# Brine Migration in Heated Salt: Lessons Learned from Field Experiments

MR13A-0311
SAND2017-12965C

Kristopher L. Kuhlman[1], Edward N. Matteo[2], Melissa M. Mills[1]

Sandia National Laboratories, Albuquerque, NM

[1]Applied System Analysis & Research, [2]Nuclear Waste Disposal Research & Analysis

## Background

The US Department of Energy Office of Nuclear Energy is planning a borehole heater test in salt at the Waste Isolation Pilot Plant (WIPP), near Carlsbad New Mexico. We plan to observe brine-migration related phenomena in heated 4.75" diameter boreholes. We base our design on past heater tests, observing 1) thermal-hydrological-mechanical (THM) coupling during heating and cooling events; 2) chemical brine composition; and 3) any acid gas (i.e., HCl) generation. There are other aspects of the test not presented here, including acoustic emissions (AE), electrical resistivity tomography (ERT), and use of deuterated water ($D_2O$) as a tracer.

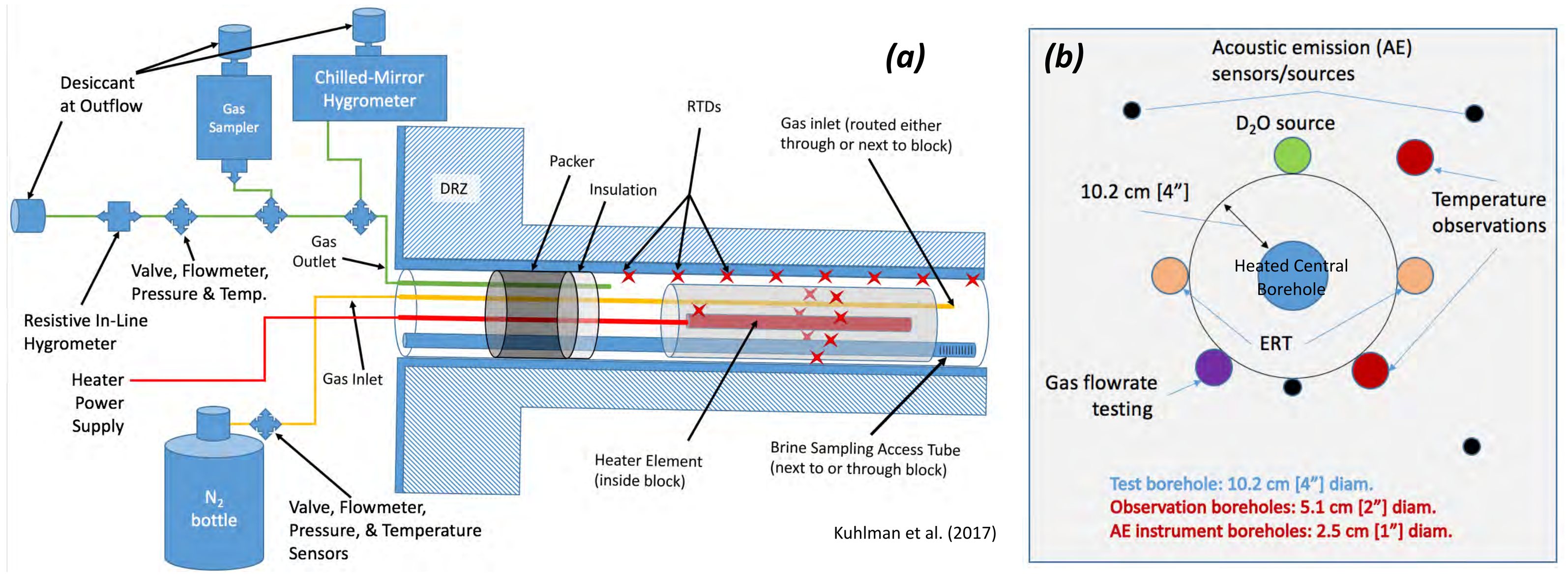


**Figure 1:** *Borehole Heater Test Concept. Schematic of heated central (a) borehole and satellite boreholes (b).*

## What will we Measure?

The heated borehole test (Fig 1) aims to monitor water inflow, brine and gas composion, temperature, borehole closure, salt resisivity, and acoustic emissions through time. Water inflow will be quantified by flowing $N_2$ gas through the borehole, measuring the humidity with a hygrometer. Temperature will be measured with resistive temperature devices (RTDs), AE will be measured with piezoelectric sensors, and resistivity will be monitored using ERT.

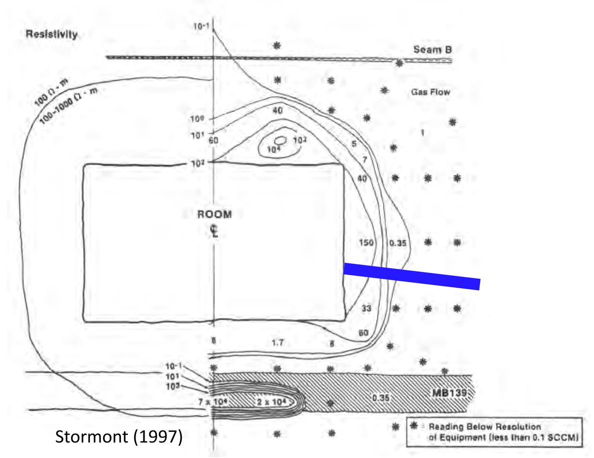


**Figure 2:** *WIPP DRZ and planned borehole*

## Brine Production from Salt (THM coupling)

Salt deposits produce brine when intersected by a borehole. Unheated boreholes produce less brine than heated boreholes (Fig 3a-b). Bedded salt deposits have non-halite layers (e.g., anhydrite, clay, polyhalite: Fig 3c), which can produce much more brine than the pure halite layers. This test aims to avoid mapped non-salt layers with a horizontal configuration. The borehole will be completed with packers to isolate it from the distrubed rock zone (DRZ) surrounding the room (Fig 2).

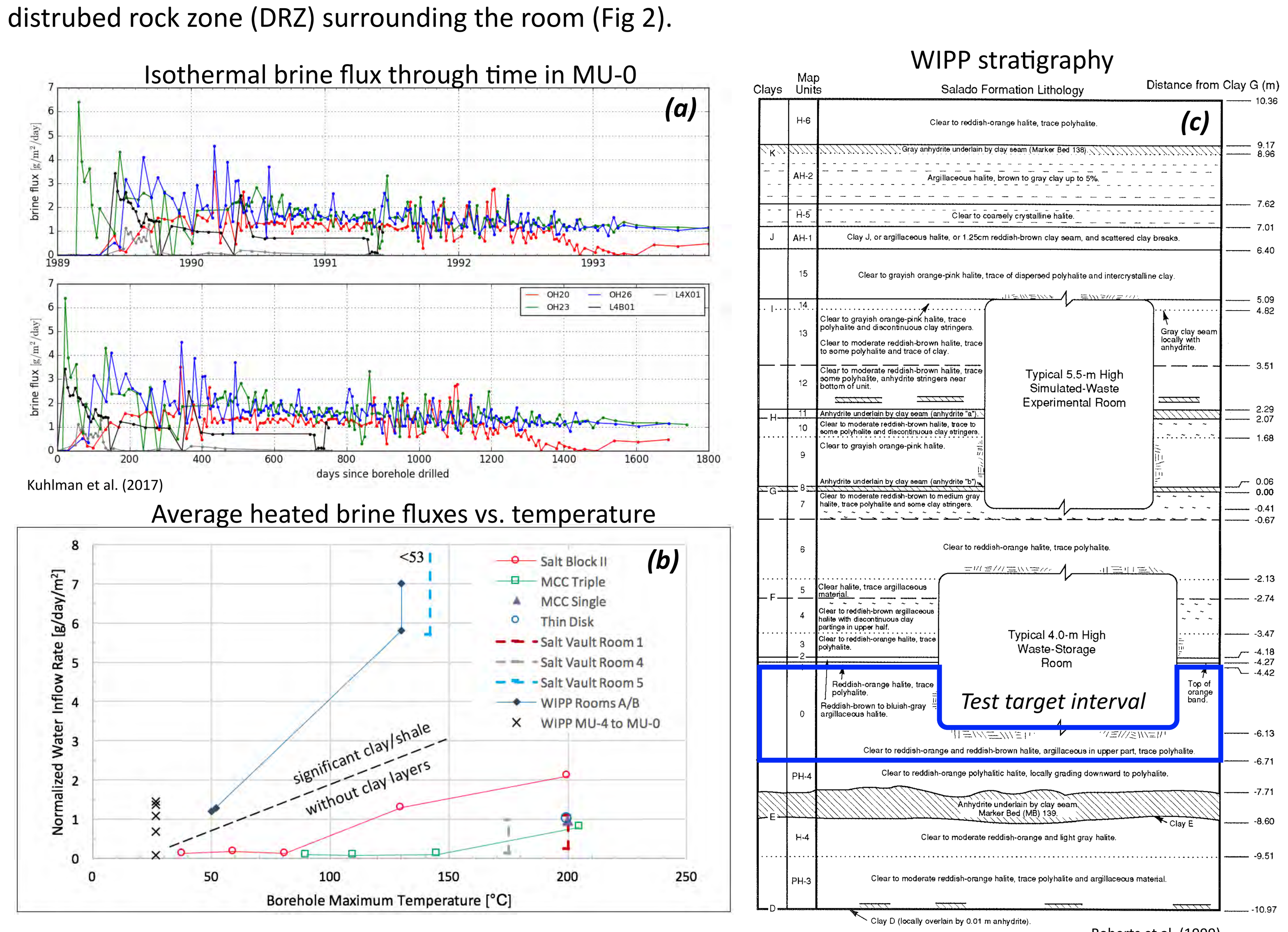


**Figure 3:** *(a) Isothermal brine flux at WIPP, (b) steady brine flux for different temperature, (c) WIPP geolopgy*

## Brine Chemical Composition

Halite in bedded salt deposits is quite dry, from its low porosity (≤1%). Brine produced from the salt may come from several sources (Fig 4). Brine of variable composition will flow into the borehole, and the chemistry of the brine will evolve as the water is removed and salts precipitate.

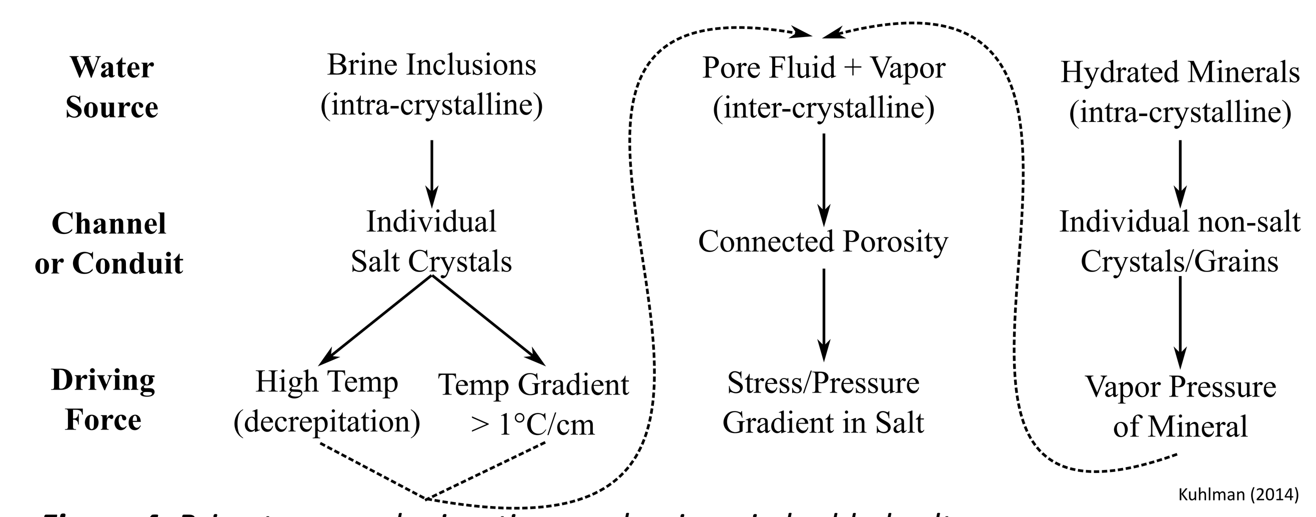


**Figure 4:** *Brine types and migration mechanisms in bedded salt.*

Brine composition of the salt is complex, showing variablility between fluid inclusions (intragranular brine), brine in anhydrite and clay marker beds, and brine that has been concentrated by evaporation (Fig 5).

Pre-test EQ3/6 geochemical simulations of evaporation (Fig 6) predict solid phases that will precipitate and re-dissolve, and the concentration of dissolved species in solution. Fig 5 shows these data compared to lab evaporation observations (orange & black lines).

We have refined our laboratory analytical methods to analyze dense brines. We use ion chromatography (IC) for anions and inductively coupled plasma optical emission spectroscopy (ICP-OES) for cations. The ionic strength of the brines requires significant dilution to remain within the calibration range of the instruments.

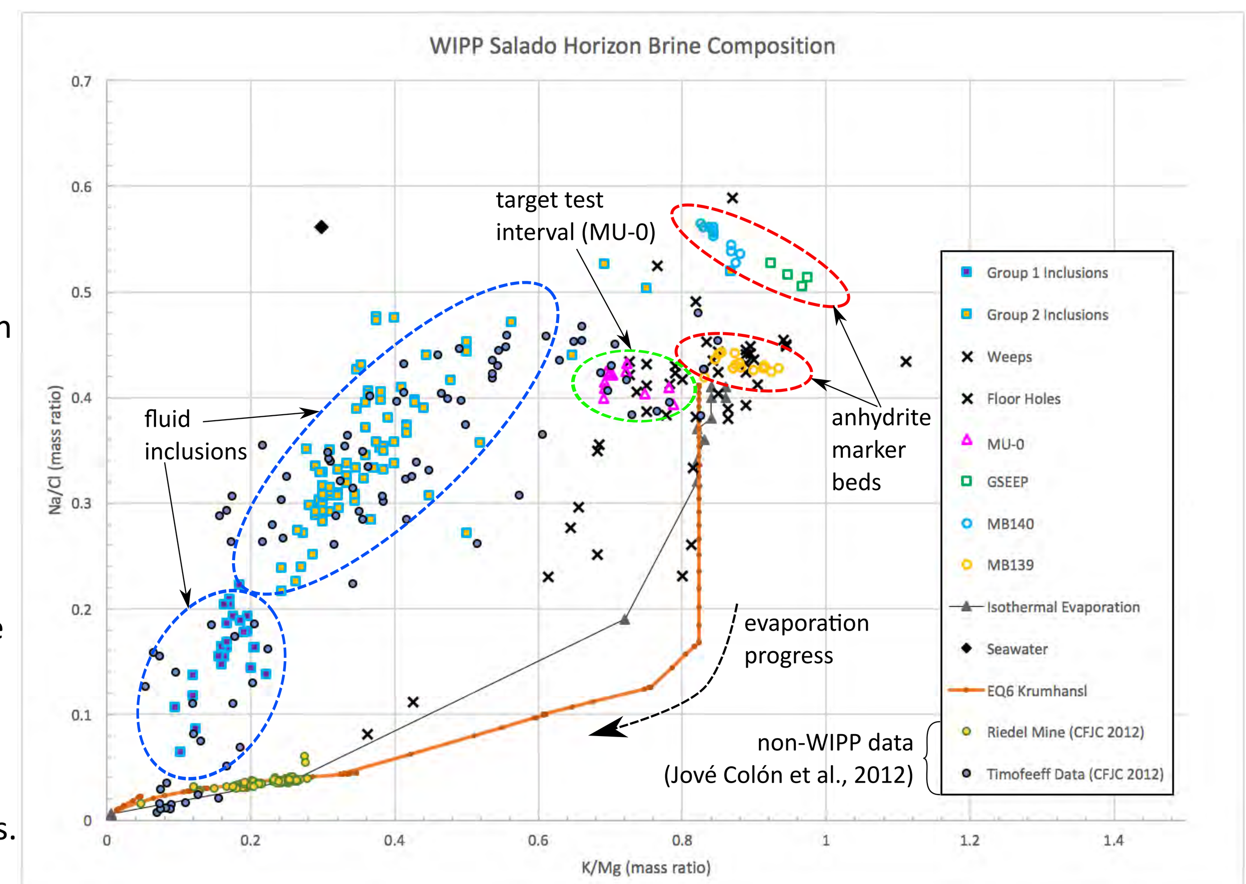


**Figure 5:** *Brine composition data*

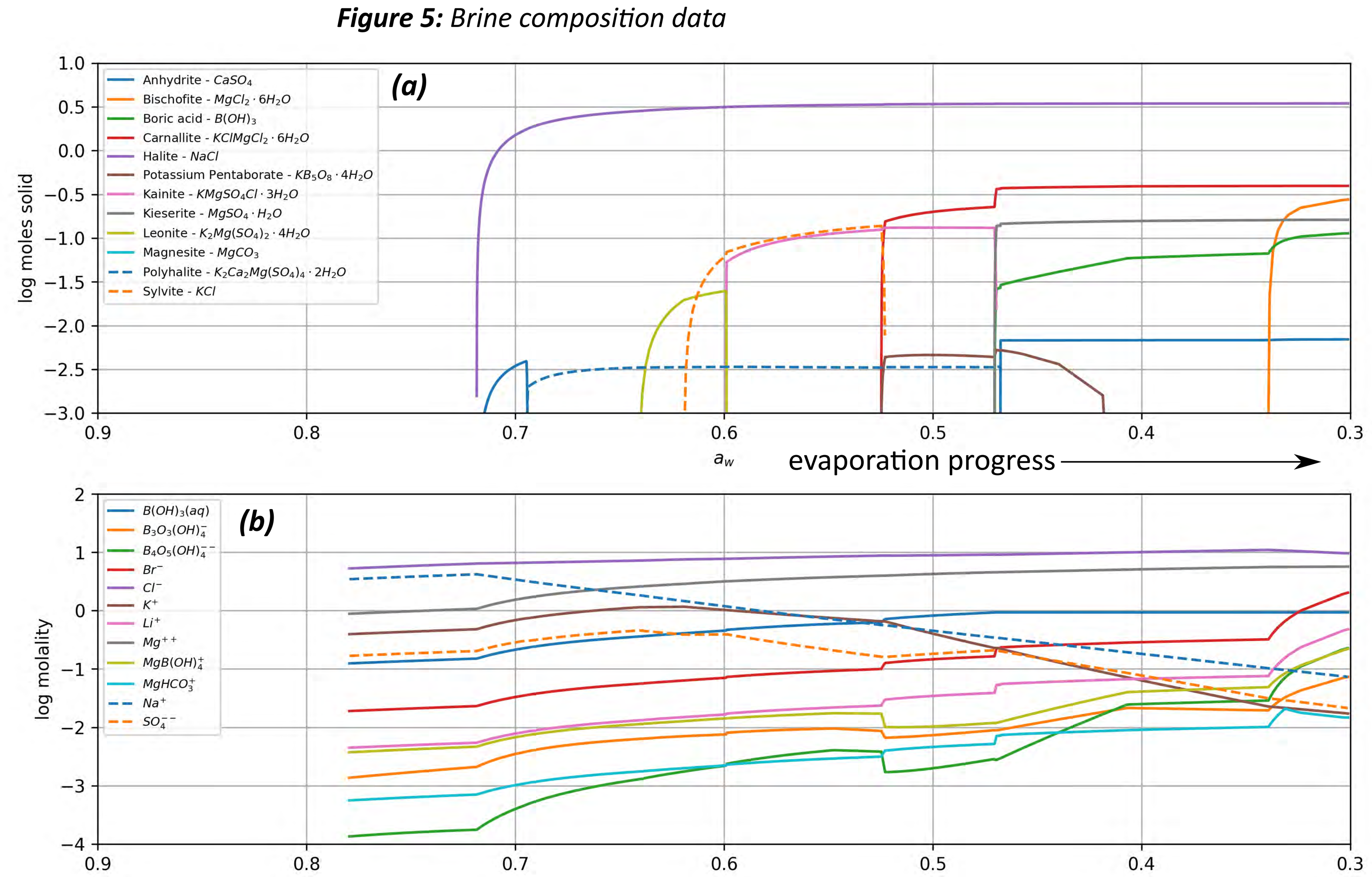


**Figure 6:** *EQ3/6 results for brine evaporation (30°C) showing solid (a) and liquid (b) components vs. water activity*

## Salt Precipitation and Acid Gas Generation

Previous heater tests in salt have shown that significant "salt crust" to precipitate around the heater, where temperatures are above boiling. Mineralogical observations of the salt crust on the heater are consistent with geochemical model predictions of salts in an evaporation experiment (Kuhlman et al. 2017). Laboratory evaporation experiments are being conducted to provide validation datasets for EQ3/6 models at higher temperatures, relevant to interpreting samples collected from the field test.

**Figure 7:** *Images of heaters during overcoring and removal at WIPP Room B (Kuhlman et al. 2017).*

Acidic condensate has been observed in several salt heater tests (Kuhlman et al. 2017). Typically, at a cool downstream location where steam condenses, $HCl_{(g)}$ also condenses and results in very low pH (≤1.5), because the condensate has no buffering capacity. Two mechanisms have been proposed for this acidification process.

**1.** Hydrous Mg-Cl salts can degas $HCl_{(g)}$ when heated. But these also produce periclase (MgO), which is typically not observed under expected conditions.

$$MgCl_2 + H_2O \longrightarrow MgO + 2HCl$$
$$MgCl_2 \cdot H_2O \longrightarrow MgO + 2HCl$$
$$MgCl_2 \cdot 2H_2O \longrightarrow MgO + 2HCl + H_2O$$
$$MgCl_2 \cdot 4H_2O \longrightarrow MgO + 2HCl + 4H_2O$$

**2.** Another mechanism produces $Cl_{(g)}$ directly from the liquid phase, since Cl partial pressure is elevated over the brine. Moving this gas over condensed steam then leads to an acidic solution. Higher ionic strength seen during evaporation (Fig 6b) further enhances this process.

One of the goals of this field test is to collect brine and mineral composition data to determine the importance of these two mechanisms in acid gas and acidic condensate generation.

## Testing to Improve Technical Basis, Rebuild Experince

The proposed heater test will be used to collect data for validation of numerical models on the thermal-hydraulic-chemical nature of salt during heating. The conditions expected during the test will provide information relevant to early-time behavior in a radioactive waste repository with heat-generating waste. The distribution of temperature and brine is an initial condition for long-term performance assessment calculations, used to confirm the predicted safety of the repository.

Testing is also being conducted to get a new generation of salt researchers underground experience, as many key field tests were conducted 30 years ago; those researchers are retiring.

The photo at right shows staff from Sandia and Los Alamos at WIPP in Feb. 2017 performing reconnaissance for the heater test planning.

*The authors acknowledge contributions from Phil Stauffer, Hakim Boukhalfa, and Peter Johnson at LANL, Jonny Rutqvist and Yuxin Wu at LBNL, and Carlos Lopez, Courtney Herrick, and Robert Moore at SNL.*

## References

Jové Colón, C.F., P.F. Weck, T. Hadgu, J.E. Bean, M.J. Martinez, J.G. Arguello, C.D. Leigh & F.D. Hansen, 2012. *Thermo-mechanical, Hydrological, and Chemical (THMC) Model Development*. SAND2013-1412P.

Kuhlman, K.L., 2014. *Summary Results for Brine Migration Modeling Performed by LANL, LBNL, and SNL for the UFD Program*. SAND2014-18217R.

Kuhlman, K.L., M.M. Mills & E.N. Matteo, 2017. *Consensus on Intermediate Scale Salt Field Test Design*, SAND2017-3179.

Roberts, R.M., R.L. Beauheim, P.S. Domski, 1999. *Hydraulic Testing of the Salado Formation Evaporites at the Waste Isolation Pilot Plant: Final Report*. SAND98-2537.

Stormont, J.C., 1997. In situ gas permeability measurements to delineate damage in rock salt. *International Journal of Rock Mechanics, Mineral Science & Geomechanics Abstracts*, 34(7):1055-1064.

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