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May 2001

Engineered Barrier System — Pilot Scale Test #3 Heated Drip Shield Test Results

By
C.L. Howard, R.L. Finley, R.L. Johnston, R.S. Taylor, J.T. George, W.E. Lowry, and N.G. Mason

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DISCLAIMER

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May 2001

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EXECUTIVE SUMMARY

The Yucca Mountain Project (YMP) is currently developing the Site Recommendation (SR) design for the underground facilities. A subset of this SR design is the emplacement drifts and the engineered barrier system (EBS) components within them. The SR design also includes an evaluation of alternative configurations of key subsystems to determine which configurations will enhance the repository performance by retarding radiological releases. One such subsystem includes engineered barriers placed within the emplacement drifts.

The experimental work described here details EBS Pilot Scale Test #3 (a ¼-scale experiment) to directly evaluate the performance of EBS alternative designs. The EBS Pilot Scale tests are conducted at the Atlas Facility in North Las Vegas, Nevada. The first two Pilot Scale tests were a capillary barrier configuration of a fine granular material overlying a coarse granular material and a standard coarse granular backfill. This report presents the results of EBS Pilot Scale Test #3, which was a heated experiment intended to evaluate at quarter scale the environment within a simulated EBS that includes a drip shield. Data and observations from the test start date of September 2, 1999 through the end date of November 18, 1999 are presented and discussed.

The information presented in this report has been included in an accompanying CD-ROM. A description of the CD-ROM is given in Appendix A.

This report was prepared under guidance from development plan TDP-EBS-GE-000005 (CRWMS M&O 1999b) and procedure AP-3.11Q.

Data presented in this report have been submitted to the YMP Technical Data Management System (TDMS) under the following Data Tracking Numbers (DTNs): SN0003L1011398.003 and GS000883351030.010.

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ACRONYMS

AMR	Analysis Model Report
CRWMS	Civilian Radioactive Waste Management System
DAS	Data Acquisition System
DTN	Data Tracking Number
EBS	Engineered Barrier System
HDP	heat dissipation probe
HBM	Hottinger Baldwin Measurements
LA	License Application
LANL-TCO	Los Alamos National Laboratory Test Coordination Office
M&O	Management & Operating Contractor
PC	personal computer
PVC	polyvinyl chloride
QA	Quality Assurance
RTD	Resistance Temperature Device
SNL	Sandia National Laboratories
SR	Site Recommendation
TCP	thermocouple psychrometer
TDMS	Technical Data Management System
TDR	time domain reflectometer
TWM	Tank Weigh Module
USGS	United States Geological Survey
YMP	Yucca Mountain Project

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1. INTRODUCTION

1.1 BACKGROUND

This document presents data and results of temperature, humidity, test cell weight, injected water weight, effluent weight, and visual observations for the Engineered Barrier System (EBS) Pilot Scale Test #3 (a ¼-scale test with drip shield) conducted at the Department of Energy Atlas Facility in North Las Vegas, Nevada. Data and observations from the test start date of September 2, 1999 through the test end date of November 18, 1999 are presented and discussed. These data have been submitted to the Yucca Mountain Project (YMP) Technical Data Management System (TDMS) under Data Tracking Numbers (DTNs): SN0003L1011398.003 and GS000883351030.010. This document also presents as-built information regarding configurations and gage locations for the test. The data presented and discussed were collected with an automated data acquisition system for electronic sensors and with manual measurements.

The data from this test are used to substantiate the validity of models relating to heat and moisture transport under expected repository conditions and support the EBS post-closure performance assessment. These data specifically support validation of the Analysis/Model Report entitled *In-Drift Thermal-Hydrological-Chemical Model* (CRWMS M&O 2000a). The data also support the higher-level EBS Process Model Report entitled *Engineered Barrier System Degradation, Flow, and Transport Process model Report* (CRWMS M&O 2000b).

The data presented here were collected under a qualified Quality Assurance (QA) program and bear the designation QA: QA (CRWMS M&O 1999a). The data from both the data acquisition system and from manual measurements are presented in graphical format in this document and are given in tabular format in data files on the CD accompanying this document. This document was prepared in accordance with procedure AP-3.11Q and using the Development Plan (CRWMS M&O 1999b) and the CRWMS Publishing Style Guide, Rev. 4.1 (CRWMS M&O 1999c).

Much of the acquired data involved the use of scales to record weight (more specifically, force). For this report, weight data are expressed in SI units of kilograms (kg) and US Customary units of pounds (lb). For presentation, weight measurements recorded originally in pounds, were converted to kilograms using a multiplier of 0.453592.

1.2 EBS DESCRIPTION

The YMP is currently developing the Site Recommendation (SR) design for the underground facilities. Subsets of the SR design are the emplacement drifts and the EBS components within them. The SR design also includes alternative configurations for key subsystems that will demonstrate the ability of the SR design to accommodate various conditions that could come to exist in the proposed repository. The Pilot Scale experiment described here is intended to develop an engineering assessment of the viability of key engineered barrier components for use at Yucca Mountain.

Two previous tests have been conducted to evaluate these components. The first was a capillary barrier configuration of a fine granular material overlying a coarse granular material, and the second was a standard coarse granular backfill. These two tests were described in a previous report (CRWMS M&O 2000c). The third EBS Pilot Scale test configuration consists of a granular invert material, a steel simulated waste package, and a stainless steel drip shield.

2. EBS PILOT SCALE TEST #3 CONFIGURATION—PLANNED

This section provides a descriptive definition of EBS Pilot Scale Test #3. This definition includes the test objectives, test configuration, and test conduct. The test configuration is presented in overview format with verbal descriptions and layout sketches. More detailed as-built configurations of test layout and gage and equipment coordinates are given in Section 3.

The basic configuration consists of a nominally 1.4-m (4.6-ft) diameter and 4-m (13-ft) long mild steel (ASTM A 709/A 709M-97b) hollow cylinder (Howard 2000, Vol. 1, Section 4.3). This configuration allows an approximately quarter-scale test setup with the steel cylinder (expressed as test cell or canister throughout this report) representing the emplacement drift walls. A simulated waste package and drip shield are placed within the simulated drift at the nominally appropriate design locations. EBS Pilot Scale Test #3 includes the test cell (which simulated a repository emplacement drift), simulated waste package (heater) and drip shield, granular invert materials, guard heaters on the outside of the test cell, drip system for application of water, temperature control system, hydraulic boundary control equipment, temperature sensors, water potential and content sensors, load cells, platform scales, humidity sensors, chemical sampling, waste package material coupons, and data acquisition system. These elements are discussed in further detail in Section 2.3 below.

2.1 TEST OBJECTIVE AND SCOPE

The overall objective of EBS Test #3 (CRWMS M&O 1999b) was to evaluate the environmental conditions (temperature, relative humidity) surrounding the simulated waste package with and without the drip shield in place, with and without dripping water, and under heated conditions. Other objectives were (1) to assess a feasible and practical construction process for the proposed design and (2) to evaluate moisture potential in the invert. A fundamental uncertainty addressed by this experiment was how much, if any, condensation would occur under the drip shield. The target temperatures of 80°C (176°F) on the simulated waste package and 60°C (140°F) on the test cell surface (simulated drift surface) were selected to represent achievable thermal conditions with readily available equipment and configurations. Temperatures were measured on the simulated waste package surface, on the drip shield (when installed), within the granular invert material, and on the inner surface of the test cell. Water content and potential were measured at several locations within the granular invert material. Humidity was measured both between the simulated waste package and the drip shield, and exterior to the drip shield.

2.2 QUALITY ASSURANCE

This test was conducted consistent with Development Plan TDP-EBS-GE-000005 (CRWMS M&O 1999b). The details of the test are documented in Scientific Notebook SN-SNL-SCI-013-V1, V2, and V3, entitled *EBS Testing Program – Pilot-Scale Testing: ¼ Scale Engineering Demonstration Testing Canister #3*. The scientific notebook was prepared in accordance with AP-SIII.1Q, *Scientific Notebooks*. It contains all the records for gage calibrations and gage coefficient derivation. Electronic data collection activities are documented in Scientific Notebooks SN-LANL-SCI-164-V1 (BSC 2001) and SN-LANL-SCI-210-V1 (BSC 2001),

entitled *Engineered Barrier System (EBS) Data Collection System (DCS) #1* and *Engineered Barrier System (EBS) Data Collection System (DCS) #2,* respectively. These notebooks address quality assurance requirements for software configuration management. The software used to control electronic data collection was commercially available and designed to support such data collection activities (BSC 2001). An evaluation was performed in accordance with AP-SV.1Q that prompted the control of electronic data. Electronic data used in this report were controlled according to instructions specified in the Scientific Notebook (Howard 2000, Vol. 3, Section 8.1). Data from this test have been submitted to the TDMS under DTNs SN0003L1011398.003 and GS000883351030.010. All the data charts have been derived from these data sets. The data in this report were prepared consistent with the guidance of Development Plan TDP-EBS-ND-000001 (CRWMS M&O 1999d) and procedure AP-3.11Q.

2.3 EBS PILOT SCALE TEST CONFIGURATION

The EBS Test #3 (heated drip shield) test was conducted at a scale approximately one quarter of the emplacement drift to evaluate performance of the drip shield at a scale larger than can be conducted in the laboratory. The baseline repository design and scaled dimensions are depicted in Figure 1 (CRWMS M&O 2000d). The test cell length and diameter are scaled proportionally at ¼ scale, and the slope of the test cell was approximately the same slope as the anticipated slope of the emplacement drifts (0.25 to 0.75%) (CRWMS M&O 1997). The drip shield thickness was the one test component that was not scaled by ¼, but left at a dimension nearly equal to that specified for the repository design. The thickness of the drip shield in this test was 19.1 mm (0.75 in.) and the thickness in the repository design is 20 mm (0.79 in.). Scaling the thickness by a factor of ¼ would result in the temperature gradient across the shield increasing by a factor of four because the temperatures of the simulated waste package and the test cell wall were set to create conditions consistent with those predicted for the repository. This configuration resulted in a nominal test cell (cylinder) diameter of 1.4 m (4.6 ft) and a length of 4 m (13 ft). Specific details of the as-built configuration for EBS Test #3 are given in Section 3.

2.3.1 Test Premise Overview

The pilot scale EBS Test #3 engineering demonstration tests included three distinct parts, with and without the drip shield present. Each part is described in detail in Section 2.4. Granular invert materials are discussed in Section 2.3.3.

The infiltration condition for the EBS Pilot Scale Test #3 engineering demonstration test was a sub-superpluvial rate equivalent to about 250 ml/hr/m (2.58 oz/hr/ft) length of test cell. The infiltration was controlled by injecting city tap water through holes along the top of the test. It is expected that the most critical infiltration condition at Yucca Mountain arises from concentrated flow into the emplacement drifts from discrete fractures. Consequently, the infiltration condition evaluated was approximately one-third as high as an artificially high, concentrated infiltration calculated from an equivalent 300 mm/yr (11.8 in/yr) infiltration flux (superpluvial rate) acting over each emplacement drift and adjacent pillars. The superpluvial rate was developed in the following manner. A rate equaling 300 mm per year for a drift spacing of 28 m (CRWMS M&O 1997, Section 4.1.6, p 11) is directed to the emplacement drift. The infiltration rate for the test is

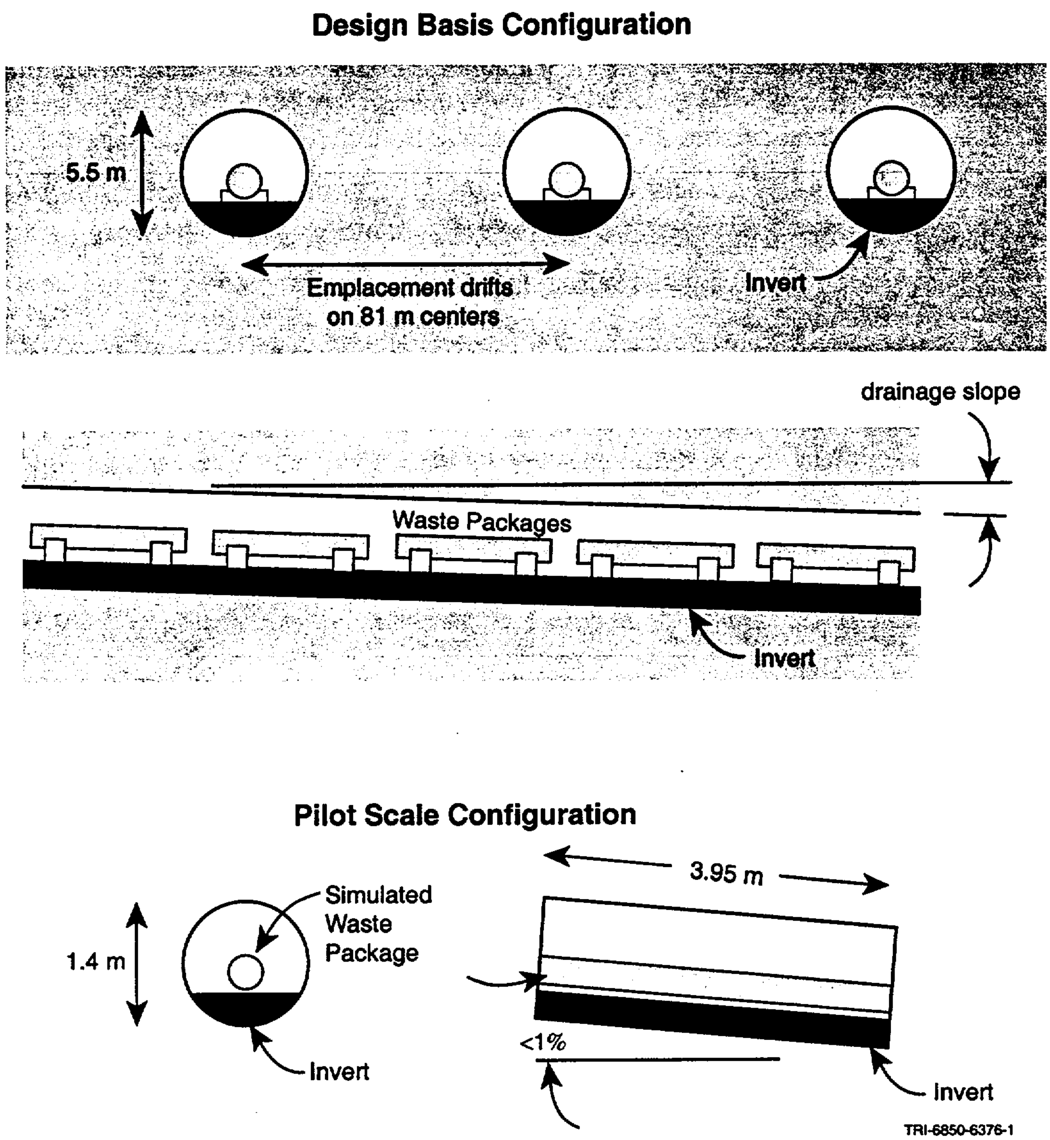

Figure 1. Design Basis and Scaled Configurations (Emplacement Drift Diameter 5.5 m [18.0 ft], Waste Package Diameter 2.0 m [6.6 ft]) (CRWMS M&O 2000d)

conservatively calculated by taking the mean annual precipitation rate of 300 mm per year (CRWMS M&O 1998), dividing by the drift diameter of 5.5 m (CRWMS M&O 2000e), and then scaling by a factor of four for the test. The infiltration rate, expressed in per meter of canister, is estimated to be 239 ml/hr/m, which was rounded up to 250 ml/hr/m (2.58 oz/hr/ft).

2.3.2 Test Cell Configuration

The final test configuration included the test cell, drip shield, simulated waste package, supports, granular invert materials, instrumentation, heaters, and insulation. Figure 2 shows a generalized cross-sectional layout for EBS Test #3 with some key dimensions. Figure 3 shows a detail of the test from the side view with the "front" of the test cell to the left. Figure 3 also shows the

general locations of the instrumentation cross-section locations at 1 m, 2 m, and 3 m from the front face and a longitudinal view of the waste package support "V" trough. The simulated waste package was fabricated from 0.48 cm (3/16 in.) carbon steel (ASTM A 36/A 36M-96).

The waste package support "V" trough, and "V" trough supports were slightly thicker (0.64 cm [1/4 in.] thick) and made from the same carbon steel.

The drip shield (when installed) was located on guide rails and installed in three segments with overlapping flanges. The drip shield was constructed of 304 stainless steel (ASTM A 240/A 240M-95a). Figures 4 through 7 show details of the drip shield segments and drip shield overlaps.

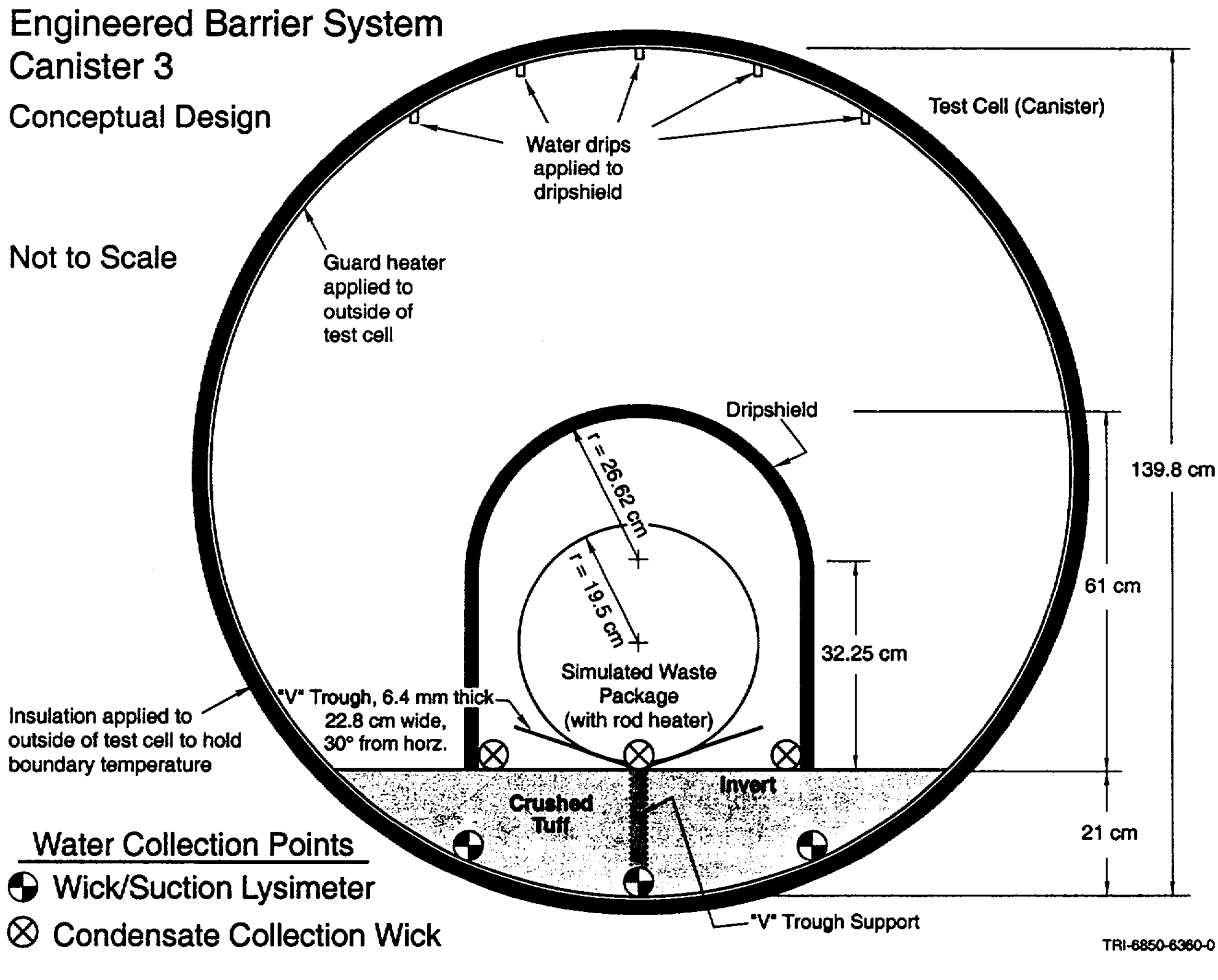

Figure 2. Generalized Cross-Sectional Layout for EBS Test #3 Showing Simulated Waste Package, Drip Shield, Supports, Granular Invert Material (Backfill), and Test Cell (Howard 2000, Vol. 1, Section 5.1.1)

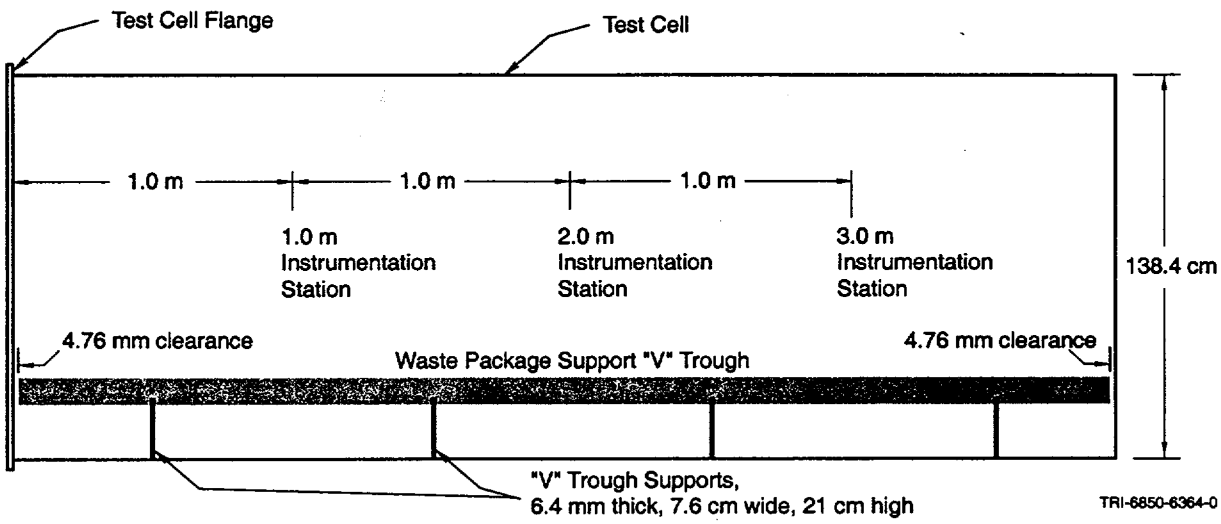

Figure 3. Side View of EBS Test #3 with "Front" of Canister to the Left (Howard 2000, Vol. 1, Section 5.1.1)

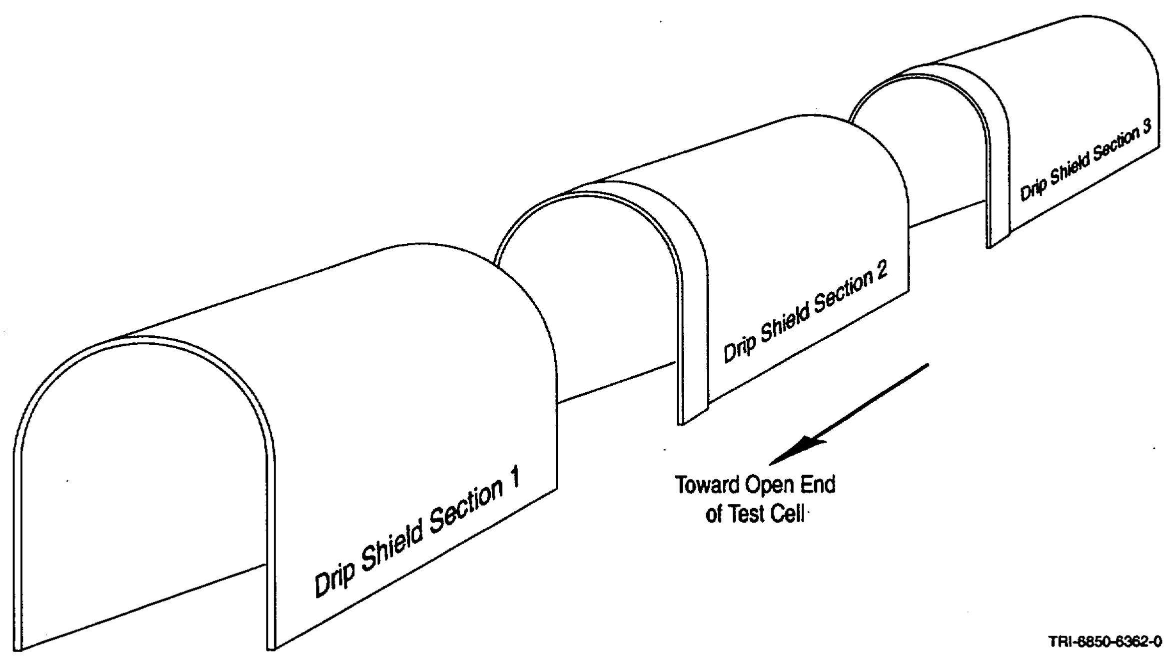

Figure 4. Schematic of EBS Test #3 Drip Shield Configuration (Perspective View)

The primary controls for the test included the sealed test cell geometry, water injection rate and location, thermal control of the waste package and test cell, and control of the moisture potential boundary condition where the crushed welded tuff invert contacted the test container. Injection of water was accomplished by discrete injection points located on the top of the container, as discussed in Section 2.3.4 below (and shown in Figure 2). The test configuration is described below. The instrumentation layout is discussed in Section 3 of this report.

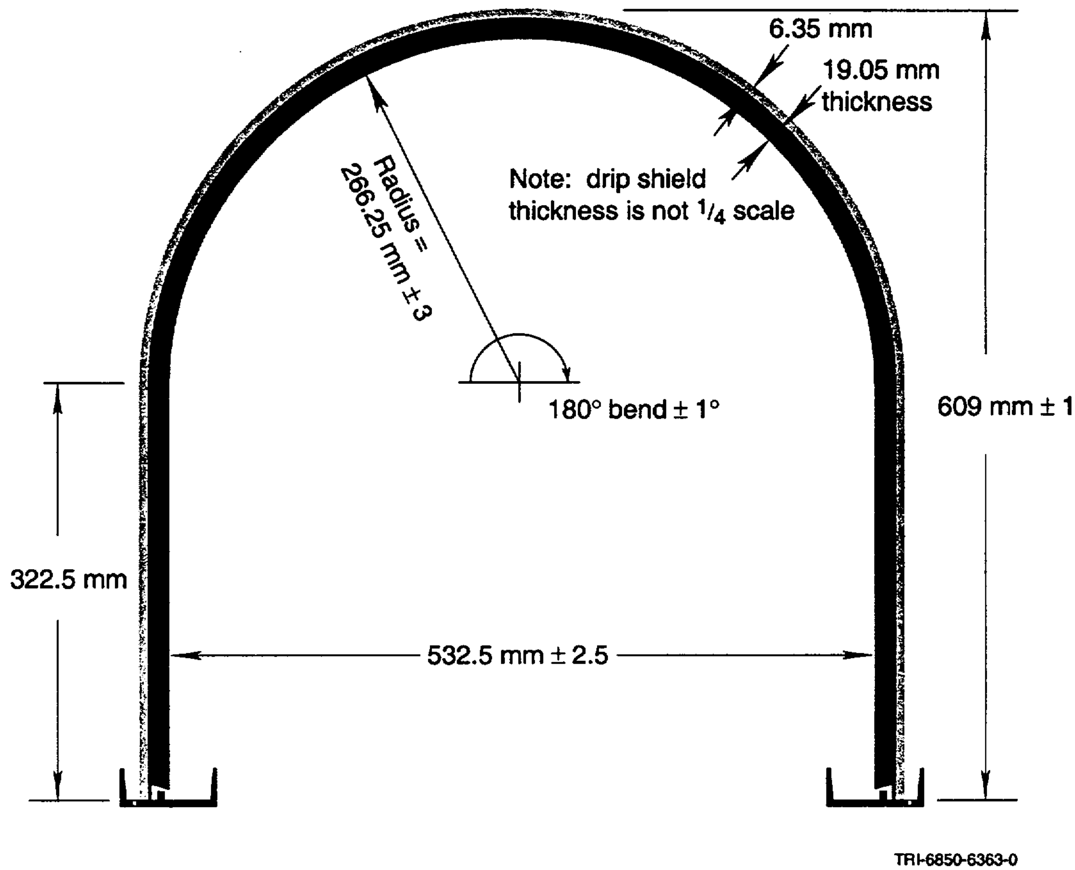

Figure 5. End View Details of EBS Test #3 Drip Shield Segments (Howard 2000, Vol. 1, Section 5.1.3)

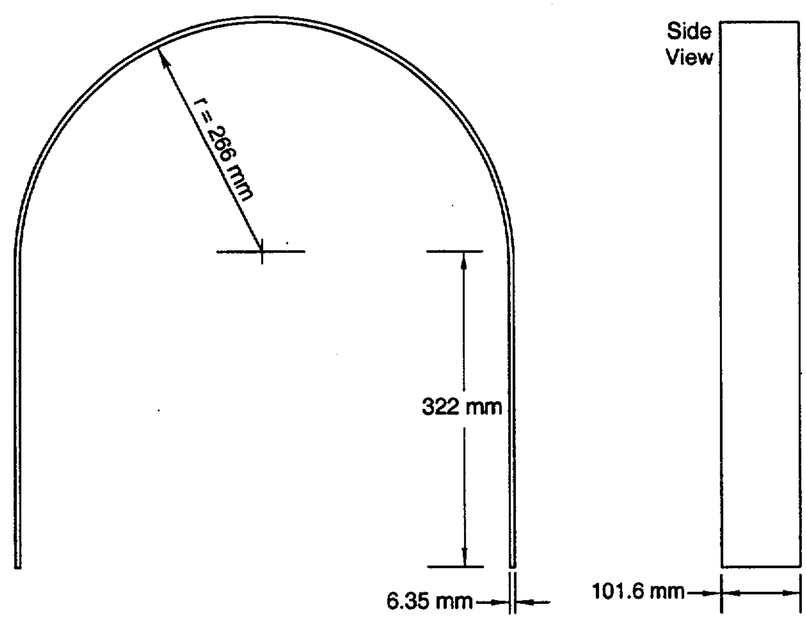

Figure 6. EBS Test #3 Drip Shield Overlap Segment Details (Howard 2000, Vol. 1, Section 5.1.3)

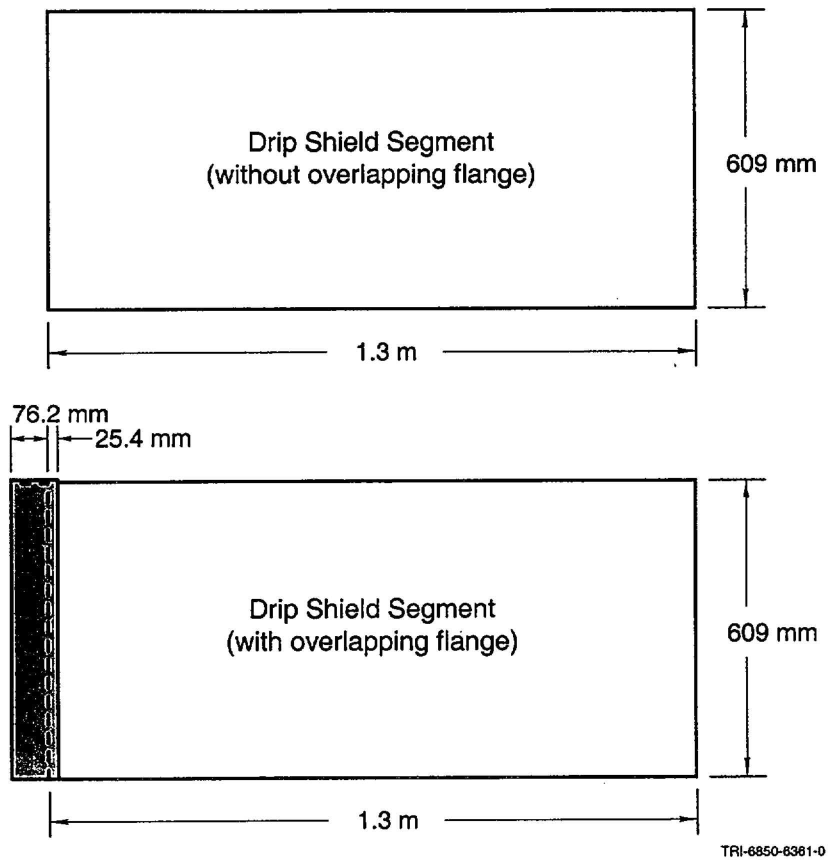

Figure 7. Side View Details of EBS Test #3 Drip Shield Segments (Howard 2000, Vol. 1, Section 5.1.3)

The injection of liquid water from the test system was likewise controlled and monitored. Inflow from the natural system is expected to occur largely through unsaturated fractures intersecting the roof. Saturated fracture flow from ponded water in the bottom of the drift could also occur. The flow mode in the floor is simulated in the pilot scale test by wicking drains installed along the base of the test cell apparatus and suction lysimeters within the crushed tuff backfill, which drained through holes at the lower end of the test cell.

2.3.3 Materials Description

This section defines the construction and backfill materials used for EBS Test #3 (CRWMS M&O 1999b), as well as the test container(s) and drip shield.

- *Test Cell*: steel (ASTM A 709/A 709M-97b), nominally 0.64 cm (1/4 in.) thick, 1.4 m (4.6 ft) in diameter, and 3.9 m (12.9 ft) long.
- *Granular Invert Material*: coarse crushed welded tuff seived (between 2.0 and 4.75 mm) from YMP tunnel rock. The properties of the invert are discussed in the Water Diversion AMR (CRWMS M&O 2000f); the data are archived under DTN: GS980808312242.015.

- *Water*: Standard city water containing blue dye was used for the infiltration testing.

- *Drip Shield*: 304 stainless steel (ASTM A 240/A 240M-95a), minimally 1.9 cm (0.75 in.), 609 mm (24 in.) high, with radius of curvature of 266.25 mm (10.5 in.) and length of each segment of 1.3 m (4.3 ft).

- *Simulated Waste Packages*: mild carbon steel (ASTM A 36/A 36M-96), 0.48 cm (3/16 in.) thick, with outside diameter of 39.1 cm (15.4 in.), and a length of 3.88 m (12.73 ft).

- *"V" trough*: mild carbon steel (ASTM A 36/A 36M-96), 0.64 cm (1/4 in.) thick, with 7.6 cm (15.4 in.) wide sides, and a length of 3.88 m (12.73 ft).

2.3.4 Drip System Control

Thirty injection holes were arranged along the top centerline of the test cell. The holes were located in rows of two or three holes oriented perpendicular to the long axis of the test cell. The holes were spaced to distribute the injection water droplets across the drip shield surface. The exact location of the drip holes is given in Section 3.1.1 and Appendix C of this report.

The EBS Pilot Scale test injection system was developed to provide controllable, uniformly distributed liquid injection to multiple points in the test cell. The basic components of the system were the distributed injection points, the injection syringe pumps, injection water tanks, and the injection water weighing system (see Figures 8 and 12). Figure 9 illustrates a detailed view of a single injection point.

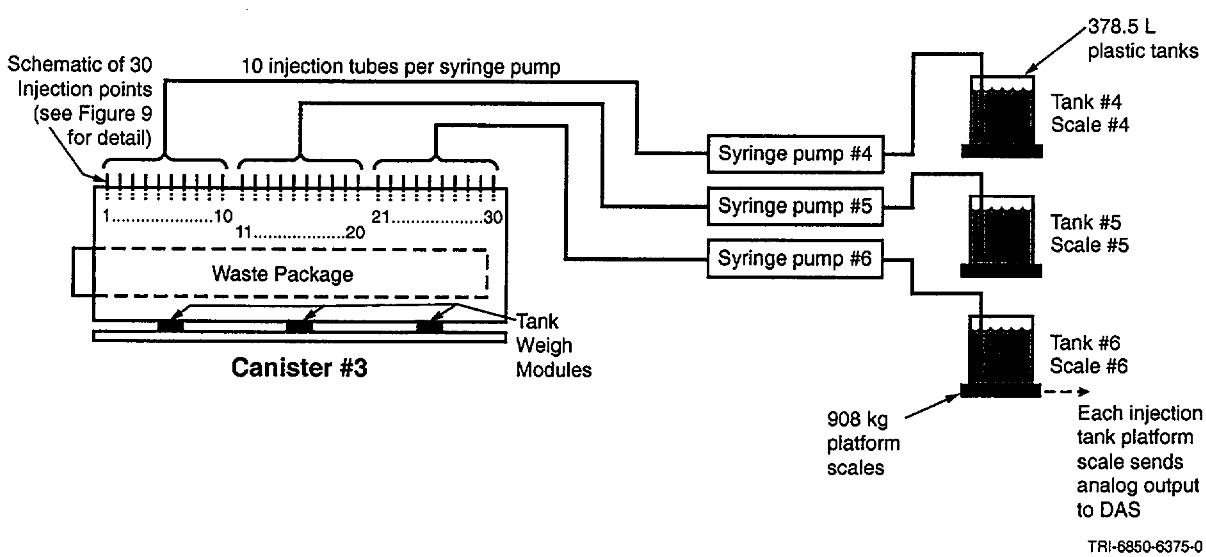

Figure 8. Injection System Layout for EBS Test #3 (Howard 2000, Vol. 1, Section 5.1.4)

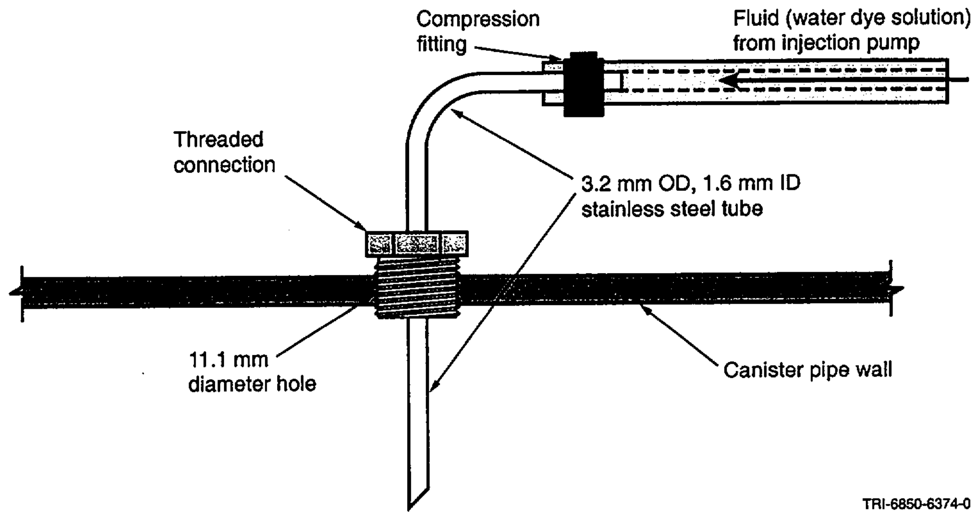

Figure 9. Close-up View of Injection Point (Howard 2000, Vol. 1, Section 5.1.4)

Multiple lines of injection points across the top of the test cell were created. This configuration simulated dripping fractures, collecting the infiltration from mid-pillar to mid-pillar and concentrating it near the centerline of the test cell. Water containing blue dye was injected into the test cell through 30 injection points spaced along the top of the test cell. Twelve rows of three and two holes, respectively, were drilled into the top of the test cell. Multichannel syringe pumps provided pulsed injections of constant volume. Each pump supported ten syringes (10 ml [0.3 oz] syringe capacity), with each pump stroke transmitting a nominal volume of 5 ml (0.15 oz) to each injection point in approximately five seconds. For the target injection rate of 250 ml/hr/m (2.50 oz/hr/ft) of test cell length (1 L/hr [0.26 gal/hr] over the total 4 m [13 ft] test cell length), the syringe pumps operated on approximately nine-minute intervals, controlled with a timer internal to the syringe pump. Vinyl tubing (3.2 mm ID by 6.4 mm OD [0.125 in. ID by 0.25 in. OD]) transmitted the fluid with dye from the syringe pumps to the test cell.

Each injection pump drew water/dye solution from a 378.5 L (100 gallon) plastic tank placed on a platform scale. Each scale was a high-precision 908 kg (2000 lb) floating beam unit (see Appendix B) with digital display and analog output to the EBS data system. Differences in recorded weights from scales were used to govern flow to each syringe pump. From the syringe pumps, flow through the ten injection tubes was assumed to be uniformly distributed.

2.3.5 Temperature Control

EBS Test #3 was a heated test in which the simulated waste package and the outer test cell surface temperatures were controlled. The temperature for the outer surface of the simulated waste package was set at 80°C (176°F). Likewise, the temperature for the surface of the outer test cell was set at 60°C (140°F). This nominal temperature gradient was maintained by regulating heater power throughout the heated portions of the test during both dry and wet phases of the test. As described previously, temperatures were measured during the test by resistance temperature devices situated at various locations throughout the test setup. Temperature

fluctuations from the ambient air were minimized by applying layers of fiberglass insulation to the outside of the test cell. Insulation thickness and application details are discussed in sections 2.4.1 and 2.4.3.

The simulated waste package was heated using a 4-m (13-ft) long 5kW rod heater manufactured by Watlow. The rod heater was centered within the simulated waste package. The surface of the test cell was heated using high-temperature outer-film blanket heaters with a capacity of nominally 6.6 W/lineal meter (20 W/lineal foot, or about 18 W/ft^2). The total power capacity on the outer test cell surface was nominally 4800 W. The film heaters were attached to the outer surface of the test cell. The fiberglass insulation was then applied over the film heaters after the test setup was completed.

The outer film blanket heater configuration is shown in a side view in Figure 10. This view shows the blanket film heaters with the front of the test cell at the top. The film heaters were attached to the outside circumference of the test cell. Fourteen of these heaters were installed along the test cell length and electrically connected in parallel. As shown in the figure, the heated section is nominally 25.4 cm (10 in.) wide for each heater. Figure 11 shows the film blanket heater application at the ends of the test cell. Because of the rectangular configuration of the film blanket heaters, the coverage on the ends of the test cell was not complete. In addition, "windows" for observing behavior in the interior of the test cell were installed at each end of the test cell.

Thermal control to maintain the 80°C (176°F) and 60°C (140°F) boundaries (simulated waste package and outer test cell) was provided using two Watlow series #96 auto-tuning controllers. These controllers use set-point temperature measurements (Type K thermocouples) on the simulated waste package and the outer test cell surface to adjust power to each of the rod and film heaters. An additional "high-limit" controller was used to limit the maximum temperature on the simulated waste package to 85°C (185°F) and/or the outer test cell surface to 65°C (149°F).

2.3.6 Hydraulic Boundary Control

The outer boundary of the EBS Test #3 test cell represented the wall of the emplacement drifts. Because water was added to the test setup, a method to remove water was developed. Suction wicks of braided fiberglass were installed in the invert (shown as Wick/Suction Lysimeters in Figure 2) and at the base of the drip shield (shown as Condensate Collection Wicks in Figure 2).

The wick/suction lysimeters were placed as three lines parallel to the long axis of the test cell at the lower test cell boundary underneath the granular invert materials. Hydraulic conductivities and other performance characteristics of such wicks are discussed in Knutson and Selker (1994, pp. 721-729). Three lines of braided fiberglass were wrapped around three suction lysimeters. These lysimeters applied a suction to remove water from the system. The collected water was weighed using a platform scale. Tensiometers were placed at various points within the invert material (see Figure 2) to record the range of negative pressures.

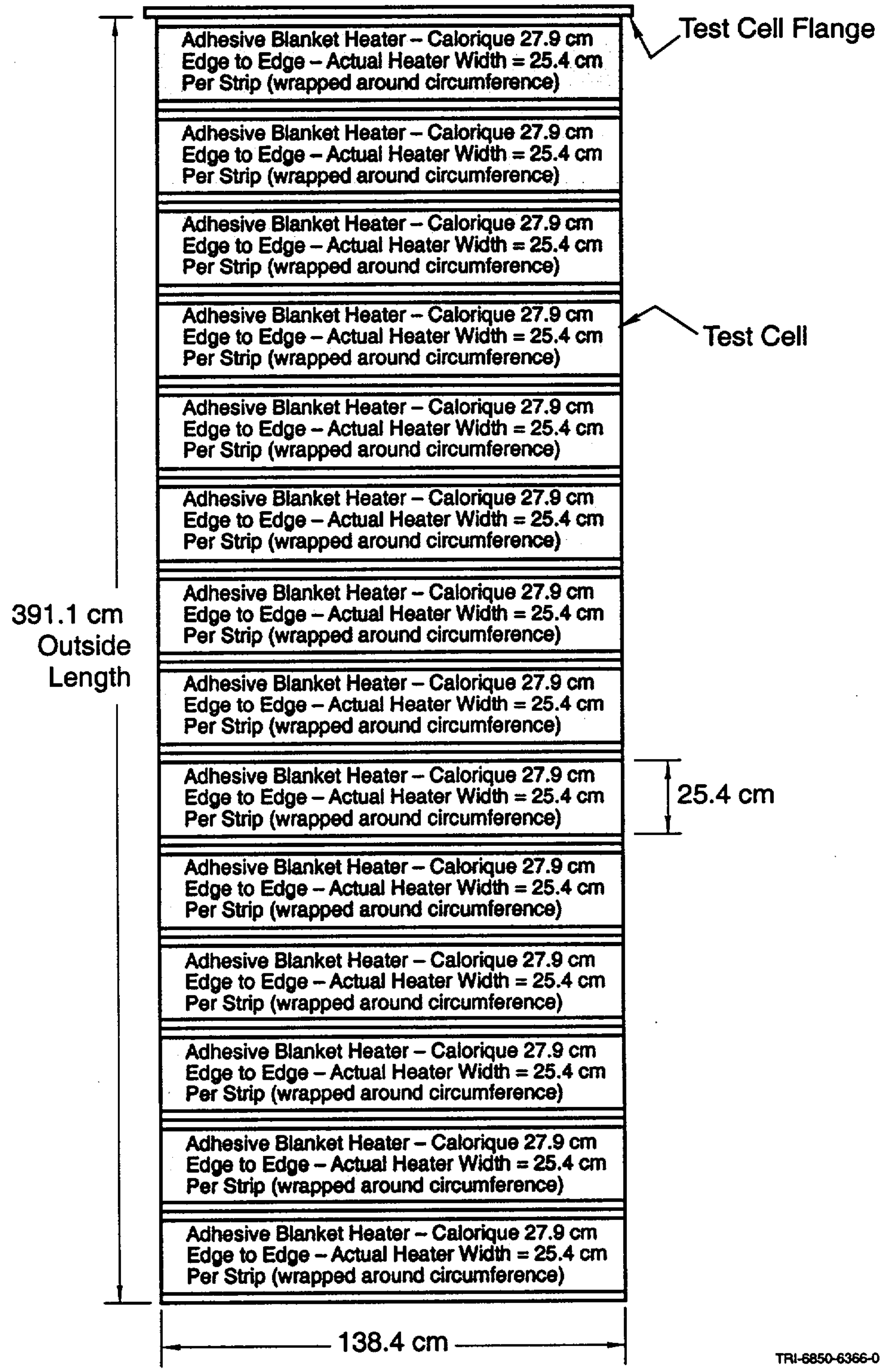

Figure 10. Blanket Film Heater Application (Plan View) on Test Cell (Howard 2000, Vol. 1, Section 5.1.1)

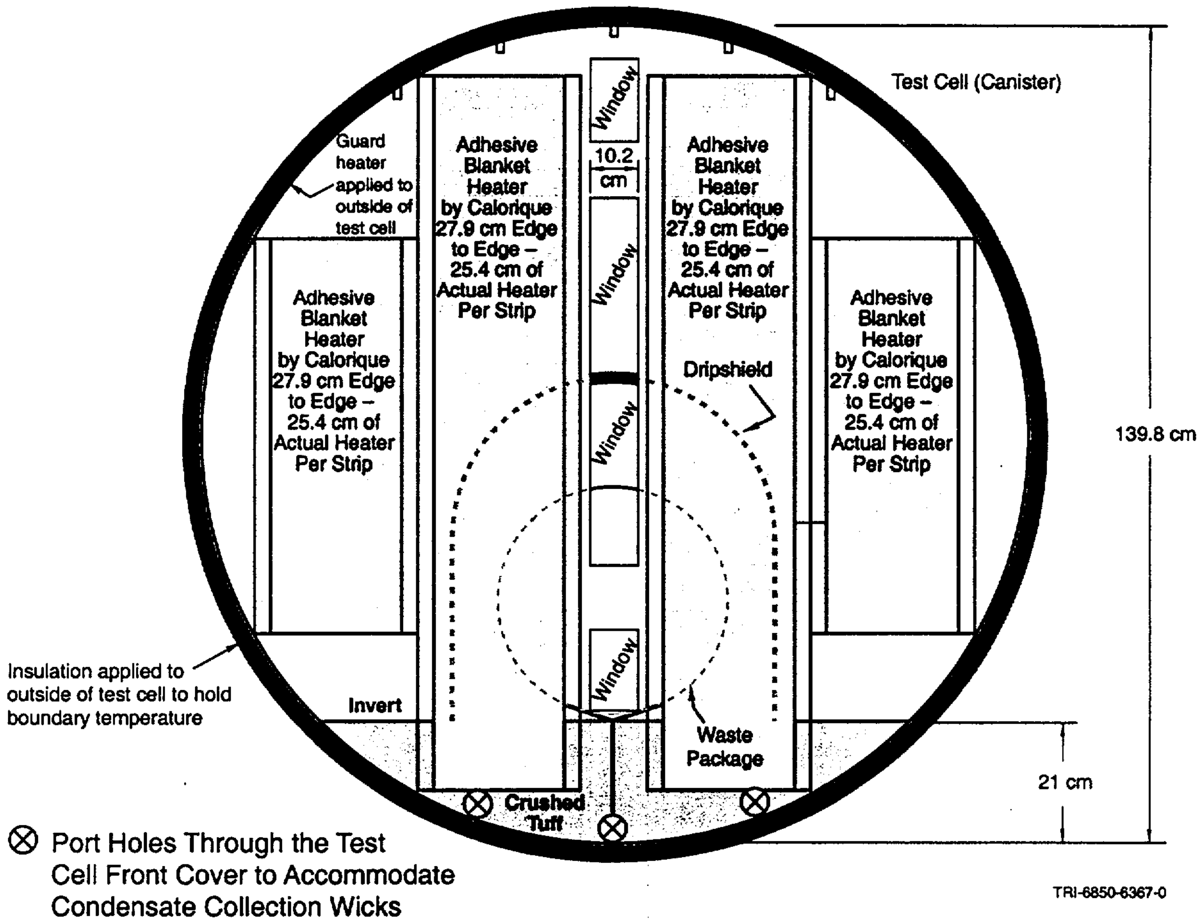

Figure 11. Blanket Film Heater and Window Application on Each End of the Test Cell (Howard 2000, Vol. 1, Section 5.1.1)

The condensate collection wicks were placed so that two lines collected moisture from inside the drip shield walls while a third line collected moisture from the simulated waste package support trough. These wicks exited the test cell through holes in front test cell cover and then drained by gravity into containers. Any collected water was weighed using a platform scale.

2.3.7 Instrumentation Layouts and Description

The instrumentation for EBS Pilot Scale Test #3 is positioned at three cross-sections in the test cell: 1 m, 2 m, and 3 m from the front face (see Figure 3). Additional instruments and equipment were installed at other locations within the test, including suction lysimeters, braided fiberglass wicks, water injection holes on top of the test cell, heaters installed within the simulated waste package and on the outer test cell surface, and temperature measurement devices on the outer test cell surface. Specific locations for these gages are provided in Section 3 and Appendix C of this report and in the Scientific Notebook covering this work (Howard 2000). Instruments were calibrated prior to installation and recalibrated after the test was complete. For EBS Test #3 the following instrumentation was installed:

- Eighty-seven RTDs were installed on the test cell, simulated waste package, within the insulation, and on the drip shield segments.

- Three Vaisala temperature/humidity probes were installed inside the test cell to measure temperature and humidity changes in the test cell.

- One Vaisala temperature/humidity probe was placed in the ambient air outside the test cell to measure the ambient temperature and humidity outside the test cell.

- Eighteen thermocouple psychrometers (TCPs) were installed between the simulated waste package and the drip shield, and between the drip shield and the test cell wall to measure relative humidity during the test. These gages were located at each of the three cross-sections at 1 m, 2 m, and 3 m from the front face of the test cell.

- Thirteen heat dissipation probes (HDPs) were placed within the granular invert material at the bottom of the test cell and in the test cell atmosphere to measure water potential. These gages were located at each of the three cross-sections at 1 m, 2 m, and 3 m from the front face of the test cell.

- Eight time domain reflectometers (TDRs) were placed within the granular invert material at the bottom of the test cell to measure water content. These gages were located at each of the three cross-sections at 1 m, 2 m, and 3 m from the front face of the test cell.

- Six tensiometers were placed within the granular invert material at the bottom of the test cell to measure water tension.

- Three suction lysimeters were placed within the granular invert material at the bottom of the test cell to remove water and to provide a constant suction boundary condition within the invert.

- Six Hottinger Baldwin Measurements (HBM) tank weigh modules (TWMs) were installed within the support cradle under the test cell to monitor the weight and weight change of the test cell during the test.

- Three GSE Inc. platform scales were used to monitor the weight of the water injected into the test cell.

2.3.8 Data Collection — Manual

Water from wicks and suction lysimeters was collected and manually weighed on a platform scale and the data were recorded on data collection forms. In addition, notes from visual observations were recorded in the field notebook covering this work.

2.3.9 Data Collection — Computer Based

A dedicated data acquisition system was configured for EBS testing. The data acquisition system was a computer-based system with Hewlett Packard peripherals and LabView for

Windows software. The data acquisition system monitored the HBM TWMs, GSE Inc. platform scales, Vaisala temperature/humidity probes, and Omega RTDs. Data from HDPs, TDRs, and tensiometers were collected using a Campbell Scientific data acquisition system. Each gage was monitored hourly with the data recorded in the computer.

2.4 TEST CONDUCT

This section presents details regarding how the test was implemented and conducted. It describes the more salient activities and observations from the field notes. The test was conducted in three main phases, referred to as Part 1, Part 2, and Part 3 (CRWMS M&O 1999b). These parts corresponded to a physical configuration or conditions imposed on the test. Part 1 refers to a configuration that included the simulated waste package and the insulated test cell without the drip shield and with no dripping. Part 2 of the test refers to the time after the drip shield was installed but prior to the initiation of dripping. Part 3 refers to the main part of the test when water was injected from a grid of injection holes in the top of the test cell, onto the drip shield, and drained out the bottom through suction lysimeters and condensate collection wicks. The inside of the test cell wall was maintained at a nominal temperature of 60°C (140°F), and the top of the waste package was maintained at nominally 80°C (176°F) throughout all three parts of the test.

2.4.1 Test Conduct During Part 1

The test cell for Part 1 was configured in early June 1999, and the test heaters were energized starting from that time. A calibrated power monitor, which was felt to be an important component of the test, was not available for installation until early September. Preliminary observations were made prior to the installation of the calibrated monitor. It was noted that the invert and lower sections of the test cell were about 5°C (9°F) cooler than higher elevations in the test. This was because the warmer air would rise, and the temperature control for the inside of the test cell wall was placed at the top of the test cell. Thus lower regions of the cell would be cooler. In an effort to reduce this effect, an extra 8.9 cm (3.5 in.) of insulation (R-Value=11 [$ft^2 \cdot hr \cdot °F/BTU$]; Howard 2000, Vol. 1) was added to the bottom of the test cell over an area that corresponded to the extent of the invert. This modification resulted in reducing the differential temperature between the top and bottom of the test cell to less than 1°C (1.8°F). All subsequent R-Values given in this report infer units of $ft^2 \cdot hr \cdot °F/BTU$.

On 9/2/99 (Day 0 in elapsed time), the power to the test was shut off at 13:40 and a calibrated power monitor was installed. The test was re-energized at 16:00 the same day. The data in the report start from 00:00 on 9/2/99 with the exception of the power monitor data, which start from 16:00. A short duration temperature drop caused by this power outage can be seen in the data on 9/2/99. The test ran in this configuration until 9/6/99 (Day 4) at 12:45, when the heaters were de-energized in order to install the drip shield. Starting on 9/7/99 (Day 5), the front of the test cell was removed and the drip shield was installed in three sections, each 1.3 m (4.3 ft) long, as shown in the as-builts. Each section had ten RTDs attached to it with epoxy glue. Concurrent with the drip shield installation was the installation of two Vaisala humidity probes, 3-HUM-2 and 3-HUM-3, under the drip shield. These gages were being monitored by the data collection system prior to this time, so the data prior to 9/9/99 (Day 7) from these gages reflect conditions

in the Atlas Facility high bay. Once the drip shield installation was complete and the new gages had been terminated to the data collection system, the test cell was closed up and insulation was reapplied to cover the front of the test cell. Concurrent with closing the test cell, nine RTDs were applied external to the test cell—three applied to each of the ends and three applied in the insulation outside the test cell.

2.4.2 Test Conduct During Part 2

With the drip shield installed, Part 2 of the test was started on 9/10/99 (Day 8) at 12:00 when the heaters were energized. Conditions in the test cell were then monitored for steady state. After four days, temperatures in the test cell components had stabilized and dripping was started, which ended Part 2 of the test.

2.4.3 Test Conduct During Part 3

On 9/14/99 (Day 12) at 12:00, the drip pumps were turned on. The drip water was dyed with a blue color to differentiate it from condensate. As discussed previously, the design called for applying water evenly through a series of thirty holes in the top of the test cell at a rate of nominally 250 ml/hr/m (2.56 oz/hr/ft) of test cell length, or about 1 L/hr (0.26 gal/hr) for the entire test cell. The injection system was less efficient than expected, and the initial injection rate averaged 0.74 L/hr (0.20 gal/hr). The pump system, which comprised three pumps, had outages fairly routinely during the test period and required frequent maintenance. During these outages, water was not injected to specific sections of the test cell, depending on which pump was not working.

On 9/17/99 (Day 15), water was observed leaking from the seal between the front cover of the test cell and test cell flange. There was also minor condensate leakage out from the seal of a front window mounted below the centerline of the waste package. Total leakage was estimated to be about 1 L (0.26 gal). Some of the water that leaked out was blue, indicating that it originated from injected tap water. Other leaks were clear, indicating that they originated from condensation that had collected on the cooler sections of the front cover and subsequently ran down to the bottom of the test cell where they came through the seal. These leaks were fixed.

On 9/20/99 (Day 18), condensate started to accumulate from wicks running under the simulated waste package and along the inner drip shield base. The source of this condensate was determined not to be from collection zones under the drip shield but rather from moisture accumulating on the inside surface of the unheated front cover of the test cell. This surface was cooler than other parts of the test cell. The condensate ran down, intercepted the wicks in its descent, and was diverted out of the test cell (see Figure 11). A total of 610 ml (20.6 oz) of condensate was collected from WIC-2, which was located below the observation windows in the front of the test cell. This unwanted accumulation of condensate was rectified by inserting stainless steel tubes over the wicks and through the port holes that penetrated the front cover and then sealing around the tubes with a heat-resistant sealant. On 9/22/99 (Day 20), the glass window located below the centerline of the simulated waste package was removed and replaced with a stainless steel plate that contained the stainless steel tube to protect the wick. This

allowed the test cell air to mix with external air for about 90 minutes and may have contributed to a brief period of lower relative humidity readings.

While these leaks were being fixed, the insulation on the lower part of the front face was cut and patched at several places. On 9/22/99 (Day 20), an extra 8.9 cm (3.5 in.) of fiberglass batting (R-Value=11; Howard 2000, Vol. 1) was added to the lower third of the front of the test cell to improve the insulation in this region.

During the first two weeks of testing, water was observed condensing at the top of the test cell, mostly around five aluminum tubing pass-throughs that were used to support psychrometers and cameras. These were recognized to be cooler "spots" in a test that was designed to have a uniform boundary temperature. On 9/24/99 (Day 22.62), to address these cool spots, patches of insulation, 2.5 cm (1 in.) thick (R-Value=4; Howard 2000, Vol. 1) by 0.3 m (1 ft) square were centered over the penetrations. At this same time, an additional 2.5 cm (1 in.) of insulation (R-Value=4; Howard 2000, Vol. 1) 1.5 m (5 ft) wide was laid down, centered along the length of the test cell.

The condensation at the top of the test cell was not seen again. However, the extra insulation caused the power consumption by the boundary heater to decrease from 1100 W to about 650 W. Apparently, much of the heat lost from the test cell was being lost through the upper third of the cell so that when the extra insulation was added the heat loss decreased. This decrease caused the drop in the power required to hold the set point temperature at the top of the cell. A result of these actions was to reduce the temperature in the lower half of the test cell by about 4°C (7.2°F).

No condensation was visible on the inside of the drip shield (as observed through the windows) at any time during the test. After the leaks through the front plate were fixed and the insulation was added, no other major configuration changes were made to the test, which ran for another 38 days. On 11/1/99 (Day 60) at 14:14, the power to the test was shut off and the drip pumps, which had largely quit functioning, were shut off. The electronic gages were monitored for the next seven days and visual observations were also made during this cool-down time. The test was disassembled between 11/16/99 and 11/18/99. There was some evidence of drip water wicking to surfaces on the edges of the drip shield under the overlaps and along the bottom of the shield.

3. EBS PILOT SCALE TEST #3 CONFIGURATION—AS-BUILT

The configuration for EBS Pilot Scale Test #3 instrumentation is given here in terms of the locations of each gage. The as-built locations in Cartesian coordinates are tabulated in Appendix C for EBS Test #3. Each as-built location is referenced to an origin located at the longitudinal centerline of the test cell on the inside of the front cover plate. The as-built locations and configurations were determined from fabrication specifications and field measurements made during construction of the test. Details of the test cell, simulated waste package, granular invert materials, and drip shield were presented and discussed in Section 2 of this report.

3.1 INSTRUMENTATION AND EQUIPMENT CONFIGURATION

The instrumentation used in EBS Test #3 was described in Section 2.3.7 of this report. These gages (and measurement features) include water injection points, temperature sensors (RTDs and Vaisala gages), humidity sensors (Vaisala gages and TCPs), tank weigh modules, platform scales, suction lysimeters, water potential sensors (HDPs and tensiometers), and water content sensors (TDRs). The locations and configurations for each of these gage types are presented below, and tables of gage coordinates (x,y,z) are given in Appendix C.

3.1.1 Fluid Injection System (Scales and Injection Points)

The fluid injection system was described in Section 2.3.4 of this report, and the as-built configuration is shown in Figure 12. The injection points were located on the top of the test cell and drilled and tapped to provide thorough coverage over the drip shield segments. As stated previously, the injection points were staggered along twelve rows of two and three holes each along the entire length of the test cell. The pattern started with two holes at 0.33 m (1.08 ft) from the front face followed by three holes at 0.63 m (2.07 ft), then two again at 0.93 m (3.05 ft) from the front face. The sequence was continued at 0.3 m (0.98 ft) intervals (from the front face) culminating with three holes at 3.63 m (11.91 ft). The holes were aligned at –0.38 m (–1.25 ft), –0.19 m (–0.62 ft), 0 m (0 ft), +0.19 m (0.63 ft), and +0.38 m (+1.25 ft) as measured from the centerline of the test cell. Therefore, the injection holes extend over a rectangular area 0.78 m (2.56 ft) wide and 3.3 m (10.82 ft) in length along the test cell. The platform scales used to measure the injected water are located outside the test itself. The precise location of these scales is unimportant for the as-built configuration. Actual x,y,z coordinates for the drip locations are given in tabular form in Appendix C.

3.1.2 Temperature Sensors

Two types of temperature sensors were installed in EBS Test #3. The Vaisala gages included both temperature and humidity measurement components. Four of these gages were installed within and outside the test cell. Additionally, 87 RTDs were installed to measure temperature in EBS Test #3. The manufacturer, accuracy, range, and precision for these gages are given in Appendix B of this report. The temperature sensors were not all operational throughout all parts of EBS Test #3 testing. The test sequence was described in Section 2.4. As stated there, the RTDs applied to the drip shield were not operational until the drip shield segment of testing was

initiated. The following figures and the tables in Appendix C represent the gage locations for all temperature gages regardless of the part of testing.

Figures 13 through 17 show approximate gage locations for temperature sensors installed in EBS Test #3. Figures 13 through 15 provide cross-sections at 1 m, 2 m, and 3 m from the front face. Figures 16 and 17 show approximate gage locations on the front and back faces of the test cell, respectively. There are 22 RTDs and one Vaisala gage located at each of the 1-m and 3-m cross-sections. At the 2-m cross-section there are significantly more temperature measurements (34 RTDs and one Vaisala gage). Gages installed in the insulation and the ambient air are not shown in these figures; however, their locations are given in tabular form in Appendix C.

3.2 HUMIDITY SENSORS

As with the temperature sensors, there are two types of sensors for measuring humidity within the test cell. The first type of gage is the Vaisala humidity probe previously described, which measures both temperature and relative humidity. The locations of these gages are shown by the small ovals in Figures 13 through 15. They are located between the simulated waste package and the drip shield, and between the drip shield and the test cell wall. Cartesian coordinates (x,y,z) for these gages are given in Appendix C, and the manufacturer, accuracy, range, and precision for the gages are given in Appendix B.

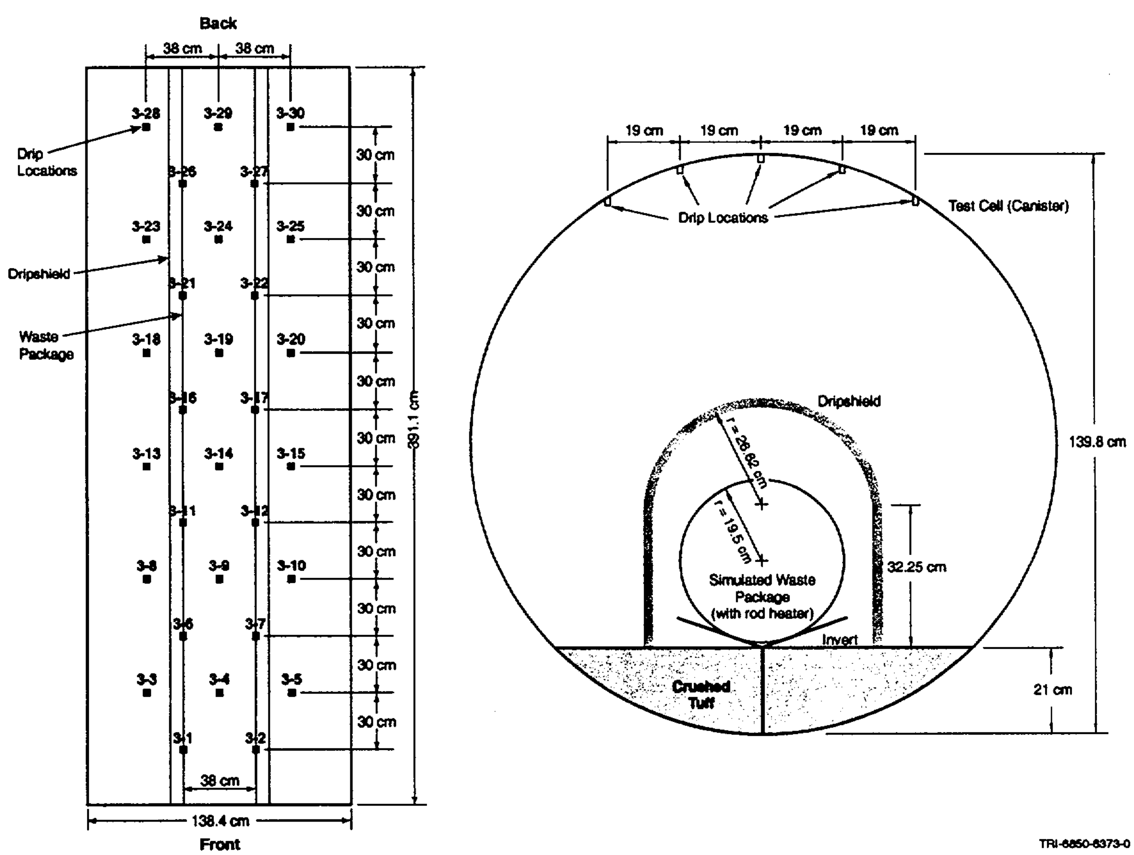

Figure 12. EBS Test #3 Drip Hole Layout (Howard 2000, Vol. 1, Section 4.3)

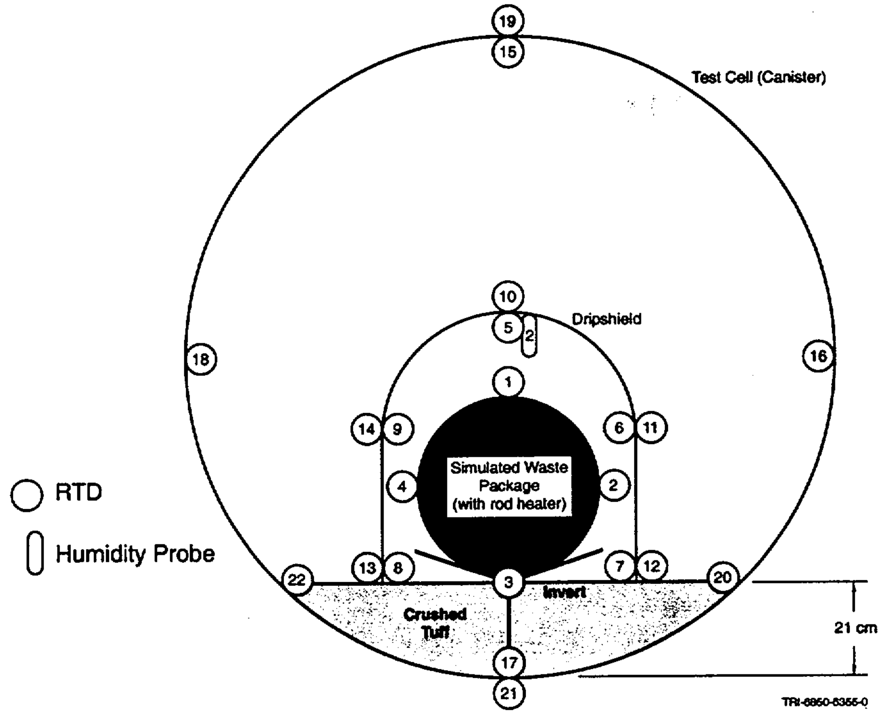

Figure 13. EBS Test #3 Temperature Instrumentation Configuration in Cross-Section, 1 m (3.28 ft) from Front Face (Howard 2000, Vol. 1, Section 5.2)

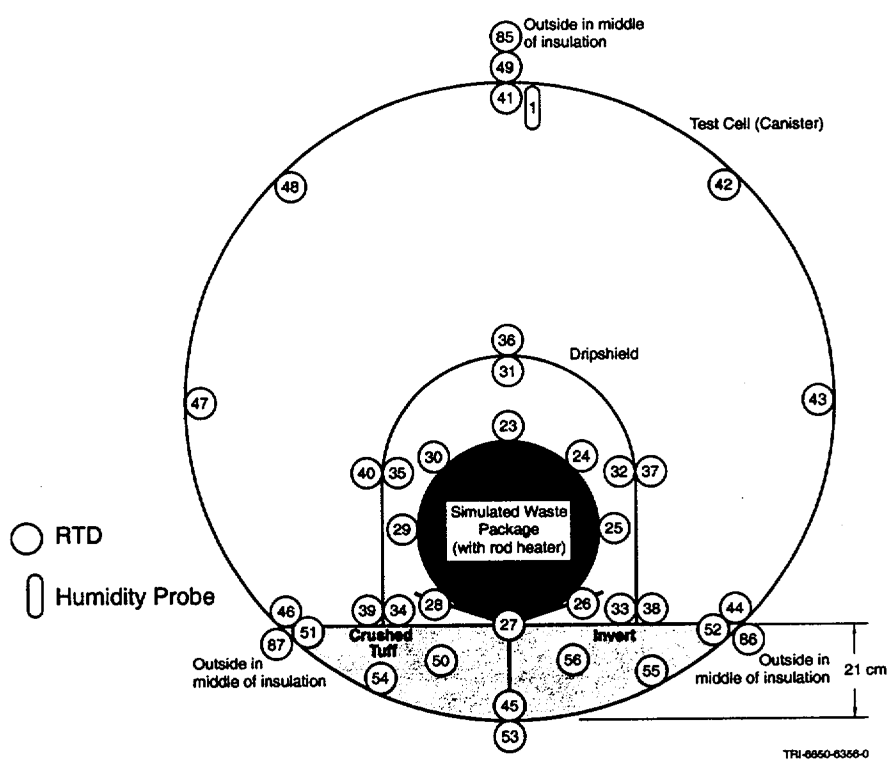

Figure 14. EBS Test #3 Temperature Instrumentation Configuration in Cross-Section, 2 m (6.56 ft) from Front Face (Howard 2000, Vol. 1, Section 5.2)

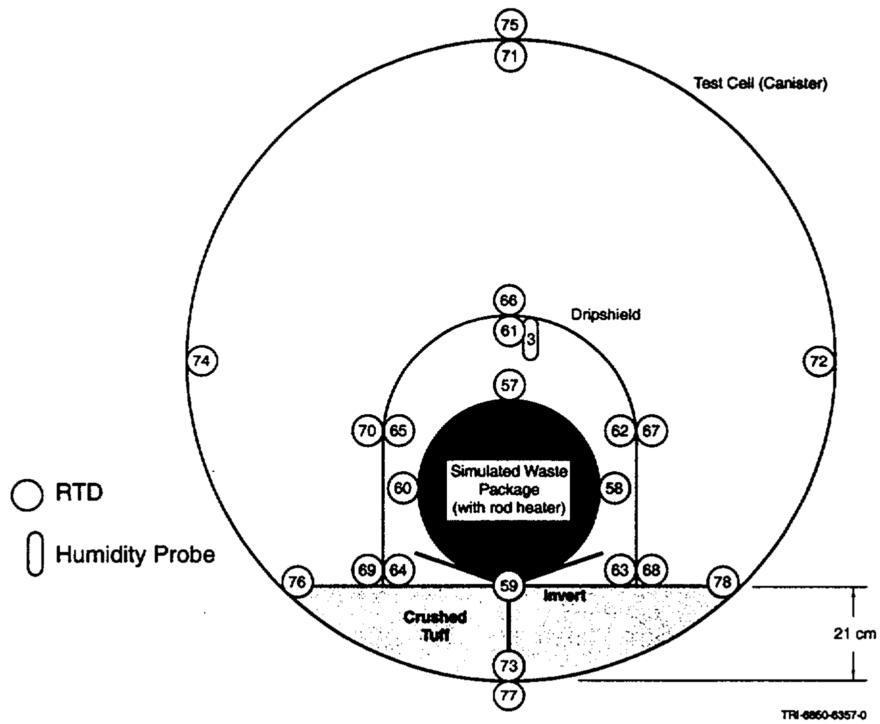

Figure 15. EBS Test #3 Temperature Instrumentation Configuration in Cross-Section, 3 m (9.84 ft) from Front Face (Howard 2000, Vol. 1, Section 5.2)

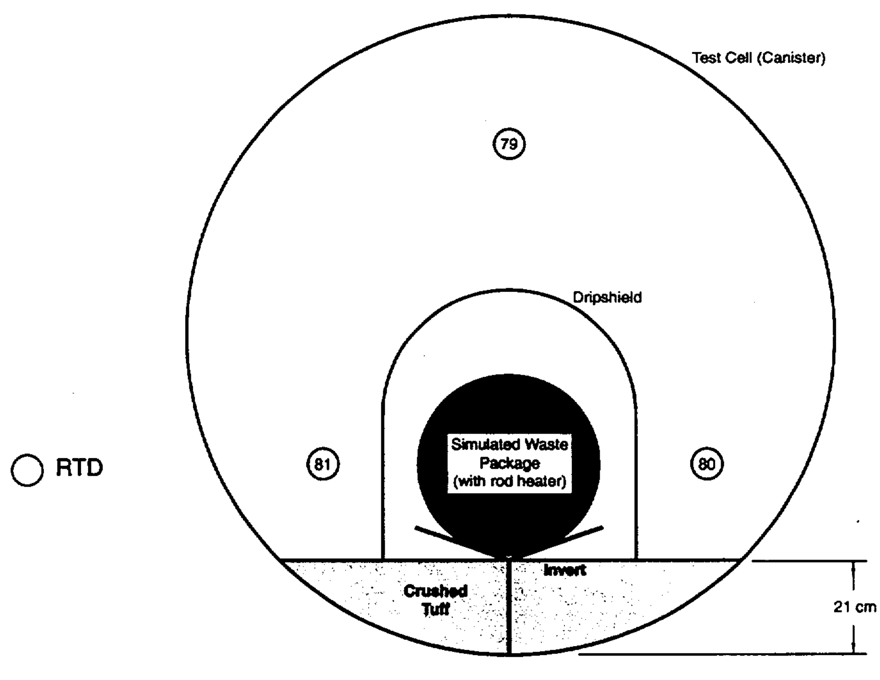

Figure 16. EBS Test #3 Instrumentation Applied to Front Face (Howard 2000, Vol. 1, Section 5.2)

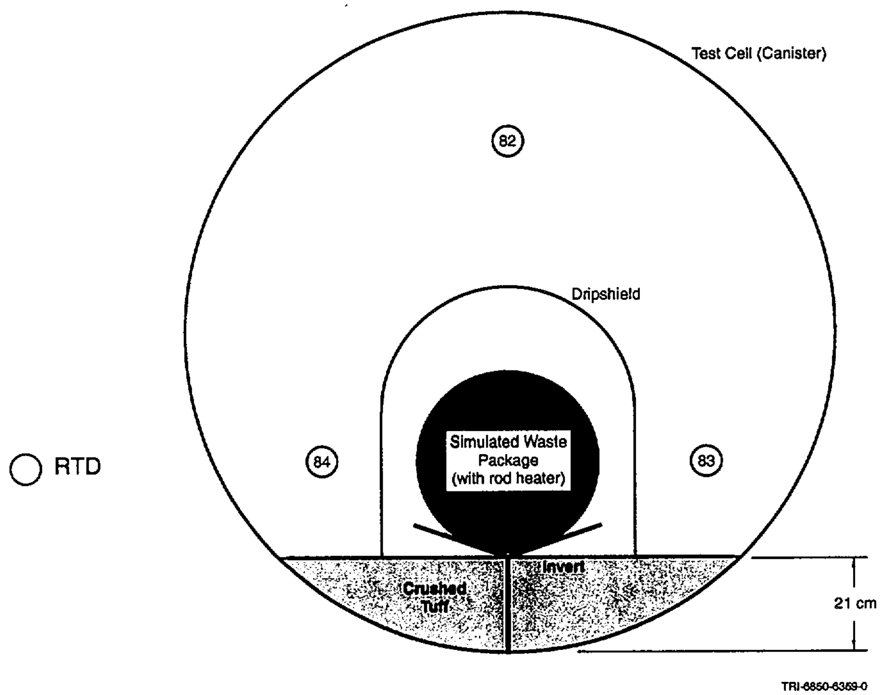

Figure 17. EBS Test #3 Instrumentation Applied to Back Face (Howard 2000, Vol. 1, Section 5.2)

A second type of humidity gage was installed in EBS Test #3 to monitor humidity changes. These gages, thermocouple psychrometers (TCPs), are described below.

Relative humidities in the 96–100% range were expected during the testing period. TCPs were installed because they are able to resolve small changes in relative humidities between 96–100% with a much higher accuracy than the Vaisala sensors also installed. The Vaisala humidity sensors have an accuracy of ±2% relative humidity between 90 and 100% relative humidity (Appendix B), whereas the TCPs have an accuracy of ±0.15% in the same range.

The TCP is a high precision device, about 2.5 cm (1.0 in.) in length, which contains a copper-constantan thermocouple junction and a chromel-constantan psychrometer junction encased in a fine mesh stainless steel screen. A polyvinyl chloride (PVC) insulated cable containing the copper and constantan wires is attached to the base of the device and carries input and output voltage signals to and from the psychrometer (see Figure 18).

The dewpoint method and psychrometric method were the two procedures used to determine the equilibrium relative humidity (Briscoe 1986). The dewpoint method is the preferred technique because it is affected much less by changes in the ambient temperature and it produces a continuous output instead of a falling plateau, which is the output of the psychrometric method. In the dewpoint method, the copper-constantan junction is cooled by a reverse polarity current so that a bead of moisture forms. Once the bead has formed, heat will tend to flow from the

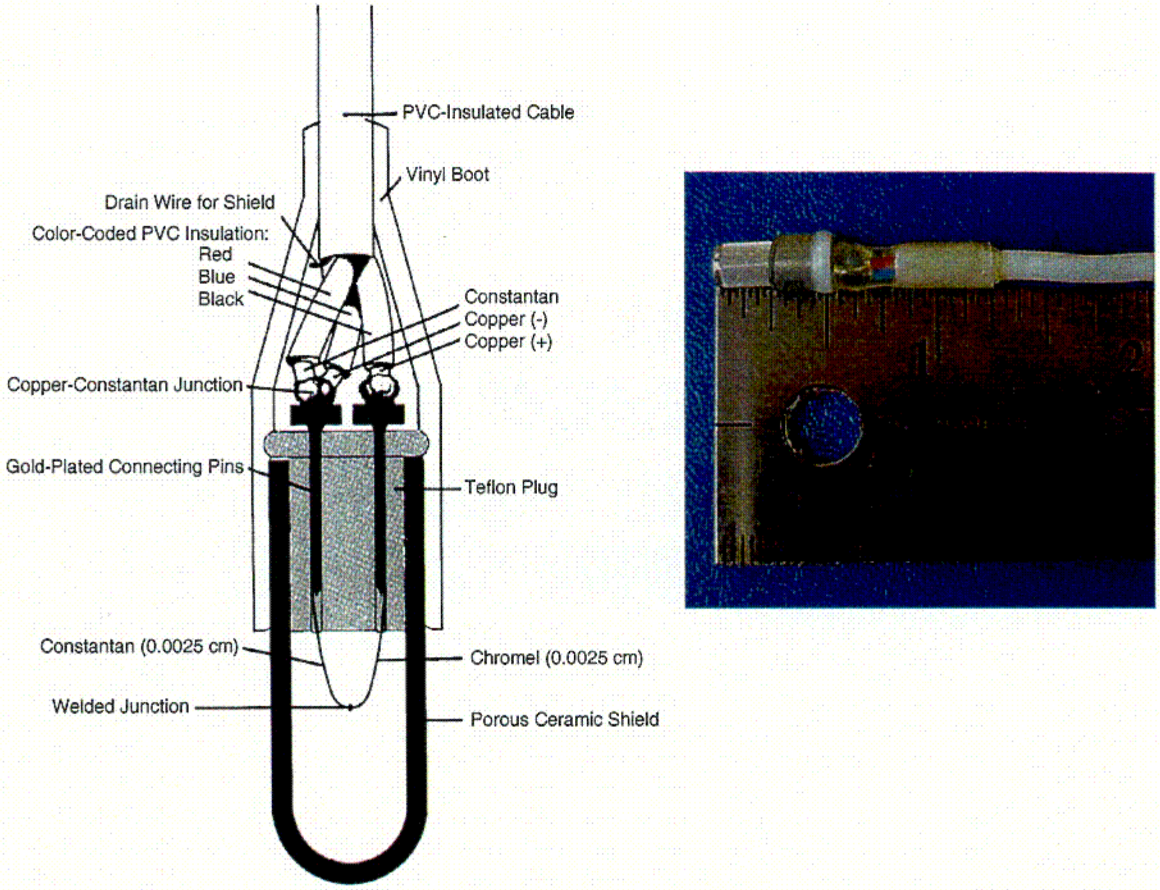

Figure 18. Thermocouple Psychrometer Diagram and Photograph Showing its Approximate Size (Briscoe 1986).

surroundings to the junction. The dewpoint method uses an electrically adjustable cooling current to balance the inflow of heat from the surroundings in such a way that the net energy transfer is zero. This latent heat exchange causes the thermocouple to converge to the dewpoint temperature. At the dewpoint temperature, the psychrometer's output (microvolts) is linearly related to the relative humidity.

Eighteen Wescor PST-55 TCPs were installed in planes 1 m, 2 m, and 3 m from the front of the test cell. Each psychrometer was fed through a phenolic tube and inserted into a 1.27 cm (0.5 in) shielded Teflon housing that was vented to the atmosphere at the cylinder ends. The shielded Teflon housing was used to prevent air currents from contacting the sensor, to shield the sensor from thermal radiation, and to prevent drips (from irrigation or condensation) from contacting the sensor. Nine of the TCPs were attached through the shell of the test cell with hermetic compression fittings. The remaining nine TCPs were attached above the waste package or were clamped to the right or left of the waste package support. See Figure 19 for the positions and serial numbers of all TCPs installed in EBS Test #3.

C01

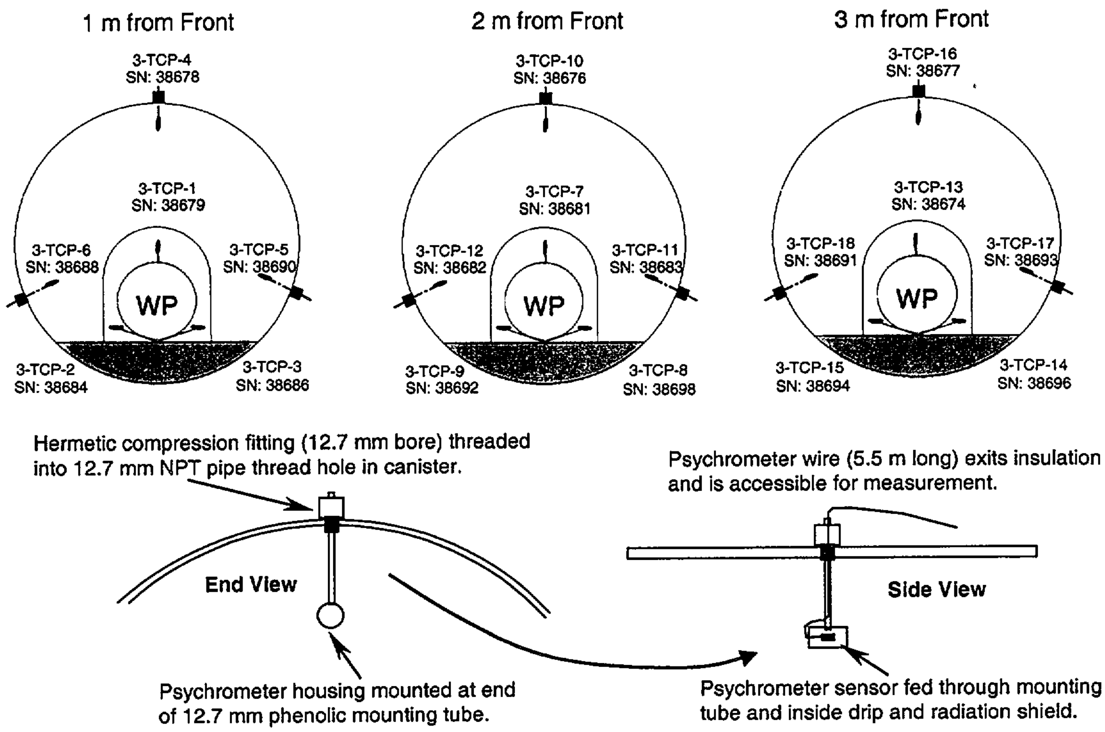

Figure 19. TCP Layout in EBS Test #3 (Howard 2000, Vol. 1, Sections 4.3 and 4.4)

3.2.1 Tank Weigh Modules

Six HBM TWMs were installed within the support cradle of each container to monitor the weight and weight change of the EBS Test #3 system. Data from these gages can be related to the quantity of applied water that is imbibed in the granular invert material during the test. These gages were installed outside the test cell; therefore their absolute locations relative to the x,y,z coordinate system are not specifically important in further analyses of the test. However, the gage locations (x,y) are given in Appendix C. The x and y coordinates define the points along the axis and to which side (left or right) the HBM TWMs are located. The gage manufacturer's range, accuracy, and precision are given in Appendix B.

3.2.2 Suction Lysimeters

Suction lysimeters were installed within the granular invert material along with the braided fiberglass wicks to provide a suction boundary condition for test analyses and to remove collected water. These suction lysimeters applied a suction potential of -150 mbar and were wrapped with a braided fiberglass wick to promote a physical and hydrologic connection. The general locations of these lysimeters and wicks are shown in Figure 20.

3.2.3 Water Potential Sensors

Six tensiometers were installed at two cross-sections (0.3 m and 1.0 m) within the granular invert material to measure water potential. The locations of these gages are shown in Figures 21 and 22.

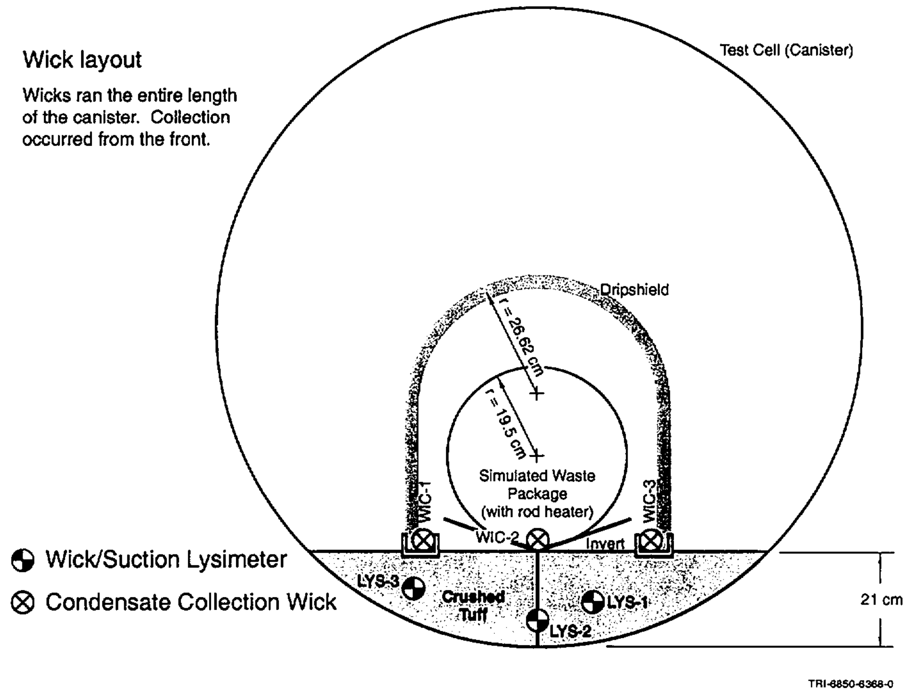

Figure 20. Generalized Locations of Suction Lysimeters and Wicks in EBS Test #3 (Howard 2000, Vol. 1, Section 5.2)

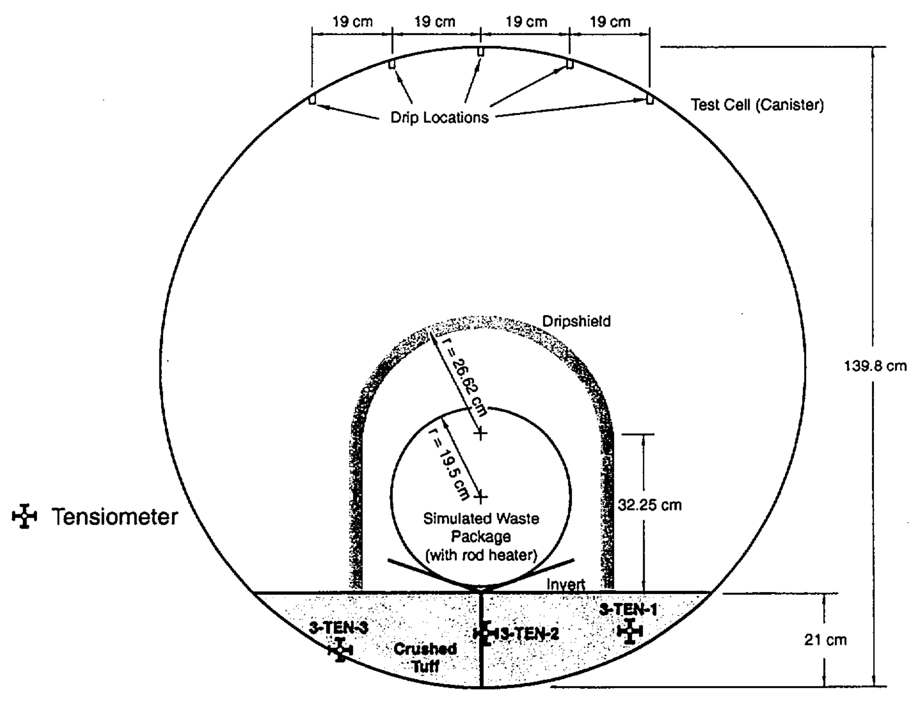

Figure 21. Tensiometer Gage Locations at 0.3-m Cross-Section, EBS Test #3 (Howard 2000, Vol. 1, Section 5.2)

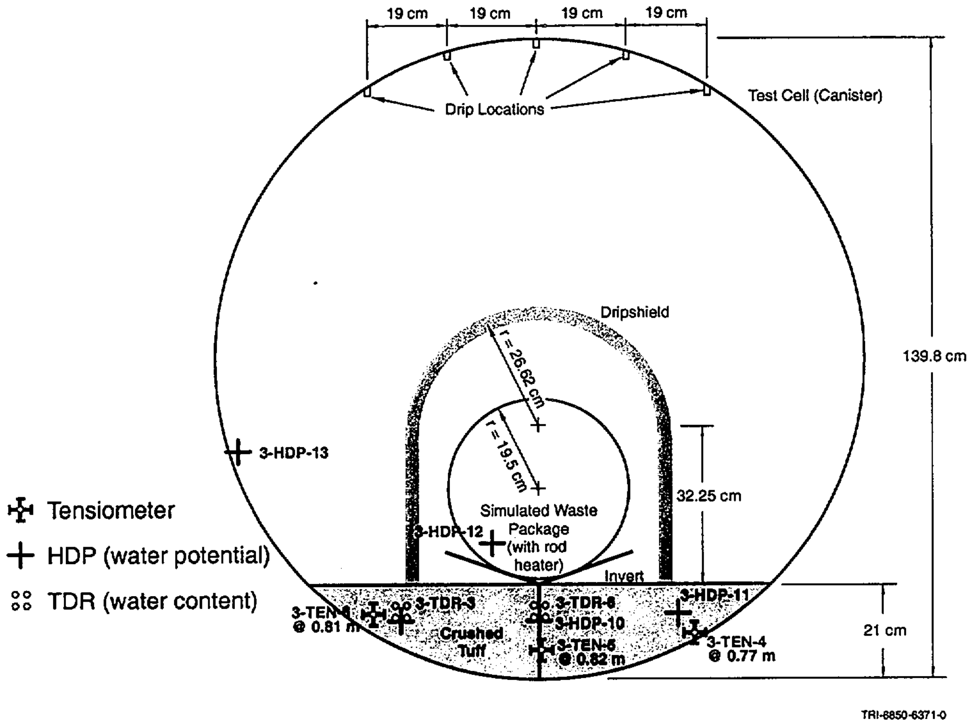

Figure 22. Heat Dissipation Probe, Time Domain Reflectometer, and Tensiometer Gage Locations at 1-m Cross-Section, EBS Test #3 (Howard 2000, Vol. 1, Section 5.2)

Eleven heat dissipation probes (HDPs) were installed within the granular invert material at each of the three instrumentation cross-sections (1 m, 2 m, 3 m). Two HDPs were installed in the test cell atmosphere, one outside and one inside the drip shield. These thirteen probes measure the matric potential in the granular material and elsewhere at each cross-section. The general locations of these gages are shown in Figures 22 through 24. Also shown in these figures are the generalized locations of the water injection points at the top of the test cell. Figures 22 through 24 show the y = 1 m (3.28 ft), y = 2 m (6.56 ft), and y = 3 m (9.84 ft) cross-sections, respectively. Actual gage locations are provided in Appendix C.

3.2.4 Water Content Sensors

Water content sensors were also installed in EBS Test #3. TDRs were installed at each of the three instrumentation cross-sections that house the remainder of the water sensing instrumentation. These TDRs are shown in Figures 22 through 24 for each of the three cross-sections at y = 1 m (3.28 ft), y = 2 m (6.56 ft), and y = 3 m (9.84 ft), respectively. Actual gage locations are provided in Appendix C.

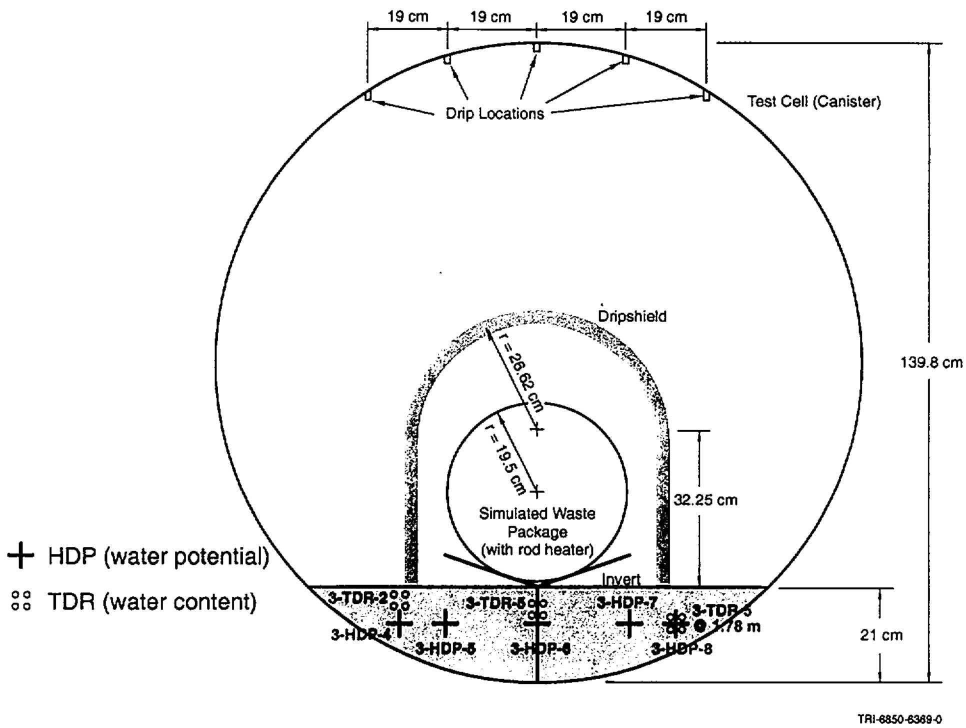

Figure 23. Heat Dissipation Probe, Time Domain Reflectometer, and Tensiometer Gage Locations at 2-m Cross-Section, EBS Test #3 (Howard 2000, Vol. 1, Section 5.2)

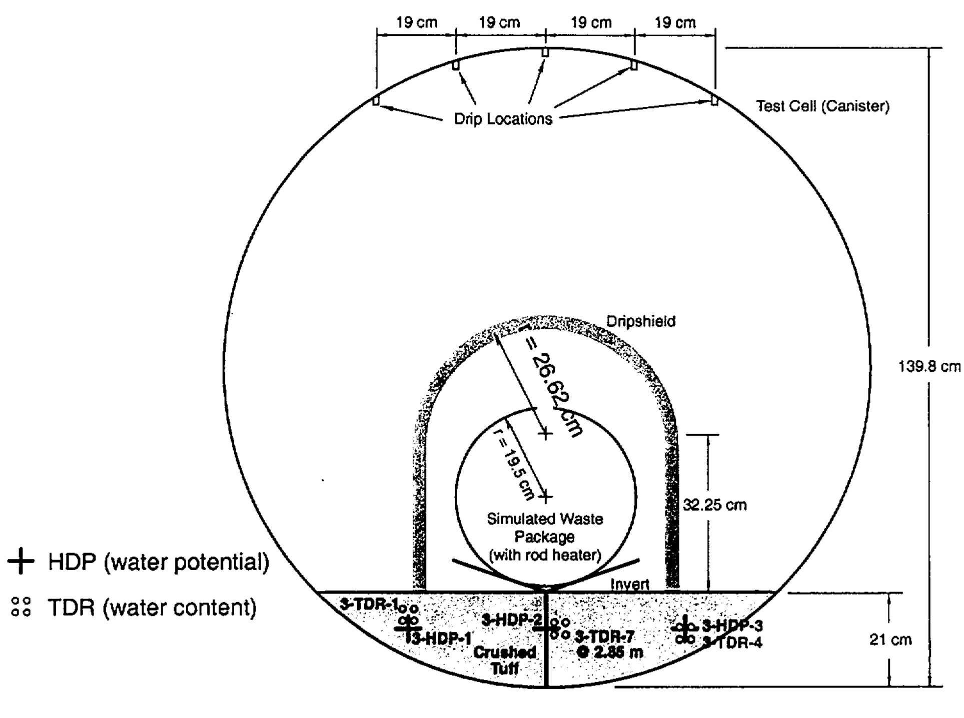

Figure 24. Heat Dissipation Probe, Time Domain Reflectometer, and Tensiometer Gage Locations at 3-m Cross-Section, EBS Canister #3 (Howard 2000, Vol. 1, Section 5.2)

4. EBS PILOT SCALE TEST #3 DATA

The data presented in this section include the RTD temperature data, the Vaisala temperature data, the Vaisala relative humidity data, the TCP results, the heater power data, the injected water weight data, the moisture potential in the crushed invert material, and the effluent water weight data. Also discussed are visual observations recorded during the conduct of the test. The test sequence, as previously described in Section 2.4 of this report, was divided into three separate parts. The results presented here do not specifically distinguish between test parts, but rather present the data in a temporally continuous manner. Most tabulated data from EBS Test #3 have been transmitted to the TDMS on CD-ROM format under the following DTN #: SN0003L1011398.003. Raw data can be obtained from the LANL-TCO for selected data acquisition system-collected data. Lysimeter and tensiometer data obtained by the USGS were transmitted to the TDMS under DTN # GS000883351030.010.

4.1 SUMMARY OF THE EBS TEST #3 DATA

The most prevalent parameter monitored in this test was temperature. Almost all the temperature profiles generated by the temperature gages show the influence of diurnal temperature fluctuations outside the test cell imposed by the test facility air conditioning system. A weekly pattern can be traced on most gage outputs consistent with the diurnal fluctuations during the five working days and the lesser variations for the weekend when the facility air temperatures varied less. These temperature changes also influenced the output of the tank weigh modules (TWMs), where a 5°C (9°F) temperature change would induce a weight redistribution in some weigh modules of up to 9 kg (20 lb). Larger weight redistributions of 100 to 200 kg (220 to 440 lb) were associated with heater activation and deactivation. These weight redistributions were caused by support frame flexing associated with thermal expansion.

Temperature distributions during the test were stratified, for the most part, with high elevations having higher temperatures than lower elevations. This trend was seen on the drip shield and on the simulated waste package. The drip shield projected simulated waste package heat into the invert, making areas under the shield warmer than comparable areas not under the shield. Temperatures on the drip shield at the 3-m station are consistently higher than comparable measurements at the 1 m (3.28 ft) station. This might be attributable in part to the slope of the test setup and to the smaller amount of water dripped on this part of the drip shield. The addition of the 2.5 cm (1 in.) of insulation (R-Value=4; Howard 2000, Vol. 1) to the top of the test cell had the effect of lowering the test cell boundary temperature by 2 to 4°C (3.6 to 7.2°F) below the spring line. (The spring line is the point on the test cell, drip shield, and waste package where the tangent is vertical.)

The relative humidity measurements indicate that the vapor pressure throughout the test cell varied by about 10%, depending on position (see Section 4.6.4). Diurnal variations due to barometric effects were observed. Vapor pressures at the locations of measurement correlated fairly well with average temperatures in those regions. The relative humidity under the drip shield was about 20% less than in the upper part of the test cell because its temperature was about 5°C (9°F) higher.

4.2 WATER INJECTION SYSTEM DATA

Three water reservoirs supplied three injection pumps for the test, and these were placed on three platform scales that were monitored by the data collection system. Scale 4 provided data on water injected into the holes between 0.33 m (1.08 ft) and 1.23 m (4.03 ft) from the front face of the test cell. Scale 5 provided data on water injected into holes from 1.53 m (5.02 ft) to 2.43 m (7.97 ft). The injection holes monitored by Scale 6 started at 2.73 m (8.94 ft) and ended at 3.63 m (11.91 ft). Hence, the Scale 4 injection rate had the greatest influence over conditions at the 1-m (3.28-ft) station, the Scale 5 injection rate influenced conditions primarily at the 2-m (6.56-ft) station, and the Scale 6 rate influenced conditions at the 3-m (9.84 ft) station.

Data from the scales are shown in Figure 25. All three reservoirs start with a total weight of between 327 and 336 kg (720 and 740 lb) of water. The weights began decreasing concurrent with the start of water injection on Day 12.5. Outages to the injection systems show up as flatter places on the curves in Figure 25. This trend continues until about Day 38, when a more pronounced injection system outage leaves the weights of reservoirs 4 and 6 essentially unchanged for about three days. After this outage, the Scale 6 injection system consistently pumps less water than the other systems. Starting around Day 54, pumps for reservoirs 4 and 5 began to pump noticeably less. The injection rates tapered off until the pumps were shut off on Day 60. The average injection rate from the start of dripping until Day 60 when the pumps were shut off was 645 ml (19.3 oz) per hour.

The injection rate as a function of time has been derived from the data in Figure 25 and is shown in Figures 26, 27, and 28. The places on the data curves of Figure 25 that have a lesser slope indicate an injection system outage, and these show up in Figures 26, 27, and 28 as dips in the injection rate. These dips can be often correlated to temperature profiles on the drip shield – temperatures generally rising when injection rates fall. The total water injected during the course of the test was 758 kg (1671 lb).

4.3 LYSIMETER AND TENSIOMETER DATA

Three suction lysimeters and six tensiometers were installed in the test cell invert. The lysimeters provided a suction boundary condition for test analysis and also removed collected water. Pressure data from the lysimeters are shown in Figure 29. The three lysimeters tracked closely through the test. Data taken from Day 0 to 13 show pretest conditions. The suction lysimeters were activated on Day 13. Vacuum pressure, which was initially set at -150 mbar, was adjusted to -80 mbar after about 35 days.

The tensiometers measured negative pressures in the invert material. Data recorded after the drip system was activated (day 12 on Figure 30) reflected several wet and dry cycles. More positive values (upward trends) indicate a relatively wetter soil. Over the subsequent two weeks, tensiometer water recharges were occasionally needed until the soil moisture stabilized. Data recorded after the lysimeter vacuum was decreased (day 35 on Figure 30) showed little reaction to the change in pressure. Two decreases in the tensiometer pressures, resulting from water drip system pump failures, appear as downward spikes in the data on Days 38 and 52. As expected,

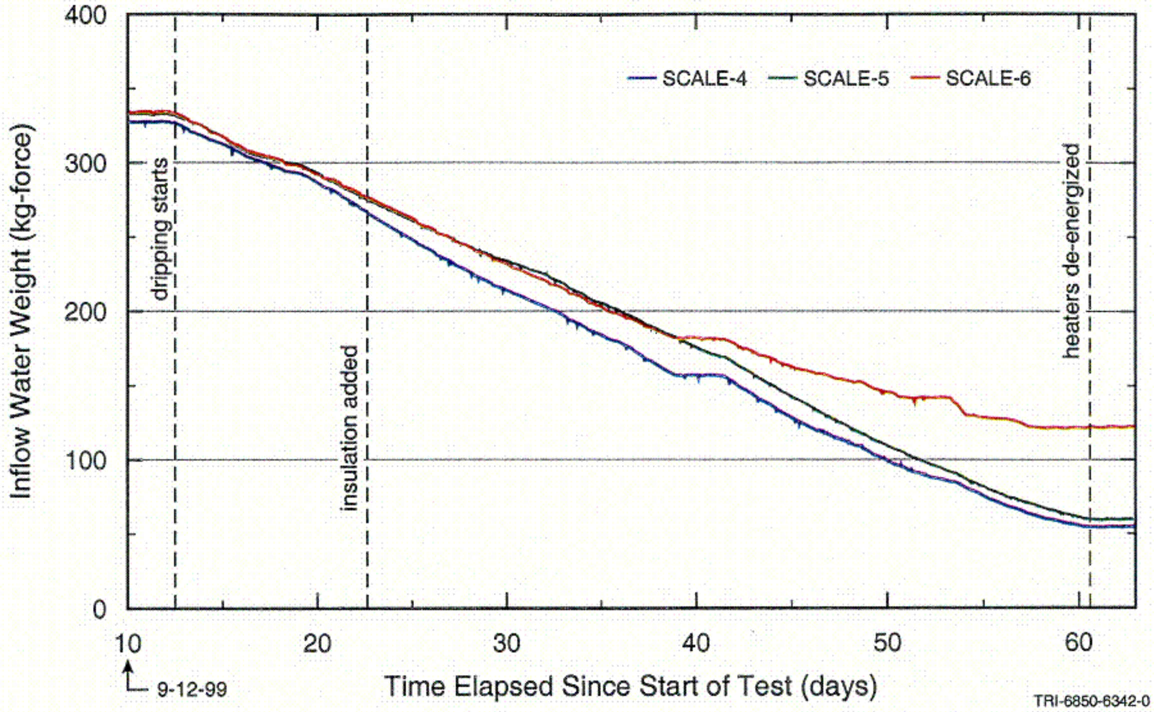

Figure 25. Data from Platform Scales (Weight Change in Reservoirs Due to Water Injection)

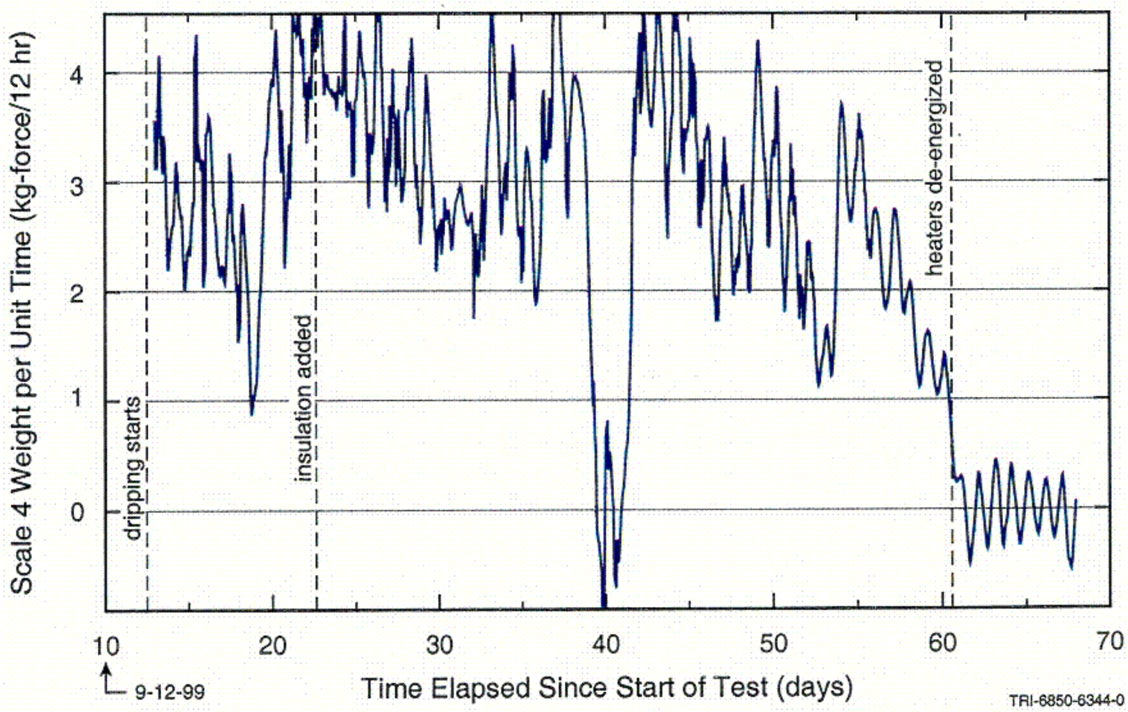

Figure 26. Weight of Water Injected from Tank #4 over Previous 12-Hour Period at 1-m Station

C02

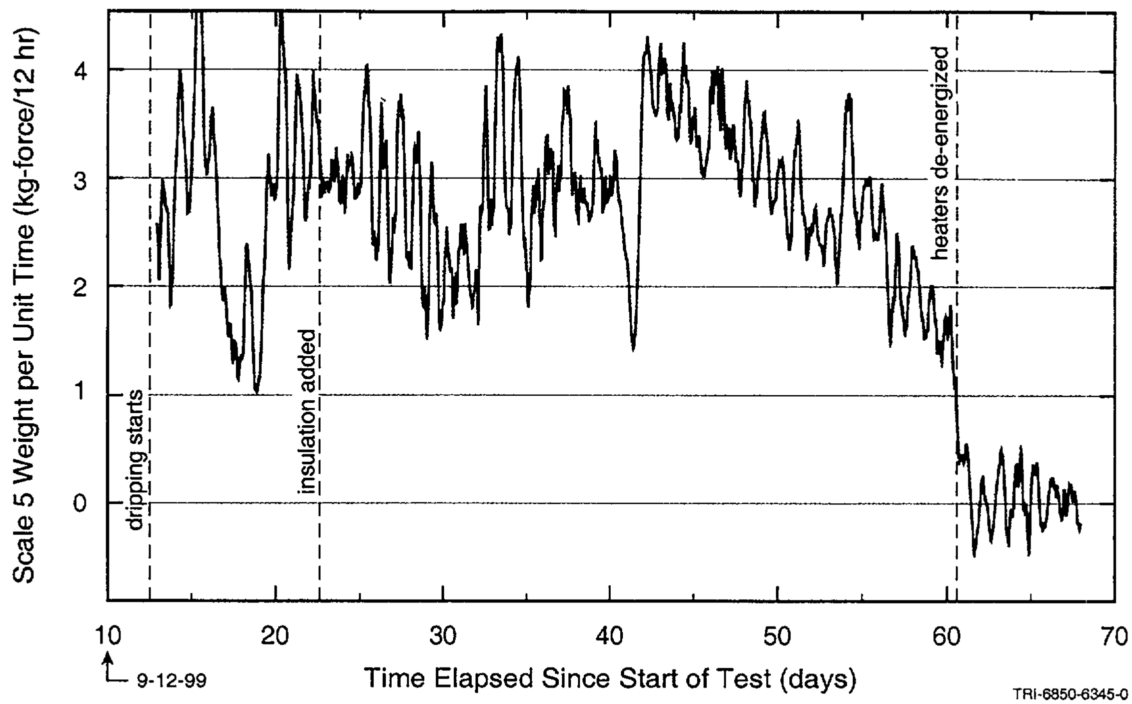

Figure 27. Weight of Water Injected from Tank #5 over Previous 12-Hour Period at 2-m Station

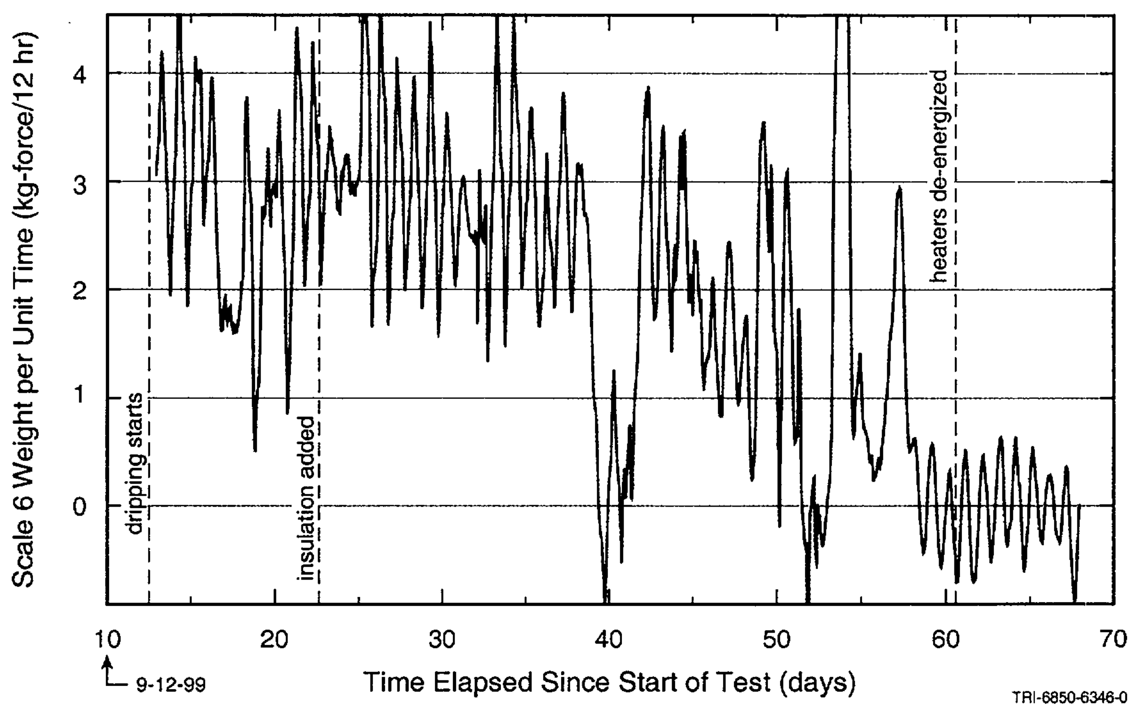

Figure 28. Weight of Water Injected from Tank #6 over Previous 12-Hour Period at 3-m Station

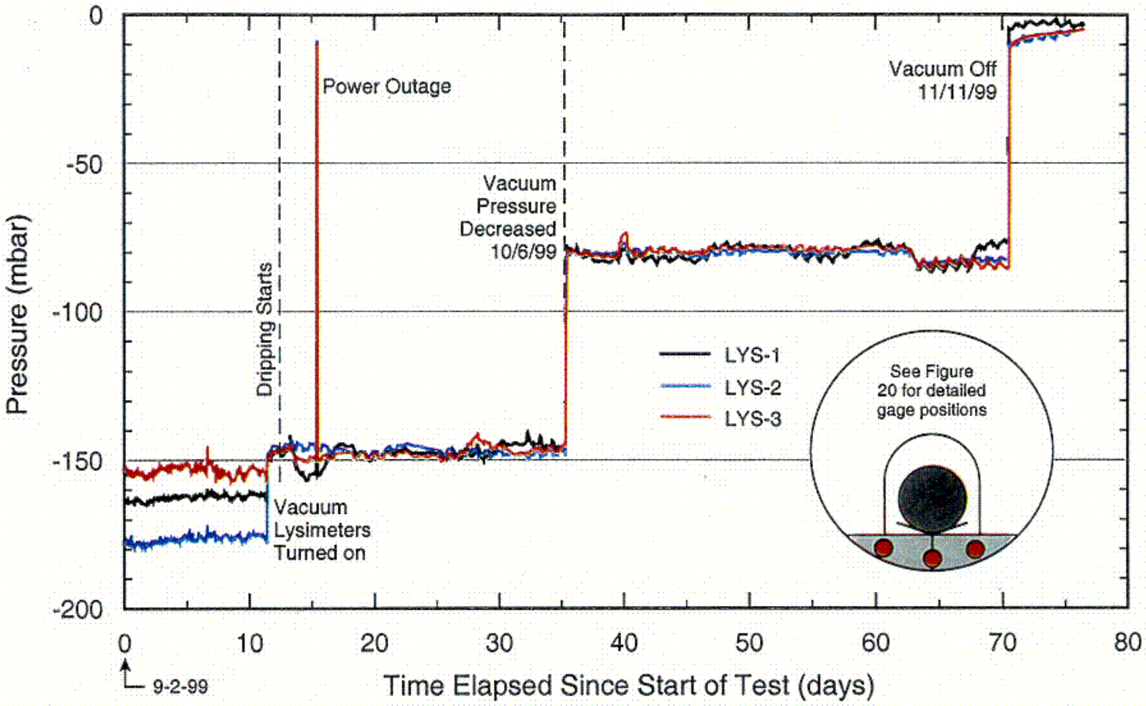

Figure 29. Pressure Data from Three Parallel Suction Lysimeters

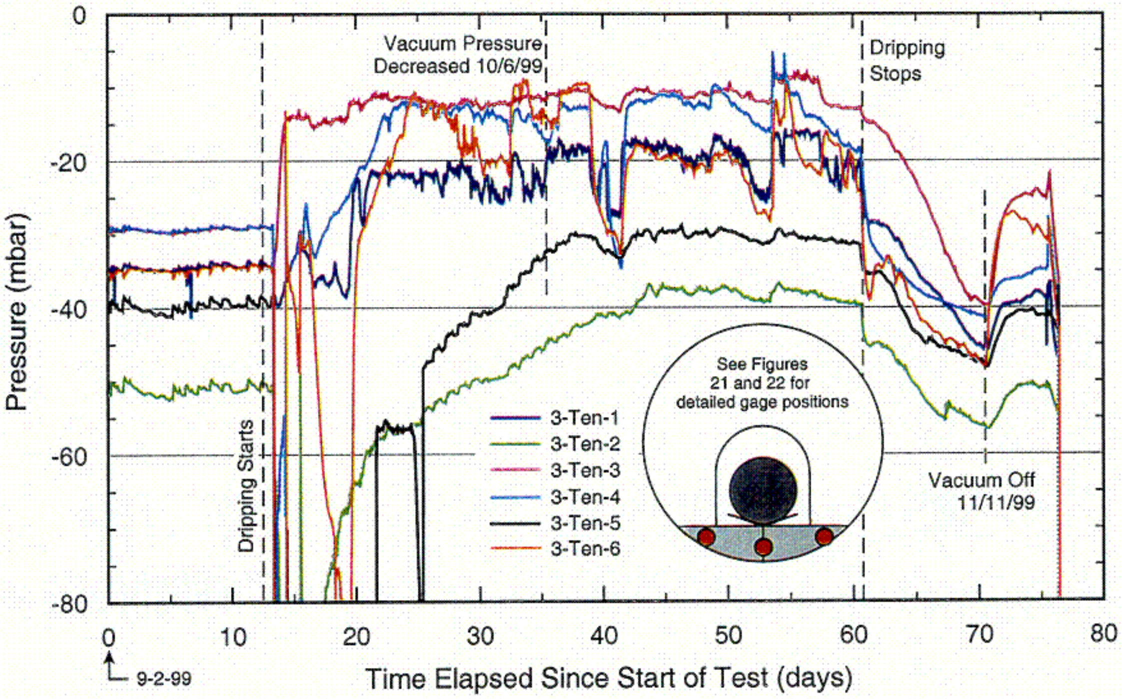

Figure 30. Pressure Data from Tensiometers Located at 0.3 m and 1.0 m Cross-Sections

C03

tensiometers 3-Ten-1, 3-Ten-3, 3-Ten-4, and 3-Ten-6, located outside the drip shield, were most affected by the pump failures. Conversely, tensiometers 3-Ten-2 and 3-Ten-5, located under the drip shield, remained drier throughout the test. Data recorded after the drip system was shut off (day 60 on Figure 30) show a downward trend indicating a drier invert. The invert became wetter when the lysimeter vacuum was halted on Day 70.

4.4 HEATER POWER DATA

The heater power data for this test are shown in Figure 31. During Part 1 of the test, when no drip shield was in place, power to the simulated waste package averaged about 700 W, and power to the wall heaters was about 500 W. Fluctuations in the data can be attributed to the fact that both these systems were controlled by temperature set points. Such a configuration causes the heaters to operate either at a high or low power output, with little between, depending on the readout of the control temperature sensor.

After the drip shield was installed for Part 2, power spikes occurred during the heating phase when the heaters were operated at full power to achieve temperatures set by the test operator. After the initial spike, output of the wall heaters leveled off to average around 1200 W, and the simulated waste package heater dropped to about 300 W. The reversal in the relative power levels between the simulated waste package and the wall heaters is explained by the fact that the drip shield holds more of the waste package heat closer to the temperature control sensor, in effect insulating it from the 60°C (140°F) boundary. With less simulated waste package heat being transferred to the boundary, more heat must be added by the wall heaters. When the dripping started for Part 3 of the test, the power levels were not substantially changed.

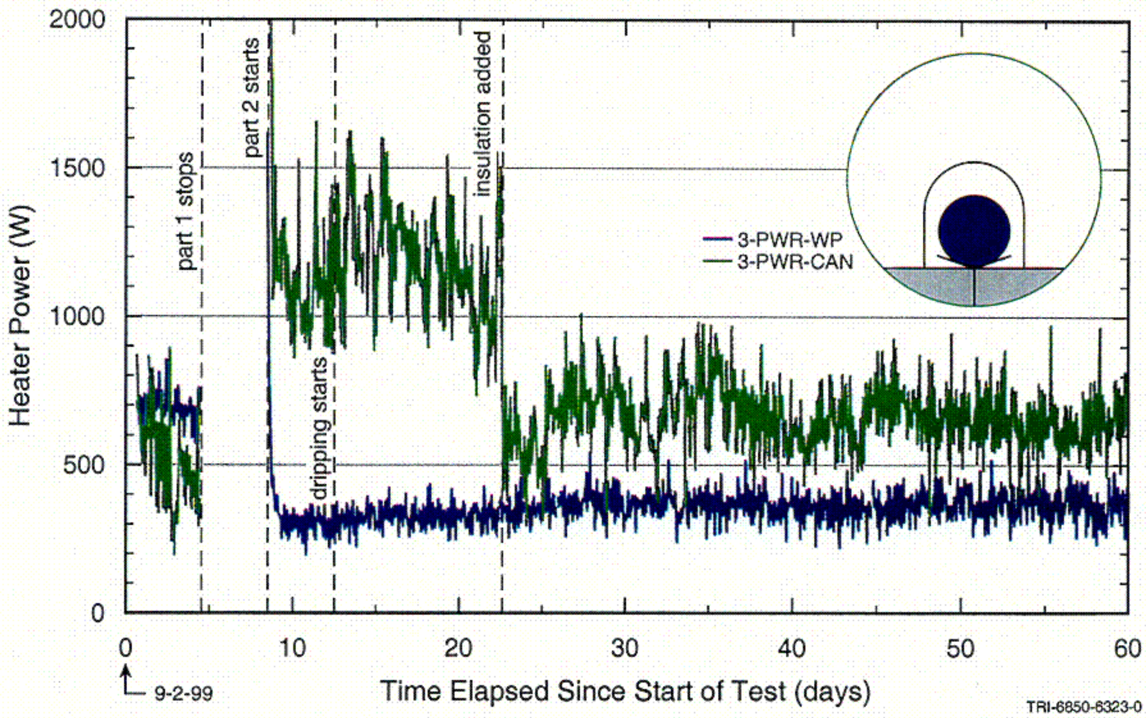

Figure 31. Heater Output Power

C04

These power levels continue until Day 22.62, when the extra insulation was added to the top of the test cell. The insulation reduced power consumption by the wall heaters from around 1200 W to about 700 W. The power consumption by the waste package was not noticeably affected. The drop in the wall heaters' output can be attributed to heat loss from the top of the test cell, which was substantially reduced by the extra insulation. Power levels then remain at the 300 and 700 W averages on the simulated waste package and test cell wall, respectively, through the remainder of the heated test.

4.5 TEMPERATURE DATA

Temperatures were measured at five general locations as follows: (1) on the simulated waste package, (2) on the drip shield, (3) on the test cell wall, (4) on the ends of the test cell, and (5) in the insulation outside the test cell. The discussion of temperatures from the test is categorized by these locations.

As discussed earlier, temperature boundaries were defined by control set points at the top of the simulated waste package and the inside top of the test cell. The top of the simulated waste package was controlled to be nominally 80°C (176°F), and the inside top of the test cell was set to nominally 60°C (140°F). Temperatures at other locations in the test were influenced primarily by these boundary conditions. Two other factors were important to temperature profiles in the test: First was the water dripping from the top of the test cell. This water was introduced to the test cell through a series of injection holes distributed along the top. The system was designed so that the injection water would be introduced to the test cell interior at a temperature of 60°C (140°F). Second was the addition of the 0.39-cm (1-in.) blanket of insulation 1.5 m (5 ft) wide along the crown of the test cell on Day 22.62. This insulation significantly reduced the power input by the wall heater, which in turn caused a 2 to 4°C (3.6 to 7.2°F) drop in the lower spaces of the test cell. However, the waste package heater output was not affected.

4.5.1 Temperatures on the Simulated Waste Package

Waste Package Crown–Temperatures on the simulated waste package crown are shown in Figure 32. Three of the measurements were at the apex of the cylindrical package – RTDs-1, 23, and 57 – and these are located at the 1 m, 2 m, and 3 m stations, respectively. The heater control set point was located at the apex of the package very near 3-RTD-23. The temperature at this point was around 81.1°C (178°F) prior to installation of the drip shield – 1.1°C (2°F) higher than the intended set point. This was likely caused because the set temperature was controlled by a thermocouple that produced a reading slightly lower than the RTD at the comparable location. After the drip shield was installed, the temperature rose closer to 81.7°C (179°F). This slight rise was probably caused by the different "tuning" settings of the heater control circuit, which was automatically reprogrammed after the drip shield was installed. The drip shield impeded the flow of heat from the waste package, effectively shielding the simulated waste package from the cooler temperature of the boundary. The result was that much less power was required by the rod heater to maintain the simulated waste package set temperature, as can be seen in Figure 31. Concurrent with the beginning of the dripping, RTDs 24, 30, and 57 drop in temperature while RTD 1 rises. The temperature redistributions could be attributable to increased thermal

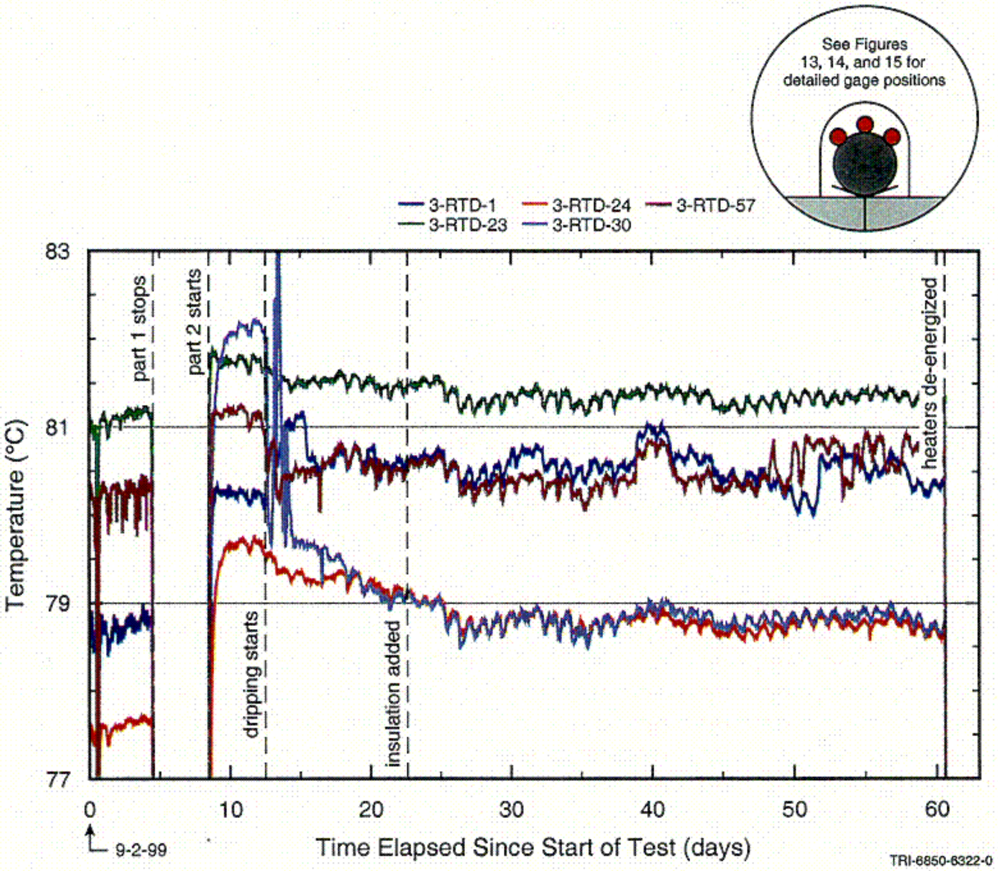

Figure 32. Temperatures on Waste Package Crown

conductivity of the air brought about by the increased humidity. Data presented in Section 4.5.3 show the increased relative humidity under the drip shield.

The temperatures from this time forward seem to group in a consistent pattern. The temperatures at the simulated waste package apex at the 1-m and 3-m stations fluctuate fairly closely around 80.5°C (177°F), slightly cooler than at the 2-m station. This result was probably caused by heat dissipation to the test cell ends, which were held near 58°C (136°F) on much of the metal surfaces. Temperatures from the test cell ends are provided in Section 4.4.4. The glass windows in the ends, as shown in Figure 11 (Section 2.3), were probably significantly cooler than this temperature. RTDs 24 and 30, which were located at the 2-m station at 45° down each side off the center of the crown of the simulated waste package, fluctuate around 78.9°C (174°F), slightly cooler than the gages at the apex. Temperatures at these points exemplify the general trend of the relatively cooler temperatures being located at lower elevations along the waste package.

Waste Package Spring Line–Temperatures from the simulated waste package spring line are shown in Figure 33. Starting from Day 0, when the data start, the gages located along the simulated waste package spring line averaged about 75°C (167°F), noticeably less than the gages located at the crown. The temperature difference was likely induced by natural convection.

C05

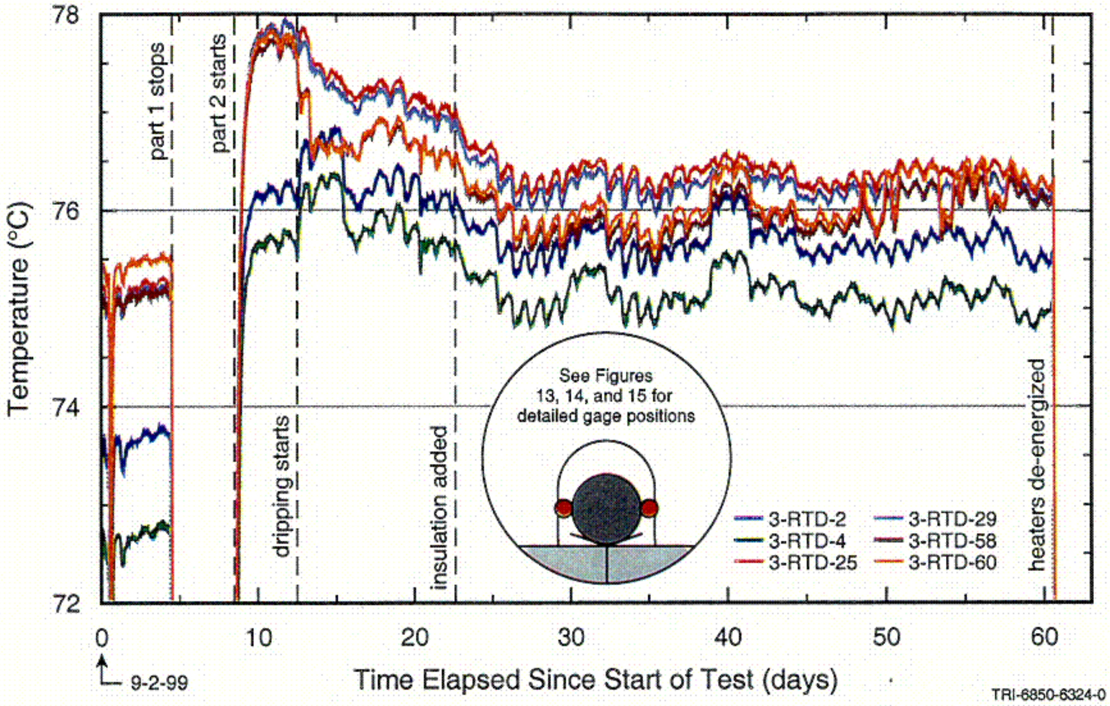

Figure 33. Temperatures on Waste Package Spring Line

These temperatures then increased about 2°C (3.6°F) to average about 77°C (171°F) after the drip shield was installed. This increase is attributable to the drip shield directing more heat downward near the waste package. The gages at the 1-m station are about 1.5°C (2.7°F) cooler than the other gages. Once dripping starts, however, the temperatures at this station rise about 0.5°C (0.9°F) and the comparable gages at the 3-m station drop by about 1.0°C (1.8°F). Temperatures at the 2-m station drop by about 0.5°C (0.9°F) over the next three to four days.

Temperatures held fairly steady for about a week after Day 15.5, until Day 22.62 when the additional insulation was added to the top of the test. This added insulation induced a temperature drop of about 0.5°C (0.9°F) on all the gages at the simulated waste package spring line. This same added insulation had the effect of reducing the temperature of the invert and bottom of the test cell by anywhere from 2 to 4°C (3.6 to 7.2°F), as can be seen in the plots at the end of Section 4.4.3, which show temperatures on the test cell wall below the invert. The insulation also reduced the temperature of the drip shield. Thus the reduced temperature of the simulated waste package can be attributed to the much larger drop in the lower test cell and commensurate drop in the drip shield temperatures. The simulated waste package temperatures at the spring line then stay fairly constant throughout the remainder of the test, with some noticeable short duration rises at the 1-m and 3-m stations at times that correlate to drip system outages over these same general test areas.

C06

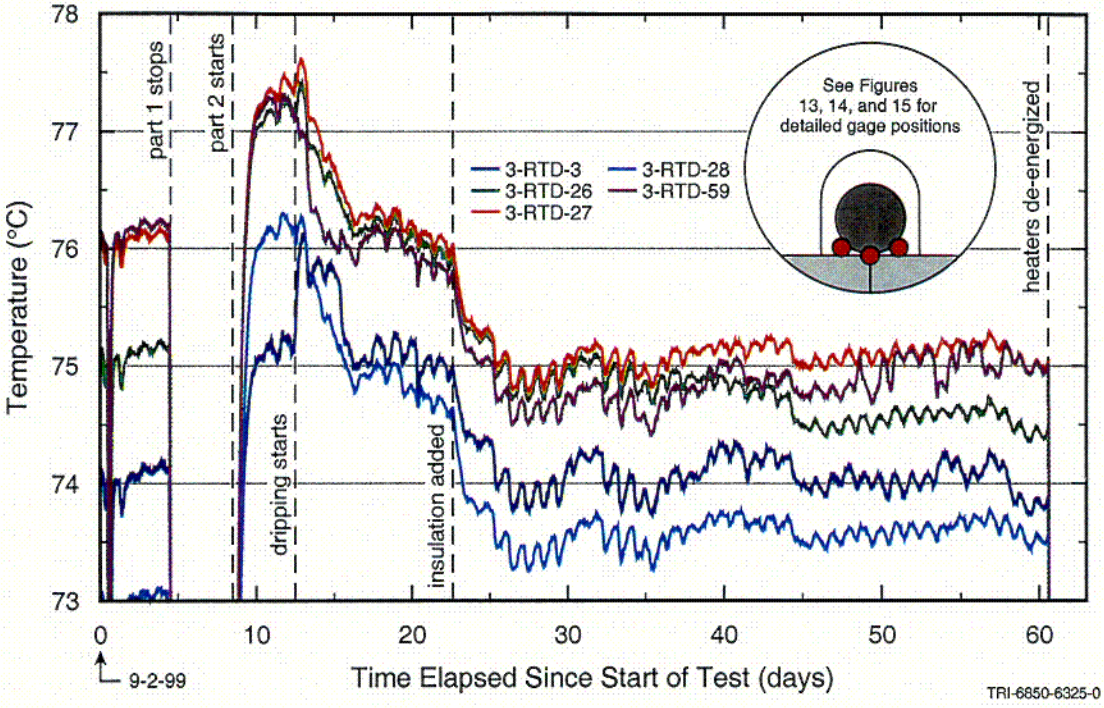

Figure 34. Temperatures on Waste Package Below Spring Line

Waste Package Below Spring Line–Trends for the data below the spring line along the simulated waste package follow the patterns generally traced by comparable gages at the spring line, as shown in Figure 34. RTD 3, located at the 1-m station, has a value lower than the comparable gages at the 2-m and 3-m stations. The presence of the drip shield increases temperatures on the simulated waste package in this region. With the application of the drip water, the temperature of RTD 3 rises about 1°C (1.8°F) while there is a 1°C (1.8°F) drop in RTD 59 located at the 3-m station. The RTDs at the 2-m station subsequently all drop by about 1.5°C (2.7°F) over the next few days. All gage temperatures drop about 1°C (1.8°F) as a result of the extra insulation added to the top of the test cell on Day 22.62.

4.5.2 Temperatures on the Drip Shield

Drip Shield at the Crown–Temperatures along the drip shield crown are shown in Figure 35. Within the first two days after energizing the simulated waste package, temperatures rise to between 68 and 70°C (154.4 and 158.2°F). Once dripping started, all these temperatures dropped between 2 and 4°C (3.6 and 7.2°F) as water carried heat away from the drip shield crown, down the side of the shield, and into the invert. Temperature fluctuations from a few days after the start of dripping can be attributed to variations in the water injection rate for the section of test cell where the measurements were being made. Temperatures at the 3-m station averaged approximately 1.5°C (2.7°F) above comparable temperatures at the 1-m station during the elevated temperature phase of the test, perhaps because of the slightly higher elevation. When the dripping slowed, temperatures rose. Rates of injection to the various parts of the test cell are discussed in Section 4.2 and shown in Figures 26, 27, and 28. The cooling of the invert beginning at Day 22.62 appears to have induced a cooling of the drip shield at the crown by about 1.0°C (1.8°F).

C07

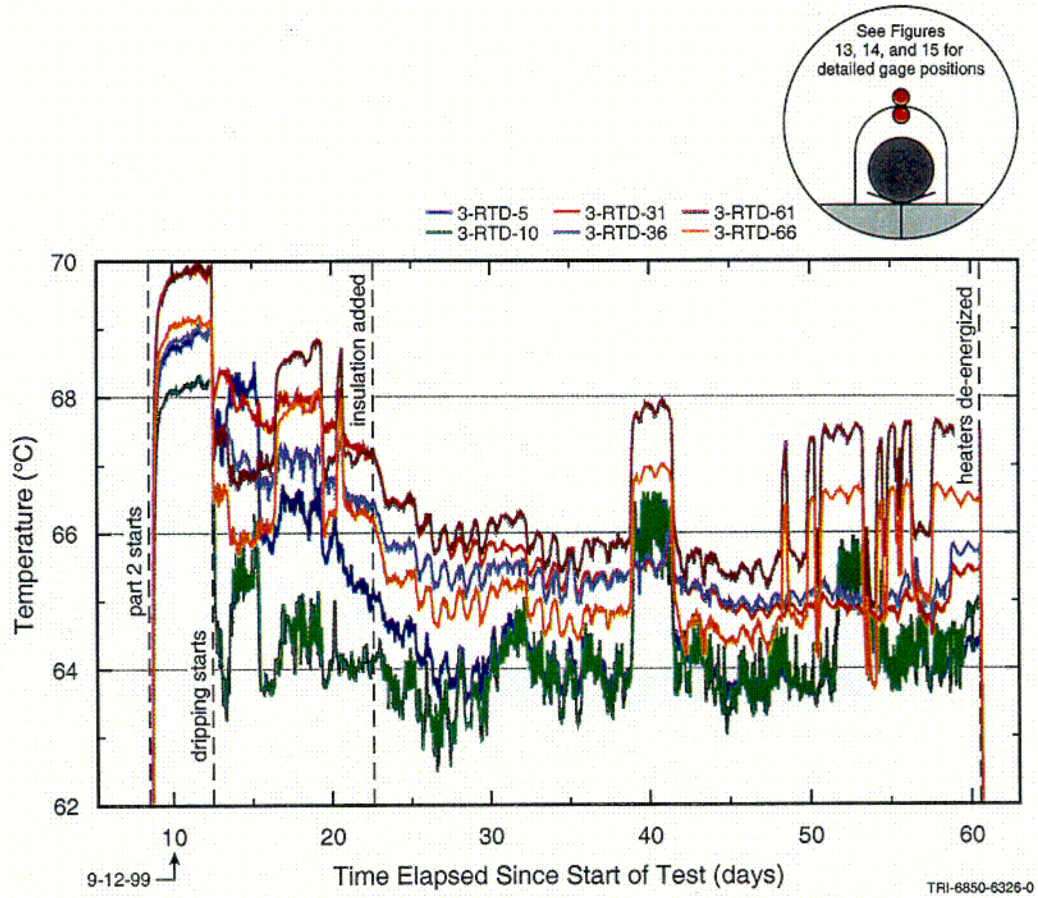

Figure 35. Temperatures on Drip Shield Crown

Temperatures measured by humidity probes 3-HUM-2 and 3-HUM-3, which were mounted in the air space at the crown of the drip shield at the 1-m and 3-m stations respectively, are shown in Figure 36. Note that when the drip injection rate decreased (for example, around Day 40 on Figures 35 and 36), the temperatures increased. Temperatures closely tracked those of the RTDs at the comparable locations (RTDs 5 and 61). They registered the air temperature as being about 0.8°C (1.4°F) above the RTD temperatures when the simulated waste package was first energized. This difference continued through the test for 3-HUM-3, but by the end of the test 3-HUM-2 registered the air temperature as being 3°C (5.4°F) higher than the temperature of RTD 5. As with the RTD measurements on the surface of the drip shield, temperatures responded to the drip rate and the invert temperature decrease.

Drip Shield at the Spring Line–Temperatures from the drip shield spring line are shown in Figure 37. The term "spring line" for the drip shield refers to the part of the shield where the shield legs meet the curvature of the crown, which is about 32 cm (12.6 in.) up from the invert. The gages at this location on the drip shield have temperature profiles similar to those at the drip shield crown, except they are overall about 1 to 2°C (1.8 to 3.2°F) less depending on position. The overall lower temperature can be attributed to the rising of heated air, with the warmest air rising to the crown. When the waste package heater was energized, temperatures rose to

C08

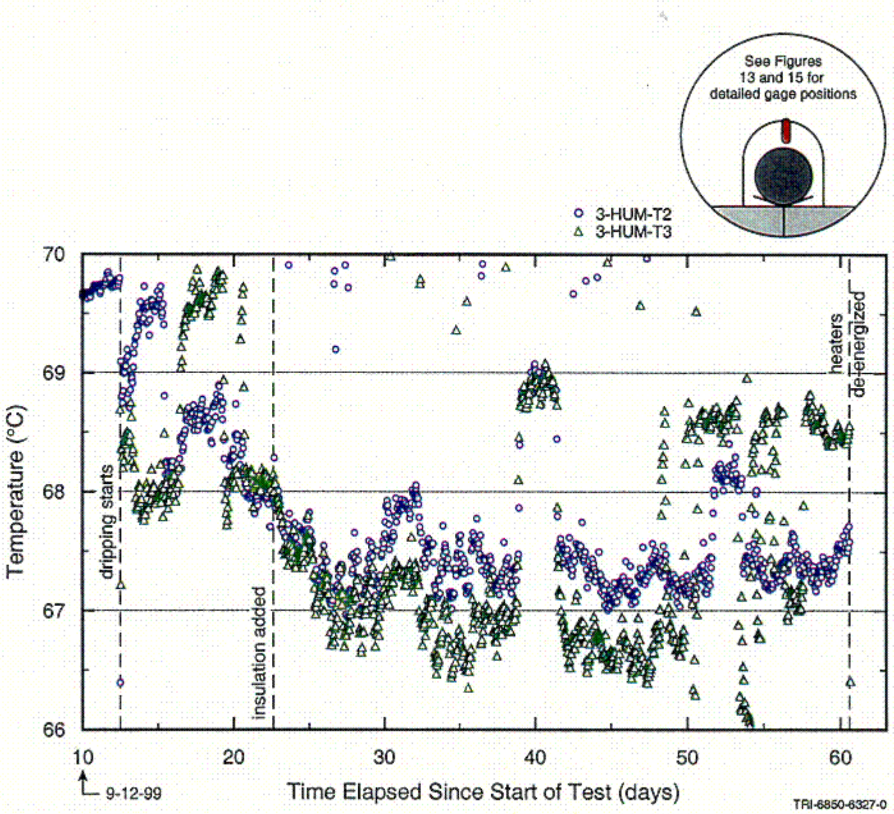

Figure 36. Temperatures (Vaisala gages) under Drip Shield at Crown

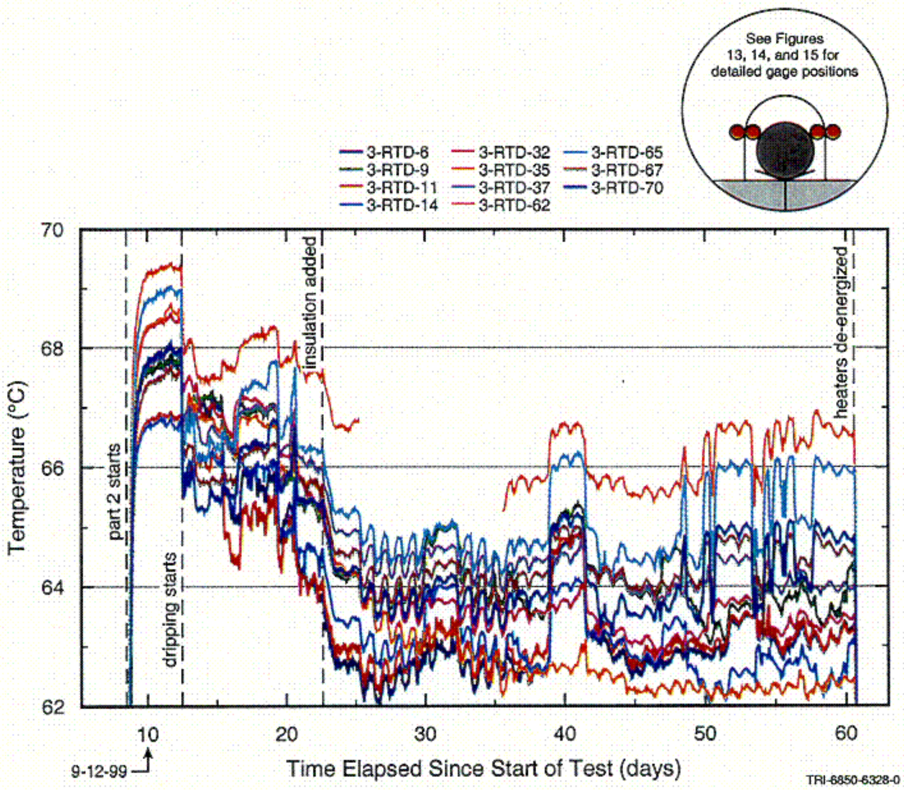

Figure 37. Temperatures on Drip Shield at Spring line

C09

between 66.5 and 69.5°C (151.7 and 157.3°F). Once dripping started, all temperatures fell by 1.5 to 2.5°C (2.7 to 4.5°F). This is thought to be due to evaporation of water off of the drip shield. All temperatures fell by about 1°C (1.8°F) after Day 22.62, when insulation was added to the top of the test cell. Temperatures at the 1-m station consistently ran below the comparable temperatures at the 3-m station. As with other locations on the drip shield, temperature fluctuations can be correlated to the amount of water dripping onto the shield at the location of measurement.

Drip Shield at the Support/Invert–Temperatures at the base of the drip shield are shown in Figure 38. The gages that produced these data were mounted on the drip shield just above the lowest part of the drip shield, which rested on a carbon steel rail that sat atop the crushed tuff invert. The gages at this location on the drip shield have temperature profiles similar to those at the drip shield spring line, except they are overall about 1 to 1.5°C (1.8 to 2.7°F) less. The temperature of the drip shield at the invert is comparable to the temperatures within the invert. The higher temperatures above the invert can be attributed to convection moving the warmer air to higher spaces under the shield. When the waste package heater was energized, temperatures rose to levels between 65.5 and 68°C (149.9 to 154.4°F). Once dripping started, all temperatures fell by 1.0 to 1.5°C (1.8 to 2.7°F), which was due to evaporation of water and the release of latent heat of vaporization. All temperatures fell by about 1.5°C (2.7°F) after Day 22.62, when insulation was added to the top of the test cell. As with other locations on the drip shield, temperature fluctuations can be correlated to the amount of water dripping onto the shield at the location of measurement.

4.5.3 Temperatures on the Test Cell Wall

Temperatures discussed in this section were measured by the gages attached to the test cell wall. Most were located on the inside, but some were mounted to the outside (3-RTD-19, 21, 49, 53, 75, and 77).

Test Cell Wall Above Spring Line–Temperatures on the test cell wall from sensors located above the spring line are shown in Figure 39. Understanding the trends in the data during Part 1 of the test (Day 0 to Day 3.79) requires that test conduct be understood over the test phase. Prior to Day 0, heat was applied in the same configuration as for Part 1 of the test, with the crown of the test cell being held at nominal target of 60°C (140°F) and the crown of the waste package being held at nominally 80°C (176°F). The test was de-energized for about 2.5 hours from Day 0.56 to Day 0.67 in order to install new power monitors. This power outage caused a short-term drop in temperature of about 10°C (18°F) for gages on the test cell wall. Temperatures recovered after this outage and stabilized between 59.8 and 62.5°C (140 and 145°F). After the drip shield was installed and the test was re-energized, temperatures rose to levels very comparable to those before the shield was installed. These temperatures continued along this same pattern until Day 22.62, when the insulation was applied to the top of the test cell. Insulation was added because of observed condensation along the crown (see Section 2.4.3). At this time, the temperatures measured closer to 60°C (140°F), with RTDs 19 and 49 (located outside the test cell) rising about 2°C (3.6°F) and RTDs 42, 48, and 71 dropping about 1.5°C (2.7°F). The temperature registered by RTD-41 decreased gradually from the time the insulation

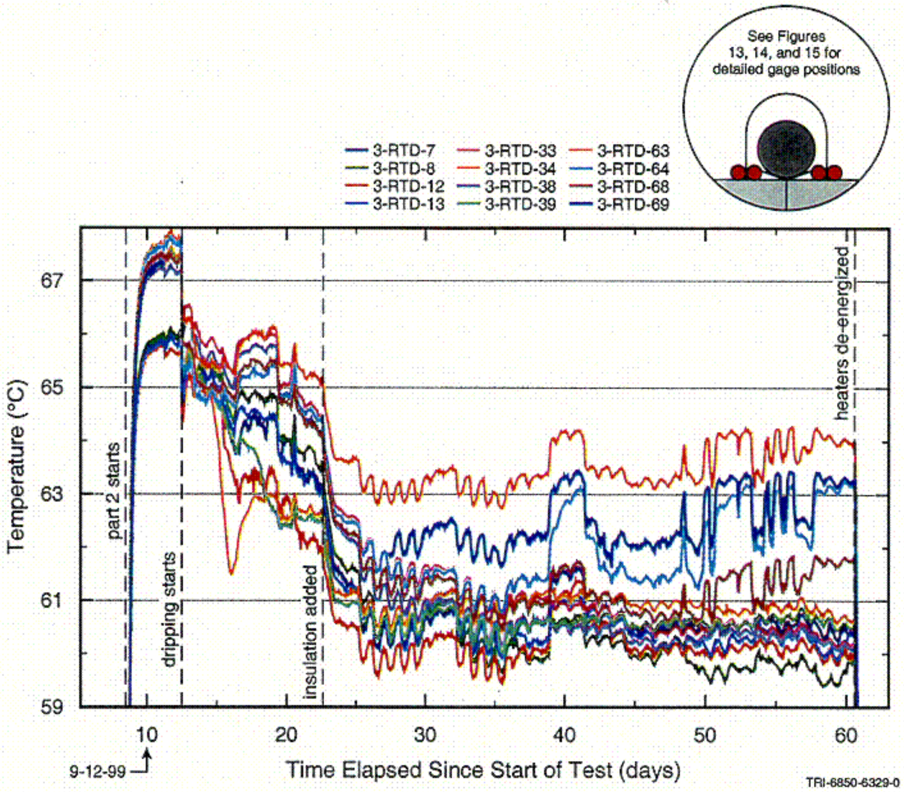

Figure 38. Temperatures on Drip Shield at Invert

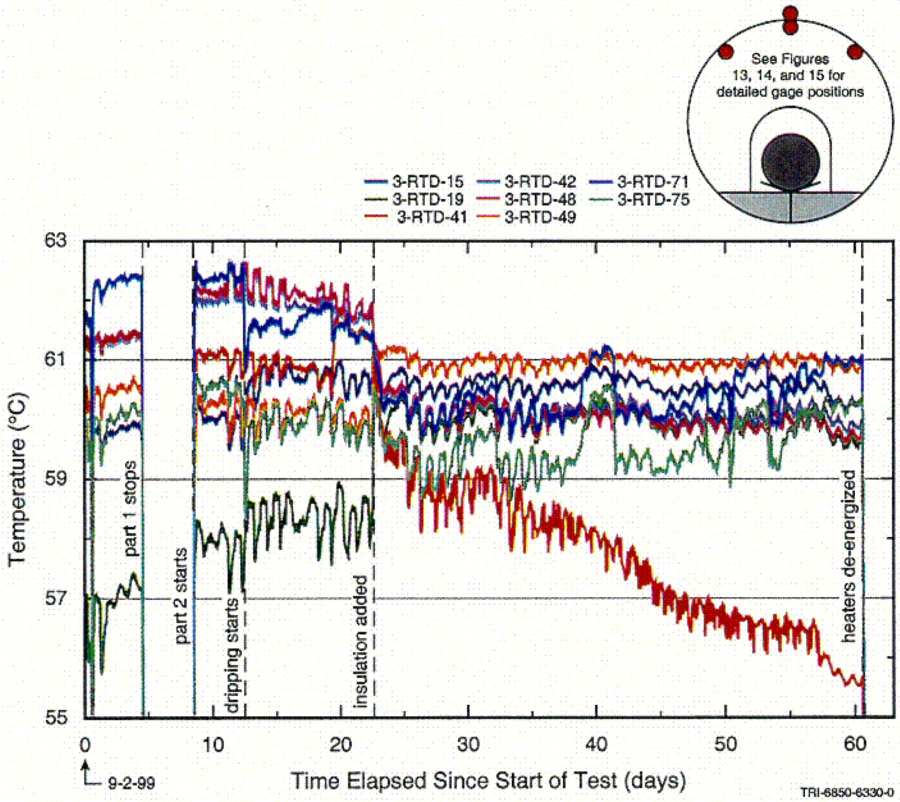

Figure 39. Temperature on Test Cell above Spring line

C10

was added, from 60°C (140°F) to about 55.5°C (132°F) when the test was terminated. This decline is sufficiently different from comparable gages to suggest that the gage was perhaps beginning to fail. After the insulation was added, temperature increases of 2°C (3.2°F) on the drip shield at the 3-m station can be seen manifested as temperature rises of about 1°C (1.8°F) on the test cell wall. The temperature recorded by humidity probe 3-HUM-T1, which is located at the top of the test cell at the 2-m station in the air, is shown in Figure 40. The profile produced by this gage generally tracks those produced by RTDs 42 and 48, as expected.

Test Cell Spring Line–Temperatures on the test cell spring line are shown in Figure 41. During Part 1 of the test, temperatures were between 59.5 and 61.2°C (139 and 142°F), averaging 0.5 to 1°C (0.9 to 1.8°F) less than temperatures at the crown. After the drip shield was installed and the test re-energized for Part 2, these temperatures rose about 1.5°C (2.7°F) above the Part 1 levels to be about equal to temperatures on the crown of the test cell. Once the dripping started, the temperatures grouped into a tighter range, with some temperatures rising slightly and others falling slightly. These temperatures persisted until the insulation was added to the top of the test cell, which induced an average 2.5°C (4.5°F) temperature drop over the next approximately three days. Temperatures then held steady between about 58 and 59.5°C (136.4 and 139.1°F) until the end of the test, fluctuating about 0.5°C (0.9°F) each day because of temperature swings in the test facility.

Test Cell Below Invert–Temperatures in the lower half of the test cell, including two gages located in the invert, are shown in Figures 42 and 43. Gages at the 2-m station are shown in Figure 42, while gages at the 1-m and 3-m stations are shown in Figure 43. During Part 1 of the test, the gage outputs at the edge of the test cell group between 60 and 65°C (140 and 149°F). The two gages in the invert at the 2-m station average about 65°C (149°F) during the same time. This behavior is consistent with heat from the simulated waste package producing higher temperatures at the top of the invert while the edge of the test cell is held around 60°C (140°F). Once the drip shield is in place and the heat is applied for Part 2 of the test, the temperatures of all the gages rise, but there appear to be two groupings of temperatures – one group composed of gages located vertically below the shield, either in the invert or on the test cell wall, and the other group composed of gages outside the vertical projection of the shield. The gages located below the shield group between 69 and 72°C (156.2 and 161.6°F), and those not below the shield group between 64 and 66°C (147.2 and 150.8°F). This behavior can be explained by the presence of the shield, which projected more of the simulated waste package heat downward in Part 2 than in Part 1, when no shield was present. Undulations in temperatures that occurred just prior to the start of dripping appear to correlate fairly well with external temperature fluctuations. After dripping starts, temperatures in the gages below the shield rose about 0.5°C (0.9°F), possibly as a result of hot water draining off the shield down into the invert and onto the bottom of the test cell. This temperature pulse dissipated within about two days, and temperatures below the shield decreased 4 to 5°C (7.2 to 9.0°F), to between 65 and 68°C (149 to 154.4°F). Temperatures outside the downward projection of the shield trended down from the peak at the start of dripping from about 66°C (150.8°F) to about 62°C (143.6°F) over the same time frame. This marked drop can be attributed to two things: (1) more heat being dissipated through the drip shield as a result of the drip water increasing the gradient between the inside and outside of the shield, and

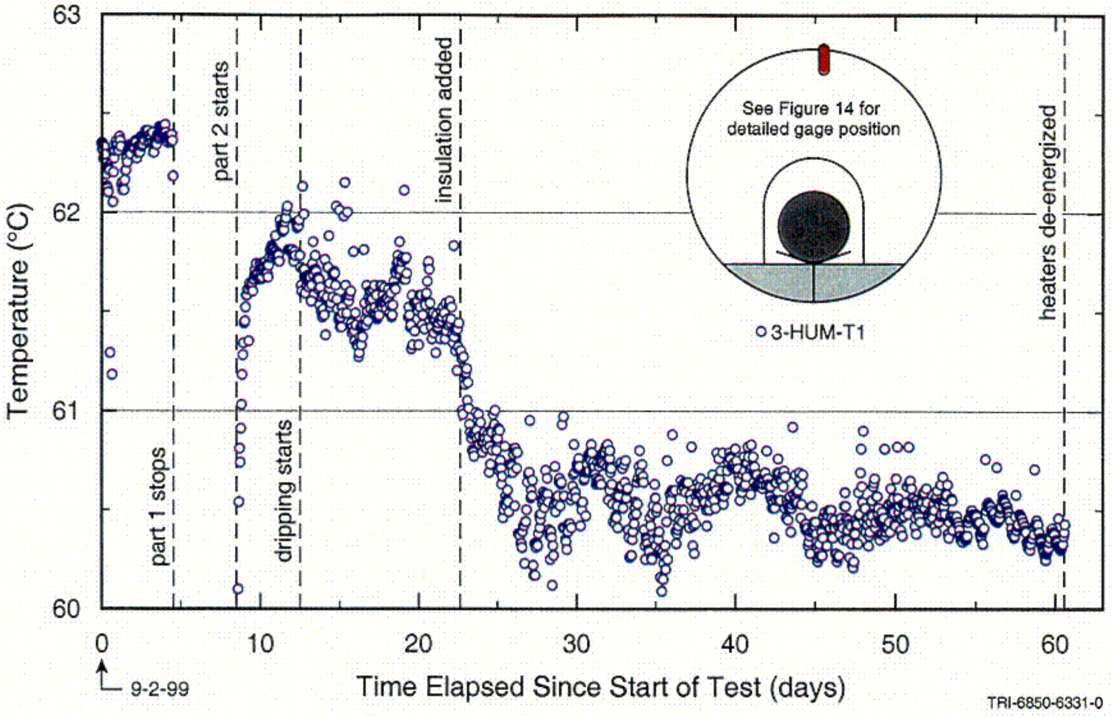

Figure 40. Temperature from Humidity Probe (Vaisala gage) on Top of Test Cell

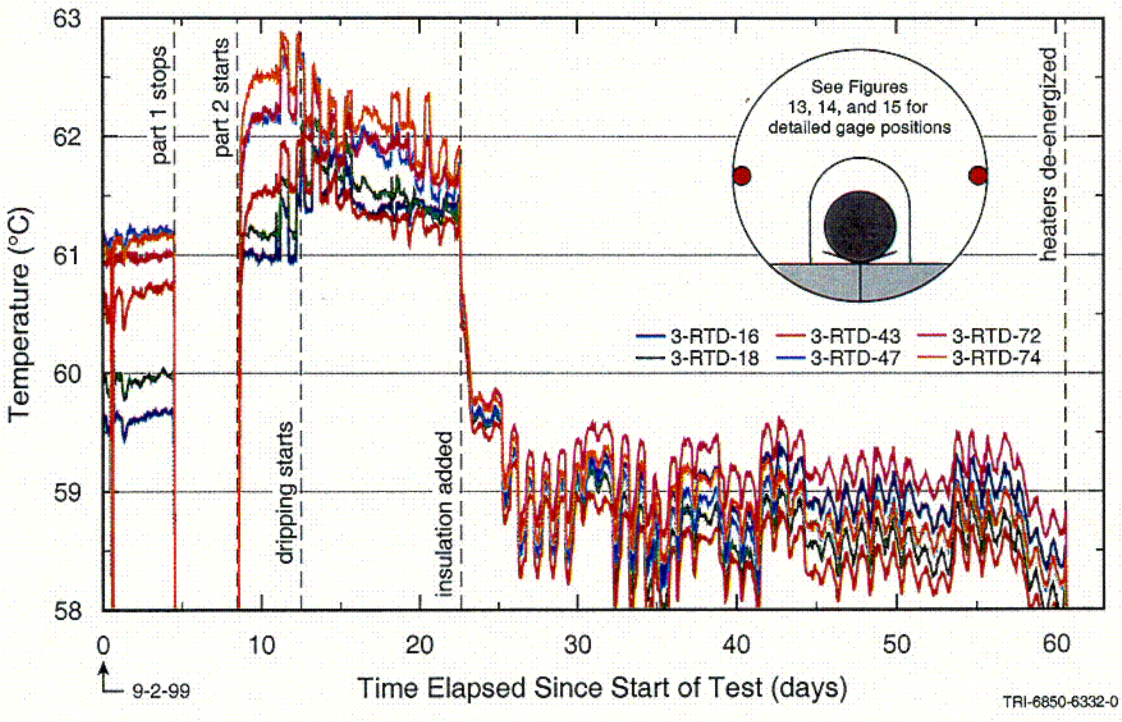

Figure 41. Temperatures on Test Cell Spring Line

C11

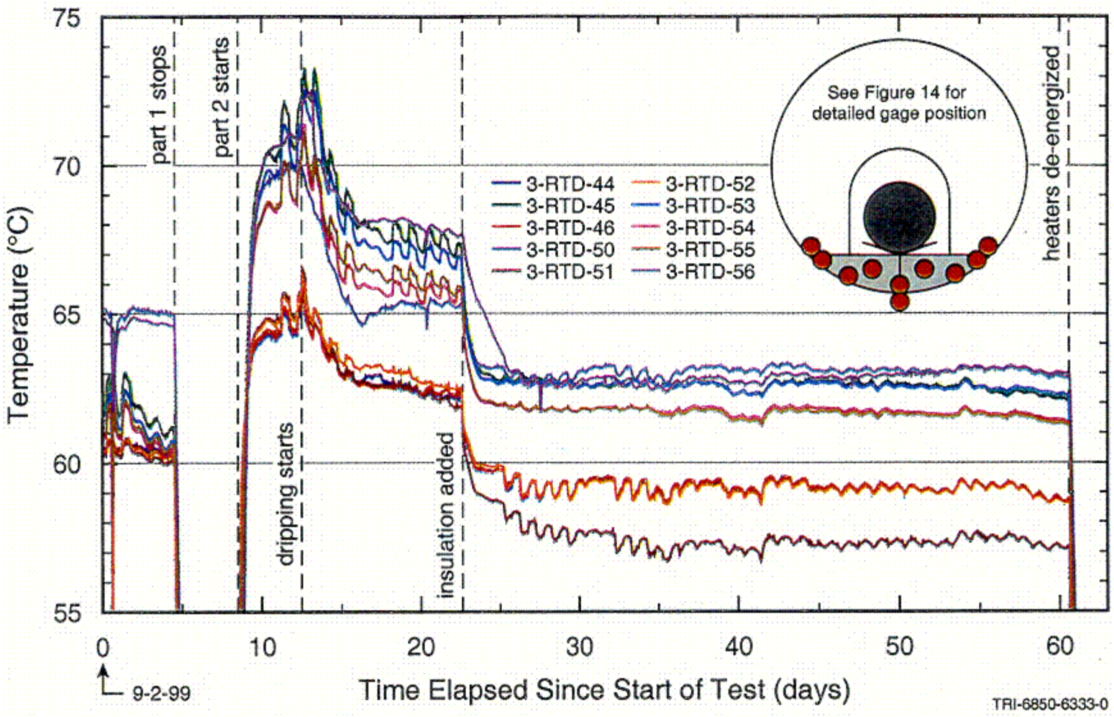

Figure 42. Temperatures on Test Cell below Invert at 2-m Station

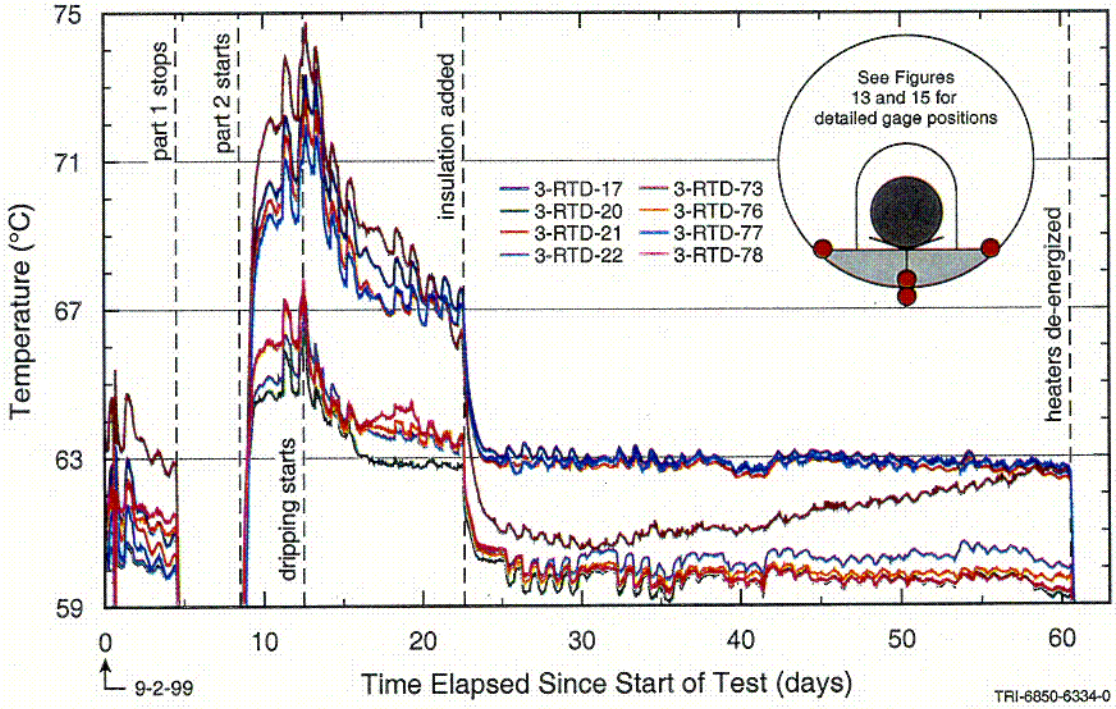

Figure 43. Temperatures on Test Cell Below Invert at 1 and 3-m Stations

C12

(2) an increased moisture content in the invert material outside the shield vertical projection, which would increase its thermal conductivity and cause it to dissipate heat more rapidly than the drier invert under the shield. With more heat leaving through the drip shield, less heat was directed down through the invert. After the extra insulation was added, all the gages, both below and outside the drip shield projection, fell by about 4 to 5°C (7.2 to 9.0°F) over about the next five days and maintained this value consistently until the heaters were de-energized.

A comparison of the temperatures on the coolest part of the drip shield (Figure 38) with those in the coolest part of the invert (Figure 42, RTDs 44, 46, 51, 52) shows that the drip shield temperatures are higher than the invert temperatures.

4.5.4 Temperatures on Ends of the Test Cell

Temperatures on the exterior ends of the test cell are shown in Figure 44. These gages were installed prior to initiating Part 2 of the test, and once the heaters were energized for this phase of the test the temperatures rose to between 56 and 60.5°C (132.8 and 140°F). Once dripping started, the temperatures rose to group between 58 and 61°C (136.4 and 141.8°F). The profiles are quite spurious after dripping started, probably because test observers opened the insulation flaps in the front and back. When these flaps were opened, cool air could contact relatively large areas of the test cell end for a short period of time, perturbing the temperature recorded by these gages. After the extra insulation was added to the top of the test cell, an effort was made to reduce the frequency that the insulation flaps were opened. This change is reflected in the data, which demonstrate a more repetitive pattern after this time until the heater power was de-energized at the end of the test. As with other locations in the test, temperatures dropped as a result of the insulation added on Day 22.62 and group between about 56 and 60°C (132.8 and 140°F). It is relevant to a subsequent discussion of relative humidity that the gages monitoring temperatures on the ends were placed in locations where they could be affixed to metal. Hence these gages could not record the coolest temperatures, which were on the glass windows, as was evident by the condensation seen on the windows and their comparatively lower thermal conductivity. There were also relatively large areas of the test cell ends that were not heated directly, as can be seen in Figure 11 in Section 2.3.

4.5.5 Temperatures in the Insulation Outside the Test Cell

Three gages were located in the insulation outside the test cell at the 2-m cross section, as shown in Figure 45. The output from these gages is also shown in Figure 45. The large rise in the temperature of RTD 85 occurs when additional insulation was placed on top of the gage. This response was expected.

4.6 RELATIVE HUMIDITY DATA

Relative humidity was measured at three general locations using four gages. One measurement was made in the Atlas Facility high bay, where the test was conducted. Another measurement was made inside the test cell at the crown, and two more measurements were made under the drip shield. Relative humidity is directly related to temperature at the point of measurement, so the temperature data from these measurements are also referenced in this section.

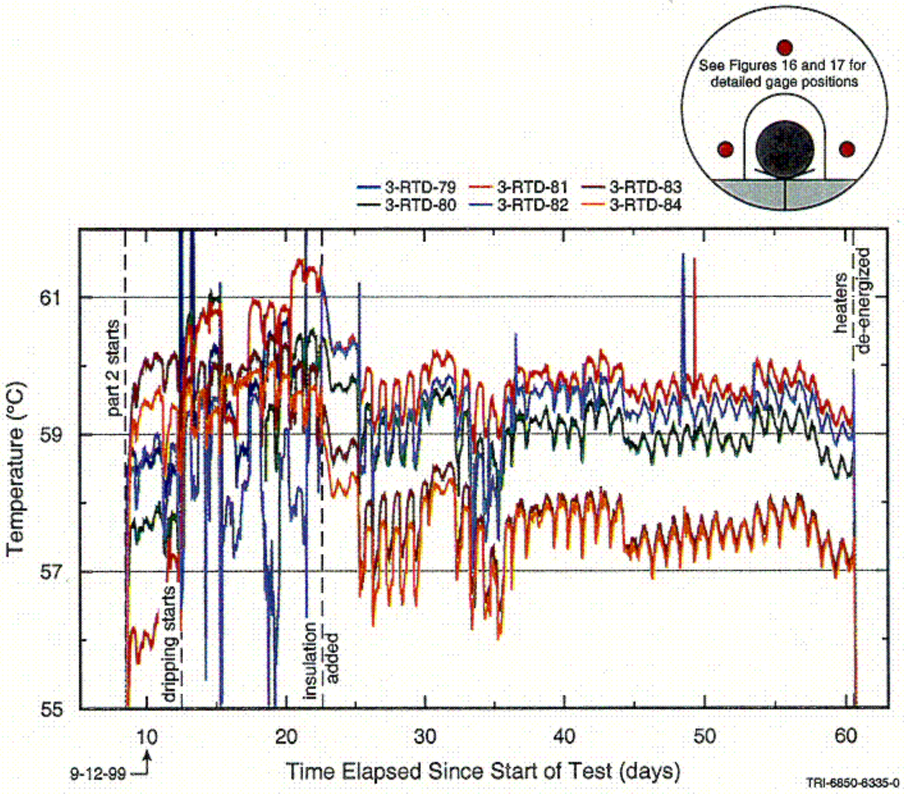

Figure 44. Temperatures on Ends of Test Cell

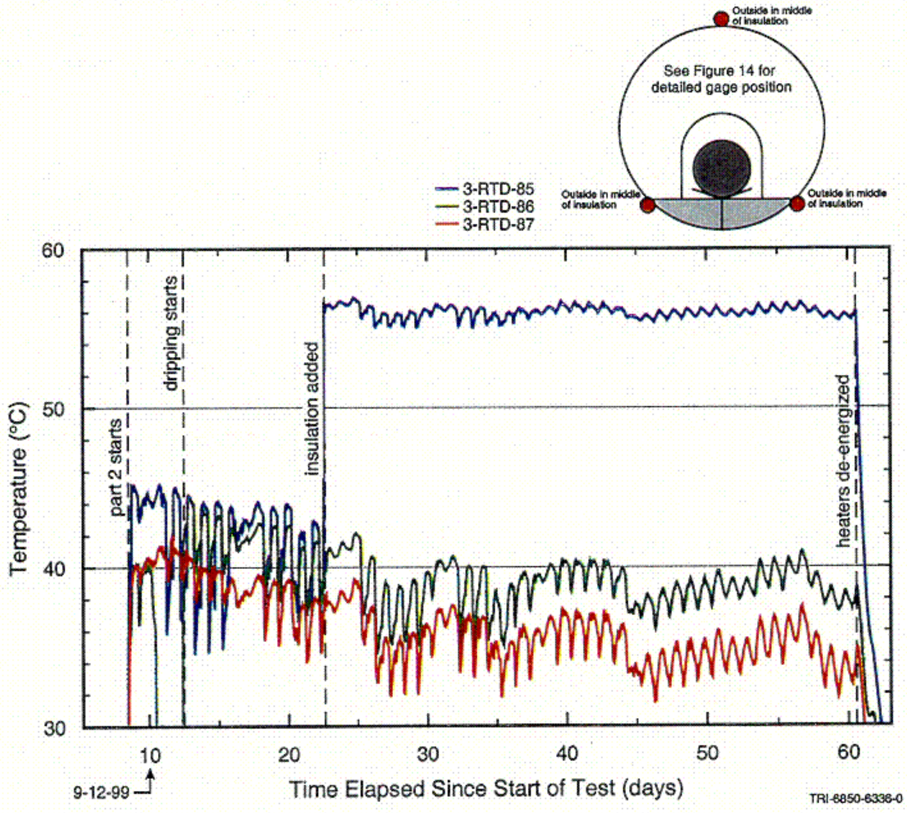

Figure 45. Temperatures in Insulation Outside Test Cell

C13

4.6.1 Relative Humidity in the Atlas High Bay

Temperature measurements in the Atlas high bay are plotted in Figure 46. Relative humidity measurements corresponding to this location are shown in Figure 47. The relative humidity swings by about 25 to 30% RH each day, concurrent with temperature swings of 4° to 7°C (7.2 to 12.6°F). This pattern persists throughout the test.

4.6.2 Relative Humidity at the Test Cell Crown

The relative humidity measured at the top of the test cell crown at the 2-m station is shown in Figure 48. The outlying data points (plotted about 5% RH below the main trend) are attributable to gage malfunction. Even though output was spurious, the main trend of the data is believed to accurately reflect the relative humidity conditions at the top of the test cell. Concurrent with the initiation of dripping, relative humidity rose to about 84% and trended higher over the next ten days to peak at about 87%. When the insulation was added, relative humidity rapidly dropped (within about 15 hours) to about 83.5% and remained between 81 and 84% until the heaters were de-energized toward the end of the test. The larger fluctuations in the humidity correlate to the rate of water application: when water application rates fall, so does the relative humidity. When the test heaters were de-energized, the relative humidity approached 93% as temperatures in the test cell decreased to ambient levels.

4.6.3 Relative Humidity under the Drip Shield

Relative humidity measurements made at the 1-m and 3-m stations under the drip shield are shown in Figures 49 and 50. Figure 49 shows a longer time frame and larger scale. These gages were located at the crown of the shield. The humidity profiles from these gages are similar to the humidity gage at the crown of the test cell, but at a level about 20% RH lower because of higher temperatures under the shield. The humidity started low but rose when drip water was applied. Within three to five days, relative humidities began to stabilize around 64% while temperatures still fluctuated. These fluctuations continued until about Day 20 when the humidity under the shield began to stabilize again, this time at around 69%. At Day 22.62, when the insulation was added, the humidity dropped by 4 to 5% RH. The relative humidity at the 3-m station stayed consistently 5% to 8% higher than the humidity at the 1-m station. When the larger temperature increases induced by outages of the drip system occurred, such as those starting at Day 39 and Day 51 (see Figure 36), the relative humidity dropped. During a smaller temperature increase, caused by a less pronounced water injection decrease starting at Day 30, the relative humidity was not affected. The relative humidity from these gages increased to between 90 and 93% RH when the heaters were de-energized at the end of the test—consistent with a more uniform temperature throughout the test cell.

4.6.4 Vapor Pressures Associated with Relative Humidity Measurements

The Tetens formula, as published in Campbell and Norman (1998, p. 41) and shown in Equation 1, allows one to calculate a theoretical saturated equilibrium vapor pressure that would

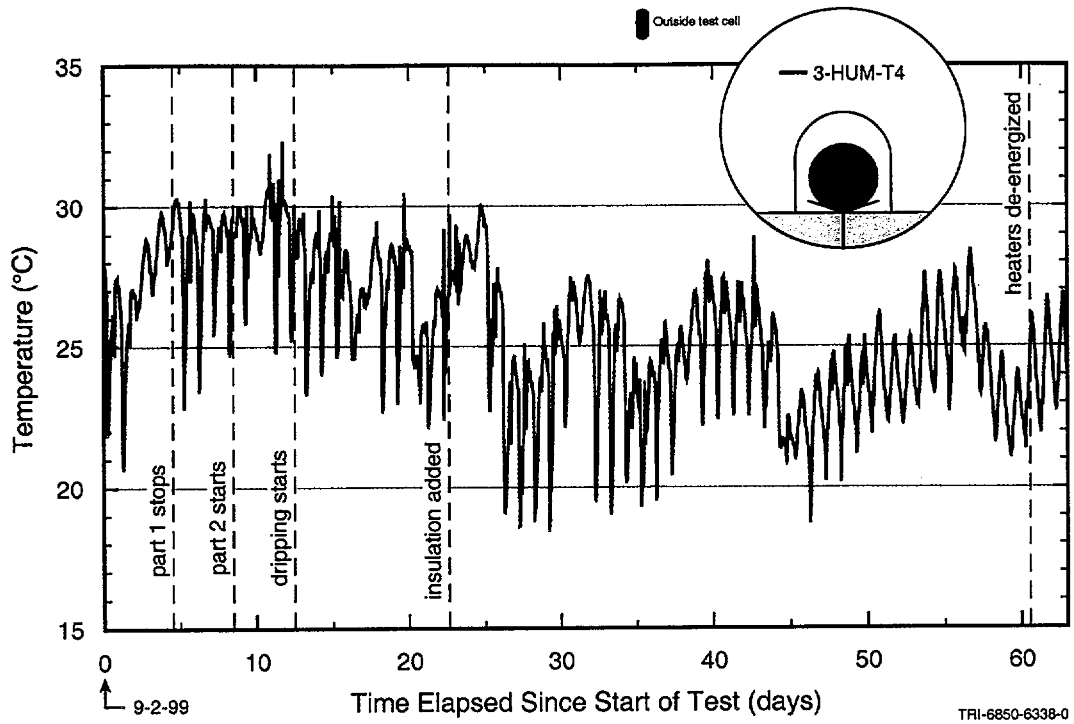

Figure 46. Temperatures in the Atlas High Bay

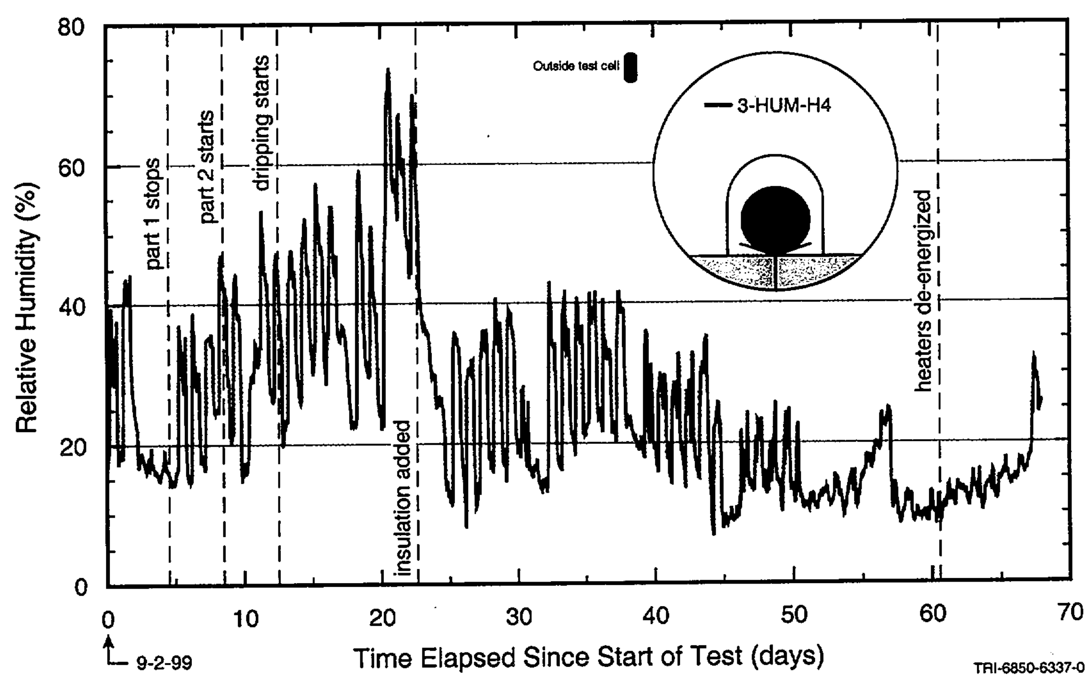

Figure 47. Relative Humidity in the Atlas High Bay

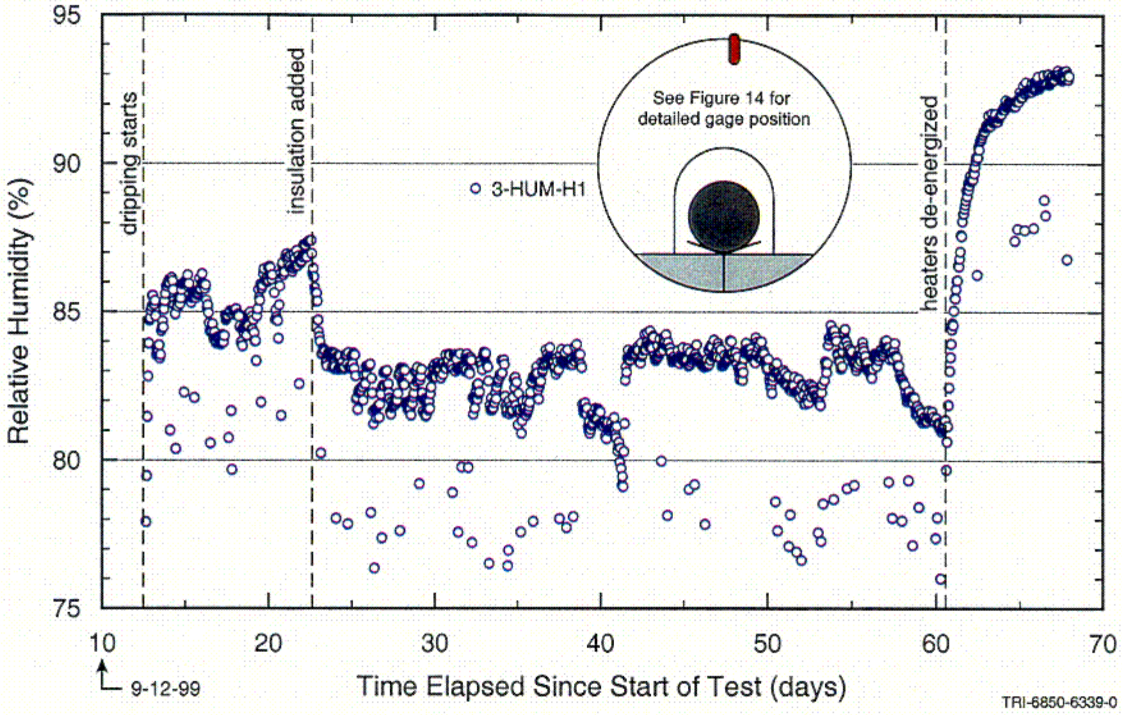

Figure 48. Relative Humidity at Top of Test Cell

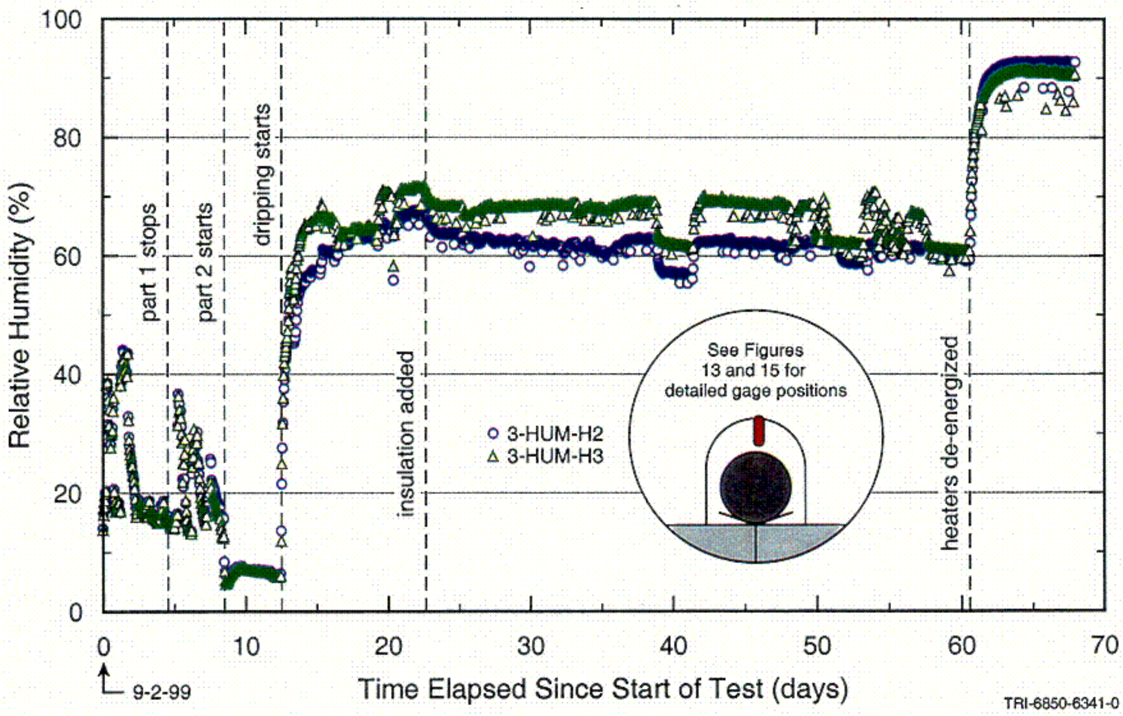

Figure 49. Relative Humidity under Drip Shield at Crown (Starting at Day 0)

C14

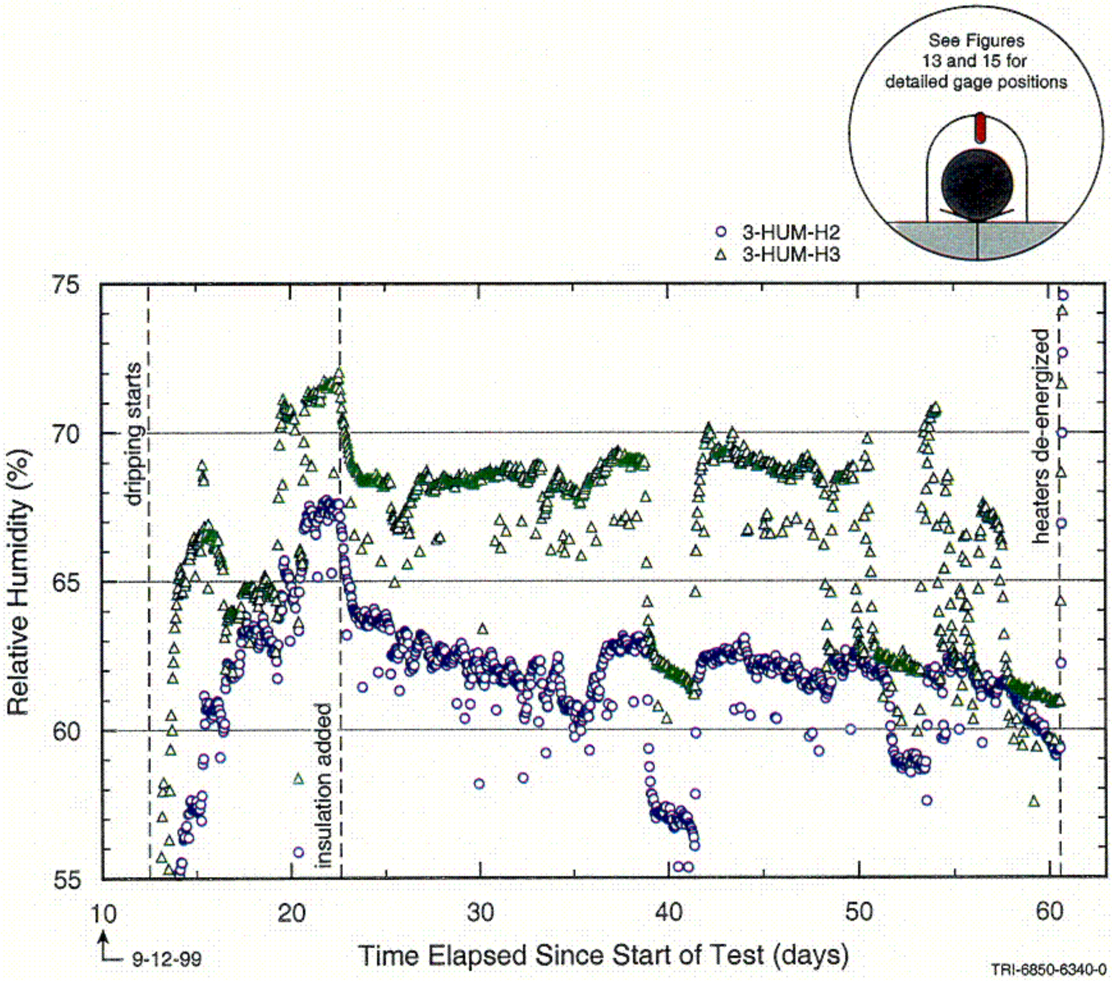

Figure 50. Relative Humidity under Drip Shield at Crown (Starting at Day 12)

exist above liquid water at a given temperature. This equation predicts vapor pressures very close to those published in Weast and Astle (1981, p. D-168).

$$e_s(T) = a \exp (bT/T+c) \qquad \text{(Eq. 1)}$$

where

$e_s(T)$ = the vapor pressure in kPa (and a function of temperature)
T = the temperature in degrees Celsius

and a, b, and c are constants:

a = 0.611 kPa
b = 17.502
c = 240.97°C.

C15

Relative humidity at a specific point is defined as the ambient vapor pressure at that point divided by the theoretical saturated equilibrium vapor pressure at that same point for a given temperature, as shown in Equation 2 (Campbell and Norman 1998, p. 46).

$$h_r = e_a/e_s(T) \qquad \text{(Eq. 2)}$$

where

h_r = the relative humidity
e_a = the ambient vapor pressure at the point of interest
$e_s(T)$ = the saturated vapor pressure at temperature T.

The relative humidity and the temperature measurements from the relative humidity gages can be used then to calculate the ambient vapor pressure at the measurement locations. Equations 1 and 2 are combined as shown in Equation 3 to calculate the ambient vapor pressure (in kPa) based on the measured relative humidity and temperature.

$$(h_r)\ a \exp\left(bT/T{+}c\right) = e_a \qquad \text{(Eq. 3)}$$

Once this pressure is known, dewpoint temperatures can be calculated to estimate average minimum temperatures that would exist to create the ambient vapor pressure, as shown in Equation 4 (Campbell and Norton 1998, p. 44). Equation 4 is derived by solving Equation 3 for temperature.

$$T_d = c \ln(e_a/a)/[(b - \ln(e_a/a)] \qquad \text{(Eq. 4)}$$

where

T_d = the dewpoint temperature in degrees Celsius.

The difference between the theoretical equilibrium vapor pressure $e_s(T)$ and the ambient vapor pressure e_a at a point will yield the vapor deficit for that point. Figure 51 shows the ambient vapor pressure calculated from the data for the three relative humidity probes of the test, where VP-1, 2, and 3 correspond to the gage positions of 3-HUM-1, 2, and 3, respectively. Figure 52 shows the predicted dewpoint temperatures, where DP 1, 2, and 3 correspond to the gage positions of 3-HUM-1, 2, and 3, respectively. Figure 53 shows the calculated vapor deficits, where Vapor Def 1, 2 and 3 correspond to the gage positions of 3-HUM-1, 2, and 3, respectively.

Vapor pressures rose when dripping was initiated. The pressure at the top of the test cell stabilized within about 1 day at a value of about 18.5 kPa (2.7 psi). Vapor pressures under the drip shield rose at a slower rate and were not stabilized prior to Day 22.62, when the insulation was added to the test cell. The vapor pressure was highest at the 3-m station, rising to a peak of almost 20 kPa (2.9 psi); the peak vapor pressure at the 1-m station was about 19.5 kPa (2.8 psi) if the spurious data points are discounted. After application of the extra insulation, and the associated cooling of the lower part of test cell and invert, vapor pressures dropped by about 1.5 kPa (0.2 psi) at all locations. The relative distribution of pressure as a function of position remained about the same throughout this time and persisted until the heaters were de-energized.

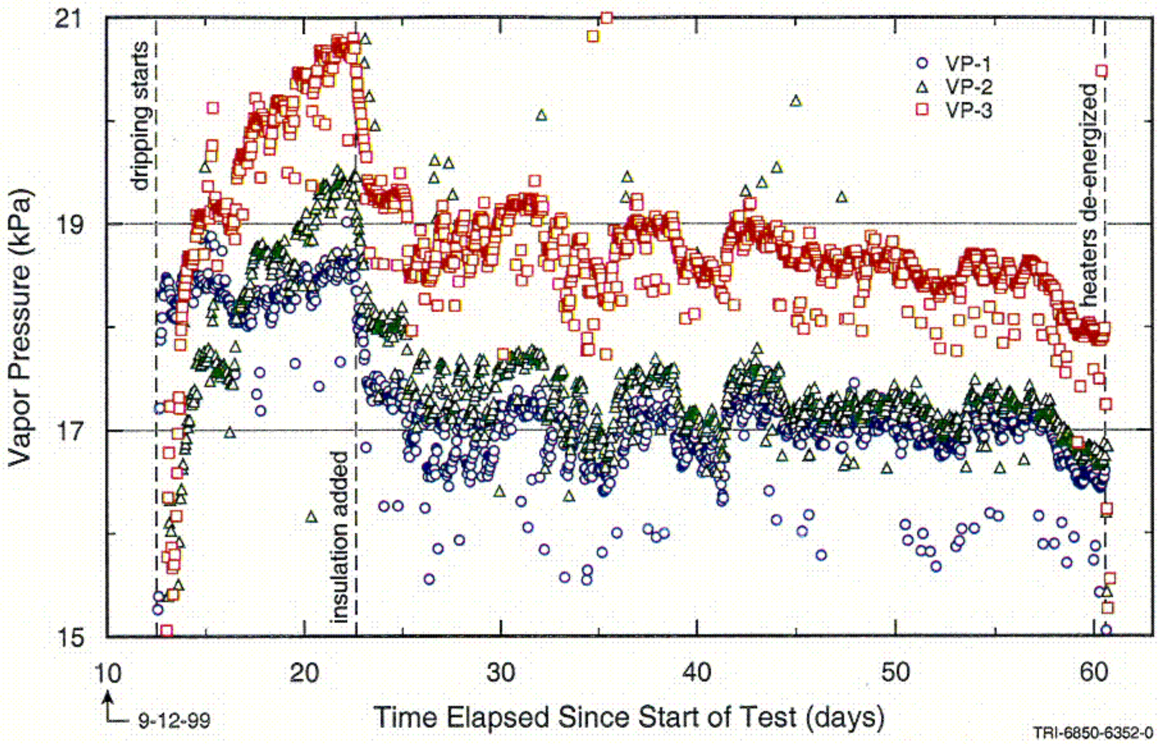

Figure 51. Vapor Pressure in Test (Calculated from Relative Humidity Data)

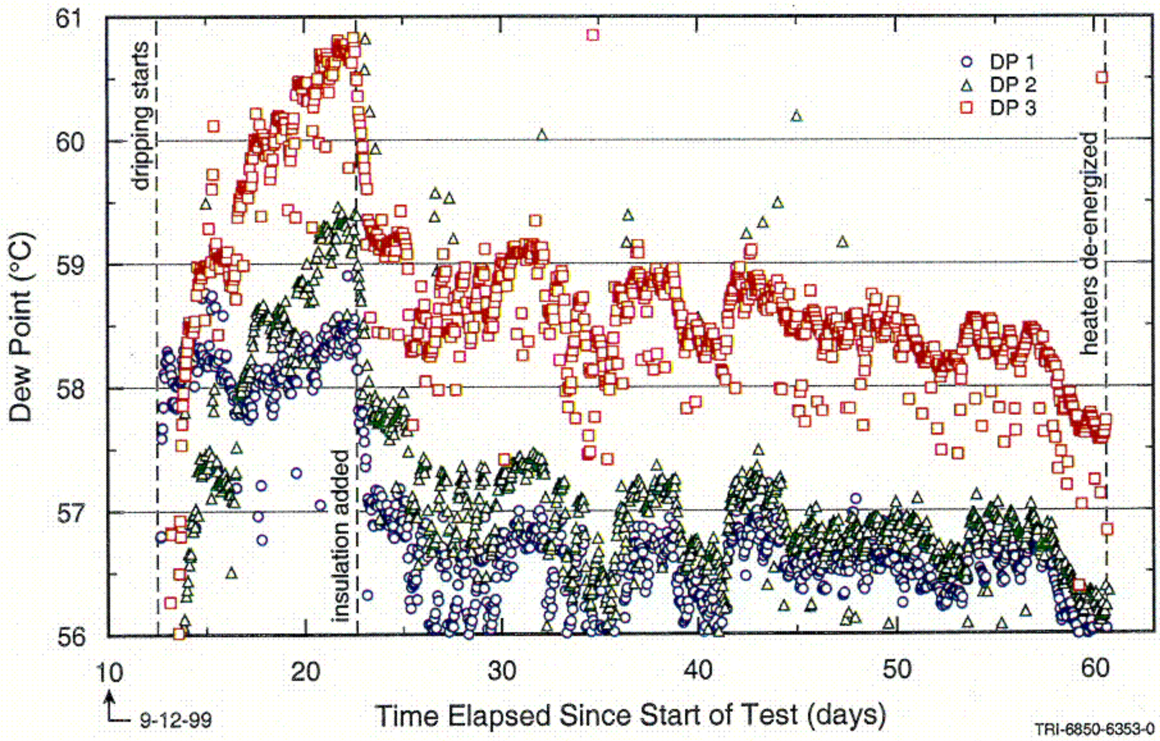

Figure 52. Dewpoint Temperature in Test (Predicted)

C16

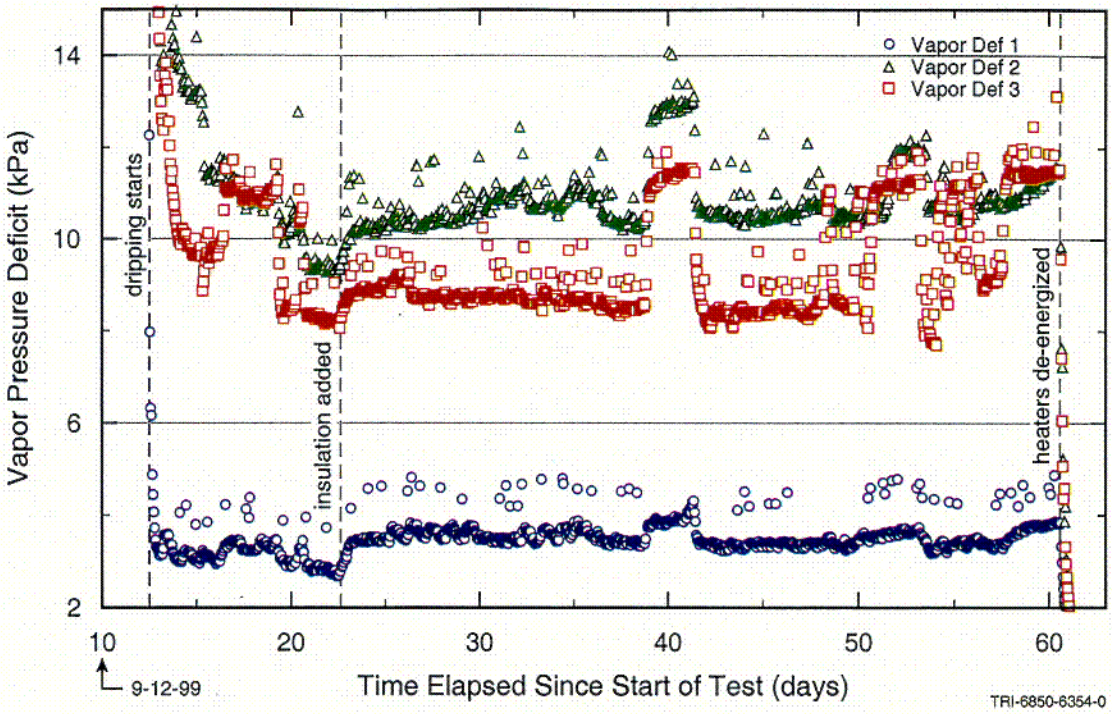

Figure 53. Vapor Deficit in Test (Calculated)

Dewpoint temperatures for the humidity probe measurements made in the test cell are shown in Figure 52. Because the dewpoint temperatures were derived from a manipulation of the ambient vapor pressure, the graphs have identical profiles with the exception of vertical scale. The general layout of the temperatures indicates a higher dewpoint temperature for the gages under the drip shield than the gage at the crown of the test cell, and a higher dewpoint temperature for the 3-m station than at the 1-m station. This difference can be explained by the generally higher temperatures that existed under the drip shield than in the test cell, and the higher temperatures at the 3-m station on the drip shield than at the 1-m station. The average temperatures from ten RTD gages attached to the drip shield at each of the 1-m and 3-m stations are shown in Figure 54. The average temperature at the 3-m station trends consistently above the average temperature at the 1-m station by 1.5 to 2°C (2.7 to 3.6°F). Dewpoint temperatures under the drip shield were likely controlled by some combination of temperatures in the invert material under the shield (because of its relatively large surface area) and the test cell ends, where there was less heater coverage and the glass windows contributed to condensate. The dewpoint temperature for the gage at the test cell top was likely controlled by the invert material external to the shield, test cell ends, and wall—where cooler temperatures were recorded and condensate was observed and collected. When comparing the dewpoint temperatures with the drip shield temperature, at no point was drip shield temperature equal to the dewpoint temperature.

The vapor deficit for the three humidity probes is plotted in Figure 53. Vapor deficit was high with the initiation of dripping, as expected, but leveled out by about Day 13 for gages at the top

C17

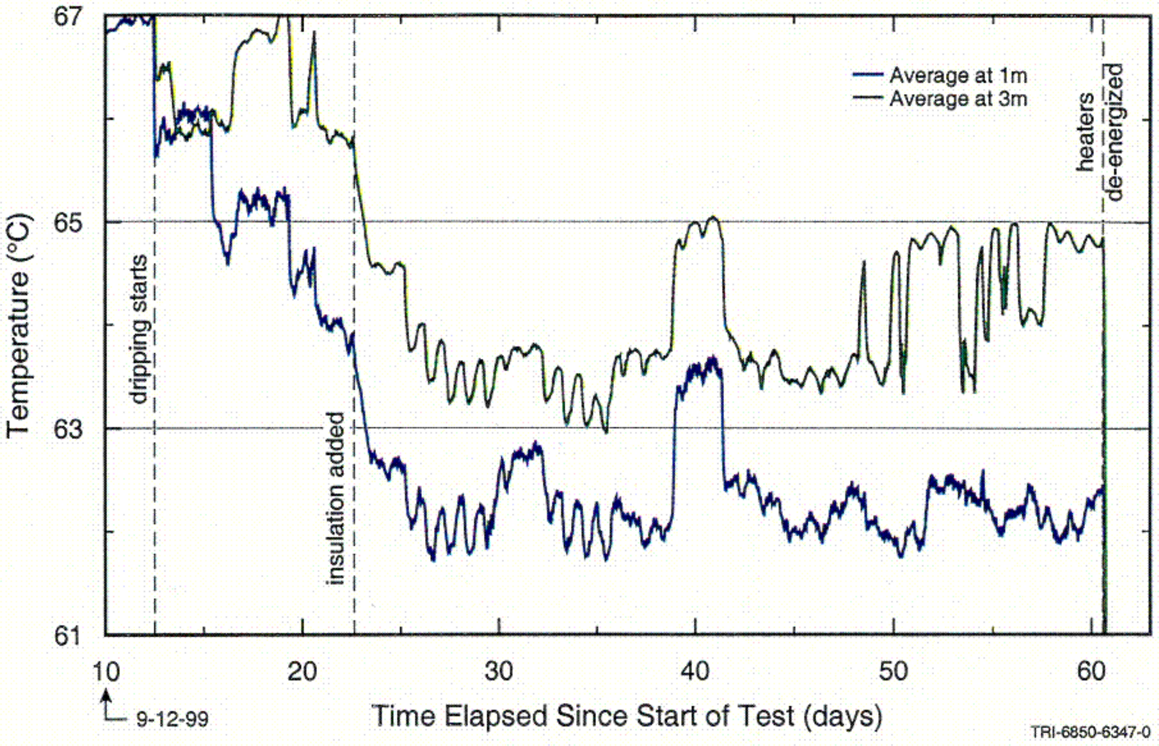

Figure 54. Average Temperatures on Drip Shield, 1-m, and 3-m Stations

of the test cell, and leveled by about Day 17 for gages under the shield, concurrent with a temperature increase induced by an outage of the drip water system. The vapor deficit at the 1-m station was consistently higher than at the 3-m station starting from about Day 20. Vapor deficits increased when temperatures increased. When the test heaters were de-energized, vapor deficits trended to zero.

4.6.5 Thermocouple Psychrometer Relative Humidity Measurements

On September 17, 1999 a full suite of measurements was attempted on the 18 TCPs installed in EBS Test #3. A matric potential reading was difficult to obtain because the needle did not converge to a dewpoint temperature; instead the needle experienced a 1 to 2 second pause at a voltage output and then fell to zero. The voltage output at the 1 to 2 second pause was recorded for each TCP. This voltage was then used to solve for relative humidity. The resulting thermocouple psychrometer relative humidity measurements, attempted in EBS Test #3, are suspect because the needle did not exhibit a standard voltage response to a matric potential measurement. The measurement difficulty experienced on September 17 was tied to the low relative humidity environment in EBS Test #3 during the measurements. The Vaisala sensors were reading low humidities (between 55% and 85%) on September 17, which is out of the measurement range of the TCPs. It is likely that a bead of moisture would not be able to form on the TCP copper-constantan junction when the relative humidity is in that range. In summary, the TCP measurements attempted on September 17 are not considered satisfactory because the

C18

relative humidity conditions were out of the instrument's calibrated measurement range and the measured voltage output was not typical for a dewpoint measurement.

4.7 WATER BALANCE DATA

As explained earlier, the test cell support frame sat atop six load cells so that weight changes to the overall system could be monitored. Output from the load cells is shown in Figure 55. This plot shows that when the heat was turned off to install the drip shield, the weight distribution on the load cells shifted. The total test cell weight increased by more than 907.2 kg (2000 lb) when the drip shield was installed, as expected. When the test was re-energized to start Part 2, the total weight was again redistributed on the load cells. The weight redistributions apparently caused some support frame flexing resulting from increased temperature and associated thermal expansion. Because the frame was bolted to the load cells, minor flexures induced large weight shifts.

A summation of the load cell outputs between Day 8 and Day 68 (a time frame starting just after drip shield installation) is shown in Figure 56. Starting when the dripping began, the total weight increased 52 kg (115 lb) to 3284 kg (7241 lb) over a period of about 15 days. This net weight gain can be explained by the invert material retaining water, with the balance of the water being removed as effluent (by suction lysimeters). Starting about Day 26, the total weight decreased by about 11.34 kg (25 lb) over the next four days as the rate of drip water injection decreased while the effluent removal continued at a steady rate. The rate of total drip water injection is shown in Figure 57. Starting on about Day 38, there is a marked drop in the total weight of about 34 kg (75 lb) over the next three days. This drop corresponds to a sharp decrease in the injection rate, as shown in Figure 57. Starting from about Day 41 until the end of the test, total test cell weight stayed between 3243 and 3289 kg (7151 and 7252 lb). The larger undulations in data can be correlated to the injection rate.

The water balance for the test is shown in Figure 58. The uppermost line is the cumulative weight of injected water, which steadily increases as water is dripped into the test cell. The slope started out at 16.79 kg (37 lb) per day, with the exception of short intervals (a couple of days) when outages of the injection pump occur. The stepped lines of data below this line display the cumulative effluent from the test collected from lysimeters at the bottom of the test cell. The stepped lines show a steady trend of water removal of 14.06 kg (31 lb) per day. The water retained in the test cell is also shown; it quickly rose when dripping was initiated, and then leveled off at 45.36 kg (100 lb). These data were derived by taking the total test cell weight prior to dripping and subtracting it from subsequent weights of the test cell as the test progressed. Thus the retained water curve follows the same profile as the total weight curve; its undulations are discussed in the previous paragraph.

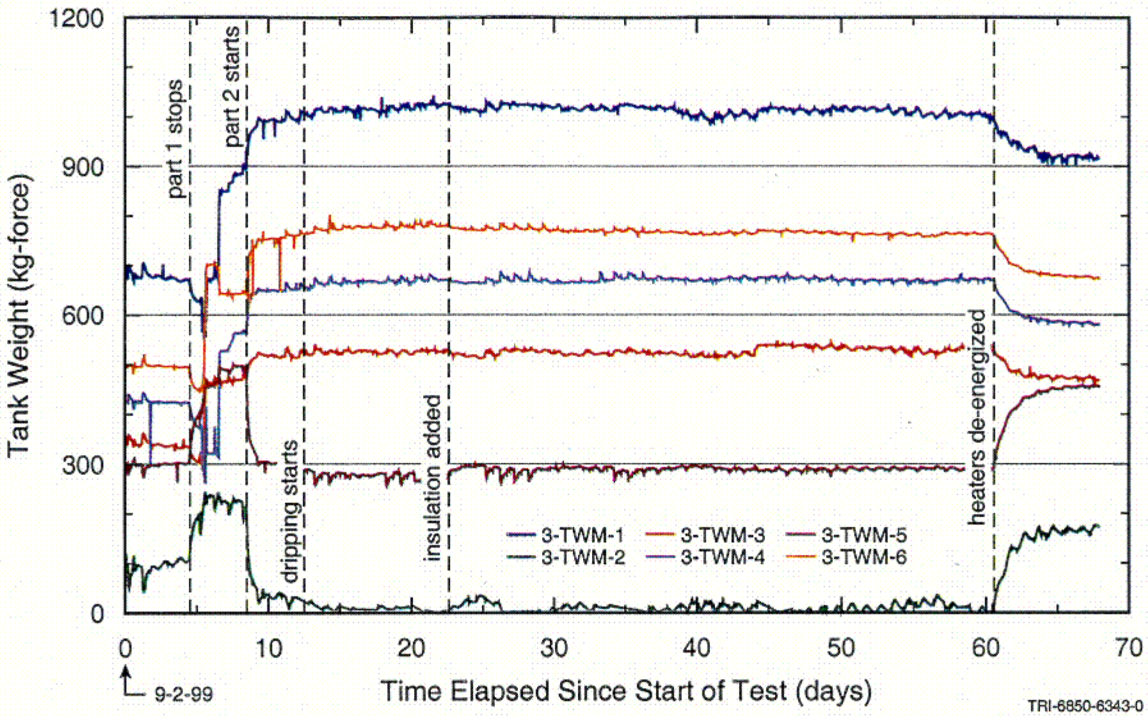

Figure 55. Tank Weigh Modules Output

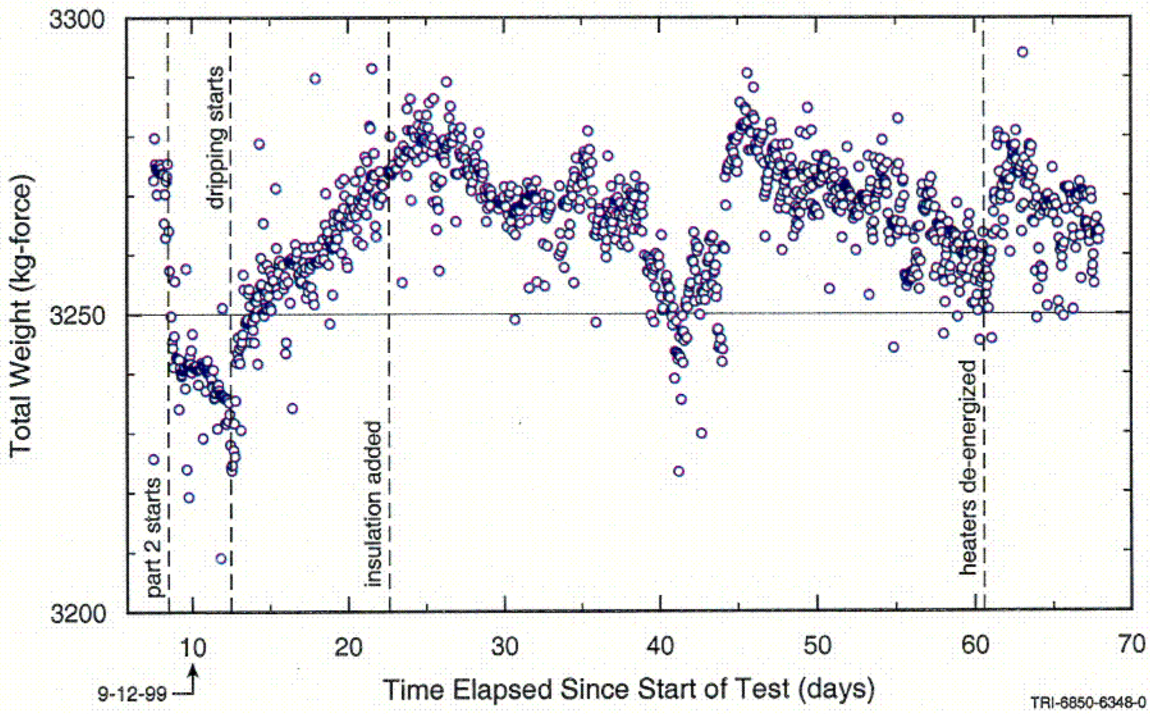

Figure 56. Tank Weigh Modules

C19

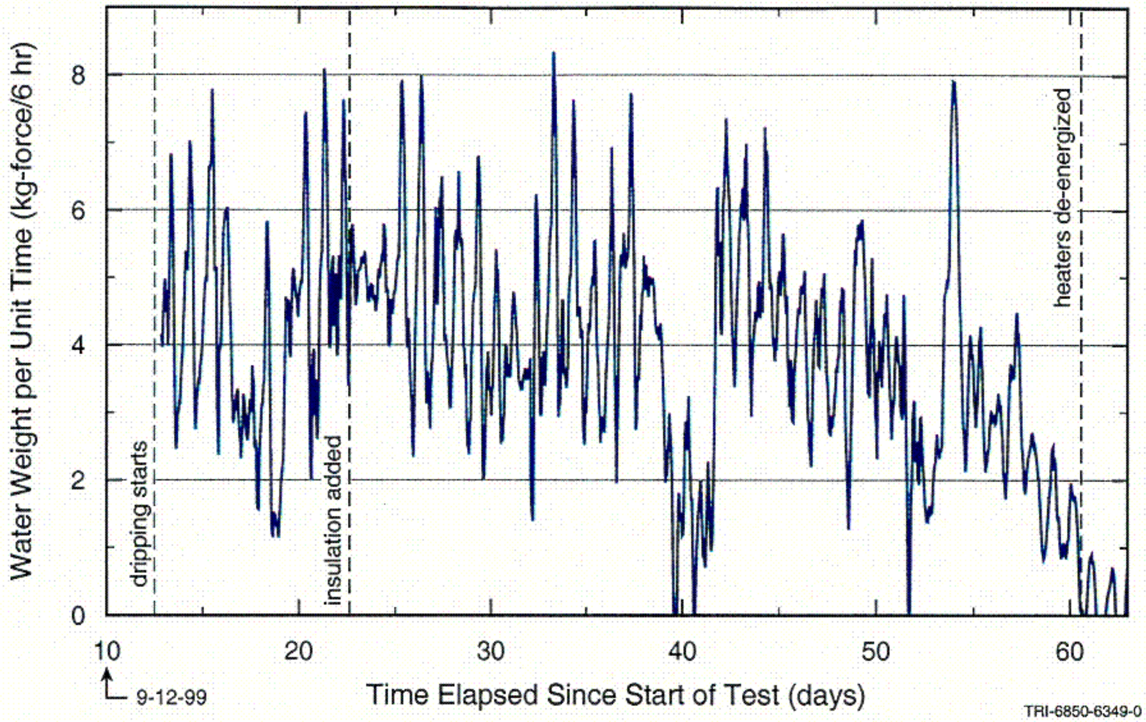

Figure 57. Total Injected Water During Previous Six Hours

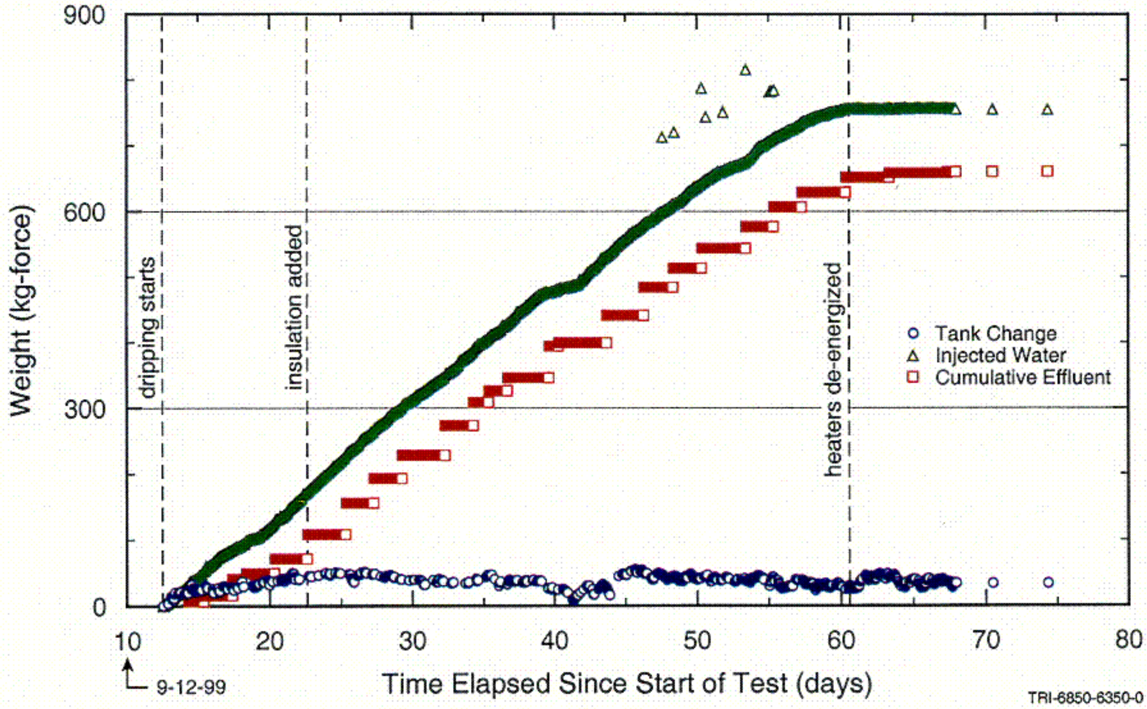

Figure 58. Water Balance Data (Tank, Injection, and Effluent Weights)

C20

Water applied to the test cell but not retained in the invert or collected as effluent can be calculated by subtracting the effluent and retained water weights from the total injected water weight. This water was apparently lost from the system through evaporation. The apparent water loss is shown in Figure 59. Total water lost during the period of dripping was about 72.6 kg (160 lb). This equates to about 63 cm^3 (3.8 $in.^3$) per hour, or 1.5 kg (3.3 lb) per day. The large saw-tooth pattern in the data is traceable to the effluent data being recorded at a frequency of once per several days and the injection data being recorded at a frequency of once per hour. Data after the heaters were de-energized was not used to calculate water loss because such a calculation would require comparing the output of the tank weigh modules under heated conditions with those under ambient conditions.

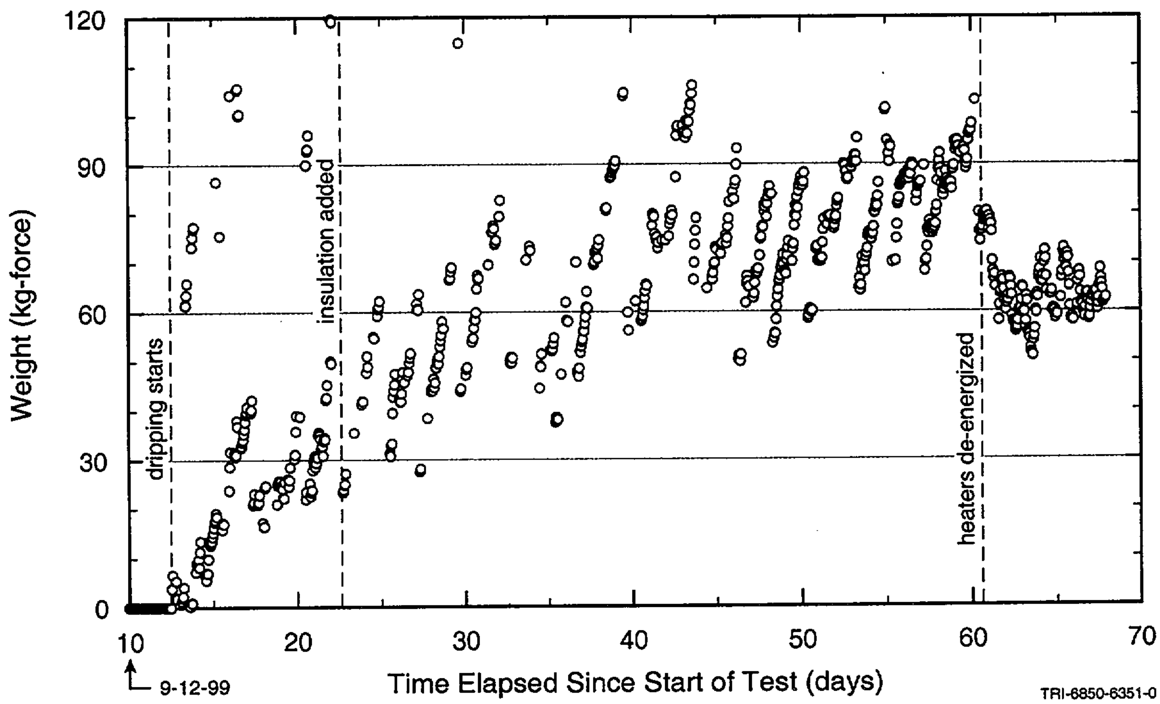

Figure 59. Apparent Water Loss

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5. RESULTS

The data being collected from EBS Pilot Scale Test #3 and other preceding tests are used to increase the understanding and validate many of the key assumptions affecting the numerical models that form the basis of the EBS performance assessment. The pilot scale tests have also demonstrated the viability and practicability of implementing potential repository designs.

Significant observations from this test are listed below.

- After heater power-up, temperatures approached steady state conditions within a period of 3 to 5 days.
- Temperature differences were observed along the waste package surface due to natural convection.
- The coolest temperatures on the drip shield were higher than the coolest parts of the invert.
- No condensation of water was observed below the drip shield.
- Relative humidities increased during dripping. When comparing the dewpoint temperatures with the drip shield temperature, at no point was drip shield temperature equal to the dewpoint temperature.

EBS Pilot Scale Test #3 validates the concept of a drip shield to effectively protect simulated waste packages from infiltrating water under heated conditions at the ¼-scale. No drip water or condensation was seen under the drip shield or on the simulated waste package for conditions simulated in the test. The relative humidity at the top of the test cell stayed at about 85%, and under the drip shield it was about 65%. Based on the temperatures and relative humidity, the water vapor pressure appeared to be approximately the same at these locations with slight variation resulting as a function of temperature variations. The vapor pressure appeared to be consistent with condensation occurring somewhere in the test cell at a temperature between 55°C (131°F) and 60°C (140°F).

The data and models developed and validated by these tests will be used to increase confidence in selecting, designing, and demonstrating the robustness of the final repository design. The information gathered can be extrapolated to predict performance of other potential configurations and material combinations not yet tested.

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Appendix A

Information about the CD-ROM Accompanying this Report

The CD-ROM that accompanies this report provides data files that correspond to each plot presented in Section 4.0. All of the files are tab delimited ascii format compatible for use with MS Excel. A list of file names from the CD-ROM is provided below along with a general description of the data.

File Name	Data Description
figure25.dat	Injection water weight
figure26.dat	Injection water weight
figure27.dat	Injection water weight
figure28.dat	Injection water weight
figure29.dat	Lysimeter pressure
figure30.dat	Tensiometer pressure
figure31.dat	Heater power
figure32.dat	Temperature
figure33.dat	Temperature
figure34.dat	Temperature
figure35.dat	Temperature
figure36.dat	Temperature
figure37.dat	Temperature
figure38.dat	Temperature
figure39.dat	Temperature
figure40.dat	Temperature
figure41.dat	Temperature
figure42.dat	Temperature
figure43.dat	Temperature
figure44.dat	Temperature
figure45.dat	Temperature
figure46.dat	Temperature
figure47.dat	Relative humidity
figure48.dat	Relative humidity
figure49.dat	Relative humidity
figure50.dat	Relative humidity
figure51.dat	Vapor pressure
figure52.dat	Dew point
figure53.dat	Vapor pressure deficit
figure54.dat	Temperature
figure55.dat	Test cell (canister) weight
figure56.dat	Test cell (canister) weight
figure57.dat	Injection water weight
figure58.dat	Test water balance
figure59.dat	Apparent water loss

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Appendix B

Instrumentation and Equipment Specifications

The following table summarizes measurement systems, including instrumentation/ equipment, manufacturer, accuracy, range, and the source of information. The table is limited to measurement systems that were used to acquire data presented in this report.

Measurement System	Manufacturer	Range/Accuracy	Reference
Temperature/humidity probes	Vaisala, Inc.	Temperature – 15° to +100°C / ± 0.2°C Relative humidity – 10 to 90% / ± 2.0% 90 to 100% / ± 3%	Howard 2000, Vol. 2, Section 7.3
Resistance Temperature Devices (RTDs)	Omega, Inc.	15° to 100°C / ± 0.3°C	Howard 2000, Vol. 2, Section 7.2
Platform Scales	GSE Inc.	0 to 2000 lbs / ± 0.02% full scale (0.4lbs)	Howard 2000, Vol. 2, Section 7.6
Tank Weigh Modules (TWMs)	Hottinger Baldwin Measurements, Inc.	0 to 5000 lbs / 2 ± 0.2 mV/V Non-linearity <0.02% full scale Hysteresis < 0.02% full scale	Howard 2000, Vol. 2, Section 7.4
Lysimeter pressure transducer	Microswitch	0 to 800 mbar / ± 2.0% full scale (16 mbar)	Howard 2000, Vol. 2, Section 7.11.2
Engineered Wicks	Pepperell Braiding Co. 3/8 in. thick	Suction proportional to lysimeter	Knutson and Selker (1994)
Tensiometer pressure transducer	Microswitch	0 to 800 mbar / ± 2.0% full scale (16 mbar)	Howard 2000, Vol. 2, Section 7.11.1
Effluent scale	Ohaus, Inc.	0 to 50 lbs / ± 0.03% full scale (0.015 lbs)	Howard 2000, Vol. 2, Section 7.8

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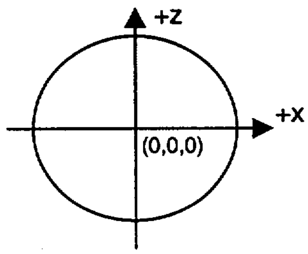
Appendix C

Canister #3 As Built Gage Location Tables

EBS Canister #3 Gage Locations:
Injection System

Cartesian Coordinates



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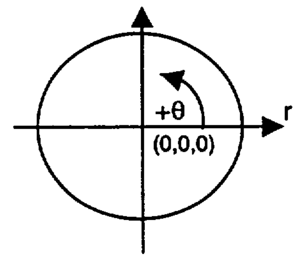
Cylindrical Coordinates



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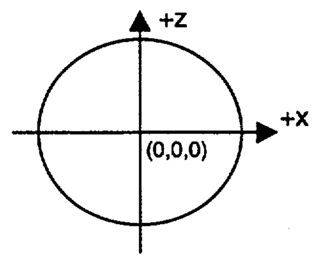
Injection Point	General Location	Cartesian Coordinates			Cylindrical Coordinates		
		x (m)	y (m)	z (m)	r (m)	θ(°)	z (m)
3-1	top left	-0.19	0.315	0.672	0.699	105.78	0.315
3-2	top right	0.19	0.315	0.672	0.699	74.22	0.315
3-3	top left	-0.38	0.615	0.586	0.699	122.96	0.615
3-4	top □	0	0.615	0.699	0.699	90.00	0.615
3-5	top right	0.38	0.615	0.586	0.699	57.04	0.615
3-6	top left	-0.19	0.915	0.672	0.699	105.78	0.915
3-7	top right	0.19	0.915	0.672	0.699	74.22	0.915
3-8	top left	-0.38	1.215	0.586	0.699	122.96	1.215
3-9	top □	0	1.215	0.699	0.699	90.00	1.215
3-10	top right	0.38	1.215	0.586	0.699	57.04	1.215
3-11	top left	-0.19	1.515	0.672	0.699	105.78	1.515
3-12	top right	0.19	1.515	0.672	0.699	74.22	1.515
3-13	top left	-0.38	1.815	0.586	0.699	122.96	1.815
3-14	top □	0	1.815	0.699	0.699	90.00	1.815
3-15	top right	0.38	1.815	0.586	0.699	57.04	1.815
3-16	top left	-0.19	2.115	0.672	0.699	105.78	2.115
3-17	top right	0.19	2.115	0.672	0.699	74.22	2.115
3-18	top left	-0.38	2.415	0.586	0.699	122.96	2.415
3-19	top □	0	2.415	0.699	0.699	90.00	2.415
3-20	top right	0.38	2.415	0.586	0.699	57.04	2.415
3-21	top left	-0.19	2.715	0.672	0.699	105.78	2.715
3-22	top right	0.19	2.715	0.672	0.699	74.22	2.715
3-23	top left	-0.38	3.015	0.586	0.699	122.96	3.015
3-24	top □	0	3.015	0.699	0.699	90.00	3.015
3-25	top right	0.38	3.015	0.586	0.699	57.04	3.015
3-26	top left	-0.19	3.315	0.672	0.699	105.78	3.315
3-27	top right	0.19	3.315	0.672	0.699	74.22	3.315

Injection Point	General Location	Cartesian Coordinates			Cylindrical Coordinates		
		x (m)	y (m)	z (m)	r (m)	θ(°)	z (m)
3-28	top left	-0.38	3.615	0.586	0.699	122.96	3.615
3-29	top □	0	3.615	0.699	0.699	90.00	3.615
3-30	top right	0.38	3.615	0.586	0.699	57.04	3.615

Note: Origin x=0m, y=0m, z=0m at front face center with long axis (y) along centerline. Coordinates are right hand rule with respect to origin (front face). +θ measured counterclockwise from +x axis. Coordinate data are archived in the YMP TDMS under DTN SN0003L1011398.003.
Gage locations were given in a general sense in the original plan. Exact locations were defined in the field by the Principal Investigator and submitted to the YMP TDMS under DTN SN0003L1011398.003.

EBS Canister #3 Gage Locations:
RTDs

Cartesian Coordinates



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Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-1	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	-.067	top of heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-2	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.196	1	-.263	right side heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-3	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	-.458	bottom of heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-4	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.196	1	-.263	left side heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-5	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	0.106	inner-top drip shield	Omega	RTD tem-perature	SNL
3-RTD-6	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.266	1	-.161	inner right side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-7	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.266	1	-.483	inner right side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-8	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.266	1	-.483	inner left side drip shield bottom	Omega	RTD tem-perature	SNL

Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-9	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.266	1	-.161	inner left side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-10	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	0.126	outer-top drip shield	Omega	RTD tem-perature	SNL
3-RTD-11	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.286	1	-.161	outer right side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-12	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.286	1	-.483	outer right side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-13	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.286	1	-.483	outer left side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-14	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.286	1	-.161	outer left side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-15	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	0.693	inner-top canister	Omega	RTD tem-perature	SNL
3-RTD-16	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.693	1	0	inner-right canister	Omega	RTD tem-perature	SNL
3-RTD-17	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	-0.693	inner-bottom canister	Omega	RTD tem-perature	SNL
3-RTD-18	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.693	1	0	inner-left canister	Omega	RTD tem-perature	SNL
3-RTD-19	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	0.699	outer-top canister	Omega	RTD tem-perature	SNL
3-RTD-20	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.497	1	-0.483	soil/can interface right side inside	Omega	RTD tem-perature	SNL
3-RTD-21	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	1	-0.699	outer-bottom canister	Omega	RTD tem-perature	SNL

Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-22	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.497	1	-0.483	soil/can interface left side inside	Omega	RTD tem-perature	SNL
3-RTD-23	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	-0.092	outer-top heater	Omega	RTD tem-perature	SNL
3-RTD-24	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.098	2	-0.19	outer-right +45 heater	Omega	RTD tem-perature	SNL
3-RTD-25	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.196	2	-0.288	outer-right heater	Omega	RTD tem-perature	SNL
3-RTD-26	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.098	2	-0.386	outer-right -45 heater	Omega	RTD tem-perature	SNL
3-RTD-27	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	-0.483	outer-bottom heater	Omega	RTD tem-perature	SNL
3-RTD-28	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.098	2	-0.386	outer-left -45 heater	Omega	RTD tem-perature	SNL
3-RTD-29	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.196	2	-0.288	outer-left heater	Omega	RTD tem-perature	SNL
3-RTD-30	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.098	2	-0.19	outer-left +45 heater	Omega	RTD tem-perature	SNL
3-RTD-31	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	0.106	inner-top drip shield	Omega	RTD tem-perature	SNL
3-RTD-32	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.266	2	-.161	inner right side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-33	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.266	2	-.483	inner right side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-34	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.266	2	-.483	inner left side drip shield bottom	Omega	RTD tem-perature	SNL

Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-35	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.266	2	-.161	inner left side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-36	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	0.126	outer-top drip shield	Omega	RTD tem-perature	SNL
3-RTD-37	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.286	2	-.161	outer right side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-38	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.286	2	-.483	outer right side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-39	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.286	2	-.483	outer left side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-40	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.286	2	-.161	outer left side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-41	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	0.693	inner-top canister	Omega	RTD tem-perature	SNL
3-RTD-42	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.347	2	0.347	inner-right +45 can-ister	Omega	RTD tem-perature	SNL
3-RTD-43	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.693	2	0	inner-right canister	Omega	RTD tem-perature	SNL
3-RTD-44	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.347	2	-.347	inner-right -45 canis-ter	Omega	RTD tem-perature	SNL
3-RTD-45	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	-0.693	inner-bottom canister	Omega	RTD tem-perature	SNL
3-RTD-46	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.347	2	-.347	inner-left -45 canister	Omega	RTD tem-perature	SNL
3-RTD-47	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.693	2	0	inner-left canister	Omega	RTD tem-perature	SNL

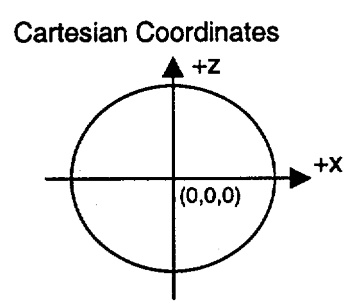
Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-48	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.347	2	0.347	inner-left +45 can-ister	Omega	RTD tem-perature	SNL
3-RTD-49	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	0.699	outer-top canister	Omega	RTD tem-perature	SNL
3-RTD-50	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.196	2	-0.513	in backfill down 3-cm under heater left side	Omega	RTD tem-perature	SNL
3-RTD-51	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.497	2	-0.483	soil/can interface left side inside	Omega	RTD tem-perature	SNL
3-RTD-52	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.497	1	-0.483	soil/can interface right side inside	Omega	RTD tem-perature	SNL
3-RTD-53	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	-0.699	outer-bottom canister	Omega	RTD tem-perature	SNL
3-RTD-54	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.249	2	-0.647	under backfill halfway between centerline and left interface	Omega	RTD tem-perature	SNL
3-RTD-55	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.249	2	-0.647	under backfill halfway between centerline and right interface	Omega	RTD tem-perature	SNL
3-RTD-56	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.196	2	-0.513	in backfill down 3-cm under heater right side	Omega	RTD tem-perature	SNL
3-RTD-57	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	-.067	top of heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-58	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.196	3	-.263	right side heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-59	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	-.458	bottom of heater canister (outside)	Omega	RTD tem-perature	SNL

Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-60	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.196	3	-.263	left side heater canister (outside)	Omega	RTD tem-perature	SNL
3-RTD-61	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	0.106	inner-top drip shield	Omega	RTD tem-perature	SNL
3-RTD-62	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.266	3	-.161	inner right side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-63	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.266	3	-.483	inner right side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-64	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.266	3	-.483	inner left side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-65	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.266	3	-.161	inner left side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-66	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	0.126	outer-top drip shield	Omega	RTD tem-perature	SNL
3-RTD-67	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.286	3	-.161	outer right side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-68	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.286	3	-.483	outer right side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-69	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.286	3	-.483	outer left side drip shield bottom	Omega	RTD tem-perature	SNL
3-RTD-70	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.286	3	-.161	outer left side drip shield top	Omega	RTD tem-perature	SNL
3-RTD-71	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	0.693	inner-top canister	Omega	RTD tem-perature	SNL
3-RTD-72	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.693	3	0	inner-right canister	Omega	RTD tem-perature	SNL

Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-73	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	-0.693	inner-bottom canister	Omega	RTD tem-perature	SNL
3-RTD-74	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.693	3	0	inner-left canister	Omega	RTD tem-perature	SNL
3-RTD-75	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	0.699	outer-top canister	Omega	RTD tem-perature	SNL
3-RTD-76	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-0.497	3	-0.483	soil/can interface left side inside	Omega	RTD tem-perature	SNL
3-RTD-77	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3	-0.699	outer-bottom canister	Omega	RTD tem-perature	SNL
3-RTD-78	"1,2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.497	3	-0.483	soil/can interface right side inside	Omega	RTD tem-perature	SNL
3-RTD-79	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	-0.006	0.35	outer front face	Omega	RTD tem-perature	SNL
3-RTD-80	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.35	-0.006	-.35	outer front face	Omega	RTD tem-perature	SNL
3-RTD-81	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.35	-0.006	-.35	outer front face	Omega	RTD tem-perature	SNL
3-RTD-82	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	3.936	0.35	outer back face	Omega	RTD tem-perature	SNL
3-RTD-83	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0.35	3.936	-.35	outer back face	Omega	RTD tem-perature	SNL
3-RTD-84	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	-.35	3.936	-.35	outer back face	Omega	RTD tem-perature	SNL
3-RTD-85	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/ °C nominal	0	2	0.851	middle of insulation top	Omega	RTD tem-perature	SNL

Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-RTD-86	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/°C nominal	0.426	2	-0.426	middle of insulation lower right -45	Omega	RTD tem-perature	SNL
3-RTD-87	"2,3"	100-Ohm 4-wire RTD	Omega model RTD-809	-200°C to +230°C .00385 ohms/ohm/°C nominal	-0.426	2	-0.426	middle of insulation lower left -45	Omega	RTD tem-perature	SNL

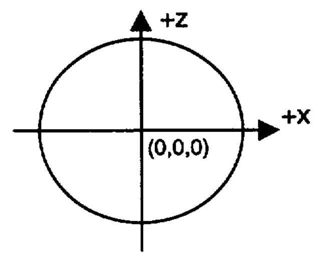
EBS Canister #3 Gage Locations: Humidity Gages



Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-HUM-H1	"2,3"	Humidity Probe	Viasala HMP 235	0-100 % RH -> 0-10 v	0	2	0.693	inner-top canister	Viasala	Relative humidity	SNL
3-HUM-H2	"2,3"	Humidity Probe	Viasala HMP 235	0-100 % RH -> 0-10 v	0	1	0.126	Inside-Top Drip Shield	Viasala	Relative humidity	SNL
3-HUM-H3	"2,3"	Humidity Probe	Viasala HMP 235	0-100 % RH -> 0-10 v	0	3	0.126	inner - top Drip Shield	Viasala	Relative humidity	SNL
3-HUM-H4	"2,3"	Humidity Probe	Viasala HMP 235	0-100 % RH -> 0-10 v	Atlas High Bay	NA	NA	Atlas High Bay	Viasala	Relative humidity	SNL
3-HUM-T1	"2,3"	Humidity Probe	Viasala HMP 235	0-10 v -> 0-180° C	0	2	0.693	inner-top canister	Viasala	Tem-perature	SNL
3-HUM-T2	"2,3"	Humidity Probe	Viasala HMP 235	0-10 v -> 0-180° C	0	1	0.126	Inside-Top Drip Shield	Viasala	Tem-perature	SNL
3-HUM-T3	"2,3"	Humidity Probe	Viasala HMP 235	0-10 v -> 0-180° C	0	3	0.126	inner - top Drip Shield	Viasala	Tem-perature	SNL
3-HUM-T4	"2,3"	Humidity Probe	Viasala HMP 235	0-10 v -> 0-180° C	Atlas High Bay	NA	NA	Atlas High Bay	Viasala	Tem-perature	SNL

EBS Canister #3 Gage Locations: Thermocouple Psychrometers

Cartesian Coordinates



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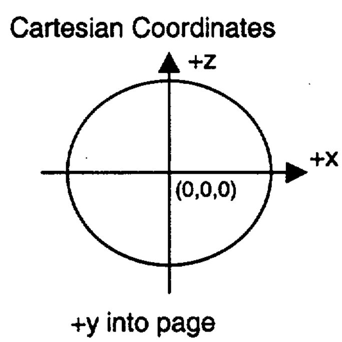
Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Measurement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-TCP-1	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0	1	0.02	inside DS top	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-2	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0.25	1	-0.45	inside DS lower right	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-3	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	-0.25	1	-0.45	inside DS lower left	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-4	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0	1	0.6	inside canister top	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-5	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0.35	1	-.161	inside canister lower right	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-6	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	-0.35	1	-.161	inside canister lower left	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-7	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0	2	0.02	inside DS top	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-8	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0.25	2	-0.45	inside DS lower right	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA

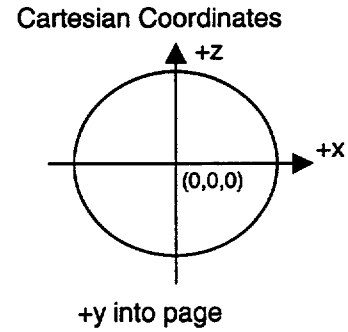
Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Measurement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-TCP-9	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	-0.25	2	-0.45	inside DS lower left	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-10	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0	2	0.6	inside canister top	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-11	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0.35	2	-.161	inside canister lower right	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-12	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	-0.35	2	-.161	inside canister lower left	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-13	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0	3	0.02	inside DS top	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-14	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0.25	3	-0.45	inside DS lower right	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-15	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	-0.25	3	-0.45	inside DS lower left	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-16	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0	3	0.6	inside canister top	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-17	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	0.35	3	-.161	inside canister lower right	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA
3-TCP-18	"2,3"	type-T thermo-couple/ chro-mel-constatan psychrometer junction	Wescor model PST-55	SEA Read-out/-.75 mV/bar	-0.35	3	-.161	inside canister lower left	Wescor	Temperature/ RH thermo-couple psy-chrometer	SNL/SEA

EBS Canister #3 Gage Locations:
Tank Weigh Modules



Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-TWM-1	"1,2,3"	5Klb load cell	HBM:RTM -15100	0-5000lbs/ 15V excitation/ 1.9/0-30mV output	+	0.728	NA	right front	HBM	Tank load	SNL
3-TWM-2	"1,2,3"	5Klb load cell	HBM:RTM -15100	0-5000lbs/ 15V excitation/ 1.9/0-30mV output	+	1.958	NA	right mid-dle	HBM	Tank load	SNL
3-TWM-3	"1,2,3"	5Klb load cell	HBM:RTM -15100	0-5000lbs/ 15V excitation/ 1.9/0-30mV output	+	3.195	NA	right back	HBM	Tank load	SNL
3-TWM-4	"1,2,3"	5Klb load cell	HBM:RTM -15100	0-5000lbs/ 15V excitation/ 1.9/0-30mV output	-	0.728	NA	left front	HBM	Tank load	SNL
3-TWM-5	"1,2,3"	5Klb load cell	HBM:RTM -15100	0-5000lbs/ 15V excitation/ 1.9/0-30mV output	-	1.958	NA	left middle	HBM	Tank load	SNL
3-TWM-6	"1,2,3"	5Klb load cell	HBM:RTM -15100	0-5000lbs/ 15V excitation/ 1.9/0-30mV output	-	3.195	NA	left back	HBM	Tank load	SNL

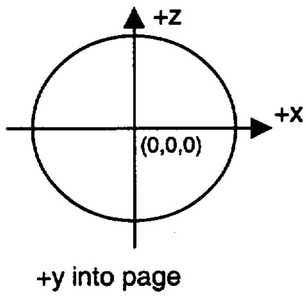
EBS Canister #3 Gage Locations:
Platform Scales



Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-SCALE-4	"2,3"	2klb plat-form scale	GSE:4456-2000lb	0-2000 lb/ 0-10VDC full scale	NA	NA	NA	outside CAN#3	GSA	Injected water weight	SNL
3-SCALE-5	"2,3"	2klb plat-form scale	GSE:4456-2000lb	0-2000 lb/ 0-10VDC full scale	NA	NA	NA	outside CAN#3	GSA	Injected water weight	SNL
3-SCALE-6	"2,3"	2klb plat-form scale	GSE:4456-2000lb	0-2000 lb/ 0-10VDC full scale	NA	NA	NA	outside CAN#3	GSA	Injected water weight	SNL

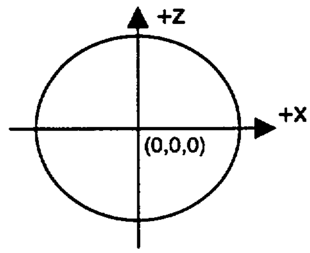
EBS Canister #3 Gage Locations:
Heat Dissipation Probes

Cartesian Coordinates



Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manufacturer	Measurement Type	Responsibility
					x (m)	y (m)	z (m)				
3-HDP-1	"2,3"	Heat dissipation probe	229	USGS DAS	-0.3	3.0	-0.57	invert, left side at drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-2	"2,3"	Heat dissipation probe	229	USGS DAS	0.0	3.0	-0.57	invert, center under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-3	"2,3"	Heat dissipation probe	229	USGS DAS	0.3	3.0	-0.57	invert, right side under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-4	"2,3"	Heat dissipation probe	229	USGS DAS	-0.3	2.0	-0.57	invert, left side at drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-5	"2,3"	Heat dissipation probe	229	USGS DAS	-0.2	2.0	-0.57	invert, left side under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-6	"2,3"	Heat dissipation probe	229	USGS DAS	0.0	2.0	-0.57	invert, center under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-7	"2,3"	Heat dissipation probe	229	USGS DAS	0.2	2.0	-0.57	invert, right side under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-8	"2,3"	Heat dissipation probe	229	USGS DAS	0.3	2.0	-0.57	invert, right side at drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-9	"2,3"	Heat dissipation probe	229	USGS DAS	-0.3	1.0	-0.57	invert, left side at drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-10	"2,3"	Heat dissipation probe	229	USGS DAS	0.0	1.0	-0.57	invert, center under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-11	"2,3"	Heat dissipation probe	229	USGS DAS	0.3	1.0	-0.57	invert, right side at drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-12	"2,3"	Heat dissipation probe	229	USGS DAS	-0.1	1.0	-0.4	air, left side under drip shield	Campbell	water potential-heat dissipation probe	USGS
3-HDP-13	"2,3"	Heat dissipation probe	229	USGS DAS	-0.65	1.0	-0.2	air, left side outside drip shield	Campbell	water potential-heat dissipation probe	USGS

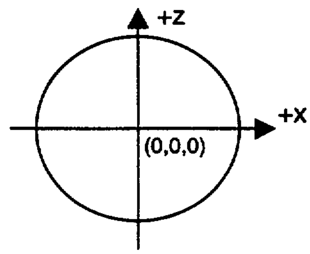
EBS Canister #3 Gage Locations: Time Domain Reflectometers



Instrument Name	Parts 1,2 or 3	Instrument Type	Instru-ment Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Measurement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-TDR-1	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	-0.3	3.0	-0.54	invert, left side at drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-2	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	-0.3	2.0	-0.52	invert, left side at drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-3	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	-0.3	1.0	-0.55	invert, left side at drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-4	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	0.0	3.0	-0.58	invert, center under drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-5	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	0.0	2.0	-0.54	invert, center under drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-6	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	0.0	1.0	-0.55	invert, center under drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-7	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	0.3	2.85	-0.57	invert, right side at drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-8	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	0.3	1.78	-0.57	invert, right side at drip shield	Camp-bell	water content-time domain reflectometer	USGS
3-TDR-9	"2,3"	Time Domain Reflectometer	CS165	USGS DAS	0.3	1.15	-0.57	invert, right side at drip shield	Camp-bell	water content-time domain reflectometer	USGS

EBS Canister #3 Gage Locations:
Tensiometers

Cartesian Coordinates



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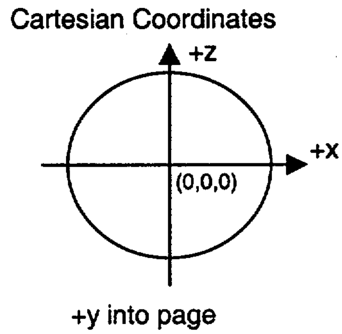
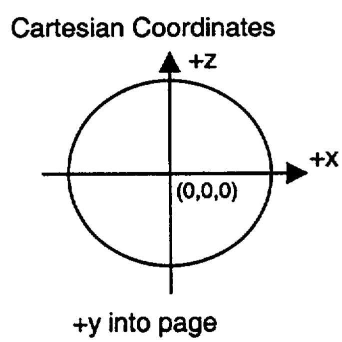
Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-TEN-1	"2,3"	Tensi-ometer	236PC15GW	USGS DAS	0.32	0.34	-0.575	invert, right side at drip shield	Camp-bell	backfill water potential	USGS
3-TEN-2	"2,3"	Tensi-ometer	236PC15GW	USGS DAS	-0.08	0.33	-0.59	invert, center under drip shield	Camp-bell	backfill water potential	USGS
3-TEN-3	"2,3"	Tensi-ometer	236PC15GW	USGS DAS	-0.31	0.25	-0.615	invert, left side at drip shield	Camp-bell	backfill water potential	USGS
3-TEN-4	"2,3"	Tensi-ometer	236PC15GW	USGS DAS	0.36	0.77	-0.63	invert, right side outside drip shield	Camp-bell	backfill water potential	USGS
3-TEN-5	"2,3"	Tensi-ometer	236PC15GW	USGS DAS	-0.06	0.82	-0.635	invert, center under drip shield	Camp-bell	backfill water potential	USGS
3-TEN-6	"2,3"	Tensi-ometer	236PC15GW	USGS DAS	-0.36	0.81	-0.655	invert, left side out-side drip shield	Camp-bell	backfill water potential	USGS

EBS Canister #3 Gage Locations:
Lysimeters



Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Respon-sibility
					x (m)	y (m)	z (m)				
3-LYS-1	"2,3"	Lysimeter	236PC15GW	USGS DAS	0.12	NA	-0.605	invert, right side under drip shield	Camp-bell	effluent volume	USGS
3-LYS-2	"2,3"	Lysimeter	236PC15GW	USGS DAS	0	NA	-0.64	invert, center under drip shield	Camp-bell	effluent volume	USGS
3-LYS-3	"2,3"	Lysimeter	236PC15GW	USGS DAS	-0.27	NA	-0.57	invert, left side at drip shield	Camp-bell	effluent volume	USGS

EBS Canister #3 Gage Locations:
Miscellaneous Gages



Instrument Name	Parts 1,2 or 3	Instrument Type	Instrument Model	Instrument range/scale factor	Cartesian Coordinates			General location	Manu-facturer	Meas-urement Type	Re-sponsi-bility
					x (m)	y (m)	z (m)				
3-HDPREFT-1	"1,2,3"	Thermistor	CS108	USGS DAS	at HDP Multi-plexer	NA	NA	Reference Tempera-ture	Camp-bell	tem-perature	USGS

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