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Assessment of Contaminated Brine Fate and Transport in MB139 at WIPP

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Assessment of Contaminated Brine Fate and Transport in MB139 at WIPP

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Abstract

Following the radionuclide release event of February 14, 2014 at the Waste Isolation Pilot Plant (WIPP), actinide contamination has been found on the walls and floor in Panel 7 as a result of a release in Room 7 of Panel 7. It has been proposed to decontaminate Panel 7 at the WIPP by washing contaminated surfaces in the underground with fresh water (Nelson, 2014a). A cost-effective cleanup of this contamination would allow for a timely return to waste disposal operations at WIPP.

It is expected that the fresh water used to decontaminate Panel 7 will flow as contaminated brine down into the porosity of the materials under the floor – the run-of-mine (ROM) salt above Marker Bed 139 (MB139) and MB139 itself – where its fate will be controlled by the hydraulic and transport properties of MB139. Due to the structural dip of MB139, it is unlikely that this brine would migrate northward towards the Waste-Handling Shaft sump. A few strategically placed shallow small-diameter observation boreholes straddling MB139 would allow for monitoring the flow and fate of this brine after decontamination. Additionally, given that flow through the compacted ROM salt floor and in MB139 would occur under unsaturated (or two-phase) conditions, there is a need to measure the unsaturated flow properties of crushed WIPP salt and salt from the disturbed rock zone (DRZ).

CONTENTS

FIGURES

NOMENCLATURE

AMSL	Above Mean Sea Level
BSEP	Brine Sampling and Evaluation Program
DOE	Department of Energy
DRZ	Disturbed Rock Zone
INL	Idaho National Laboratory
MB139	Marker Bed 139
ROM	Run-of-Mine
SCCM	Standard Cubic Centimeter per Minute
SNL	Sandia National Laboratories
WIPP	Waste Isolation Pilot Plant

1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a US Department of Energy facility for disposal of transuranic radioactive waste located approximately 2150 feet below ground near Carlsbad, New Mexico in the Permian Salado evaporite deposit. WIPP has been operational since 1999, and the first six panels of the excavated underground are filled with transuranic waste. Emplacement operations had begun in Panel 7 when a truck fire on February 5, 2014 stopped operations. During the operational hiatus associated with the truck fire investigation, a radionuclide release was detected on February 14, 2014 from a source within Room 7 of Panel 7.

Panel 7 (Figure 1) was constructed using a slightly different approach from other waste panels at WIPP. Whereas the floors of the panels typically comprise intact Salado halite, the floor of panel 7 was reportedly mined down to MB139, to a depth of approximately 3 to 5 feet below the floor of the disposal room (Figure 2). It was then replaced with run-of-mine (ROM) salt, which was used to build the floor back up to its original elevation.

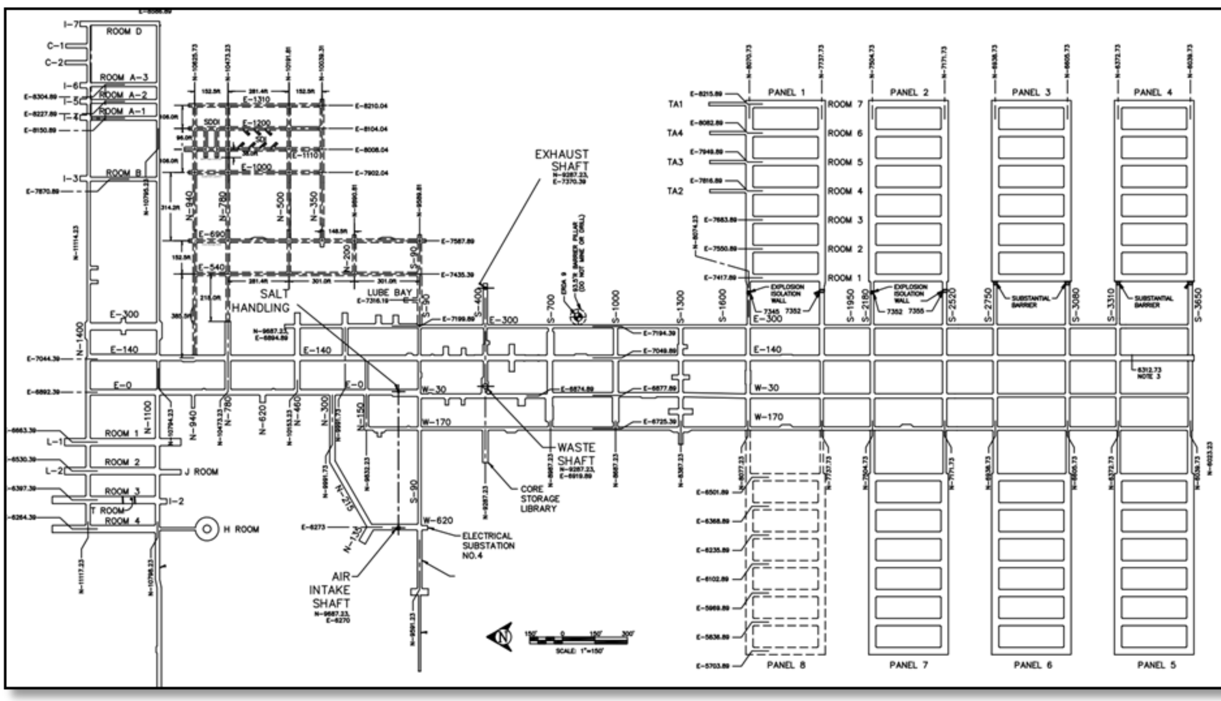

Figure 1. WIPP underground layout

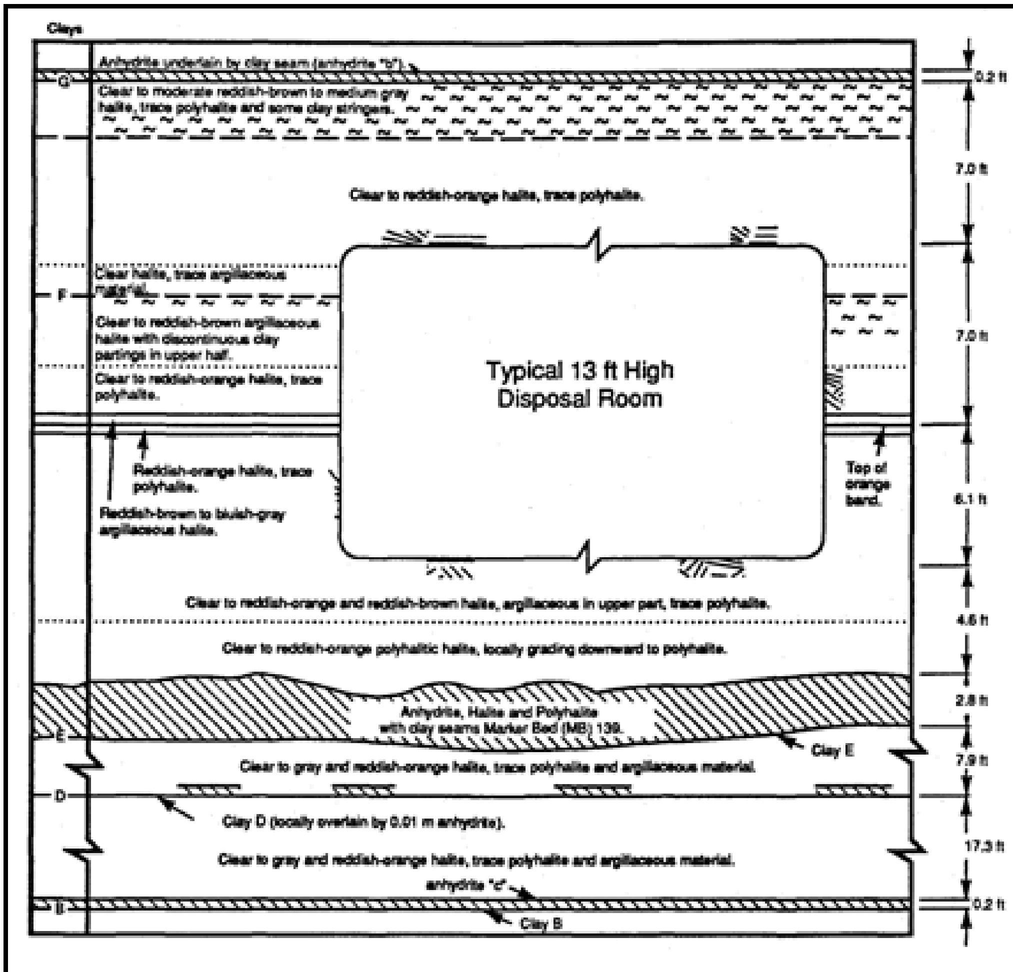

Figure 2. Typical geology cross-section of WIPP disposal horizon.

1.1. Amount of brine required for decontamination

Given the large uncertainty involved in estimating realistic values of fresh water and brine volumes required for, and generated by decontamination at WIPP, we estimate two extreme values. The first estimate is the minimum amount of water required to decontaminate the salt, given the results of laboratory tests at Idaho National Laboratory (INL). In practice, additional water will be needed to "chase" the contamination down the walls, into the porosity of the floor. More water will need to be applied near the floor, compared to the upper parts of the room (which have less upstream area). The second estimate is the maximum amount of brine the crushed salt in the floor of Panel 7 can hold. It is assumed the exact amount of brine used for decontamination will be more than the minimum required under a laboratory setting, and it should be less than the capacity of the floor.

The amount of fresh water required to clean the actinide contamination (Figure 3) has been estimated by INL in the laboratory as 186 ml/ft^2 (INL, 2014). This is a minimum value required to decontaminate surfaces in WIPP; any real-world application technique will end up using more water, since, from a decontamination point of view, it is preferable to use too much water than not enough. To generalize our estimates to different sized rooms and to make them compatible with those made by Nelson (2014a), we compute the brine required for a disposal room strip of one linear foot. For a disposal room with a 10m × 4m cross-sectional area (i.e., a 28 m perimeter), this uniform application of water would require approximately 4.5 gallons of fresh water for a surface area of 28 m × 1 ft:

$$(28\ \mathrm{m} \times 0.3048\ \mathrm{m})\left(\frac{1\ \mathrm{ft}^2}{0.3048^2\ \mathrm{m}^2}\right)\left(\frac{0.186\ \mathrm{l}}{\mathrm{ft}^2}\right)\left(\frac{1\ \mathrm{gal}}{3.79\ \mathrm{l}}\right) = 4.5\ \mathrm{gal}$$

The resulting brine would flow by gravity down into the ROM salt backfill above MB139 and into MB139 itself. The porosity of uncompacted ROM salt is typically between 30 and 40% (Bechthold et al., 2004; §2.2), while that of compacted salt can be much lower than this, approaching "intact" salt porosity of approximately 2 to 5% near excavations (Stormont & Daemen, 1992). The reconsolidation of crushed salt is a relatively slow process when the salt is not subjected to significant loads, or has not been dynamically re-compacted. In previous experiments in the WIPP shaft seals development, dynamic compaction of ROM salt resulted in consolidation to up to 90% of the intact salt density (~10% porosity) (Hansen et al., 1996).

Figure 3. Laboratory test at INL to determine quantities of brine required to clean actinides from salt (INL, 2014)

The "storage capacity" of the compacted ROM salt directly below the rooms and above MB139 (not including MB139 itself) would likely be between 113 gallons (10% porosity) and 339 gallons (30% porosity) for a section of disposal drift floor with surface area of 10 m × 1 ft.

$$(10\ \mathrm{m} \times 0.3048\ \mathrm{m})(4.6\ \mathrm{ft\ to\ MB139})\left(\frac{1\ \mathrm{ft}^2}{0.3048^2\ \mathrm{m}^2}\right)\left(\frac{7.48\ \mathrm{gal}}{1\ \mathrm{ft}^3}\right)(0.1\ \mathrm{porosity}) = 113\ \mathrm{gal}$$

This calculation assumes the brine is saturated with dissolved halite by the time it reaches the floor (i.e., no new porosity is created due to floor ROM salt dissolution in the brine resulting from decontamination), and no brine flows laterally out of the footprint of the room or vertically down into MB139 (i.e., the porosity of MB139 itself is not included in this estimate). The latter assumption is based on the fact that although the fractures in MB139 may constitute significant pathways for brine flow, they are not a significant source of porosity (brine storage capacity), compared to the compacted ROM salt. The volume of brine generated by the decontamination exercise should be much smaller than the estimated ROM salt storage capacity.

Assuming the brine attains saturation, applying 339 gallons of water (Nelson (2014a) considered 250 gallons per linear foot of drift) uniformly to each area of 28 m × 1 ft (i.e., a cross-sectional foot) of disposal drift would dissolve approximately an inch of salt from the floor, ceiling, and walls, using standard values for NaCl solubility and density (Burgess, 1978)

$$\left(\frac{339\text{ gal brine}}{28\text{ m}\times 0.3048\text{ m}}\right)\left(\frac{3.79\text{ l}}{1\text{ gal}}\right)\left(\frac{360\text{ g NaCl}}{1\text{ l brine}}\right)\left(\frac{1\text{ cm}^3\text{NaCl}}{2.17\text{ g NaCl}}\right)\left(\frac{0.3048^2\text{ m}^2}{1\text{ ft}^2}\right)\left(\frac{1\text{ ft}^3}{28{,}317\text{ cm}^3}\right)=0.082\text{ ft NaCl.}$$

This upper limit is significantly more salt than would need to be removed for decontamination purposes alone.

These calculations only indicate order-of-magnitude, since they do not take the detailed geometry of the disposal rooms and access drifts into account, and they consider the drifts to be one dimensional. In reality the drifts are not all of exactly uniform cross section, the access drifts are different size from disposal rooms, and the disposal rooms and panels have intersections and ends, which may over- or under-account for drift walls (e.g., areas where drifts intersect – where there is no wall on one side – would be over-accounted for, while corners and ends might not be accounted for enough). These simplifications in the calculations do not detract from their usefulness in estimating the magnitude of brine required for decontamination and the brine capacity of the crushed salt beneath the floor of Panel 7.

2. MB139 AND BRINE MOVEMENT

MB139 is comprised mostly of anhydrite and clay (Figure 4), but is quite variable in its composition, thickness (Borns, 1985), and brine inflow potential (Finley et al., 1992) across the WIPP underground. It is known to be a relatively permeable layer near excavations, due to significant fracturing (Borns and Stormont, 1988). Unlike salt, its fractures do not readily heal through creep closure when subject to confining pressure. The permeability of MB139 near excavations (in the DRZ) of about $5 \times 10^{-17}\ \mathrm{m}^2$, is roughly three orders of magnitude greater than that of undamaged MB139 (about $8\times 10^{-20}\ \mathrm{m}^2$) or salt in the DRZ (Beauheim et al., 1991; 1993; Kuhlman & Malama, 2013). Hence, brine flow is more likely to occur preferentially in the damaged MB139 than in intact anhydrite and halite.

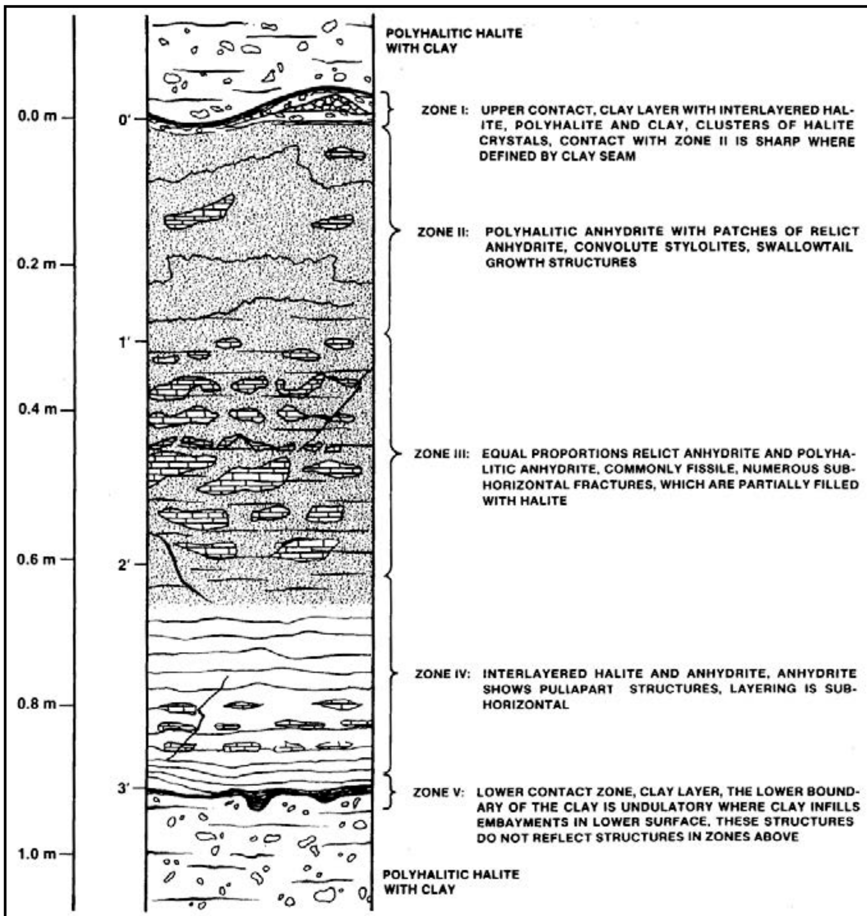

Figure 4. Typical MB139 geologic structure at WIPP (Borns, 1985)

2.1 Repository flow system

Due to its close proximity to the floor of waste-disposal level excavations (Figure 2), MB139 has increased porosity (both macro- and micro-fractures) from excavation-induced damage (Figure 5). Brine which flows into or is added to an excavation tends to percolate into the floor due to gravity. Due to its stratigraphic position and increased permeability, MB139 may act like a drain or sump within each room. In Panel 7, where the salt above MB139 was removed and replaced with compacted ROM salt, MB139 is likely more damaged than in other parts of the WIPP underground where permeability tests on MB139 were conducted. The high-permeability damage-induced pathway in MB139 at the repository level follows the network of drifts (Figure 1), with wider drifts and drift intersections having more damage than narrow isolated drifts. The salt below MB139 is assumed to be essentially impermeable, compared to MB139 itself.

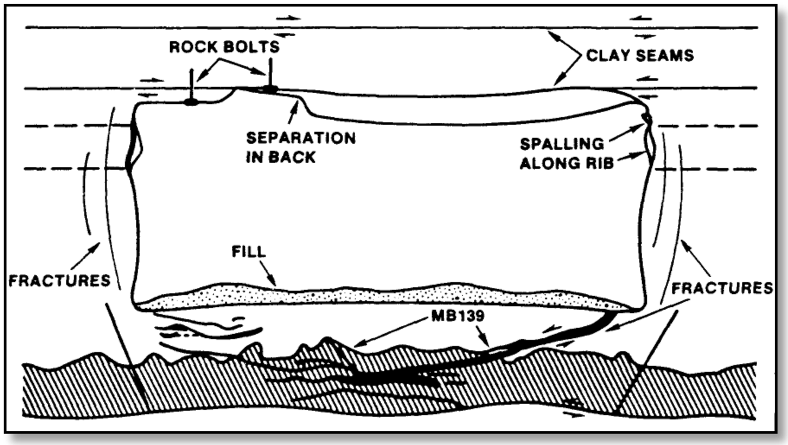

Figure 5. Cartoon illustrating typical damage surrounding WIPP disposal room (Borns and Stormont, 1988)

2.2 Brine driving forces

For brine to move through a porous or fractured medium, regardless of its properties, a driving force must exist. Brine moves due to:

- **Elevation/topography changes:** Salado geology (specifically the base of MB139) varies as much as 70 feet across the WIPP; i.e., all other things being equal, brine will flow down a "slanted" surface by gravity.
- **Brine mound elevation:** mounding due to accumulation of brine in the floor of the disposal rooms of Panel 7 will drive brine out; i.e., brine will flow away from the highest point in the mound. The shape and extent of the mound in the DRZ and MB139 below Panel 7 would be unknown without observations, but the driving force from the hydrostatic pressure is likely less significant than that due to elevation changes in MB139.
- **Fluid pressure:** it is assumed brine in MB139 under drifts will be exposed to atmospheric pressure, and the brine is essentially unconfined (i.e., a water table exists in boreholes completed down to MB139). Pressure gradients due to confinement will largely be insignificant near excavations compared to topographic and brine mound elevation gradients.
- **Capillarity**: brine will be drawn into unsaturated DRZ cracks, since brine is a wetting fluid in salt (a minor effect – but it has capacity to wick water "uphill" in damaged, but otherwise intact salt/anhydrite/clay). Some waste water from decontamination will be "wicked" into the porosity of the wall, rather than flowing down into the floor; this portion of the water is likely small and not problematic. Residual brine will also be

retained in the floor of compacted ROM salt by capillarity after gravity drainage. The moisture associated with this residual brine would most likely be transported from the WIPP underground by evaporation.

- **Hygroscopy:** salt has the ability to attract and hold water from the humidity in the air, once the air relative humidity is at or above 75%. While this is a small amount of fresh water added to the system, adding fresh water to Room 7 will increase its humidity and some moisture will propagate through air-filled macroscopic fractures via vapor convection. As for the case of capillary action, some residual brine will be retained for some time in the DRZ and compacted ROM salt floor by salt hygroscopy.
- **Density differences**: fresher brine will float on heavier brine. It is assumed that any water that flows large distances in fractures would quickly become saturated with respect to NaCl, making this driving force's effects minor and localized.

2.2.1. Topography

In general MB139 (and the rest of the layers in the Salado) dips to the southeast (towards Panel 4), but there can be both significant small-scale (e.g., see Figure 10) and large-scale variability (Figure 6). There is a local minimum MB139 elevation surrounding the Waste Handling Shaft (see Figure 6 and Figure 7). There is also a local maximum in the North Experimental area (Figure 7). Data from the WIPP Design Validation Report (Bechtel, 1986) are sparse in the WIPP disposal area, because only the E140 drift had been mined in 1986. Projecting the waste panels on Figure 6 shows there is a slight "divide" or "saddle" in MB139 elevation between Panel 7 and the Waste-Handling Shaft. MB139 drops off in elevation along E140 south of Panel 7 more steeply than to the north of Panel 7. Based on topography alone, brine is most likely to flow southward in MB139.

2.2.2. Brine mound elevation

Brine movement from Panel 7 north towards Panel 8 and the Waste-Handling Shaft would be through flat or slightly uphill MB139 topography (Figure 6). Therefore any brine flowing in that direction would be mostly driven by the height (hydrostatic pressure) of the brine mound created during decontamination activities. The worst-case scenario would be if the brine level at the north edge of the entrance to Panel 7 (W170 and S1600) was near the floor (4.6 feet above the top of MB139), and MB139 was saturated with brine along its entire course (so brine from Panel 7 would not be used to fill the open porosity of MB139).

Assuming flow moves north along the W170 drift from S2180 to S1300 (880 ft) – where the topography of MB139 becomes steeper (see blue label in Figure 6), under a driving force of 4.6 feet of brine head (1.2 times denser than fresh water), through MB139 ($T = 2\times10^{-3}$ ft^2/min; Deal et al., 1995), with a porosity of 5%, Darcy's law ($v = q/n \approx (K/n)\, \Delta h/\Delta L$, where v is pore velocity [ft/min], q is Darcy flux [ft/min], n is advective porosity, K is hydraulic conductivity [ft/min], Δh is change in head [ft], ΔL is distance over which change in head is applied [ft]) predicts an average linear velocity of

$$\left(\frac{0.002\ \text{ft}^2}{\text{min}}\right)\left(\frac{1}{\text{MB139 3 ft thick}}\right)\left(\frac{1440\ \text{min}}{1\ \text{day}}\right)\left(\frac{4.6\ \text{ft head}}{880\ \text{ft length}}\right)\left(\frac{\text{specific gravity 1.2}}{\text{porosity 0.05}}\right)=\frac{0.1\ \text{ft}}{\text{day}}.$$

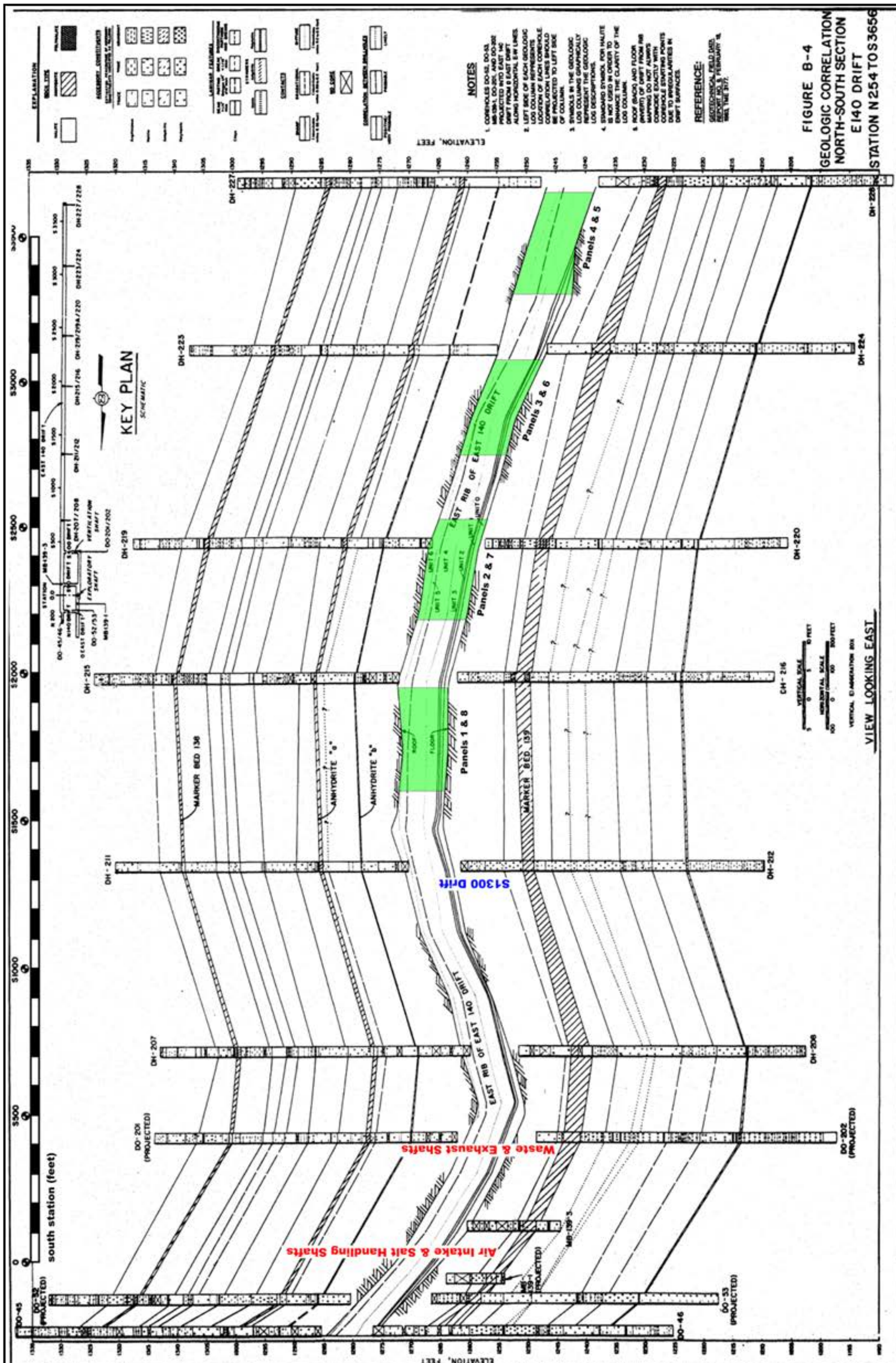

Figure 6. North-south cross section along E140 drift showing general dip to south, with local minimum near waste handling shaft (Bechtel, 1986). Panels approximately projected in green, shafts projected in red. Vertical distances exaggerated by factor of 20.

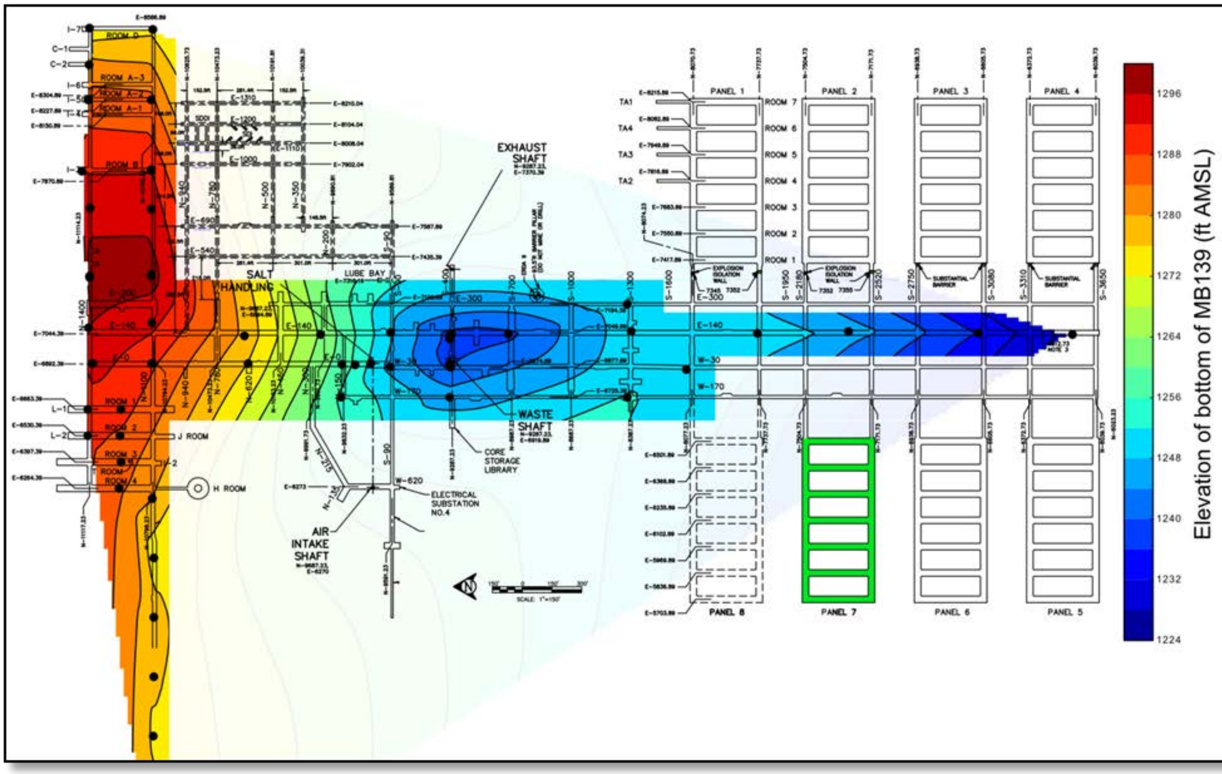

Figure 7. Elevation contours for bottom of MB139, based on data from Bechtel (1986). Black dots show location of MB139 elevation control points (data listed in Appendix A).

2.2.3 Capillarity

Moisture-release curves have been measured in the laboratory on cores of MB139 (Howarth & Christian-Frear, 1997). The data indicate damaged but otherwise intact anhydrite can exert significant capillary suction on brine (Figure 8). This implies that brine can travel significant distances in unsaturated MB139 under the action of capillarity, which can even exceed gravitational pull. This flow of brine under capillary suction in MB139 is compared to data obtained by Cinar et al. (2006) for relatively fine crushed and unconsolidated salt (finer than typical ROM salt) in Figure 9. The crushed salt requires much lower capillary pressures than the MB139 cores to imbibe brine or to attain residual saturation values under drainage; a lower capillary pressure is observed in the crushed salt for at every value of saturation, and the capillary rise in crushed salt would be significantly smaller than in MB139. This behavior would be expected in a comparison of a consolidated material (MB139 core) where the pore-sizes are small, to an unconsolidated material (crushed salt) with larger pores, because capillary pressure scales inversely with pore size.

Under field conditions, the flow and transport behavior of damaged MB139 is dominated by large-aperture fractures (Holcomb et al., 1995) that develop due to changes in the stress state induced by excavations. Such fractures do not exist in intact laboratory samples, like those tested by Howarth & Christian-Frear (1997). This notwithstanding, the data from Howarth & Christian-Frear (1997) give an indication of the ability of capillarity to wick brine away from crushed salt (compare 0.1 MPa to the range 2-20 MPa at 30% saturation).

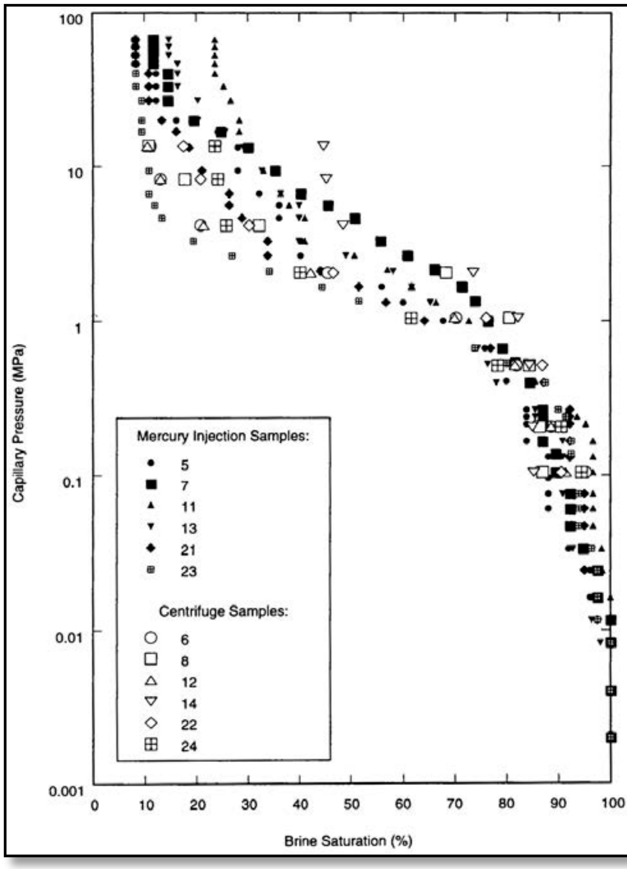

Figure 8. Capillary pressure data obtained from MB139 cores (Howarth & Christian-Frear, 1997)

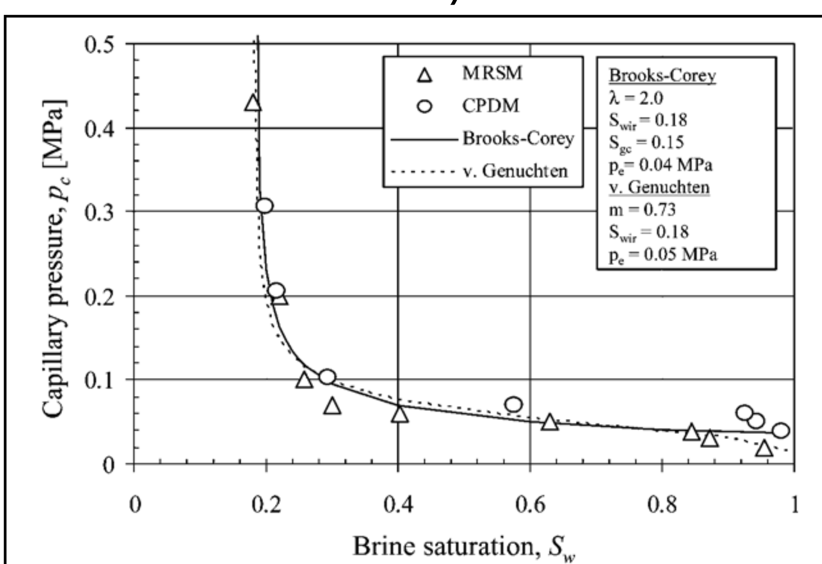

Figure 9. Capillary pressure data obtained from crushed salt (Cinar et al., 2006)

2.3 Disturbed rock zone MB139 properties

Although topography is the primary driving force, the distribution of increased permeability in MB139 follows the excavated drifts at WIPP. There is a rapid decrease in permeability away from drifts, which largely prevents brine from migrating through pillars and across un-excavated areas. MB139 has higher permeability under drifts than in undamaged areas, and permeability increases with increasing drift size.

Stormont et al. (1987) discussed the distribution of enhanced permeability in MB139, based on results of several rounds of borehole-based permeability testing:

> *When the test interval containing an interbed layer was well removed from the excavation, the measured flow rates were low. [...] When Marker Bed 139 was tested far removed (about 10 m) from the excavation, the measured flow rates were less than 1 SCCM [standard $cm^3/min \approx 3\times10^{-6}$ darcy].*
>
> *Relatively high flow rates occur when the interbed is within about 2 m of the excavation and the measurement has been made near the center of a drift or intersection […]. The interbed layers within 2 m of the test room excavations are Seam B above and Marker Bed 139 below. As illustrated in [Figure 10 right], measured flow rates are always less than 1 SCCM when the measurement is made from near the rib or just removed from the excavation, and the vast majority of measurements made from near the center are greater than 1 SCCM. If data from the first panel tests [circled in red] are excluded, the remaining data are all consistent with flow rates greater than 1 SCCM when measured from near the center of a drift, and less than 1 SCCM when measured near the rib or just removed from the drift. The first panel tests were conducted only about one month after excavation and were the narrowest drifts from which measurements were made, suggesting that time elapsed since excavation, drift size, and test interval position with respect to the excavation affect the flow characteristics of the interbed layers. Flow measurements have been made in 4.3-m-high drifts of three basic widths: 4.6, 6.6, and 11 m. As shown in [Figure 10 left], the wider the drift, the more flow is measured in MB139. The influence of the time excavations existed prior to measurement is not yet obvious, except perhaps that all first panel test data were relatively low. This might be attributed to the smaller size and/or the early age of the drifts at the time of the measurements.*

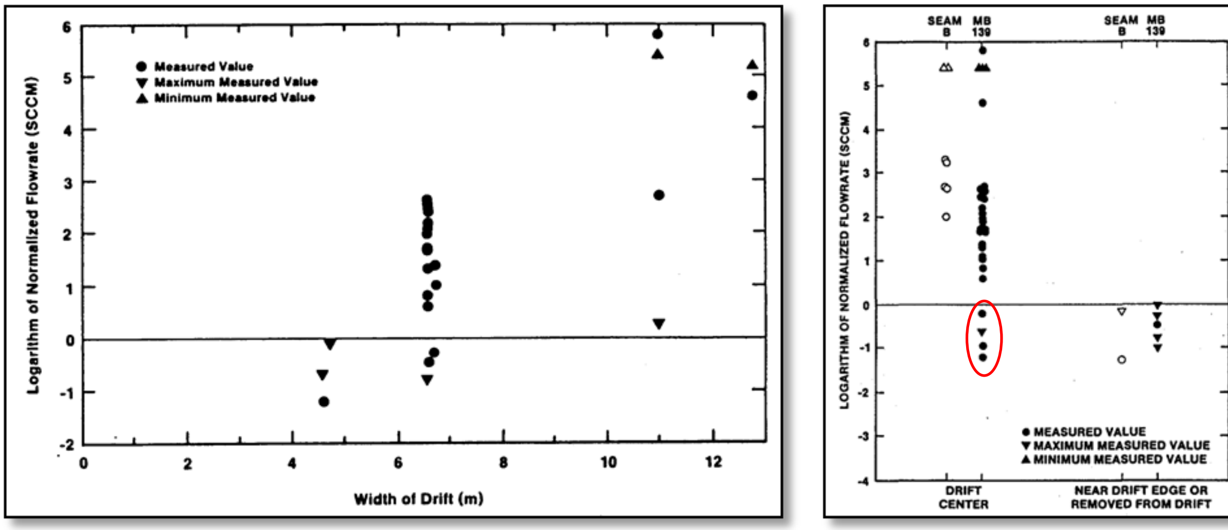

Figure 10. (Left) Normalized gas flow rate in MB139, as a function of drift width and (Right) comparison of flowrates observed in test intervals near drift center and near drift edge. Measurements from Panel 1 wade within 1 month of room excavation date are circled (Stormont et al., 1987).

The following additional tests and observations in the WIPP underground support the observations of Stormont et al. (1987):

- The WIPP Brine Sampling and Evaluation Program (BSEP) (Deal et al., 1991a; 1991b; 1993; 1994; 1995) performed small-scale short-duration (48 hour) low flowrate (20-30 liters/hour) "pumping tests" in open 10-cm boreholes completed to MB139 (Figure 11). They estimated transmissivity and storativity from observed data (geometric average $T = 2\times10^{-3}$ ft^2/min; $S\approx10^{-3}$). No recovery data were collected, and the short test durations made results somewhat inconclusive. Boundary effects were observed in some boreholes, indicating MB139 was not behaving like an infinite horizontal medium (i.e., effects of finite size of permeable MB139 region under drift). Effects of pumping were not seen in all observation wells, further indicating the permeability estimates were associated with a spatially limited highly fractured area.

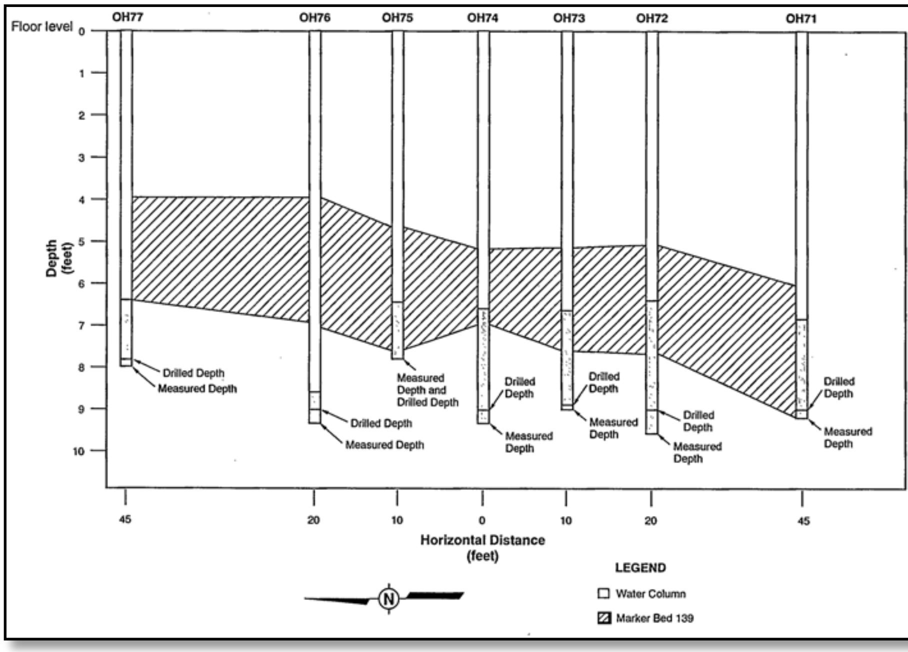

Figure 11. MB139 and water table in BSEP boreholes along E0 Drift centered on N620 (Deal et al., 1995: Appendix E)

- SNL performed gas permeability tests in the DRZ and MB139 (Peterson et al., 1985; 1987), estimating permeability both in slanted 45-degree boreholes under the rib ($\leq 10^{-5}$ darcy) and in vertical boreholes in the middle of the drift (10^{-3} darcy). These tests show at least two orders of magnitude change in permeability of MB139 between the middle and edge of the drift.
- SNL performed air flow tests in boreholes surrounding drift N1100 (Borns and Stormont, 1988; Figure 12). Contours of gas flowrate in Figure 12 show the high-permeability zone in MB139 is confined to the center of the drift (stars in Figure 12 show no-flow intervals, indicating little to no damage, specifically $<3\times10^{-6}$ darcy).

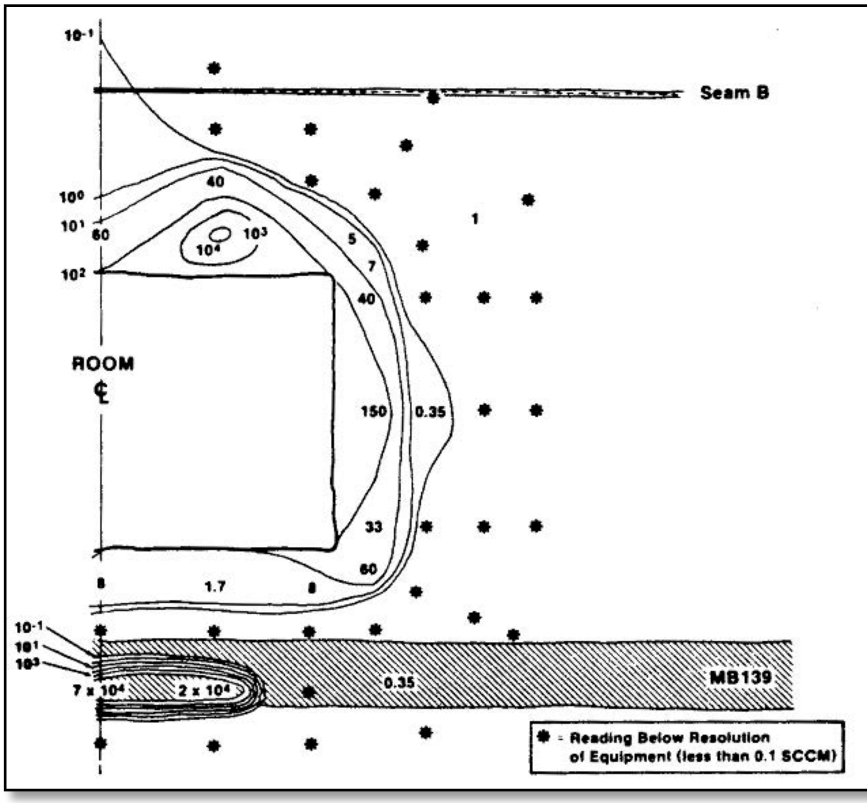

Figure 12. Contours of normalized gas flowrate in 1m intervals of 13-cm boreholes due to 70 kPa in N1100 drift at WIPP (Borns and Stormont, 1988).

- SNL performed SF_6 and Freon gas tracer tests in MB139 (Stormont et al., 1987).Tests near intersection of L1/L2 rooms with N1420 drift found very high permeabilities and very short travel times (10 minutes) for tracer gas, as well as significant tracer gas leaked from the injection point in MB139 to the floor of the room (captured by tarps placed across floor). Maximum fracture apertures were interpreted to be 0.04 cm and 0.02 cm in the horizontal and vertical directions, respectively. Similar gas tracer tests in N1420 (away from room intersections) resulted in estimates of maximum horizontal fracture aperture of 0.002 cm. Drift intersections had permeabilities that could be associated with a 5 times increase in maximum fracture aperture.
- SNL performed coupled permeability and hydrofracture tests in MB139/MB140 in Room C1 (Wawersik et al., 1996). These tests provide a large amount of data about MB139, its permeability before and after hydrofracture, and the least principal stress. These tests were conducted in a room in the WIPP North Experimental Area, where MB139 is 21 ft below the floor, and therefore MB139 is much less damaged than at the waste disposal horizon or Room 7, which was excavated down to MB139.

2.4 Air-intake shaft related MB139 brine migration

Significant fresh water was used during Air-Intake Shaft construction (May 1 through Aug 25, 1988), resulting in a large pulse of water that was predicted to migrate toward Room Q access drift. Five vertical boreholes (QBP01-05) were drilled to MB139 (Figure 13) approximately halfway between the Air-Intake Shaft and Room Q to monitor possible interference of this pulse of water with the Room Q brine inflow test (Finley et al., 1992).

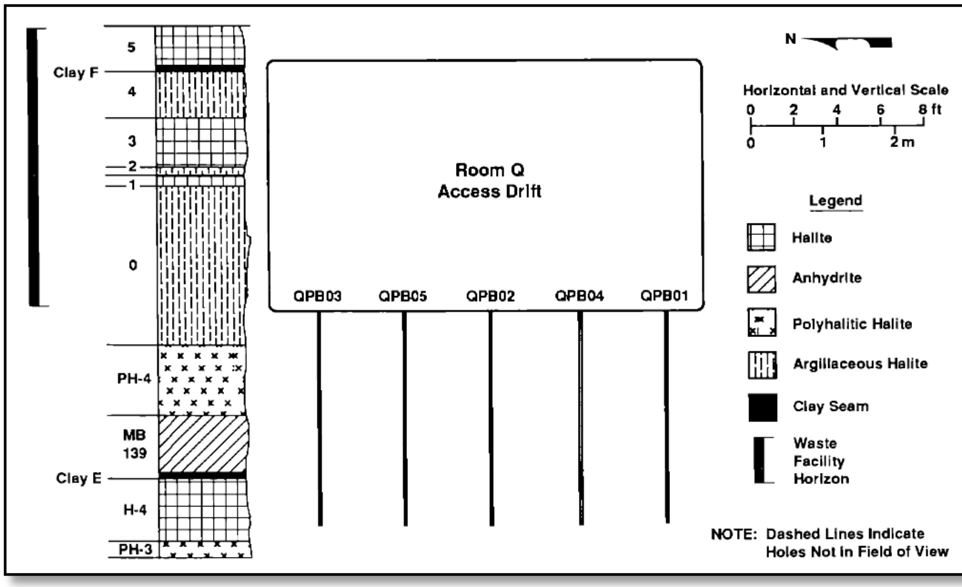

Figure 13. Room Q access drift boreholes completed across MB139 and monitored for brine inflow (Finley et al., 1992)

Brine inflow to the QPB01-05 boreholes was low initially, with an unexplained increase on about May 18, 1990 (see “1” in triangles in Figure 14). It is possible this increase is the pulse of water from the Air-Intake Shaft construction (begun two years previously), which had finally migrated into the Room Q access drift due to increased permeability in MB139 associated with the Room Q access drift excavation size and age. MB139 gas flow measurements were low in Panel 1 during the first month after excavation (see circled observations in Figure 10 right), indicating there may be a delay between initial room excavation, and the increase in permeability in MB139, especially away from drift intersections.

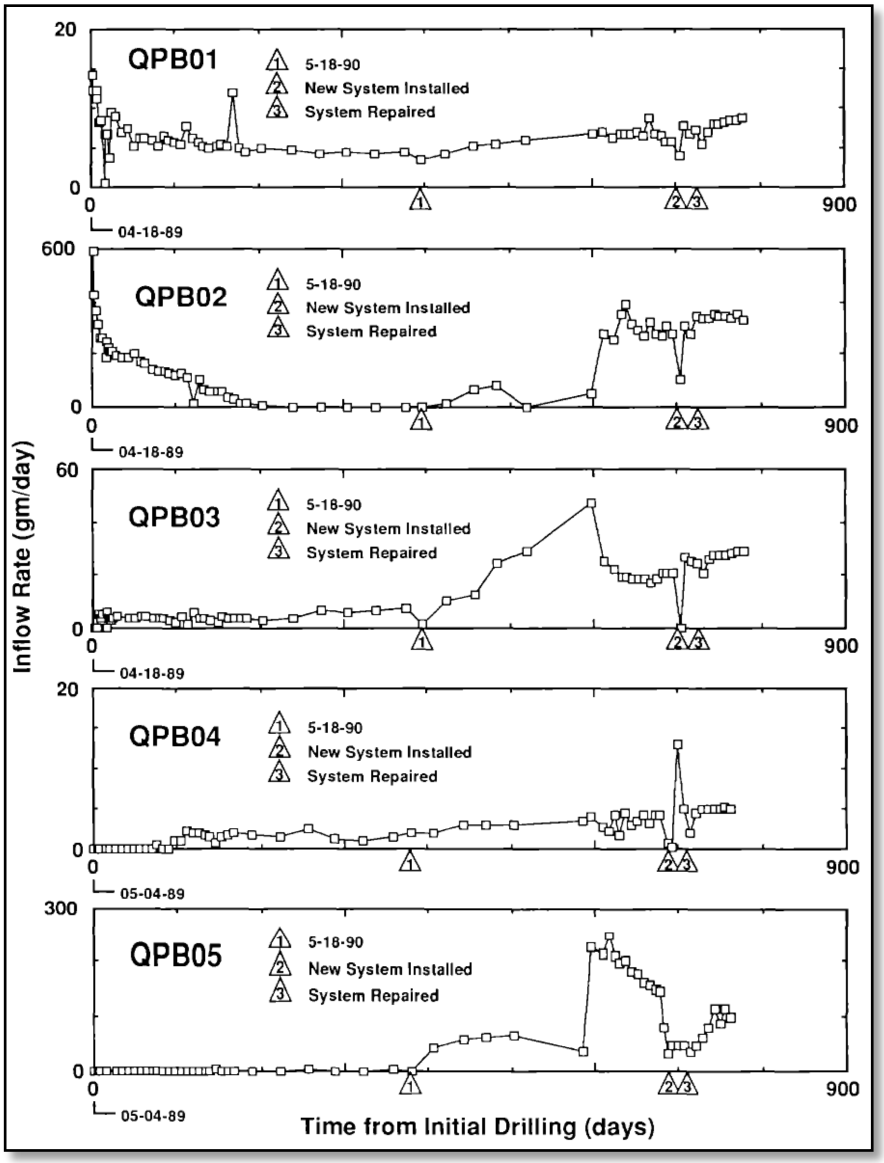

Figure 14. Brine inflow observed in Room Q access drift boreholes completed to MB139. (Finley et al., 1992)

2.5 Exhaust shaft MB139 brine migration

Water has leaked into the WIPP underground via the Exhaust Shaft from a shallow perched aquifer at the WIPP site (Nelson, 2014b). This water enters MB139, which is immediately below the floor of the drift, and flows along the N400 drift to the Waste-Handling Shaft about 500 feet to the west (see Figure 6 and 7). Under normal operating conditions, this brine is collected through interceptor wells. This brine is moving to a low point in MB139 (Figure 6 and 7), which coincides with the Waste-Handling Shaft sump.

This process will not likely occur for added decontamination water because the topography of MB139 is such that MB139 is several feet higher north and east of Panel 7 (see Figure 6 and 7), between Panel 7 and the Waste-Handling Shaft.

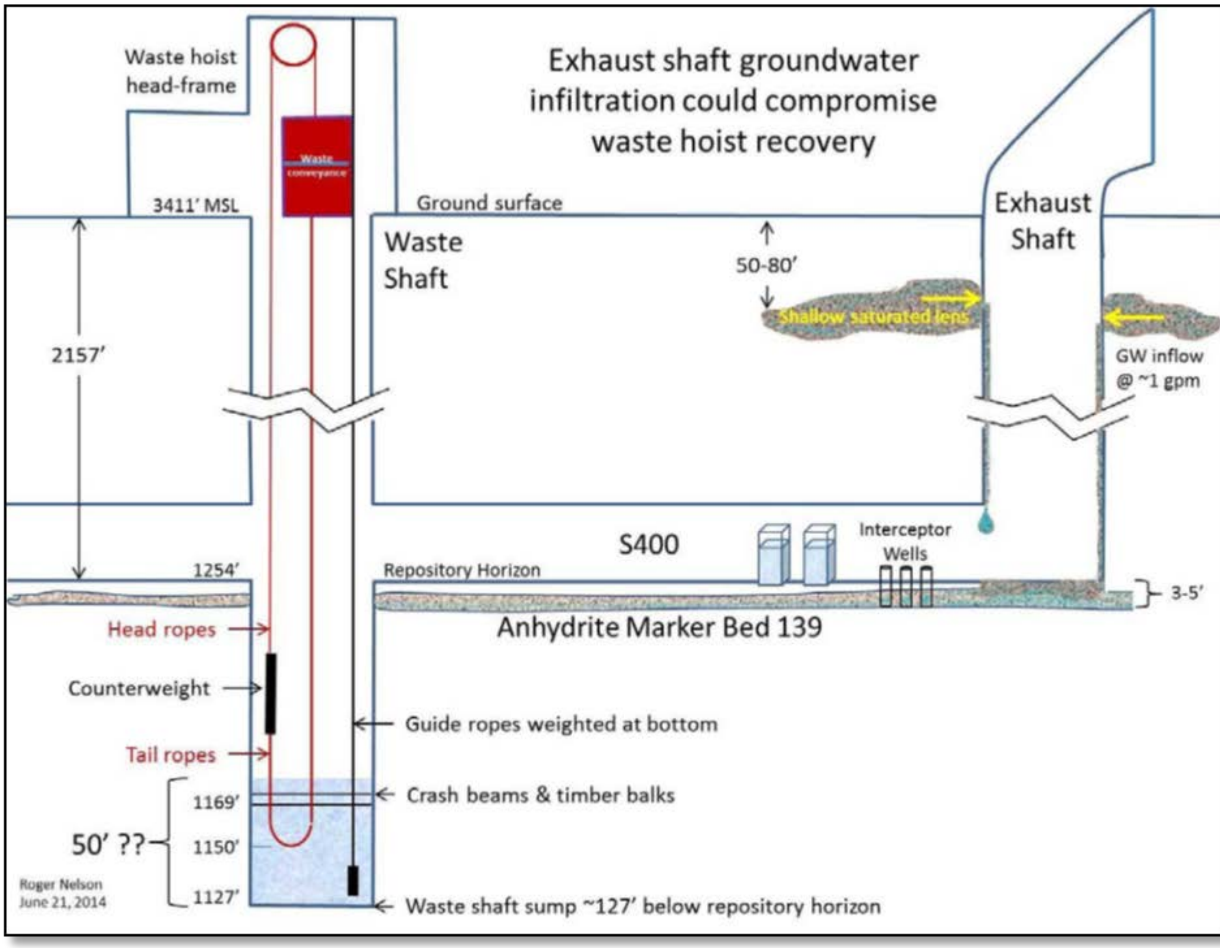

Figure 15. Illustration of connection between Exhaust and Waste shafts at WIPP through MB139 and interceptor well system (Nelson, 2014b)

2.6 Predicted fate of MB139 brine from Panel 7

Brine added to the walls, roof and floor in Panel 7 will remove surface contamination, dissolve salt, and flow down into the crushed salt and MB139 beneath Panel 7 under the force of gravity. The high porosity in the ROM salt located between the floor of Panel 7 and MB139 will act as a short-term reservoir for this brine. The crushed salt will also provide more opportunity for the fresh water applied to the walls to rapidly become saturated with respect to NaCl. The saturated brine will then migrate down into MB139 (which is highly damaged since the Panel 7 was once excavated down to that level). Once in MB139, the brine will migrate under rooms and drifts, where MB139 permeability is greatest (especially at intersection of wide and older drifts). Given available surveyed borehole locations and MB139 elevations in Bechtel (1986), brine from Panel 7 will move to the south (towards Panels 4 and 5).

Radionuclide transport will occur to a small degree in the dissolved state (it is assumed the radionuclide contamination is relatively insoluble), which will likely be highly retarded – due to the high clay content of MB139 (Figure 4). The most likely transport pathway for particles is as colloids, which may be transported unimpeded with the brine through fractures in MB139. Much higher flow velocities may occur in connected fractures compared to flow velocities associated with uniform Darcy flow, which are difficult or impossible to predict using a porous media flow conceptualization.

3. RECOMMENDED ACTION

If a decision is made to decontaminate the WIPP using fresh water, we recommend monitoring brine levels in MB139 in and near the entrance to Panels 6, 7, and 8 in the W170 and W-30 drifts (near field). These near-field monitoring locations should be constructed as small-diameter boreholes drilled down to the bottom of MB139 (like those in Figure 11 and Figure 13) before decontamination efforts begin. This will provide an initial condition brine level in MB139 before any water is added to Panel 7. If necessary, brine levels may also be monitored in access drifts between Panel 7 and the Waste-Handling Shaft sump (far field). These boreholes could be monitored with low-cost pressure transducers mounted in the boreholes, recording data at a relatively high frequency. Similar to the QPB01-05 boreholes in the Room Q access drift (Finley et al., 1992), these boreholes could be built with sub-surface completions, allowing normal mine traffic around and over them. These boreholes would be a simple and effective way to monitor the movement of brine in MB139, possibly allowing sampling to test for radionuclide content. It would be important to locate the boreholes at room intersections, where MB139 permeability is highest and interconnected fractures permeate the formation; at drift intersections the fractured marker bed most likely behaves like a porous medium (Deal et al., 1995).

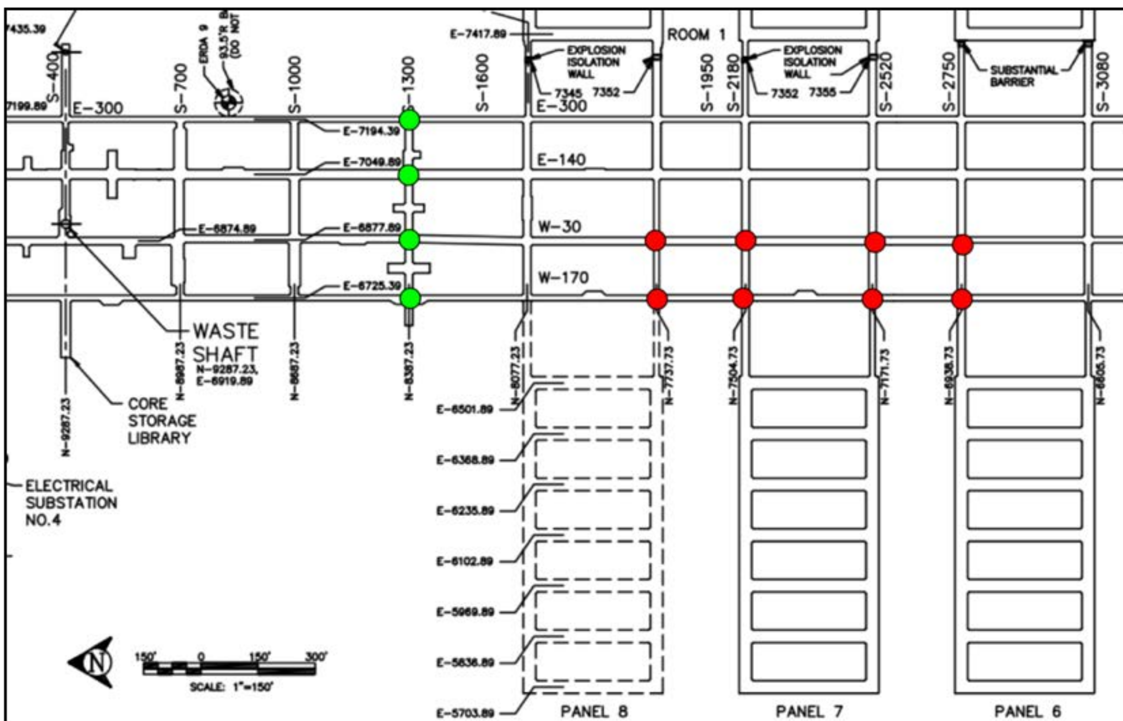

Figure 16. Proposed near-field (red) and far-field (green) borehole locations to monitor brine movement in MB139. See location of S1300 drift (in blue) in relation to MB139 elevation in Figure 6.

Grouting of MB139 could be completed to reduce permeability associated with large-aperture fractures in the highly damaged portions of MB139 at drift intersections. SNL completed a test plan to seal MB139 with grout and test reduction of permeability, but the test was never implemented (Ahrens, 1992). This test plan contains a good summary of the known nature of MB139 in the early 1990s, and presents the possibility of grouting the open fractures (macroporosity) in MB139 to reduce its permeability. If near-field brine monitoring indicates brine is moving towards the Waste Handling Shaft, it may be prudent to grout MB139 at the intersection of the north-south drifts with S1300 drift (i.e., location of far-field monitoring boreholes).

MB139 generally dips to the south east (away from the Waste-Handling Shaft) and brine will likely flow in that direction (away from the S1300 drift). Assuming the topography driving force is not effective, the mound height driving force would only drive brine towards the S1300 drift at a rate on the order of 0.1 ft/day. Based on this estimate, it would likely not be necessary to perform any grouting in MB139 at S1300 before decontamination operations at Panel 7, since flow velocities from between the near-field observation wells to the S1300 observation locations would be on the order of years, rather than days or weeks. There is a large amount of uncertainty in the estimate of 0.1 ft/day, based on the uncertainty in the conceptual model (porous media flow vs. fracture flow), the estimate of the driving force (mound height), and the material properties used (especially porosity).

Despite the apparently favorable dip of MB139 to the south (away from the Waste-Handling Shaft) and slow flow velocities predicted through MB139 under the driving force of mound height, we recommend the minimum possible fresh water be used to decontaminate the walls, roof, and floor of Panel 7 (i.e., much closer to the estimate related to INL's laboratory tests than the maximum capacity of the ROM salt in the floor of Panel 7). Using more water than is minimally necessary (e.g., dissolving up to an inch of salt from the panels as indicated in Section 1.1) will lead to a larger amount of contaminated brine in MB139, which will be more difficult to confine to a limited area and would be more difficult to treat – if that became necessary.

Collection of additional data on the two-phase flow properties of ROM salt of various compaction levels and DRZ salt cores would complement the database of MB139 two-phase flow data (Howarth & Christian-Frear, 1997), and allow more quantitative estimation of brine fate and transport in WIPP and other salt repositories.

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APPENDIX A. MB139 ELEVATION DATA

Borehole	page	NS station [ft]		EW station [ft]		reference elevation [ft AMSL][*]	depth to MB139 bottom [ft]	MB139 bottom elevation [ft AMSL][*]
Waste Shaft	10	S	400	E	0	1240	3	1237
Salt Shaft	67	S	0	E	0	1254	3	1251
MB-139-1	208	N	79	W	6	1264.1	8.6	1255.5
MB-139-2	209	S	410	E	150	1251.2	12.9	1238.3
MB-139-3	210	S	101	E	157	1260.5	11.9	1248.6
MB-139-4	211	S	99	W	17	1258.7	11.9	1246.8
DH-02B	218	N	1424	E	442	1306.3	8.3	1298
DH-04	224	N	1112.5	E	444	1309.56	11.65	1297.91
DH-4B	227	N	1112	E	450.5	1309.7	11.6	1298.1
DH-06	231	N	1463	E	972	1317.9	26.1	1291.8
DH-08	235	N	1112	E	976.5	1318.8	26.6	1292.2
DH-08A	237	N	1112	E	975	1318.7	26.4	1292.3
DH-08B	239	N	1112	E	979.5	1318	26.9	1291.1
DH-10	244	N	1432	E	1332.5	1312.1	26.5	1285.6
DH-12	248	N	1112	E	1332.5	1311.1	25.9	1285.2
DH-14	254	N	1425	E	1695	1299.5	26.45	1273.05
DH-16	258	N	1104	E	1688	1300.3	25.2	1275.1
DH-18	263	N	1429	E	181	1305.1	9.1	1296
DH-20	268	N	1109	E	206	1306.2	13	1293.2
DH-22	272	N	1421.5	E	785.5	1318.8	24.3	1294.5
DH-24	276	N	1112	E	781	1319.51	24	1295.51
DH-24A	278	N	1112	E	780	1318.49	23.95	1294.54
DH-26	282	N	1427	E	1510	1307.2	25.9	1281.3
DH-28	286	N	1107	W	682	1289.9	9.9	1280
DH-30	292	N	1099	W	982	1289.2	16	1273.2
DH-32	299	N	1099	W	1282	1289.6	11.3	1278.3
DH-34	305	N	1099	W	1582	1289.4	11.05	1278.35
DH-36	310	N	1102	W	1882	1284.6	10.4	1274.2
DH-38	314	N	1101	W	2182	1287	9.45	1277.55
DH-40	318	N	1101	W	2482	1286.1	10.95	1275.15
DH-42	322	N	1101	W	2782	1285.9	10.1	1275.8
DH-208	329	S	698	E	150	1251.6	12.6	1239
DH-212	333	S	1320	E	163	1261.7	12.6	1249.1
DH-216	339	S	1960	E	153	1262.6	11.5	1251.1
DH-220	346	S	2421	E	162	1257.4	11	1246.4
DH-224	352	S	3079	E	154	1246.6	10.7	1235.9
DH-228	358	S	3556	E	147	1237.8	11.5	1226.3
DH-302	363	N	150	W	170	1264.9	9.6	1255.3
DH-304	367	S	400	W	170	1254.3	8.75	1245.55
DH-306	369	S	400	E	140	1244.1	5	1239.1
DH-306A	371	S	400	E	125	1244	5.45	1238.55
DH-314	381	S	1300	E	300	1258.3	7.6	1250.7
DH-316	385	S	1300	W	170	1259.9	7.65	1252.25
DH-318	392	S	1600	W	30	1258.5	7.3	1251.2
DO-46	403	N	254	E	147	1276.5	13	1263.5
DO-53	409	N	146	W	4	1266.6	8.6	1258
DO-57	414	N	621	E	0	1288.1	12.2	1275.9
DO-64	420	N	1110	E	0	1301.5	12.8	1288.7
DO-67	423	N	1265	W	231.5	1296.8	6.8	1290
DO-77	429	N	1270	W	364.5	1294.6	7.25	1287.35
DO-90	438	N	1265	W	497.5	1292.1	5.7	1286.4

Borehole	page	NS station [ft]		EW station [ft]		reference elevation [ft AMSL]*	depth to MB139 bottom [ft]	MB139 bottom elevation [ft AMSL]*
DO-91	441	N	1275	W	630.5	1292.1	7.2	1284.9
DO-202	450	S	406	W	19	1248.6	7.6	1241
DO-204	456	N	640	E	140	1290.5	11.5	1279
DO-206	462	N	1410	E	0	1308	14.4	1293.6
OH-13	470	N	1433	W	231.5	1298	8.1	1289.9
OH-14	471	N	1433	W	364.5	1296	6.95	1289.05

page numbers are references to geologic data reported in Bechtel (1986)
*AMSL=above mean sea level

APPENDIX B. NELSON (2014) WHITE PAPERS

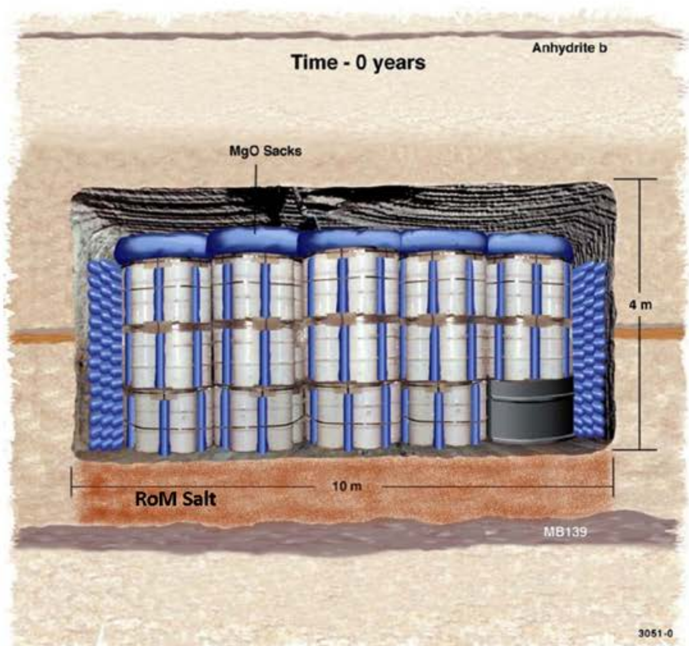
These two two-page white papers were written by Roger Nelson at the DOE Carlsbad Field Office. They are included in their entirety, since they were not widely distributed and form part of the basis for the arguments presented in this report.

Decontaminating the WIPP Underground from the 2014 Valentines Day Event
Roger Nelson, May 27, 2014

The event that released airborne radioactivity from the WIPP underground is still being investigated. Regardless of the source, it is known that several hundred airborne milli-curies reached the surface HEPA filtration system, with a predominant Am-241 content. It also appears that a heat source helped aerosolize the material. While the extent of surface contamination in the underground drifts has not been mapped, it is likely that there are areas in the immediate vicinity of the release, and along down-stream exhaust air drifts towards the exhaust shaft, that will need to be decontaminated before workers can gain access without respiratory protection. This paper describes a potential decontamination solution that could uniquely be applied in a cost effective and rapid campaign.

The WIPP underground is a very large space in which to contemplate the use of conventional decontamination techniques. It is also a very unique space because the repository is already intended to permanently contain and isolate many millions of Curies from the biosphere forever. The WIPP host rock is predominantly Halite, which is highly soluble in plain water. This unique combination makes decontamination by simple washing a very promising possibility. A small amount of fresh water applied to any Halite surface will remove the surface to any desired depth, along with any affixed radioactive particulate. However, additional testing should be done to confirm this attractive hypothesis.

The geophysical configuration and cross section of Panel 7, where the release event occurred, is shown in the adjacent figure. This configuration is also unique among the mined panels at WIPP. The important distinction is that the floor of the entire Panel 7 has been mined down to Anhydrite Marker Bed 139, and Run of Mine (RoM) salt brought back in to the floor grade. This was done to avoid floor heave potential due to the marker bed bucking over the 2-3 year period of waste emplacement in Panel 7. But it also resulted in a porous layer not routinely available in the rest of the repository (shown as the darker brown layer between the floor and the marker bed in the figure). This porosity could be used as a sump to wash contamination into. Based on an assumed 30% porosity of RoM salt, and typical stratigraphy, it is estimated that there are more than 250 gallons of sump capacity per linear foot along all drifts in Panel 7. Once in the porosity, the contaminants will be trapped there as the brine evaporates, and re-crystallization binds the RoM salt gravel together. If additional assurance is desired, more RoM salt mined from a clean area could be brought in and the floor built up further. WIPP's >25-year mining experience has shown that RoM Halite placed in such a fashion, with surface healing augmented by water spray, can easily withstand heavy equipment loads without crushing or



displacement (thereby avoiding any re-entrainment of radioactivity during subsequent waste handling operations).

While the decontamination of Panel 7 may be facilitated by its porous RoM salt floor layer, there is no such porosity along the exhaust drift S-2180 and E-300 to the exhaust shaft. This means the decontamination of these two drifts will likely involve collection of the brine. One possibility is that decon brine collected during washing S-2180 and E-300 could be simply pumped to Panel 7 and spread throughout the remaining porosity. Alternatively, if the Panel 7 floor porosity was filled by decon of the panel itself, the exhaust drift decon brine could be pumped to the surface, treated and disposed of as low-level waste. Although there should be adequate volume in the Panel 7 porosity for all decon brine, the possibility of a commercial disposal solution should be examined anyway.

The efficacy of using fresh wash water for decontamination of the event can be easily tested at no risk in Panel 7 during the re-entry activities that are currently ongoing. One simple measure would be to pick a few test areas, off of the routine path to and from the waste face. Quantitative surface alpha decay rate measurements could be made before and after application of small amounts of fresh water sprayed on small areas to gain some sense of method effectiveness. This should be done as soon as possible, and could be accomplished in rooms other than Room 7 to avoid any questions the Accident Investigation Board might have on the impact to their ongoing investigation.

Another consideration is related to the impact of the use of fresh water for decon on long-term repository performance. How would the quantity of fresh water needed compare to the total brine already assumed to be present in the waste or in the formation? Conservatively assuming the full porosity of the RoM salt floor in Panel 7 was required and subsequently filled, the total amount of brine would be about 900K gallons (3400 cubic meters). This can be compared with the assumed volume of water in the waste itself, which is set at 1% (or 1750 cubic meters for a full repository). It can also be compared with the modeled brine volume in the performance assessment calculations used for WIPP certification by EPA. That brine volume is calculated based on the rock's brine content and the extent of the disturbed rock zone. The volume released as inflow to the repository varies over time and depends on the repository pressure history, but the mean volume is 650 cubic meters per panel, for a total of 6500 cubic meters. Thus, the conservatively assumed filled porosity of the Panel 7 RoM floor represents about 40% of the brine already assumed to be present in the performance assessment demonstration of compliance with long term repository standards. This added brine would not be expected to significantly change the compliance arguments (especially because it is dwarfed by the inflow expected from the castile in an human intrusion event). However, as part of the recovery planning process, EPA should be consulted, and discussion about how the added brine would be accounted for in a planned change notice to be submitted during the decon efforts.

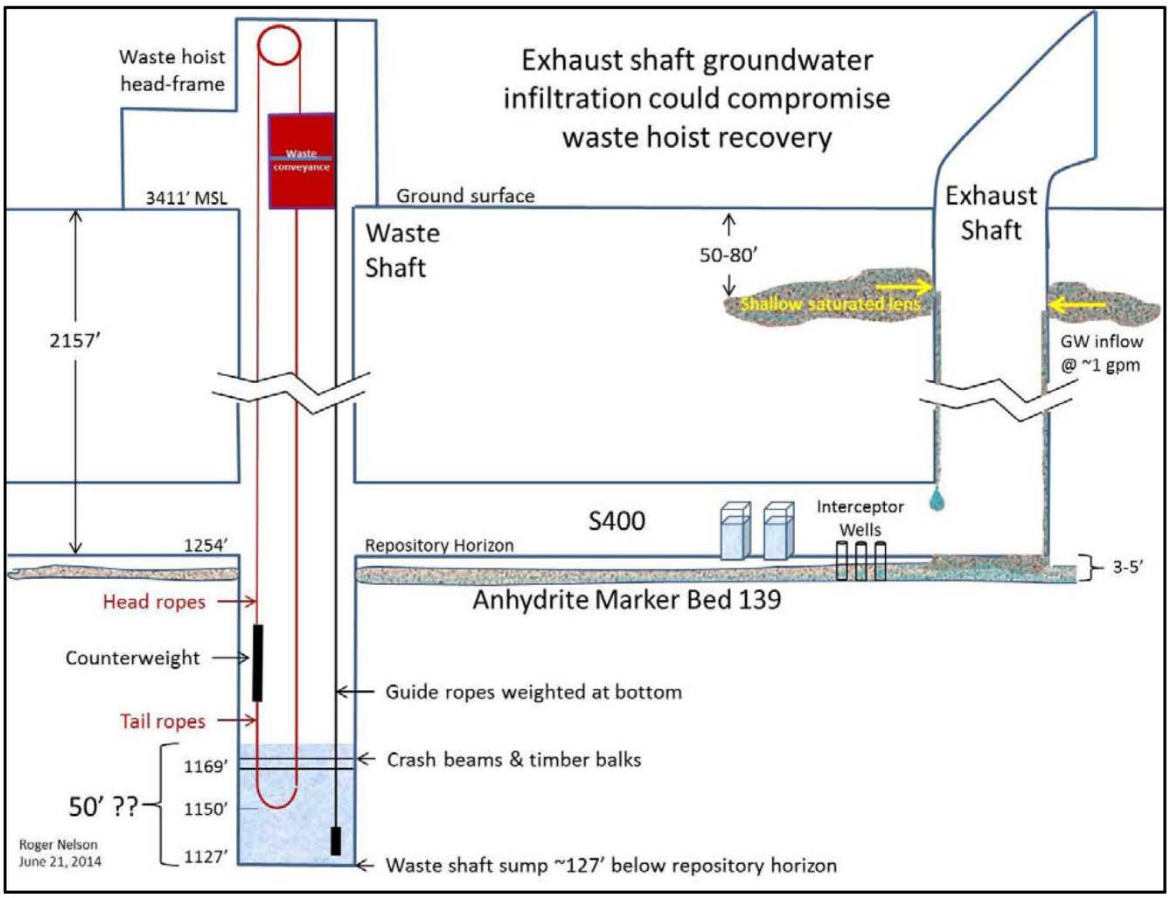
In conclusion, a simple decontamination solution has been discussed that may provide a much less expensive and faster path to routine worker and heavy equipment access than traditional decontamination techniques. This concept employs the unique properties of the repository rock itself. Halite (common salt) is very soluble, and fresh water washing will dissolve the surface layers and bring any surface contamination particulate along with the wash into an underlying porosity sump below the floor of Panel 7. The capacity of the RoM porosity to contain the wash is large and will likely hold all of the brine from decontaminating Panel 7, and the exhaust drifts S-2180 and E-300 that do not have similar floor porosity.

Exhaust Shaft Groundwater Infiltration Could Compromise Waste Hoist Recovery Efforts

Roger Nelson, June 21, 2014

Recovery efforts at WIPP will depend greatly on the rate at which the waste hoist is returned to service. Due to egress limitations without the waste hoist, access to the underground is limited to less than 24 miners. With the waste hoist back in service, many more personnel can be allowed in the underground. With hoist system preventative maintenance and HEPA filter change on the critical path, the current schedule shows the waste hoist returning to service July 17. However, there are many unknowns that could significantly delay this availability.

One of the unknowns is the potential that the waste shaft sump has filled with brine originating from a shallow water bearing unit near the top of the exhaust shaft. The potential issues are illustrated in the following schematic.



Fluid seeps into the exhaust shaft through cracks in the exhaust shaft liner located between 50-80 feet below the surface with the principal seepage cracks located at 75-80 feet below ground surface (bgs). Fluid is located in the sandstones of the Lower Santa Rosa Formation and mudstones of the upper Dewey Lake Red Bed Formations. The fluid level around the exhaust shaft has remained between 46 and 50 feet below ground surface since monitoring began in 1996 when three wells C-2505, C2506, and C2507 were drilled near the shaft.

Based on two pumping tests using these wells, and observations of quarterly exhaust shaft video inspections, it is estimated that 1.0 gpm, generating 1440 gallons of fluid, leak into the exhaust shaft per day. With reduced underground ventilation of 60,000 cfm or less, it has been historically observed that essentially all the infiltrating fluid reports to the base of the exhaust shaft. For this reason, a series of interceptor wells were installed in the underlying anhydrite marker bed 139, several feet below the disposal horizon. MB139 is a fractured unit through which rapid flow can occur along mined drifts. The extent of fracturing under pillars adjacent to mined drifts is not known, but it has been consistently observed that MB139 Is extensively fractured beneath all open drifts. To capture flow through MB139 to the waste shaft sump, the interceptor wells pump any brine reporting to the bottom of the exhaust shaft to storage tanks underground. These tanks are periodically sampled for RCRA metals. If necessary, the water is disposed of as hazardous waste by a vendor. If the samples from each tank pass TCLP testing, the brine is brought to the surface and placed in the lined evaporation ponds.

The ~500 gallon tanks into which the brine is pumped are equipped with limit switches, so it is likely that the flow passed by the interceptor wells within a few days of lowering the ventilation rate in mid-February as the tanks reached capacity. If a major fraction of the brine leaking into the exhaust shaft has been reporting to the MB139 outcrop in the waste shaft sump, there could be considerable accumulation.

At 1 gpm (~43,000 gallons per month), a rise of ~17 feet per month could accumulate in the waste shaft sump. If there were no outflow, this would mean that the bottom of the tail ropes for the waste hoist could be submerged. Other components of the waste hoist system within the sump could also be submerged (crash beams, timber balks and guide rope weights).

While submersion in brine might not deleteriously affect these components, a thorough inspection and subsequent engineering analysis would be prudent before hoisting operations resume. This problem could be significantly exacerbated if the brine inflow carried contamination from the exhaust shaft all the way over to the waste hoist sump, which is unlikely. Even though the flow though MB139 is in fractures, it is extremely unlikely that any insoluble particulate would be transported though that distance. Therefore, contamination in the brine (if any) reporting to the waste shaft sump would be dissolved. The solubility of the material aerosolized from the MIN02 waste stream is expected to be very small in the high ionic strength brine. However, prudence dictates that samples of any waste shaft sump brine be radiologically analyzed before work is performed on the sump equipment.

Returning the waste hoist to service will depend on the sump condition. It is imperative that conditions be determined as early as possible. The highest priority should be placed on the next re-entry to determine how much brine has accumulated and collect samples for analysis. Regardless of whether the waste shaft sump brine is contaminated, it will need to be pumped out if the levels have reached the waste hoist components. If it must be treated as low-level waste, it will just make the sump brine disposal more problematic and delay waste hoist recovery. The guide rope cable weights extend almost to the bottom of the sump, and the brine level should be lowered below them. Sump brine management and potential disposal is not considered in the current plan for the waste hoist recovery.

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