We put science to work.™

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

# IN SITU DECOMMISSIONING SENSOR NETWORK, MESO-SCALE TEST BED – PHASE 3 FLUID INJECTION TEST SUMMARY REPORT

**M.G. Serrato**

September 2013

SRNL-STI-2013-00569

SRNL.DOE.GOV

# DISCLAIMER

**Printed in the United States of America**

**Prepared for**
**U.S. Department of Energy**

SRNL-STI-2013-00569
Revision 0

Key Words:
In Situ Decommissioning
Nuclear Facilities
Performance Monitoring
Sensor Network

Retention:
Permanent

# IN SITU DECOMMISSIONING SENSOR NETWORK, MESO-SCALE TEST BED – PHASE 3 FLUID INJECTION TEST SUMMARY REPORT

M.G. Serrato

SEPTEMBER 2013

Prepared for the U.S. Department of Energy
under contract number DE-AC09-08SR22470.

Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

# REVISIONS

| Revision | Date | Significant Changes | Revision Approved |
|---|---|---|---|
| 0 | 9/27/2013 | Initial Issue | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

# ACKNOWLEDGEMENTS

The In Situ Decommissioning Sensor Network (ISDSN), Meso-Scale Test Bed (MSTB) – Phase 3 Fluid Injection Test was collaborative effort in achieving success. Andrew Szilagyi and George Cava, DOE EM Office of Deactivation and Decommissioning and Facility Engineering (EM-13) are acknowledged for their sponsorship of this project. Acknowledge Leo Lagos and Florida International University Applied Research Team for their tireless commitment in hosting, preparing, executing without any safety mishaps, and providing project participants the remote electronic access to this activity across four states. Acknowledge Clark Scott and Idaho National Laboratory Team for their tireless effort in operating the INL sensor systems and providing results in a timely manner. Acknowledge Chuji Wang and Mississippi State University Team for their tireless effort in operating the MSU sensor system and providing results in a timely manner.

# EXECUTIVE SUMMARY

The DOE Office of Environmental Management (DOE EM) faces the challenge of decommissioning thousands of excess nuclear facilities, many of which are highly contaminated. A number of these excess facilities are massive and robust concrete structures that are suitable for isolating the contained contamination for hundreds of years, and a permanent decommissioning end state option for these facilities is in situ decommissioning (ISD). The ISD option is feasible for a limited, but meaningful number of DOE contaminated facilities for which there is substantial incremental environmental, safety, and cost benefits versus alternate actions to demolish and excavate the entire facility and transport the rubble to a radioactive waste landfill. A general description of an ISD project encompasses an entombed facility; in some cases limited to the below-grade portion of a facility. However, monitoring of the ISD structures is needed to demonstrate that the building retains its structural integrity and the contaminants remain entombed within the grout stabilization matrix. The DOE EM Office of Deactivation and Decommissioning and Facility Engineering (EM-13) Program Goal is to develop a monitoring system to demonstrate long-term performance of closed nuclear facilities using the ISD approach. The Savannah River National Laboratory (SRNL) has designed and implemented the In Situ Decommissioning Sensor Network, Meso-Scale Test Bed (ISDSN-MSTB) to address the feasibility of deploying a long-term monitoring system into an ISD closed nuclear facility.

The ISDSN-MSTB goal is to demonstrate the feasibility of installing and operating a remote sensor network to assess cementitious material durability, moisture-fluid flow through the cementitious material, and resulting transport potential for contaminate mobility in a decommissioned closed nuclear facility. The original ISDSN-MSTB installation and remote sensor network operation was demonstrated in FY 2011-12 at the ISDSN-MSTB test cube located at the Florida International University Applied Research Center, Miami, FL (FIU-ARC). A follow-on fluid injection test was developed to detect fluid and ion migration in a cementitious material/grouted test cube using a limited number of existing embedded sensor systems.

This In Situ Decommissioning Sensor Network, Meso-Scale Test Bed (ISDSN-MSTB) – Phase 3 Fluid Injection Test Summary Report summarizes the test implementation, acquired and processed data, and results from the activated embedded sensor systems used during the fluid injection test. The ISDSN-MSTB Phase 3 Fluid Injection Test was conducted from August 27 through September 6, 2013 at the FIU-ARC ISDSN-MSTB test cube. The fluid injection test activated a portion of the existing embedded sensor systems in the ISDSN-MSTB test cube: Electrical Resistivity Tomography-Thermocouple Sensor Arrays, Advance Tensiometer Sensors, and Fiber Loop Ringdown Optical Sensors. These embedded sensor systems were activated 15 months after initial placement. All sensor systems were remotely operated and data acquisition was completed through the established Sensor Remote Access System (SRAS) hosted on the DOE D&D Knowledge Management Information Tool (D&D KM-IT) server.

The ISDSN Phase 3 Fluid Injection Test successfully demonstrated the feasibility of embedding sensor systems to assess moisture-fluid flow and resulting transport potential for contaminate mobility through a cementitious material/grout monolith. The ISDSN embedded sensor systems activated for the fluid injection test highlighted the robustness of the sensor systems and the importance of configuring systems in-depth (i.e., complementary sensors and measurements) to alleviate data acquisition gaps.

# TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# LIST OF ABBREVATIONS

| | |
|---|---|
| AT | Advanced Tensiometer |
| D&D | Deactivation and Decommissioning |
| DOE | US Department of Energy |
| DOE EM | US Department of Energy, Office of Environmental Management |
| D&D KM&IT | Deactivation and Decommissioning Knowledge Management and Information Tool |
| EM-13 | Office of Deactivation and Decommissioning and Facility Engineering |
| ERT-T | Electrical Resistivity Tomography-Thermocouple |
| FIU | Florida International University |
| FIU-ARC | Florida International University Applied Research Center |
| FLRD | Fiber Loop Ringdown |
| FY | Fiscal Year |
| INL | Idaho National Laboratory |
| ISD | In Situ Decommissioning |
| ISDSN | In Situ Decommissioning Sensor Network |
| MSTB | Meso-Scale Test Bed |
| MSU | Mississippi State University |
| PI | Principal Investigator |
| PVC | Poly Vinyl Chloride |
| SRAS | Sensor Remote Access System |
| SRNL | Savannah River National Laboratory |
| SRNS | Savannah River Nuclear Solutions, LLC |
| SRS | Savannah River Site |
| URF | Universal Resistivity Format |

# 1. PURPOSE

This In Situ Decommissioning Sensor Network (ISDSN), Meso-Scale Test Bed (MSTB) – Phase 3 Fluid Injection Test Summary Report summarizes the test implementation, acquired and processed data, and results from the activated embedded sensor systems used during the fluid injection test.

The ISDSN-MSTB goal is to demonstrate the feasibility of installing and operating a remote sensor network to assess cementitious material durability, moisture-fluid flow through the cementitious material and resulting transport potential for contaminate mobility in a decommissioned closed nuclear facility. The original installation and remote sensor network operation was demonstrated in FY 2011-12 and is outlined in Test Plan – In Situ Decommissioning Sensor Network, Meso-Scale Test Bed [1]. The fluid injection test concept is outlined in Test Plan – In Situ Decommissioning Sensor Network, Meso-Scale Test Bed – Phase 3 Fluid Injection Test [2].

As part of the Technical Task Plan SR-09-17-01, In Situ Decommissioning Technology Development and Demonstration, the Department of Energy's (DOE), Office of Deactivation and Decommissioning and Facility Engineering (EM-13) funded the Savannah River National Laboratory (SRNL) to design and implement the ISDSN-MSTB to address the feasibility of deploying a long-term monitoring system into an in situ decommissioning (ISD) closed nuclear facility.

# 2. BACKGROUND

The DOE Office of Environmental Management (DOE-EM) is presently decommissioning excess industrial, radiological, and nuclear facilities that no longer have a continuing mission. Some nuclear facilities are massive and robust concrete structures that are suitable for isolating the contained contamination for hundreds of years, and the DOE closure strategy for these nuclear facilities, estimated to be as high as 125 facilities, is defined as in situ decommissioning (ISD) [3]. The ISD strategy is to grout certain areas of a nuclear facility to contain the hazardous and radioactive elements within the massive outer concrete walls and foundation slabs, allowing the building to be abandoned in place and avoiding the cost consequences of demolition, waste packaging, transport, and disposal, and potential health hazards from worker exposure scenarios. However, monitoring of the ISD structures is needed to demonstrate that the building retains its structural integrity and the contaminants remain entombed within the grout.

The "Technology Requirements for In Situ Decommissioning (ISD) Workshop Report" [4] identified the need to develop a monitoring system to demonstrate that the long-term performance of ISD facilities meets the DOE program goals, conforms to project-planning predictions, and satisfies stakeholder expectations. A diverse suite of mechanical and chemical sensors distributed throughout the facility would provide information on the structural properties of the exterior facility shell and the migration of fluids through the grouted sections that contain radioactive and hazardous waste. Additionally, the collected data could be used to validate the assumption used in performance assessment models.

In October 2010, an independent panel of scientists and engineers met to assist the DOE EM 13 and SRNL with the identification of the best sensing technologies and deployment strategies for monitoring highly-radioactive nuclear structures that are designated for closure using the ISD approach. The expert panel report [5] identifies short- and long-term objectives needed to develop and deploy a remote monitoring network for the 105-C Reactor Building at the Savannah River Site, which is DOE-Savannah River's next candidate structure for closure using the ISD approach. A key short-term objective for FY 2011 is the recommendation of the expert panel to construct and operate a grout-filled, MSTB to assess the performance of the sensors when embedded in grout, evaluate the sensor response as the grout cures, establish baseline measurement response, and demonstrate that the sensors can detect fluid and ion migration in the grout. The expert panel considers the MSTB to be a requirement prior to deploying a network in a nuclear facility because of the uncertainty in both the performance of the sensors in a massive grout monolith and the interpretation of the measurement data.

Characteristics of the sensor deployment and operation that affect the uncertainty of the measurements include:

- Embedding sensor modules in grout: location of the point of deployment, physical tolerances (mechanical bending, crushing, impact, etc.), and physical dimensions of sensor modules.
- Installation: connection and multiplexing of various sensor types (electrical vs. fiber) within the sensor system, wiring from the sensor to the logger, and transferring data from the logger to a user.
- Power requirements: estimated total power for all of the sensor types, tolerance of power fluctuations, and consequences of power outage (must be self-protected or insensitive to power outage, short recovery times).
- Power sources: flexibility of using land lines, batteries, and solar cells (with AC-DC converters).
- Data acquisition system requirements: instrumentation integration, compatibility, environmental conditions, sensor drift, and longevity.
- Data output from sensors: Data management and transmission, distribution, formatting, processing, quality assurance/quality control (QA/QC), and reporting protocols.

Based on the expert panel recommendations and DOE's EM-13 Program Goal to develop a monitoring system to demonstrate long-term performance of closed nuclear facilities using the ISD approach, the ISDSN MSTB Project was initiated.

The initial activity for the ISDSN – MSTB Project was focused on commercial off-the-shelf (COTS) and/or laboratory-tested (ready for field deployment) sensor systems to assess fluid flow and ion transport parameters through grout and/or concrete. Selected sensor systems for the sensor network were:

- Idaho National Laboratory (INL)
    - Electrical Resistivity Tomography with Thermocouples Arrays (ERT-T)
    - Advanced Tensiometers (AT)
- Mississippi State University (MSU)
    - Fiber Loop Ringdown – Fiber Optical Sensors (FLRD)
- University of Houston (UH)

  - SMART Aggregate® - Piezoelectric Sensor (SA)
  - Fiber Bragg Grating – Fiber Optical Sensors (FBG)
- University of South Carolina-Columbia (USC)
  - Acoustic Emission - Piezoelectric Sensor (AE)
  - pH/Temperature Sensor (pH-T)
  - Moisture/Temperature Sensor (M-T)

The ISDSN-MSTB test cube was designed to install/embed the sensor network into a cementitious material/grout. The sensor network was operated to monitor during grout placement and curing period. The embedded sensor network was completed at the end of FY 2012. Results from this activity are reported in SRNL Report, "*In Situ Decommissioning Sensor Network, Meso-Scale Test Bed – Phase 1 and Phase 2 Final Report*", SRNL-STI-2013-00050 [6].

## 3. PARTICIPANTS

The Phase 3 – Fluid Injection Test participants were:

- Savannah River National Laboratory (SRNL)
- Florida International University Applied Research Center (FIU-ARC)
- Idaho National Laboratory (INL)
- Mississippi State University (MSU)

The Savannah River National Laboratory was the ISDSN-MSTB Phase 3 – Fluid Injection Test Project Director in collaboration with Florida International University Applied Research Center. Sensor System Principal Investigators were Idaho National Laboratory with the electrical resistivity tomography-thermocouple sensor arrays, and advance tensiometer sensor systems; and Mississippi State University with the Fiber Loop Ringdown Optical Sensors. The remaining sensor systems embedded in the grout monolith test cube were not activated during the Phase 3 – Fluid Injection Test.

Savannah River Nuclear Solutions/SRNL procurement actions were completed with Florida International University, Idaho National Laboratory, and Mississippi State University to secure their participation. Florida International University coordinated the necessary environmental reviews and actions to conduct the fluid injection test at the ISDSN-MSTB test cube site.

## 4. OBJECTIVES

The ISDSN-MSTB Phase 3 – Fluid Injection Test objectives are:

1. Inject an inert solution into the pre-positioned injection wells in the ISDSN-MSTB test cube.
2. Detect fluid and ion migration in a cementitious material/grouted test cube using a limited number of the existing embedded sensor systems in the ISDSN-MSTB test cube.

3. Determine the resulting transport potential for contaminate mobility/release through a cementitious material.

Data sets collected from the MSTB will be evaluated to assess the accuracy and sensitivity of the various sensor systems and to determine if different sensor types produce measurements that can be correlated to boost decision confidence. Information and data obtained from this work will serve as the baseline data set for the selection of future sensors. Sensor selection should include the design and deployment of a sensor to either monitor key component(s) and/or augment an existing surveillance and maintenance protocol for a deactivated or decommissioned nuclear facility.

## 5. TEST PARAMETERS

The test parameters identified below are key indicators to assess the presence of excess moisture/fluid in the grout and the potential for ion migration within a grout monolith. Target values and response ranges for the test parameters are identified below in Table 1.

**Table 1. – Phase 3 Test Parameters**

| Test Parameter | Target Value | Response Range | Comments |
|---|---|---|---|
| Water | Presence | 10 to 100 mL to detect water | Assessment of water/fluid present, not volume |
| Temperature | 20 $^0$C | 10 $^0$C – 50 $^0$C | Target is expected to be near ambient temperature |
| Fluid/Contaminant Ion Mobility Potential | 10 $^{-7}$ cm/sec | 10 $^{-5}$ cm/sec – 10 $^{-8}$ cm/sec | Target value to assess the qualitative transport potential |
| Ion Concentration | 3% or less | 5% to 1% | Target value to assess the qualitative transport potential |

The data sets collected from the individual sensor systems are qualitative in nature, since the sensor system field of view is limited to an area adjacent to the sensor head. This data quality is similar to groundwater well monitoring data, but transport behavior is within the grout monolith.

# 6. TEST CONCEPT

The Phase 3 - Fluid Injection Test was conducted at the ISDSN-MSTB test cube located at Florida International University Applied Research Center (FIU-ARC). The fluid injection test activated a portion of the existing embedded sensor systems in the ISDSN-MSTB test cube; electrical resistivity tomography-thermocouple (ERT-T) sensor arrays, advance tensiometer (AT) sensors, and Fiber Loop Ringdown (FLRD) Optical Sensors.

The injection fluid was an inert dilute non-hazardous material solution. The selected inert solution was potassium chloride (KCl), which provided sufficient conductivity contrast for sensor systems. Target concentration for the injection fluid was 5% or less by volume. FIU-ARC coordinated the necessary environmental permits for this activity.

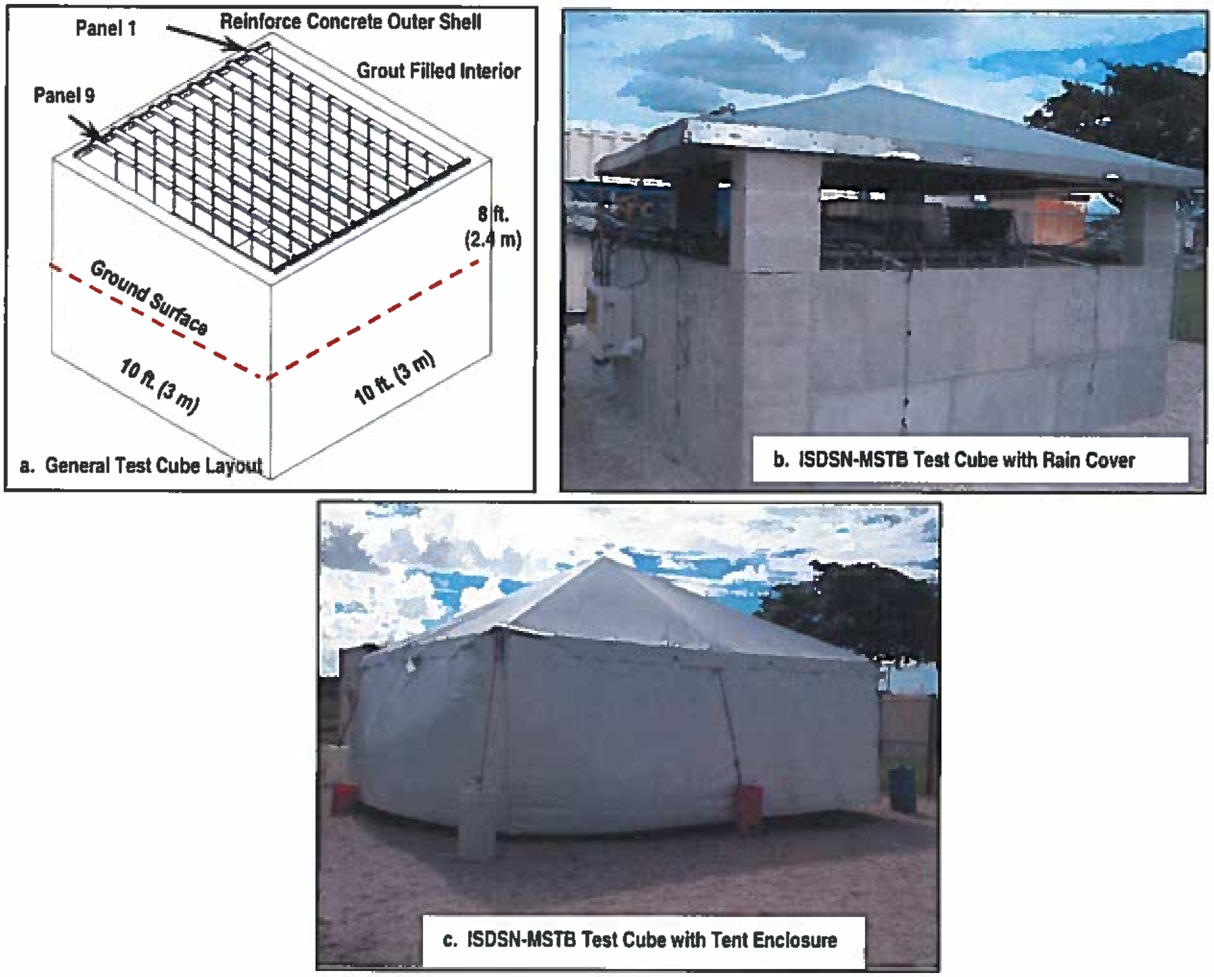
Fluid injection was conducted in two events by FIU-ARC. The initial fluid injection event used an inert injection fluid solution. The subsequent event used deionized water. The injection rate is essentially gravity drainage as controlled by the hydraulic properties of the test cube. Test cube injection wells located in panels 2, 3, 4, 5, and 6 were filled simultaneously. The embedded injection wells vertical lengths range from 2 ft. to 6 ft. (0.6 m to 1.8 m), nominally. Sensor system data acquisition was proposed to be conducted for approximately 14 days or less to detect fluid and ion migration through the cementitious material/grouted test cube.

# 7. FLUID INJECTION TEST

Information presented below is summarized from the Florida International University Applied Research Center Technical Report, "In Situ Decommissioning Sensor Network Phase 3 – Fluid Injection Test Final Report", September 2013 [7].

### Test Cube Preparation

The Fluid Injection Test was conducted at the ISDSN-MSTB test cube located at Florida International University Applied Research Center (FIU-ARC). The ISDSN-MSTB test cube has internal dimensions of 10 ft.-W by 10 ft.-L by 8 ft.-D (3 m by 3 m by 2.4 m). The test cube was installed with its base 4 ft (1.2 m) below ground surface; see Figure 1 for general test cube configuration. The rain cover was removed from the test cube and a tent enclosure was placed around the test cube to minimize rainfall intrusion during the fluid injection test.



a. General Test Cube Layout

b. ISDSN-MSTB Test Cube with Rain Cover

c. ISDSN-MSTB Test Cube with Tent Enclosure

**Figure 1. – General ISDSN-MSTB Test Cube Configuration**

Injection wells are located on panels 2, 3, 4, 5 and 6 and general well locations within the test cube are shown in Figure 2. Table 2 shows the dimensions of each well – 1 inch diameter PVC pipe (2.5 cm). Detail drawings of each well and their corresponding sensor panel are shown in the Appendix A – As-Built Drawings of Sensor Panels 2, 3, 4, 5 and 6.

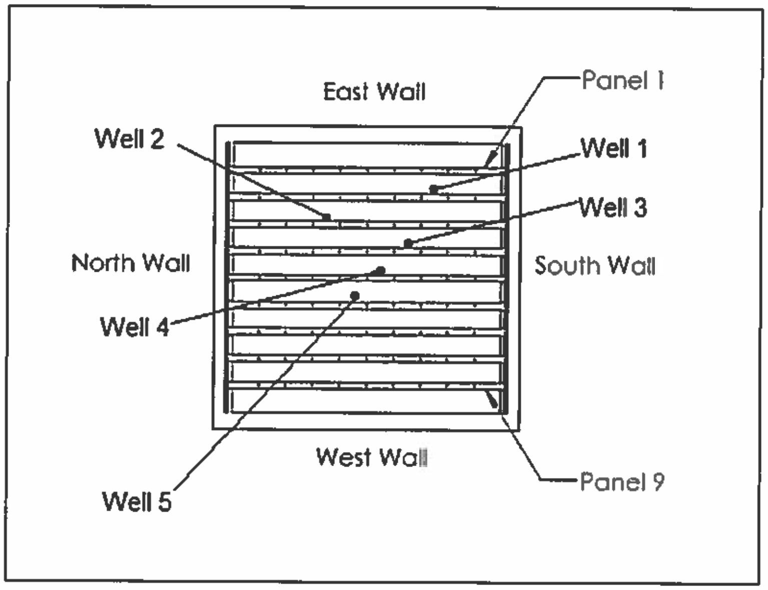


**Figure 2. – General Well Locations within the Test Cube**

**Table 2. – Injection Well Depths**

| Injection Well # | Pipe Height – in. (cm) | Stub Height – in. (cm) | Well depth – in. (cm) |
|---|---|---|---|
| 1<br>(Panel 2) | 76.6<br>(194.6 cm) | 4.3<br>(10.9 cm) | 72.3<br>(183.6 cm) |
| 2<br>(Panel 3) | 41.1<br>(104.4 cm) | 4.6<br>(11.7 cm) | 36.5<br>(92.7 cm) |
| 3<br>(Panel 4) | 76.3<br>(193.8 cm) | 4.3<br>(10.9 cm) | 72<br>(182.9 cm) |
| 4<br>(Panel 5) | 28.7<br>(72.9 cm) | 4.5<br>(11.4 cm) | 24.2<br>(61.5 cm) |
| 5<br>(Panel 6) | 52.9<br>(134.4 cm) | 5<br>(12.7 cm) | 47.9<br>(121.7 cm) |

During the initial installation of the wells during test cube grout placement, the bottom end of the well was sealed with duct tape to prevent grout from entering and filling the well. In preparation for the fluid injection test, the bottom seal was removed using a hole saw on a rod extension. The top of each well pipe was capped to prevent foreign objects from entering the well. These caps were removed prior to testing activities.

Once the wells were re-opened, a bore scope was used to inspect each of the wells. The bottom of well 1 was submerged in water, while the bottoms of wells 2 & 3 were moist and wells 4 & 5 were dry; Figure 3 shows the bore scope images from the well inspection.

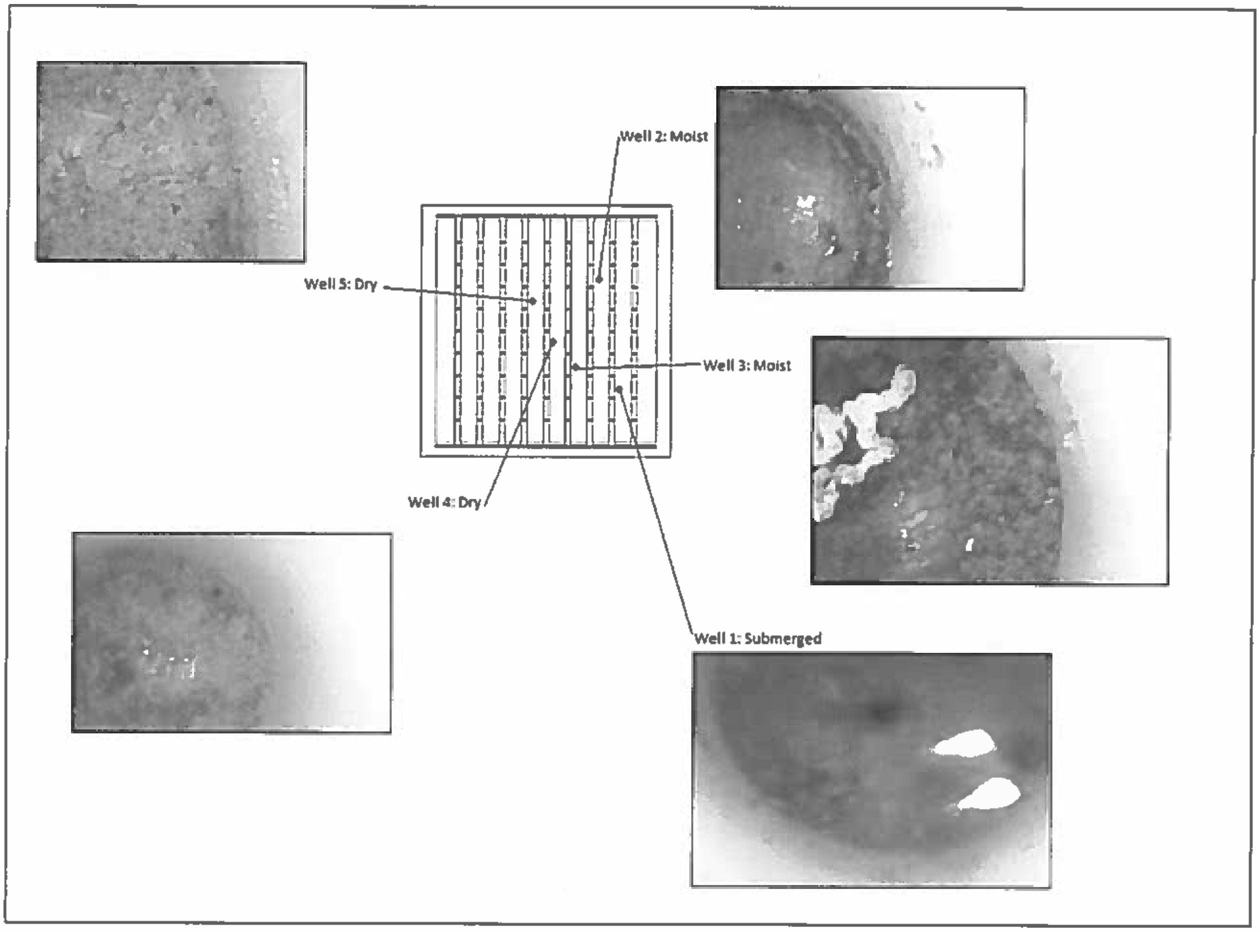


**Figure 3. – Well Inspection Images Using a Bore Scope**

Wells 1, 2 and 3 were pumped dry and monitored for water intrusion. After 24 hours of monitoring, no water re-entered the wells. Water present in the wells was speculated to be caused by condensation and the proximity of the well to the test cube perimeter where exposure to rain water was possible. All wells were dry prior to initiating the fluid injection test.

## Injection Fluid and Delivery System

The injection fluid used was a non-hazardous inert solution of potassium chloride 5% by volume (KCl) and deionized (DI) water. The fluid injection delivery system was designed and fabricated at FIU, which allows fluid to be injected into any of the five wells at the same time or independently. The system consisted of a 5-gallon tank connected to a PVC pipe manifold; (Figure 4). Plastic tubing was connected to the manifold and injection wells to convey the fluid.

Figure 4. – Fluid Injection Delivery System

## Fluid Injection Test

Fluid injection was conducted over a 3 day period from August 27 – 30, 2013. The first day consisted of injecting a 5% KCl solution into all of the injection wells, while during the remaining two days only deionized water was injected. At the beginning of the first day of injection (8/27/13), all the wells were filled to the top with 5% KCl. Throughout the day; each well was monitored and topped off whenever the fluid level dropped by more than a 0.25 in. (0.63 cm) from the top; see Figure 5.

Figure 5. -- FIU Researcher Monitoring Well Levels.

At the end of the day, all the wells were filled to the top and left overnight. Each morning, the well fluid level for each well was recorded. At conclusion of the first 24 hour period, the injection fluid transitioned from KCl to DI water and the same injection methodology was followed for a 48 hour period. After completing the fluid injection period, an additional eight day monitoring period was accomplished. The total fluid injection volumes for each injection day are shown in Table 3.

**Table 3. – Fluid Injection Volumes**

| Date | Initial Fill Volume Liters (gallons) | Daytime Volume Change Liters (gallons) | Overnight Volume Change Liters (gallons) | Total Injected Volume Liters (gallons) |
|---|---|---|---|---|
| 8/27/13<br>(KCl Sol.) | 4.02<br>(1.06) | 0.13<br>(0.03) | 0.25<br>(0.07) | 4.40<br>(1.16) |
| 8/28/13<br>(DI Water) | 4.02<br>(1.06) | 0.10<br>(0.03) | 0.15<br>(0.04) | 4.27<br>(1.13) |
| 8/29/13<br>(DI Water) | -- | 0.07<br>(0.02) | 0.13<br>(0.03) | 0.20<br>(0.05) |
| | | | **Total Volume Injected** | **8.87**<br>(2.34) |

Weather data was collected during the testing period from a local weather station located 1.63 miles northeast of the test site and groundwater elevation was obtained from USGS well G-3565, located 5.13 miles southwest of the test site. Weather and groundwater level data are presented in Appendix B - Weather and Groundwater Level Data for August 25 through September 7, 2013.

## Fluid Injection Test Summary

The fluid injection test at the ISDSN-MSTB test cube was conducted using two injection fluids; a non-hazardous inert solution of potassium chloride 5% by volume (KCl) and deionized (DI) water. The injection fluid was conveyed into five injection wells located in panels 2, 3, 4, 5, and 6 over a three day test period. The total volume of KCl solution injected into the test cube during the day 1 injection period was 4.40 liters. DI water was injected into the test cube for two days after the KCl injection period was completed. The total volume of the DI water injected was 4.47 liters.

Fluid migration was monitored by the activated embedded sensor systems and data collected for an additional eight days. Sensor System Principal Investigators were able to monitor the fluid injection event through the established Sensor Remote Access System (SRAS) hosted on the DOE D&D Knowledge Management Information Tool (D&D KM-IT) server. An internet video link was also established to facilitate field observation during the fluid injection event. The fluid injection and follow-on monitoring period was shortened to accommodate the fiscal year funding cycle.

# 8. SENSOR SYSTEMS

The fluid injection test activated a portion of the existing embedded sensor systems in the ISDSN-MSTB test cube; electrical resistivity tomography-thermocouple (ERT-T) sensor arrays, advance tensiometer sensors (AT), and Fiber Loop Ringdown (FLRD) Optical Sensors. Summarized below are the results from the data collected for each of activated sensor system during the test.

## 8.1. ELECTRICAL RESISTIVITY TOMOGRAPHY ARRAYS

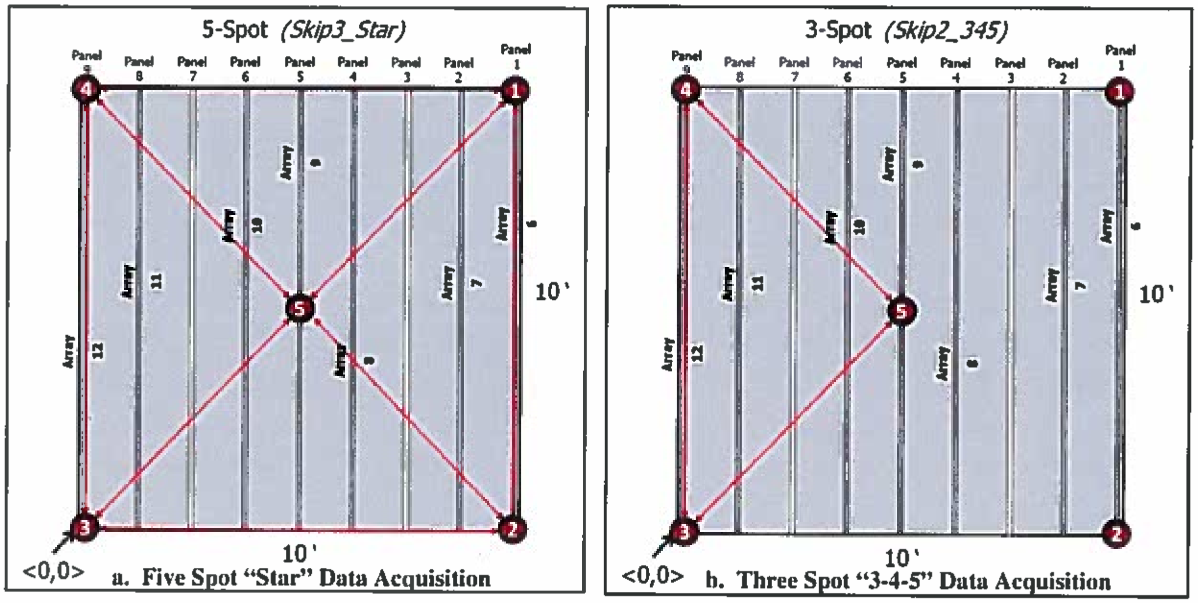
Information presented below is from the Idaho National Laboratory Project Report, "Phase 3 – ERT, Temperature, & Tensiometer Monitoring", September 27, 2013 [8]. The INL supplied the ERT-T and AT sensors previously embedded in the ISDSN-MSTB test cube and collected data to monitor grout curing during the 2012 ISDSN-MSTB Phase 2 Sensor Network Installation. The ERT-T and AT sensors were activated for the Phase 3 Fluid Injection Test.

### ERT-T Survey Design

The ERT-T arrays comprised of electrical resistivity tomography electrodes dispersed 10 in. (25.4 cm) apart attached on an 8 ft (2.4 m) non-metallic pole and thermocouples were evenly attached in-between the electrodes. The ERT-T array make-up consisted of 10 electrodes and 5 thermocouples. The data collection schedules were changed from the previous setting to reflect the expected rapid movement of fluid through the system. Original data collection schedules required approximately 7.5 hours to collect a full data set while the new schedules require two hours per data set. Three ERT-T array geometries were collected including a 5-spot "well" data set using the vertical arrays 1-5 with a skip value of 3 (Figure 6-a), a three spot "well" array set using arrays 3-5 with a skip value of 2 (Figure 6-b), and a base set using the horizontal arrays (9-12) with a skip value of 3 (Figure 6-c). These geometries represent the best chance for monitoring as they bound the area of the fluid injection.

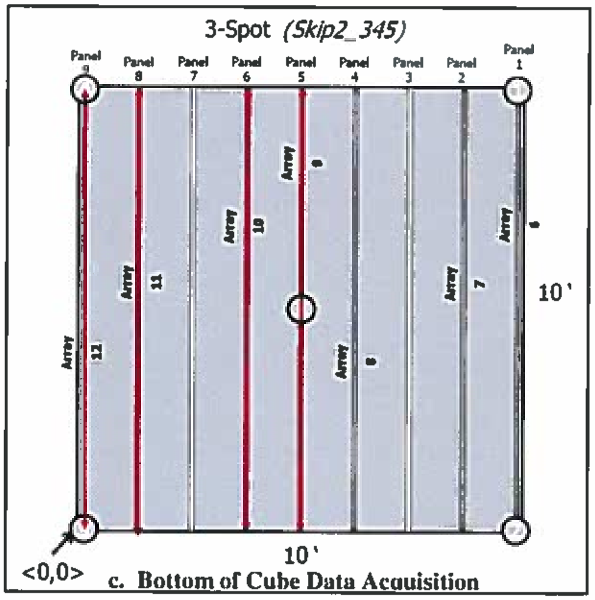
### System Activation

The embedded ERT-T arrays were activated prior to the fluid injection test and baseline data was collected to establish sensor functionality after being dormant for 15 months. Remote data collection was conducted as part of an initial system operability test. The sensor array generally functioned as expected. A minor amount of noise was observed in the signals from electrodes 8-10; however, sensor performance remained within acceptable limits.



a. Five Spot "Star" Data Acquisition

b. Three Spot "3-4-5" Data Acquisition



c. Bottom of Cube Data Acquisition

Figure 6. – ERT-T Array Geometry for Data Acquisition

## ERT-T Data Quality Assessment

Data quality in ERT-T surveys is measured by conducting a reciprocal measurement. This is a measurement where the transmitting electrode pair and receiving electrode pair, from an earlier measurement, are repeated with the pairs switched. The two different measurements are compared, and assuming the system is linear and constant, the reciprocal measurements should match. The degree to which they don't match is a measure of a non-linear or changing system which will invalidate some of the main assumptions underlying geophysical processing and inversion techniques. The reciprocal measurements for these data collection schedules had measurements being performed after 200 of the 'regular' measurements. This meant that only a few minutes had passed before reciprocals were measured, thus ensuring a 'constant' system in the event of rapid infiltration.

Figure 7 shows an example of the percent difference for some of the reciprocal measurements from these data sets. This data set showed good reciprocal behavior with the vast majority of reciprocal error being less than 10% (red dashed line). This indicates acceptable data quality and little systematic change between measurements.

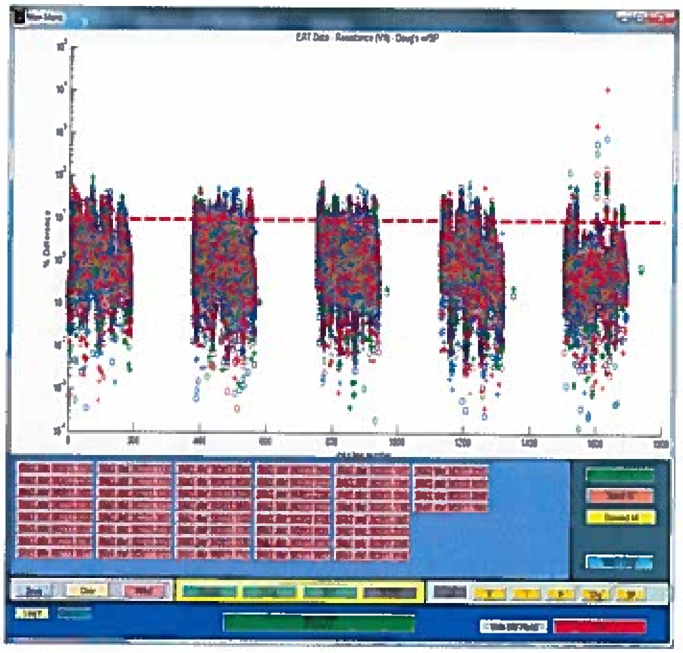


**Figure 7. – Example of ERT-T Reciprocity Results**

## ERT-T Data Acquisition during Fluid Injection Test

ERT Data was collected continuously from mid-day August 26th through mid-day August 30th. A system error occurred on August 30th and data collection was not started again until September 3rd. However, the initial data was sufficient to bound the infiltration periods. After downloading the ERT-T files, the data was imported into an INL developed program for inspecting and eventually writing the data to Universal Resistivity Format (URF) type inversion input files. The data is inspected for quality (reciprocity) and in this case the degree of change to estimate if inversion was a reasonable next step. Figures 8 through 10, the base data set (Arrays 9 through 12, Horizontal), 5-spot data set (Arrays 1 through 5, Vertical) and the 3-spot data set (Arrays 3 through 5, Vertical) respectively, show data collected over the periods of injection, roughly August 27th-30th. The data sets show little change with some variation seen in the lower values, a typically noisy area. These trends in the data observed were not consistent, with successive points randomly varying within the range. This result indicated the observed changes were probably due to a source of noise in the system.

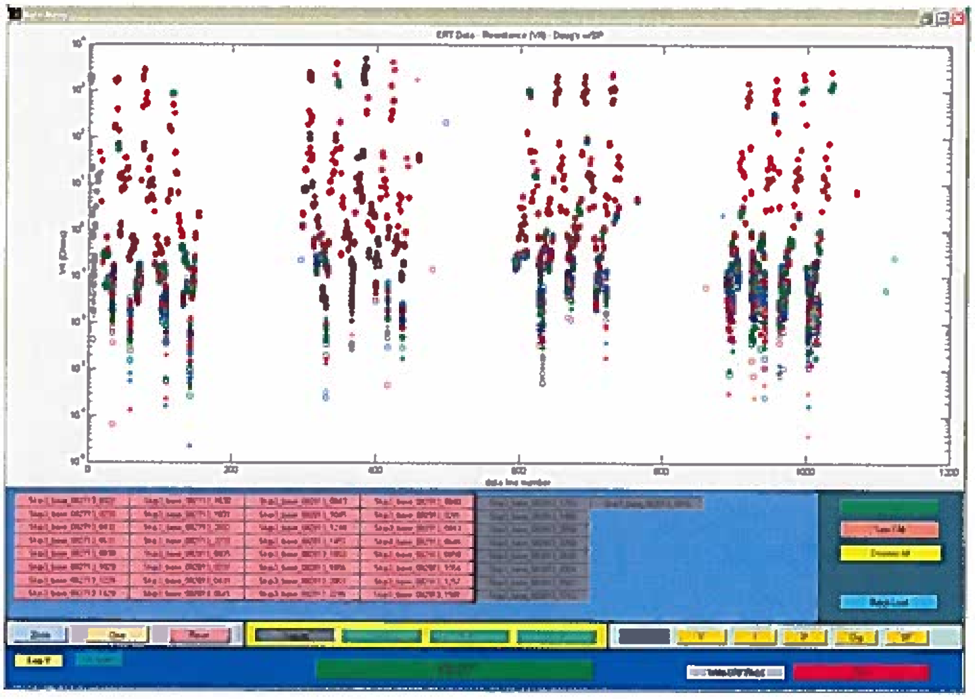


Figure 8. - Raw ERT-T Data from the Base Data Set (Arrays 9 through 12, Horizontal) for August 27th - 30th.

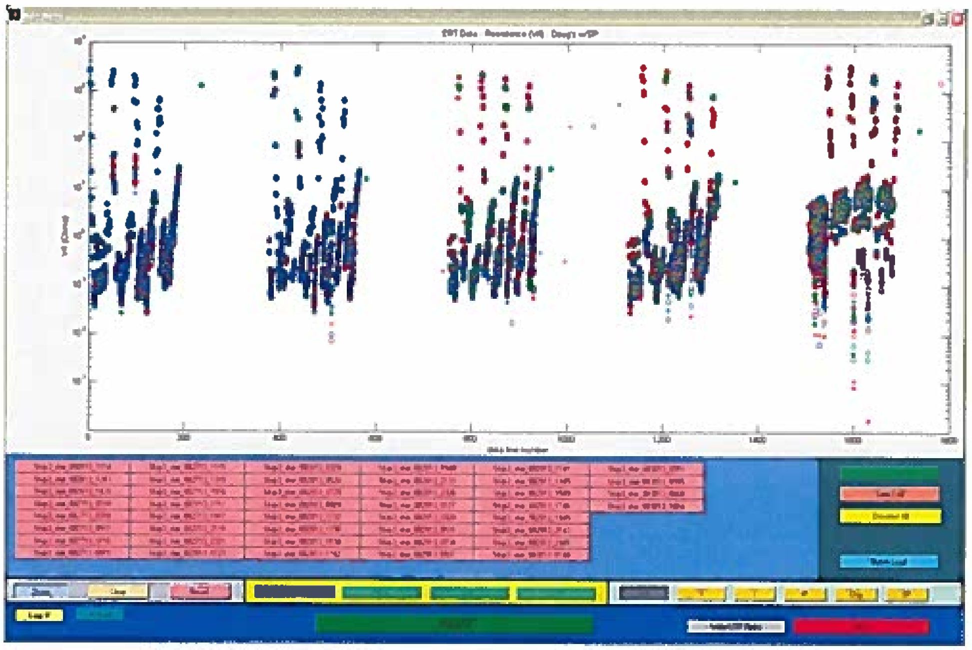


Figure 9. - Raw ERT-T Data from the 5-Spot (star) Data Set (Arrays 1 through 5, Vertical) for August 27th - 30th.

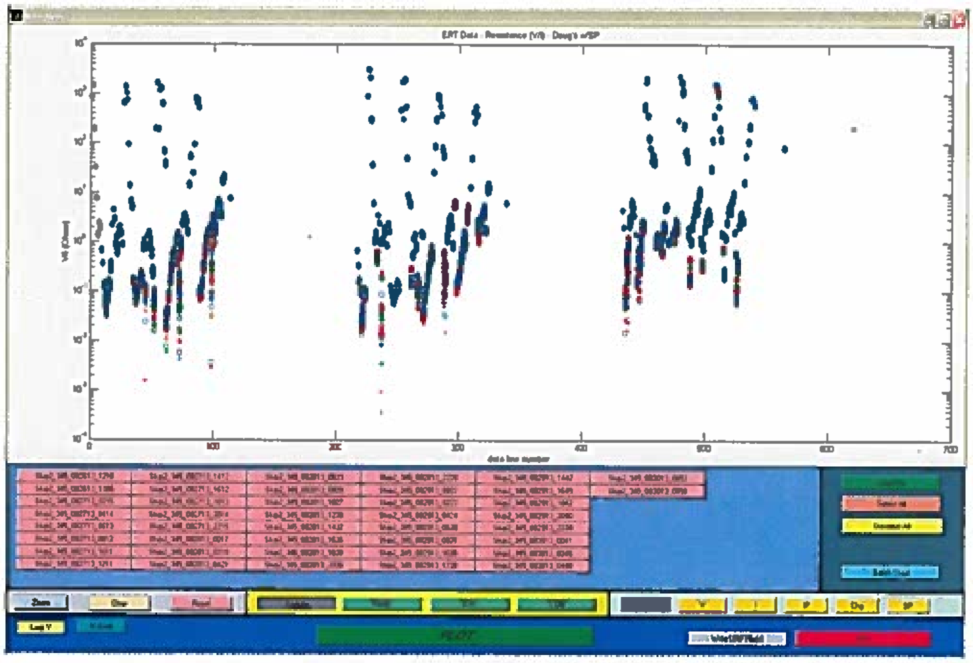


**Figure 10. - Raw ERT-T Data from the 3-spot data set (Arrays 3 through 5, Vertical) for August 27th -30th.**

### ERT Array Summary

The ERT-T arrays did not adequately monitor fluid migration during the fluid injection test. The data acquired showed slight signal changes, but these changes were at the lower end of the system's performance envelope. Other contributing factors were the relative short duration of the test and low volume of injected fluid into the test cube. The ERT-T system is the most constant and comprehensive data set with respect to the infiltration period, but shows only small and inconsistent changes in the noisier parts of the data. Further development is recommended to process acquired data and analyze the acquired data at the lower end of the ERT-T system's performance envelope to filter environmental noise levels.

## 8.2. THERMOCOUPLES

### Thermocouple Data Acquisition During the Fluid Injection Test

The temperature data was collected sporadically from August 26th through September 3rd. There were a few days of continuous measurements, but based on the data uploaded to the database, temperature data acquisition did not occur between midnight and almost 4 PM on a number of days. This missing data tends to introduce jumps or tares in the data and makes trend analysis difficult.

There appears to be three main temperature trends in the data, dependent upon physical position. Figure 11 shows the typical behavior of the vertical temperature arrays at the corners of the block. While the missing data masks the trends, the few full days of data indicate these arrays were dominated by diurnal variations of one to two degrees Celsius, a value close to the limit of these sensors. In the case of all four arrays at the corners (Arrays 1, 2, 3, and 4), there appears to be no signature associated with injection. The lack of signal change at the corners indicates that lateral fluid migration had not occurred during the test period.

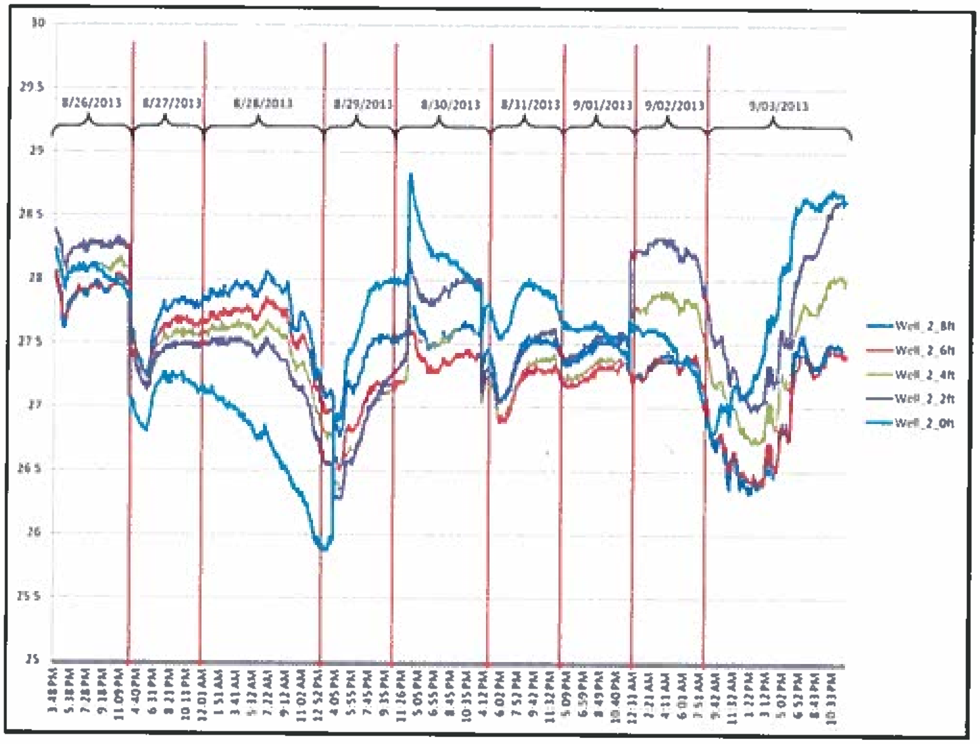


Figure 11. – Thermocouple/Temperature Logs for Array 2

Figure 12 shows results from the vertical array in the center of the block (Array 5). Again missing data makes interpreting difficult but this array shows a decreasing temperature profile, with a smaller diurnal signature then the corner arrays. The noted signal change was close to the error level of the thermocouple data acquisition system.

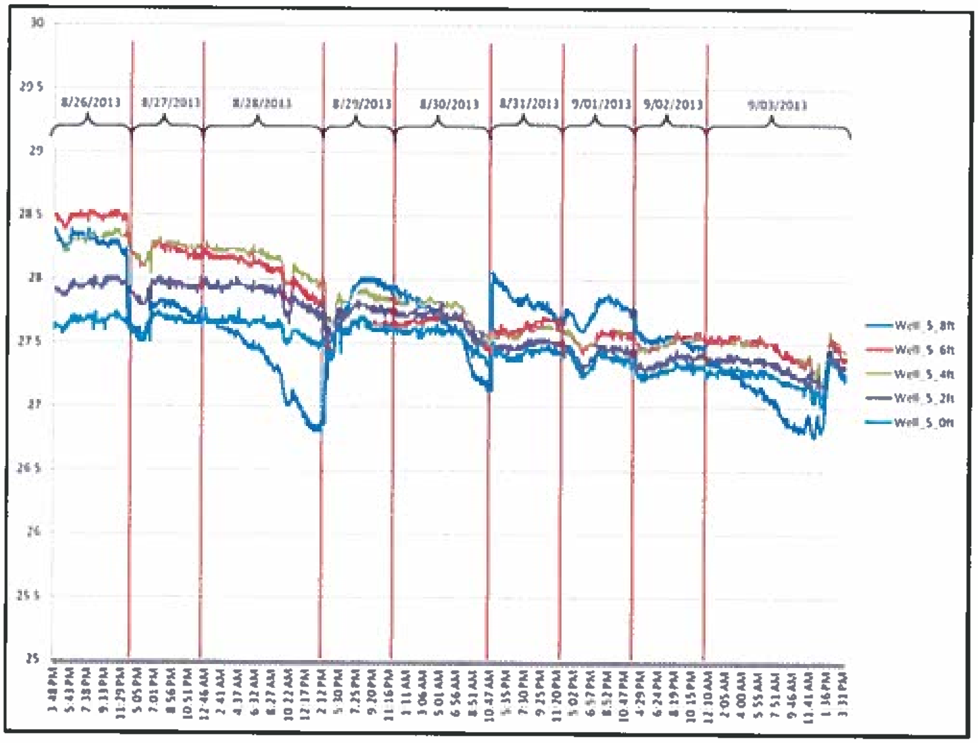


Figure 12. – Thermocouple/Temperature Logs for Array 5

The horizontal arrays along the bottom of the test cube showed a slight downward trend and no diurnal effects. Significant temperature signal change was not observed due to fluid injection. The lack of signal change at the bottom of the test cube indicates that full fluid vertical migration had not occurred during the test period.

### Thermocouples Summary

The thermocouple system attached to the ERT-T arrays did not adequately monitor any significant temperature changes associated with the fluid injection test. Data acquisition was incomplete during the fluid injection test period. Temperature changes indicate diurnal variations and a very slow cooling of the overall system within the grouted test cube.

## 8.3. ADVANCED TENSIOMETERS

The advanced tensiometer did not adequately monitor any significant temperature changes associated with the fluid injection test. Data acquired was erratic and initial instrument calibration data was missing. The erratic data acquired for these instruments reflects the influence of atmospheric pressure changes indicating a faulty seal between the rubber tip of the tensiometer and the porous cup. The extended instrument dormancy (15 months) was a contributing factor to this system's inoperability.

## 8.4. FIBER LOOP RINGDOWN OPTICAL SENSOR

Information presented below is summarized from the Mississippi State University Project Report, "Phase III – ISDSN Fluid Injection Test Using Fiber Optics Sensor", September 2013 [9].

The Fiber Loop Ringdown Optical Sensor System (FLRD) was previously embedded in the ISDSN-MSTB test cube and collected data to monitor grout curing during the 2012 ISDSN-MSTB Phase 2 Sensor Network Installation. The FLRD sensors embedded consisted of fluid sensors and crack-strain sensors. The FLRD sensors activated for the Phase 3 Fluid Injection Test were the embedded fluid sensors on sensor panel 5 of the test cube. FLRD crack-strain sensor results from the Phase 2 Sensor Network Installation indicated a high potential for micro-crack development inside the grout monolith [6]. Other embedded sensor systems within the grout monolith indicated a similar result. No destructive sample recovery was conducted to validate material cracking affects.

### System Activation

The embedded FLRD fluid sensor was activated prior to the fluid injection test and baseline data was collected to establish sensor functionality after being dormant for an extended period (15 months). The baseline data showed the ringdown response time was very stable within 1 minute of data collection and fairly constant at around 22.8 micro-second (μs) with trigger level of 0.05 Volts (V). A second baseline was collected with a trigger level of 0.06 V and the ringdown response time stabilized around 22.5 μs.

## FLRD Sensor Data Acquisition During the Fluid Injection Test

The FLRD sensor data acquisition was conducted using a remote network connection through the DOE-EM KM-IT server to a Mississippi State University (MSU) laboratory computer. The FLRD water sensors experienced a significant amount of signal change, approximately 10 hours after the KCl solution injection had commenced. The FLRD signal change indicated a moisture shift within the grout material surrounding the FLRD fluid sensor. The increased signal response time continued for the KCl solution injection period (24 hours). The injection fluid transition from a KCl solution to DI water commenced the following day and continued for 48 hours. The FLRD fluid sensor signal response during the fluid injection period is presented in Figure 13.

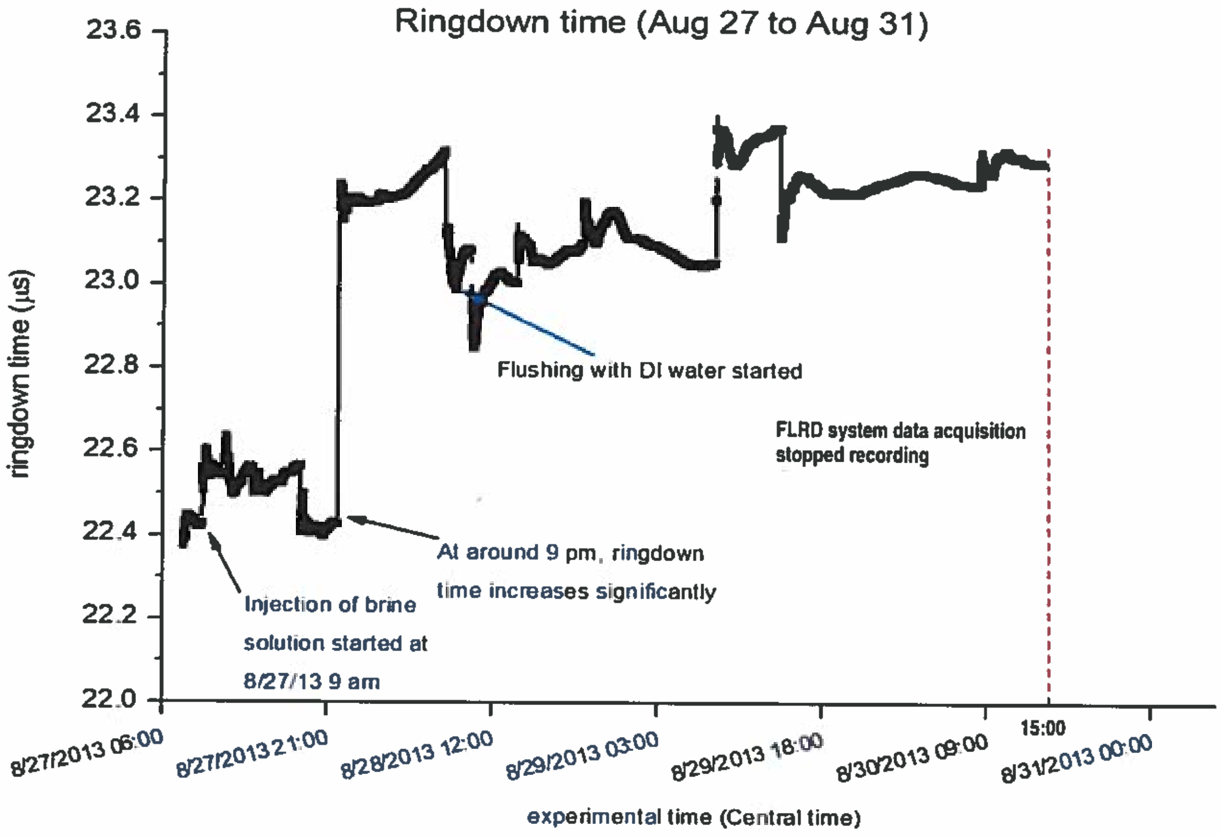


**Figure 13. - FLRD Fluid Sensor Signal Response During the Fluid Injection Period**

The FLRD system data acquisition stopped recording at 1500 hrs on August 30 and a data gap of nearly 12 hours was experienced. Data acquisition was re-established by changing the trigger level from 0.06 V to 0.05V. The trigger level change increased the ringdown response time to approximately 31.5 µs. Since a baseline ringdown response time was recorded for a trigger level of 0.05 V before the test started, the FLRD sensor still indicated the presence of fluid within the test cube (Figure 14). The FLRD sensor response time decreased as moisture level decreased during fluid monitoring period. The data collection gap appears to be related to the data collection software storage capacity. Increasing the trigger level voltage, decreased the ringdown response time interval and decreased the data volume to be stored.

A composite plot for the entire testing period was developed by adjusting the baseline response time to 23.3 μs. The FLRD response time data showed an increase in signal response when moisture level increased and a decrease in signal response as moisture level decreased; (Figure 15). After reviewing the composite plot (Figure 15), fluid quality during the entire fluid injection period (KCl – DI water injection) influenced the FLRD ringdown response time. It is speculated a wavelength shift occurs when the light travels through differing fluid quality. The FLRD ringdown response time slightly decreased when injection fluid transitioned from KCl (average ringdown response time – 23.4 μs) to DI water (average ringdown response time – 23.2 μs). Technical discussion regarding this influence is discussed in Sensors and Actuators B Journal, 2013, "*Reproducibly Reversible Fiber Loop Ringdown Water Sensor Embedded in Concrete and Grout for Water Monitoring*" [10].

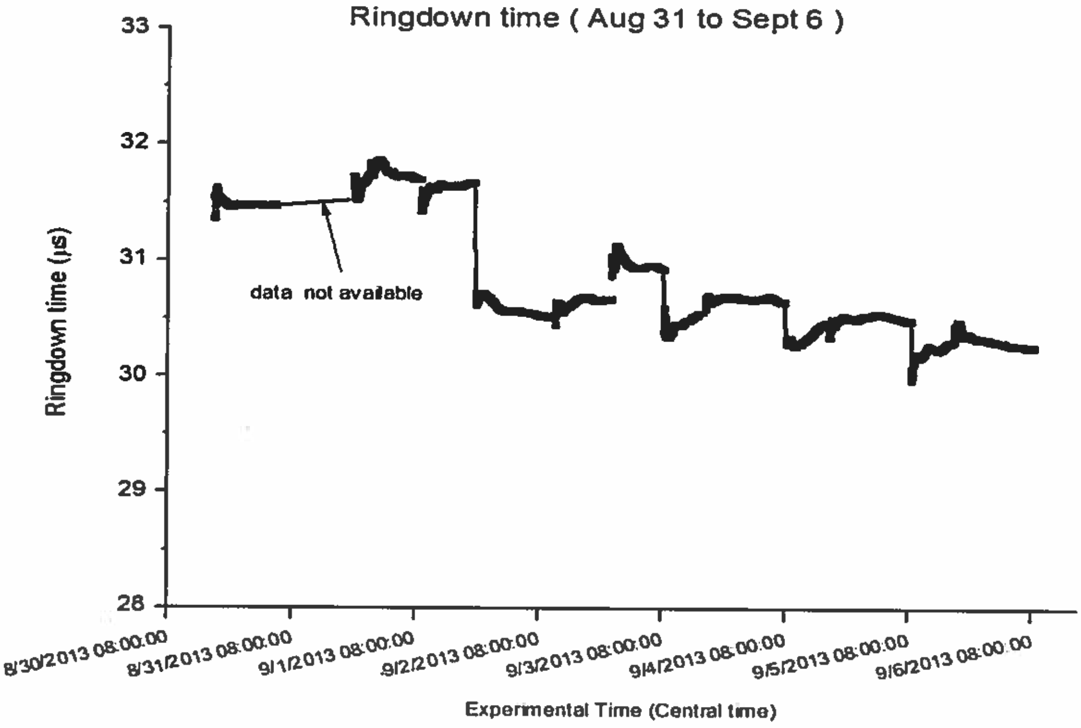


**Figure 14. - FLRD Fluid Sensor Signal Response During the Fluid Monitoring Period**

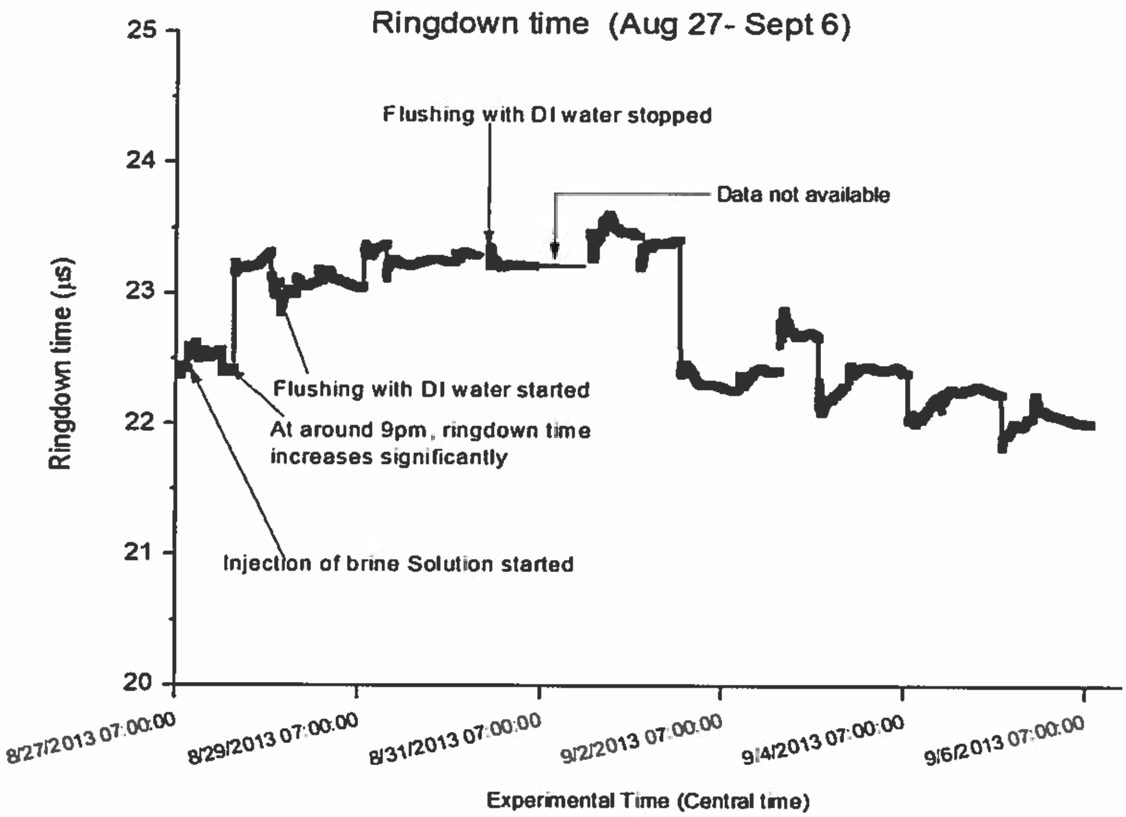


**Figure 15. – Composite FLRD Fluid Sensor Signal Response for Fluid Injection Test**

## FLRD Summary

The FLRD fluid sensors detected moisture level changes during the fluid injection test. The sensor system was able to be re-activated after 15 months and functioned satisfactorily. FLRD data showed after about 10 hours of the initial fluid injection (KCl), the ringdown response time indicated the fluid had reached the sensor location. Adjusting the sensor trigger level from 0.06 V to 0.05 V increased the average ringdown time of 31.5 µs (at trigger level of 0.05 V) as compared to 28.8 µs (at trigger level of 0.06 V) which supplied a continuous data stream indicating the presence of fluid in the grout. The FLRD response time data showed an increase in signal response when moisture level increased and a decrease in signal response as moisture level decreased. Further refinement of the data collection software capacity is recommended. The FLRD fluid sensor data also indicated fluid quality can influence the ringdown response time, but further investigation is needed to confirm this observation.

# 9. CONCLUSIONS AND RECOMMENDATIONS

The ISDSN-MSTB Phase 3 Fluid Injection Test was conducted from August 27 through September 6, 2013 at the ISDSN-MSTB test cube located at the FIU-ARC. The fluid injection test activated a portion of the existing embedded sensor systems in the ISDSN-MSTB test cube; electrical resistivity tomography-thermocouple sensor arrays, advance tensiometer sensors, and fiber loop ringdown optical sensors. These embedded sensor systems were activated 15 months after initial placement. All sensor systems were remotely operated and data acquisition was completed through the established Sensor Remote Access System (SRAS) hosted on the DOE D&D Knowledge Management Information Tool (D&D KM-IT) server.

An inert, non-hazardous KCl solution (5% by volume) was initially conveyed into five pre-embedded injection wells in the ISDSN-MSTB test cube. The KCl solution was injected over a 24 hour duration followed by a subsequent fluid injection with DI water over 48 hour duration. The activated portion of the embedded sensor systems monitored the presence of excess moisture/fluid in the grout and the potential for ion migration within a grout monolith. The Phase 3 Fluid Injection Test Parameters and results are captured in Table 4. Fluid/Contaminant Ion Mobility Potential could not be determined due the limited data collected.

The Fiber Loop Ringdown Optical Sensor System (FLRD) fluid sensors detected moisture level changes during the fluid injection test. This sensor system was able to be re-activated after 15 months of dormancy and functioned satisfactorily. The FLRD response time data showed an increase in signal response when moisture level increased and a decrease in signal response as moisture level decreased. A secondary finding from data analysis was fluid quality can influence the ringdown response time and recommend further investigation to confirm this observation.

The electrical resistivity tomography-thermocouple (ERT-T) sensor arrays and advanced tensiometer (AT) instruments did not adequately display significant signal response during the fluid injection test period. The ERT-T data showed slight signal changes, but these changes were at the lower end of the system's performance envelope. Further investigation is recommended to process acquired data at the lower end of the ERT-T system's performance envelope to mitigate environmental noise levels. Thermocouple data acquisition was incomplete and a majority of the temperature changes detected appears to be indicating diurnal variations and a very slow cooling of the overall system within the grouted test cube. Advanced tensiometer data acquired was erratic and incomplete. The advanced tensiometer extended instrument dormancy (15 months) was a contributing factor to this system's inoperability. Recommend further refinement of the advanced tensiometer be pursued to resolve extended instrument dormancy when embedded in a cementitious material/grout monolith.

Table 4. - Phase 3 Fluid Injection Test Parameters and Results

| Test Parameter | Target Value | Fluid Injection Test Average Result | Comments |
|---|---|---|---|
| Water | Presence | FLRD – Fluid Present<br>ERT-T – Undetermined | ERT-T system showed slight signal changes, but these changes were at the lower end of the system's performance envelope. |
| Temperature | 20 $^0$C | ERT-T -- Undetermined | Thermocouple data acquisition system operated sporadically. Temperature trend analysis was not completed due to data gaps. |
| Fluid/Contaminant Ion Mobility Potential | $10^{-7}$ cm/sec | AT - Undetermined | Insufficient data to determine this result. |
| Ion Concentration | 3% or less | FLRD – Fluid quality (KCl to DI water) influenced sensor ringdown response time. | An indirect result from the FLRD system ringdown response time. |

AT – Advanced Tensiometer
ERT-T – Electrical Resistivity Tomography-Thermocouple Sensor Array
FLRD -- Fiber Loop Ringdown Optical Sensor System

The ISDSN Phase 3 Fluid Injection Test successfully demonstrated the feasibility of embedding sensor systems to assess moisture-fluid flow and resulting transport potential for contaminate mobility through a cementitious material/grout monolith. The ISDSN embedded sensor systems activated for the fluid injection test highlighted the robustness of the sensor systems and the importance of configuring systems in-depth (i.e. complementary sensors and measurements) to alleviate data acquisition gaps. The ISD Sensor Network will be focused for field demonstration on a deactivated nuclear facility within the DOE Complex.

## 10. REFERENCES

1. Serrato, Michael G, and Richard J Abitz, 2011. *Test Plan – In Situ Decommissioning Sensor Network, Meso-Scale Test Bed*, SRNL-TR-2011-00216, Revision 0, Savannah River National Laboratory, Savannah River Site, Aiken, SC

2. Serrato, Michael G, 2013. *Test Plan – In Situ Decommissioning Sensor Network, Meso-Scale Test Bed- Phase 3 Fluid Injection Test*, SRNL-TR-2013-00165, Revision 0, Savannah River National Laboratory, Savannah River Site, Aiken, SC

3. U. S. Department of Energy (DOE). 2009. *DOE EM Strategy and Experience for In Situ Decommissioning*. Office of Environmental Management (EM), Office of Engineering and Technology (EM-20), Washington DC.

4. Lee, Patricia L, John B. Gladden, G. Timothy Jannik, Christine A. Langton, Michael G. Serrato, Chuck Urland, Erick Reynolds. 2009. *Technology Requirements for In Situ Decommissioning Workshop Report.* SRNL-RP-2009-00269, Revision 0. Savannah River National Laboratory, Savannah River Site, Aiken, SC.

5. Savannah River National Laboratory. 2010. *Development of a Remote Monitoring Sensor Network for In Situ Decommissioned Structures, Panel Report.* SRNL-RP-2010-01666, Revision 0. Savannah River National Laboratory, Savannah River Site, Aiken, SC.

6. Serrato, Michael G., 2013. *In Situ Decommissioning Sensor Network, Meso-Scale Test Bed – Phase 1 and Phase 2 Final Report,* SRNL-STI-2013-00050, Revision 0, Savannah River National Laboratory, Savannah River Site, Aiken, SC.

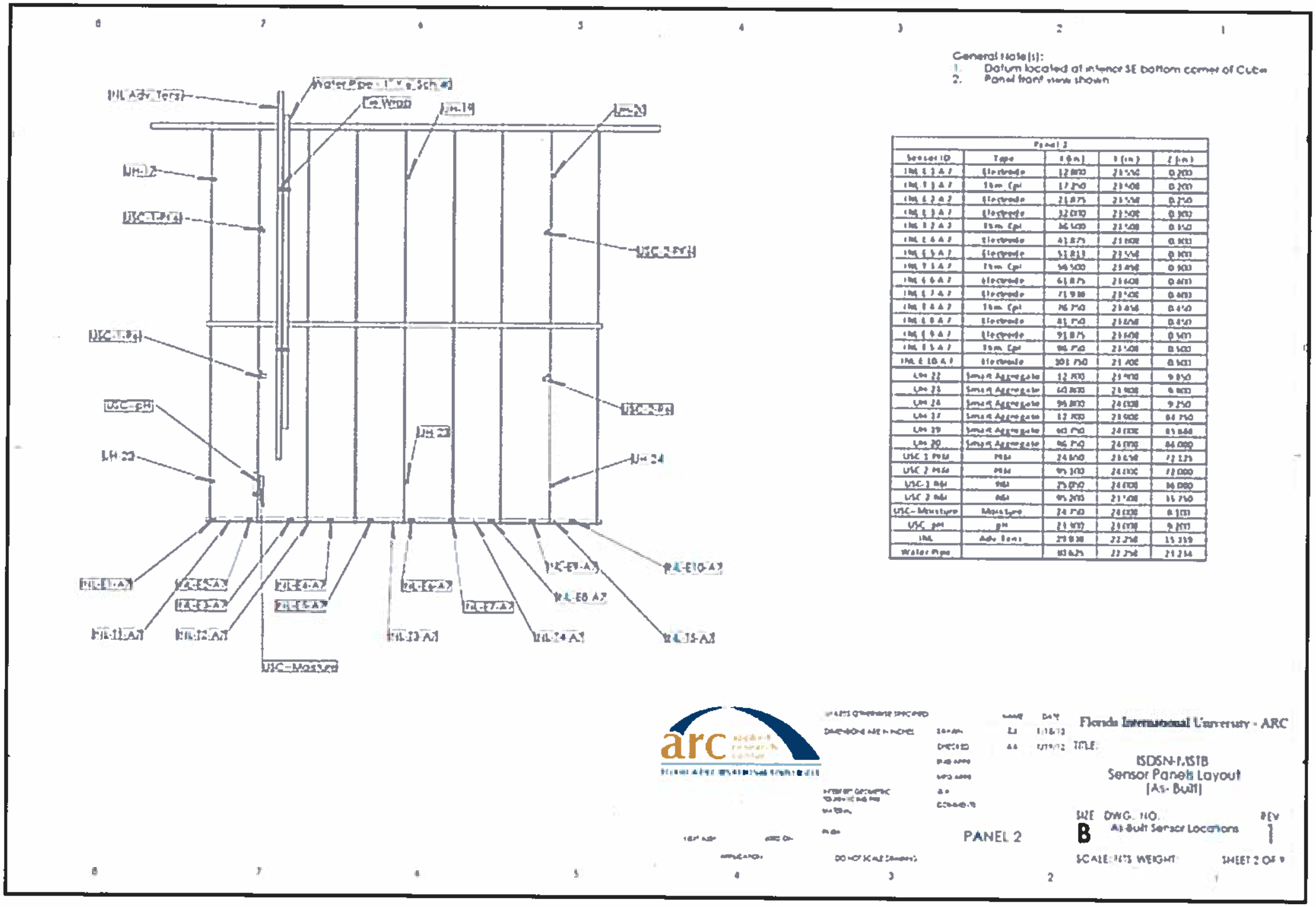
7. Lagos, Leonel, Amer Awwad, Jario Crespo, Jose Rivera., 2013, *In Situ Decommissioning Sensor Network Phase 3 – Fluid Injection Test Final Report*. FIU-ARC-2013-AWD000000003423-04c-001, Revision 0, Florida International University Applied Research Center, Miami, FL.

8. Scott, Clark, Trent Armstrong, 2013, Idaho National Laboratory Project Report, "Phase 3 – ERT, Temperature, & Tensiometer Monitoring", September 27, 2013, INL/EXT-13-30358, Idaho National Laboratory, Idaho Falls, ID.

9. Wang, Chuji, Maheshwar Ghimire. 2013, *Phase III – ISDSN Fluid Injection Test Using Fiber Optics Sensor Project Report*, September 2013, Mississippi State University Department of Physics, Starksville, MS.

10. Kaya, Malik; Peeyush Sahay, and Chuji Wang , Reproducibly Reversible Fiber Loop Ringdown Water Sensor Embedded in Concrete and Grout for Water Monitoring, Sensors and Actuators B, 2013, 803–810.

# Appendix A. As-Built Drawings for Sensor Panels 2, 3, 4, 5 and 6



General Note(s):
1. Datum located at interior SE bottom corner of Cube
2. Panel front view shown

| Panel 2 | | | | |
|---|---|---|---|---|
| Sensor ID | Type | X (in) | Y (in) | Z (in) |
| INL E 1 A 2 | Electrode | 12.000 | 21.536 | 0.200 |
| INL T 1 A 2 | Therm Cpl | 17.250 | 21.406 | 0.200 |
| INL E 2 A 2 | Electrode | 21.875 | 21.536 | 0.250 |
| INL E 3 A 2 | Electrode | 32.000 | 21.508 | 0.300 |
| INL T 2 A 2 | Therm Cpl | 36.500 | 21.508 | 0.350 |
| INL E 4 A 2 | Electrode | 41.875 | 21.608 | 0.300 |
| INL E 5 A 2 | Electrode | 53.813 | 21.536 | 0.300 |
| INL T 3 A 2 | Therm Cpl | 56.500 | 21.498 | 0.300 |
| INL E 6 A 2 | Electrode | 61.875 | 21.608 | 0.400 |
| INL E 7 A 2 | Electrode | 71.938 | 21.408 | 0.400 |
| INL T 4 A 2 | Therm Cpl | 76.750 | 21.414 | 0.450 |
| INL E 8 A 2 | Electrode | 81.750 | 21.608 | 0.450 |
| INL E 9 A 2 | Electrode | 91.875 | 21.608 | 0.500 |
| INL T 5 A 2 | Therm Cpl | 96.750 | 21.508 | 0.500 |
| INL E 10 A 2 | Electrode | 101.750 | 21.406 | 0.500 |
| UH 22 | Smart Aggregate | 12.500 | 21.900 | 9.050 |
| UH 23 | Smart Aggregate | 60.000 | 21.938 | 9.000 |
| UH 24 | Smart Aggregate | 96.000 | 24.000 | 9.250 |
| UH 17 | Smart Aggregate | 12.500 | 21.938 | 84.750 |
| UH 19 | Smart Aggregate | 60.750 | 24.000 | 85.848 |
| UH 21 | Smart Aggregate | 96.750 | 24.000 | 84.000 |
| USC 1 PYH | PYH | 24.000 | 21.638 | 72.125 |
| USC 2 PYH | PYH | 95.300 | 24.000 | 72.000 |
| USC-1 RS | RS | 25.050 | 24.000 | 84.000 |
| USC 2 RS | RS | 95.200 | 21.408 | 35.750 |
| USC-Moisture | Moisture | 24.750 | 24.000 | 0.100 |
| USC_pH | pH | 21.900 | 21.938 | 9.500 |
| INL | Adv. Tens | 29.938 | 22.258 | 35.359 |
| Water Pipe | | 103.625 | 22.258 | 21.254 |

Florida International University - ARC

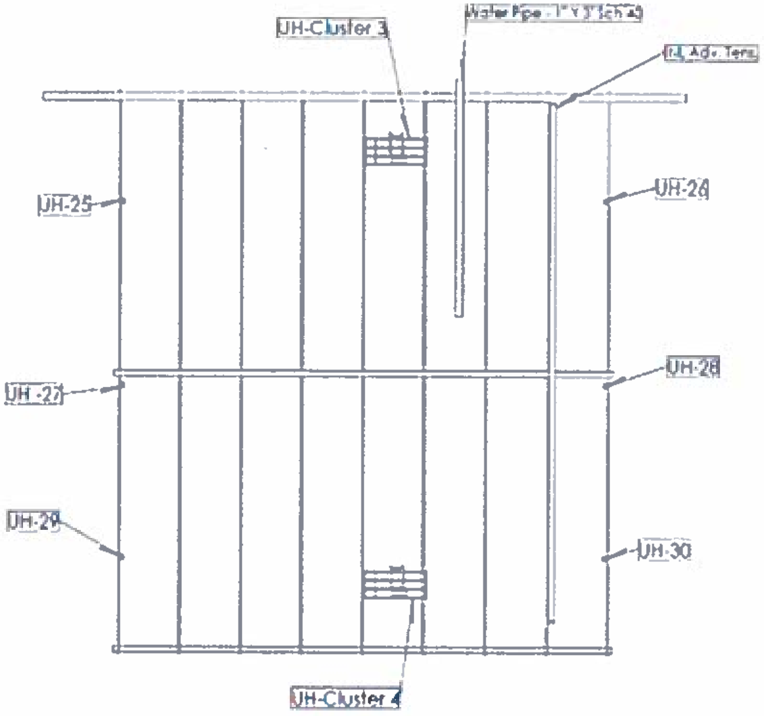
TITLE:
ISDSN-MSTB
Sensor Panels Layout
(As- Built)

PANEL 2

SIZE B
DWG. NO.
As-Built Sensor Locations
REV 1

SCALE: NTS WEIGHT:
SHEET 2 OF 9

General Note(s):
1. Datum located at interior SE bottom corner of Cube
2. Panel front view shown



| Sensor ID | Type | X (in) | Y (in) | Z (in) |
|---|---|---|---|---|
| UH-25 | Smart Aggregate | 12.700 | 36.000 | 18.958 |
| UH-27 | Smart Aggregate | 12.700 | 36.000 | 47.358 |
| UH-29 | Smart Aggregate | 12.700 | 36.000 | 79.858 |
| UH-30 | Smart Aggregate | 107.400 | 36.000 | 18.959 |
| UH-28 | Smart Aggregate | 107.300 | 36.000 | 47.458 |
| UH-26 | Smart Aggregate | 107.400 | 36.000 | 79.958 |
| UH-Cluster 4 | Cluster | 60.400 | 36.500 | 9.859 |
| UH-Cluster 3 | Cluster | 60.100 | 36.500 | 88.258 |
| IN4 | Adv. Tens. | 97.000 | 35.125 | 5.464 |
| Water Pipe | | 76.625 | 32.625 | 59.672 |

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

| | NAME | DATE |
|---|---|---|
| DRAWN | EJ | [illegible] |
| CHECKED | AA | [illegible] |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |
| COMMENTS: | | |

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

PANEL 3

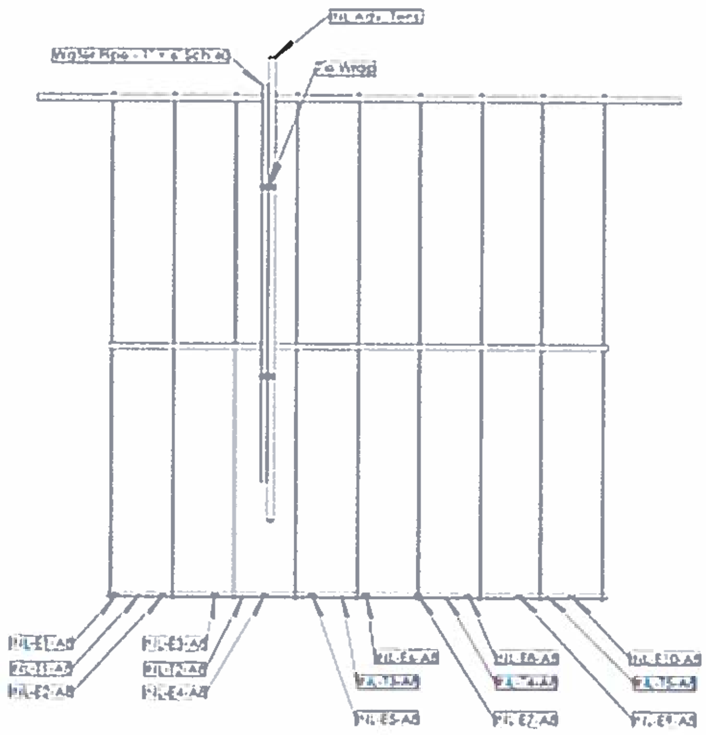
Florida International University - ARC

TITLE:

ISDSN-MITSB
Sensor Panels Layout
(As- Built)

SIZE B
DWG. NO. As-Built Sensor Locations
REV 1

SCALE: NTS WEIGHT:
SHEET 3 OF 9



General Note(s):
1. Datum located at interior SE bottom corner of Cube
2. Panel front view shown

| Panel 4 | | | | |
|---|---|---|---|---|
| Sensor ID | Type | X (in) | Y (in) | Z (in) |
| FIU-E1-A8 | Electrode | 12.750 | 47.625 | 0.484 |
| FIU-T1-A8 | Ther Cpl | 17.500 | 47.500 | 0.547 |
| FIU-E2-A8 | Electrode | 21.938 | 47.500 | 0.547 |
| FIU-E3-A8 | Electrode | 32.188 | 47.438 | 1.109 |
| FIU-T2-A8 | Ther Cpl | 36.875 | 47.500 | 0.484 |
| FIU-E4-A8 | Electrode | 42.063 | 47.250 | 0.609 |
| FIU-E5-A8 | Electrode | 51.250 | 47.375 | 0.672 |
| FIU-T3-A8 | Ther Cpl | 54.750 | 48.563 | 0.734 |
| FIU-E6-A8 | Electrode | 61.813 | 47.375 | 0.734 |
| FIU-E7-A8 | Electrode | 72.000 | 47.438 | 0.672 |
| FIU-T4-A8 | Ther Cpl | 77.125 | 47.375 | 0.484 |
| FIU-E8-A8 | Electrode | 81.625 | 47.313 | 0.609 |
| FIU-E9-A8 | Electrode | 91.750 | 47.250 | 0.609 |
| FIU-T5-A8 | Ther Cpl | 96.750 | 47.500 | 0.672 |
| FIU-E10-A8 | Electrode | 102.188 | 47.500 | 0.547 |
| FIU | Adc Temp | 41.000 | 50.125 | 14.875 |
| Water Pipe | | 41.625 | 50.125 | 22.922 |

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

| | NAME | DATE |
|---|---|---|
| DRAWN | JJ | 11/6/13 |
| CHECKED | AA | 11/7/13 |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |
| COMMENTS | | |

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

Florida International University - ARC

TITLE:

ISDSN-MSTB
Sensor Panels Layout
(As- Built)

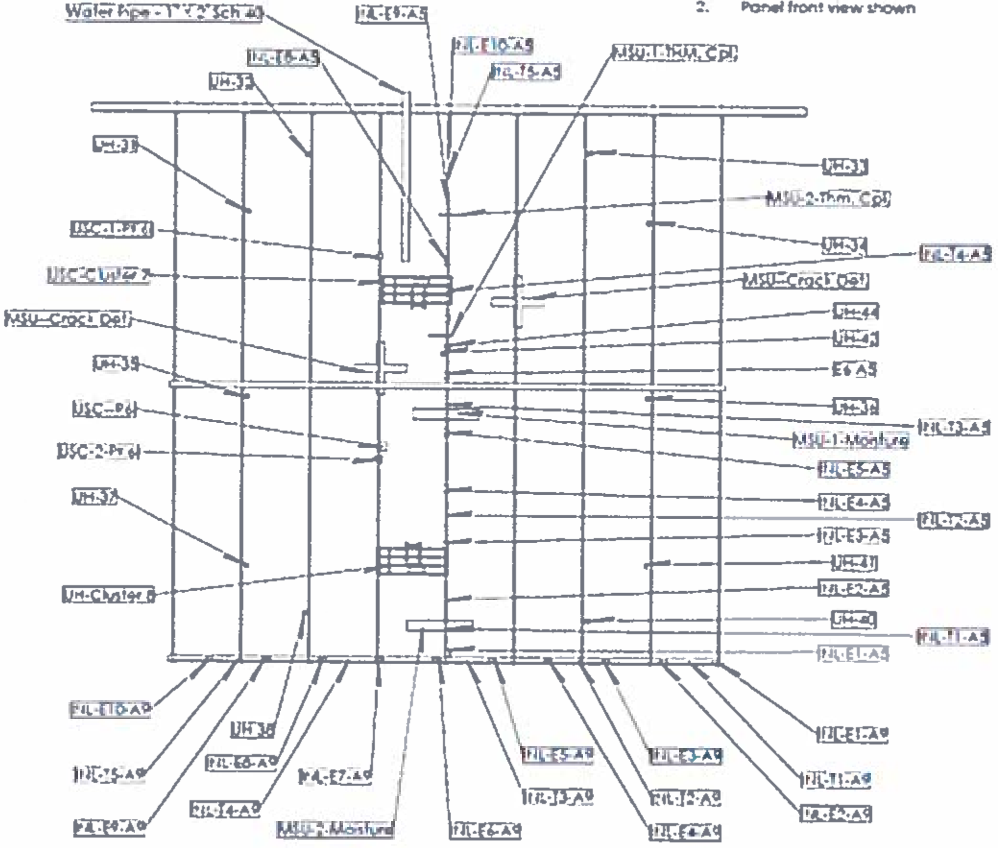
PANEL 4

SIZE B
DWG. NO. As-Built Sensor Locations
REV 1

SCALE: NTS WEIGHT:
SHEET 4 OF 9

| Panel 5 | | | | |
|---|---|---|---|---|
| Sensor ID | Type | X (in) | Y (in) | Z (in) |
| UH-11 | Smart Aggregate | 24.700 | 59.900 | 80.079 |
| UH-15 | Smart Aggregate | 15.750 | 59.900 | 9.059 |
| UH-42 | Smart Aggregate | 15.750 | 60.000 | 90.219 |
| USC-1-PR4 | PR4 | 48.000 | 59.900 | 95.859 |
| USC-B4 | B4 | 48.800 | 59.250 | 88.359 |
| USC-2-PR4 | PR4 | 48.000 | 59.900 | 72.959 |
| MSU-Crack Det | Crack Det | 48.000 | 61.700 | 32.459 |
| UH-43 | Smart Aggregate | 59.320 | 60.200 | 33.059 |
| UH-44 | Smart Aggregate | 60.000 | 60.650 | 36.859 |
| MSU-1-Moisture | Moisture | 59.000 | 61.200 | 6.859 |
| MSU-2-Moisture | Moisture | 59.900 | 61.200 | 44.959 |
| MSU-1-Therm Cp | Therm. Cp | 58.700 | 60.000 | 30.259 |
| MSU-2-Therm Cp | Therm. Cp | 60.300 | 60.000 | 79.659 |
| UH-40 | Smart Aggregate | 84.800 | 60.000 | 7.809 |
| UH-13 | Smart Aggregate | 84.800 | 60.000 | 93.659 |
| UH-41 | Smart Aggregate | 95.800 | 60.000 | 17.659 |
| UH-36 | Smart Aggregate | 95.400 | 60.000 | 47.359 |
| UH-34 | Smart Aggregate | 95.400 | 60.000 | 78.459 |
| UH-Cluster 8 | Cluster | 48.500 | 60.500 | 15.859 |
| UH-Cluster 7 | Cluster | 48.400 | 60.000 | 61.959 |
| UH-37 | Smart Aggregate | 24.450 | 60.000 | 17.959 |
| UH-35 | Smart Aggregate | 24.650 | 60.000 | 47.359 |
| FIU-E1-A9 | Electrode | 107.400 | 59.600 | 0.359 |
| FIU-T1-A9 | Therm. Cp | 102.800 | 59.600 | 0.659 |
| FIU-E2-A9 | Electrode | 98.100 | 59.500 | 0.359 |
| FIU-E3-A9 | Electrode | 88.200 | 59.500 | 0.359 |
| FIU-T2-A9 | Therm. Cp | 81.500 | 59.500 | 0.559 |
| FIU-E4-A9 | Electrode | 78.100 | 59.500 | 0.859 |
| FIU-E5-A9 | Electrode | 68.200 | 59.500 | 0.659 |
| FIU-T3-A9 | Therm. Cp | 63.500 | 59.400 | 0.659 |
| FIU-E6-A9 | Electrode | 58.800 | 59.900 | 0.759 |
| FIU-E7-A9 | Electrode | 48.800 | 59.800 | 0.759 |
| FIU-T4-A9 | Therm. Cp | 41.300 | 59.500 | 0.659 |
| FIU-E8-A9 | Electrode | 38.800 | 59.400 | 0.659 |
| FIU-E9-A9 | Electrode | 28.800 | 59.400 | 0.759 |
| FIU-T5-A9 | Therm. Cp | 21.500 | 59.400 | 0.859 |
| FIU-E10-A9 | Electrode | 18.100 | 59.500 | 0.609 |
| FIU-E1-A5 | Electrode | 60.500 | 59.600 | 1.959 |
| FIU-T1-A5 | Therm. Cp | 60.200 | 59.700 | 6.359 |
| FIU-E2-A5 | Electrode | 60.000 | 59.600 | 11.459 |
| FIU-E3-A5 | Electrode | 59.800 | 59.600 | 21.759 |
| FIU-T2-A5 | Therm. Cp | 60.000 | 59.500 | 26.659 |
| FIU-E4-A5 | Electrode | 59.900 | 59.900 | 31.159 |
| FIU-E5-A5 | Electrode | 59.800 | 59.400 | 41.159 |
| FIU-T3-A5 | Therm. Cp | 60.000 | 59.400 | 46.859 |
| FIU-E6-A5 | Electrode | 59.800 | 59.200 | 51.259 |
| FIU-E7-A5 | Electrode | 59.800 | 59.500 | 61.159 |
| FIU-T4-A5 | Therm. Cp | 60.000 | 59.300 | 66.359 |
| FIU-E8-A5 | Electrode | 59.700 | 59.400 | 71.459 |
| FIU-E9-A5 | Electrode | 60.000 | 59.400 | 81.459 |
| FIU-T5-A5 | Therm. Cp | 60.500 | 59.400 | 85.859 |
| FIU-E10-A5 | Electrode | 60.200 | 59.400 | 91.459 |
| Water Pipe | | 52.500 | 58.740 | 71.440 |

General Note(s):
1. Datum located at interior SE bottom corner
2. Panel front view shown



arc applied research center
FLORIDA INTERNATIONAL UNIVERSITY

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY | USED ON
APPLICATION
DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | EP | 11/1/12 |
| CHECKED | AA | 11/19/12 |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |
| COMMENTS: | | |

PANEL 5

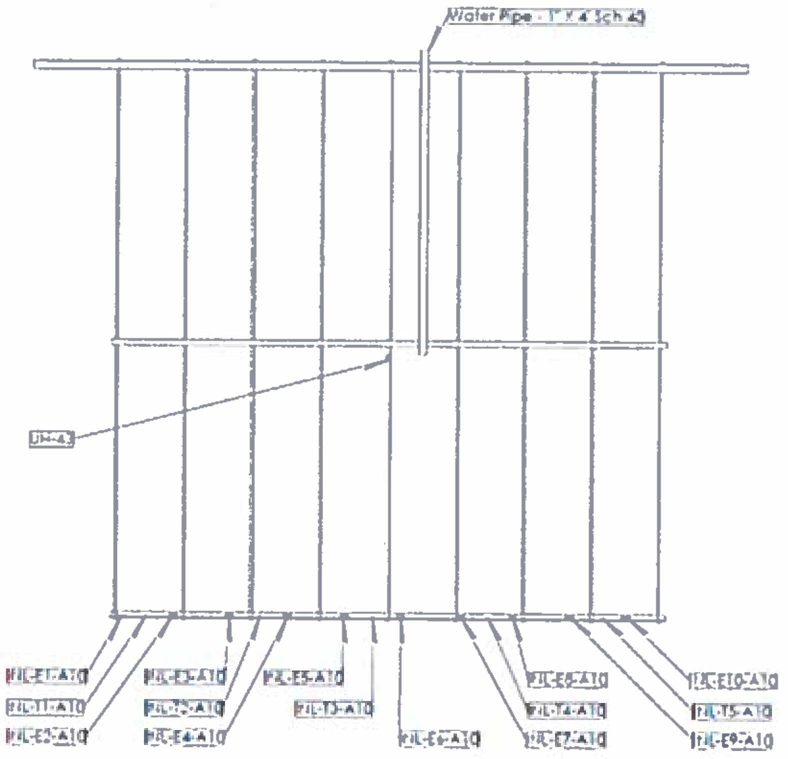
Florida International Universi

TITLE:

ISDSN-MSTB
Sensor Panels Layout
(As-Built)

SIZE B
DWG. NO. As-Built Sensor Locations
SCALE: NTS WEIGHT:
SHE

General Note(s):
1. Datum located at interior SE bottom corner
2. Panel front view shown



| Panel 6 | | | | |
|---|---|---|---|---|
| Sensor ID | Type | X (in.) | Y (in.) | Z (in.) |
| P6L-E1-A10 | Electrode | 15.100 | 71.600 | 0.759 |
| P6L-T1-A10 | Therm Cpl | 22.200 | 71.400 | 0.709 |
| P6L-E2-A10 | Electrode | 27.300 | 71.500 | 0.659 |
| P6L-E3-A10 | Electrode | 32.100 | 71.500 | 0.609 |
| P6L-T2-A10 | Therm Cpl | 37.100 | 71.500 | 0.609 |
| P6L-E4-A10 | Electrode | 42.400 | 71.500 | 0.759 |
| P6L-E5-A10 | Electrode | 52.400 | 71.900 | 0.709 |
| P6L-T3-A10 | Therm Cpl | 57.200 | 71.350 | 0.659 |
| P6L-E6-A10 | Electrode | 62.300 | 71.400 | 0.709 |
| P6L-E7-A10 | Electrode | 73.000 | 71.500 | 0.709 |
| P6L-T4-A10 | Therm Cpl | 77.300 | 71.500 | 0.659 |
| P6L-E8-A10 | Electrode | 82.150 | 71.400 | 1.009 |
| P6L-E9-A10 | Electrode | 92.100 | 71.500 | 0.859 |
| P6L-T5-A10 | Therm Cpl | 97.100 | 71.400 | 0.809 |
| P6L-E10-A10 | Electrode | 102.150 | 71.500 | 0.859 |
| UH-41 | Smart Aggregate | 60.000 | 71.300 | 46.759 |
| Water Pipe | | 78.000 | 69.750 | 47.234 |

arc applied research center

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

| | NAME | DATE |
|---|---|---|
| DRAWN | EA | [illegible] |
| CHECKED | AA | [illegible] |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |
| COMMENTS: | | |

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

Florida International Univers

TITLE:
ISDSN-MSTB
Sensor Panels Layout
(As- Built)

SIZE B
DWG. NO.
As-Built Sensor Locations

PANEL 6

SCALE: NTS WEIGHT:
SHE

# Appendix B. Weather and Groundwater Level Data for August 25 through September 7, 2013

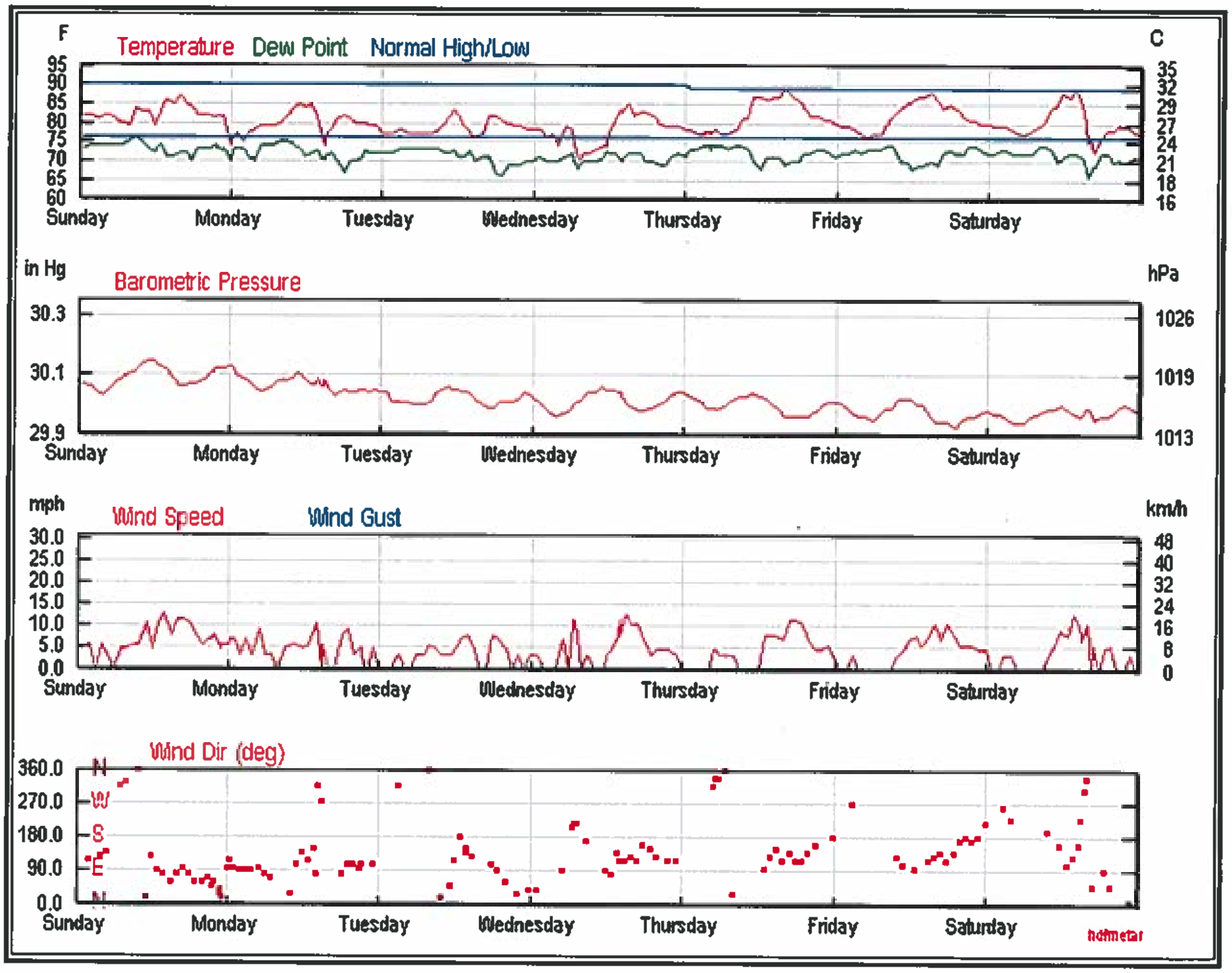


Figure B-1. - Weather Data for 8/25/13 - 9/1/13 (Wunderground.com)

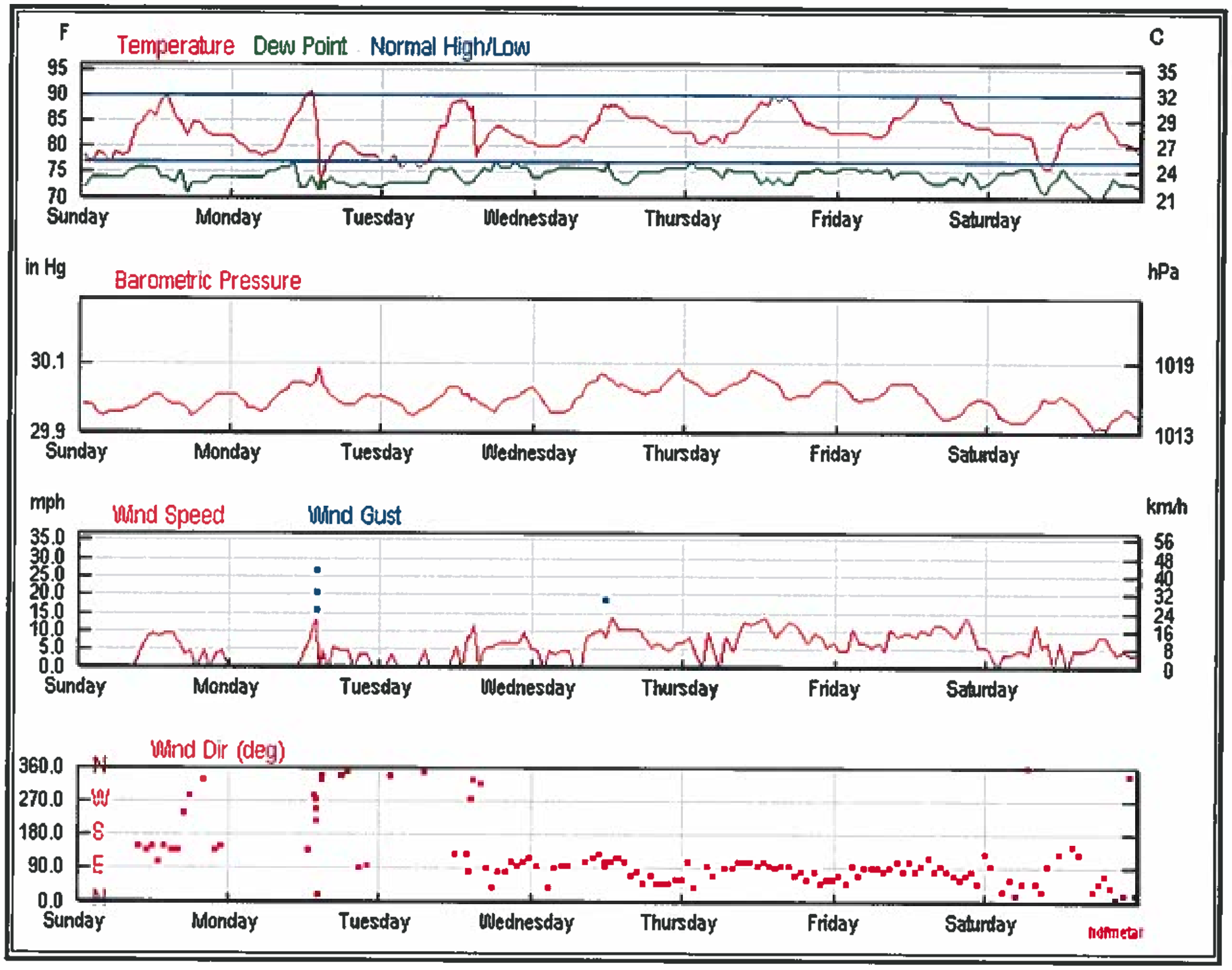


Figure B-2. - Weather Data for 9/1/13 - 9/7/13 (Wunderground.com)

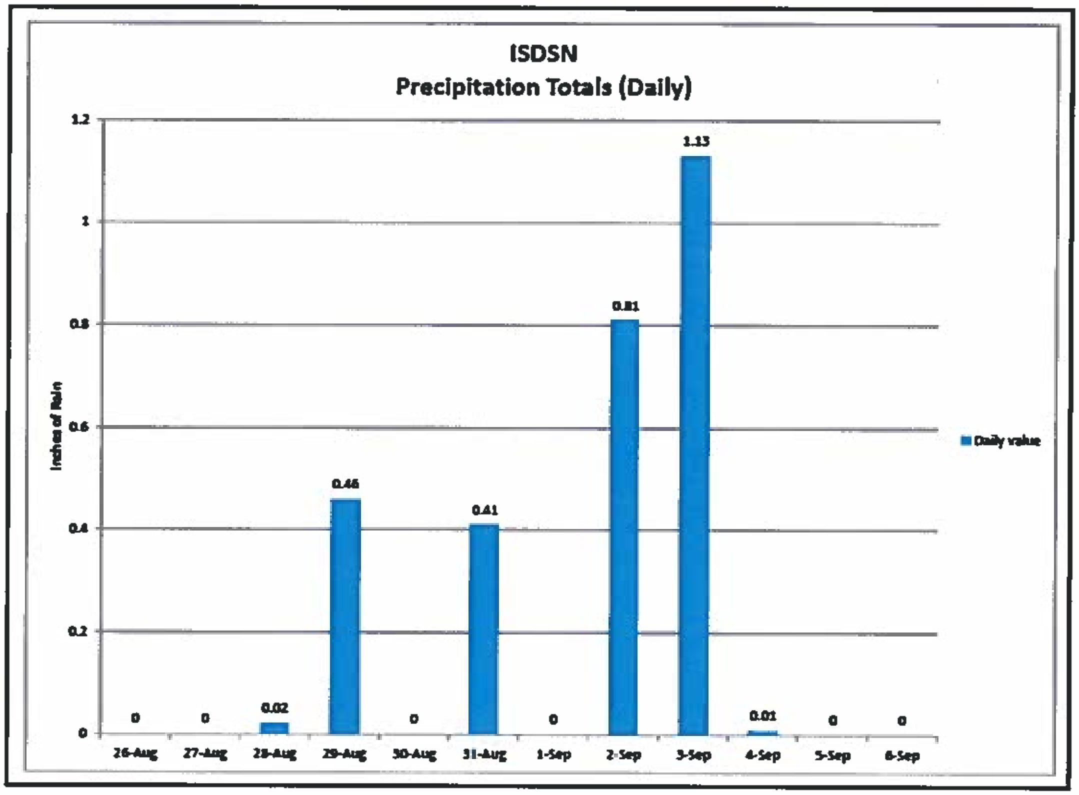


Figure B-3. Daily Precipitation during Fluid Injection Testing Period.

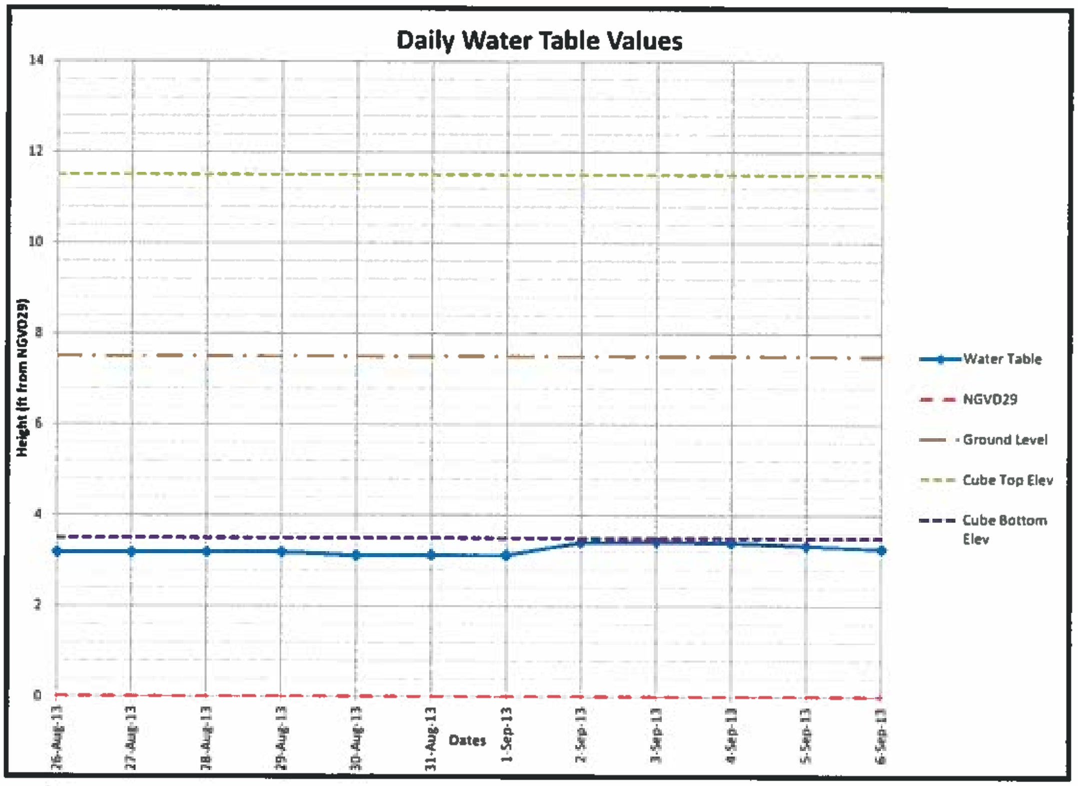


Figure B-5. - Groundwater Level in Reference to the ISDSN-MSTB Test Cube Location

## DISTRIBUTION:

### DOE EM 13

Andrew Szilagyi, EM 13
George Cava, EM 13

### Savannah River National Laboratory

R S. Aylward, 773-42A
T. O. Oliver, 773-42A
A. P. Fellinger, 773-42A
J.E. Hyatt, 773-A
J. J. Mayer, 773-42A
K. L. Dixon, 773-42A
M.G. Serrato, 773-42A
Records Administration (EDWS)

### Idaho National Laboratory

Clark Scott, INL
Trent Armstrong, INL
Gretchen Matthern, INL

### Florida International University

Leonel Lagos, FIU
Amer Awward, FIU
Himanshu Upadhyay, FIU
Clint Miller, FIU
Jose Rivera, FIU
Jario Crespo, FIU

### Mississippi State University

Chuji Wang, MSU
Maheshwar Ghimire, MSU