figure 5. Comparison of Total Normalized Releases.
Figures 6 and 7 show the mean values for the component releases for each case. Cuttings and cavings, and spallings dominate the total releases, with direct brine releases about one order of magnitude less. Releases through the Culebra are three orders of magnitude below direct brine releases in both calculations.

Figures 8 and 9 compare the statistics for each case’s distribution of releases by spallings and direct brine release. The analysis of BRAGFLO results identified some differences in pressures and saturations between the two panel closure cases (Hansen, 2002). These differences can affect spallings and direct brine releases; cuttings are not affected by differences in pressure and saturation. The figures show that the differences in pressure and saturation between the two cases do not significantly affect releases by spallings and by direct brine release.
Figure 6. Distribution of Mean Normalized Releases, PAVT Case.

Figure 7. Distribution of Mean Normalized Releases, Option D Case.
Figure 8. Comparison of Spallings Releases.

Figure 9. Comparison of Direct Brine Releases.
Corroborating Analyses

In this section, we present analyses corroborating the conclusions presented in the previous section. We outline two concerns about the detail employed to represent the panel closures in the Option D case. To resolve these concerns, we compare the results of the Option D case to those obtained for the TBM to determine if the level of detail in the Option D case affects our conclusions.

Summary of Findings

Our comparison of the Option D case with the TBM concludes that the releases calculated for the Option D case are representative of releases calculated by more detailed modeling. Consequently, we conclude that this impact assessment adequately identifies the effects on releases of varying the panel closure permeability.

There are three principal mechanisms for releases from the repository: cuttings and cavings; direct brine releases; and spallings. Releases by cuttings and cavings are not affected by the panel closures. We found that direct brine releases in the Option D case for this impact assessment are conservative with respect to the effects of the panel closures. The Option D case in this analysis produces significantly greater direct brine releases than will the TBM, due to the higher saturations in the waste regions.

We found that the Option D case in this impact assessment may underestimate releases due to spallings but not by more than 10%. However, even if spallings releases in the Option D case increased by 10%, the total releases would remain below the compliance limit by nearly one order of magnitude. We conclude that the underestimate of spallings in the Option D case is not large enough to affect the conclusions of this impact assessment.

Concerns about the Option D Case

This panel closure impact assessment supports a request by DOE to change the approved panel closure design, and therefore employs the models, codes and parameter values that are qualified for compliance calculations. The current baseline performance assessment is the PAVT. However, the PAVT computational grid is not sufficiently refined to explicitly represent the features of the Option D panel closures. Consequently, we identified two potential concerns with the Option D case in this analysis: the use of effective properties; and the effect on the DRZ of the Option D panel closures. We outline our concerns in this section.

Use of Effective Properties

As shown in Figure 2, the Option D panel closure design specifies three components: a concrete monolith 7.9 m wide constructed of Salado Mass Concrete; an adjacent empty drift 9 m wide; and an explosion wall of mortared concrete block 3.7 m in width. The concrete monolith extends into the DRZ above and below the entry drifts. The PAVT computational grid does not provide sufficient resolution to explicitly represent these components. To represent the Option D panel closures within the
Effect on DRZ of Option D Panel Closures

The conceptual model of the DRZ assumes that the DRZ extends above the excavated areas approximately 12 meters to Marker Bed 138. The permeability of the DRZ is sampled across a wide range, from $3.98 \times 10^{-20}$ m$^2$ to $3.16 \times 10^{13}$ m$^2$. This permeability is applied homogeneously throughout the DRZ. The Option D panel closures are expected to cause back stresses in the DRZ above the monolith. These stresses will cause the DRZ in those locations to heal and will greatly reduce its permeability (Stein, 2002). However, the Option D case does not include any healing of the DRZ above the panel closures, as this would require a change to the approved conceptual model for the DRZ. Consequently, even with the low effective permeability of the Option D panel closures, the DRZ may provide a highly permeable path around the panel closures. Removing these highly permeable paths would affect pressure and saturation in the waste regions, which in turn may affect repository performance.

Comparison with the Technical Baseline Migration

In this section we compare the results obtained from the panel closure impact assessment calculations with the results obtained from the Technical Baseline Migration (TBM) calculations. The TBM calculation refined the computational grid and modified the PAVT input parameters to explicitly represent the Option D panel closures. In addition, the TBM modified the conceptual model of the DRZ to account for healing in the halite surrounding the panel closure monolith. We believe that the TBM better represents the effects of the Option D panel closures on the repository than does the Option D panel closure case in this analysis. We compare the results of the Option D case to the TBM to determine if the absence of detail in the Option D case affects our conclusions about the effects of the Option D panel closures on releases.

The TBM computational grid, shown in Figure 10, is more refined than the PAVT grid and allows the components of the Option D panel closures to be represented. Stein (2002) documents the representation of the Option D panel closures in the TBM. The TBM calculations are in progress; the results of the BRAGFLO calculations for the TBM are documented in Hansen et al (2002a). The TBM calculation used the same sampling of input parameters as was used in the Option D case in this analysis, allowing a direct comparison of results.
Differences between the Option D Case and the TBM

In the Option D panel closure case in this impact assessment, a single column of grid cells represented the panel closures. We calculated effective permeabilities, porosities, and initial saturations for the panel closure material, as described earlier in this report. In contrast, the TBM added cells to the computational grid to explicitly represent the two components of the Option D panel closure, the concrete monolith and the adjacent drift. The concrete monolith was extended above and below the excavated drift as specified by the Option D design. Appropriate properties were assigned to each two materials as documented in Stein (2002).

In contrast to the Option D panel closure case in this impact assessment, the TBM assumed that the DRZ immediately above the concrete monolith would heal. In the TBM this column of halite was assigned permeabilities ranging from \( 2 \times 10^{-21} \text{ m}^2 \) to \( 1 \times 10^{-17} \text{ m}^2 \), using a triangular distribution with most likely value of \( 1.7 \times 10^{-19} \text{ m}^2 \). To allow for pressure-induced fracturing around the bottom of the concrete monolith, which lies in Marker Bed 139, we applied the anhydrite fracture model to the lower DRZ and to the bottom cell of the concrete monolith. In combination with the low permeabilities assigned to the concrete monolith, the TBM removed all high-permeability paths around the panel closures except those opened by pressure-induced fracturing.

The TBM divided the rest of repository into two separate blocks of cells, separated by an additional panel closure. This refinement more accurately represents the effects of the panel closures on flow within the waste-filled regions of the repository. In the PAVT grid used in this impact assessment, the waste panel acts as a surrogate for any intruded panel, but is only separated from the region representing the other nine waste panels by a single panel closure.

Finally, the TBM incorporated a number of corrections and improvements to the BRAGFLO code and to parameters that have been identified as needed since the PAVT. The computational grid’s scaling and flaring algorithms were modified to correct an error in the PAVT grid and to improve numerical accuracy. Analysis has shown that the shaft is not a significant pathway for releases; hence the shaft was removed to improve the numerical conditions of the grid. The molecular weight of cellulose was corrected, resulting in slightly more gas generated in the TBM than in the PAVT. Analysis of the BRAGFLO calculations for the TBM identifies the effects of these corrections and improvements separately from the effects of the Option D panel closures (Hansen et al, 2002a). The TBM analysis concluded that the effects of these improvements and corrections were minor when compared to the effects of the Option D panel closures.
Comparison of Releases

In this section, we compare the releases calculated for the Option D case in this impact assessment with the releases expected from the TBM calculations. The TBM calculations have not yet concluded; consequently, we estimate the TBM releases from the BRAGFLO results for the TBM. BRAGFLO computes pressure and saturation in the waste regions over time, as well as brine flow in and out of the repository. We discuss the principal releases mechanisms: cuttings and cavings; direct brine releases; and spallings.

Cuttings and Cavings

Releases by cuttings and cavings are not dependent on pressure or saturation in the waste panels. These releases are determined completely by the mechanical properties of the waste and the assumed drilling techniques. Waste properties and the drilling techniques are unchanged from the PA VT to the TBM; hence, release by cuttings and cavings are the same in the Option D case and in the TBM.

Direct Brine Releases

We compared results from the BRAGFLO calculations for the Option D case with the TBM (Hansen, 2002). The comparison showed that brine saturation is generally reduced in the TBM as compared to the Option D case. In the CCA, lower brine saturations were associated with smaller direct brine releases. Hence, we expect that the TBM will show smaller direct brine releases than are calculated in the Option D case in this impact assessment. We conclude that the direct brine releases in this impact assessment are likely conservative with respect to the effects of the panel closures.

Spallings

Spallings releases occur when the pressure in the waste panel at the time of intrusion exceeds a threshold of 8 MPa. The volume of each spallings release is determined by an independently sampled parameter that is the same for both the Option D case and the TBM. Hence, we can identify differences in spallings releases by comparing pressures between the Option D case and the TBM.

We compared pressures from the BRAGFLO calculations for the Option D case with the TBM (Hansen, 2002). We found that pressures in undisturbed scenarios were similar; however, the TBM showed higher pressures in the waste regions after an intrusion than were calculated in the Option D case. In the TBM, the Option D panel closures greatly delayed the equilibration of pressure differences between the intruded panel and the other waste panels. These higher pressures result from the incorporation of the details of the Option D panel closure materials and the effects on the DRZ of the concrete monolith, and may lead to increased releases due to spallings.
We estimated the spallings releases from the TBM to determine if the differences in pressure between the Option D case and the TBM produce significant differences in spallings releases. Higher pressures in the waste regions after the first intrusion increase the probability of spallings from subsequent intrusions. The TBM data show that the probability of spallings occurring for a second intrusion into a previously undisturbed waste panel is 0.45 (see Appendix A). In contrast, in the Option D case, the probability of spallings occurring for a second intrusion into a previously undisturbed waste panel is 0.42. The probability of spallings from the third and subsequent intrusions is conservatively assumed to be the same as the probability of spallings from the second intrusion. Releases from spallings are directly proportional to the probability of spallings occurring. Thus, releases from spallings in the TBM may be approximately 10% higher than in the Option D case in this impact assessment. It is clear, however, that spallings releases in the TBM will not be an order of magnitude larger than in the Option D case in this impact assessment. Hence, although spallings may be underestimated in the Option D case, the underestimate is small enough that it does not change our conclusions.
Conclusions

We applied the performance assessment methodology to assess the impact on repository performance of varying the panel closure properties. We defined two panel closure cases: the PAVT case, in which the panel closure permeability was relatively high; and the Option D case, in which the panel closures have low permeability. Using the qualified performance assessment models we calculated releases from the repository for both cases. We found that the two cases produced releases that are nearly identical, indicating that repository performance is not significantly affected by changes in the panel closure properties.

To corroborate this conclusion, we compared the results of the Option D case to results obtained for the TBM. The TBM used a refined computational grid to explicitly represent the Option D panel closures and their effects on the surrounding DRZ. The TBM indicates that the panel closures can significantly alter brine and gas flow within and around the repository (Hansen et al, 2002a). Releases have not been completely calculated for the TBM at the time of this report. We estimated direct releases for the TBM from the pressure and saturation results, and compared these estimates to the releases from the Option D case in this impact assessment.

The comparison showed that the releases from Option D case in this impact assessment are representative of releases obtained by more detailed modeling of the panel closures. The Option D case is conservative with respect to the effect of the panel closures on direct brine releases. The Option D case may underestimate releases due to spallings but only slightly. Releases by other mechanisms, such as cuttings and cavings, are unaffected by the panel closures.
References


Appendix A. Estimating the Probability of Spallings

We estimate the probability of spallings from a second intrusion in the TBM calculation. At the time of this report, the TBM calculation is in progress and the spallings releases have not been calculated. However, sufficient data is available to estimate the probability of spallings occurring.

We used the PAVT spallings model in this calculation. The PAVT model of spallings is quite simple: if pressure in the intruded waste panel exceeds 8MPa, then spallings occur. The volume of material released is uniformly distributed between 0.5 m$^3$ and 4.0 m$^3$, and determined by an independently sampled parameter.

Pressure in the repository is computed by the BRAGFLO code; the BRAGFLO runs were finished in May 2002. The code CUTTINGS_S uses the pressures from BRAGFLO and the sampled spallings volume to compute spallings release volumes at specific points in time for each scenario and vector. The code CCDFGF randomly generates sequences of drilling intrusions for each vector, and computes spallings releases by combining the output of CUTTINGS_S (the spallings volume) with the output of the source term calculation (time-dependent activity of the waste.)

The code CCDFGF determines the time between drilling intrusions and the releases from each intrusion by interpolation from the various BRAGFLO scenarios (DOE, 1996c). Four BRAGFLO scenarios (S2 through S5) determine the effect on pressure of the first drilling intrusion. Scenarios S2 and S3 model an E1 intrusion at 350 and 1000 years, respectively; scenarios S4 and S5 model an E2 intrusion at 350 and 1000 years. An E1 intrusion penetrates through the waste and encounters a pressurized brine reservoir below the repository. In an E2 intrusion the borehole stops at the waste panel.

For a given time interval $(t_1, t_2)$ the probability of spallings $P_{sp}$ from an intrusion during this interval is:

$$P_{sp}(t_1, t_2) = \int_{t_1}^{t_2} P_{pres}(t) \cdot P_m(t) \, dt \tag{1}$$

where $P_{pres}(t)$ is the probability that pressure exceeds 8MPa at time $t$, and $P_m(t)$ is the probability of an intrusion taking place at time $t$. For each scenario, we estimated the probability that pressure exceeds 8 MPa at a specific point in time by tabulating the percentage of BRAGFLO vectors in which pressure exceeds the threshold value at that time. The time between intrusions is modeled with an exponential distribution with a constant rate. Since the output from BRAGFLO provides pressures at discrete points in time (usually at 100 year intervals), a summation replaces the integral in equation (1).

For the S3 and S5 scenarios, we computed the probability of spallings release from the second drilling intrusion during the time period from 1,000 to 10,000 years for each
waste-filled region in the repository. The PAVT grid has two waste-filled regions, the waste panel and the rest of repository. The TBM grid subdivides the rest of repository into two smaller regions. Table A.1 shows the results. The probability of spallings is much higher in the S3 scenario due to the large amount of brine that flows up the borehole from the Castile, which generates additional gas by steel corrosion.

Table A.1. Probabilities of Spallings Release From Second Drilling Intrusion.

<table>
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<tr>
<th>Option D Panel Closure Case</th>
<th>S3 Scenario</th>
<th>S5 Scenario</th>
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<tbody>
<tr>
<td>Waste Panel</td>
<td>0.60</td>
<td>0.34</td>
</tr>
<tr>
<td>Rest of Repository (RoR)</td>
<td>0.52</td>
<td>0.38</td>
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<table>
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<tr>
<th>TBM</th>
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<tbody>
<tr>
<td>Waste Panel</td>
<td>0.55</td>
<td>0.30</td>
</tr>
<tr>
<td>South RoR</td>
<td>0.54</td>
<td>0.44</td>
</tr>
<tr>
<td>North RoR</td>
<td>0.51</td>
<td>0.42</td>
</tr>
</tbody>
</table>

The code CCDFGF chooses whether each intrusion is an E1 and E2 intrusion based on the probability of a borehole encountering a pressurized brine reservoir. This probability is independently sampled from a uniform distribution between 0.01 and 0.60. Averaged over 100 vectors, the probability of an E1 intrusion is the mean value of this distribution, or 0.305.

To compute the probability of spallings from the second drilling intrusion, we weight the probabilities in Table A.1 by the size of the each repository area, and combine the S3 and S5 scenarios by using the mean value of the probability of encountering a pressuring brine reservoir. The Rest of Repository contains 9 waste panels, of which 4 are in the South Rest of Repository and the remaining 5 comprise the North Rest of Repository. Thus, in the PAVT, the probability of spallings from the second intrusion is:

\[
0.305 \left( \frac{0.60 + 9 \times 0.52}{10} \right) + 0.695 \left( \frac{0.34 + 9 \times 0.38}{10} \right) = 0.42
\]

and in the TBM the probability of spallings from the second intrusion is:

\[
0.305 \left( \frac{0.54 + 4 \times 0.52 + 5 \times 0.51}{10} \right) + 0.695 \left( \frac{0.30 + 4 \times 0.44 + 5 \times 0.32}{10} \right) = 0.45
\]
ATTACHMENT C
Part 2

Analysis of BRAGFLO Results for the Panel Closure Impact Assessment, Revision 1
Analysis of BRAGFLO Results for the Panel Closure Impact Assessment

Revision 1

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Executive Summary

The Department of Energy (DOE) is proposing to modify the design of the panel closure system for the Waste Isolation Pilot Plant (WIPP). In support of that proposal, DOE tasked Sandia National Laboratories (SNL) to assess the long-term impact of alternate panel closure systems on the performance of the WIPP. In response, SNL conducted a series of calculations, using the EPA-approved WIPP performance assessment models, which characterized the potential impact on repository performance of a range of panel closure designs.

This report presents the analysis of the panel closure's effects on the output of the two-phase flow performance assessment code, BRAGFLO. This code computes pressures and brine saturations in the repository over time. Pressures and brine saturations are the primary variables that determine releases due to spallings, direct brine release, and transport.

In this analysis, we considered two panel closure cases: one modeled upon the mandated Option D panel closure design, and a second modeled upon the generic panel closure included in the performance assessments conducted for the Compliance Certification Application (CCA) and the Performance Assessment Verification Test (PAVT). The primary distinction between these two panel closure cases is the permeability of the panel closure material, which ranges from quite low in the case of the Option D panel closure to fairly permeable in the CCA and PAVT panel closure case. For all other material parameters, we used the values specified for the PAVT.

We found that the two panel closures cases produce pressure and brine saturations that are quite similar. Consequently, we expect that the full performance assessment will show that the two panel closure cases produce similar releases.

To corroborate our analysis, we compared the results of this analysis to the Technical Baseline Migration (TBM), which models the Option D panel closures with greater detail. The comparison indicates that the Option D case in this analysis may underestimate releases due to spallings. The degree to which spallings releases may be underestimated will be determined after the rest of the performance assessment codes are run.
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Introduction

In May of 1998 the Environmental Protection Agency (EPA) issued its final rule on the certification of the Waste Isolation Pilot Plant (WIPP). EPA certified WIPP's compliance with 40 CFR Part 194 subject to specific conditions, the first of which mandated the design of the panel closure system (PCS). As stated in the EPA ruling, "In its Compliance Certification Application (CCA), the Department of Energy (DOE) presented four options for the design of the PCS, but did not specify which one would be constructed at the WIPP. The EPA based its certification decision on the condition that DOE implement the most robust design (referred to in the CCA as “Option D”). The Agency found the Option D design to be adequate, but also determined that the use of a Salado Mass Concrete – using brine rather than fresh water – would produce concrete seal permeabilities in the repository more consistent with the values used in DOE’s performance assessment. Therefore, Condition 1 of EPA’s certification requires DOE to implement the Option D PCS at the WIPP, with Salado Mass Concrete.” (EPA, 1998a)

DOE is proposing to modify the design of the PCS. In support of that proposal, DOE tasked Sandia National Laboratories (SNL) to assess the long-term impact of alternate panel closure systems on the performance of the WIPP. In response, SNL conducted a series of calculations, using the EPA-approved WIPP performance assessment (PA) models, which characterized the potential impact on repository performance of a range of panel closure permeabilities.

This document reports the analysis of the panel closure’s effects on the output of the two-phase flow performance assessment model. We first outline the methodology we applied to this impact assessment, describing the panel closures considered and the method we used to analyze the model results. We summarize the constraints under which the analysis was conducted and the consequent limits on the analysis. We present our findings of the effects on repository pressures and brine saturations of the panel closures. We compare this analysis with the results of the Technical Baseline Migration (TBM) calculations.
**Methodology**

We applied the performance assessment methodology to assess the impact on repository performance of varying the panel closure characteristics. As the first step in the performance assessment of the repository, we analyzed two-phase flow in and around the repository. We outline our approach to the analysis of two-phase flow and describe our method for identifying the effects of varying the panel closures.

**Approach**

As described in the analysis plan for the impact assessment, we investigated repository performance for two cases:

1. the Option D case in which the panel closures are modeled after the Option D design;
2. the PAVT case where the panel closures model a generic material with a fairly high permeability.

We developed a representation of the Option D panel closures within the approved performance assessment models of the repository and used the parameter set from the PAVT performance assessment to execute the necessary calculations (Hansen et al., 2002a). Since the PAVT performance assessment implemented the PAVT panel closures in the calculations, we retrieved the PAVT calculation results from the archives and did not re-run the PA codes for this case.

**Method of Comparison**

We compared the results of calculations for the two panel closure cases to identify the effects on two-phase flow of varying the panel closure characteristics. The two cases employed nearly identical model codes and parameter sets in order to isolate the effects of the different panel closures. We also employed the same sampling of input parameters as was used in the PAVT, allowing direct comparison of the results for each vector.

We restricted our comparison to those output variables that are significant to repository performance, namely: pressure and brine saturation in the waste-filled regions of the repository, and total brine flow away from the repository. Of the six scenarios calculated for the PAVT performance assessment, we examined the undisturbed scenario (S1) and two disturbed scenarios (S3 and S5) in which a single drilling intrusion takes place 1,000 years after closure of the repository. In the S3 scenario, a borehole penetrates through the repository into a brine reservoir in the Castile formation; in the S5 scenario, the borehole stops at the repository. These three scenarios are sufficient to determine the effects on the output variables of the panel closures. The S2 and S4 scenarios repeat the S3 and S5 scenarios but place the drilling intrusion at 350 years after repository closure; the S6 scenario is a combination of the S3 and S5 scenarios in which two drilling intrusions occur in the same panel, with the second borehole penetrating a brine reservoir beneath the repository.
Panel Closure Cases

In this section we describe the two panel closures, summarize the differences between the two panel closure cases, and discuss limitations on this analysis.

Option D and PAVT Panel Closures

The plan for this analysis describes how the Option D panel closures are represented in the PAVT grid (Hansen et al, 2002a). To account for the detailed features of the Option D panel closure within the resolution of the PAVT grid, we calculated an effective permeability, and volume-averaged porosity and initial brine saturation for the panel closure material PAN_SEAL. We did not change any grid dimensions or any other material assignment within the grid. For the PAVT panel closure case, we used the results of the 1997 PAVT performance assessment. The PAVT assumed a generic panel closure material with relatively high permeability. Table 1 summarizes the properties of the panel closure material for both cases; justification for the values in Table 1 is provided in Hansen et al., 2002a.

Table 1. Panel Closure Properties.

<table>
<thead>
<tr>
<th></th>
<th>Option D Panel Closure</th>
<th>PAVT Panel Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability (X-direction)</td>
<td>$9.01 \times 10^{-17}$ m$^2$</td>
<td>$1 \times 10^{-15}$ m$^2$</td>
</tr>
<tr>
<td>Permeability (Y-direction)</td>
<td>$1.93 \times 10^{-13}$ m$^2$</td>
<td>$1 \times 10^{-15}$ m$^2$</td>
</tr>
<tr>
<td>Permeability (Z-direction)</td>
<td>$1.93 \times 10^{-13}$ m$^2$</td>
<td>$1 \times 10^{-15}$ m$^2$</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.15</td>
<td>0.075</td>
</tr>
<tr>
<td>Initial Brine Saturation</td>
<td>0.21</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Other Differences between Baseline and Alternate Cases

Besides the differences in the panel closure material, the baseline and alternate cases differ in:

1. The fracture model in the upper DRZ.
2. Fourteen of the parameters for materials other than the panel closures.
3. The versions of the codes that were used for computation.

We discuss each of these differences and their potential effect on the outcome of the two-phase flow models.

In the PAVT, the anhydrite fracture model was applied to the DRZ as part of the sensitivity analysis. This fracture model is not part of the certified conceptual model of the DRZ. Thus, we did not apply the fracture model to the DRZ in the Option D panel closure case. This difference in the DRZ conceptual model has a slight effect on brine saturation, as we show later in this report.

Since the PAVT was calculated, the parameter database has been migrated to new database software. During the migration various errors in the PAVT parameter database were corrected. (Lechel and Tisinger, 2002) In the Option D case we used the parameter values from the PAVT with the corrections to erroneous parameter values. Table 2
summarizes the differences between the parameter set used in the two panel closure sets. We judge that none of the differences listed in Table 2 have any observable effect on the output from the two-phase flow code.

As a consequence of the new database software, several codes had to be modified to read from the new parameter database. All codes were tested with the new database to verify that the codes produced equivalent results. (Lechel and Tisinger, 2002) No other changes were made to the codes, so the two code versions produce equivalent results and the different code versions do not affect our comparison of code output. Table 3 lists the code versions that were used in each panel closure case.

Table 3. Code Versions that Differ Between the PAVT and the PCS Impact Assessment

<table>
<thead>
<tr>
<th>Code</th>
<th>PAVT version</th>
<th>Version used for PCS Impact Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATSET</td>
<td>9.00</td>
<td>9.10</td>
</tr>
<tr>
<td>PRELHS</td>
<td>2.10</td>
<td>2.30</td>
</tr>
</tbody>
</table>

Constraints on this Analysis

The panel closure impact assessment is intended to support a request by DOE to change the approved panel closure design. Hence, the impact assessment must employ the models, codes and parameter values that are certified for compliance calculations. The requirement to use the certified models imposes several constraints on the Option D panel closure case in this analysis.

The PAVT computational grid included two panel closures, each represented as a columns of 3 cells, 40 or 80 m wide, filled with a single material (PAN_SEAL). In contrast, the Option D panel closure design specifies three materials: a concrete monolith 7.9 m wide constructed of Salado Mass Concrete; an adjacent empty drift 9 m wide; and an explosion wall of mortared concrete block 3.7 m in width.

The PAVT grid does not provide sufficient resolution to explicitly represent these features. In order to represent some of the details of Option D panel closures within the PAVT grid, we calculated effective permeabilities for the components of the Option D panel closures and assigned these permeabilities to the material PAN_SEAL. In contrast, the TBM calculations explicitly represented the features of the Option D panel closures in an improved grid. (Stein, 2002). Since the TBM is not certified as part of the compliance baseline, we use the TBM results only to assist in understanding the result of this calculation.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>PAVT value</th>
<th>Present value</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPHALT – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>S_ANH_AB – SAT_RBRN</td>
<td>Residual brine saturation</td>
<td>Min: 6.884e-02</td>
<td>Min: 7.7846e-03</td>
<td>Correction</td>
</tr>
<tr>
<td>S_ANH_AB – SAT_RGAS</td>
<td>Residual gas saturation</td>
<td>Value 1.20000e-01 (Student dist.)</td>
<td>Value 1.16370e-01 (Student dist.)</td>
<td>Rounding error</td>
</tr>
<tr>
<td>S_MB138 – SAT_RBRN</td>
<td>Residual brine saturation</td>
<td>Min: 7.8460e-03</td>
<td>Min: 7.7846e-03</td>
<td>Correction</td>
</tr>
<tr>
<td>S_MB138 – SAT_RGAS</td>
<td>Residual gas saturation</td>
<td>Min: 1.3980e-02</td>
<td>Min: 1.3981e-02</td>
<td>Rounding error</td>
</tr>
<tr>
<td>S_MB139 – SAT_RBRN</td>
<td>Residual brine saturation</td>
<td>Min: 7.8460e-03</td>
<td>Min: 7.7846e-03</td>
<td>Correction</td>
</tr>
<tr>
<td>S_MB139 – SAT_RGAS</td>
<td>Residual gas saturation</td>
<td>Min: 1.3980e-02</td>
<td>Min: 1.3981e-02</td>
<td>Rounding error</td>
</tr>
<tr>
<td>S_MB139 – PRESSURE</td>
<td>Brine far-field pore pressure</td>
<td>Min: 1.111e+07 Max: 9.380e+06</td>
<td>Min: 9.380e+06 Max: 1.294e+07</td>
<td>Correction</td>
</tr>
<tr>
<td>SALT_T1 – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>SALT_T2 – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>SALT_T3 – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>SALT_T4 – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>SALT_T5 – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
<tr>
<td>SALT_T6 – POSE_DIS</td>
<td>Brooks-Corey pore distribution parameter</td>
<td>Max: 8.48</td>
<td>Max: 8.1</td>
<td>Correction</td>
</tr>
</tbody>
</table>
The conceptual model of the disturbed rock zone (DRZ) assumes that the DRZ extends above the excavated areas approximately 12 meters to Marker Bed 138. The permeability of the DRZ is sampled across a wide range, from $3.98 \times 10^{-20}$ m$^2$ to $3.16 \times 10^{-13}$ m$^2$. This permeability is applied homogeneously throughout the DRZ and changes only in response to pressure-induced fracturing. Analysis of the Option D panel closures in preparation for the TBM calculations concluded that halite creep in the DRZ immediately above the rigid concrete monolith would greatly reduce the permeability of this material. (Stein, 2002) The Option D panel closure case in this impact assessment does not include any healing of the DRZ above the panel closures, as this would require a change to the approved conceptual model for the DRZ. Consequently, even with the low effective permeability of the Option D panel closures, the DRZ may provide a highly permeable path around the panel closures.

As a consequence of these constraints, this analysis may not expose all the effects of varying the panel closure characteristics. Comparison with the TBM results should reveal the extent to which the above constraints influence the two-phase flow results, and if the constraints are significant in determining repository performance.
Analysis of Panel Closure Cases

In this section, we describe the results of the two-phase flow code for the two panel closure cases, and compare the cases to determine the differences caused by changing the panel closure properties.

We first summarize our conclusions from the analysis of the two-phase flow results. The analysis focused on those output variables that are significant to the remainder of the performance assessment models: pressure and brine saturation in the waste, and brine flow out of the repository through the marker beds and up a borehole. These output variables largely determine repository releases by spallings, direct brine release, and transport.

**Summary of Findings**

The PA VT and Option D panel closures represent a range of panel closure designs, distinguished primarily by their permeability to gas and brine. We found that pressures are slightly affected by the panel closure permeability, with less permeable panel closures increasing pressure in the waste regions. However, this increase in pressure only occurs when the DRZ also has a low permeability. The increase in pressure is transient, lasting only a few thousand years; over the long-term, pressures equilibrate even across the less permeable panel closures. Furthermore, neither panel closure has a noticeable effect on pressure after a drilling intrusion.

We found that the different panel closures do not significantly alter either the brine saturation in the waste regions or the coarse measures of brine flow into and out of the repository.

The increased pressures in the Option D panel closure case may increase the likelihood that the first drilling intrusion causes a release due to spallings. Since brine saturations are similar in both panel closures cases, we expect that direct brine releases will be similar. Likewise we do not expect that releases by transport to be different since brine flows are comparable in both panel closure cases. The effect of the panel closures on releases will be calculated in the remainder of the PA codes, and reported in a subsequent analysis.
Undisturbed Scenario (S1)

We discuss the effects of the panel closures on repository pressure, brine saturation and cumulative measures of brine flow in the undisturbed scenario.

Pressure

Figures 1 through 4 show pressure in the waste panel and rest of repository for all 100 vectors in the undisturbed scenario. These figures show that the long-term pressures behave similarly in either case. For many vectors, the short-term pressures are also equal in either case. However, in some vectors, the less-permeable panel closure causes a small, transient increase in pressure in the waste regions as compared to a highly permeable panel closure. The difference in pressure lasts only a few thousand years, after which the pressures in the waste regions equilibrate for either panel closure.

We found that this transient increase in pressure occurs only when the DRZ permeability is also low. Figure 5 compares pressure in the waste panel for the Option D panel closures to pressure in the waste panel for the PAVT panel closures, at 1,000 years. In this scatterplot we separated the vectors into two groups: those with DRZ permeability less than \(10^{-16}\) (low DRZ permeability vectors); and those with DRZ permeability at least \(10^{-16}\) (high DRZ permeability vectors.) The scatterplot shows that for vectors with high DRZ permeability, the pressure in the waste panel is essentially the same with either panel closure. However, for vectors with low DRZ permeability, pressures in the waste panel are increased by the less permeable panel closure. When the DRZ has a relatively high permeability, gas can readily move around the panel closures to equilibrate differences in pressures. When the DRZ permeability and the panel closure permeability are both low, there is no highly permeable path between adjacent regions through which gas can move to equilibrate pressures.

Figure 5 also indicates the effects of the panel closures on spallings releases from a first drilling intrusion. Spallings releases occur if pressure in the waste panel exceeds \(8 \times 10^6\) Pa at the time of intrusion. Figure 5 shows that, at 1,000 years, roughly 10 out of 100 vectors have pressure below \(8 \times 10^6\) Pa with the PAVT panel closures and pressure above \(8 \times 10^6\) Pa with the Option D panel closures. Hence, if a drilling intrusion occurs at 1,000 years, spallings releases in the Option D panel closure case will be about 10% more than in the PAVT panel closure case. The degree to which total spallings releases may increase will be calculated and presented in the final report for this impact assessment.
Figure 1. Pressure in Waste Panel, Option D Panel Closures, Undisturbed Scenario.

Figure 2. Pressure in Waste Panel, PAVT Panel Closures, Undisturbed Scenario.
Figure 3. Pressure in Rest of Repository, Option D Panel Closures, Undisturbed Scenario.

Figure 4. Pressure in Rest of Repository, PAVT Panel Closures, Undisturbed Scenario.
We computed the difference in pressure in the waste panel for each vector for both panel closure cases. We performed a sensitivity analysis that computed the correlation between the differences in pressure in the waste panel (variable WAS_PRES) between the two panel closure cases and all the sampled input parameters. Figure 6 shows the partial rank correlation coefficients for the sampled input variables whose correlations exceeded 0.5 at some time. The sensitivity analysis confirmed that the variation in DRZ permeability (DRZPRM) is responsible for the variation in the differences in pressure for the first 6,000 years. After 6,000 years, the variation in the porosity of the surrounding halite (HALPOR) becomes equally significant in explaining the variation in the difference in pressures. The waste wicking factor (WASTWICK) appears on the plot but its correlation exceeds the threshold only briefly; for almost all of the 10,000 year period this parameter is not significant.
Brine Saturation

Figures 7 through 10 show brine saturation in the waste panel and rest of repository for all 100 vectors in the undisturbed scenario. These figures show that brine saturations are not greatly affected by the different panel closures. Comparisons of brine saturation show that, for about half the vectors the brine saturation in the waste panel is slightly lower in the Option D panel closure case than in the CCA panel closure case. This difference in brine saturation results primarily from the reduction in brine flow within the repository downhill across the panel closure material. Our sensitivity analysis showed that the variation in the difference in brine saturation is explained by the variation in DRZ permeability, indicating that brine flows around the panel closures when the DRZ is fairly permeable.
Figure 7. Brine Saturation in Waste Panel, Option D Panel Closures, Undisturbed Scenario.

Figure 8. Brine Saturation in the Waste Panel, PAVT Panel Closures, Undisturbed Scenario.
Figure 9. Brine Saturation in Rest of Repository, Option D Panel Closures, Undisturbed Scenario.

Figure 10. Brine Saturation in the Rest of Repository, PAVT Panel Closures, Undisturbed Scenario.
For two vectors, however, brine saturation in the Option D panel closure case is significantly less over the long-term than in the PAVT with CCA panel closures. Figure 11 compares brine saturation in the waste panel for vector 28 and 58. The difference in brine saturation for these two vectors is due to the different application of the fracture model to the upper DRZ. In the PAVT with CCA panel closures, pressure-induced fracturing greatly increases the permeability of the DRZ, which in turn permits a large inflow of brine at the time of fracturing. We did not apply this fracture model in the Option D panel closure case, thus, in this case there is no additional brine inflow and brine saturation remains low. One other vector (vector 51) showed significant fracturing in the PAVT with CCA panel closures. However, the sampled DRZ permeability (material DRZ_1 property PRMX_LOG) for this vector is $6.16 \times 10^{-14}$, which can't be significantly increased by fracturing. Hence, in vector 51 there is no additional brine inflow and no consequent increase in brine saturation.

Figure 11. Brine Saturation in Waste Panel for Vectors 28 and 58, Undisturbed Scenario.

Since the effect on brine saturation of different panel closures is not significant for almost all vectors, we do not further explore the reasons for the small differences in brine saturation between the two cases. We expect that the two panel closure cases will show similar direct brine releases from the first drilling intrusion.
Brine Flow in the Undisturbed Scenario

As illustrated in Figures 12 and 13, we compared two coarse measures of brine flow into the repository for the two panel closure cases:

- Cumulative brine flow into the waste-filled regions of the repository from all sources (BRNREPTC)
- Cumulative brine flow into the DRZ from all marker beds (BRAALIC)

As discussed earlier, in vectors 28 and 58, the fracture model applied to the upper DRZ greatly increases the brine flow from the upper DRZ in the PAVT panel closure case. The increased flow is evident in the PAVT, as shown in Figure 12. No other vectors had fracturing that affected the BRAGFLO results.

Figure 13 shows that cumulative flow from all marker beds changed significantly for vector 100. The PAVT showed much greater flow from the marker beds into the experimental area at the north of the repository. Investigation revealed an error in the BRAGFLO input files for the PAVT, where bulk compressibility was used in place of pore compressibility for a few materials. This error affected the two-phase flow properties of the shaft concrete, and prevented gas flow from the southern regions of the repository into the experimental area. Consequently, pressure in the experimental area remained low, permitting larger volumes of brine to flow in from the marker beds.

We corrected the error in the Option D case. We observed that gas flowed into the experimental area after the correction, increasing pressure and thus retarding brine flow from the marker beds. No other vectors were significantly affected by this error correction.

Except for these three vectors, we observed no significant differences between the two panel closure cases in either of the variables above. We conclude that the panel closure properties do not significantly affect total brine flows into or out of the repository in the undisturbed scenario.
Figure 12. Total Brine Flow into Waste Regions, Undisturbed Scenario.

Figure 13. Total Brine Flow from all Marker Beds, Undisturbed Scenario.
Disturbed Scenarios (S3 and S5)

In the disturbed scenarios, a drilling intrusion into the waste panel takes place at 1,000 years. Repository pressure and brine saturation are identical to the undisturbed scenario until the time of intrusion. In the S3 scenario, the borehole penetrates through the repository into a reservoir of brine in the Castile formation. This brine may flow up the borehole into the repository. In the S5 scenario, the borehole does not encounter a brine reservoir below the repository. Boreholes are plugged above the repository at the time of intrusion. These plugs degrade after 200 years and are replaced by a sandy, much more permeable material (DOE, 1996).

Pressure in the S3 Scenario

Figures 14 and 15 show pressure in the waste panel for all 100 vectors in the S3 scenario for both panel closure cases. Pressure sharply increases at the time of intrusion due to the brine flowing up the borehole from the Castile, which results in additional gas generation. After 200 years, the borehole plugs above the repository degrade, and pressure is sharply reduced by gas flow up the borehole. Pressure in the rest of repository behaves similarly.

Figures 14 and 15 show that pressure generally behaves the same for both panel closure cases over the long-term. As discussed in the analysis of the undisturbed scenario, less permeable panel closures result in slightly higher pressures at the time of intrusion (at 1,000 years). After intrusion, however, pressure in the waste regions is dominated by brine and gas flow in the borehole rather than brine and gas flow across panel closures within the repository. Consequently, after the drilling intrusion pressures in the waste panel and in the rest of repository are quite similar in the two panel closure cases.

We anticipated that less permeable panel closures would result in the intruded panel’s pressure being lower than in the rest of repository area. However, this anticipated effect was minimal in the S3 scenario due to the inflow of brine from the Castile. Figure 16 shows mean pressures in the waste panel and rest of repository for both panel closure cases in the S3 disturbed scenario; the figure shows little transient difference in pressures immediately after the intrusion. Brine flow up the borehole from the Castile generates additional gas and maintains pressure in the waste panel, so there is no large difference in pressure across the panel closure. Figure 17 shows mean pressures in the waste panel and rest of repository for both panel closure cases in the S3 disturbed scenario averaged across only the vectors in which DRZ permeability (material DRZ_1 property PRMX_LOG) was lower than $1 \times 10^{-18}$ m$^2$. After about 3,000 years, there is a small but persistent difference in pressure across the panel closure when the DRZ also has a low permeability.

Pressure in the S5 Scenario

Figures 18 and 19 show pressure in the waste panel for all 100 vectors in the S5 scenario for both panel closure cases. In the S5 scenario, the borehole does not penetrate a brine reservoir below the repository. Hence there is no effect on pressure until 1,200 years, when the borehole plugs above the repository degrade and become highly permeable. At that time pressure in the repository is sharply reduced. Figures 18 and 19 show that pressures generally behave the same for the two panel closure cases over the long-term.
Figure 14. Pressure in Waste Panel, Option D Panel Closures, S3 Scenario.

Figure 15. Pressure in Waste Panel, PAVT Panel Closures, S3 Scenario.
Figure 16. Mean Pressures, S3 Scenario, All Vectors.

Figure 17. Mean Pressures, S3 Scenario, Vectors with Low DRZ Permeability.
Figure 18. Pressure in Waste Panel, Option D Panel Closures, S5 Scenario.

Figure 19. Pressure in Waste Panel, PAVT Panel Closures, S5 Scenario.
We anticipated that less permeable panel closures would result in the intruded panel's pressure being lower than in the rest of repository area. This anticipated effect was minimal in the S3 scenario due to the inflow of brine from the Castile, which rapidly builds pressure in the intruded panel. In contrast, the S5 scenario shows a pronounced difference in pressure between the intruded panel and the rest of repository.

Figure 20 compares mean pressures in the waste panel and rest of repository for both panel closure cases for the S5 scenario. In the Option D case, the less permeable panel closures result in slightly higher pressures in the waste panel before the intrusion at 1,000 years. After intrusion, in the Option D case there is a pronounced difference in pressure between the rest of repository and waste panel, which slowly decays over time. This difference in pressure between the rest of repository and waste panel is not observed in the PAVT panel closure case. The less permeable panel closures impede the flow of gas from the rest of repository to the waste panel. In the S5 scenario, there is far less brine flow through the borehole into the waste than in the S3 scenario, and consequently less pressure.

Figure 20. Mean Pressures, S5 Scenario, All Vectors.
Brine Saturation in the Disturbed Scenarios
Figures 21 through 24 show brine saturation in the waste panel for all 100 vectors in the S3 and S5 scenarios for both panel closure cases. These figures show that brine saturation results are similar in the disturbed scenarios for either panel closure case. For many vectors, brine saturation is affected by the differences in panel closures in a complex manner. However, the statistical distribution of volume-averaged saturations remains similar. Figures 25 and 26 compare the mean, median, 10th and 90th quantiles of the distribution of brine saturations in the waste panel in the S3 and S5 scenario, respectively. These figures show that the different panel closures do not alter the distribution of brine saturations.

Brine Flow in the Disturbed Scenarios
In the disturbed scenarios, we compared the following coarse measures of brine flow into and out of the repository for the two panel closure cases:

- Cumulative brine flow into the waste-filled regions of the repository from all sources (BRNREPTC)
- Cumulative brine flow into the DRZ from all marker beds (BRAALIC)
- Cumulative brine flow up the borehole from the Castile (BNBHLDNZ, S3 scenario only)
- Cumulative brine flow up the borehole out of the repository (BNBHUDNZ)
- Cumulative brine flow down the borehole from the above the repository (BNBHNDNUZ)

As in the undisturbed scenario, we observed only slight differences between the two panel closure cases for each of the variables above. We conclude that the panel closure properties do not significantly affect total brine flows into or out of the repository in the disturbed scenarios.
Figure 21. Brine Saturation in Waste Panel, Option D Panel Closures, S3 Scenario.

Figure 22. Brine Saturation in Waste Panel, PAVT Panel Closures, S3 Scenario.
Figure 23. Brine Saturation in Waste Panel, Option D Panel Closures, S5 Scenario.

Figure 24. Brine Saturation in Waste Panel, Option D Panel Closures, SS Scenario.
Figure 25. Distribution of Brine Saturation in Waste Panel, S3 Scenario.

Figure 26. Distribution of Brine Saturation in Waste Panel, S5 Scenario.
Comparison with the Technical Baseline Migration

In this section we compare the results obtained from the panel closure impact assessment calculations with the results obtained from the TBM calculations. Among other changes and corrections, the TBM calculation refined the computational grid and modified the PAVT input parameters to explicitly represent the Option D panel closures (Stein, 2002). In addition, the TBM modified the conceptual model of the DRZ to account for healing in the halite surrounding the panel closure monolith. For materials other than those representing panel closures, the TBM calculation used the same sampling of input parameters as was used in this analysis and the PAVT, allowing a direct comparison of results.

The results of the BRAGFLO calculations for the TBM are documented in Hansen et al, 2002b. The analysis of the TBM BRAGFLO calculations isolates the effects of the various changes and corrections to the BRAGFLO model and computational grid. The analysis shows that the most of the differences between the TBM and PAVT BRAGFLO calculations are due to the Option D panel closures. The effects of the other changes and corrections are minor by comparison.

The comparison between the Option D case in this impact assessment and the TBM is motivated by the difference in the level of detail included in each calculation. We believe that the TBM analysis better represents the effects of the Option D panel closures on the repository than does the Option D panel closure case in this impact assessment. Comparison of this impact assessment with the TBM seeks to determine whether the difference in the level of detail is significant to estimating releases from the repository. In this report, we compare pressure and saturation of the Option D panel closure case, since pressure and saturation largely determine releases due to spallings and direct brine releases.

Summary of Findings

We found that pressures are somewhat higher in the TBM than in the Option D case in this impact assessment, but that brine saturations in the TBM are significantly lower. Consequently, we expect that the Option D case will produce larger direct brine releases than are calculated in the TBM, and hence the Option D case can be viewed as conservative with respect to direct brine releases. However, the differences in pressures may lead to larger spallings releases in the TBM than in the Option D case in this impact assessment, indicating the possibility that this impact assessment may underestimate releases due to spallings. The degree to which spallings may be underestimated will be determined after the rest of the performance assessment codes are run.
Differences between the Option D Case and the TBM

The Option D panel closure case modified only the material properties assigned to the panel seal material as described earlier in this report. The TBM added cells to the computational grid to explicitly represent the two components of the Option D panel closure, the concrete monolith and the adjacent drift. The concrete monolith was extended above and below the excavated drift as specified by the Option D design. Appropriate properties were assigned to these two materials as documented in Stein, 2002.

In addition, the TBM assumed that the DRZ immediately above the concrete monolith would heal. In the TBM this column of halite was assigned permeabilities ranging from $2 \times 10^{-21} \text{ m}^2$ to $1 \times 10^{-17} \text{ m}^2$, using a triangular distribution with most likely value of $1.7 \times 10^{-19} \text{ m}^2$ (material DRZ_PCS property PRMX_LOG). To allow for pressure-induced fracturing around the bottom of the concrete monolith, which lies in Marker Bed 139, we applied the anhydrite fracture model to the lower DRZ and to the bottom cell of the concrete monolith. In combination with the low permeabilities assigned to the concrete monolith, the TBM removed all high-permeability paths around the panel closures except those opened by pressure-induced fracturing.

The TBM divided the rest of repository into two separate blocks of cells, separated by an additional panel closure. This refinement more accurately represents the effects of the panel closures on flow within the waste-filled regions of the repository. In the PAVT grid, the waste panel acts as a surrogate for any intruded panel, but is only separated from the region representing the other nine waste panels by a single panel closure.

Finally, the TBM incorporated a number of corrections and improvements to the BRAGFLO code and to parameters that have been identified as needed since the PAVT. The computational grid’s scaling and flaring algorithms were modified to correct an error in the PAVT grid and to improve numerical accuracy. The molecular weight of cellulose was corrected, resulting in slightly more gas generated in the TBM than in the PAVT.

In its comparison with the PAVT, the TBM analysis identifies the effects of these corrections and improvements separately from the effects of the Option D panel closures. (Hansen et al, 2002b) The analysis showed that most of the differences between the TBM and the PAVT arise from the Option D panel closures. The effects of the other corrections and improvements are minor by comparison.

Undisturbed Scenario

In the performance assessment, the undisturbed scenario is used to calculate release for the initial drilling intrusion. In this section we compare pressures and saturations for the Option D panel closure case to the TBM. We observe that the Option D panel closure case has similar pressures but higher saturations, resulting in similar spillings releases but higher direct brine releases. We conclude that the Option D panel closure case likely overestimates releases from the first drilling intrusion.
The distribution of pressures in the Option D panel closure case is similar to that in the TBM. Figure 27 compares pressure distributions between the Option D panel closure case and the TBM. Since the two panel closure cases in this analysis have similar distributions of pressure in the waste panel, we conclude that this analysis will result in roughly the same amount of spallings releases from the first drilling intrusion as will the TBM.

Figure 27. Distribution of Pressure in Waste Panel, Undisturbed Scenario.

We observed some small differences in pressure between the Option D panel closure case and the TBM. Figure 5 shows that pressure in the waste area is generally higher in the Option D panel closure case than in the PAVT panel closure case. The figure shows that this transient increase in pressure occurs for vectors with low DRZ permeability; for other vectors pressures are nearly equal. In contrast, in the TBM this increase in pressure is evident in almost all vectors, rather than just those vectors with low DRZ permeability. The TBM included healing in the DRZ above the panel closures, which placed a low permeability barrier in the DRZ above the panel closures, thus increasing pressure for almost all vectors.

We found that the brine saturations in the waste panel are significantly higher in the Option D panel closure case than in the TBM. Figure 28 compares the distributions of brine saturation in the waste panel for both calculations. In the TBM, the Option D panel

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closures extended down into the lower DRZ, blocking brine flow from the uphill regions of the repository. In addition, the TBM grid corrected an error in the flaring of the PAVT grid, which had placed the waste panel adjacent to a much larger volume of country rock, and thus artificially increased the brine saturation in the waste panel. These differences combined result in significantly lower saturations in the waste panel in the TBM than observed in the Option D panel closures case in this impact assessment. As a consequence, we believe that this impact assessment is likely to overestimate direct brine release for the first drilling intrusion.

**Figure 28. Distribution of Brine Saturation, Undisturbed Scenario.**

![Graph showing brine saturation distribution](image)

**Disturbed Scenario (S3)**

The S3 scenario determines repository response after an initial drilling intrusion that intersects a brine reservoir in the Castile below the repository. Pressures and saturations in the S3 scenario are used to calculate the releases from subsequent drilling intrusions into the previously intruded panel and from first intrusions into the other panels, represented by the rest of repository. We found that the Option D panel closure case may underestimate spallings and may overestimate direct brine releases from intrusions into the rest of repository.
We compared the distributions of pressures and saturations in the waste panel and rest of repository between the Option D panel closure case and the TBM. We found that the two calculations produced similar pressures in the waste panel and in the rest of repository, as illustrated in Figures 29 and 30. Although the distributions of pressures in the rest of repository are similar, the median pressures are concentrated around $8 \times 10^6$ Pa, the threshold pressure above which spallings releases occur. Hence, the TBM's slightly higher pressures in the rest of repository may translate to large differences in spallings releases between the TBM and the Option D case.

Figure 29. Distribution of Pressure in Waste Panel, S3 Scenario.

Brine saturation in the waste panel is similar in the two calculations. However, the rest of repository is significantly more saturated with brine in the Option D panel closure case as compared to the TBM. Figure 31 illustrates the differences in saturation. We conclude that the Option D panel closure case will overestimate direct brine releases from intrusions into the rest of repository and hence is conservative.
Figure 30. Distribution of Pressure in Rest of Repository, S3 Scenario.

Figure 31. Distribution of Brine Saturation in Rest of Repository, S3 Scenario.
**Disturbed Scenario (S5)**

The S5 scenario determines repository response after an initial drilling intrusion that does not intersect a brine reservoir in the Castile below the repository. Pressures and saturations in the S5 scenario are used to calculate the releases from subsequent drilling intrusions into the previously intruded panel and from first intrusions into the other panels, represented by the rest of repository. We found that the Option D panel closure case may underestimate spallings and may overestimate direct brine releases from intrusions into the rest of repository.

In the S5 scenario in the TBM, we observed a significant transient difference in pressure between the waste panel and the adjacent rest of repository, which persisted for several thousand years after the intrusion. This difference in pressure is caused by the Option D panel closures, which impede flow of gas and brine between adjacent regions of the repository, and lengthen the time required to equilibrate differences in pressure. Figure 32 compares mean pressure in the rest of repository for the two panel closure cases and the TBM for the S5 scenario. The Option D panel closure case shows a smaller difference in pressure between the waste panel and the rest of repository than in the TBM. Hence, we conclude that this impact assessment may underestimate pressures in the rest of repository in the S5 disturbed scenario, which may in turn underestimate releases due to spallings from drilling intrusions into the rest of repository.
In the TBM we found that the waste panel and the rest of repository were significantly less saturated with brine in the S5 scenario than in the PAVT. Figure 33 compares mean brine saturation in the waste panel for the two panel closure cases and the TBM; differences in brine saturation in the rest of repository between the two panel closure cases and the TBM are similar. We conclude that this impact assessment overestimates brine saturation in the waste panel and in the rest of repository in the S5 scenario, and hence is likely to overestimate direct brine releases from subsequent drilling intrusions.
Figure 33. Mean Brine Saturation in Waste Panel, S5 Scenario.
Conclusions

This report presents the analysis of the panel closure's effects on the output of the two-phase flow performance assessment code, BRAGFLO. We considered two panel closure cases: one modeled upon the mandated Option D panel closure design, and a second modeled upon the generic panel closure included in the performance assessment conducted for the PAVT. The primary distinction between these two panel closure cases is the permeability of the panel closure material, which ranges from quite low in the case of the Option D panel closure to fairly permeable in the PAVT panel closure case.

We found that the two panel closure cases produce pressure and brine saturations that are not significantly different. Consequently, we expect that the full performance assessment will show that the two panel closure cases produce similar releases.

We compared the results of this analysis to the preliminary results of the TBM to corroborate our analysis. The TBM models the Option D panel closures with greater detail than was applied in the Option D case in this impact assessment. We found that the Option D case in this impact assessment may overestimate direct brine releases; however, we found that the Option D case may underestimate releases due to spallings. The degree to which spallings releases may be underestimated will be determined after the rest of the performance assessment codes are run.
References


Appendix A. Run Control Documentation

Purpose
This appendix contains run control documentation for BRAGFLO component of the Performance Assessment for the Option D panel closure (PAD) calculation. Similar documentation for the PAVT is provided in Aragon et al, 1997. This information in this appendix ensures reproducibility for the calculation.

History of the Qualified Computational Environment
The Option D panel closure calculation is referred to as the PAD calculation in the code management system (CMS) libraries. The calculations were completed during May and June 2002 on Sandia's VAX cluster running OpenVMS 7.2. A summary of the changes to the performance assessment computing system since the CCA is provided in Lechel and Tisinger, 2002.

Selection of script, code and input file versions
Table A I lists the version and build date for each code used in the BRAGFLO component of the PAD calculation. We modified the run scripts from the TBM calculation to run the PAD.

Table A.1. Code versions used in the PAD Calculations.

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<tr>
<th>Code name</th>
<th>Version</th>
<th>File Spec/Build Date</th>
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<td>ALGEBRACDB PA96 - 31-JAN-1996</td>
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<tr>
<td>BRAGFLO</td>
<td>4.10</td>
<td>BRAGFLO PA97 - 8-MAY-1997</td>
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<td>GENMESH</td>
<td>6.08</td>
<td>GM PA96 - 31-JAN-96</td>
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<td>ICSET</td>
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<td>ICSET PA96 - 1-FEB-1996</td>
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<td>2.41</td>
<td>LHS PA96 2 - 6-MAR-1996</td>
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<td>MATSET QA0310- 29-NOV-2001</td>
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<td>POSTBRAG PA96 - 6-FEB-1996</td>
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<td>POSTLHS PA96 - 7-FEB-1996</td>
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</table>

Explanation of Run Control Tables
Tables A.2 and A.3 list the files used in the BRAGFLO PAD Calculation. The tables include a heading indicating the code being run, and the process step. Many code sets are broken down into a first step (step 1) that runs utility codes such as Genmesh (GM), Matset (MS), and LHS, and the second step (step 2) that runs the primary code along with any pre and post processors. Step 1 codes are generally run once, or once per scenario, step 2 codes are generally run once per vector.
The run control tables are intended to provide all the information normally required to document a calculation. The tables contain six columns:

1. **Code** – the descriptive common code name (ICSET, ALGEBRACDB, BRAGFLO, etc) indicating the row relates to that code, “script” indicating the row relates to the run control system, or blank indicating the row relates to the previous code label. Completely blank rows are for visual separation only.

2. **File name** – VMS file name in the form filename extension. Placeholders are included when multiple scenarios or vectors are being represented.

3. **File type** – indicates the type of file being identified from the point of view of the current step of the run control system. These include script, script log, executable, input, and output. The output from one step may be the input of another step.

4. **CMS library** – contains the CMS library name where the controlled version of the file can be found, or contains the string ”not in CMS”. Many files generated by a calculation are for debug purposes, or are intermediate in nature, and are not retained after execution. Files that have been identified as required are stored in CMS.

5. **Source** – when needed, identifies the source for a file. For example many input files were copied from CCA CMS libraries. Files were copied so that the RH-TRU libraries would be self-contained, enhancing reproducibility.

6. **Comment** – various comments including some run dates, database views, code version numbers, and so on.
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<th>File Type</th>
<th>CMS Library</th>
<th>Source</th>
<th>Comments</th>
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<td>script</td>
<td>pad_eval</td>
<td>n/a</td>
<td>Instance Script</td>
</tr>
<tr>
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<td><code>eval bf_pad_run_master.com</code></td>
<td>script</td>
<td>pad_eval</td>
<td>n/a</td>
<td>Distribution Script</td>
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<td>pad_alg</td>
<td>Provided by</td>
<td>CWHANSE</td>
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Table A. 3 BRAGFLO Step 2.

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<td></td>
<td>Built 2/6/1996</td>
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<td></td>
<td>bf1_pad_r1_sy.inp</td>
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<td>Provided by Jim Bean</td>
<td>S1, S3, S5</td>
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<td>pad_alg</td>
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<td>n/a</td>
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<td>n/a</td>
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