In-Situ Testing and Performance Assessment of a Redesigned WIPP Panel Closure – 13192

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ABSTRACT

There are two primary regulatory requirements for Panel Closures at the Waste Isolation Pilot Plant (WIPP), the nation's only deep geologic repository for defense related Transuranic (TRU) and Mixed TRU waste. The Federal requirement is through 40 CFR 191 and 194, promulgated by the U.S. Environmental Protection Agency (EPA). The state requirement is regulated through the authority of the Secretary of the New Mexico Environment Department (NMED) under the New Mexico Hazardous Waste Act (HWA), New Mexico Statutes Annotated (NMSA) 1978, §§ 74-4-1 through 74-4-14, in accordance with the New Mexico Hazardous Waste Management Regulations (HWMR), 20.4.1 New Mexico Annotated Code (NMAC). The state regulations are implemented for the operational period of waste emplacement plus 30 years whereas the federal requirements are implemented from the operational period through 10,000 years. The 10,000 year federal requirement is related to the adequate representation of the panel closures in determining long-term performance of the repository. In Condition 1 of the Final Certification Rulemaking for 40 CFR Part 194, the EPA required a specific design for the panel closure system. The U.S. Department of Energy (DOE) Carlsbad Field Office (CBFO) has requested, through the Planned Change Request (PCR) process, that the EPA modify Condition 1 via its rulemaking process. The DOE has also requested, through the Permit Modification Request (PMR) process, that the NMED modify the approved panel closure system specified in Permit Attachment G1.

The WIPP facility is carved out of a bedded salt formation 655 meters below the surface of southeast New Mexico. Condition 1 of the Final Certification Rulemaking specifies that the waste panels be closed using Option D which is a combination of a Salado mass concrete (SMC) monolith and an isolation/explosion block wall. The Option D design was also accepted as the panel closure of choice by the NMED. After twelve years of waste handling operations and a greater understanding of the waste and the behavior of the underground salt formation, the DOE has established a revised panel closure design. This revised design meets both the short-term NMED Permit requirements for the operational period, and also the Federal requirements for

† Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This research is funded by WIPP programs administered by the Office of Environmental Management (EM) of the U.S Department of Energy.

long-term repository performance. This new design is simpler, easier to construct and has less of an adverse impact on waste disposal operations than the originally approved Option D design.

The Panel Closure Redesign is based on: (1) the results of in-situ constructability testing performed to determine run-of-mine salt reconsolidation parameters and how the characteristics of the bedded salt formation affect these parameters and, (2) the results of air flow analysis of the new design to determine that the limit for the migration of Volatile Organic Compounds (VOCs) will be met at the compliance point.

Waste panel closures comprise a repository feature that has been represented in WIPP performance assessment (PA) since the original Compliance Certification Application of 1996. Panel closures are included in WIPP PA models principally because they are a part of the disposal system, not because they play a substantive role in inhibiting the release of radionuclides to the outside environment. The 1998 rulemaking that certified WIPP to receive transuranic waste placed conditions on the panel closure design to be implemented in the repository. The revised panel closure design, termed the Run-of-Mine (ROM) Panel Closure System (ROMPCS), is comprised of 30.48 meters of ROM salt with barriers at each end. The ROM salt is generated from ongoing mining operations at the WIPP and may be compacted and/or moistened as it is emplaced in a panel entry. The barriers consist of bulkheads, similar to those currently used in the panels as room closures. A WIPP performance assessment has been completed that incorporates the ROMPCS design into the representation of the repository, and compares repository performance to that achieved with the approved Option D design. Several key physical processes and rock mechanics principles are incorporated into the performance assessment. First, creep closure of the salt rock surrounding a panel entry results in consolidation of the ROM salt emplaced in the entry. Eventually, the ROM salt comprising the ROMPCS will approach a condition similar to intact salt. As the ROM salt reaches higher fractional densities during consolidation, back stress will be imposed on the surrounding rock mass leading to eventual healing of the disturbed rock zone above and below the panel closure. Healing of the disturbed rock zone above and below the ROMPCS reduces the porosity and permeability in those areas.

Analysis of the new design demonstrates that: (1) the WIPP continues to meet regulatory compliance requirements when the ROMPCS design is implemented instead of Option D, and (2) there is no impact on the short-term effectiveness of the panel closure to limit the concentration of VOCs at the WIPP site boundary to a fraction of the health-based exposure limits (HBLs) during the operational period.

INTRODUCTION

The regulations governing WIPP are a combination of both Federal and State requirements. The primary Federal regulatory requirements for WIPP are through 40 Code of Federal Regulations, Title 40, Part 191 (40 CFR Part 191) and 40 CFR Part 194 and are regulated by the EPA for long-term repository performance. The timeframe for long-term repository performance is from closure to 10,000 years. WIPP’s Federal certification is reviewed every five years for renewal. The state regulatory compliance requirements for WIPP fall primarily under the New Mexico Hazardous Waste Act (HWA), New Mexico Statutes Annotated (NMSA) 1978, §§ 74-4-1 through 74-4-14, in accordance with the New Mexico Hazardous Waste Management

Regulations (HWMR), 20.4.1 New Mexico Annotated Code (NMAC). This results in the issuance of the WIPP Hazardous Waste Facility Permit (HWFP), otherwise known as the Permit. The Permit is reviewed every ten years for renewal and cover the operational period plus 30 years.

Regulatory History and Panel Closure Design Evolution

40 CFR Part191 establishes the environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes. 40 CFR Part 194 establishes the criteria for the certification and re-certification of the Waste Isolation Pilot Plant's compliance with the 40 CFR Part 191 disposal regulations. Part 194 sets forth the specific functions of the Panel Closure System.

The DOE submitted the Compliance Certification Application (CCA) to the EPA in October of 1996 [1]. The CCA is a detailed document that establishes how the DOE will comply with the requirements of 40 CFR 194. Chapter 3 and Appendix Panel Closure System, of the CCA, offered five options for the design of the panel closure system. On May 18, 1998, the EPA issued a certification decision showing that WIPP met the radioactive waste disposal standards [2]. This certification decision identified as Condition 1 of the certification, that the most robust design offered, Option D (Figure 1), is required to perform Panel Closures.

"*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 [CCA] 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 CCA Appendix SEAL of Docket A-93-02, Item II-g-1) instead of fresh water concrete.*"

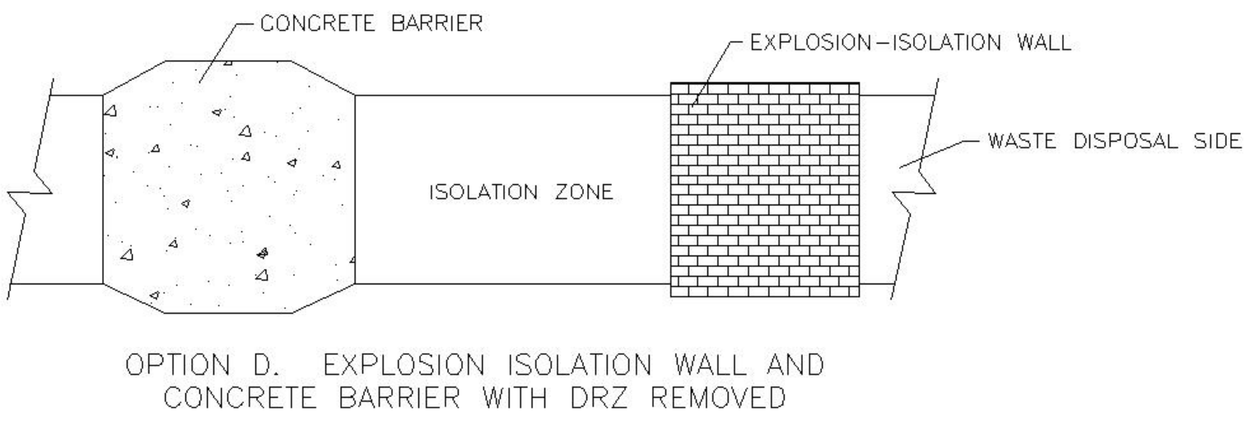

Fig. 1. Option D Panel Closure.

Condition 1 of 40 CFR Part 194 specifically requires that the DOE shall use Salado Mass concrete which is used in the design of the shaft seals. On October 27, 1999, the NMED also specified that the most robust Panel Closure design, Option D, was to be constructed for all panel closures [3]. NMED specifically stated that the concrete to be used for panel closures would be salt-saturated Salado Mass Concrete (specified in Permit Attachment I1, Appendix G, 2000).

These specifications for the use of Salado Mass concrete was an unusually specific requirement by the regulators that upon further review by the DOE would be extremely difficult to comply with.

In 2001, the DOE realized that the specifications required in the original Certification decision, and subsequently the Permit, would be difficult to implement along with the schedule required for implementation of the Panel Closure System. As a result, the DOE requested changes to the Panel Closure System design and schedule to both the EPA and NMED.

Upon further review, and the release of additional scientific research in the area of salt repositories, the DOE withdrew the 2001 Panel Closure change requests in order to evaluate their strategy forward.

In 2002, the DOE submitted a new Panel Closure Design to the EPA and NMED that consisted of two components: a concrete block wall and ROM salt backfill. The timing of the submittal of this new Panel Closure Design conflicted with the submittal of the first Certification Reapplication for WIPP. Due to this submittal conflict the EPA notified the DOE that the new Panel Closure Design would not be evaluated until after the Certification Reapplication review was completed and that the change request would require a rulemaking. However, the NMED did grant an extension to the Permit schedule for closure of Panel 1.

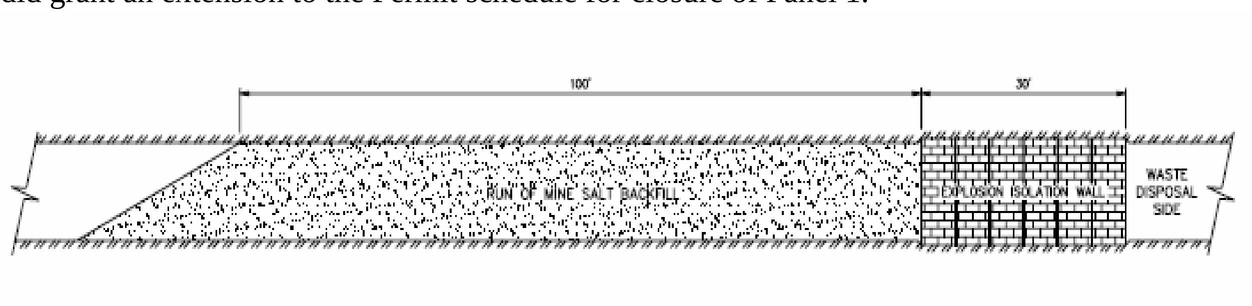

Fig. 2. 2002 Panel Closure Conceptual Design.

In 2003, the DOE submitted a request to both the EPA and NMED to amend the closure schedule for Panel 1 to allow for placement of only the block wall component of the Option D design (Figure 3). This request was followed by an additional request to reduce the block size for the block wall portion of the Option D design. This second request was to aide in production of the salt based concrete block and increase worker safety due to the extreme weight of the block. The block wall construction in Panel 1 was completed in 2004.

Fig. 3. Panel 1 block wall construction.

In 2005, the DOE notified both the EPA and NMED of their intent to install the block wall component of the Option D closure design for Panel 2, in accordance with the Permit requirements. The NMED approved the new closure schedule for Panel 2 later that year and the block wall emplacement was completed for Panel 2 in 2006.

In 2007, the DOE requested the renewal of the 2002 Panel Closure Planned Change Request to the EPA and recommended delaying permanent panel closure to allow for gas monitoring (Hydrogen and Methane) in the filled panels and scheduling the installation of the final panel closure to be dependent upon the results of the monitoring. The EPA agreed that gas monitoring of the filled panels would provide useful information for the long-term performance of the repository. The DOE then advised the EPA that they were withdrawing the planned change request for Panel Closure until gas monitoring of filled panels could be completed and reviewed. DOE advised the EPA that a new planned change request for Panel Closure System would be identified in the 2014 timeframe.

In 2011, the DOE submitted a new Panel Closure System conceptual design planned change request to the EPA, three years ahead of schedule [4]. This new conceptual design consisted of standard bulkheads and ROM salt emplaced to three levels of compaction, 70% - 85% (Figure 4). ROM salt densities are reported as a percentage of in-place salt which is assumed to have a density of 135 pounds per cubic foot. This new conceptual design does not consist of a block wall. This is the result of the gas monitoring for Hydrogen and Methane that showed no Methane and very low levels of Hydrogen forming in the filled panels. For panels that already have had a block wall emplaced, the new design is adapted to consist of a bulkhead, compacted ROM salt, and the block wall (Figure 5). This new conceptual design had been evaluated to meet the standards set forth by the CCA and HWFP.

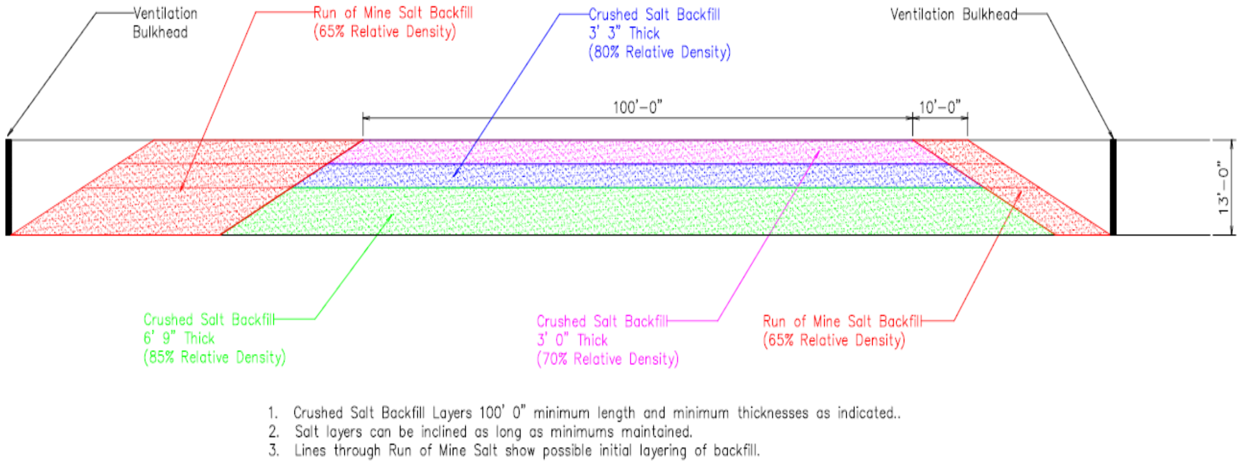

Fig. 4. Conceptual Panel Closure Design.

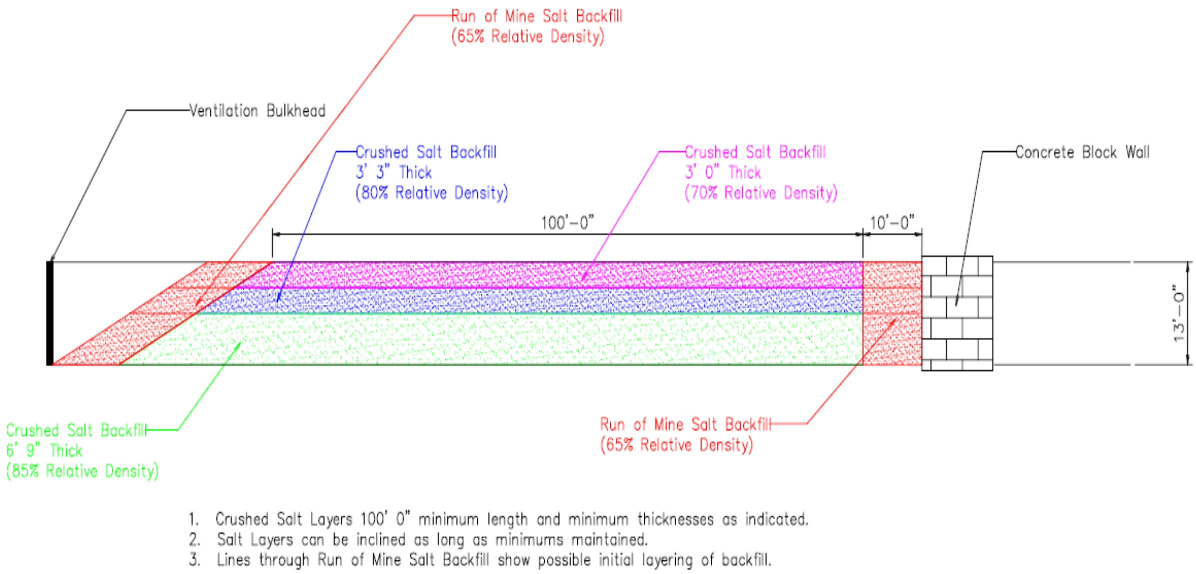

Fig. 5. Conceptual Panel Closure Design with Existing Block Wall.

Following numerous technical discussions with the EPA, the new conceptual design was adjusted to encompass a range of acceptable parameters, and thus designs, in lieu of just one specific design. Allowing for a range of acceptable parameters resulted in an increased flexibility in the design options.

IN-SITU TESTING

Compaction of ROM salt in layers per the 2011 proposed conceptual design had not been performed at the WIPP. Concerns over the constructability of the 2011 panel closure conceptual design arose due to the limited size of the drifts in which the panel closure would be installed and the expected performance of the available equipment. A test plan was developed to demonstrate if the 2011 proposed panel closure could be constructed in accordance with the proposed compaction specifications using equipment currently at the WIPP or equipment that is readily available [5]. If the compaction specifications could not be met, then the test plan would identify what level of compaction could be achieved. Additionally, the best practices for the construction of the proposed conceptual panel closure design would be established.

Three scenarios were developed for the test plan. The first scenario consisted of one percent (by weight) of water added to the ROM salt and compaction of the material. The second scenario consisted of compaction of the ROM salt with no additional water added. The third scenario consisted of the ROM salt simply being placed and pushed up tight to the back without adding water or compaction (Figure 6). The test plan included laboratory testing to determine the moisture/density properties of the salt used for the demonstration (Table 1).

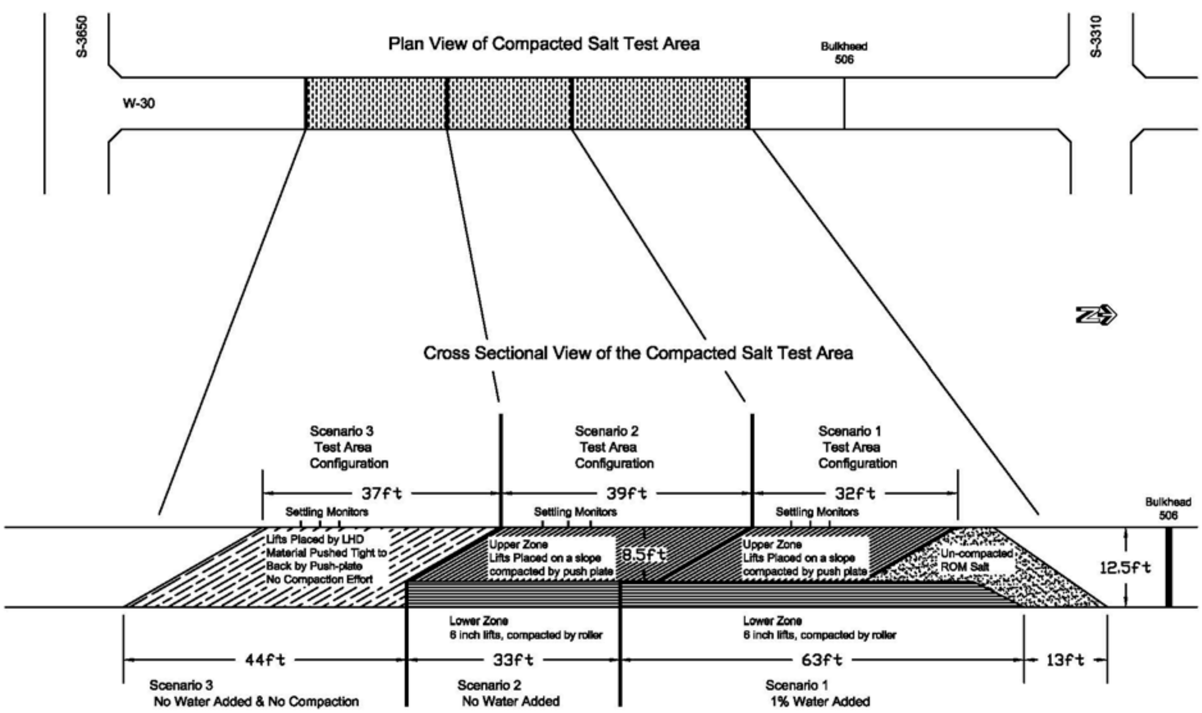

Fig. 6. Compacted Salt Test Area Plan and Cross Section.

TABLE I. Test Area Compaction Data.

Distance from Back	Moisture %	Dry Density %
Test Area 1		
3 feet	1.2	63.4
5 feet	1.3	64.6
7 feet	1.4	61.5
Test Area 2		
3 feet	0.4	62.9
5 feet	0.5	63.1
7 feet	0.3	61.5
Test Area 3		
3 feet	.5	66.5
5 feet	.4	68.0
8 feet	.4	66.0

In-Situ Testing Summary

Scenario 1 and Scenario 2 produced very similar results. The compaction achieved in both scenarios for the lower zone was about 75%. Based on the results from Scenario 2, both the walk-behind roller compactor and the LHD achieved the same compaction level. Scenario 1 and Scenario 2 also had similar results for the upper zone with a compaction of about 63% achieved. Both scenarios did show a slight variation in compaction 3 feet, 5 feet and 7 feet from the back at 63% to 64% and 62% respectively.

Scenario 3 is similar to the upper zone on Scenario 1 and Scenario 2 in both construction technique and achievable compaction. The average compaction achieved for Scenario 3 was about 67%. This is slightly higher than the 63% achieved by Scenario 1 and Scenario 2.

Scenario 1, Scenario 2 and Scenario 3 were able to achieve the draft compaction specification. These scenarios did show what level of compaction can be achieved with the equipment available at the WIPP.

The three scenarios provided an estimate on WPC construction time. The fastest construction time is for Scenario 3, which is the simplest to construct, at about 15 shifts to construct the intake and exhaust drift WPCs. For Scenario 2 the construction time for the WPCs would be about 42 shifts and for Scenario 1 the construction time would be about 61 shifts. The construction of Scenario 1 and 2 are identical except that Scenario 1 adds 1% water by weight to the ROM salt. The Scenario 2 construction time is faster than that of Scenario 1 primarily due to the improved equipment operator proficiency placing and compacting both the lower zone and upper zone lifts.

It was identified that the addition of 1% moisture by weight (Scenario 1) and performing initial compaction to 75% (Scenarios 1 and 2) resulted in fractional densities that were only 10% greater than ROM salt emplacement (Scenario 3) and did not support the cost of the increased effort involved.

PANEL CLOSURE FINAL DESIGN

The design complies with all aspects of the design basis established for the WIPP Panel Closure (Figure 7 and Figure 8). The design can be constructed in the underground environment with no special requirements at the WIPP facility. To investigate several key aspects of the design and to implement the design, design evaluations were performed. The conclusions reached from the evaluations are as follows:

- A gap forms between the excavation roof and the top of the salt fill due to settlement of the ROM salt. Structural modeling results using the three dimensional finite difference code FLAC3D predict the change in gap height and density of the salt with time. The salt compacts from its initial placement density to approximately 90% of the intact salt density under its own weight 23 years after panel closure.
- A VOC Flow Model accounts for gas generation, panel-creep closure, and the effects of underground ventilation of the adjacent main exhaust drift. The VOC Flow Model evaluates the reduction in air conductivity that occurs with the increase in salt density, reduction in gap size and reduction in porosity. The low air flow through the WPC is initially caused by the effects of ventilation of the adjacent main exhaust drift. About 23 years after closure, the gap above the ROM salt is eliminated. The ROM salt consolidates due to panel-entry closure and air conductivity is significantly reduced. This results in low air flow rates.
- The passive design components of the WPC require minimal routine maintenance during the nominal operational life. Out-by bulkheads must be maintained to provide 2,200 Practical Units resistance for 23 years after installation.
- The WPC provides for flexibility over the remaining operational life in construction scheduling and construction material transportation and therefore minimizes the effect on waste receipt operations.

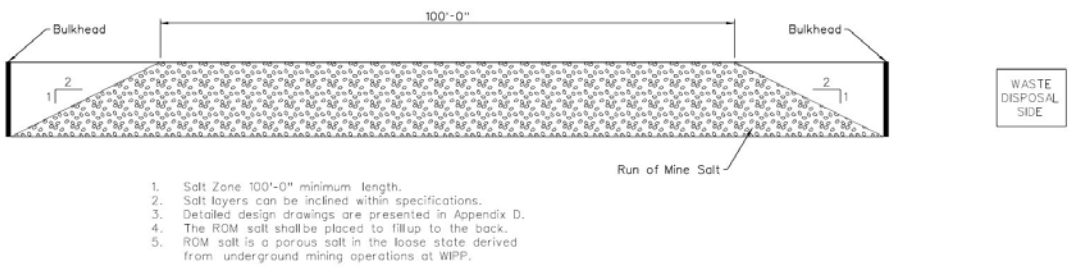

Fig. 7. Typical WPC for Drifts without Block Walls.

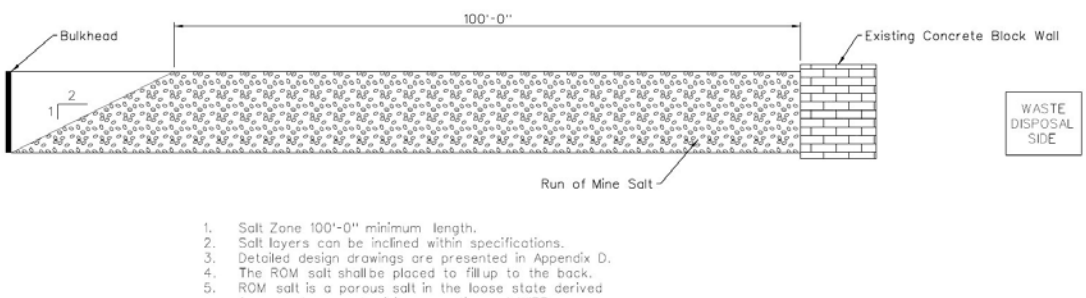

Fig. 8. Typical WPC for Drifts with Existing Block Walls.

In addition to the design requirements stated above, the design includes a construction QA program to verify material properties and construction practices.

The predicted mass flow rates for carbon tetrachloride and other VOCs through the WPC (including flow through the disturbed rock zone (DRZ), the steel bulkheads and the ROM salt) will result in concentrations that are below the HBLs established at the WIPP site boundary. Modeling results of the WPC did not produce VOC concentrations from combined effects that would exceed limits for the repository.

It was also concluded that:

- The WPC provides for flexibility over the remaining operational life in construction scheduling and construction material transportation effects on facility operations.
- The existing shafts and underground access can accommodate the construction of the WPC.

While no specific requirements exist for closing disposal areas under MSHA regulations, the intent of the regulations is to safely isolate abandoned areas from active workings using barricades of substantial construction. The ROM salt is considered substantial construction.

Regulatory Compliance Impacts

In support of the federal rulemaking process needed to change the WIPP panel closure from the currently approved Option D design, a PA has been completed that incorporates the proposed ROMPCS design into the current PA baseline established by the 2009 Performance Assessment Baseline Calculation (PABC-2009) [6]. The name given to the new panel closure PA is PCS-2012. PCS-2012 PA results are compared to PABC-2009 results as a means to quantify potential panel closure redesign impacts. The PCS-2012 PA was developed so that the structure of calculations performed therein was as similar as possible to that used in the PABC-2009. In particular, the PCS-2012 PA utilized the same waste inventory information, drilling rate and plugging pattern parameters, and radionuclide solubility parameters as were used in the PABC-2009.

By federal regulation, repository performance is quantified in terms of Complementary Cumulative Distribution Functions (CCDFs). The CCDF for a quantity of interest provides the probability of that quantity being greater than a particular release value. Releases values are specified in terms of “EPA units”. Releases in EPA units result from a normalization by radionuclide and the total inventory.

ROMPCS properties in the PCS-2012 PA are based on three time periods: from 0 to 100 years, from 100 years to 200 years, and from 200 years to 10,000 years. Three time periods are appropriate because the process to consolidate the run-of-mine (ROM) salt occurs over a primary time scale of approximately 100 years, while the process to heal fractures in the surrounding DRZ occurs over a longer time scale of approximately 200 years [7]. The ROM salt comprising the ROMPCS is therefore represented by three materials, defined over time periods of 0 to 100 years, 100 to 200 years, and 200 to 10,000 years. Analyses and calculations have shown that the time-dependent back stress imposed on the DRZ by the re-consolidated ROM salt panel closure does not become appreciable until roughly 200 years after emplacement of the ROM salt in the drift. As a result, the DRZ material above and below the ROMPCS for the first 200 years after closure is indistinguishable from the DRZ surrounding the disposal rooms. After 200 years, the DRZ above and below the ROMPCS is modeled as having healed in the PCS-2012 PA.

WIPP PA quantifies repository performance for both undisturbed and disturbed repository conditions, and these conditions are represented by six scenarios. The six scenarios used in the PCS-2012 PA are unchanged from those used for the PABC-2009. The scenarios include one undisturbed scenario (S1-BF), four scenarios that include a single inadvertent future drilling intrusion into the repository during the 10,000 year regulatory period (S2-BF to S5-BF), and one scenario investigating the effect of two intrusions into a single waste panel (S6-BF). Two types of intrusions, denoted as E1 and E2, are considered. An E1 intrusion assumes the borehole passes through a waste-filled panel and into a pressurized brine pocket that may exist under the repository in the Castile formation. An E2 intrusion assumes that the borehole passes through the repository but does not encounter a brine pocket. Scenarios S2-BF and S3-BF model the effect of an E1 intrusion occurring at 350 years and 1000 years, respectively, after the repository is closed. Scenarios S4-BF and S5-BF model the effect of an E2 intrusion at 350 and 1000 years. Scenario S6-BF models an E2 intrusion occurring at 1000 years, followed by an E1 intrusion into the same panel at 2000 years.

The solid material removed from the repository and carried to the surface by the drilling fluid during the process of drilling a borehole is divided into cuttings and cavings. Cuttings are removed directly by the drill bit, while cavings are eroded from the walls of the borehole by shear stresses from the circulating drill fluid. The replacement of the Option D panel closure with the ROMPCS design has no impact on cuttings and cavings releases. As a result, cuttings and cavings releases obtained in the PCS-2012 PA are identical to those found in the PABC-2009.

For both undisturbed and intruded repository conditions, implementation of the ROMPCS yields higher long-term waste panel pressure (on average) than was seen in the PABC-2009 [8]. Spallings releases consist of waste that enters the intrusion borehole through the release of waste-generated gas escaping into the borehole, which is at lower pressure. As a result, changes in repository pressures seen in the PCS-2012 PA impact spallings releases. There is a minimum threshold pressure of 10 MPa required for a spallings release volume, and so an increase in repository pressure typically increases the frequency of spallings releases and their magnitude. The overall trend found in the PCS-2012 PA was a slightly higher average nonzero spallings volume, a larger maximum volume, and a higher frequency of nonzero spallings volumes [9].

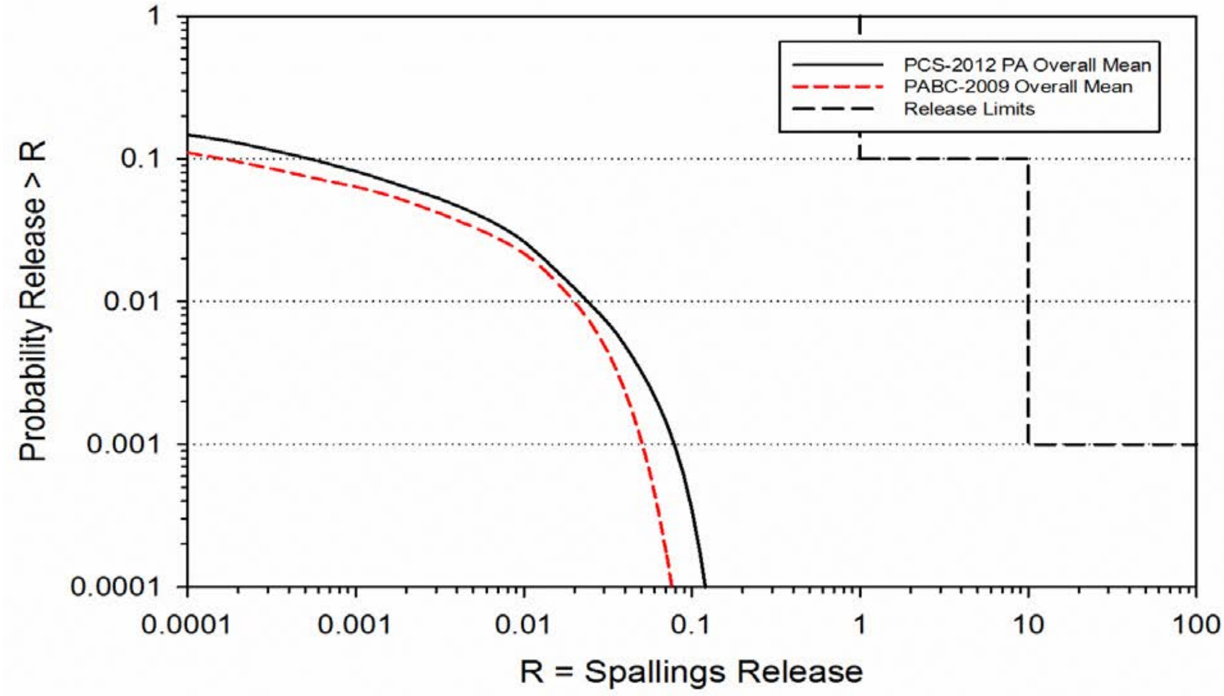

Fig. 7: PCS-2012 PA and PABC-2009 Mean CCDFs for Normalized Spallings Releases.

The impacts of the changes in spallings volumes on the overall mean CCDF for normalized spallings releases obtained in the PCS-2012 PA can be seen in Figure 7. As seen in that figure, the CCDF of spallings releases obtained in the PCS-2012 PA is consistently higher than that found in the PABC-2009 [10]. The increases in spallings volumes and in the number of vectors that result in a nonzero spallings volume translate to an increase in spallings releases as both analyses use the same waste inventory.

In addition to increases in waste panel pressure, implementation of the ROMPCS design results in increased mean waste panel brine saturation for undisturbed conditions as well as intrusion scenarios that do not intersect a Castile brine pocket. For intrusion scenarios that intersect a region of pressurized Castile brine, increases in pressure are accompanied by only slight reductions in the mean waste panel brine saturation in the PCS-2012 PA. Direct brine releases (DBRs) are releases of contaminated brine originating in the repository and flowing up an intrusion borehole during the period of drilling. In order for DBR to occur, two criteria must be satisfied:

1. Volume averaged brine pressure in the vicinity of the repository encountered by drilling must exceed drilling fluid hydrostatic pressure (calculated to be 8 MPa).
2. Brine saturation in the repository must exceed the residual brine saturation of the waste material (sampled from a uniform distribution ranging from 0.0 to 0.552).

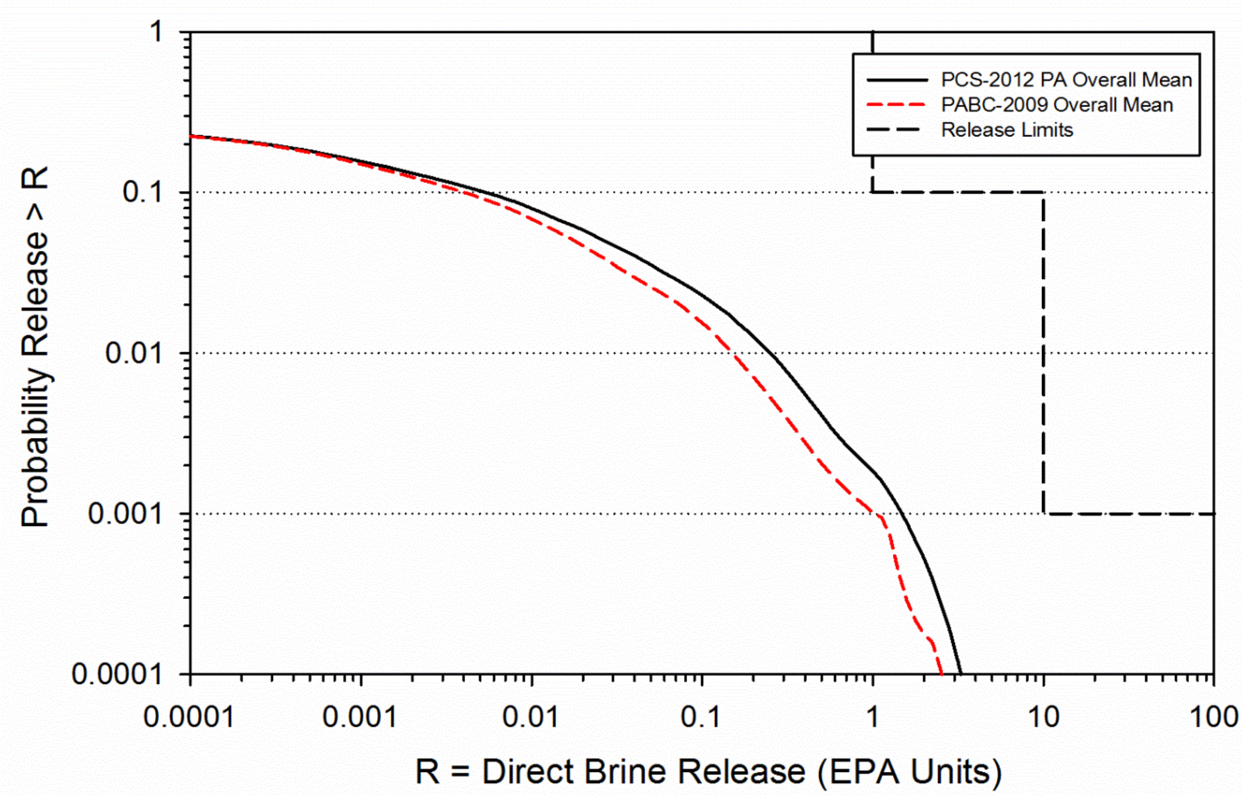

Fig. 8: PCS-2012 PA and PABC-2009 Mean CCDFs for Normalized Direct Brine Releases.

As a result, changes to repository pressure and brine saturation seen in the PCS-2012 PA calculations yield changes to direct brine releases as compared to PABC-2009 results. The general trend seen in the PCS-2012 PA was a modest (~6%) increase in the number of non-zero DBR volumes accompanied by modest increases in the average DBR volumes for all scenarios [11]. Consequently, the CCDF curve obtained for DBRs shows greater mean probabilities in the PCS-2012 PA for the majority of release values as compared to PABC-2009 results (Figure 8).

Total normalized releases are calculated by forming the summation of releases across each potential release pathway. PCS-2012 PA and PABC-2009 mean CCDFs for total releases are shown together in Figure 9. As seen in that figure, the overall mean CCDFs obtained in the two analyses are nearly identical for release values less than approximately 0.1 EPA units. For releases greater than 0.1 EPA units, the CCDF curve obtained in the PCS-2012 PA is higher than that found in the PABC-2009. This increase corresponds primarily to the differences found for direct brine releases between the two analyses as discussed above [10]. Total normalized releases calculated in the PCS-2012 PA are greater than those found in the PABC-2009, but continue to remain below their regulatory limits. As a result, replacement of the Option D panel closure with the ROMPCS design would not result in WIPP non-compliance with the containment requirements of 40 CFR Part 191.

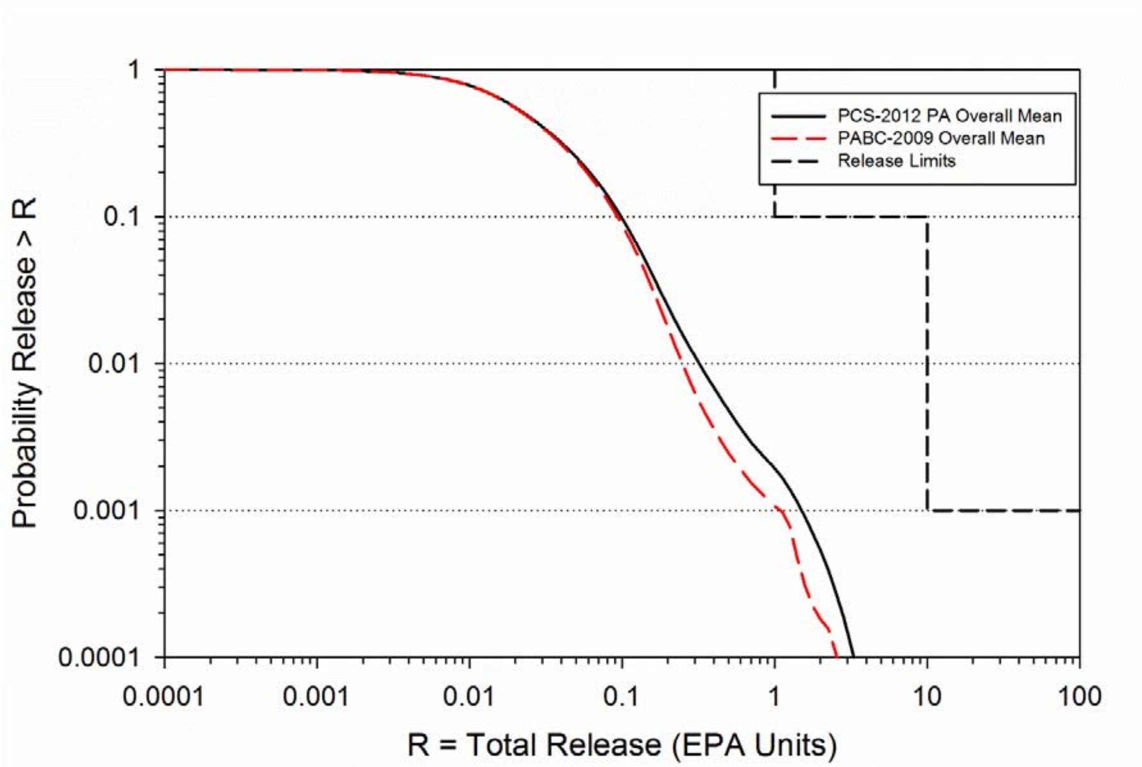

Fig. 9: PCS-2012 PA and PABC-2009 Mean CCDFs for Total Normalized Releases.

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