Test Plan Document for Thermal Testing in Salt

Spent Fuel and Waste Disposition

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
DOE Milestone M3SF-18LA010303013

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Appendix E
FCT Document Cover Sheet

Name/Title of Deliverable/Milestone	**Test Plan Document for Thermal Testing in Salt**	
Work Package Title and Number	SF-18LA01030301	Salt Disposal R&D - LANL
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(Participant/National Laboratory Name)

QA program which meets the requirements of
☒ DOE Order 414.1 ☐ NQA-1-2000

This Deliverable was subjected to:

☐ Technical Review	☐ Peer Review
Technical Review (TR)	**Peer Review (PR)**
Review Documentation Provided	**Review Documentation Provided**
☐ Signed TR Report or,	☐ Signed PR Report or,
☐ Signed TR Concurrence Sheet or,	☐ Signed PR Concurrence Sheet or,
☒ Signature of TR Reviewer(s) below	☐ Signature of PR Reviewer(s) below

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Michelle Bourret

[signature]

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REVISION HISTORY

Revision **Number**	Effective **Date**	Pages **Revised**	**Description of Revision**
0		N/A	Initial Issue

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ACRONYMS

AE	Acoustic emission
CBFO	Carlsbad Field Office
CRDS	Cavity ring-down spectrometer
DOE	Department of Energy
DOE-EM	Department of Energy Office of Environmental Management
DOE-NE	Department of Energy Office of Nuclear Energy
DRZ	Disturbed rock zone
EDZ	Excavation damage zone
ERT	Electric resistivity tomography
ISMS	Integrated safety management system
LANL	Los Alamos National Laboratory
LANL-CO	Los Alamos National Laboratory – Carlsbad Operations
LBNL	Lawrence Berkeley National Lab
LVDT	Linear variable differential transformer
M&O	Management & Operations
M&TE	Measuring and test equipment
NWP	Nuclear Waste Partnership LLC (WIPP M&O contractor)
PI	Principal investigator
QA	Quality assurance
ROM	Run-of-mine salt
RTD	Resistive temperature device
SDI	Salt disposal investigations
SDDI	Salt defense disposal investigations
SEM	Scanning electron microscope
SNL	Sandia National Laboratories
TCO	Test Coordination Office
WIPP	Waste Isolation Pilot Plant

1 INTRODUCTION

The long-range goals of the US Department of Energy Office of Nuclear Energy (DOE-NE) field-testing campaign for salt are related to the long-term isolation safety case for disposal of heat generating waste in salt. This intermediate-scale borehole heater test is one component of the field-testing campaign, focused on the quantification of brine inflow and composition. The transient evolution of brine inflow and the brine composition after excavating a drift or borehole can be thought of as initial conditions in the performance assessment modeling of a generic salt repository system over long time scales.

The proposed borehole heater test will be relatively low cost and performed at a small spatial scale. The first test set will be used to develop instrumentation and methods for further *in situ* testing, demonstrations, and characterization activities. A borehole heater test will be used to assess changes in physical-chemical properties associated with brine and vapor liberation and migration at elevated temperature. A follow-on to these borehole tests may include international collaborations for model prediction and validation (Hansen et al., 2016; Kuhlman et al. 2017).

The source and fate of brine in heated salt is a research topic of interest in nuclear waste repository science, especially pertaining to the long-term integrity and short-term safety of the repository. We seek additional field data to further quantify brine availability, brine migration, and brine composition in heated bedded salt (Kuhlman et al., 2017; Johnson et al., 2017). These processes are relevant to three aspects of the waste isolation safety case: (1) water-driven corrosion of the waste package and waste form; (2) closure and stability of the excavation; and (3) short-term drift-scale processes. Regarding long-term repository performance, we seek to enhance understanding of brine availability from the far field, and to collect datasets that can be used to validate and improve numerical models, which are necessary to make long-term performance predictions about the repository. Recent work (Kröhn et al. 2017; Bourret et al., 2017; Johnson et al., 2017) has shown divergent predictions regarding granular or run-of-mine (ROM) salt reconsolidation, affected by the amount of available brine.

As a follow on to the proposed SDI and SDDI programs at WIPP, a phased testing plan was initially proposed in Stauffer et al. (2015) and further refined in the Kuhlman et al. (2017) consensus document as a joint LANL-CO, LBNL, SNL, and LANL effort. This test plan is developed in accordance with Phase 1 of Kuhlman et al. (2017). Section 1.1 of that document laid out four goals:

1) Constrain brine availability and brine chemistry in bedded salt;
2) Collect datasets that can be used to validate numerical models and improve understanding of the constitutive and conceptual models applied to generic salt repository science;
3) Collect field data to improve understanding of acid gas generation mechanisms; and
4) Maintain the legacy of underground tests at WIPP and ensure continuity of knowledge and experience.

A further aim is to develop and refine field measurement methods including methods not previously tested at WIPP. Brine inflow rate observed in boreholes decays exponentially from the time they are first drilled; new boreholes would be ideal, but conditions at WIPP and funding currently do not allow immediate construction of new boreholes. A sequence of three tests is therefore proposed. In the first phase, four existing 4.75” (12.065 cm) diameter sub-horizontal boreholes will be leveraged, with a heater installed in a central borehole and supporting instruments installed in the nearby boreholes. Temperature through time, brine inflow rate, acoustic emissions, liquid brine composition samples, and relative gas permeability of borehole intervals will be measured. In addition to data collection, this phase will allow for demonstration and improvement of new and alternative experimental techniques and the identification and possible resolution of technical issues which can be addressed before designing follow-on experiments in newly-drilled boreholes. However, due to the use of existing >4-year-old boreholes, it will be difficult to accurately quantify salt hydraulic diffusivity that is needed to predict brine availability because the early high-inflow period has already passed in these existing boreholes. Insufficient data will be available to uniquely fit an exponential model and characterize hydraulic material properties of the salt from the late-time near-constant-inflow period expected to be observed in these existing boreholes.

Electrical resistivity tomography (ERT) can be used to estimate brine-filled porosity, brine ionic strength, and temperature in geological media, including rock salt (see references in §A-8 of Kuhlman et al. 2017). While the equipment we are planning to use has not been field tested at WIPP, previous experiments in the lab using rock salt cores from WIPP have shown large sensitivity of the resistivity signal to brine concentrations (Stauffer et al., 2015). In this initial test, electrodes will be installed into small-diameter vertical boreholes in the floor to avoid metallic chain-link fencing and rock bolts in the wall. A string of electrodes will be installed into vertical boreholes using a conductive backfill (e.g., a bentonite paste or grout). As part of the initial experiment, a small-scale ERT test is planned to evaluate the sensitivity of electrical resistivity to brine migration and porosity changes during heating in an adjacent vertical borehole.

Following the completion of the first two scoping tests, an experiment is planned in newly-drilled boreholes (Phase 1b). This phase will involve the placement of heaters and instruments between inflatable packers in 4" diameter experimental boreholes surrounded by smaller diameter satellite observation boreholes (Figure 2.1-1). Instrument types, instrument installation techniques, and measurement or sampling methods will be utilized in this later phase that incorporate lessons learned in the first two stages. Because the methods used in this later experiment are subject to revision, this test plan focuses on the first two experiments.

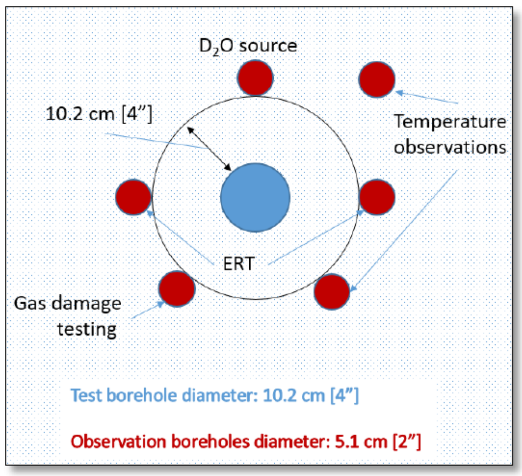


Figure 2.1-1: New borehole layout (Kuhlman et al. 2017)

Background work has been conducted for the horizontal borehole experiments including laboratory experiments and numerical modeling predictions (Johnson et al., 2017; Rutqvist et al., 2017). A separate heater experiment in progress at WIPP (see Otto, 2014) uses some equipment identical to equipment proposed for the horizontal borehole experiments. The test plan therefore aims to leverage existing expertise and equipment types which are already in use at WIPP (in addition to using best available and industry standard equipment), facilitating quick and efficient deployment of equipment.

2 WORK SCOPE

2.1 PURPOSE AND SCOPE

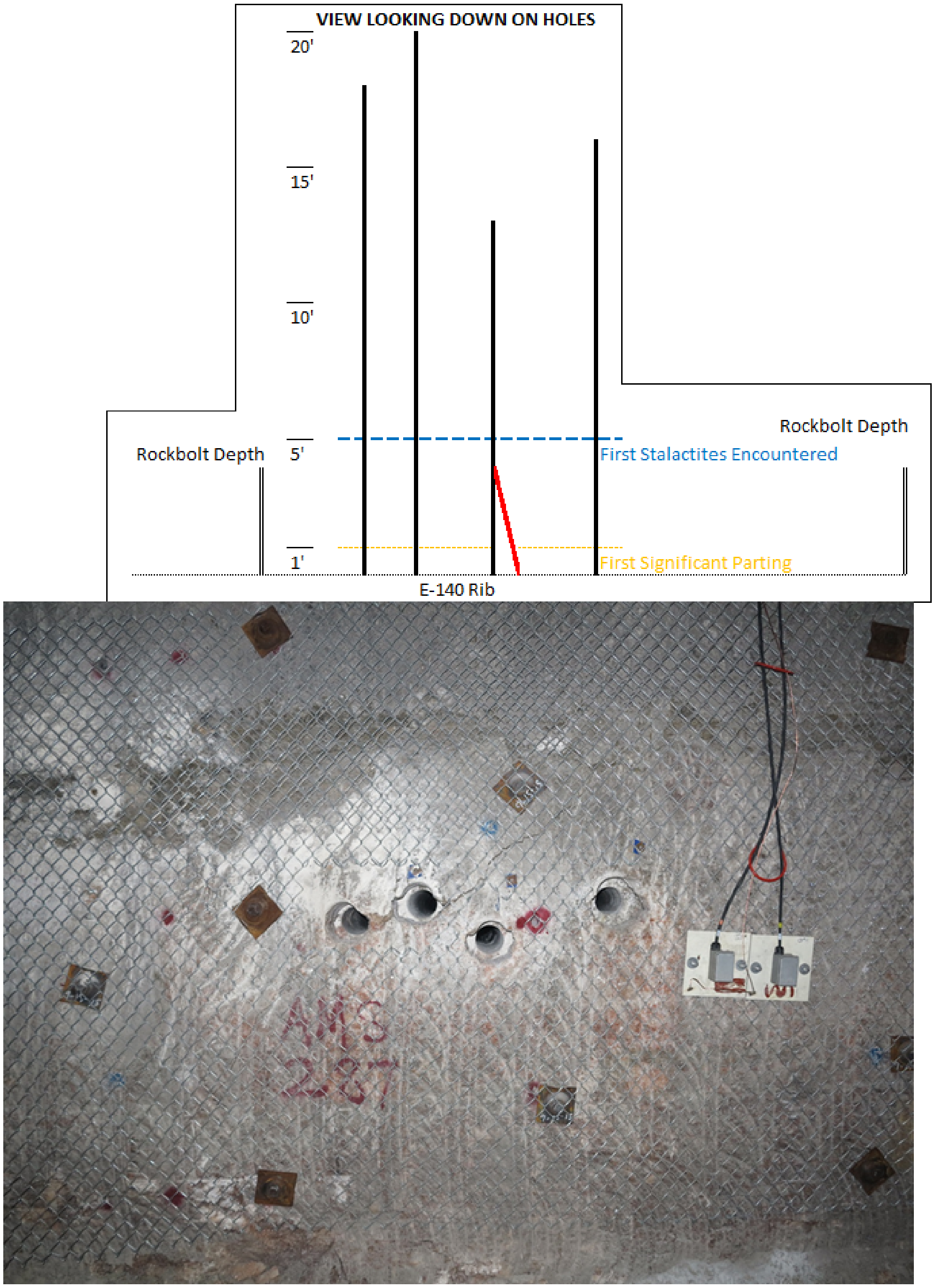
Work conducted under this test plan aims to accomplish the proposed Phase 1 test of Kuhlman et al. (2017). Therefore, all test components described herein are classified as Phase 1 with further subdivision into a scoping stage (Phase 1a), consisting of two separate experiments (Tests 1 and 2), and a second stage (Phase 1b) comprising an experiment with the full array of instruments in newly-drilled boreholes using lessons learned from the scoping work. The purpose of this testing program is to monitor brine migration, sample liquid brine, and observe host rock deformation in heated salt. Additional goals include characterization of the extent and material properties of the salt excavation damaged zone (EDZ – more typically called damaged rock zone or DRZ in the US) and testing or demonstration of field measurement equipment, equipment installation methods, and sampling methods. In light of uncertainty in available resources in subsequent years, the work scope defined herein aims to allow for flexibility in project scale and objectives to fit the funding or availability of other key resources (e.g., personnel and mining equipment).

2.2 MAJOR ACTIVITIES

Phase 1a will consist of two separate experiments to develop methods and gather initial results. Test 1 will take place in existing approximately 4.75” diameter horizontal boreholes and is designed to directly address the goals outlined in Section 1 (Figure 2.2-1). Test 2 will use newly-drilled 1” diameter shallow (<2’ long) vertical boreholes and is designed to test instrumentation compatibility with salt and the underground WIPP environment, ensure correct instrument installation methodology, and constrain technical challenges that might arise in interpretation of the ERT data. Phase 1b will apply the techniques developed in Phase 1a to newly-drilled boreholes for a complete experiment set. Phase 1b will require a revision to this test planning document and a commitment from the test-funding organizations (DOE Office of Nuclear Energy – DOE-NE) to garner the required support from the WIPP site management organization (DOE Office of Environmental Management – DOE-EM, Carlsbad Field Office – CBFO). A proposed test sequence is shown in Table 2.2-1.

Table 2.2-1: Test sequence for Phase 1 testing.

Phase and Test	**Description**
Phase 1a Test 1	Four existing 4.75” sub-horizontal boreholes; brine migration studies and equipment/methods test. Test includes two stages: 2-3 weeks isothermal followed by 2-3 weeks heated.
Phase 1a Test 2	New, 1” diameter vertical boreholes with ERT electrodes and heater.
Phase 1b	Newly-drilled sub-horizontal boreholes (larger diameter heater and smaller diameter observation boreholes); revised experiment based on lessons learned from Phase 1a.



Borehole Depth in feet: 17.83 19.58 12.83 15.75

Note 1: All holes slant downward slightly

Note 2: E140/N1050 was initially mined in 1983. Boreholes were drilled in 2013.

Figure 2.2-1: Existing sub-horizontal 4-borehole layout at WIPP.

2.2.1 PHASE 1A TEST 1

A heater package (Figure 2.2-2) containing both resistive temperature devices (RTDs) and thermocouples will be emplaced into a central borehole (e.g. SNLCH-112). Supporting instruments will be installed in the adjacent boreholes (e.g. SNLCH-111, -113, and -114). Short (<2’), small-diameter (1”) boreholes may be drilled for additional instrumentation. This test will be used to evaluate and compare instrument types and refine instrument emplacement and data collection methods. The test will have a total duration of approximately 6 weeks, in two stages. The isothermal first stage (~30°C) will be 2 to 3 weeks to determine if instruments and data collection are working as planned under unheated conditions. In the second stage, the heater will be set to a constant surface temperature to heat the salt for another 2 to 3 weeks.

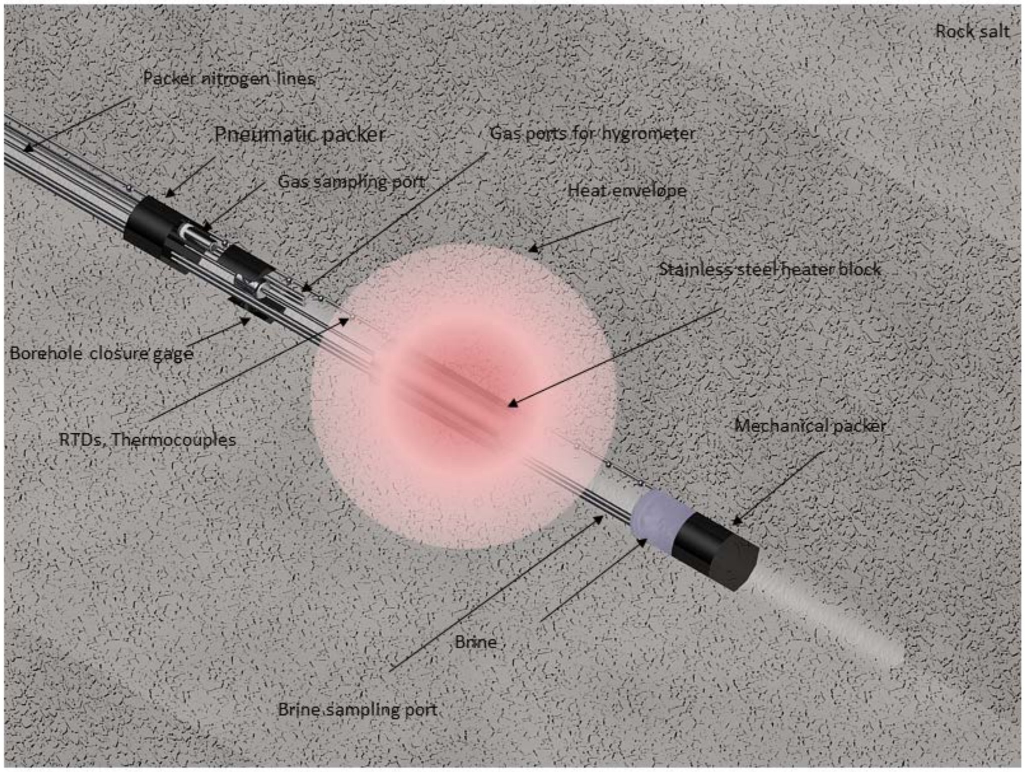


Figure 2.2-2: Schematic representation of a dual packer heater package for existing 4.75” diameter sub-horizontal boreholes.

The instrument package in the heated borehole will include a small-diameter resistive rod heater embedded in a larger-diameter block of high-thermal conductivity material (e.g., aluminum or stainless steel) either behind one or between two inflatable packers to isolate a segment of the borehole. Temperature will be measured with both thermocouples and RTDs placed along the length of the heater. Several pass-through ports in the drift facing (exterior) packer will allow tubes or cables to access the heated portion of the borehole while the packers are inflated. One port will include power cables to drive the heater and leads for RTDs and thermocouples. A second port will have a tube connected to a gas cylinder in the drift, providing an input stream of dry N_2 gas. A third port, with tubing running to the interior packer (labeled as 'mechanical packer' on Figure 2.2-2), will allow water vapor to be removed from the packed interval (via the nitrogen stream) and high-frequency (~minute) humidity measurements to be made by a hygrometer located in the drift. Plumbing on the hygrometer connection will be used to also allow lower-frequency (<three times weekly) gas composition sampling from this port. A fourth port will be connected to a sampling access tube or well to allow collection of liquid brine from near the base of the interior packer. The sampling tube will be closed except when collecting samples. During the collection process, a sample extractor will be inserted into the tube to remove liquid samples for analysis. Extraction and collection of hot, salt-saturated liquid brine samples may present technical challenges, so several sampling methods will be attempted. We intend to compare the various sampling methods as to their efficacy for sampling both isothermal and heated brine while the packer system is inflated. Alternatively, solid salt samples deposited from evaporated brine will be collected near the heater after the completion of the heating period. The samples will be analyzed by x-ray florescence and scanning electron

microscope (SEM) to map changes in composition as a function of the sample size/distance from borehole wall. Borehole closure gages (e.g. remote calipers to measure the borehole diameter through time) will be placed in the heated borehole to measure closure during both the isothermal and heated portions of the experiment. Limited closure is expected in the >4-year old boreholes during the isothermal part of Test 1, but borehole closure during the heated part of the test should increase. The borehole closure rate is expected to be largest in heated and/or newly-drilled boreholes, so larger closure is expected during the heated part of Phase 1b than in Phase 1a.

During rapid heating and cooling, salt will produce acoustic emissions (AE) related to micromechanical brittle deformation. AE sensors (i.e., ultrasonic piezoelectric transducers) will be installed into observation boreholes either with grout or epoxy or a mechanical swage and a couplant (e.g. syrup or molasses) to ensure a good acoustic connection between the rock and sensors. We initially intend to observe and identify AE from the heating and cooling portions of the experiment, but if enough piezoelectric sensors are included (minimum 4, practically 6 or more) they could be used in a tomographic manner to estimate source locations. The transducers can also be driven with an applied voltage to produce ultrasonic waves in a source-receiver manner to measure the changes in ultrasonic wave velocity properties between transducers with time. There will likely be too much electrical noise in the heated borehole itself. Therefore, the first test will have one or two piezoelectric sensors emplaced in 1” diameter <2’ deep horizontal observation boreholes to assess the ability to monitor and discriminate AE from the heating and cooling of salt, in the presence of ambient WIPP acoustic and electrical noise. Piezoelectric sensors will be placed in boreholes deep enough to be located beyond significant partings, in the largely intact salt surrounding the borehole. If sufficient AE events are observed during the first heated test, an arrangement of six or more AE sensors may be justified for subsequent tests to allow estimate of source locations, especially with repeated heating and cooling episodes.

Instrumentation in the existing 4.75” diameter satellite boreholes may include thermocouples and/or RTDs and gas sampling or deuterated water (tracer) injection equipment. A single packer will isolate these boreholes, with one port to allow temperature probe cables to connect to a central data logger. A second port may be included to allow for gas tracers to be injected, and a brine sampling port may also be incorporated to allow collection of brine samples from the observation borehole.

2.2.2 PHASE 1A TEST 2

Three small diameter (1”) vertical boreholes (<2’ deep and approximately 1’ apart) will be drilled into the floor. The central borehole will contain a small-diameter resistive rod heater with adjacent boreholes containing the ERT electrodes (Figure 2.2-3). The ERT experiment could be located near the sub-horizontal holes on the wall, but its location will be more flexible and may be located elsewhere depending on space availability, avoidance of metal and electrical components in the underground, or operational logistics. The experiment will test the efficacy of ERT for monitoring changes in the electrical conductivity of salt as a result of heating. These changes may include temperature-dependence of electrical conductivity, brine migration impacts on conductivity, and changes in the salt’s total porosity due to processes such as creep closure and thermal expansion that impact conductivity. A schematic design of the test layout is shown in Figure 2.2-3. Ten to twelve stainless steel electrodes will be emplaced a few inches apart along each of the two electrode boreholes, mounted on the outside of small-diameter PVC tubes. These electrodes will be connected to the ERT controller, and will be used as both current sources and electrodes for voltage measurements during different parts of each ERT survey. The annulus of the electrode boreholes (between PVC pipe and borehole wall) will be filled with a conductive bentonite paste or grout (waiting for the grout to cure or bentonite to hydrate) to ensure the electrodes have a good electrical connection with the salt. The ERT controller (i.e., current source and data acquisition system) will be used to acquire data both before and during a heating experiment. The heater temperature will be set to 120°C, similar to the tests in existing sub-horizontal boreholes. The ERT data acquisition can be automated and remotely controlled if an internet connection is available at the site.

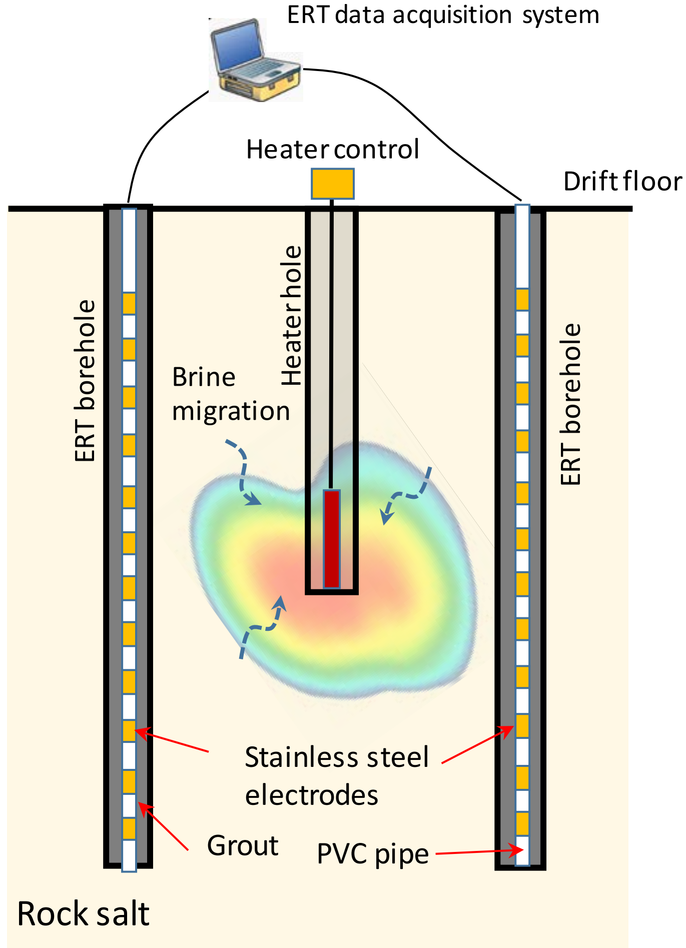


Figure 2.2-3: ERT test design. The central hole is heated, and the two outer boreholes contain ERT electrode arrays. All electrodes will be grouted into their boreholes.

2.2.3 PHASE 1B

Following completion of the first two tests in Phase 1a, an experiment will be conducted in newly-drilled boreholes, if resources for such are available. Packers will be installed into the boreholes, with the final design based on results and lessons learned from the Phase 1a tests. Smaller-diameter monitoring boreholes will be completed sub-parallel to and surrounding the larger-diameter central heater borehole. If feasible, the monitoring boreholes will be drilled with an inclination angle that would allow brine flow towards the entrance of the borehole to facilitate brine collection. Additional instrumentation for temperature and brine flow measurements will be placed in some of these satellite boreholes. An enhanced ERT test will be installed in other satellite boreholes, with final design of this system to incorporate lessons learned in Test 2 of Phase 1a. All instruments and the packer assembly will be installed as quickly as achievable after initial drilling and characterization of the boreholes. Boreholes will be geologically mapped, and the extent of the DRZ at each borehole will be estimated by packer-based gas-flow tests. The proposed duration of the test set from Kuhlman et al. (2017) is shown in Table 2-1. Since these are longer-duration tests, it would be advantageous to conduct them in parallel if equipment and personnel are available. Possible locations for the new boreholes in the WIPP SDI area are shown in Figure 2.2-4.

This phase of the testing program is resource intensive for WIPP personnel, with the construction of new boreholes, routing power for the experiment, communications, and access to the northern test facility. Budget commitment from the funding organization will need to be commensurate with the higher costs associated with coring and conducting multiple longer-duration monitoring tests in parallel to move into Phase 1b. This phase of the experimental program will be modified based on the results of Phase 1a experiments and it will be necessary to revise this test plan.

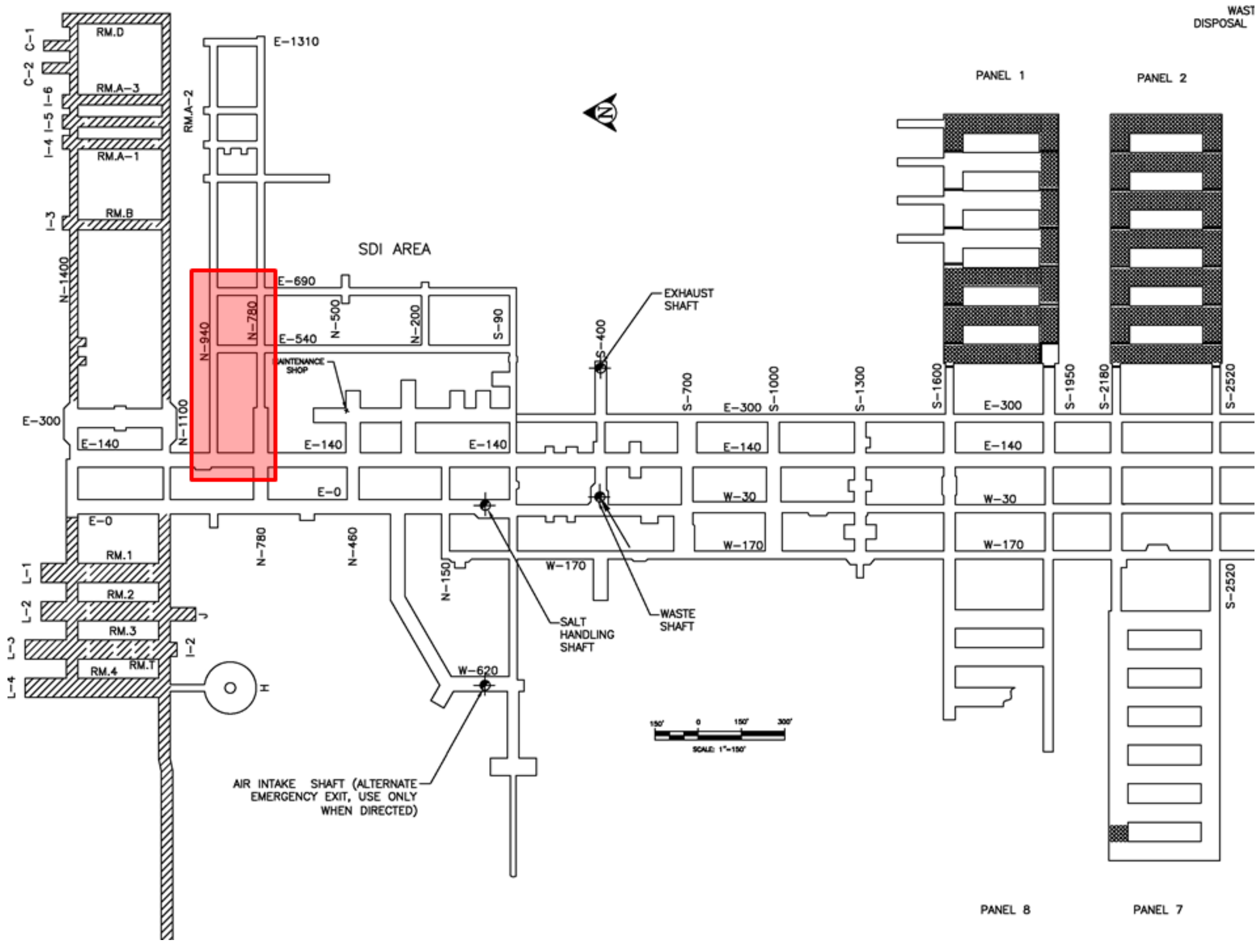


Figure 2.2-4: Anticipated location of Phase 1b boreholes within WIPP (Kuhlman et al. 2017).

2.3 INTENDED USE OF DATA AND PRODUCTS

All data will be disseminated to partner organizations as required, and will add knowledge to the international salt repository technical basis on the topic of in-situ brine migration in response to applied heat (Jordan et al., 2015; Kuhlman et al., 2017). Data collected and lessons learned in early tests will support the numerical modeling and design of subsequent tests. These data will provide an improved understanding of brine composition in generic bedded salt repositories. Brine quantity and composition data through time will be used to further improve constitutive relationships for numerical models for water source terms and porosity-permeability-strain-dissolution-precipitation relationships observed around the boreholes and access drifts. Temperature and fluid flow data will provide supporting information for numerical modeling efforts using TOUGH-2 and FLAC at Lawrence Berkeley National Laboratory (LBNL), PFLOTRAN at Sandia National Laboratories (SNL), and FEHM at Los Alamos National Laboratory (LANL). Simulation of thermal tests will allow estimation of the material heat transport properties, especially thermal conductivity of the EDZ and intact salt. Results will be presented in regular milestone reports submitted to DOE-NE by the respective partner organizations and in journal publications when unique contributions are identified.

2.4 ORGANIZATIONS PERFORMING THE WORK

2.4.1 RESPONSIBILITIES AND INTERFACES

Responsibilities and interfaces for conducting underground work at the WIPP site are defined in DOE/CBFO-13-3515, *Science and Testing Activities in the WIPP Underground – Integrated Project Team Charter*.

In summary, the Principle Investigators (PI) from LANL, SNL, and LBNL are responsible to provide the resources to plan, model, implement, operate, and evaluate the installed test program. The PIs will provide the test equipment (e.g. inflatable packers, resistive heater, acoustic emission transducers, and ERT system) and work within the controls established by this test plan and work authorization documentation to implement and operate the program. The PIs may request support from on-site Test Coordination Office (TCO) staff for activities such as data collection and sampling.

LANL, SNL, and LBNL PIs are responsible for their own data reduction and will provide input for testing parameters, including data acquisition frequencies, sample collection frequencies, and data saving/exporting configurations such as measurement averages, sample only, minimums, and/or maximums.

The TCO is responsible for coordinating the underground operations with the Maintenance and Operations (M&O) contractor including test work control that establishes the expectations, responsibilities, and controls to ensure the safe conduct of physical scientific work protecting people, the environment, and property through implementation of the Integrated Safety Management System (ISMS). As identified by the PIs, the TCO will be responsible for providing a data collection system for the Phase 1a Test 1 portion of this test as described below and will provide brine sampling during the times when the PIs are not present in Carlsbad.

The TCO Data Collection Lead as authorized by the PIs is responsible for implementing a data acquisition system that measures and stores data in the WIPP underground including instrumentation compatible with the data acquisition system (i.e., 0 to 5 volt output and 4 to 20 milliamp output). Additionally, the TCO Data Collection Lead is responsible for the initial data reduction that entails preliminary checks of the data for error and suspect readings (which will be noted as found) and data acceptance and validation. The Data Collection Lead will generate a data file in an appropriate format (e.g., MS-Excel or a text file) and test documentation in a scientific notebook.

SNL and LANL personnel will analyze liquid brine samples for their dissolved constituent composition and other general physical properties (e.g., pH, specific gravity, electrical conductivity, and turbidity). LANL and LBNL personnel will conduct both preexperiment and post-experiment numerical modeling in support of each phase of the experiments. Each organization will produce their respective DOE-NE milestone reports and other documentation as necessary.

Nuclear Waste Partnership LLC (NWP) is the M&O contractor at WIPP and will provide engineering, construction (e.g. borehole coring, electrical, survey, hoisting, ground control, and ventilation), and test support labor and general underground science infrastructure and maintenance in accordance with applicable budget authorization and Contracting Officer direction. Other NWP provided services include training, lockout/tagout, safety and health, and industrial hygiene. The CBFO holds NWP accountable for safe operations at the WIPP and gives NWP authority to enforce safety rules and policies on all WIPP science participant organizations.

3 EXPERIMENTAL METHODS

3.1 OVERALL TEST STRATEGY AND PROCESS

3.1.1 TEST VARIABLES AND METHODS

Temperature will be monitored approximately every minute in the heated borehole along a line parallel to the heater and in one ring around the heater. At least one temperature probe will be installed directly on the heater block, and it will be fed back into the heater power control to fix a constant heater temperature (120°C). Relatively high spatial resolution of the temperature distribution is necessary to constrain and pose the thermal boundary condition for numerical models, and also to constrain any temperature-dependent chemical reactions that may produce or consume free water. Further temperature measurements will be taken in at least two satellite boreholes at two different radial distances from the heater borehole using a set of temperature probes down the length of the observation boreholes. Temperature will be monitored approximately every minute in the drift air, and on the drift wall near the borehole openings at multiple locations. Temperature observations in the heated borehole will help constrain the thermal source term, while the temperature in the drift air and wall will help constrain the thermal boundary condition.

Relative humidity will be measured at a high frequency in the gas sampling port to allow calculation of water mass removal from the constant flow of nitrogen gas (N_2) through the packer-isolated interval (Kuhlman et al., 2017). The openings of inlet and outlet tubes will be located on opposite ends of the packer-isolated interval to maximize the flushing of water out of the interval. Water, non-condensible gases (e.g., CO_2, CO, or H_2) and other condensable gases (e.g., HCl(g)) will be flushed from the packer-isolated interval by the flow of dry N_2. The non-condensible gases will be measured in daily to weekly gas composition samples and sent to a laboratory for analysis. Water content will be measured onsite at a high frequency (~minute) by a downstream measurement station that includes a hygrometer, a gas pressure sensor, a gas flowmeter, and a gas temperature sensor. Monitoring these state variables will allow estimation of the water mass flow rate out of the borehole. Desiccant canisters can also be placed downstream of the hygrometer. The canisters would be weighed before and after installation to quantify the total mass of water leaving the borehole during a specified period. Time between readings will be constrained by the maximum capacity of the desiccant canisters to absorb water. The cumulative mass will be compared to the cumulative hygrometer reading of water mass during the same time interval for validation purposes.

Brine composition sampling presents several technical challenges because brine accumulation will tend to be deep in the packer-isolated interval. This requires a system that can extract liquid salt-saturated brine over the length of the borehole and keep it as a stable liquid sample through the changing temperature field surrounding the heater. Several alternative systems were discussed in Kuhlman et al. (2017), including using small-diameter one-use capillary tubes, fine grained or fibrous wicking samplers, or pumps attached to larger-diameter tubes. Several alternative approaches will be compared in Phase 1a for ease of use and completeness of results. Based on these tests, a final system can be developed for Phase 1b. Liquid brine samples will be collected during the isothermal test phase and, if feasible, during the heating phase. If liquid samples are unattainable during the heating phase, solid salt samples from brine evaporates will be collected from the borehole before and after heating and compared to gain an understanding of how brine composition changes. The composition of the brine will be determined in the laboratory by mass spectrometry following standard brine analysis protocols. The composition of solid salt/brine evaporates will be monitored by x-ray fluorescence and SEM. Monitoring how brine composition changes over time during the isothermal phase and during heating will allow a better understanding of the source of brine and mechanisms that induce its migration. This information will also help define accurate conditions for waste package interactions with brine.

An estimation of higher-permeability and -porosity damaged salt extent (the EDZ or DRZ) will be made using a packer-based gas flow measurement system. The one- or two-packer system isolates a borehole interval. A low constant gas pressure (15 to 30 psi gage) is applied to the packer-isolated interval while the gas flowrate and gas temperature are recorded between the N_2 bottle and the packer, as gas flows into the packed-off interval. The test is run until a steadystate flowrate is achieved, typically within a few seconds or minutes. One possible outcome of the experiment is that the equilibrium gas flowrate is zero or below the lower limit of the gas flowmeter. Gas pressure can be applied using one of the pass-through ports in the external packer, connected to a N_2 cylinder with a gas flowmeter and gas pressure-temperature gage. Moving the packers and re-running the test will isolate portions of the borehole in order to characterize the EDZ extent. Gas flow will be higher in the damaged salt than intact salt, where flow may be below detection limits. Two flowmeters may be used, one for lower flowrates and the other for higher flowrates, if separate flowmeters with narrower measurement ranges are cheaper than a single broader-range flowmeter.

Limited closure is expected in the >4-year old boreholes during the isothermal part of Test 1, but borehole closure during heated part of the test should increase. The borehole closure rate is expected to be largest in heated or newly-drilled boreholes, so the largest closure is expected during the heated part of Phase 1b. Borehole closure gages or linear variable differential transformer (LVDT) gauges can be used to accurately measure changes in the radial dimension of the borehole in multiple directions to identify the closure of the borehole. LVDT gages are installed and left in the borehole, where they are pressed against the wall of the borehole and can measure small displacements. Borehole calipers measure the diameter of the borehole and are simpler, but less accurate, since two measurements must be differenced to estimate closure. These devices will be used in phase 1a in order to determine their utility and ease of use in the experiment system and ensure that they can be consistently applied in phase 1b.

Time-lapse ERT data collected before, during, and after heating will be analyzed to characterize the baseline electrical resistivity structure of the host rock, and to evaluate its sensitivity to heating, heating-induced brine migration, and porosity changes due to rock deformation. These data will provide valuable insights regarding the applicability of ERT as a minimally-invasive monitoring technology to provide spatiotemporally dense data for brine migration induced by heat generating materials.

To characterize flow and transport properties, a deuterated water (D_2O) tracer will be added to an isolated interval of a monitoring borehole. Gas samples from the heated borehole will be analyzed using a cavity ring-down spectrometer (CRDS) for stable water isotope composition. The D_2O tracer will be injected by placing a D_2O-saturated sponge in a packer-isolated interval of an observation borehole (Kuhlman et al., 2017). We will primarily monitor for the first breakthrough of tracer from the observation borehole in the heated borehole. Secondarily, we will quantify mass balance of D_2O by estimating D_2O remaining in the source borehole at the end of the test, measuring D_2O in gas samples from the heated borehole, and by testing for D_2O content in hydrous minerals precipitated in the heated borehole. Finally, cores will be collected after the test between the source and heated boreholes to better estimate the spatial distribution of D_2O trapped within the formation after the tracer test. These tracer tests will provide an advection and diffusion dataset that can be used to validate THC models of flow and transport.

The deformation induced by heating and cooling the salt will result in some brittle failure in the surrounding salt. During initial heating, small-scale deformation might occur along cracks or fracture planes, either by crack growth or by slippage along pre-existing planes of weakness.

These discrete incidents will result in microseismic events or acoustic emissions (AE). If heating is significant, large-scale fracturing can occur farther from the heated borehole as creep closure is accelerated through heating. Solely identifying AE the occurrence of events can be used to characterize the development of the DRZ, including the extent of fracturing and information about the fracture mechanism. A passive AE monitoring system will provide insight into the presence and source of brittle phenomena. Only one AE sensor is needed to get the timing of events, but data interpreted jointly from multiple sensors will help eliminate noise and provide redundancy if a sensor fails or has a bad connection with the host rock. Observation of the natural AE from heating and cooling in conjunction with observations of a driven piezoelectric source will assist in data interpretation and estimation of the distribution and evolution of the DRZ. More than four (likely six) sensors would be required to accurately estimate event location. Piezoelectric sensors used to observe AE require good coupling between the sensor and the salt. This can be accomplished with grout or epoxy in a borehole, or a viscous acoustic couplant (i.e., corn syrup) in temporary installations. Piezoelectric sensors require a datalogger capable of high-frequency monitoring of a low-voltage signal. When using multiple sensors, the leads between the sensors and the logger must be the same length for each sensor to maximize the similarity of signals from all the sensors and maximize likelihood of signal correlation.

Constraint of in-drift environmental effects (i.e. influences on the drift wall from atmospheric conditions due to active ventilation in the open drift) can be accomplished using the central WIPP weather station or other WIPP ventilation datasets, depending on the distance from the test site to the WIPP central weather station. Air temperature and relative humidity will be recorded at the highest available frequency. The importance of this variable varies depending on the final location of boreholes in Phase 1b because of the homogenization of air as it passes from the intake through the gallery. The temperature, air pressure, and humidity of air change spatially as it passes through the mine as well as temporally through the day, and as the weather at the surface changes.

The primary variables for testing as defined in Kuhlman et al. (2017) and specified for each test are described in Table 3.1-1.

Table 3.1-1: Test variables of interest for each experiment.

Phase 1a – Test 1	Gas stream relative humidity Gas composition samples Borehole wall temperature Liquid sample brine chemistry Brine evaporates composition Cumulative and time-rate water inflow to borehole Borehole closure Acoustic emissions
Phase 1a – Test 2	Salt and brine resistivity and temperature
Phase 1b	Gas stream relative humidity Gas composition samples Borehole wall temperature Liquid sample brine chemistry Brine evaporates composition Cumulative and time-rate water inflow to borehole Borehole closure Salt and brine resistivity Acoustic emissions and ultrasonic wave tomography

3.1.2 PRETEST PREDICTIONS AND EXPECTED RESULTS

Model predictions of THM deformation were presented in Rutqvist et al. (2017). Heat and brine flow models were conducted in both Rutqvist et al. (2017) and Johnson et al. (2017). Geochemical experiments on WIPP salt samples were also presented in Johnson et al. (2017). Heating of the salt surrounding the borehole will lead to increased flow of brine into the borehole (compared with isothermal conditions), that will subsequently decay with time. The water component of brine flowing into the borehole will be quantified with humidity measurements. Brine and water composition, including tracer concentration, will be measured through liquid sample collection. The newly-drilled boreholes in phase 1b should produce higher rates of brine inflow than the >4-year-old boreholes in phase 1a. Borehole closure is expected to occur more rapidly when the host rock is heated, with up to perhaps a few mm of borehole closure during the 2 to 3 weeks of heating.

The following measurable results are expected from the tests:

(1) Additional brine will flow towards the borehole in the heated cases due to thermal mobilization of water from accessory minerals associated with rock salt, the migration of immobilized brine in inclusions within the salt crystals, and thermal expansion of brine. Chemical reactions causing dissolution (i.e., changes in solubility of salts with temperature) or dehydration (i.e., dehydration is typically accompanied with a volume change) of the evaporite minerals will generate additional water and increase the permeability of the salt near the borehole. Isothermal boreholes in phase 1b will have brine inflow rates similar to observations from historic isothermal horizontal boreholes in

this interval at WIPP (Kuhlman et al. 2017). Brine composition data may show evidence of brine-rock interactions.

(2) Brine in the borehole will become more Mg- and K-rich over time due to precipitation of halite as water is removed from the packer-isolated portion of the borehole with dry N_2 gas.

(3) Acid gas generation from magnesium chloride salt dehydration will lead to low-pH in condensed liquids that have no buffering capacity from dissolved minerals.

(4) Resistivity of salt will change in space and time as brine saturation, temperature, and mineral phases vary through the test. Inverse modeling of resistivity measurements in combination with the fluid flow and chemistry results will provide insight into the details of these changes.

(5) Boreholes will deform and close due to creep, with faster rates of deformation in heated boreholes compared to isothermal boreholes, especially in the hottest intervals of the heated boreholes.

(6) Gas samples from the heated borehole will be analyzed for D_2O content. Hydrous salts will precipitate in the borehole and may include tracer D_2O. Collection and sampling of precipitates will allow for constraint of fluid migration rates and tracer retention.

(7) Acoustic emissions (AE) will occur, especially when the salt is rapidly heated or cooled (i.e., the beginning or end of the test). We will initially monitor just the time series of AE near the heated borehole using >4 sensors to provide data for estimation of the source location of AE. Piezoelectric sensors can be used both actively and passively to estimate the time-evolution of travel time between sensors as the properties of the salt change with time (i.e., the acoustic analog of ERT surveys).

3.1.3 ACCEPTANCE CRITERIA AND DATA VALIDATION

For data collected on the primary data logger (e.g. temperature at sensors in the heated and observation boreholes, relative humidity of the gas stream, gas stream temperature, and gas stream pressure), acceptance and validation will be conducted through qualitative graphical reviewing of all measurements on a frequent basis. Since the observations should be changing in a relatively slow and predictable manner during the isothermal portion of the test, frequent reviews of the data should find errors and suspect readings that will be documented as such. If no obvious errors are found, the data reviews will determine that the instrumentation is measuring as expected within instrument accuracies, and the data will be accepted and considered valid enough for further analysis by the PIs. Validated data will be distributed for supporting information in modeling and scientific analysis.

The ERT data collected during the experiment will be compared with results from previous laboratory experiments to check if results are reasonable, using WIPP cores as well as tests conducted at other locations, such as at the Asse mine in Germany. In addition, repeated and reciprocal measurements collected under isothermal conditions will be used to evaluate the repeatability of the measurements. The data error presented in the raw ERT data will be evaluated, and data points with high errors (e.g. >10%) will be removed before data inversion and visualization.

Brine samples will be analyzed for concentrations of dissolved species of interest (e.g., Na^{+}, Cl^{-}, K^{+}, SO_4^{--}, Ca^{++}, Mg^{++}, Br^{-}, and $B(OH)_3$), pH, temperature, electrical conductivity, and specific gravity in a capable laboratory, and their analysis and interpretation will fall under laboratory test plans or analysis plans. Constitutive relationships in numerical models will be constructed and constrained based on the chemistry data.

3.1.4 TEST REQUIREMENTS, STANDARDS, AND REGULATIONS

The testing will be conducted as non QA-1 (i.e., nuclear safety or compliance-related processes), however PIs will follow data acquisition, instrumentation protocols, and scientific notebook documentation from the relative laboratories' internal QA programs (generally congruent with SDI-SP-003, *Scientific Notebooks*).

There are no applicable nationally-recognized testing standards or regulations associated with this testing.

Brine analysis will be performed according to existing EPA methods for groundwater analyses. The samples will be diluted to bring the concentration of the brine constituents to within the operational standards. The following protocols will be used: anions EPA 300.0, major cations EPA 200.7, and trace metals EPA 200.8.

3.1.5 TEST PROCEDURES AND IMPLEMENTING DOCUMENTS

To document the scientific studies, scientific notebook(s) will be used to document the testing in accordance with each laboratory's internal QA system (generally congruent with procedure SDI-SP-003, *SDI Scientific Notebooks*). Sample collection, handling, logging, and shipping will be controlled through relevant procedures from the PI's laboratory procedure(s) or through SDI-SP-005, *Sample Control*.

All physical work activities at WIPP will be conducted in accordance with the processes defined in DOE/CBFO-13-3515, *Science and Testing Activities in the WIPP Underground –*

Integrated Project Team Charter. As such, test work authorization and control will be implemented through procedure SDI-SP-001, *Testing Work Authorization and Control*.

3.1.6 SCIENTIFIC NOTEBOOKS AND DATA PACKAGES

Scientific notebooks will be used to document experiment design, record information associated with data collection, develop new methodologies, record performance check information, prototyping, and research associated with field testing in sufficient detail that the entire process could be replicated by someone with a similar background. The data will be documented in the scientific notebook so end-users will understand the data set, and relevant environmental conditions or metadata are recorded. Errors or suspect data will be clearly identified when first discovered to avoid future issues regarding interpretation of the data.

Since the test is not QA-1, the electronic data and scientific notebook can be translated to a data package and/or report that provide supporting data for modeling or scientific analysis if necessary. Otherwise an informal process (such as emailing of electronic data and any relevant scientific notebook entries) will be used to share data that will clearly identify error and suspect data.

Laboratory data regarding samples collected as part of the testing (e.g., liquid brine samples, salt samples, and gas samples) will be analyzed according to the applicable laboratory procedures. All data, along with its requisite uncertainty and metadata, will be reported to the participating labs, and reported in milestone reports to the funding agency (DOE-NE).

3.1.7 PREREQUISITES AND SPECIAL CONTROLS

The data acquisition system will be controlled via lock and key access in a facility where only trained personnel have access. All reduced data will be delivered to the PI accompanied by the original, non-manipulated data set, and any relevant laboratory notebook data, to show traceability. Only trained and qualified personnel will distribute the data.

Brine samples will be filtered through 0.45 micron filters in Teflon bullets. The anion samples will not require any preservation. Samples for major cations and trace metal samples will be acidized using nitric acid to bring the overall acid content in the sample to 2%. The pH of the sample will be measured on site using electrodes calibrated with buffers prepared at the appropriate ionic strength.

3.2 SAMPLE CONTROL

3.2.1 SAMPLE COLLECTION, PRESERVATION, AND CONTROL

Brine samples will be collected underground by TCO staff or the PIs. Sample collection, handling, logging, and shipping will be controlled through the PI scientific notebook or through SDI-SP-005, *Sample Control*. Brine samples are expected to be collected at least once per week and will be collected in accordance with the sampling requirements defined in the sample request form in SDI-SP-005.

A sampling matrix for brine composition studies is shown in Table 3.2-1:

Table 3.2-1: Sampling matrix for brine sampling data.

Measurements and samples	Lab/field	Collection Frequency	Acidification	Filtration	Field Storage
pH	Field	TCO staff will measure in the field every week (use calibrated pH probe)	no	no	N/A
Anions	Lab (LANL SNL)	Sample every week (125-ml plastic bottle)	no	NF	refrigerate
Cations/ Metals	Lab (LANL SNL)	Sample every week (125-ml plastic bottle)	yes	Yes (0.45 micron)	refrigerate
Stable Water Isotopes	Lab (LANL)	Sample every week (125-ml gas sampling bags)	N/A	N/A	refrigerate

3.3 DATA ACQUISITION AND QUALITY CONTROL

3.3.1 MEASURING AND TEST EQUIPMENT

Table 3.3.1-1 shows the measuring and test equipment that is planned to be used to collect data in Phase 1b tests. Equipment will be tested in Phase 1a.

Table 3.3-1: Proposed borehole test components (Kuhlman et al. 2017).

	Packer/plug equipment	**Internal equipment**	**External equipment**	**Data collected**
Borehole Test Interval	Inflow/outflow gas lines		Dry N_2 gas Gas flowmeters Data collector and power Chilled-mirror hygrometer Two-ended sample container	Relative Humidity Gas composition
	Pass-through	RTDs/thermocouples	Data collector and power	Temperature
	Brine sampling access tube		One-use samplers	Liquid brine samples
	Pass-through	Heater / heater block	Power	Power applied, T on heater block
	Pass-through	LVDTs on heater block	Data collector and power	Borehole closure
		Cement plug near borehole end	Over-core after test to retrieve samples	Cement/salt interface characteristics
Monitoring Borehole	Inflow/outflow gas lines		Gas source (w/ Ar & Xe tracers) Gas flowmeters Gas pressure & T Data collector and power	Characterization of DRZ extent and permeability of damaged regions
		RTDs/thermocouples	Data collector and power	Temperature
		Deuterated water tracer	In-drift sampling to assess leakage	Tracer breakthrough to test borehole and distribution
		AE sensors / sources	Data collector and power	Passive monitoring of AE events and damage mapping via active sources
		ERT electrodes	ERT controller	Salt resistivity in space and time

3.3.2 CALIBRATION AND DATA QUALITY

Instrumentation and equipment will consist of "off-the-shelf" items ordered directly from reputable suppliers and will be evaluated prior to use for proper functionality. ERT electrode arrays will be designed, built, and tested at LBNL. Other ERT system components will use in-house equipment from commercial vendors that are already in use at LBNL. All equipment will be used according to the supplier's operation specifications. Redundancy in instrumentation will help ensure data quality. Additional QA calibration will not be performed on the instruments. Manufacturer provided resolution, precision, and accuracy is sufficient confidence for these scoping activities.

Brine analysis will be performed according to previously mentioned EPA methods. The data will be checked for consistency according to existing QA protocols at the GGRL laboratory in Los Alamos and released to the person in charge or loaded into the database if such a data management system is in place.

3.3.3 KNOWN SOURCES OF EXPERIMENTAL ERROR AND UNCERTAINTY

Test boreholes for phase 1a-test 1 have been open for >4 years prior to emplacement of the packer and heater system. Partial drainage and depressurization of the neighboring salt has occurred. Chemical, thermal, and hydrologic effects dependent on brine inflow will be inferred mostly from the expected condition in phase 1b.

The main sources of error and uncertainty for the ERT data are typically associated with high contact resistance between the electrodes and the formation. The application of grouting in the boreholes can help improve such contact. On the other hand, the grouts that will be used in the boreholes to improve coupling can have a lower resistivity when compared with the rock salt, therefore can promote preferential electrical current flow in the cement, resulting in errors of the imaging results. To mitigate this, our data acquisition will primarily focus on cross-well current injection schemes.

Quantifying the composition of high ionic strength brines is difficult. Significant dilution factors are needed depending on the analytical instrument, and methods for pH and electrical conductivity measurement must be modified, compared to similar methods for dilute aqueous samples. Significant charge-balance errors can be introduced by relatively small errors in the primary species (Na, Cl and Mg).

AE monitoring equipment, similar to ERT equipment, requires a good contact between the sensors and the formation. Poor acoustic connection can result in impaired or lost signal from a sensor. Differences in lead lengths from the sensors to the logger can introduce additional delays or shifts in the signal that would require additional post-processing to interpret. Depending on the presence of electrical and acoustic noise, a band pass filter may be utilized to reduce high- or low-frequency noise observed in the drift. The expected frequency of AE in the salt is not known, so a scoping survey will be conducted where all data is initially recorded, then later surveys may only record a narrow band of the overall observed spectrum.

The damp, high salinity environment and potential generation of acidic vapors and low pH liquids are likely to present challenges for the maintenance and proper functioning of test equipment. Corrosion is expected and will need to be addressed as it is detected based on its location and severity. The metal heater block and packer assembly may corrode, contaminating liquid brine samples with metal corrosion products. These corrosion products may change the brine chemistry in other ways (i.e., pH or redox), but are not expected to be in the brine otherwise.

3.3.4 DATA ACQUISITION

Data acquisition of digital data collected by the TCO for Phase 1a Test 1 will be accomplished electronically with Campbell Scientific, Inc. Measurement and Control Dataloggers, Model CR1000 (measurement range ±5000 mV or 4-20 mA, measurement accuracy ± 0.12% reading + offset, operating range -25 to 50°C) and supporting information (e.g. datalogger configuration) will be documented in the scientific notebook, SDI-SN-0001, *Salt Defense Disposal Investigations General Scientific Notebook.*

Frequent data reduction will ensure that data are recorded as expected in accordance with the datalogger configuration. Electronic data will be stored in the datalogger internal memory (~1 year capacity), on a computer connected to the datalogger, and on a second computer used for data reduction. The data will be stored on these sources and then submitted to the PI and LANL-CO Record Center.

Data transfers will be conducted by skilled personnel familiar with the data acquisition systems to minimize data transfer/conversion errors.

Data transfers to end users will be accomplished via email or other network file transfer. Larger quantities of data may require transfer on physical media to the PI from WIPP (i.e., USB flash drive or compact disc).

3.3.5 SOFTWARE

For data collected by the TCO, LoggerNet Version 4.1 Datalogger Support Software will be used with Campbell Scientific, Inc. Measurement and Control Dataloggers in the data acquisition system. The software is commercial software used for datalogger configuration and data transfers to a laptop or personal computer. ERT data collected during the test will be inverted with BERT (Boundless Electrical Resistivity Tomography), an open-source numerical code for inverting tomographic resistivity data, and visualized with Paraview. Heater temperature will be regulated with a Keithley or Agilent temperature controller and recorded with Benchlink data logger software.

3.3.6 PROVISIONS FOR HANDLING UNEXPECTED RESULTS, UNANTICIPATED TEST CONDITIONS, OR OFF-NORMAL EVENTS DURING TESTING

Unexpected results will be investigated and rectified prior to resuming testing. Nonconforming data (e.g. failed sensors) will be identified and documented in the scientific notebook, data package, data report, or a combination of these. Users will be notified of data nonconformance as necessary. If quality level 1 testing is performed, nonconforming data would be addressed as a condition adverse to quality according to SDI-QP-008, *SDI Conditions Adverse to Quality*.

A safety pressure release valve will be included as part of the packer design in order to ensure that over-pressurization of the packers does not cause hazardous propulsion of test equipment out of the borehole. A cover will also be applied to the borehole entrance with secure attachment to the wall in order to provide extra shielding from this effect.

3.3.7 DEVIATIONS FROM TEST STANDARDS OR THE TEST PLAN

Deviations from the test standards or this Test Plan will be documented in the scientific notebook(s), data package(s), and/or associated test report(s).

3.3.8 ASSESSMENT OF EQUIPMENT PERFORMANCE

In addition to direct observation results, Phase 1a tests aim to evaluate the degree of long-term degradation of equipment in the hostile acidic, saline environment of WIPP. Corrosion of the heater system and measuring equipment will be documented, imaged, and their severity noted. Any equipment failures due to corrosion or other degradation will be documented in scientific notebooks and solutions identified prior to Phase 1b tests.

3.3.9 RECORDS

Records generated from this test plan (scientific notebook SDI-SN-0001 documentation, data or reports) will be considered non-QA records and submitted to the LANL-CO Record Center using SDI-QP-007, *SDI Record Management*. Results of the testing will be summarized and reported to the funding agency (DOE-NE) in milestone reports of at least annual frequency.

Additional reports generated at partner facilities (SNL, LBNL, LANL) which include raw data will be archived as appropriate in those institutions, and released publicly through their respective review process.

4 QUALIFICATION AND TRAINING

Participants performing work under this test plan are required to read this test plan, associated technical procedures, and work control documents as applicable to the work. Site-specific training will be provided by the WIPP site and scheduled through the TCO. To conduct physical work in the WIPP underground, WIPP General Employee Training and Underground Hazard Training is required. To operate compressed gas cylinders, Compressed Gas Training is required. Each shift, a pre-job briefing will be conducted with all affected staff to communicate the tasks, potential hazards, and mitigations of the work and work area. Required training specific to technical operating procedures will be defined by the principle investigator for the activity.

5 HEALTH AND SAFETY

It is mandatory that all WIPP underground science program participants and personnel performing work associated with the science and testing activities in the WIPP underground and on the WIPP site abide by the NWP guidelines and requirements established in WP 02-EC.12, *Site Users and Tenants Guide for Organizations, Personnel, or Companies that Perform Work on U.S. Department of Energy Property or Rights-of-way on or Around the Waste Isolation Pilot Plant*, and the requirements of their home institutions or laboratories. The DOE-CBFO holds NWP accountable for safe operations at the WIPP and gives NWP authority to enforce safety rules and policies on all WIPP science participant organizations. As such, an Integrated Project Team Charter (DOE/CBFO-13-3515) was developed to define the processes, organizations, and interfaces necessary to conduct science and testing activities in the WIPP underground.

The health and safety hazards associated with this work are chemical, electrical, environmental, and thermal. The health and safety hazards are controlled and mitigated through TCO Work Control Documents and associated Job Hazard Analyses developed in accordance with SDI-SP-001, *Testing Work Authorization and Control*.

A safety document for the ERT system will be constructed based on existing LBNL procedures and documentation. The system uses between 50 and 250 volts depending on the conductivity of the formation. Electrical current is not anticipated to travel beyond the electrodes and is unlikely to impact power, grounding, communication, or other WIPP systems. Precautionary evaluations will be conducted prior to final emplacement and activation of the ERT system.

6 PERMITS AND AUTHORIZATIONS

No special permits, licensing requirements, or special authorizations are required to conduct the scientific activity. Authorization to conduct work in the underground will be obtained through the world control process defined in DOE/CBFO-13-3515, *Science Testing Activities in the WIPP Underground – Integrated Project Team Charter*. Equipment not listed and labeled by a nationally recognized testing laboratory as defined by WP 23.IS0301, *NRTL Process*, must be approved by the Authority Having Jurisdiction before being used at the WIPP site.

The ERT data acquisition system will need to be evaluated by qualified WIPP electricians before it can be used for the experiment.

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