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WIPP Small Scale Seal Performance Tests – Status and Impacts

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WIPP SMALL SCALE SEAL PERFORMANCE TESTS - STATUS AND IMPACTS

by

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Abstract

Numerous small-scale in situ seal experiments have been emplaced in boreholes up to 38 in. in diameter at the WIPP. Seal materials include expansive salt concrete, bentonite, and crushed salt. Emplacement techniques stressed conventional technology and the use of available site personnel. Preliminary evaluation of the performance of these seals has been completed by using structural data from embedded instrumentation and fluid flow data from gas and brine flow measurements. Preliminary results suggest that submicrodarcy permeabilities can be obtained using these materials and that structural performance is satisfactory.

1.0 Introduction

1.1 Background

The U.S. Department of Energy is developing the Waste Isolation Pilot Plant (WIPP) facility in southeastern New Mexico to demonstrate the safe disposal of Transuranic (TRU) radioactive wastes arising from the defense activities of the United States. The WIPP waste disposal horizon lies in a bedded salt formation approximately 2150 ft (656 m) below the ground surface. The salt is interspersed with thin clay and anhydrite layers. Figure 1 is a schematic of the WIPP facility, including the locations of major underground and surface features.

1.2 Sealing Program at WIPP

The sealing program at the WIPP is intended to develop and demonstrate technology such that seals can be designed to limit the release of radionuclides to the accessible environment. Current plans call for placement of seals in panel-access drifts for the TRU waste storage areas and in the four shafts accessing the WIPP (see Figure 1). Seal materials under consideration for use at the WIPP include concrete, crushed salt for long-term seals, and swelling clays for short-term seals. Information regarding the seal designs currently planned for the WIPP is given in Nowak et al. (1990). SNL is currently planning and performing major experiments intended to provide information that can be used to support actual WIPP facility seal designs. These experiments include Thermal-Structural Interaction (TSI) Tests, Large-Scale Seal Tests, Small Scale Seal Performance Tests (SSSPT), Disturbed Rock Zone (DRZ) characterization, and brine inflow tests. This paper discusses only the SSSPT program.

The SSSPTs are in situ experiments that are intermediate in scale between full-scale in situ seal tests and laboratory tests. The SSSPTs utilize materials and geometries similar to those currently planned for

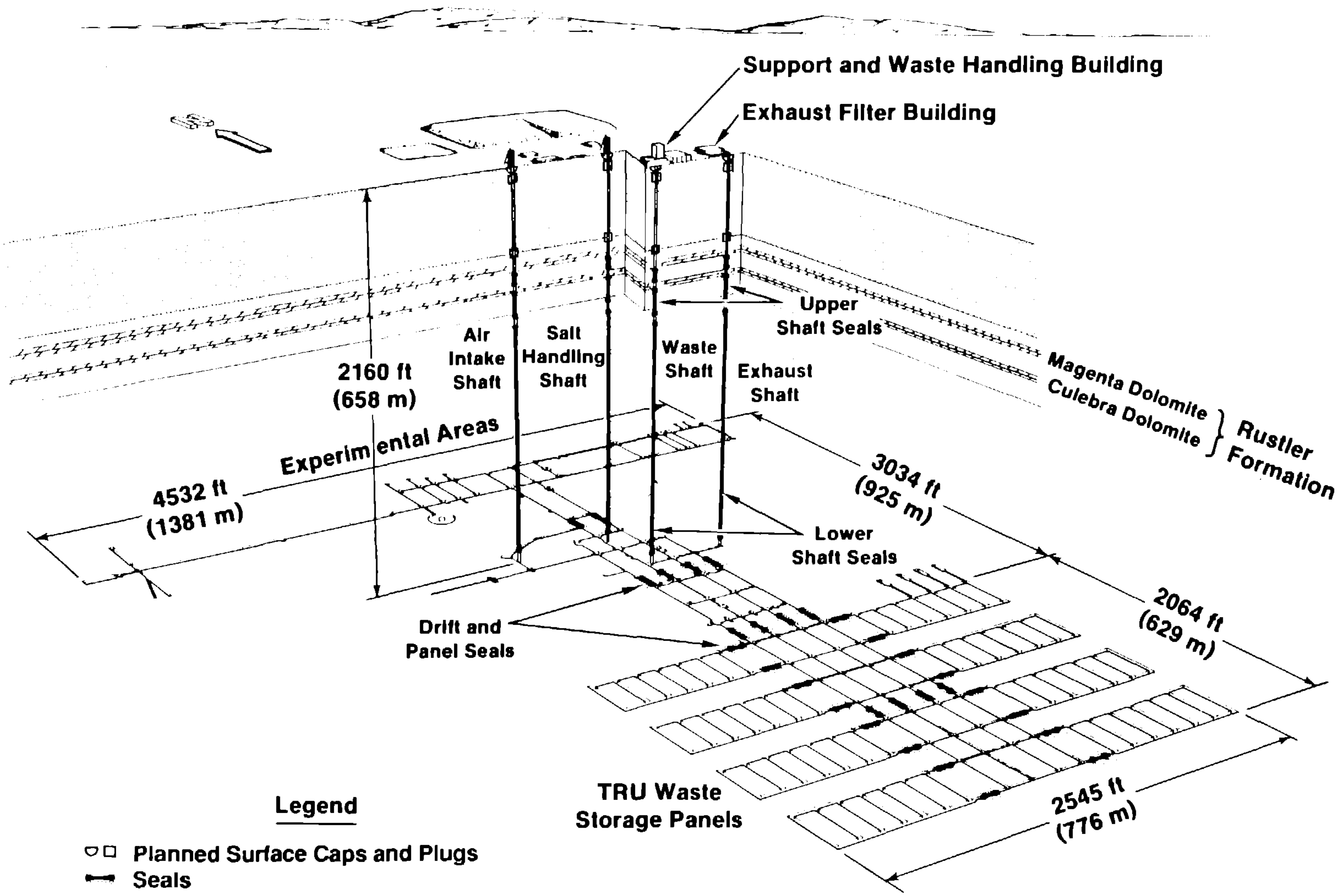

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Figure 1. Sectional View of WIPP Facility.

large-scale seal tests and seal emplacements; however, direct comparisons between the SSSPT and full-scale seals must be carefully evaluated because many of the measurements are scale dependent. These geometries, especially those intended to simulate sealing in shafts, provide demonstrations of technologies and confirmation of in situ processes that influence seal performance. This information may be useful for sealing other openings such as boreholes accessing solution mined caverns. The primary objectives (Stormont, 1985) of the Small-Scale Seal Performance Tests are as follows:

1) to determine in situ fluid flow performance for various seal systems, including evaluating flow paths, the difference between gas and brine permeabilities, and size effects,
2) to determine in situ mechanical performance of the host rock and seal materials, including material interfaces and size effects,
3) to assess seal emplacement techniques, and
4) to support the development of numerical predictive capabilities

A considerable body of work has been completed to date. This paper summarizes selected results. Many references will cite the original work.

2.0 SSSPT Test Description

The plans for the SSSPTs were developed in 1985 and are described in detail in Stormont (1985). The SSSPTs are a series of in situ experiments designed to evaluate the performance of various candidate seal materials emplaced in boreholes from 6 in. (15.2 cm) to 38 in. (96.5 cm) in diameter. The emplacement holes are oriented both vertically into the floor and horizontally into the ribs. The seal system is comprised of the seal, seal/rock interface, and the rock adjacent to the seal. Table 1 briefly describes the SSSPTs conducted to date, including a description of the primary seal material, orientation, and types of measurements made. In addition, all of the various test series utilize a similar test configuration. Figure 2 shows generalized configurations for the test series conducted to date (see Table 1). In general, an emplacement hole and an access hole (if used) are drilled either in the rib or floor of the opening. The seal material, in some cases containing instrumentation, is emplaced over a predetermined interval in the emplacement hole. A four packer fracture flow tool (FPFFT) capable of using brine or gas can be placed in the access hole (where used), and the interval beneath the seal can be pressurized for fluid flow measurements.

The emplacement techniques employed in the SSSPT test program emphasized conventional technology and the use of available personnel at the WIPP site. The seal materials used in the SSSPTs include expansive salt-based concrete, and blocks compressed from 100% crushed salt, 50/50% crushed salt/bentonite, and 100% bentonite. The blocks were pressed into workable sizes using a modified adobe block making machine (Sandia block machine) (Stormont and Howard, 1987). The manufacture and emplacement of the seal materials for each of the test series were accomplished without major difficulty, although placement of the expansive salt based concrete (SSSPT-A, SSSPT-B) required the use of chilled water and retarding admixture (sodium citrate) to maintain workability during transport underground. In addition, optimization studies to determine the most durable blocks were performed prior to the manufacture of crushed salt blocks (SSSPT-C Phase 1, SSSPT-D Phase 1), 50/50% salt bentonite blocks (SSSPT-C Phase 1), and 100% bentonite blocks (SSSPT-C Phase 2, SSSPT-D Phase 2).

3.0 Test Results

Test results for the SSSPT program are discussed in terms of the material used in the seal. The SSSPT program provides both operational information (relating to construction and materials) and performance information (relating to system response). The operational information is of a qualitative nature, whereas the performance information is obtained from direct measurements such as hole closure or gas and brine flow.

The emplacement of seals with embedded instrumentation added complexity to relatively simple seal designs. For instance, embedded instrumentation requires cabling to the surface for data acquisition. The cabling presents a potential pathway through the seal during gas and brine testing. Many of the seals tested in test series A and B showed obvious leakage along the instrumentation cable bundle when

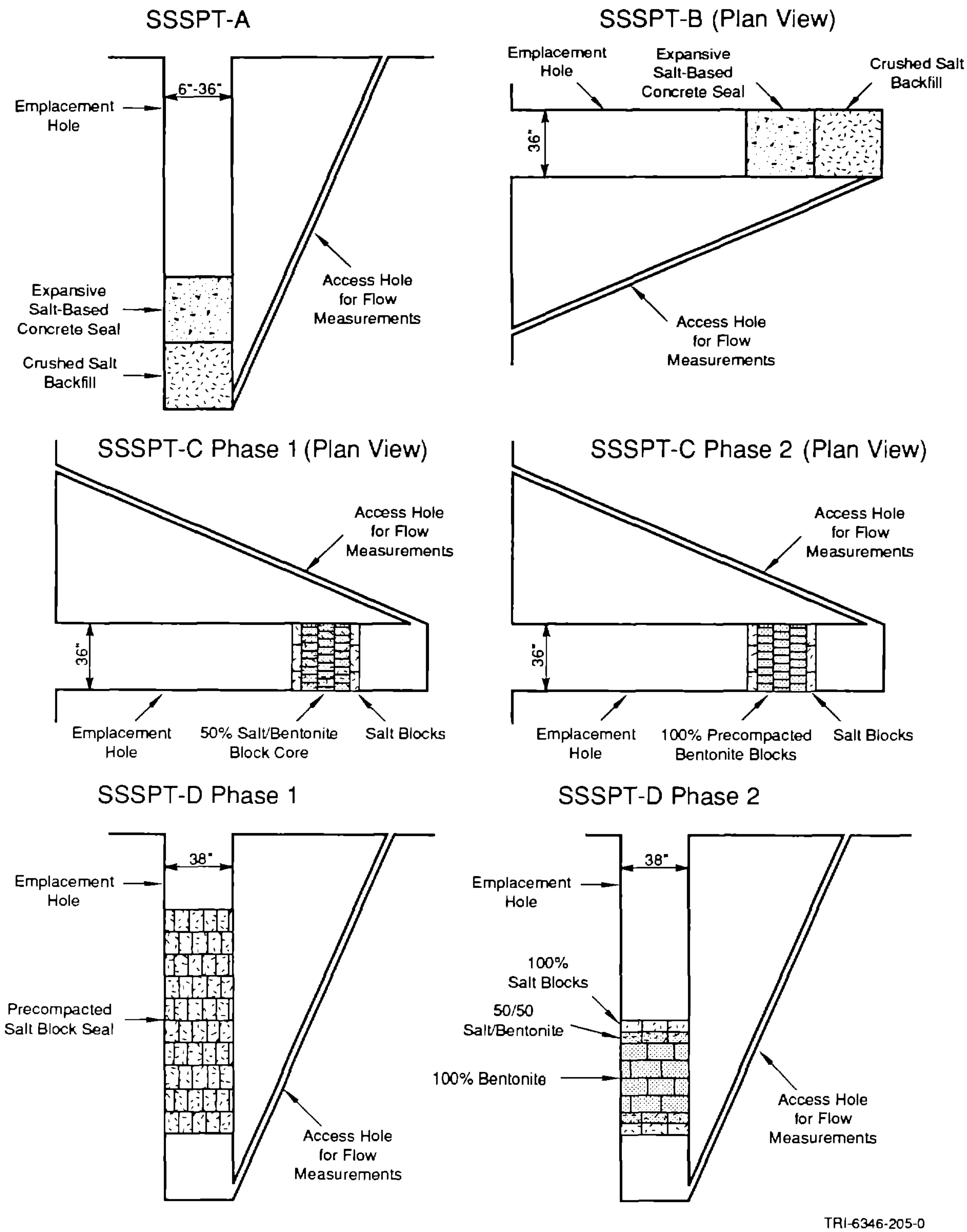

Figure 2. Generalized Test Configurations.

TABLE 1. TEST SERIES CURRENTLY PLANNED FOR SSSPT				
Test Series	Seal Material	Seal Emplacement Orientation	Emplacement Date	Measurements*
A	Salt-Based Concrete	Vertical	7/85	Seal Pressure; Displacement and Temperature; Gas and Brine Flow
B	Salt-Based Concrete	Horizontal	2/86	Seal Pressure; Gas and Brine Flow
C Phase 1	Salt and 50/50% Salt/Bentonite Block	Horizontal	9/86	Seal Pressure; Brine Flow
C Phase 2	Bentonite Block	Horizontal	12/90	Seal Pressure; Brine flow
D Phase 1	Salt Block	Vertical	1/88	Seal Pressure; Hole Closure; Floor Heave; Gas Flow
D Phase 2	Bentonite Block (short-term)	Vertical	9/89	Seal Pressure; Brine Flow

* Note: Instruments include strain gages, stress meters, thermocouples, pressure cells, borehole displacement gages, Multiple Point Borehole Extensometers (MPBX), and the Four Packer Fracture Flow Tool (FPFFT) for fluid flow measurements.

permeability testing was performed (Peterson et al., 1987). As a result, later test series included uninstrumented seals to evaluate the influence of instrumentation on seal performance.

EXPANSIVE SALT CONCRETE SEALS

SSSPT Series A and B utilized nine emplacement holes located in the floor of the D Room Alcove and in the west rib of Room M. The seal material, an expansive salt concrete developed for SNL by Waterways Experiment Station (WES) (Wakeley and Walley, 1986), was underlain by crushed salt. The aspect ratio of the seal ranged between 2:1 to 1:1. Key results from the expansive salt concrete seal tests are as follows:

EMPLACEMENT

- Emplacement of expansive salt concrete seals was successfully demonstrated as evidenced by the emplacement of nine seals in vertical and horizontal orientations using standard equipment and personnel (Stormont, 1986; Stormont and Howard, 1987)
- Standard commercial equipment and techniques were used successfully for vertical and horizontal emplacements (Stormont, 1986; Stormont and Howard, 1986)
- Concrete met emplacement criteria for slump, limited bleed, segregation, limited air entrapment, self-leveling behavior, and workability (Stormont, 1986; Stormont and Howard, 1986)

PERFORMANCE

- Submicrodarcy initial permeability was measured during brine flow testing (Peterson et al., 1987)
- A reduction in flow path size was observed by a decrease in tracer arrival times measured within a year of seal emplacement (Peterson et al., 1987)
- Brine flow rates of about 200 ml/day (Figure 3) corresponding to submicrodarcy permeabilities were measured for 91-cm-diameter seals (Peterson et al., 1987)

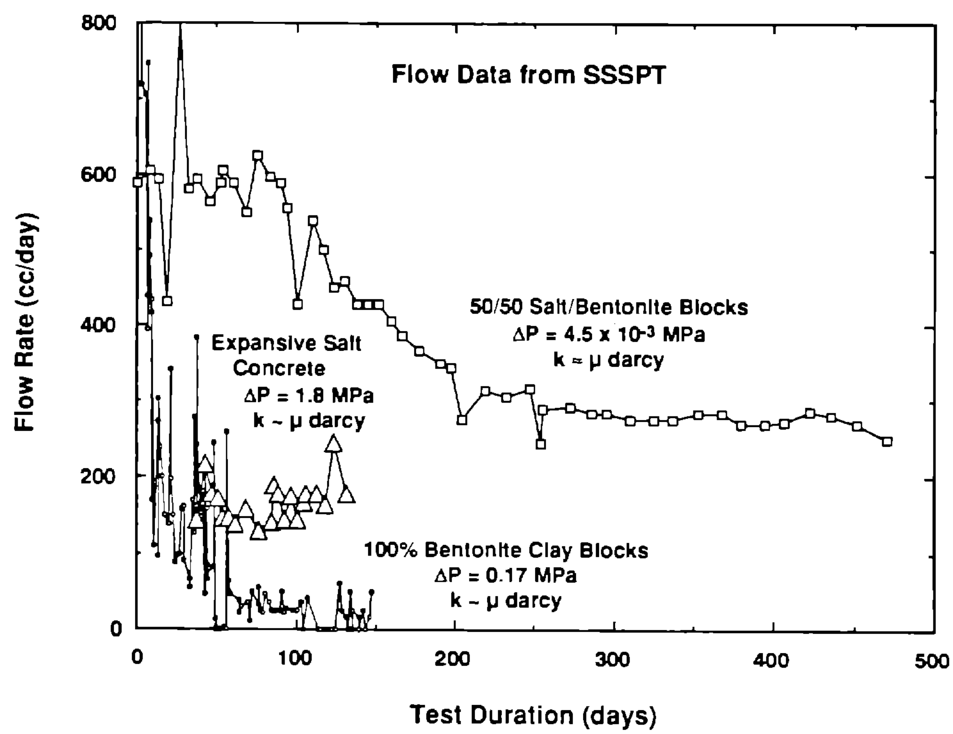

Figure 3. Comparison of Typical Brine Flow Data from SSSPT Seals.

- Structural performance of the expansive salt concrete seals was satisfactory as evidenced by the seals withstanding 1.8 MPa back pressure during brine flow testing (Stormont, 1987; Van Sambeek and Stormont, 1987; Labreche and Van Sambeek, 1988)
- The expansivity of the concrete (0.12% in the lab) provided a sufficient interface between the seal and the rock to limit fluid flow at early times (Wakeley and Walley, 1986; Peterson et al., 1987; Stormont, 1987)
- There was little evidence of thermal cracking of the concrete during cooling (Stormont, 1987)
- Thermomechanical data during early times agreed well with numerical modeling predictions, however, questions remain as our ability to predict mechanical behavior and the interactions with the surrounding salt at later times (Labreche and Van Sambeek, 1988)

100% BENTONITE BLOCKS

SSSPT-C Phase 2 and SSSPT-D Phase 2 utilize four seals constructed using blocks of 100% bentonite pressed in the Sandia block machine (Stormont and Howard, 1987). The blocks were arranged in the seals in a manner that would minimize the potential for flow along a continuous interface. Key results from the 100% compressed bentonite block seal tests are as follows:

EMPLACEMENT

- Emplacement of 100% bentonite blocks in vertical and horizontal boreholes was successfully demonstrated by the completion of four seals in a confined space although construction was very labor intensive (Torres, 1987; Torres and Howard, 1989; Torres et al., in prep)
- High density (80% of intact bentonite) durable blocks could be consistently fabricated using modified available technology (Torres and Howard, 1990)
- Seal density of >75% of intact bentonite density can be achieved in a 3-ft bentonite core (Torres and Howard, 1990)

PERFORMANCE

- Microdarcy permeability was measured after about two months of brine testing
- The only 100% bentonite seal tested showed a marked decrease in brine flow due to bentonite swelling from about 1800 cc/day to about 20 cc/day after 150 days of testing (see Figure 3) (Torres and Howard, 1990)
- Pressure measurements show a roughly twofold increase in seal pressure after about 300 days of brine testing up to values near 0.7 MPa (Torres and Howard, 1989)

50/50% SALT/BENTONITE SEALS

SSSPT-C Phase 1 utilized blocks comprised of a mixture of 50% crushed salt and 50% bentonite. The blocks were laid so as to minimize the potential for flow along a continuous joint. Key results from the 50/50% salt bentonite block seals are as follows:

EMPLACEMENT

- Emplacement of 50/50% crushed salt/bentonite block seals in horizontal boreholes was successfully demonstrated by the completion of five seals in a confined space although construction was very labor intensive (Stormont and Howard, 1987)
- High density (>77% of salt/bentonite intact density) durable blocks of 50/50% crushed salt/bentonite could be consistently fabricated using modified available technology (Stormont and Howard, 1987)

PERFORMANCE

- Millidarcy permeability was measured after about 6 months of brine testing (Torres and Howard, 1989)
- The brine flow results for the two 50/50 salt/bentonite seals indicate a flow of about 250 ml/day after about 250 days (see Figure 3) (Torres and Howard, 1989)

- Structural measurements (Stormont and Howard, 1987) suggest that the salt/bentonite block seals do not behave significantly differently than do 100% salt block seals over the time periods discussed
- Long-term permeability of the seal can possibly be tailored using different proportions of materials

An additional emplacement-related observation is that one of the 50/50% salt/bentonite seals emplaced for SSSPT-C Phase 1 failed by piping as a result of adding brine too rapidly. The rapid brine input did not allow the bentonite adequate time to take up water and swell to effectively seal potential flow paths. This seal failure was not related to instrumentation cabling. The seal was dismantled, inspected, and replaced. Subsequent slow input brine testing did not result in a piping failure (Stormont and Howard, 1987).

<u>100% CRUSHED SALT BLOCK SEALS</u>

SSSPT Series C Phase 1 and Series D Phase 1 utilized seven seals: four horizontally emplaced and three vertically emplaced. The seals were constructed using blocks of 100% crushed salt pressed in the Sandia block machine. The blocks were arranged in the seals to minimize the potential for flow along a continuous joint. Key results of the 100% salt block seals are as follows:

EMPLACEMENT

- Emplacement of 100% crushed salt block seals in vertical and horizontal boreholes was successfully demonstrated in seven seals in a confined space although construction is very labor intensive (Torres et al., in prep; Torres, 1987; Stormont and Howard, 1987)
- High density (>82% intact salt) durable blocks of 100% crushed salt could be consistently fabricated using modified available technology (Stormont and Howard, 1987)
- Tamped-in-place crushed salt can be emplaced to >75% of host rock density, suggesting a possible alternative to block seals (Howard, 1988)

PERFORMANCE OF 100% CRUSHED BLOCK SEALS

- Gas flowrate within a few months after seal emplacement exceeded the measuring capability of the equipment (Torres et al., in prep).
- Structural measurements including seal pressure and borehole displacements agree with laboratory and modeling predictions that the crushed salt seals will provide little resistance to closure and little resistance to flow until the crushed salt has achieved 90 - 95% of the intact salt density (Holcomb and Shields, 1987; Sjaardema and Krieg, 1987)

4.0 Discussion

The Small Scale Seal Performance Tests have provided preliminary information on the performance of expansive salt concretes, crushed salt, crushed salt/bentonite mixtures, and 100% bentonite as seal materials for the Waste Isolation Pilot Plant. Seals using these materials have been successfully constructed and emplaced with conventional technology and available personnel at the WIPP. The preliminary results suggest that expansive salt concretes and bentonite seals can provide seals against brine flow during early time periods, with permeabilities in the microdarcy range. The performance of 50/50% crushed salt/bentonite mixtures is inconclusive at this time; however permeabilities in the millidarcy range have been achieved. Crushed salt seals have been successfully emplaced and are currently being monitored to evaluate the long-term behavior of such seal materials for the WIPP. Information obtained to date does not contradict laboratory and modeling predictions that crushed salt must reconsolidate to 90 - 95% of the in situ density before significant reduction in fluid flow and resistance to closure occur.

The impacts of the SSSPTs on the sealing program at the WIPP are significant. The SSSPTs have provided critical information on seal materials and performance that has been used in the development of preliminary designs for the WIPP seals. The SSSPTs have also identified limitations of our knowledge of seal material performance. For instance, it is not clear from the SSSPTs whether thermal strains from cooling will induce fractures in larger expansive salt concrete seals that may be used in the WIPP. Also, test durations for the SSSPTs are so short that longer term behavior of the seal materials is unknown. Future goals for the SSSPT program will be to address these issues. It is clear that the existing SSSPT seals should be retested to evaluate time dependence on the seal performance.

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