Investigating the coupled thermo-hydro-mechanical behavior for nuclear waste storage using resistivity monitoring and distributed fiber optic sensing

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Salt bodies are an ideal repository for permanent isolation of heat-generating radioactive waste due to their ultra-low permeability and ability to creep and close fractures. However, brine movement stimulated by the waste generated heat and driven by thermal-hydro-mechanical (THM) processes also brings challenges, such as waste package corrosion and radionuclide transport. Understanding the brine migration in this environment is vital for safe radioactive waste disposal. At the underground Waste Isolation Pilot Plant (WIPP), we conducted joint in-situ observation with controlled heater, electrical resistivity tomography (ERT), and high-resolution distributed fiber optic sensing (DFOS) to study THM induced brine migration. Both ERT and fiber optic sensors were placed in the boreholes that are away from the heater borehole. While ERT is sensitive to changes in rock temperature and brine content, the high-resolution DFOS was calibrated for temperature sensing. To fully exploit the ERT resolution capabilities, an optimized survey design was employed for daily data acquisition.

During the heating and cooling processes, fiber optic sensing revealed high-resolution temperature distributions that are in agreement with independent temperature sensors and expected temperature dynamics. The resistivity changes from ERT correlate well with these observed temperature changes. While sole temperature changes can explain some of the observed resistivity changes, offsets, in particular around the heated zone, are indicative of brine movement and correlate with brine losses and restoration from the formation during the experiment. The results from the fiber optic sensing and the ERT measurement are consistent with the brine migration mechanism that is enhanced due to thermal expansion during the initial heating phase, and the salt contraction induced permeability and flow stimulation during cooling. These results are validated by separate numerical modeling, which also suggests a correlation between pore pressure in the static rock matrix and the temperature.