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DOWNFLOW DRYOUT IN A HEATED RIBBED VERTICAL ANNULUS WITH A COSINE POWER PROFILE

(Results from Test Series ECS-2, WSR, and ECS-2cE)

by

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ABSTRACT

Experiments designed to investigate surface dryout in a heated, ribbed annulus test section simulating one of the annular coolant channels of a Savannah River Plant production reactor Mark 22 fuel assembly have been conducted at the Idaho National Engineering Laboratory. The inner surface of the annulus was constructed of aluminum and was electrically heated to provide an axial cosine power profile and a flat azimuthal power shape. Data presented in this report are from the ECS-2, WSR, and ECS-2cE series of tests. These experiments were conducted to examine the onset of wall thermal excursion for a range of flow, inlet fluid temperature, and annulus outlet pressure. Hydraulic boundary conditions on the test section represent flowrates (0.1 - 1.4 l/s), inlet fluid temperatures (293 - 345 K), and outlet pressures (-18 - 139.7 cm of water relative to the bottom of the heated length [61 - 200 cm of water relative to the bottom of the lower plenum]) expected to occur during the Emergency Coolant System (ECS) phase of a postulated Loss-of-Coolant Accident in a production reactor. The onset of thermal excursion based on the present data is consistent with data gathered in test rigs with flat axial power profiles. The data indicate that wall dryout is primarily a function of liquid superficial velocity. Air entrainment rate was observed to be a strong function of the boundary conditions (primarily flowrate and liquid temperature), but had a minor effect on the power at the onset of thermal excursion for the range of conditions examined.

SUMMARY

Experiments have been conducted at the Idaho National Engineering Laboratory to examine the hydraulics and heat transfer associated with downflow in a heated, ribbed aluminum tube surrounded by a polycarbonate shroud. The annular test section designed and constructed to conduct these investigations represents a geometry and axial cosine power shape consistent with the inner-middle coolant channel of a Mark 22 fuel assembly in a Savannah River Production reactor. Experiments conducted represent hydraulic conditions expected during the ECS phase of a large break Loss-of-Coolant Accident. Data gathered during the experiments will be used to gain insight on downflow heat transfer phenomena and for assessment and verification of computer codes used in power limits setting.

Two different general categories of experiments have been conducted to date. The ECS-2, WSR, and ECS-2cE series provided information on the conditions leading to wall dryout (onset of thermal excursion) in the test section. The ECS-2b and ECS-2c series provided information on the heat transfer coefficient in the test section when the heater wall temperature was limited to a value equal to the fluid saturation temperature at the outlet plenum. This report provides results from the thermal excursion experiments. Results for the ECS-2b series were published in July 1990, with an addendum planned for November 1990 to document the results of the ECS-2c series.

Experiments conducted have provided insight on the influence of air entrainment, inlet fluid temperature, liquid flowrate, and test section back pressure on the power at which wall dryout occurs. Over the range of conditions investigated, the power at wall dryout is primarily a function of liquid superficial velocity. While air entrainment is a strong function of liquid superficial velocity, air entrainment had only a minor effect on the onset of thermal excursion. Test section back pressure had a small effect on the onset, particularly at low liquid flowrates where pooling in the test section occurred.

As expected, results from the experiments conducted show that power limits based on wall T_{sat} criteria are more conservative than dryout criteria. R factors (test section power at the criteria under consideration divided by the power required to saturate the test section outlet fluid)

calculated using wall T_{sat} criteria are approximately one-half those calculated using the thermal excursion (dryout) criteria.

Data collected from the INEL experiments are in basic agreement with data reported from test facilities using heaters with flat axial power profiles. For the superficial velocity range of major interest (0.3 to 0.8 m/s), R factors obtained from ECS-2 experiments are approximately 15% lower than those obtained from Westinghouse Savannah River Company (WSRC) experiments. This result was expected since for an equivalent power, the ECS-2 system had higher heat fluxes relative to the WSRC systems and heat flux is an important factor in dryout phenomena.

ACKNOWLEDGEMENTS

Many people contributed to the success of the experiments reported in the following pages. B. R. Merkley kept the facility hardware operating. P. R. Schwieder and J. R. Boyce solved the electronics mysteries. We are indebted to H. N. Romero for operation of the video system. B. R. Merkley, J. R. Boyce, H. N. Romero, and J. M. Hopla helped conduct the experiments.

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1. INTRODUCTION

In mid 1987, the U.S. Department of Energy (DOE) initiated a vigorous program to review the safety and operation of the nuclear materials production and nuclear testing facilities under DOE management in the U.S. A major purpose of this ongoing review effort is to ensure that the facilities in the existing research and weapons materials production complex are operated in a safe manner during normal operation and, given a hypothetical design basis accident, the risk to the public is within acceptable limits.

As part of this review effort, Westinghouse Savannah River Company (WSRC) personnel have conducted or contracted research to examine heat transfer in the Savannah River Plant (SRP) reactor fuel assembly during the Emergency Cooling System (ECS) phase of a hypothesized Loss-of-Coolant Accident (LOCA). During the ECS phase of the accident, the reactor fuel assemblies are expected to be filled with a two-phase air-water mixture. Safety requirements dictate that the power levels be low enough during the ECS phase of the accident so that no melting occurs in the fuel assemblies.

Two different criteria, wall saturation temperature and wall dryout, are being considered for use in calculating power limits. Simply stated, wall saturation temperature criterion involves determining the power for a given thermal-hydraulic condition (flowrate, inlet fluid temperature, etc) at which the maximum assembly wall temperature just reaches the local saturation temperature. This criterion would preclude bulk boiling of the liquid in the assemblies. The dryout criterion involves determining the power at which heat transfer from the surface of the heated assembly wall degrades to a point where the surface is basically dry and the wall temperature starts to increase in a nearly adiabatic fashion. Of the two criteria, wall saturation is the considerably more conservative.

Complex geometry and hydraulic interactions involving air entrainment, flooding, and heat transfer to two-phase mixtures necessitate experimental investigation of the processes involved to help determine key factors influencing assembly cooling and hence the power limit criteria. Research results from such investigations will be used in the verification and assessment of models used for establishing acceptable power limits for the reactors.

Experimental efforts conducted at the Savannah River Site (SRS) Heat Transfer Laboratory to examine ECS power limits are reviewed by Steimke [1]. Prior to 1988, experiments were conducted in an annulus consisting of a heated stainless steel surface (rather than aluminum as in actual fuel assemblies) and glass or aluminum as the other wall of the annulus [2; 3]. Stainless steel was used as the heated surface because of technical difficulties associated with resistively heating aluminum to the power levels required for the desired experiments. These facilities did not contain axial spacer ribs in the annulus, a unique feature of the reactor assembly design. Also, these test sections used a flat axial power profile and uniform azimuthal power. Facilities that included spacer ribs and an azimuthal power tilt were constructed in 1988 [4; 5; 6]. Other facilities were built in 1989 [7] for visualization studies and to incorporate thermal spray technology for the construction of aluminum heated surfaces [8; 9]. All test sections mentioned above incorporated a flat axial power profile (the FB rig had an azimuthal power tilt) and with the exception of two test sections, used stainless steel for the heated surface. Although, both of the thermal sprayed test sections used aluminum for the heated surface, current technology allowed only the outer annulus wall to be heated.

The ECS-1 facility [10] was constructed and operated at the Idaho National Engineering Laboratory (INEL) in 1989 to help address the influences of heater surface material properties and conditions on test results. The ECS-1 facility was sponsored by the Department of Energy, Office of Safety Appraisal, Environment Safety and Health and consisted of a ribbed aluminum tube heated from inside with a resistively heated stainless steel tube and surrounded by a Lexan™ shroud to permit visual observation. Nearly 50 experiments were conducted to examine the effects of air entrainment, flow regime transition, flow distribution, and flooding on the heat transfer processes in the annulus.

The success of the heater design used in the ECS-1 facility prompted the construction of the ECS-2 facility at the INEL. The ECS-2 program was sponsored by the WSRC and incorporated several improvements relative to the ECS-1 fixture. Foremost was a new inner heater with an axial power profile consistent with the power shape to be used in setting assembly power limits and improvements in the inlet and outlet geometry of the test section to make the plenums more prototypic. The ECS-2b facility succeeded the ECS-2 facility. With the exception of measurement locations and a new heater, the two facilities were essentially the same.

Two different categories of experiments were run during the course of the INEL ECS-2 program. More than 70 experiments (the ECS-2b, and ECS-2c series) were conducted to determine the hydraulic conditions that lead to heater wall temperatures that just exceed local fluid saturation temperature. Results from these experiments are discussed by Anderson, et al [11]. Approximately 50 experiments (the ECS-2, WSR, and ECS-2cE series) were conducted to establish and examine the variables and conditions that lead to sustained dryout on the heated surface in the annulus. Tests conducted in these programs were designed to parametrically examine the influence of coolant temperature, coolant flowrate, and back pressure on the heat transfer processes in the ribbed annulus. Data gathered will be used to improve understanding of the physical processes involved and in the assessment and validation of models used in the calculation of power limits criteria.

The remainder of this report details results of the thermal excursion tests conducted at the INEL. Results discussed are from the ECS-2, WSR, and ECS-2cE series of experiments conducted in the ECS-2 and ECS-2b facilities. Section 2 describes facility design, support systems, measurement capabilities, and the data acquisition system. Experiment conduct and test matrices are addressed in Section 3. Results of the experimental investigations are presented in Section 4. Conclusions and summary statements are given in Section 5. Appendices to this report provide engineering drawings, lists of measurements recorded for the various experiments, measurement uncertainty statements, test fixture design details, and other relevant information.

2. FACILITY DESCRIPTION

This section describes the test facility, support systems, instrumentation, and data acquisition system. As noted above, the experiments described in this report were conducted in the ECS-2 and ECS-2b facilities. In most respects, the ECS-2 and ECS-2b facilities are similar. In fact, the ECS-2b test section is actually made up from the upper and lower plenums and shroud from the ECS-2 test section and a heater that was intended for the dual heated annulus program. The dual heated inner heater is the same design as the ECS-2 heater with slight changes to simplify and improve the fabrication of the heater. Major differences between the ECS-2 and ECS-2b facilities include the number and location of the test section fluid temperature, absolute pressure, and differential pressure measurements and the location of the heater wall thermocouples. Since the ECS-2b facility geometry is described by Anderson [11], the description in this report is limited primarily to the ECS-2 hardware.

2.1 Loop Description

The ECS-2 loop schematic is shown in Figure 2.1. Water is pumped from the storage tank through the heated make up tank, where it is heated to the desired inlet temperature, and into the upper plenum. The flowrate is controlled remotely from the control room via an air operated flow control valve. For very low flowrates the test section bypass valve was opened to reduce pump outlet pressure. Air is allowed to naturally aspirate into the upper plenum through a 6.7 cm (2.625 in.) ID acrylic tube. The air-water mixture then flows down through the test section annulus into the lower plenum. The test section is described in more detail in Section 2.2. The test section is heated over 381 cm (150 in.) of its length by a directly heated Inconel tube inside an aluminum outer tube. Power to the heater is supplied by ten 4/0 copper leads from a Transrex DC power supply. Current to the heater is controlled manually from the control room.

The lower plenum serves as a separator, which allows the air to exit from the top of the lower plenum and the liquid from the bottom of the lower plenum. A cooling coil placed in the lower plenum can be used to condense any vapor generated in the test section, which

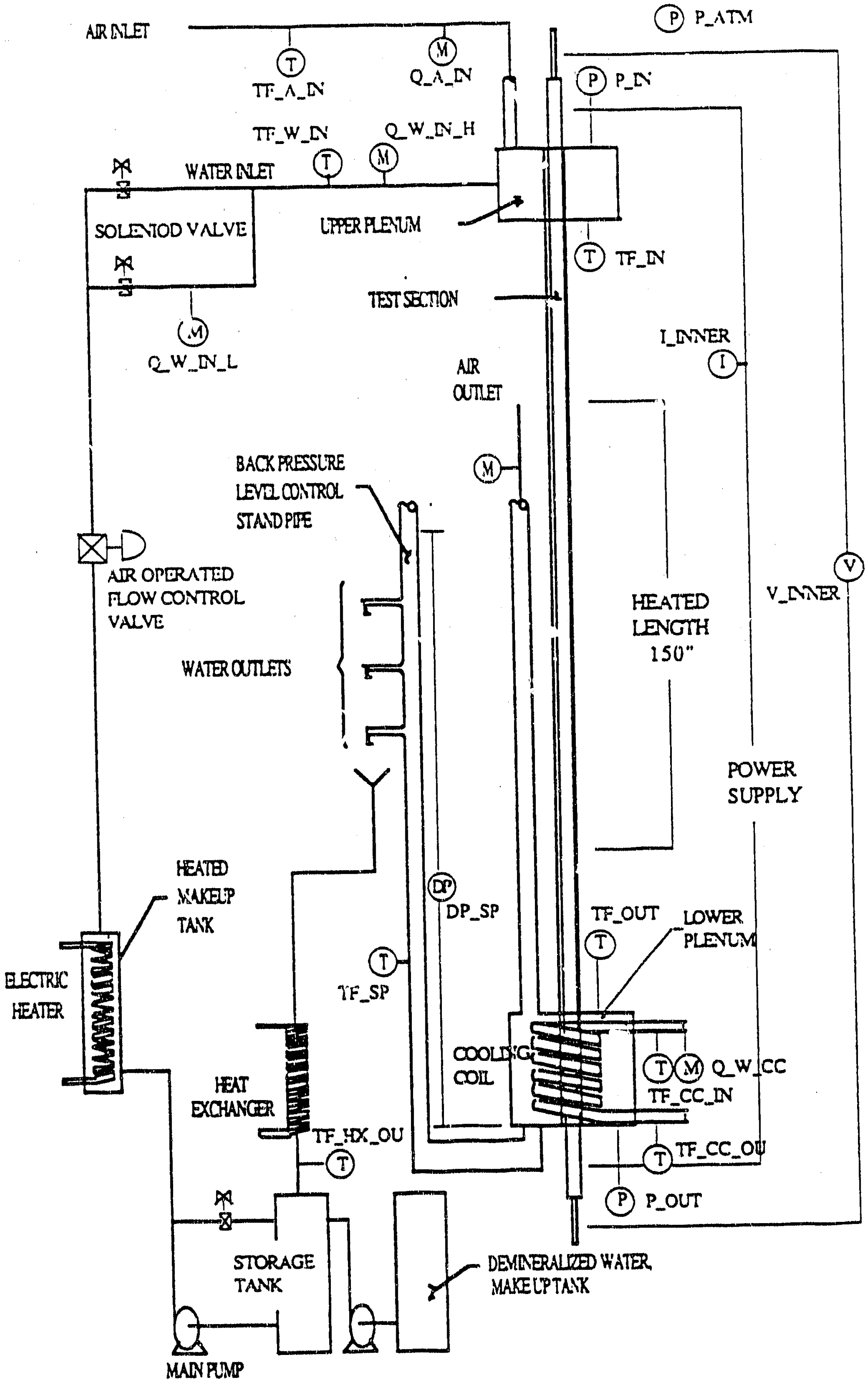


Figure 2.1. ECS-2 loop schematic

prevents the vapor from exiting through the outlet air measurement station. The water flows from the outlet tap through a heat exchanger and back into the storage tank completing the loop. The loop inventory is supplied by water from the demineralized water tank. The liquid level in the test section is controlled by the height of the water outlet taps located in the back pressure level control standpipe. For the excursion test series, these levels were -18, 0, 19, 48, 51, 110, and 140 cm (-7, 0, 7.5, 19, 20, 43, and 55 in.) above the bottom of the heated length.

2.1.1 Loop Instrumentation

Sufficient loop instrumentation is provided to control and monitor inlet conditions to satisfy program objectives and to calculate a test section energy balance. (A listing of all instrumentation for the ECS-2 and ECS-2b test sections is provided in Appendix B). The energy balance is monitored continuously on line to provide an overall integrity check and to determine when the system has reached steady state conditions following a change in power or flowrate. All fluid thermocouples are 1.5-mm (0.060-in.) type K stainless steel sheathed with a grounded junction inserted directly into the fluid stream. They are connected to type K extension wire which runs to a 339 K (150°F) reference oven. Regular copper conductors are used to connect the ovens to the data acquisition system (DAS).

The air inlet and outlet flowrates (Q_A_IN and Q_A_OUT) are measured using Teledyne/Hastings model LU-3M mass flow meters having a measurement range of 0-50 standard liters per minute (SLPM). These are very low pressure drop instruments having an internal diameter of about 6 cm (2.5 in.). The inlet and outlet air temperatures (TF_A_IN and TF_A_OUT) were measured using fluid thermocouples as described above. Both a high flow (Q_W_IN_H) and a low flow (Q_W_IN_L) turbine meter were used to measure the inlet liquid flow. Flowrates below 0.30 l/s were routed through both turbine meters. For flowrates above 0.30 l/s, only the high flow turbine was used. The liquid inlet temperature (TF_W_IN) was measured using a fluid thermocouple and was checked regularly against a calibrated glass thermometer inserted into the inlet liquid stream. The inlet liquid temperature was controlled by adjusting the heat input to the heated makeup tank. No outlet liquid flowrate measurements were made and the liquid outlet temperature was measured using a fluid thermocouple (TF_W_OUT for ECS-2 and TF_SP for ECS-2b). The inlet (TF_IN) and outlet (TF_OUT) plenum temperatures were also measured using fluid thermocouples. The inlet (P_IN) and outlet (P_OUT) plenum absolute pressures were measured using Sensotec absolute pressure transducers. The liquid temperature at the outlet of the heat exchanger (TF_HX_OUT) was measured using a fluid thermocouple. The liquid level in the level control standpipe was measured using a differential pressure cell (DP_SP) connected between the bottom of the lower plenum and a point above the highest outlet tap. During testing, the storage tank temperature was monitored to help determine the necessary secondary heat exchanger flowrate but was not recorded. The water flowrate (Q_W_CC) through the lower plenum cooling coil was measured using a turbine flowmeter and the inlet (TF_CC_IN) and the outlet (TF_CC_OU) temperatures were measured using fluid thermocouples.

The test section voltage (V_INNER) was measured with a volt meter connected directly across the test section. The current through the test section (I_INNER) was determined by measuring the voltage across a current shunt of known resistance.

Local atmospheric pressure (P_ATM) was measured using a Sensotec electronic barometer and was checked daily against the atmospheric pressure recorded at the INEL Standards and Calibration Laboratory.

2.2 Test Section Description

For this discussion the test section is defined as the upper and lower plenums, the connecting transparent shroud, and the composite heater. Figure 2.2 shows the ECS-2 test section with pertinent elevations indicated on the right side and instrumentation designations on the left side. A companion figure for the ECS-2b test section is shown in Figure 2.3 and is discussed by Anderson[1.1]. Instrumentation on the composite heater is not shown on this figure. A cross section view through the heated portion of the test section for ECS-2b is shown in Figure 2.4. Note that the heater for ECS-2 is essentially the same except that welds on the ECS-2 heater are in the A and C subchannels.

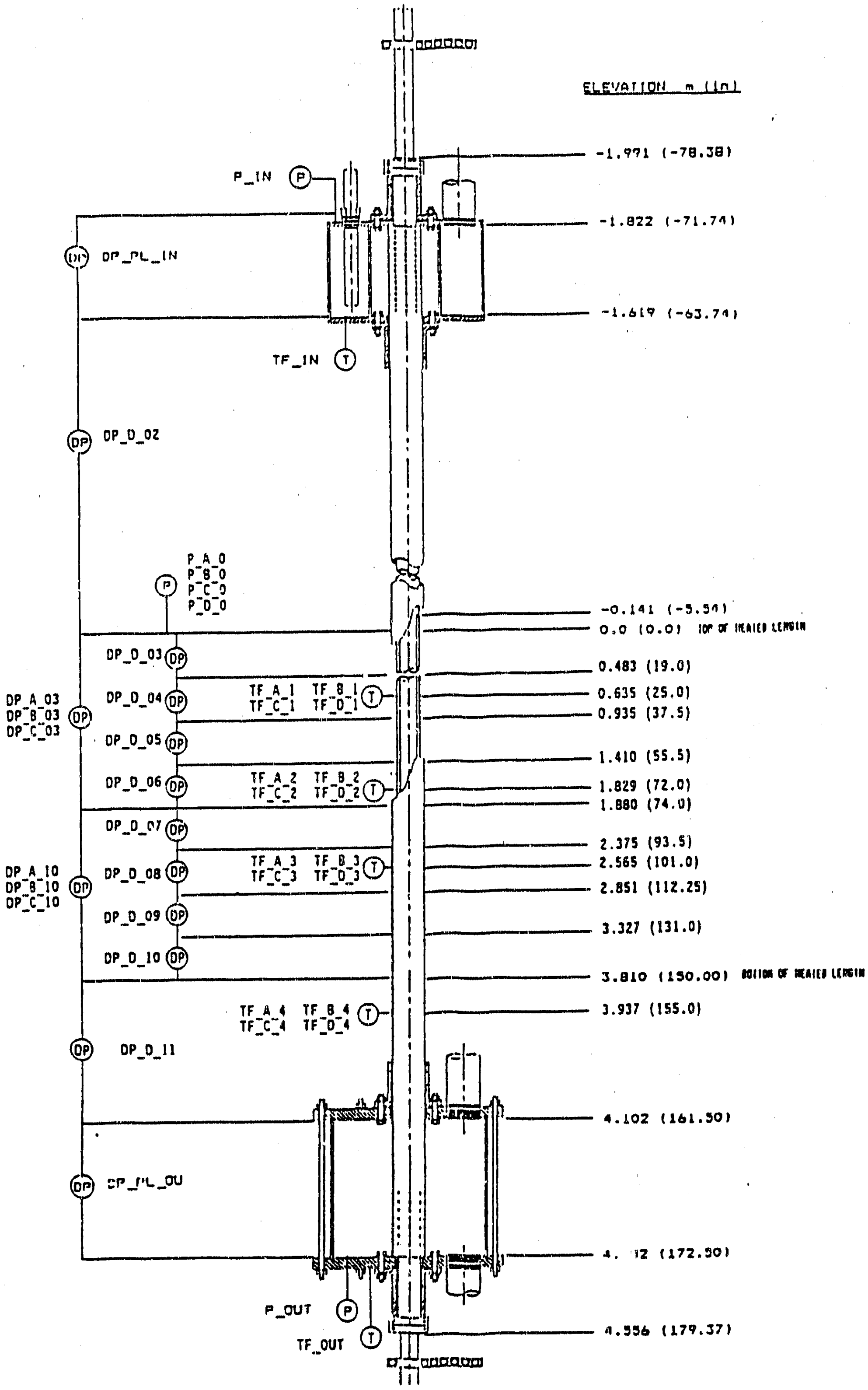


Figure 2.2. ECS-2 test section

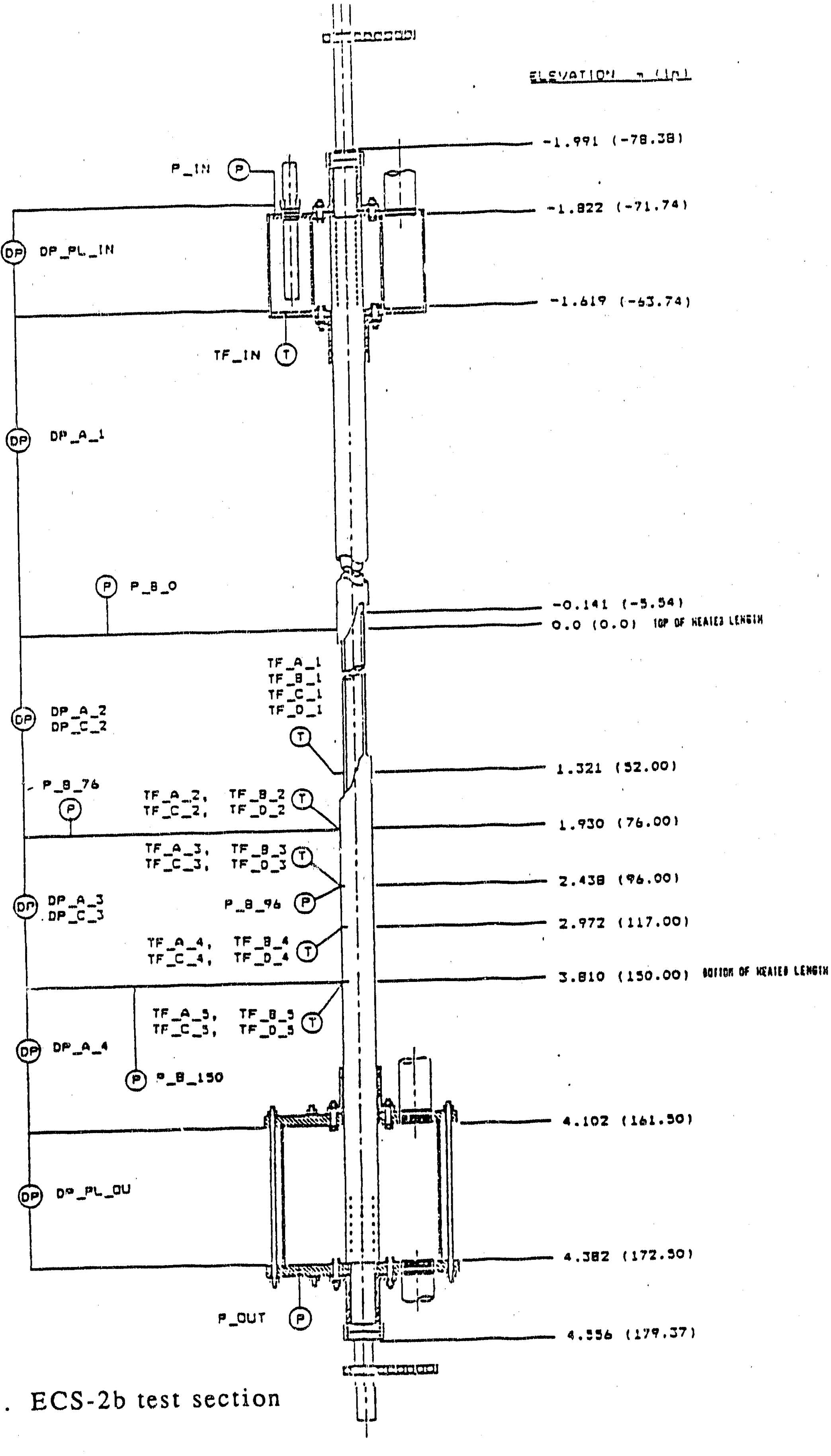
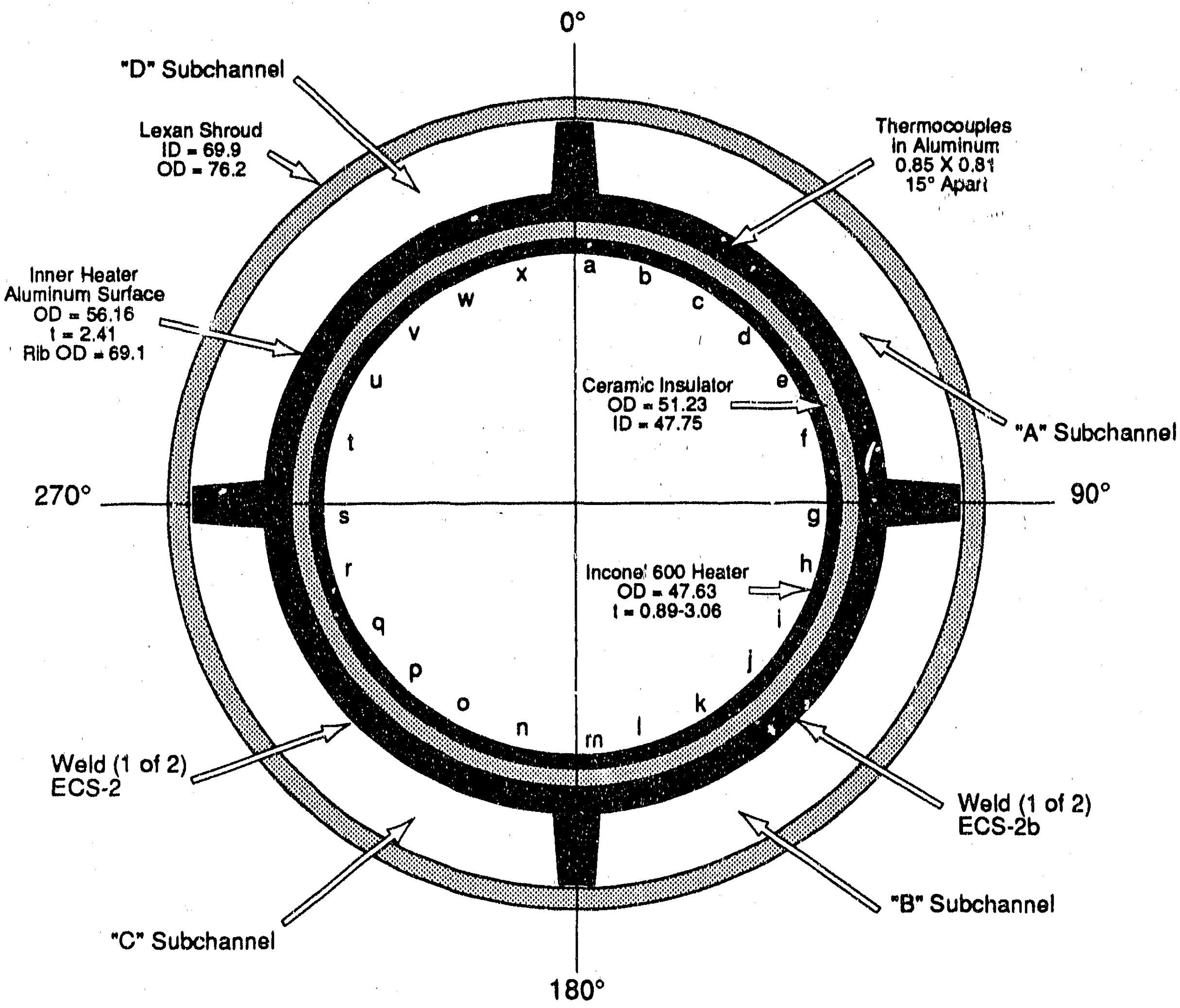


Figure 2.3. ECS-2b test section



* All dimensions in mm

Hydraulic Diameter = 1.197 cm
Flow Area = 13.31 cm^2

Figure 2.4. ECS-2 and ECS-2b test section cross section through heater, viewed from the bottom

2.2.1 Composite Heater

The composite heater, shown in Figure 2.4, consists of a 4.76 cm (1.875 in.) OD Inconel 600 resistively heated tube fitted inside a 1.75 mm (0.069 in.) thick ceramic insulator, with an aluminum outer tube in which the fins have been machined. The aluminum outer tube was made in two halves and welded onto the assembly in order to facilitate fabrication. Power leads through the unheated portion of the heater were made of copper tubing (wall thickness of 8.59 mm [0.338 in.]) brazed to the ends of the Inconel heater tube. The composite heater was fabricated by sliding the ceramic insulator over the inconel tube, placing the two aluminum halves over the insulator, and then TIG welding the aluminum halves together longitudinally, with the welds in subchannels B & D on the ECS-2b heater and in subchannels A & C on the ECS-2 heater. As the weld cooled, the composite was drawn tightly together. The weld surface was then dressed to the basic tube diameter. The completed assembly for ECS-2 is shown in Drawing 429994 in Appendix A.

The Inconel heater tube was fabricated by welding together eight sections of Inconel 600 tubing of various lengths having five different wall thicknesses in order to produce the axial power profile shown in Figure 2.5. Information for each section is presented in Table 2.1. The sections were welded together using an Astro Arc automatic tube welder. No welding filler material was required with this automatic welder. Several sample pieces for each of the weld joint thickness were made and destructively examined to determine the proper welder settings to ensure a full penetration and uniform weld for each joint. The copper power leads were then brazed to each end of the Inconel tube. The completed assembly is shown in Drawing 430437 in Appendix A. The completed assembly was then hung vertically in air and power leads attached to the copper leads and a thermocouple was attached in the center of each power zone. Power was applied to the heater until the hottest zone reached 800 K (1000°F). This maximum temperature was maintained for approximately one-half hour. The temperature profile was similar to the desired power profile indicating the correct sequence of heater sections. Any weld voids would show up as dark spots in the welded zone. None were found. The electrical resistance of the heaters were calculated from the voltage and current measurements to be 0.0206 ohm for both the ECS-2 and ECS-2b heaters. This was within 5% of the expected resistance calculated from the tube lengths and thicknesses and the published resistivity for Inconel.

The Macor machinable ceramic was purchased as cylinders slightly larger than 5 cm (2 in.) in diameter and approximately 15-cm (6-in.) in length. Each cylinder was machined to an inside diameter of 4.78-cm (1.880-in.) and an outside diameter of 5.12-cm (2.017-in.).

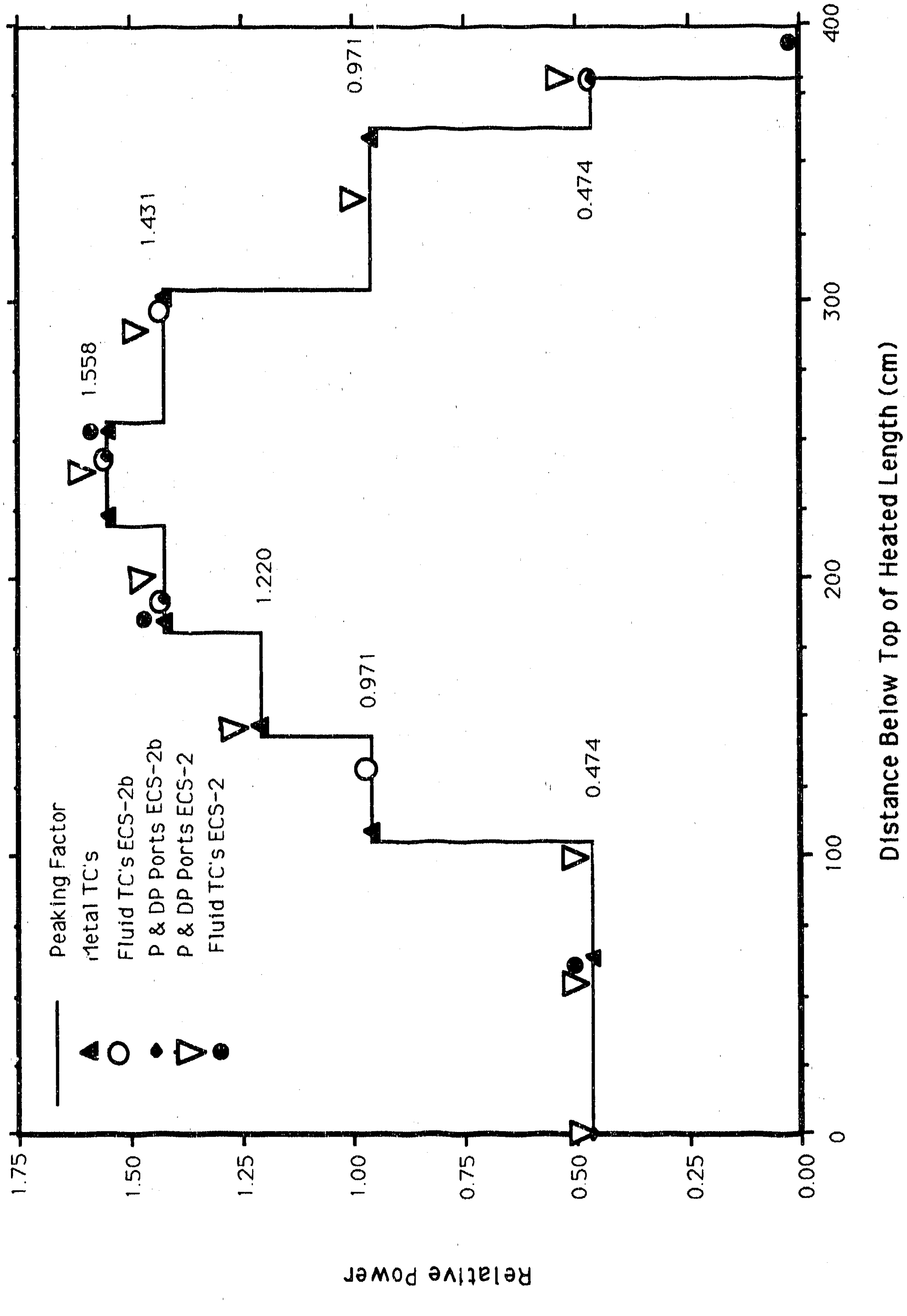


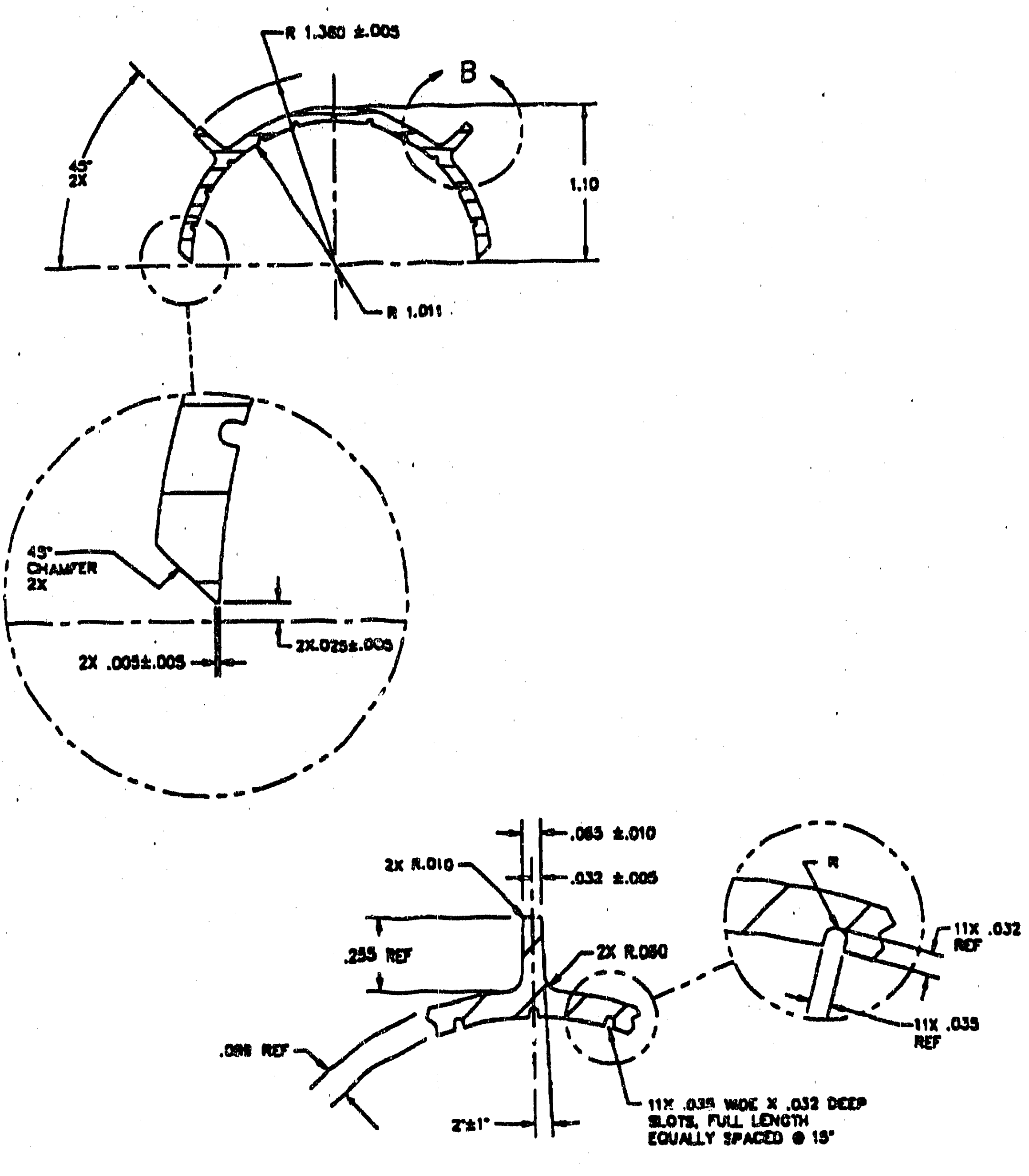
Figure 2.5. Axial power peaking factors and instrument locations for ECS-2 and ECS-2b heaters

Table 2.1. Inconel 600 heater information

Section	Power factor	Distance from top of heater (cm)	Length (cm)	Wall thickness (mm)
1	0.474	000 - 105	104.8	3.07
2	0.971	105 - 143	38.1	1.45
3	1.220	143 - 181	38.1	1.14
4	1.431	181 - 219	38.1	0.97
5	1.558	219 - 257	38.1	0.89
6	1.431	257 - 306	48.6	0.97
7	0.971	306 - 363	57.7	1.45
8	0.474	363 - 381	17.5	3.07

A cross section of the aluminum tube in the region of the fins is shown in Figure 2.6. Complete details are given in Drawing 430052 in Appendix A. The tube was made from 6061 Aluminum, instead of 1100 Aluminum as used in a SRS Mark-22 fuel assembly, because of its good machinability. The fin profile is identical to that used in the SRS Mark-22 fuel assembly. The longitudinal grooves, placed at 15 ° intervals allow for the placement of thermocouples in the aluminum tube. Location and routing of thermocouples are detailed in Drawing 430386 in Appendix A. Those portions of grooves not used for the actual thermocouples are filled with nonactive thermocouple wire. The thermocouples are 0.81-mm (0.032-in.) OD type K stainless steel sheathed having a grounded junction.

After assembly, welding, and dressing of the heater assembly, a helium leak test was performed to ensure there were no leaks in the weld joints. Helium gas at 350 kPa (50 psi) was applied inside the aluminum tube and leaks were detected by covering the surface, one side at a time, with alcohol and observing any bubbles formed. After any leaks were repaired, the heater assembly was placed inside the flow shroud, connected to the water and power supply and thermally cycled several times to temperatures expected during the test matrix. The heater assembly was removed from the flow shroud and again the



Note: Cross section shown is for the ECS-2b heater. The ECS-2 heater had square-bottomed thermocouple grooves but was the same as the ECS-2b heater in other respects.

Figure 2.6 ECS-2 and ECS-2b aluminum tube cross section welds were checked for leaks using the same helium leak test procedure. When convinced that no water could leak into the test section internals, the outer surface of the aluminum was treated to make it wettable by immersing the entire heater assembly in a bath of dilute sodium hydroxide for approximately three minutes. Verification of each thermocouple location was made by identifying each junction using a heat gun applied to the heater surface.

As shown on the drawings in Appendix A, the ECS-2 test section design included provisions for a 1.07 mm ID, 3.66 m long heater rod that could be positioned off-center inside the composite heater. The internal heater was incorporated to provide an azimuthal power tilt although it was never used.

2.2.2 Plena and Shroud

The upper and lower plena were made from acrylic plastic to allow observation of the interior and were designed to provide prototypical elevations and flow resistances. The plenum assembly details are shown in Drawings 430049 and 431747 in Appendix A. The outer flow shroud was made from an 8-cm (3.0-in.) OD polycarbonate tube. Details of the outer shroud are shown in Drawing 430050.

2.2.3 Test Section Instrumentation

Fluid measurement locations in the test section are shown in Figure 2.2 and consist of fluid temperature measurements, absolute pressure, and differential pressure measurements.

Test section fluid temperature measurements for the ECS-2 facility are summarized below:

TF_IN	Upper plenum temperature	
TF_OUT	Lower plenum temperature	
TF_A_01	Subchannel A	63.5-cm (25-in.) below top of heated length
TF_B_01	Subchannel B	63.5-cm (25-in.) below top of heated length

TF_C_01	Subchannel C	63.5-cm (25-in.) below top of heated length
TF_D_01	Subchannel D	63.5-cm (25-in.) below top of heated length
TF_A_02	Subchannel A	183-cm (72-in.) below top of heated length
TF_B_02	Subchannel B	183-cm (72-in.) below top of heated length
TF_C_02	Subchannel C	183-cm (72-in.) below top of heated length
TF_D_02	Subchannel D	183-cm (72-in.) below top of heated length
TF_A_03	Subchannel A	257-cm (101-in.) below top of heated length
TF_B_03	Subchannel B	257-cm (101-in.) below top of heated length
TF_C_03	Subchannel C	257-cm (101-in.) below top of heated length
TF_D_03	Subchannel D	257-cm (101-in.) below top of heated length
TF_A_04	Subchannel A	394-cm (155-in.) below top of heated length
TF_B_04	Subchannel B	394-cm (155-in.) below top of heated length
TF_C_04	Subchannel C	394-cm (155-in.) below top of heated length
TF_D_04	Subchannel D	394-cm (155-in.) below top of heated length

Six absolute pressure measurements are identified below:

P_IN	Upper plenum pressure	
P_OUT	Lower plenum pressure	
P_A_0	Subchannel A	at beginning of heated length
P_B_0	Subchannel B	at beginning of heated length
P_C_0	Subchannel C	at beginning of heated length

P_D_0	Subchannel D	at beginning of heated length

The following eighteen differential pressure measurements were present on the ECS-2 facility;

DP_PL_IN	top to bottom of upper plenum
DP_PL_OU	top to bottom of lower plenum
DP_A_03	Subchannel A top of heated length to 188-cm (74-in.) below top of heated length
DP_A_10	Subchannel A 188-cm (74-in.) to bottom of heated length (381-cm [150-in.])
DP_B_03	Subchannel B top of heated length to 188-cm (74-in.) below top of heated length
DP_B_10	Subchannel B 188-cm (74-in.) to bottom of heated length (381-cm [150-in.])
DP_C_03	Subchannel C top of heated length to 188-cm (74-in.) below top of heated length
DP_C_10	Subchannel C 188-cm (74-in.) to bottom of heated length (381-cm [150-in.])
DP_D_02	Subchannel D -165-cm (-65-in.) [bottom of inlet plenum] to top of heated length (0-cm)
DP_D_03	Subchannel D top of heated length to 48-cm (19-in.) below top of heated length
DP_D_04	Subchannel D 48-cm (19-in.) below top of heated length to 97-cm (38-in.) below top of heated length
DP_D_05	Subchannel D 97-cm (38-in.) below top of heated length to 142-cm (56-in.) below top of heated length
DP_D_06	Subchannel D 142-cm (56-in.) below top of heated length to 188-cm (74-in.) below top of heated length
DP_D_07	Subchannel D 188-cm (74-in.) below top of heated length to 239-cm (94-in.) below top of heated length
DP_D_08	Subchannel D 239-cm (94-in.) below top of heated length to 287-cm (113-in.) below top of heated length
DP_D_09	Subchannel D 287-cm (113-in.) below top of heated length to 333-cm (131-in.) below top of heated

	length
DP_D_10	Subchannel D 333-cm (131-in.) below top of heated length to 381-cm (150-in.) below top of heated length
DP_D_11	Subchannel D 381-cm (131-in.) below top of heated length to 409-cm (161-in.) top of lower plenum

For the heater used in the ECS-2 facility, there are 34 thermocouples embedded in the wall of the aluminum tube at the locations indicated in Table 2.2. The heater used in the ECS-2b facility has 44 thermocouples as indicated in Table 2.3.

A master list of all instrumentation for ECS-2 experiments is included as Table B-1 in Appendix B. Table B-2 in Appendix B contains the same information for ECS-2b experiments. Uncertainty information for each type of measurement is included as Appendix C. Appendix D provides design calculation information for the heater.

2.2.4 Data Acquisition System

A Megadac 2200C interfaced to an IBM System/2 PC made up the data acquisition system (DAS) used for the ECS-2 tests. The Megadac 2200C is a high-speed data acquisition, signal conditioning, and data recording system capable of a continuous sampling rate of up to 20,000 samples per second. Expandable modules allow the Megadac to provide amplification, multiplexing, and analog-to-digital conversion for up to 128 channels of differential input. Signal conditioning included low band pass 4-pole Butterworth filters set for a pass frequency of 2 Hz for thermocouples and 5 Hz for other measurements[1]. The IBM PC is used to perform engineering unit conversion and obtain calculated parameters from various measurements.

A high speed video recording system was used on several experiments to record the hydraulic behavior in the test section. Appendix H contains a detailed description of the video system components and operation.

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[1] The proper analog filter frequency is less than the Nyquist frequency, which is 1/2 the sample frequency. Thus at a recording frequency of 2 samples per second, the filters should be set at a frequency of less than 1 Hz. Unfortunately, the construction of the Megadac boards precluded installation of a filter circuit with this low of a cutoff frequency. Filters were installed at the lowest attainable frequencies.

Table 2.2. Location of wall thermocouples for ECS-2 heater

DAS Tag ID	Distance below top of heated length (cm)	Subchannel	Azimuthal[1] location (degrees)
TI_B_j_1	64	B	135
TI_D_v_1	64	D	315
TI_B_j_2	107	B	135
TI_D_v_2	107	D	315
TI_B_j_3	145	B	135
TI_D_v_3	145	D	315
TI_B_j_4	183	B	135
TI_D_v_4	183	D	315
TI_A_a_5	221	D/A	0
TI_B_g_5	221	A/B	90
TI_B_j_5	221	B	135
TI_C_m_5	221	B/C	180
TI_D_s_5	221	C/D	270
TI_D_v_5	221	D	315
TI_A_a_6	254	D/A	0
TI_A_c_6	254	A	30
TI_A_e_6	254	A	60
TI_B_g_6	254	A/B	90
TI_B_i_6	254	B	120
TI_B_k_6	254	B	150
TI_C_m_6	254	B/C	180
TI_C_o_6	254	C	210
TI_C_q_6	254	C	240
TI_D_s_6	254	C/D	270
TI_D_u_6	254	D	300
TI_D_w_6	254	D	330
TI_A_a_7	302	D/A	0
TI_B_g_7	302	A/B	90
TI_B_j_7	302	B	135
TI_C_m_7	302	B/C	180
TI_D_s_7	302	C/D	270
TI_D_v_7	302	D	315
TI_B_j_8	360	B	135
TI_D_v_8	360	D	315

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[1] See Figure 2.4 for azimuthal angle orientation.

Table 2.3. Location of wall thermocouples for ECS-2b heater

DAS Tag ID	Distance below top of heated length (cm)	Subchannel	Azimuthal[1] location (degrees)
TI_A_d_1	64	A	45
TI_C_p_1	64	C	225
TI_A_d_2	109	A	45
TI_B_k_2	109	B	150
TI_C_p_2	109	C	225
TI_D_w_2	109	D	330
TI_A_d_3	147	A	45
TI_B_k_3	147	B	150
TI_C_p_3	147	C	225
TI_D_w_3	147	D	330
TI_A_d_4	185	A	45
TI_B_i_4	185	B	120
TI_C_p_4	185	C	225
TI_D_u_4	185	D	300
TI_A_a_5	223	D/A	0
TI_A_d_5	223	A	45
TI_B_g_5	223	A/B	90
TI_B_i_5	223	B	120
TI_C_m_5	223	B/C	180
TI_C_p_5	223	C	225
TI_D_s_5	223	C/D	270
TI_D_u_5	223	D	300
TI_A_a_6	253	D/A	0
TI_A_c_6	253	A	30
TI_A_e_6	253	A	60
TI_B_g_6	253	A/B	90
TI_B_i_6	253	B	120
TI_B_k_6	253	B	150
TI_C_m_6	253	B/C	180
TI_C_o_6	253	C	210
TI_C_q_6	253	C	240
TI_D_s_6	253	C/D	270
TI_D_u_6	253	D	300
TI_D_w_6	253	D	330
TI_A_a_7	302	D/A	0
TI_A_d_7	302	A	45
TI_B_g_7	302	A/B	90
TI_B_k_7	302	B	150
TI_C_m_7	302	B/C	180
TI_C_p_7	302	C	225
TI_D_s_7	302	C/D	270
TI_D_w_7	302	D	330
TI_A_d_8	360	A	45
TI_C_p_8	360	C	225

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1. See Figure 2.4 for azimuthal angle orientation.

3. EXPERIMENT DESCRIPTION

Procedures used to conduct wall thermal excursion experiments in the ECS-2 and ECS-2b facilities and to help ensure the validity of the data base generated during the tests are briefly described in this section. System operational checkout and other tests conducted to verify the design, measurement, and support systems are discussed first. Daily procedures used in test setup and measurement calibration are then described. Finally, the procedure used to conduct actual experiments and the test matrices are addressed.

3.1 Checkout Tests

Once the facility hardware and measurements system had been completely installed, numerous checkout tests were conducted to insure that the component systems were working properly. These tests included:

(a) measurements verification
(b) system operational (SO)
(c) inner heater design and measurement system verification
(d) power pulse (conducted in air)
(e) power trip test
(f) single-phase liquid full heat transfer.

3.1.1 Measurement Verification

After the entire measurement and DAS had been installed, a number of checks were conducted to guarantee proper operation of the instrumentation and data recording system. After the DAS had been set up with necessary calibration constants and transform functions, an end-to-end check on each individual measurement was performed. This involved using known voltage insertion at the sensor location to verify the proper response of the measurement signal at the DAS. Where possible, all measurements were checked by inserting known voltages that corresponded to the endpoints of the range for which it was calibrated. This procedure also allowed verification of instrument cabling, patch panel setup, and so forth.

Air flow measurement outputs were verified using a technique involving the use of a suction fan and soap bubbles. The system was configured with a large intake pipe on the upstream side of the measurement station being checked. An air-soap bubble mixture was drawn through the measurement station to produce a flowrate. With a known cross section area of the piping, the time required for a single soap bubble to travel a known distance allowed calculation of the volumetric flowrate. This value was checked against the measurement signal output to the DAS (data was not recorded). Although crude, the methodology gave confidence in the measurement.

Turbine meters used to provide liquid flowrate measurement were verified after installation using timed measurements and calibrated collection devices.

Differential pressures, absolute pressures, and fluid and metal thermocouples in the system were verified for location and response while slowly filling the test section with water. Response of the measurements was correlated with the liquid level in the test section using both hot and cold water bottom fills.

3.1.2 System Operational (SO) Tests

The ECS-2 and ECS-2b facilities and all supporting equipment (electrical power, data acquisition, water supply, and so forth) were checked in an integral fashion prior to conducting any planned experiments by conducting System Operational tests. The objective of the SO tests was to ensure that the overall system could function as desired. Included in the SO test were component checks and a "dry run" for a bonafide experiment complete with data archiving and analysis.

3.1.3 Air Power Pulse (APP) and Liquid Full (LF) Checkout Tests

Two different tests were run to verify the design details of the inner heater. Three air power pulse tests (APP) and one liquid full (LF) power pulse test were conducted to help verify the axial and azimuthal power profile on the heater. More than 40 LF tests were conducted to examine heat transfer to single-phase liquid.

APP tests involved pulsing the test section with a low, constant power for approximately one minute with the test section in a dry air environment. Such a heatup in air was expected to result in a nearly adiabatic heatup rate of the test section. Rise rates for each wall thermocouple could then be related to the local power generation rate for comparison to expected values and to investigate evidence of azimuthal variation. Details of the APP tests and conclusions reached are documented in Appendix E of Anderson [11]. APP test results verified that the axial power profile was per design specifications and that there were no significant azimuthal power gradients.

One liquid full power pulse test and one air power trip test were conducted to help resolve questions regarding the potential effects of electrical and magnetic fields (induced by the power supply) on the aluminum wall thermocouple readings. Results of these experiments showed that there was no influence of electrical and magnetic fields on the aluminum wall thermocouple readings.

Liquid full tests were run to examine the axial variation in heat transfer to single-phase liquid. These tests were run by setting the standpipe at a level above the top of the heated length to ensure only liquid flow existed in the flow channel. Heat transfer coefficients were then computed from the data and compared with expected values to establish confidence in the data. Details of several of the LF tests and results from the analysis of LF test data are contained in Appendix F of Anderson [11]. Additional information pertaining to the results of the LF tests will be published in an addendum to Anderson's report.

3.2 Routine Data Integrity Checks

To ensure the integrity of the data produced in the ECS-2 facility, certain procedures were routinely performed (weekly, daily, or before every test) as required.

DAS balance and calibration were electronically checked daily. Even though the DAS electronics were very stable, electronic balance and two point calibration on the cards in the DAS were performed weekly, or following instrument changeout or measurement channel patch changes.

Differential pressure transducers were checked daily. The cells were valved out of the system, the sense lines were backfilled, and the instruments were checked for any abnormal zero offsets (offsets were corrected if found), and then valved back into the system.

Pretest and posttest scans of all measurements were conducted for each test. Known, steady-state thermal conditions were established in the test section. Review of this information helped to identify any problems with measurement and electronics consistency. The fluid temperature reading from a calibrated glass thermometer, installed at the inlet to the test section, was compared with the inlet fluid thermocouples to ensure measurement consistency.

Daily, barometric pressure readings, obtained from the INEL Standards and Calibration Laboratory, were recorded in the test operations log book. Water pH measurement results were also recorded daily in the test operations log book (The test operations log book for the ECS-2 experiments consists of three volumes. Copies of these volumes are located in the INEL Technical Library and have identification numbers INEL-NBU-2205, INEL-NBU-2206,and INEL-NBU-2207).

3.3 Experimental Procedure

Most thermal excursion experiments conducted in the ECS-2 and ECS-2b facilities were conducted using the same procedure. For any given experiment, the sequence of events was as follows:

Before initiation of power to the heater

- Set test section standpipe to desired value
- Initiate inlet flow and set to desired value
- Start the heated water makeup system and adjust the fluid temperature to the desired value
- Start DAS (in monitor mode)
- Verify systems operating.

Test Initiation

- Initiate DAS record 2 minutes prior to application of power
- Set Inconel test section power to approximately 20 kW and maintain sufficiently long to achieve thermal equilibrium
- Increase test section power by an increment specified by the test engineer followed by a 2-5 minute soak period
- Record video data per the direction of the test engineer
- Increase test section power by an increment of approximately 20 kW (discretion of the test engineer) followed by a 2-5

minute soak period. If thermal excursion does not occur during the power increase, maintain the power setting for approximately 5 minutes to allow system to soak and come to thermal equilibrium

- Continue increasing the test section power in steps followed by a 5 minute soak period until thermal excursion occurs or the test section is at maximum power
- When the test criteria are met (sustained thermal excursion), terminate test section power (normally done automatically by a power trip circuit that monitored specified metal temperatures)
- Terminate DAS record.

Posttest Activities

- Archive recorded data
- Conduct engineering units calculations and prepare Quick Look plots
- Conduct posttest facility check.

Experiments in the flow coastdown series (ECS-2FC) deviated somewhat from this procedure. For the flow coastdowns, the test section power was held constant while the inlet flow was decreased in discrete steps from the initial value. In the ECS-2cE experiments, permanent data recording was not initiated until the test section was near (within approximately 10 kW) thermal excursion, power increases were limited to 3 kW, and the soak time at any given power was at least 6 minutes.

The goal for tests in the thermal excursion program was to establish and measure the conditions (test section flowrate, power, inlet fluid temperature, and lower plenum pressure) leading to sustained thermal excursion at any position along the axial length of the heater. The excursion criteria and hence test termination criteria were defined based on maximum aluminum wall temperature. For the majority of the INEL experiments, this maximum temperature was 620 K. On some of the later experiments, the temperature criterion was decreased to 520 K to be consistent with similar experiments conducted at SRS. Data repeatability and the impact of the different excursion criteria are discussed in Appendix F.

In addition to the maximum wall criteria, an ancillary test section power limit criterion was implemented to provide heater protection during the thermal excursion experiments. Equipment design considerations limited the maximum heater power to less than 175 kW. Most experiments, however, were successfully completed at heater powers less than 150 kW.

3.4 Test Matrix

Three different groups of wall thermal excursion experiments were conducted in the ECS-2 and ECS-2b facilities. The major goal of these experiments was to determine the test section power required to cause a sustained dryout at some axial location on the heater wall as a function of inlet flow, inlet liquid subcooling, and test section back pressure. Tests conducted encompassed the range of test parameters shown 'n Table 3.1. In addition to the excursion experiments, a special group of air ingress tests were conducted. A detailed discussion of the air ingress test results is presented in Appendix G. A brief discussion of each test group and associated objectives is given below.

Table 3.2 provides the nominal conditions for the matrix of excursion tests conducted in the ECS-2 facility. As shown, the matrix consisted of 25 baseline (denoted by BL in the test name) experiments, two flow coastdown (denoted by FC in the test name) experiments, and eight experiments (denoted by WSR in the test name) conducted at the special request of WSRC personnel. Table 3.3 lists the nominal conditions for the matrix of excursion test conducted in the ECS-2b facility. Test names in

Table 3.1. Range of parameters for thermal excursion experiments

Parameter	Range
coolant flowrate	0 - 1.4 l/s (0 - 22 gpm)
inlet plenum pressure	86.2 kPa (local atmospheric)
outlet plenum pressure	-18 - 139.7 cm of water (-7 - 55 inches of water) referenced to the bottom of the heated length.
inlet liquid temperature	293 - 344 K (20 - 71 C)
heater power	0 - 175 kW

Table 3.2. Nominal conditions for excursion tests conducted in the ECS-2 facility

Test Name	Inlet Subcooling (K)	Inlet[1] Temp (K)	Volumetric Flow (l/s)	Liq. Superficial Velocity (m/s)	Standpipe[2] (cm)
ECS-2BL_1	75	293.5	0.1	0.075	399
ECS-2BL_1B	75	293.5	0.1	0.075	399
ECS-2BL_2	75	293.5	0.3	0.225	399
ECS-2BL_5	45.8	322.7	0.1	0.075	399
ECS-2BL_5B	45.8	322.7	0.1	0.075	399
ECS-2BL_5C	45.8	322.7	0.1	0.075	399
ECS-2BL_5D	45.8	322.7	0.1	0.075	399
ECS-2BL_6	45.8	322.7	0.3	0.225	399
ECS-2BL_7	45.8	322.7	0.5	0.376	399
ECS-2BL_7B	45.8	322.7	0.5	0.376	399
ECS-2BL_11	24.3	344.2	0.3	0.225	399
ECS-2BL_11B	24.3	344.2	0.3	0.225	399
ECS-2BL_12	24.3	344.2	0.5	0.376	399
ECS-2BL_12B	24.3	344.2	0.5	0.376	399
ECS-2BL_13	24.3	344.2	0.7	0.526	399
ECS-2BL_14	24.3	344.2	0.9	0.676	399
ECS-2BL_17	45.8	322.7	0.3	0.225	271
ECS-2BL_18	45.8	322.7	0.5	0.376	271
ECS-2BL_18B	45.8	322.7	0.5	0.376	271
ECS-2BL_22	45.8	322.7	0.3	0.225	330
ECS-2BL_23	45.8	322.7	0.5	0.376	330
ECS-2BL_23B	45.8	322.7	0.5	0.376	330
ECS-2BL_26	45.8	322.7	0.3	0.225	362
ECS-2BL_26B	45.8	322.7	0.3	0.225	362
ECS-2BL_27	45.8	322.7	0.5	0.376	362
ECS-2FC_1	45.8	322.7	0.3-0.13[3]	0.225-0.095	362
ECS-2FC_2	45.8	322.7	0.5-0.27[3]	0.376-0.203	362
WSR0380	55	315	0.38	0.285	333
WSR0580	55	315	0.58	0.436	333
WSR0580C	55	315	0.58	0.436	333
WSR0760	55	315	0.76	0.571	333
WSR0960	55	315	0.96	0.721	333
WSR1040	55	315	1.04	0.781	333
WSR1040B	55	315	1.04	0.781	333
WSR1340	55	315	1.34	1.007	333

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1. Saturation temperature at the inlet is 368.5 K based on a local atmospheric pressure of 85.6 kPa.
2. Elevation referenced to the top of the heated length. To reference to the bottom of the heated length, subtract listed number from 381 cm.
3. Flow coastdown test.

Table 3.3 contain a "c" and an "E" to denote the fact that the experiments were conducted during the "c" group of runs and were wall excursion tests.[2]

The ECS-2BL experiments were the first excursion tests conducted in the ECS-2 facility. BL tests were initiated in mid-December of 1989 and completed in mid-January of 1990. The two FC experiments and the air ingress experiments discussed in Appendix G were also conducted during this same time period. WSR tests were conducted during the latter half of January 1990. Attempted conduct of Test WSR1340 resulted in the destruction of the inner heater (as was expected) due to the high flowrates and high inner heater power levels incurred. A new inner heater that was under fabrication for the Dual Heated Annulus program was completed and installed during February 1990. Instrumentation changes were also made to the test section and the facility was then used to conduct the aforementioned ECS-2b and ECS-2c series of tests (wall saturation experiments). ECS-2c excursion tests shown in Table 3.2 were conducted in late June of 1990.

Table 3.3. Nominal conditions for excursion tests conducted in the ECS-2b facility

Test Name	Inlet Subcooling (K)	Inlet Temp (K)	Volumetric Flow (l/s)	Liq. Superficial Velocity (m/s)	Standpipe[1] (cm)
ECS-2cE11	57	311.5	0.406	0.305	333
ECS-2cE12	57	311.5	0.609	0.457	333
ECS-2cE13	57	311.5	0.811	0.609	333
ECS-2cE14	57	311.5	1.014	0.762	333
ECS-2cE21	42	326.5	0.406	0.305	381
ECS-2cE22	42	326.5	0.406	0.305	241
ECS-2cE23	75	293.5	0.406	0.305	381
ECS-2cE24	75	293.5	0.406	0.305	241
ECS-2cE31	42	326.5	0.811	0.609	381
ECS-2cE32	42	326.5	0.811	0.609	241
ECS-2cE34	75	293.5	0.811	0.609	241
ECS-2cE42	42	326.5	1.217	0.914	241

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1. Standpipe referenced to top of the heated length. To reference to the bottom of the heated length, subtract listed number from 381 cm.

All of the excursion tests conducted were specified with input from WSRC personnel and reflect boundary conditions expected to represent reactor conditions or those required to duplicate as closely as possible experiments previously conducted at the SRS Heat Transfer Laboratory. For example, the BL series was designed to provide information on the effects of a range of inlet fluid temperature, inlet flowrate, and facility back pressure. The two FC tests provided information on the effects of transient flow conditions with test section inlet temperature, flowrate, back pressure, and power held constant. Specifications for the WSR tests reflect the desire to duplicate flowrate boundary conditions for experiments that had been conducted at the SRS Heat Transfer Laboratory. Inlet flowrate was the primary variable and neither the inlet fluid temperature or the back pressure were altered during the WSR tests. Objectives of the ECS-2cE experiments were twofold. Fluid temperature and back pressure boundary conditions used are the same values used in the wall saturation tests and reflect the current best estimate values for reactor conditions.[3] Also, the facility hardware was somewhat different relative to the ECS-2 system since a new inner heater was installed and instrumentation changes were effected. ECS-2cE experimental data therefore offer an opportunity to check for any systematic effects due to system hardware.

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[2] The majority of the ECS-2b program centered around investigation of wall saturation criteria. Two different groups of runs, the "b" and "c" series, were conducted to examine conditions satisfying the wall saturation criteria.

[3] Improvements in computer code predictions and changes in assumptions about the LBLOCA since the BL tests were conducted led to small changes in the best estimate boundary conditions.

4. RESULTS

Excursion test results are presented in this section. An overview of a typical test will be given first to illustrate test conduct, provide a flavor for the nature of the time series data produced, and explain the data presentation format. Characteristics of the wall temperatures, pressures and differential pressures, fluid temperatures, and air entrainment are discussed. A general description of the factors influencing the wall temperature excursion is then provided. Finally, all the data recorded is summarized and presented in terms of the R factor (power at the limits criteria of interest divided by the power required to saturate the fluid at the outlet of the test section). Results from both the INEL experiments and the SRS experiments are included. Appendix I contains a list of the measurements that were failed or determined to be questionable for each experiment. Appendix J contains tables of data averages for the power step before excursion and the power step at which excursion occurred for all of the INEL experiments.

4.1 Typical Test Results

Data from Tests ECS-2BL_5 are presented to illustrate results from a typical thermal excursion experiment. This particular experiment was conducted on several different occasions and is the basis for the data repeatability discussion in Appendix F. ECS-2BL_5 was conducted from nominal conditions of 322.7 K inlet fluid temperature (45.8 K subcooling), an inlet flowrate of 0.1 l/s (superficial velocity of 0.075 m/s), and with an outlet standpipe setting of 43 cm referenced to the bottom of the lower plenum (399 cm relative to the top of the heated length or -18 cm relative to the bottom of the heated length). This test was typical of low flow tests with multiple dryout-rewet cycles before a sustained dryout and thermal excursion that occurred at a saturation ratio (R factor) significantly larger than unity.

ECS-2BL_5 was conducted using the procedure discussed in Section 3.3. After the desired inlet fluid temperature and flowrate were established, data recording was initiated, the heater power was increased to 10 kW and held for 5 minutes while the system came to thermal equilibrium. Power was then increased by roughly 5 kW increments with 1-2 minute hold periods over the next 35 minutes until thermal excursion occurred. This experiment represented one of the more cautious approaches to test conduct since ECS-2BL_5 was one of the first excursion experiments conducted and expectations regarding the power at which dryout would occur were not yet clear. Test results indicated that the test section underwent a sustained dryout about 35 minutes after power was initiated at a power of 53.5 kW.

Figure 4.1 shows a comparison of the measured electrical power and the power obtained from a thermal energy balance on the test section heated length. The thermal energy was calculated using a simple heat balance incorporating the measured inlet fluid temperature, flowrate, and fluid temperature at the exit of the heated length. On the ECS-2 facility, a cooling coil located in the lower plenum was used to maintain subcooled fluid conditions in the lower plenum as is expected in the reactor. Plenum temperature measurements were therefore not used for the energy balance. As indicated in Figure 4.1, thermal equilibrium was achieved on the first two power steps as evidenced by the asymptotic approach of the calculated thermal power to the electrical power. As the power was increased to 20 kW and above, the fluid at the outlet of the heated length reached saturation conditions as evidenced by the constant value of the

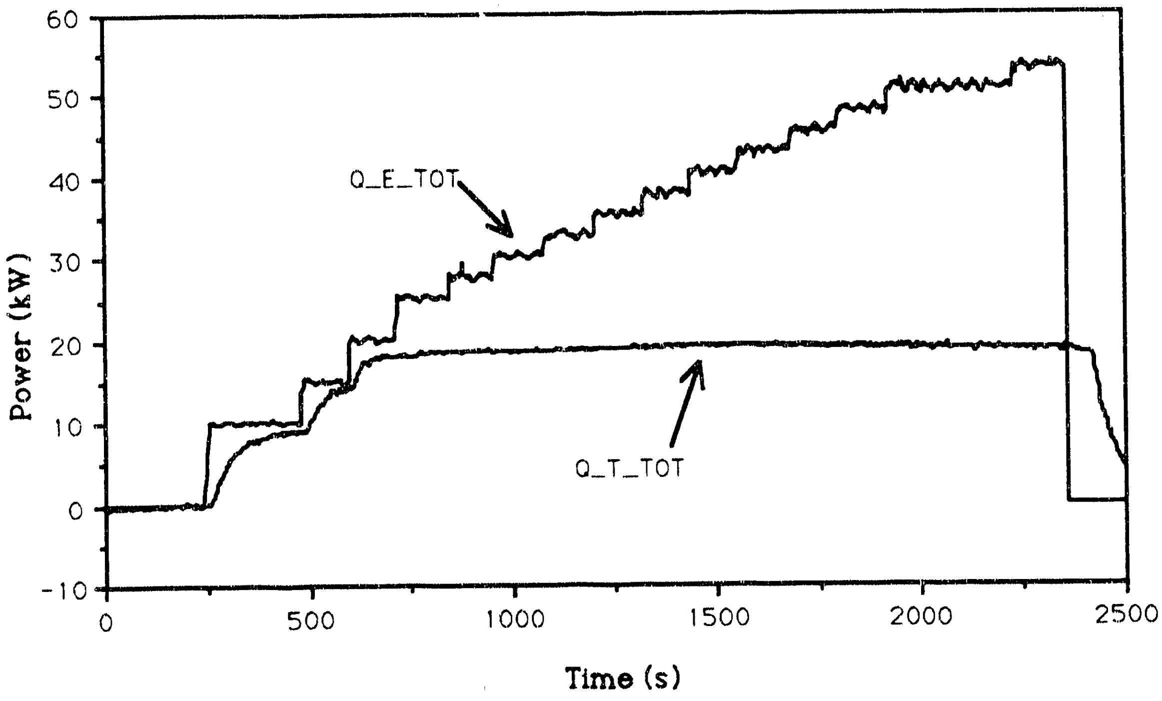

Figure 4.1. Comparison of electrical and thermal power for ECS-2BL_5

thermal power.

A cursory examination of the data in Figure 4.1 indicates that when the excursion criteria were met, the power input to the test section was nearly three times the amount of power required to saturate the fluid at the outlet of the heated length (53.5 kW relative to 20 kW required to saturate the outlet test section).

4.1.1 Wall Temperatures

Figure 4.2 shows the time history of an aluminum wall thermocouple at level 7 (302 cm location[4]) and the electrical power. The thermocouple shown is one of several at 302 cm that underwent sustained thermal excursion at 2360 seconds and ultimately caused the power to trip when the 620 K maximum temperature criterion was reached. It is interesting to note that the 302 cm thermocouples are on the power step just below the high power location (level 5 and 6 thermocouples are on the high power

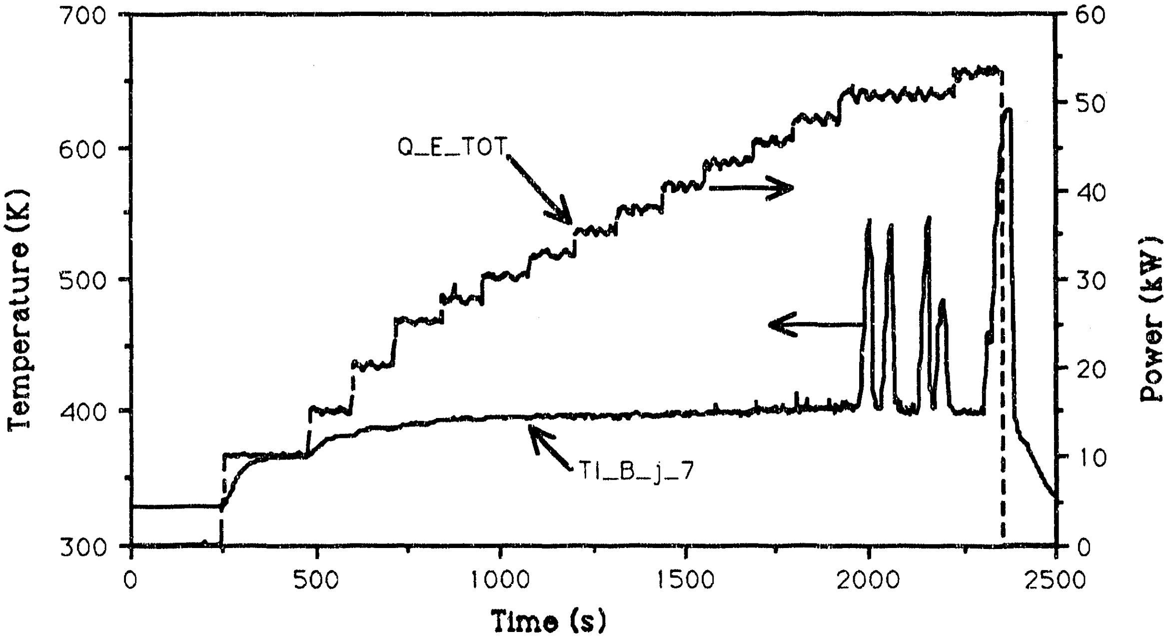

Figure 4.2. Time history of level 7 wall thermocouple and power

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[4] Level designations for wall thermocouples do not coincide with power steps on the heater. For example, level 5 and 6 thermocouples are both on the high power zone of the heater. Refer to Figure 2.5 for general information on the wall temperature measurement locations relative to the power steps on the heater.

zone). As discussed in Appendix F, sustained dryout did not always occur at level 7 and initiate the trip. Occasionally, level 6 thermocouples met the criteria before those at level 7 (see Figure 2.5).

As mentioned, TI_B_j_7 was one of several measurements that underwent sustained dryout during the ECS-2BL_5 test. Figure 4.3[5] shows the full time history of all of the level 7 thermocouples. This comparison indicates that while there are differences in the individual thermocouple readings before the sustained dryout, the dryout is azimuthally uniform at the 302 cm location. Further proof of the azimuthal uniformity is shown in Figure 4.4, which is a comparison of the same data as Figure 4.3 on an expanded time scale.

Level 7 thermocouple data shown in Figures 4.2 - 4.4, indicate that several temporary dryouts occurred before the final attainment of the trip criteria. Wall temperatures of approximately 550 K were reached during these excursions before rewetting occurred and cooled the wall back to approximately 400 K. Data shown on the expanded time scale in Figure 4.4 indicates that the dryout-rewet cycles were azimuthally uniform since all the thermocouples show dryout and rewet during the same time periods.

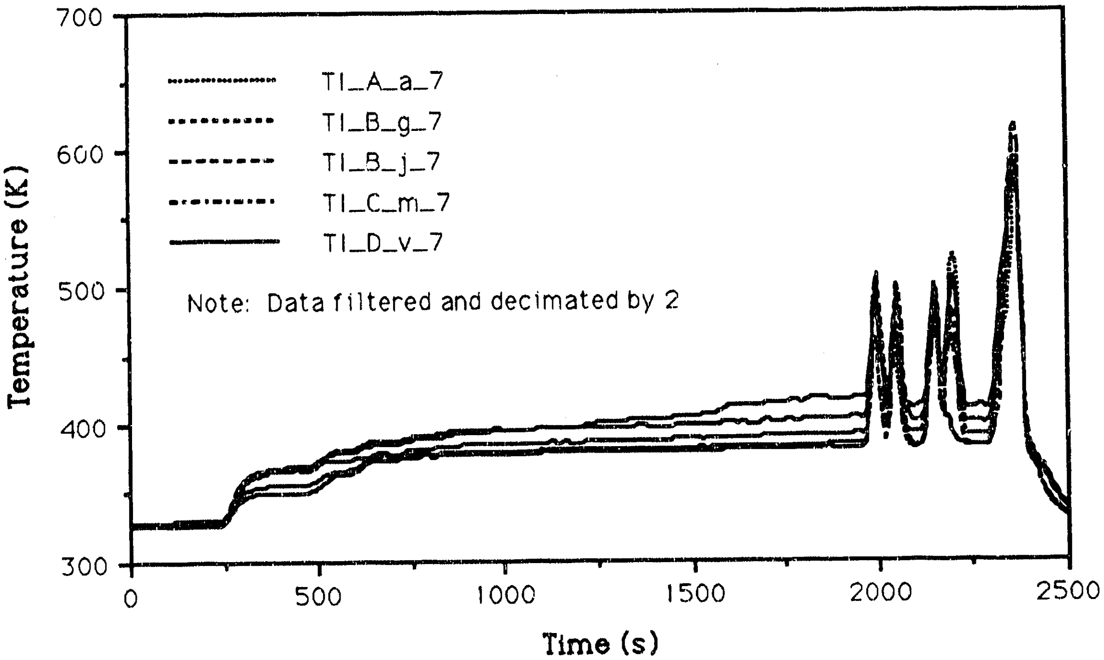

Figure 4.3. Full time history of all level 7 thermocouples for ECS-2BL_5

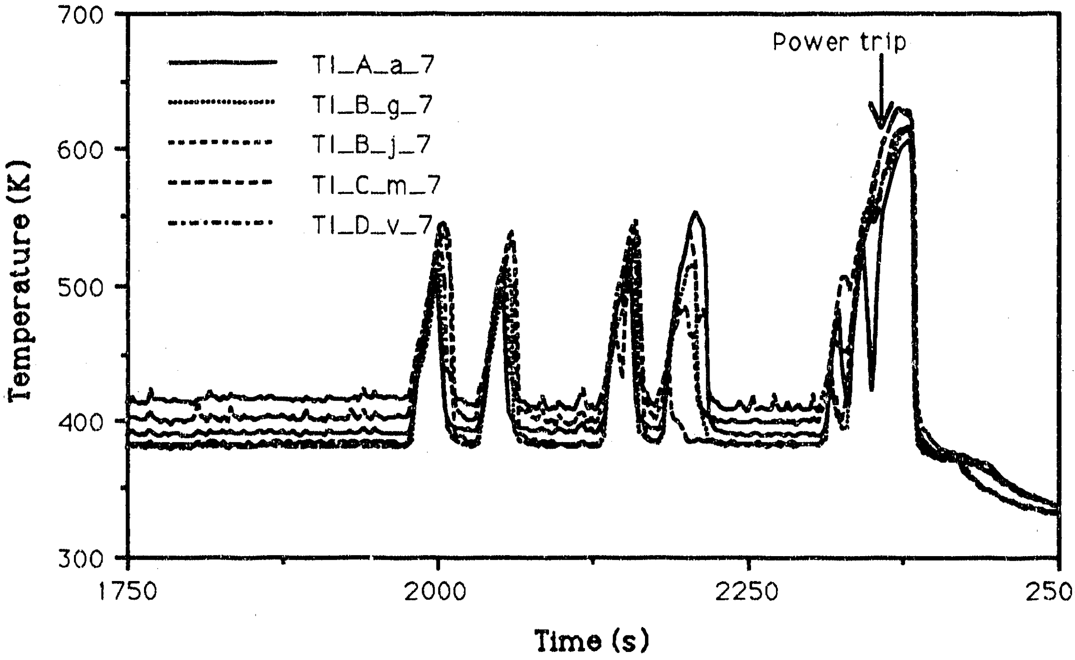

Figure 4.4 Expanded time scale comparison of level 7 thermocouples for ECS-2BL_5

The point at which the power tripped (due to exceeding the temperature criteria) is shown in Figure 4.4. Wall temperatures continued to increase even after the power had tripped because of significant stored energy in the test section.

Thermocouples at level 7 were not unique with respect to the multiple occurrences of the dryout-rewet cycle. Measurements at other levels throughout the heated length showed several cycles of dryout with subsequent rewet. Figure 4.5 demonstrates this feature by showing the axial distribution of measured wall temperatures at the "j" azimuthal location (135°) in the B flow channel for Test ECS-2BL_5. The data are displayed on an expanded time scale encompassing the initiation of the dryout-rewet cycles and the final sustained excursion. Although it is difficult (and not necessary) to discern individual thermocouple traces on this figure, it is obvious that thermocouples at all levels except level 1, which is on a low

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5. Data was filtered using a finite-impulse-response low band pass filter and then decimated (every nth point was kept) to reduce the total volume of data for ease of plotting.

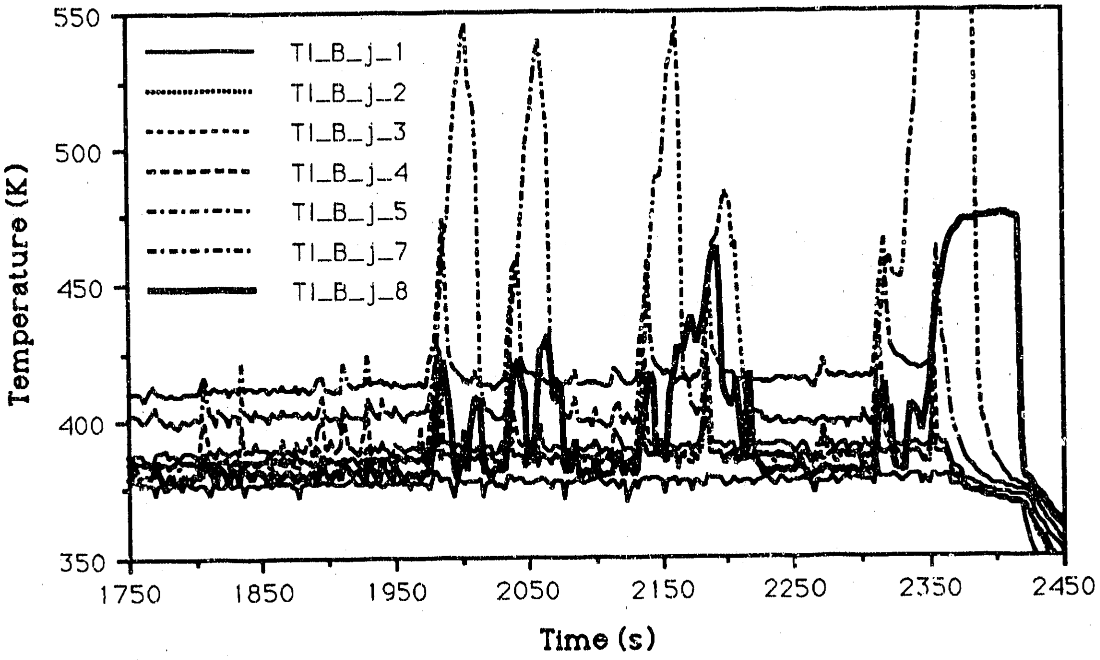

Figure 4.5. Wall thermocouple response in B subchannel for ECS-2BL_5

power step at the top of the heated length, show four or more temporary excursions followed by rewets. Results from the D flow channel, which also had a full axial compliment of wall thermocouples at the same azimuthal location (position "v" or 315°), are very similar to those in the B flow channel shown in Figure 4.5.

4.1.2 Pressures and Differential Pressures

Figure 4.6 shows the inlet plenum and the outlet plenum absolute pressure measurements compared to the measured local atmospheric pressure. Since the inlet plenum is open to the atmosphere, the pressure measured there is nearly identical to atmospheric pressure. Figure 4.7 shows the inlet and outlet plenum and the standpipe levels computed from the measured differential pressures across these components (Appendix E provides documentation on the calculation procedure). As shown, the inlet plenum head is less than 2 cm of water whereas the outlet plenum level is 28 cm indicating that it is basically full. As noted in Section 4.1, the standpipe was set to provide a back pressure of approximately 43 cm of water relative to the bottom of the outlet plenum for ECS-2BL_5. The standpipe

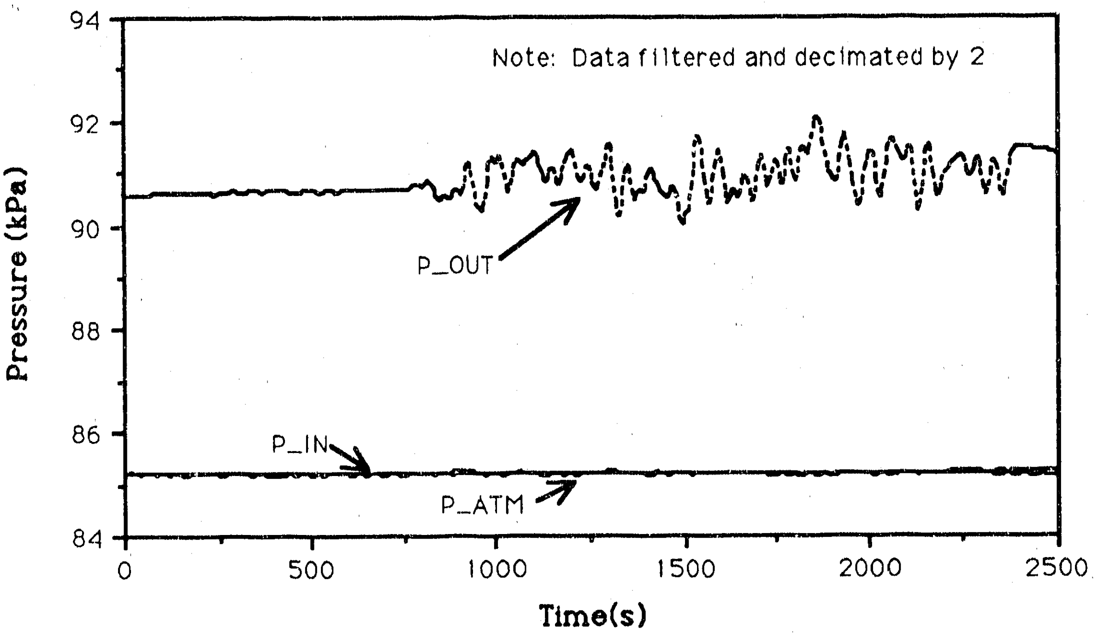

Figure 4.6. Comparison of inlet and outlet plenum pressures with local atmospheric pressure for Test ECS-2BL_5

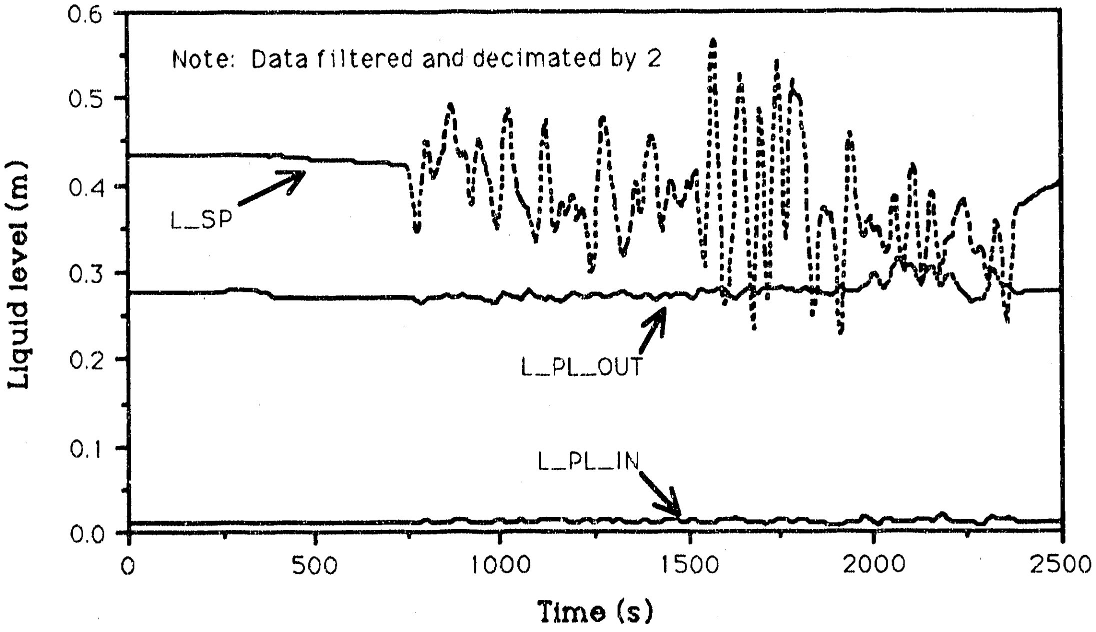

Figure 4.7 Inlet and outlet plenum levels for ECS-2BL_5

level shown in Figure 4.7 verifies the level setting.

As expected, pressure and differential pressure measurements in the test section showed substantial oscillation during the experiment, particularly after saturation conditions were achieved at the outlet of the heated length. As will be illustrated in the next section, the liquid at the outlet of the heated length reached saturation conditions just after 750 seconds. Substantial vapor generation and holdup ensued resulting in a churn-turbulent flow regime in the test section. The unsteady nature of the local flows caused the fluctuations noted in the measurements. Although not evident on ECS-2BL_5, the holdup in the test section for many experiments was sufficient to cause the inlet plenum level to increase significantly.

For Test ECS-2BL_5, an absolute pressure measurement was located in each subchannel at the beginning of the heated length. These measurements suffered from zero offsets during this test and the data are not presented here. Instead, data from Test ECS-2BL_5B (conditions on BL_5B are identical to those on BL_5 as discussed in Appendix F) are presented in Figure 4.8. Data from these two tests are directly comparable until about 1600 seconds. In order to prevent undue clutter on the figure, only the data from the B and D subchannels is shown since the response of each measurement is very similar. The pressure behavior is consistent with the wall temperature measurements presented in Section 4.1.1 in that there is azimuthal uniformity in the oscillations even though at any given time, there are slight differences in magnitude. It should be noted that the pressure data from Test ECS-2BL_5 showed the same basic response with the exception that due to an electronics problem, the magnitudes were 30 kPa above atmospheric pressure.

From the data shown in Figure 4.8, it is apparent that the pressure at the inlet to the heated length increased slightly (1-2 kPa) when the test section outlet became saturated at 750 seconds. Although the increase is minor, it is consistent with visual observations during the experiment that suggested water accumulation (void fraction was decreasing slightly) in the unheated part of the test section between the bottom of the inlet plenum and the entrance to the heated length. This observation is consistent with the expected increase in two-phase pressure drop through the test section in light of local flooding noted along the heated length.

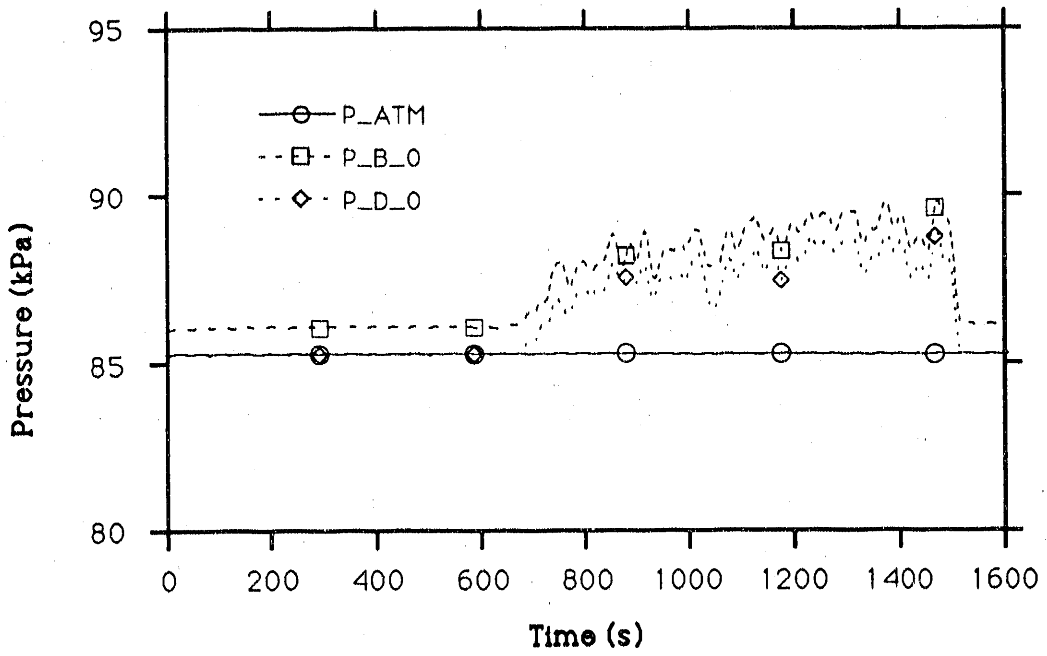

Figure 4.8. Comparison of subchannel pressure measurements at the entrance to the heated length for Test ECS-2BL_5B

Differential pressures measured from the top to the middle of the heated length (0- to 188-cm) are shown in Figure 4.9. Data in Figure 4.9 show that the differential pressures in the A and B subchannels are different than the differential pressures in the C and D[6] subchannels after saturation conditions are reached at the outlet of the heated length. For example, the measured differential pressures in the C and D channels show a slight increasing trend after 750 seconds whereas the differential pressures in the A and B channels indicate a continual decrease until the power was tripped at 2360 seconds. Close scrutiny of Figure 4.9 indicates that at least part of the time, the differential pressure oscillations in the C and D channels are out of phase with the oscillations in the A and B channels. These data are consistent with visual observations that indicated churn-turbulent flow in the test section, channel-to-channel flow variations, channel-to-channel azimuthal flows, and localized flooding.

The data in Figure 4.9 indicate that the upward flow of vapor was preferentially in subchannels C and D, resulting in higher void fractions and

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[6] The D subchannel differential pressure shown is the summation of individual differential pressure measurements from 0 to 188 cm.

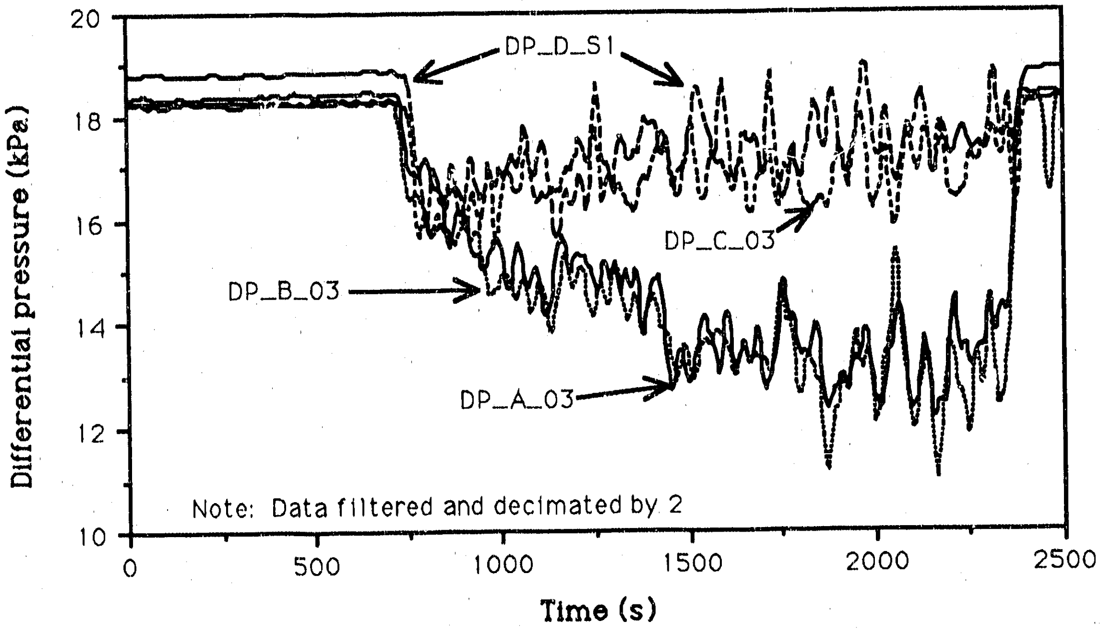

Figure 4.9. Differential pressures in upper half of the heated length for Test ECS-2BL_5

thus higher differential pressures. Differential pressure measurements were zeroed with the reference legs valved out and the legs equalized. Therefore, the measured differential pressure reflects the difference in hydrostatic heads of the reference legs for an empty test section and gives a zero reading for a full test section. Increasing void fraction, therefore, causes increasing differential pressure readings.

Figure 4.10 shows results from differential pressures measured from the middle of the heated length to the bottom of the heated length (188-cm to 381-cm). In the lower half of the heated length, the differential pressures in the A, B, and C subchannels are similar while the differential pressure in the D subchannel is different. Again, the response of the differential pressures is consistent with visual indications suggesting somewhat more uniform azimuthal behavior in the lower half of the test section relative to the upper half of the test section.

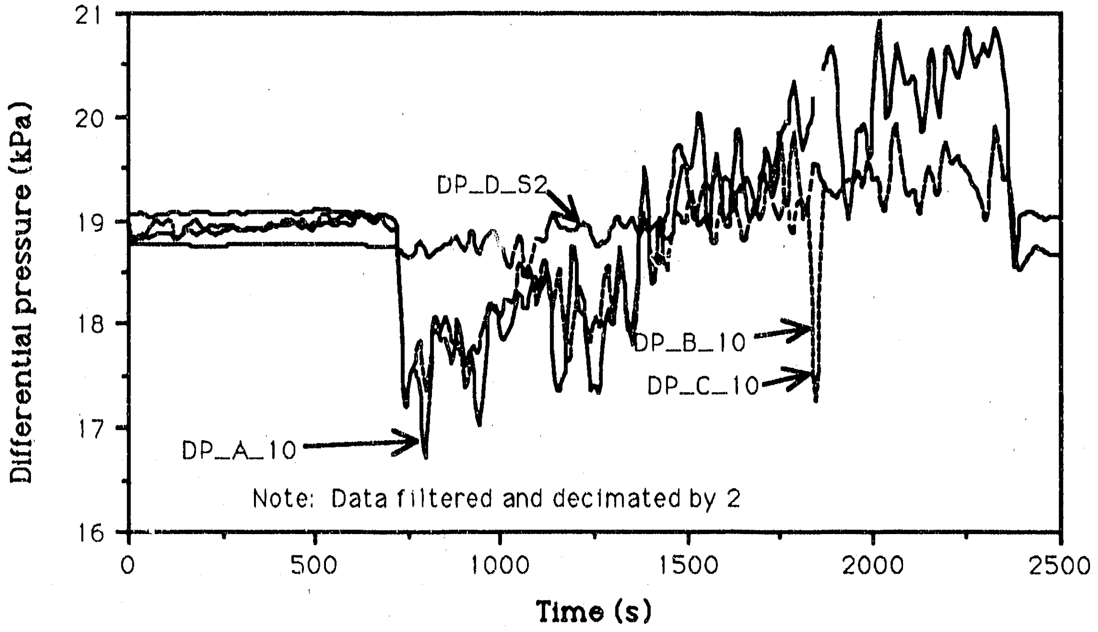

Figure 4.10. Differential pressures in the lower half of the heated length for Test ECS-2BL_5

4.1.3 Fluid Temperatures

Fluid temperatures in the inlet plenum, the outlet plenum, and the outlet of the heated length are shown in Figure 4.11 along with the saturation temperature. Saturation temperature is computed using the outlet plenum pressure. The heated length outlet temperature (TF_04_AV) is the average of the four fluid thermocouples located at the 394 cm elevation (see Appendix E for discussion of the calculated parameters).

Two points are notable with respect to the data shown in Figure 4.11. First, as mentioned in previous sections, the bulk fluid at the outlet of the heated length went saturated at approximately 750 seconds. Bulk saturation conditions are evidenced by the asymptotic approach of the data from TF_04_AV to the calculated saturation temperature. Second, the response of TF_OUT indicates that subcooled conditions were maintained in the outlet plenum as desired for the majority of the experiment. As described in Section 2.1, a cooling coil located in the outlet plenum was used to condense steam that entered the plenum in order to prevent steam from compromising the exit air flow measurements.

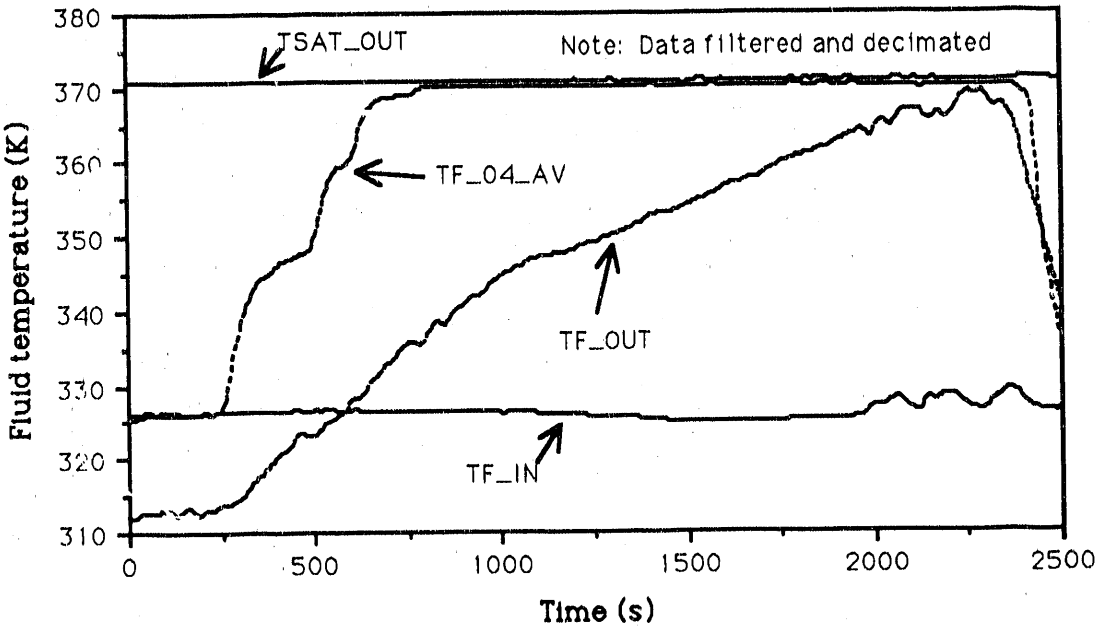

Figure 4.11. Plenum and heated length outlet fluid temperatures for Test ECS-2BL_5

In addition to the fluid temperature measurements at 394 cm (TF_04_AV in Figure 4.11), fluid thermocouples were located at three other axial positions along the heated length for Test ECS-2BL_5. At each axial location (64-, 183-, 257- and 391 cm below the top of the heated length), one fluid thermocouple was installed in the center of each flow channel. Figure 4.12 shows a comparison of the averages of all four thermocouple readings at each axial location along with the saturation temperature based on outlet plenum pressure. The data in Figure 4.12 are shown on an expanded time scale to accentuate the axial fluid temperature distribution before saturation conditions were achieved. Consistent with the comparison of electric and calculated thermal power shown in Figure 4.1, it is evident that all the fluid in the test section was saturated by 750 seconds. Before 750 seconds, the axial fluid temperature distribution is interesting in that the average fluid temperature at 257 cm is somewhat higher than the temperature at 391 cm although the uncertainty bands (± 3.3 K) on the fluid temperatures overlap. Also one must recall that the test section power is changing in discrete steps over time and true steady-state conditions may not have been achieved at all the power steps.

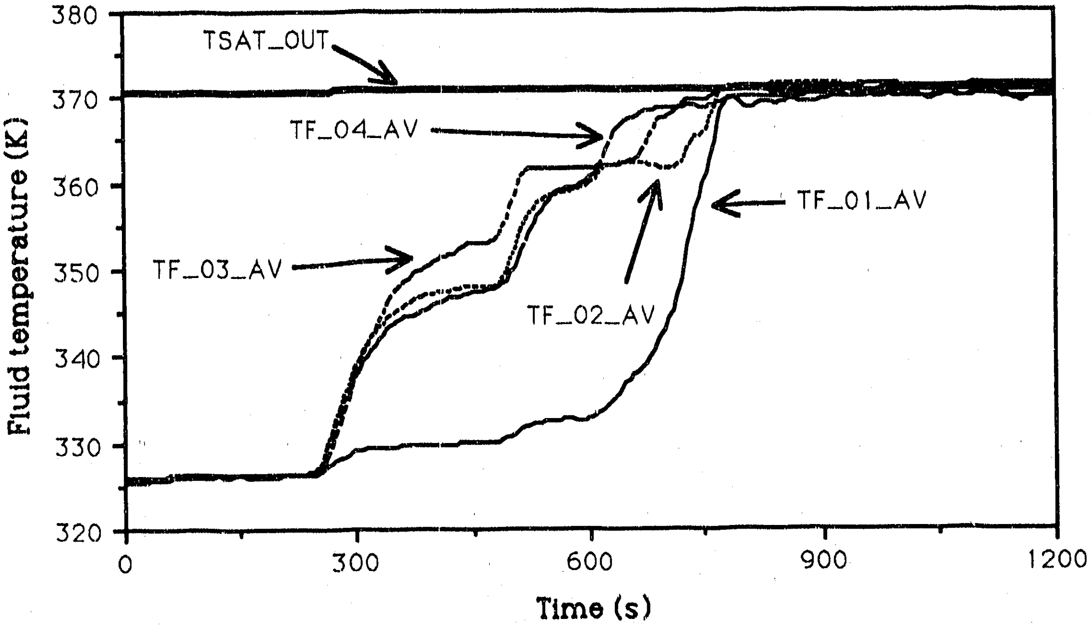

Figure 4.12. Axial fluid temperature distribution for Test ECS-2BL_5

The most significant observation from Figure 4.12 is that all the fluid temperatures indicate saturation conditions beyond 750 seconds. As discussed previously, since the thermal excursion occurred much later in time, long after the fluid in the test section had reached saturation conditions, it is apparent that neither axial or azimuthal fluid temperature distribution had much impact on the occurrence of excursion.

Figure 4.13 compares each fluid temperature at the 257 cm (level 3) location. Data in Figure 4.13 show that before attaining saturation conditions, the C subchannel fluid temperature is higher relative to the other channels. This same relationship was noted at the other three levels where fluid subchannel temperature measurements were made and suggests preferential flow channeling. Such behavior seemed to be more prevalent for the lower flowrate experiments as will be discussed below.

During the time period between 750 and 2500 seconds, all the fluid temperature measurements in the test section showed oscillatory behavior with spikes suggesting superheated vapor conditions. Figure 4.14, which shows the same data as Figure 4.13 on an expanded time scale, illustrates

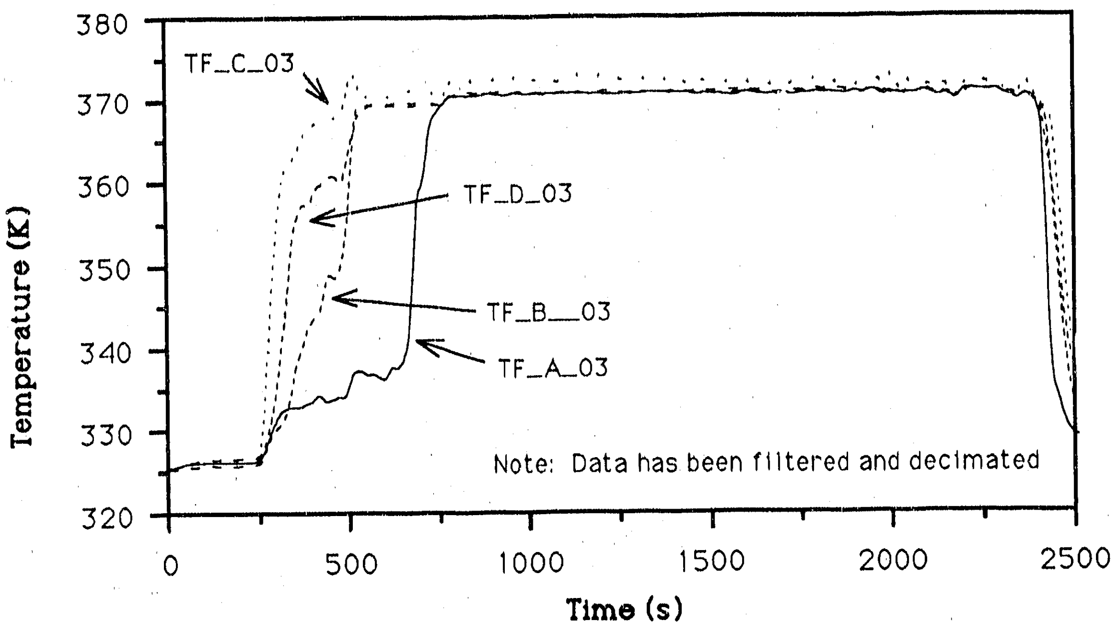

Figure 4.13. Comparison of fluid thermocouples at 257 cm for Test ECS-2BL_5

the temperature spikes even though the data presented has been filtered and decimated for graphical presentation.

4.1.4 Air Entrainment

Air entrainment was noted to be a strong function of the liquid flowrate on the excursion tests as is discussed in detail in Appendix G. For low liquid flows (<0.5 l/s [superficial velocity < 0.38 m/s]), the air entrainment was essentially zero. On Test ECS-2BL_5, the liquid flowrate was 0.1 l/s (superficial velocity of 0.075 m/s) and, as shown on Figure 4.15, the air flowrates at the inlet and outlet were near zero until the dryout-rewet cycles started at 2000 seconds. On this particular test, the measured air flowrates are essentially in the noise of the measurement device until significant thermal excursions ensued. Agreement between the inlet and outlet measurement is representative of the response of the air flow measurements observed on other excursion tests.

As is clearly indicated on Figure 4.15, both the inlet and outlet air measurement response becomes more erratic as saturation conditions were

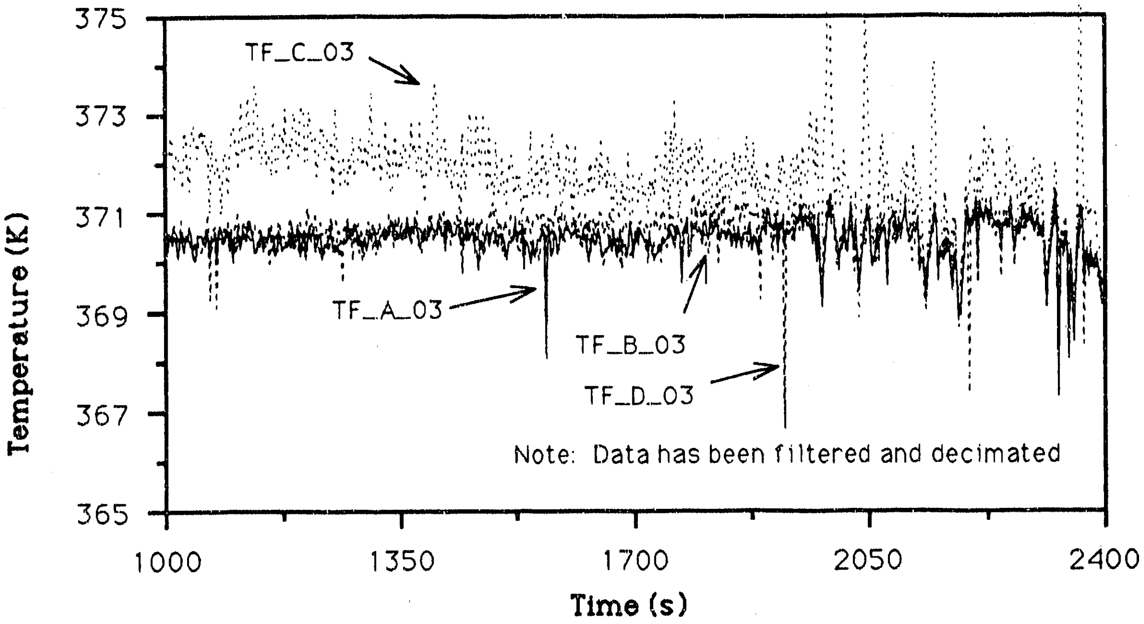

Figure 4.14. Expanded time scale comparison of fluid temperatures at 257 cm for Test ECS-2BL_5

achieved in the test section and when the dryout-rewet cycles started. This behavior is consistent with the observations of slugging (churn-turbulent flow) and flow reversals resulting from flooding during the dryout/rewet cycles in the test section.

4.1.5 Azimuthal Wall Temperature Variation

As was noted in Section 4.1.1, an interesting feature of the aluminum heater wall thermocouple response during the excursion tests conducted at the INEL was the variation among the indicated temperatures at a given axial location. This behavior was addressed in detail in connection with experiments conducted to examine the wall saturation temperature criteria [11] and is currently the subject of analysis for those experiments [12].

As was shown in Figures 4.3 and 4.4, the spread between the highest and lowest thermocouple readings at the 302 cm (level 7) was on the order of 30 K. Some spread in the wall temperature readings was noted at all of the axial levels. This spread was maintained up to the time that the sustained excursion occurred. To illustrate this spread, Figure 4.16 shows

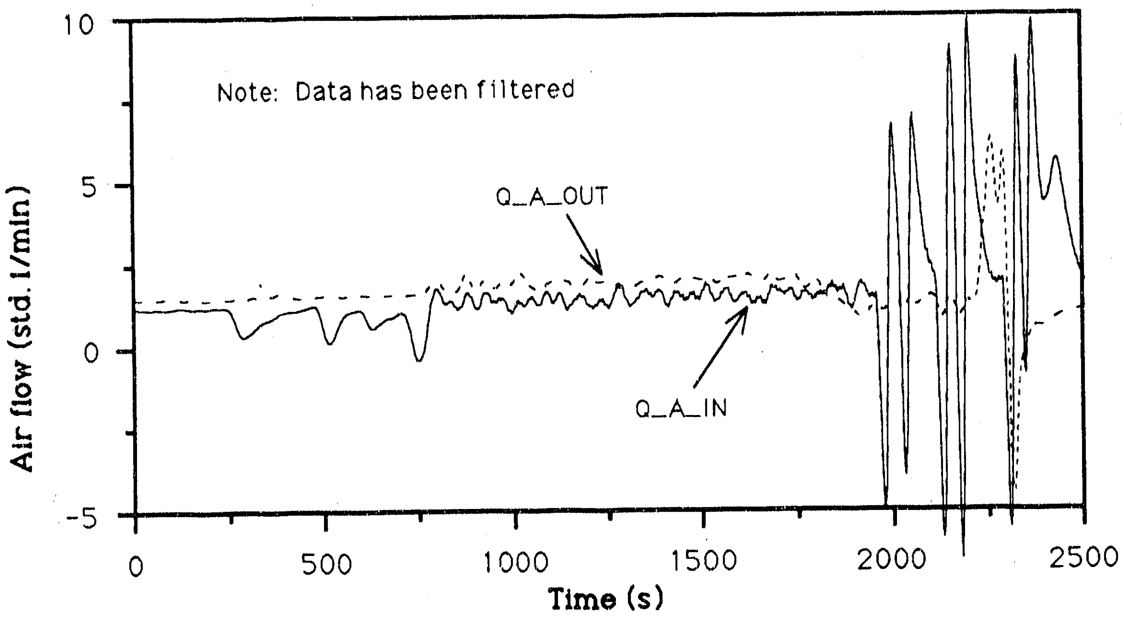

Figure 4.15. Air inlet and outlet flowrates for Test ECS-2BL_5

20 second averages (2210 - 2230 seconds) of all the wall temperature measurements during the power setting (50.9 kW) just before the setting (53.4 kW) on which sustained excursion occurred. With the exception of the thermocouples at level 7, the data shown in Figure 4.16 represents averages computed during a time period when the walls were wetted. Because of the frequency of the dryout-rewet cycles, no time frame could be located wherein all level 7 thermocouples were wetted.

The data in Figure 4.16 show reasonable azimuthal uniformity given the violent oscillatory nature of the hydraulic processes. For example, thermocouples at the high power zone (levels 5 and 6) have a spread of approximately 20 K. For reference, the overall average of the level 5 and 6 data shown in Figure 4.16 for the 2210-2230 second time frame was 405 and 399 K, respectively. Figure 4.17 displays the same type of averaged wall thermocouple information during the power step on which sustained excursion occurred. Note that the level 7 thermocouples underwent a sustained dryout during this time frame. The average of the thermocouple averages at levels 5 and 6 are 416.6 and 417 K, respectively. It is interesting to note from Figures 4.16 and 4.17 that the average wall temperatures in the C subchannel (180° to 270°) are somewhat higher relative to

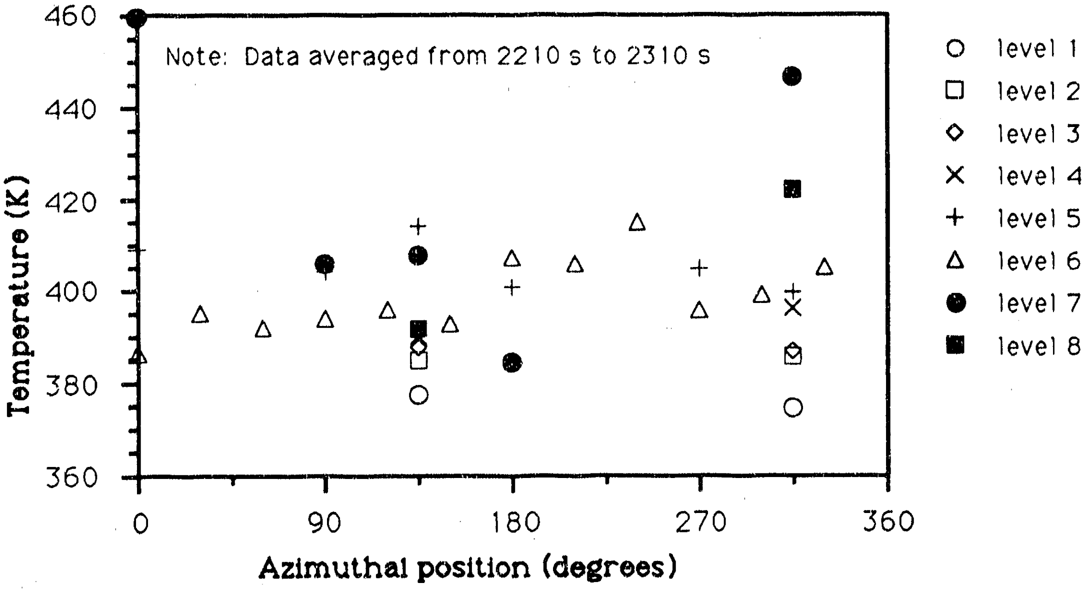

Figure 4.16. Azimuthal temperature distribution during power step just before excursion power step for Test ECS-2BL_5

the other azimuthal positions. This is consistent with the fluid temperature distribution discussed previously. Figure 4.18 shows fluid temperature averages computed for the 2210-2230 second time frame. Within the uncertainty of the fluid temperature measurements, all of the readings indicate saturation conditions. Tables 4.1, 4.2, and 4.3 list pertinent statistics for all of the aluminum wall and test section fluid thermocouples for the data presented in Figures 4.16, 4.17, and 4.18.

4.2 Overall Test Results

A primary objective of the thermal excursion experiments conducted at the INEL was to determine the conditions under which the aluminum wall of the test section underwent a sustained thermal excursion. In this section, the overall results of the excursion tests are presented. Effects of the primary variables (inlet fluid temperature, flowrate, and test section back pressure) and some secondary variables on the excursion are discussed. Finally, results from the INEL experiments including data from the ECS-1 excursion tests [10] and ECS-2b wall saturation tests [11] are compared.

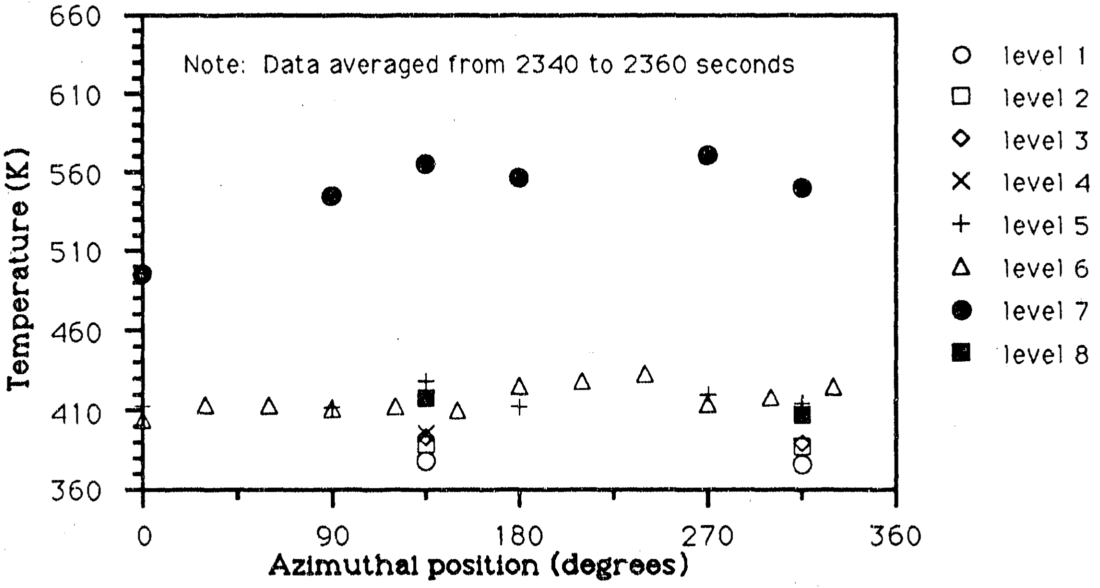

Figure 4.17. Azimuthal wall temperature distribution during power step on which sustained excursion occurred for Test ECS-2BL_5

Common practice used by WSRC researchers is to present results from thermal excursion experiments in terms of the so-called power factor, R. The R factor is defined to be the ratio of the power applied to the test section, at the time sustained thermal excursion occurred, divided by the power required to raise the fluid at the outlet of the test section to saturation conditions. Appendix E documents the calculation of the R factor for the wall thermal excursion and wall saturation temperature power limit criteria.

Table 4.4 lists a summary of results from the thermal excursion tests conducted at the INEL. Parameters listed in Table 4.4 for each test include, the test section superficial velocity, the test section inlet water temperature, the test section stand pipe height, the electrical power applied at the instance of excursion, the calculated power to saturate the outlet fluid, and the R factor. Measured data values in this table represent averages taken on the excursion power step. Similar summary tables presented in Appendix J also list data averages on the power step just before the excursion step. Appendix J also presents data averages for all the measurements for the pre-excursion and excursion power steps.

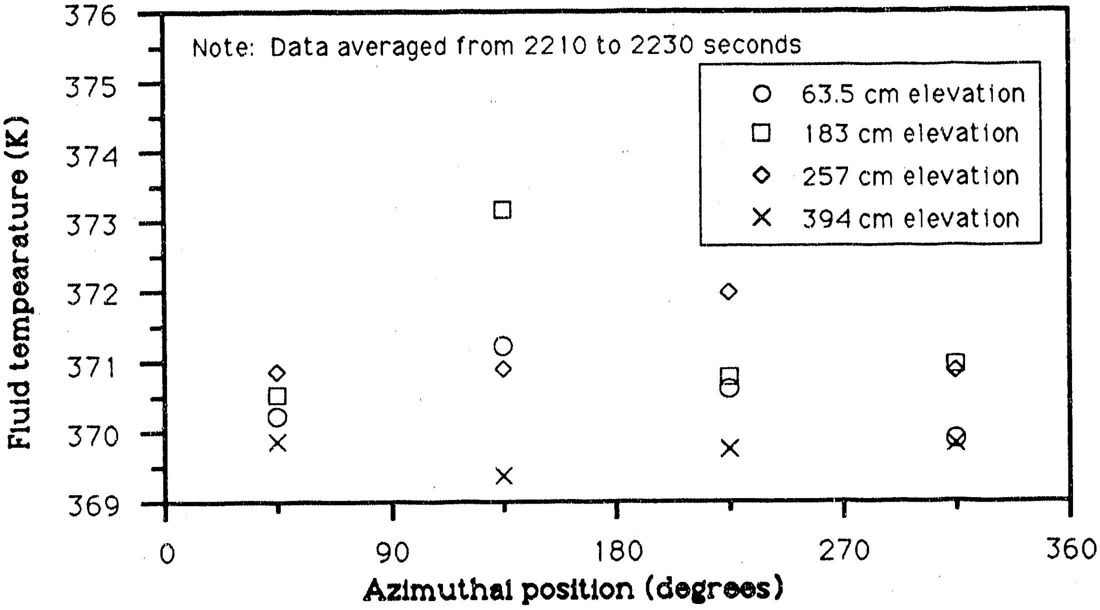

Figure 4.18. Azimuthal fluid temperature distribution during power step just prior to excursion power step for Test ECS-2BL_5

4.2.1 Effect of Inlet Flowrate

The data shown in Tables 4.4 and 4.5 can be plotted in various ways to illustrate the effects of boundary conditions. As was observed in the wall saturation experiments discussed by Anderson, et al., liquid flowrate is the major variable influencing the limiting power criteria. Figure 4.19 shows R factors plotted against liquid superficial velocity for all the ECS-2WSR data and subsets of the ECS-2BL and ECS-2cE data. The data points chosen from the three sets are from experiments with reasonably comparable standpipe settings and test section inlet temperatures.

As shown below, the trend of R factor with superficial velocity in Figure 4-19 is typical when compared to data from other sources. R is seen to decrease from a value of approximately 2.5 at the lowest superficial velocity of 0.075 m/s to a value of about 0.6 at 0.78 m/s, the highest superficial velocity available for these data sets.

R values above unity indicate that the power level at the thermal excursion was higher than the power level required to saturate the fluid at

Table 4.1. Statistics for aluminum wall temperatures for pre-excursion power step on Test ECS-2BL_5 (2210-2230 s time frame)

Meas ID	Average (K)	Maximum (K)	Minimum (K)	Range (K)	Variance (K^2)	Standard Deviation (K)
TI_B_j_1	377.35	378.43	375.81	2.62	0.73	0.85
TI_D_v_1	374.41	376.47	363.92	12.55	15.94	3.99
TI_D_v_2	384.75	386.67	376.72	9.95	9.64	3.10
TI_B_j_2	385.64	386.50	384.20	2.30	0.46	0.68
TI_D_v_3	387.71	389.29	384.75	4.54	1.96	1.40
TI_B_j_3	386.83	389.22	385.12	4.10	1.24	1.11
TI_B_j_4	390.01	390.77	388.59	2.18	0.65	0.81
TI_D_v_4	396.07	397.64	394.41	3.23	1.23	1.11
TI_A_a_5	409.14	410.39	407.68	2.71	0.84	0.92
TI_B_g_5	403.98	404.79	403.16	1.63	0.32	0.57
TI_B_j_5	413.94	415.19	412.76	2.43	0.50	0.71
TI_C_m_5	400.66	401.43	400.13	1.30	0.22	0.47
TI_D_s_5	404.58	405.32	403.50	1.82	0.33	0.58
TI_D_v_5	399.55	400.28	398.58	1.70	0.28	0.53
TI_A_a_6	386.29	387.26	385.23	2.03	0.42	0.65
TI_A_c_6	394.99	396.24	393.07	3.17	1.33	1.15
TI_A_e_6	391.82	393.09	390.09	3.00	0.91	0.96
TI_B_g_6	393.91	394.72	392.63	2.09	0.61	0.78
TI_B_i_6	395.77	396.67	393.60	3.07	0.85	0.92
TI_B_k_6	392.66	393.32	392.21	1.11	0.15	0.39
TI_C_m_6	407.21	409.26	405.77	3.49	1.43	1.19
TI_C_o_6	405.79	406.73	405.06	1.67	0.36	0.60
TI_C_q_6	414.92	416.73	413.37	3.36	1.32	1.15
TI_D_s_6	395.58	396.39	394.65	1.74	0.34	0.59
TI_D_u_6	399.01	399.44	398.40	1.04	0.16	0.40
TI_D_w_6	405.02	405.76	404.49	1.27	0.17	0.41
TI_A_a_7	459.64	552.52	391.54	160.98	5790.73	76.10
TI_B_g_7	405.82	512.84	382.14	130.70	1794.01	42.36
TI_B_j_7	407.57	441.03	398.53	42.50	172.91	13.15
TI_C_m_7	384.32	385.51	382.94	2.57	0.76	0.87
TI_D_s_7	528.51	530.60	525.96	4.64	2.10	1.45
TI_D_v_7	446.57	516.91	409.55	107.36	1576.37	39.70
TI_B_j_8	391.62	416.91	379.13	37.78	181.09	13.46
TI_D_v_8	421.92	461.71	388.39	73.32	586.53	24.22

the outlet of the heated length. Hence, steam generated must exit the top and/or bottom of the annulus. R values less than unity imply that saturation conditions were not achieved at the outlet before excursion occurred. However, local saturation and steam production were observed. Although for the test conditions shown in Figure 4.19, there is a scarcity of points in the 0.1 to 0.2 m/s superficial velocity range, the trend suggests that R is

Table 4.2. Statistics for aluminum wall temperatures on excursion power step for Test ECS-2BL_5 (2340-2360 s time frame)

Meas ID	Average (K)	Maximum (K)	Minimum (K)	Range (K)	Variance (K^2)	Standard Deviation (K)
TI_B_j_1	378.05	379.45	375.25	4.20	2.66	1.63
TI_D_v_1	376.00	377.51	373.83	3.68	1.42	1.19
TI_D_v_2	388.82	401.54	383.12	18.42	26.06	5.11
TI_B_j_2	387.46	394.38	383.42	10.96	9.48	3.08
TI_D_v_3	393.47	409.47	386.84	22.63	66.82	8.17
TI_B_j_3	389.30	404.87	383.67	21.20	38.29	6.19
TI_B_j_4	395.27	422.18	388.89	33.29	123.12	11.10
TI_D_v_4	407.83	432.55	395.74	36.81	191.60	13.84
TI_A_a_5	412.72	436.28	405.48	30.80	86.28	9.29
TI_B_g_5	411.85	432.89	402.51	30.38	107.80	10.38
TI_B_j_5	428.49	462.30	418.05	44.25	227.94	15.10
TI_C_m_5	412.39	457.00	400.24	56.76	404.70	20.12
TI_D_s_5	419.76	466.10	400.72	65.38	609.37	24.69
TI_D_v_5	414.33	449.12	400.15	48.97	338.14	18.39
TI_A_a_6	404.32	449.11	386.08	63.03	665.96	25.81
TI_A_c_6	413.47	468.27	389.91	78.36	821.76	28.67
TI_A_e_6	413.31	469.06	391.42	77.64	785.20	28.02
TI_B_g_6	411.17	463.83	391.61	72.22	732.96	27.07
TI_B_i_6	412.57	464.08	393.52	70.56	713.28	26.71
TI_B_k_6	410.11	462.75	390.71	72.04	744.64	27.29
TI_C_m_6	425.23	477.05	404.39	72.66	761.70	27.60
TI_C_o_6	428.51	484.73	405.39	79.34	903.78	30.06
TI_C_q_6	433.12	483.42	414.46	68.96	628.19	25.06
TI_D_s_6	414.06	472.22	392.69	79.53	887.19	29.79
TI_D_u_6	418.16	474.02	394.93	79.09	857.81	29.29
TI_D_w_6	425.08	472.95	407.10	65.85	532.58	23.08
TI_A_a_7	495.44	553.74	421.43	132.31	1898.91	43.58
TI_B_g_7	544.66	576.65	497.02	79.63	651.90	25.53
TI_B_j_7	564.75	603.57	513.53	90.04	920.56	30.34
TI_C_m_7	556.20	602.21	505.11	97.10	1179.04	34.34
TI_D_s_7	570.45	599.53	545.45	54.08	351.36	18.74
TI_D_v_7	549.95	578.15	525.26	52.89	223.13	14.94
TI_B_j_8	417.81	452.45	394.89	57.56	451.37	21.25
TI_D_v_8	407.42	448.93	381.45	67.48	685.06	26.17

larger than unity for velocities up to about 0.3 m/s, near unity for the 0.3-0.45 m/s superficial velocity range, and somewhat less than unity for velocities above 0.45 m/s. With the exception of one high inlet temperature data set discussed below, this trend essentially describes all of the INEL ECS-2 excursion experiments conducted.

Table 4.3. Statistics results for test section fluid temperatures on Test ECS-2BL_5 pre-excursion power step (2210 to 2230 s)

Meas ID	Average (K)	Maximum (K)	Minimum (K)	Range (K)	Variance (K^2)	Standard Deviation (K)
TF_01_AV	370.48	371.54	367.96	3.58	1.89	1.37
TF_02_AV	371.36	371.85	369.72	2.13	0.49	0.70
TF_03_AV	371.15	371.47	370.52	0.95	0.07	0.26
TF_04_AV	369.70	370.02	369.34	0.68	0.02	0.16
TF_A_01	370.22	371.00	368.97	2.03	0.36	0.60
TF_A_02	370.53	371.47	366.24	5.23	2.63	1.62
TF_A_03	370.86	371.23	369.85	1.38	0.17	0.42
TF_A_04	369.86	370.08	369.51	0.57	0.04	0.20
TF_B_01	371.22	371.80	370.02	1.78	0.38	0.61
TF_B_02	373.17	374.46	370.66	3.80	1.51	1.23
TF_B_03	370.90	371.19	370.73	0.46	0.01	0.10
TF_B_04	369.38	369.72	368.90	0.82	0.05	0.22
TF_C_01	370.60	372.14	362.92	9.22	8.61	2.93
TF_C_02	370.77	371.10	370.10	1.00	0.08	0.28
TF_C_03	371.97	372.82	371.10	1.72	0.30	0.55
TF_C_04	369.75	370.09	369.46	0.63	0.03	0.18
TF_D_01	369.89	371.48	362.10	9.38	8.64	2.94
TF_D_02	370.95	371.55	369.61	1.94	0.31	0.56
TF_D_03	370.86	371.31	369.59	1.72	0.26	0.51
TF_D_04	369.82	370.18	369.49	0.69	0.03	0.19
TF_IN	328.07	328.65	327.29	1.36	0.20	0.44
TF_OUT	366.82	367.71	365.98	1.73	0.36	0.60
TF_TS_AV	370.67	371.22	369.38	1.84	0.33	0.57
TF_W_IN	325.96	326.21	325.66	0.55	0.02	0.16
TF_W_OUT	364.89	365.32	364.61	0.71	0.05	0.23

During the excursion experiments, several observations regarding the phenomena occurring in the test section for the various flowrates and the influence this phenomena had on thermal excursion were noted. For the lowest flowrate ($j_f < 0.2$ m/s) experiments conducted before achievement of saturation conditions in the test section, the flow regime appeared to be primarily rib flow wherein the liquid ran down the wall as a thin film. As the power was increased and saturation conditions were approached, liquid holdup (localized flooding) occurred causing the appearance of a churn-turbulent flow regime. In many cases this holdup caused by steam generation along the test section heated length was sufficient to maintain a column of water between the top of the heated length and the bottom of the

Table 4.4. Summary of results from INEL ECS-2 and WSR thermal excursion experiments

TEST ID	Test Section Superficial Velocity (m/s)[2]	Water Inlet Temp. (K)	Stand Pipe Height (cm)[3]	Total Test Section Power[1] (kW)	Power to Saturate Outlet (kW)	R factor (P / Psat) -
ECS-2BL_1	0.072	296.7	394	70.80[4]	29.54	2.34
ECS-2BL_1B	0.076	296.1	402	78.69	31.37	2.51
ECS-2BL_2	0.223	296.4	394	101.48	91.88	1.10
ECS-2BL_5	0.078	326.0	409	53.48	19.07	2.80
ECS-2BL_5B	0.074	326.1	399	50.15	17.85	2.81
ECS-2BL_5C	0.074	324.0	401	47.96	18.78	2.55
ECS-2BL_5D	0.075	324.0	401	50.76	19.36	2.62
ECS-2BL_6	0.225	324.7	403	97.50[4]	56.77	1.72
ECS-2BL_7	0.400	324.4	393	99.80	101.28	0.99
ECS-2BL_7B	0.379	323.8	395	99.15	97.50	1.02
ECS-2BL_11[5]	0.225	346.5	400	50.59	29.45	--
ECS-2BL_11B	0.226	345.9	406	70.60[4]	29.93	2.36
ECS-2BL_12[5]	0.379	342.7	399	66.41	57.63	--
ECS-2BL_12B	0.374	346.5	419	96.94	48.00	2.02
ECS-2BL_13	0.526	348.6	404	101.97	62.74	1.63
ECS-2BL_14	0.676	345.9	395	112.43	90.85	1.24
ECS-2BL_17	0.227	323.7	282	63.32	61.77	1.03
ECS-2BL_18	0.377	326.0	292	97.50[4]	98.76	1.00
ECS-2BL_18B	0.373	323.4	293	98.40[4]	103.35	0.95
ECS-2BL_22	0.223	325.3	312	71.13	57.74	1.23
ECS-2BL_23	0.373	326.2	315	103.82	95.28	1.09
ECS-2BL_23B	0.373	325.1	321	96.61	97.58	0.99
ECS-2BL_26	0.228	325.8	365	93.72	57.01	1.64
ECS-2BL_26B	0.225	324.5	399	89.01	57.62	1.54
ECS-2BL_27	0.350	325.2	356	93.75[4]	89.18	1.05
ECS-2FC_1	0.113	323.0	363	40.35	30.15	1.34
ECS-2FC_2	0.225	325.9	398	80.81	55.95	1.44
ECS-2WSR0380	0.286	315.8	366	101.88	88.27	1.15
ECS-2WSR0580	0.437	315.2	329	121.22	137.18	0.88
ECS-2WSR0580C	0.434	315.4	325	110.88	136.03	0.82
ECS-2WSR0760	0.571	314.1	330	126.82	183.01	0.69
ECS-2WSR0960	0.723	314.5	340	162.50[4]	230.59	0.70
ECS-2WSR1040	0.780	313.9	323	161.39	251.70	0.64
ECS-2WSR1040B	0.778	315.4	316	161.25	244.82	0.66

---

1. Power recorded during the excursion.
2. Superficial velocity calculated using a test section flow area of 13.31 cm^2.
3. Measured standpipe level (from differential pressure DP_SP) referenced to the top of the heated length.
4. Logbook recorded value due to heater voltage offset on DAS channel.
5. Thermal excursion did not occur on this test.

Table 4.5. Summary of results from INEL ECS-2cE thermal excursion experiments

TEST ID	Test Section Superficial Velocity (m/s)[2]	Water Inlet Temp. (K)	Stand Pipe Height (cm)[3]	Total Test Section Power[1] (kW)	Power to Saturate Outlet (kW)	R factor (P / Psat) -
ECS2cE11	0.304	310.7	336	93.4	103.3	0.90
ECS2cE12	0.457	311.2	332	124.5	153.8	0.81
ECS2cE13	0.606	311.4	335	143.7	204.0	0.70
ECS2cE14	0.763	312.0	331	150.0	253.2	0.59
ECS2cE21	0.301	328.3	389	81.8	70.3	1.16
ECS2cE22	0.303	326.7	248	73.2	79.5	0.92
ECS2cE23	0.306	295.2	385	115.7	128.5	0.90
ECS2cE24	0.302	296.6	229	113.6	130.2	0.87
ECS2cE31	0.609	326.8	376	132.8	147.6	0.90
ECS2cE32	0.610	325.9	232	96.1	162.9	0.59
ECS2cE34	0.608	297.2	240	139.4	260.7	0.53

---

1. Power recorded during the excursion.
2. Superficial velocity calculated using test section flow area of 13.31 cm^2.
3. Measured standpipe level (from differential pressure DP_SP) referenced to the top of the heated length.

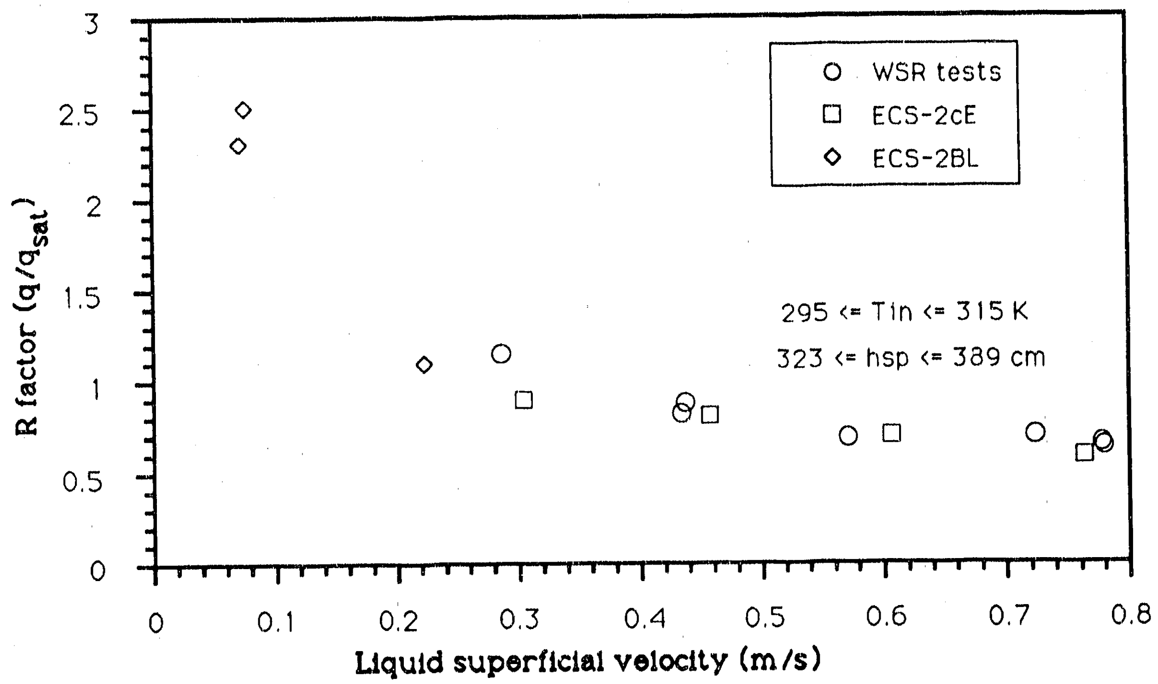

Figure 4.19. INEL thermal excursion data for 295-315 K inlet temperature and 323-383 cm standpipe setting

inlet plenum. Steam generated was noted to exit the bottom of the test section to the outlet plenum and also migrate upward through the column of liquid held above the top of the heated length. During this time, intermittent dryout-rewet cycles occurred as described in Section 4.1. Due to the low liquid flowrates, air entrainment was minimal and therefore did not have much impact on the dryout. Wall dryout appeared to be the result of holdup caused by localized flooding preventing sufficient water for cooling from reaching the the higher power zones of the heater. Thermal excursion for these flows tended to occur locally with insufficient steam generation to dryout the entire test section.

At somewhat higher flowrates, approximately $0.2 < j_f < 0.5$ m/s, air entrained with the inlet liquid seemed to play a larger role in the processes influencing the onset of wall dryout. Observations of the test section indicated that the water holdup in the section above the heated length was less pronounced than for velocities less than 0.2 m/s although considerable holdup still occurred. Air in the test section feasibly contributed to the initiation of the flooding process since it expanded (due to heating) as it flowed down the test section and provided additional pressure drop and degraded the heat transfer. However, visual observations and air flow measurements indicate that once the local flooding and flow reversals started, the air entrainment usually decreased significantly. This result suggests that the entrained air did not have much impact on the dryout process. Wall temperature excursion under these conditions was similar to those observed for the lower flows although there was less water held up in the upper part of the test section.

At the highest flows ($j_f > 0.5$ m/s) the wall dryout consisted of dry patch formation, rewetting, reformation, and eventually growth. This process was accompanied by considerable vapor generation and if the dry patch was not quickly rewetted, wall heat up occurred. The end result of the wall heatup was expulsion of water from both ends of the heated length due to the rapid expansion of the steam (essentially flooding). The initiating process, however, appeared to be heat flux dominated rather than flooding dominated. The high flow excursions were characterized by very rapid and violent flooding with dryout of the entire test section. The test section remained flooded and dry for many seconds after the power trip because of the significant stored energy (high powers were required for dryout at high flowrates) in the test section.

4.2.2 Effect of Inlet Liquid Temperature

R factors plotted against liquid superficial velocity with test section inlet temperature as a secondary variable are presented in Figure 4.20. All data from Tables 4.4 and 4.5 with the inlet temperature range indicated and a standpipe setting of 389 cm are included on this figure. Results shown encompass data gathered with three different inlet fluid temperatures ranging from 74 K subcooled water (296 K inlet temperature) to 24 K subcooled water (346 K inlet temperature).

Data shown in Figure 4.20 suggest that for a given superficial velocity and standpipe setting, higher inlet fluid temperatures have the effect of increasing the R value. For example, at a superficial velocity of 0.3 m/s, the R value increased about 40% between the 296 K and the 326 K data. Although there were only a limited number of 296 K data points taken, the data trends seem to indicate that even larger increases in R may be possible for certain flow ranges. The influence of inlet temperature on R is quite pronounced for higher temperatures as evidenced by significantly

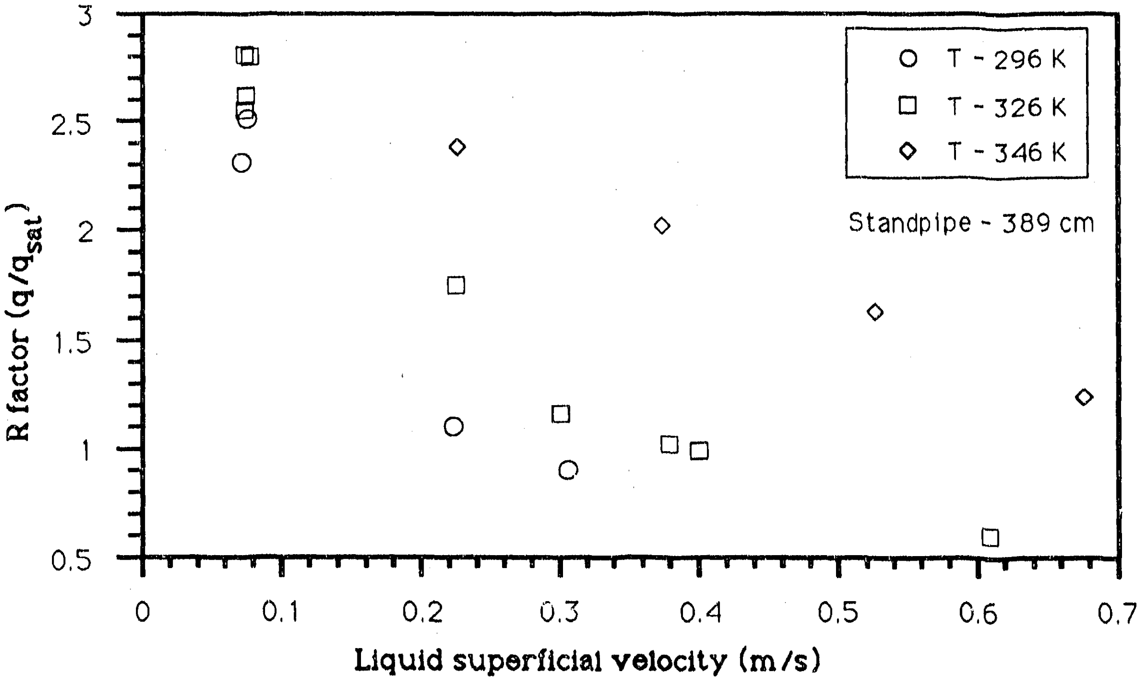

Figure 4.20. INEL thermal excursion data for three different inlet temperatures and a standpipe setting of 389 cm

higher R values for the 346 K data set relative to the remainder of the data shown in Figure 4.20. For the 346 K data set, the R value did not cross unity although the trend suggests that superficial velocities above 0.8 m/s would have resulted in a saturation ratio of one.

Several interesting observations are apparent in Figure 4.20. First, if one extrapolates all of the data sets to the lowest velocities, R appears to converge to a value somewhere between 2.5 and 3 independent of temperature. That all of the data seem to converge for the lowest flows makes sense in light of the observation that the wall temperature excursion for the lowest flowrates is dominated by local flooding. Second, all the data sets show the tendency for R to cross over unity as the flowrate increases. As inlet temperature increases, the range of velocities where R crosses through unity shifts to higher values. Obviously, as postulated above, the mechanism causing the wall excursion is flowrate dependent and is somewhat inlet temperature sensitive. Third, the data sets for inlet temperatures 326 K and lower appear to follow a power law, whereas the 346 K data is nearly linear with superficial velocity.

There are two related explanations for the 346 K data points. As discussed in Appendix G, the air entrainment rate is a strong function of the inlet liquid temperature and a lesser function of standpipe setting. For example, the air ingress data show that the air ingress rate increases by a factor of two with ambient temperature water relative to 346 K water for a given standpipe setting (see Figures G-5 through G-8). However, for a given inlet temperature, the air ingress only increases by 30% as the stand pipe setting is decreased from the highest value to the lowest value (see Figure G-3 in Appendix G). While the 346 K data points were taken with the lowest facility standpipe setting (389 cm relative to the top of the heated length or 43 cm above the bottom of the outlet plenum) which should have allowed the maximum air entrainment, the air ingress rate was minimal primarily because of the temperature effect. Air entrainment rate averages listed in Table J-1 support this observation. Entrained air then had a minimal contribution to the flooding processes that eventually caused sustained dryout. Local vapor generation thus had to be the major contributor. Higher R values could plausibly ensue under these conditions since more power was needed to generate the vapor required to support local flooding relative to cases where there was appreciable entrained air in the flow stream.

4.2.3 Effect of Standpipe Setting

R factor versus liquid superficial velocity with standpipe setting as a parameter for a constant inlet fluid temperature data set is shown in Figure 4.21. In Figure 4.21, the standpipe height has been referenced to the top of the heated length. Therefore, larger standpipe setting numbers actually imply a shorter column of water (and hence lower back pressure) on the outlet plenum. For example, the 389 cm standpipe height reflects a 43 cm head of water on the outlet plenum whereas the 241 cm setting represents a 191 cm head of water on the outlet plenum. The data are presented in this fashion to avoid potential confusion due to the use of several different reference positions (bottom of the lower plenum, bottom of the heated length, etc.) for test section standpipe setting during the course of the experiments.

The data in Figure 4.21 show the familiar trend of R with superficial velocity evident in Figures 4.19 and 4.20. Although no strong effect of standpipe setting is apparent, one concludes that for a given velocity in the 326 K data shown, R tends to increase with a decrease in the back pressure

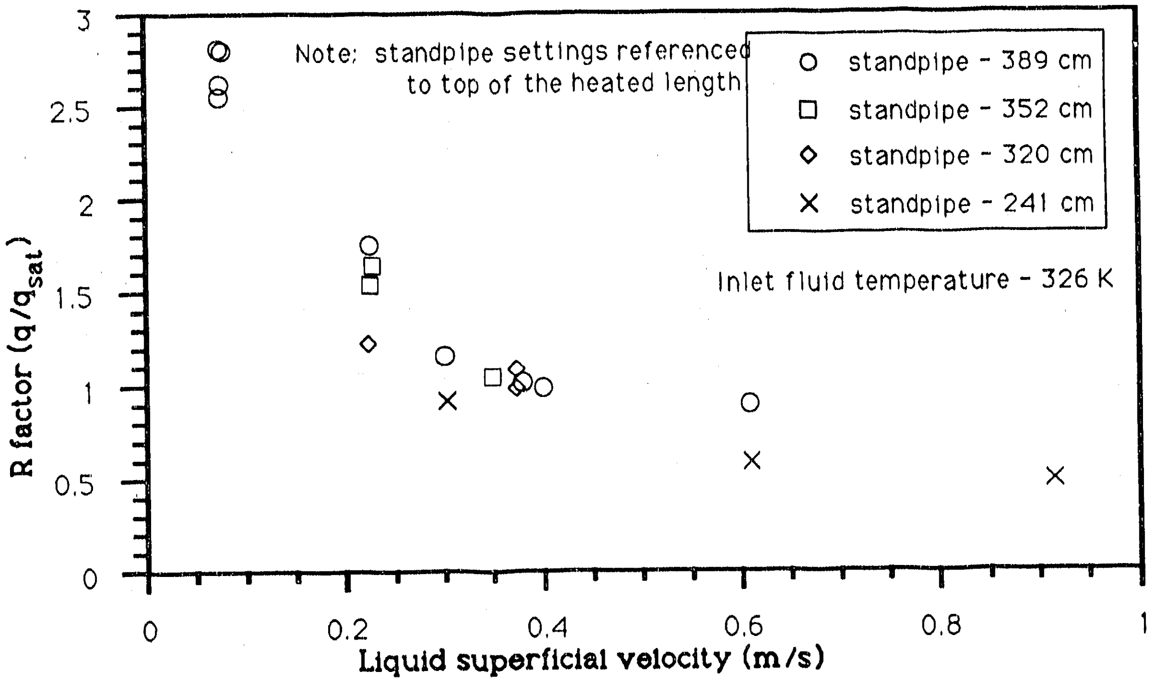

Figure 4.21. INEL thermal excursion data for 326 K inlet temperature with standpipe setting as a parameter

(increase in the standpipe setting). For the data at 0.3- or 0.6 m/s for instance, the R factor increased by about 30% over the extreme range of standpipe setting displayed. Smaller influences are evident for smaller changes in the standpipe setting (note the points at 0.2 m/s or 0.35 m/s for instance).

Figure 4.21 does not contain data from the 346 K inlet temperature tests. As previously discussed, the 346 K experiments were conducted with the lowest (relative to the bottom of the outlet plenum) standpipe settings.

4.2.4 Simple Data Correlation

From the preceding discussion, it is apparent that superficial velocity (or flowrate) is a dominant variable influencing the R factor. Also, with the exception of the 346 K data, inlet temperature and standpipe setting were lesser effects than the flowrate. Figures 4.22 and 4.23 present all of the data points contained in Tables 4.4 and 4.5, with points delineated by inlet temperature and standpipe setting, respectively. Although the overall effect of inlet temperature and standpipe setting are difficult to discern on these plots, the four 346 K points clearly stand out. As shown in Figure 4.23, the fact that these four data points appear to be unique can not be attributed to back pressure since other data points in Figure 4.23 from the 380-390 cm standpipe setting are consistent with the majority of the data.

Figure 4.24 presents the 346 K data points and all the other inlet temperature data points contained in Tables 4.4 and 4.5. It is interesting to note that the two data sets are reasonably well represented with an empirical power law fit, i.e.:

$$R = a\,(j_f)^b \qquad (4\text{-}1)$$

where

a = constant

j_f = liquid superficial velocity (m/s)

b = constant exponent

Values for the a and b constants for the two temperature data sets are shown in Figure 4.24 along with the fitted lines. Table 4.6 lists constants for power law fits developed using each temperature data set. If all the inlet temperature data sets except the 346 K data are considered together,

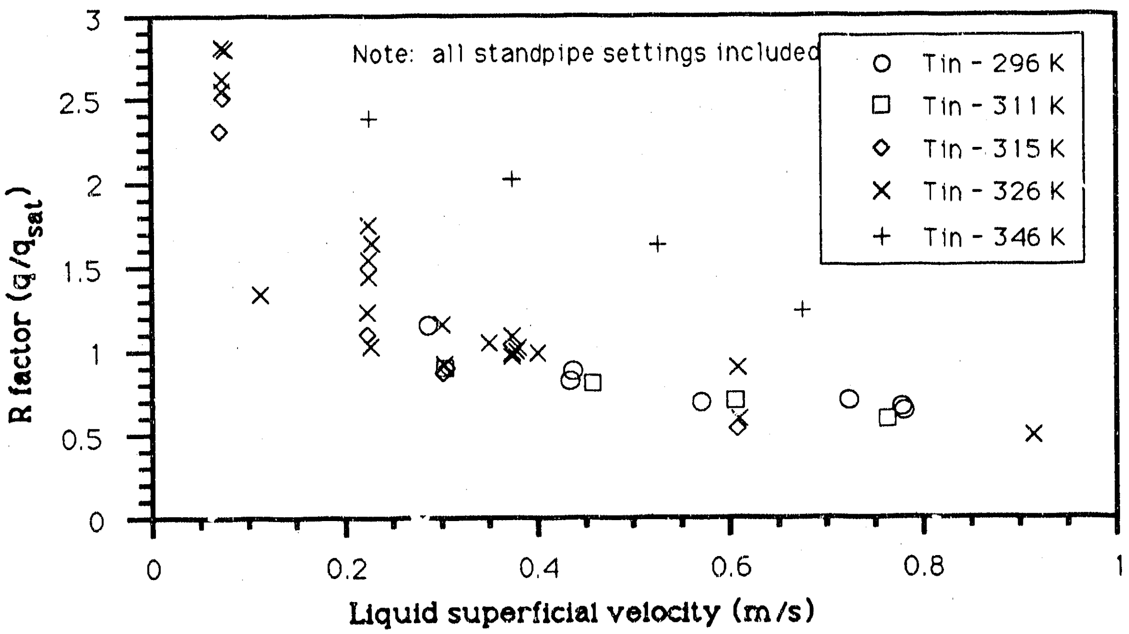

Figure 4.22. INEL thermal excursion data with inlet temperature as a parameter

the values listed in Table 4.6 suggest that a power law with a and b values of 0.5169 and -0.61, respectively can account for 91% (the residual squared value) of the variance in the saturation ratio values. This result supports the observation that superficial velocity is the dominant independent variable. Interestingly, the 346 K data is nearly a perfect fit with a linear equation with an intercept of 2.95 and a slope of -2.537 as shown in Figure 4.24.

Power law fits were calculated in a similar fashion for the data grouped by standpipe setting as shown in Figure 4.23. However, the scatter in the data shown in Figure 4.23 suggests that there should be limited correlation between the constants developed for each individual data set. Indeed, this was the case.

In order to examine the statistical significance of the influence of the superficial velocity, the inlet temperature, and the standpipe setting on the R factor, some simple regression analyses in addition to the power law fits discussed above were performed on the data. These analyses included multiple regression, polynomial regression, and stepwise regression. While

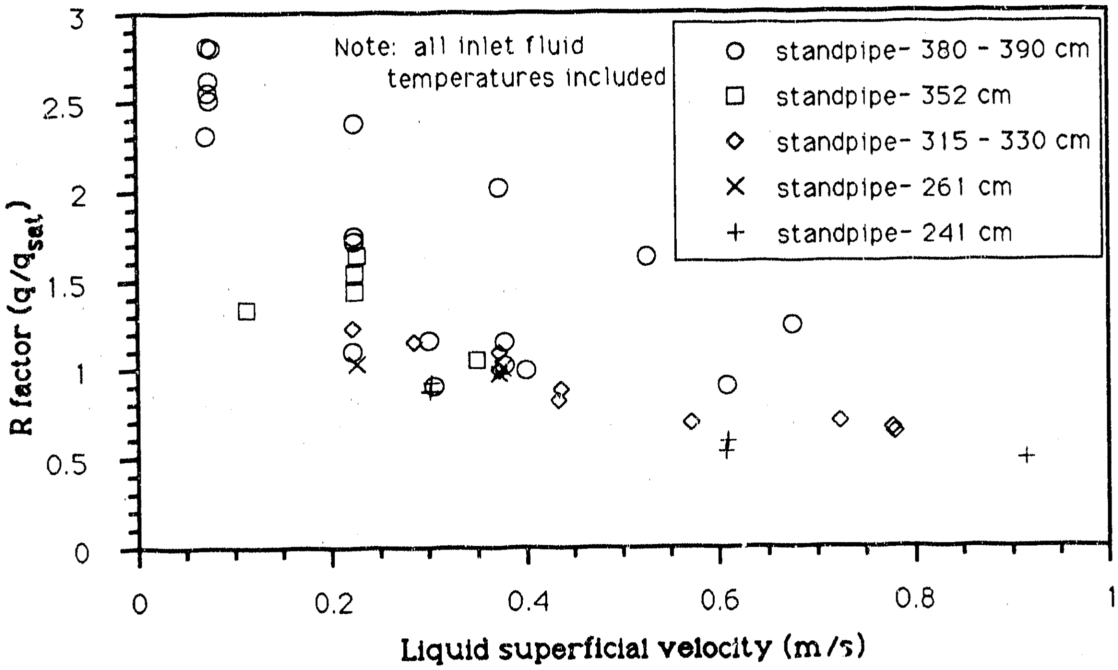

Figure 4.23. INEL thermal excursion data with standpipe setting as a parameter

certainly not an exhaustive investigation of statistical effects, such simple analyses provide insight on the relative importance of the independent variables. Furthermore, it was not expected that any of the additional regression techniques applied here would necessarily provide a better (or even as good as) fit of the data relative to the simple power law and such was found to be the case.

Multiple regression of the data produced an equation of the form:

$$R = a_0 + a_1 j_f + a_2 T_{in} + a_3 h_{sp} \tag{4-2}$$

where

$a_0 = -2.446$

$a_1 = -1.766$

$a_2 = 0.009$

$a_3 = 0.004$

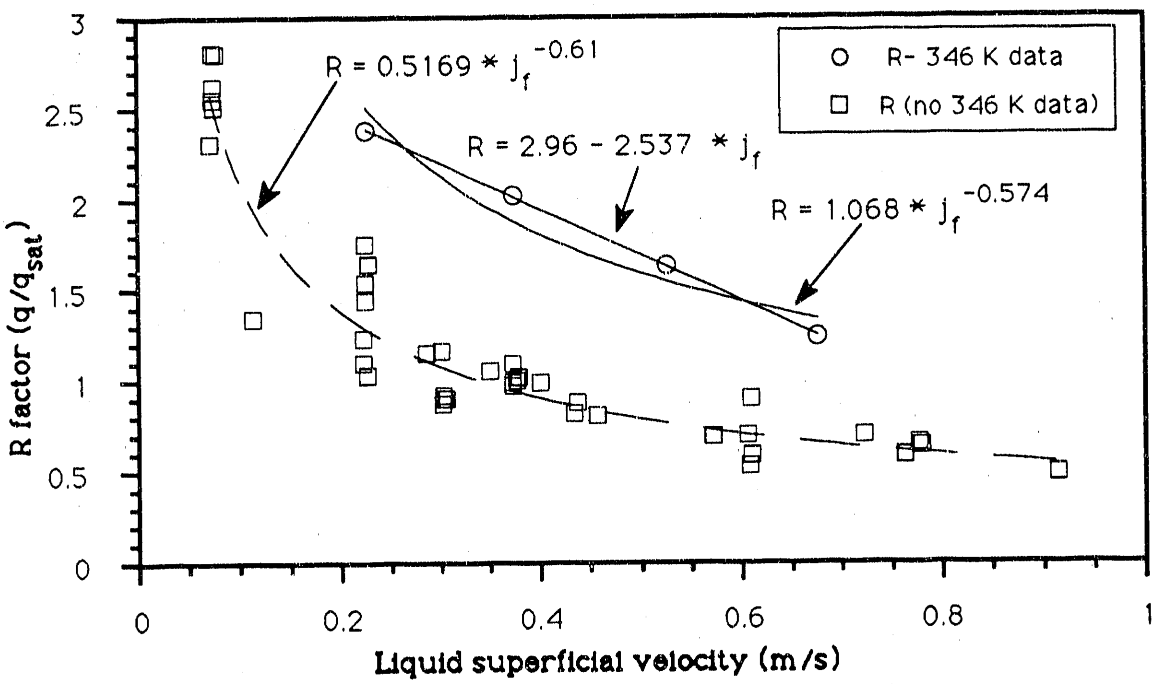

Figure 4.24. INEL ECS-2 and ECS-2cE thermal excursion data with power law fits

Equation 4-2 produced a residual squared value of 0.72, significantly worse than the power fit. The t-statistic was used to test the hypothesis that the coefficients a_1, a_2, and a_3 were statistically different than zero. Analysis of the coefficients indicated that the superficial velocity multiplier had a high probability (>0.9999) of being nonzero and there was a high probability that the temperature coefficient was not statistically dif-

Table 4.6 Power fit constants for Equation 4-1 using inlet temperature data sets

Data Set	a	b	Residual	(Residual[1])^2
296 K	0.559	-0.533	0.970	0.941
311 K	0.544	-0.450	0.972	0.945
315 K	0.376	-0.714	0.994	0.988
326 K	0.540	-0.608	0.944	0.891
346 K	1.068	-0.574	0.966	0.933
all[2]	0.517	-0.610	0.955	0.912

1. The residual squared is a measure of the ability of the independent variable (j_f) to account for the variance in the dependent variable (saturation ratio).
2. All temperature data sets except the 346 K data.

ferent from zero. Results for the standpipe setting coefficient t-test were not conclusive although there was significant probability that the coefficient was not different than zero. A partial F-test suggested that the standpipe setting coefficient was likely not statistically significant, a conclusion consistent with visual observation of the data.

Second and third order polynomial regressions of the R factor with each independent variable (liquid superficial velocity, inlet temperature, and standpipe setting) were calculated. Second and third order regressions of R factor with liquid superficial velocity produced fits (residual squared values of 0.7 and 0.751, respectively) better than regressions to inlet temperature or standpipe setting. As expected, regression with temperature did not fit the data. Somewhat surprisingly, polynomial regression of R factor with standpipe level provided some fit (albeit poor) to the data (residual squared of 0.58 and 0.63 for second and third order, respectively). However, analysis of the t-test and partial F-test results indicated that the regression coefficients for this case could not be proven to be statistically different from zero. In general and as expected, the polynomial regression results indicated that flowrate was the major significant independent variable.

Based on visual observation of the data (Figures 4-22 and 4-23, for example), the power law fits, and the regression analysis discussed above, the expectation was that flowrate (superficial velocity) was a significant independent variable, standpipe level may be significant (at least for the linear model), and with the exception of the 346 K data set, inlet temperature was not a significant variable[7] in terms of predicting the variance in the R factor. A stepwise linear regression was conducted to examine these conclusions. Although the data certainly do not suggest a linear fit, the stepwise regression confirmed that superficial velocity was the best predictor of the variance in R factor with a residual squared of 0.62. Addition of the standpipe level to the regression improved the residual squared to 0.7. As expected, the inlet temperature variable did not meet the partial F-test criteria for the stepwise regression and therefore was not included.

The simple statistical tests employed here showed that liquid superficial velocity is the dominant independent variable and that standpipe height may contribute to the prediction of the R factor. These conclusions are

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[7] The variation of the 346 K data set relative to the rest of the data is not understood at this time.

supported by the reasonable empirical fit obtained with a power law equation.

Some theoretical analyses of downflow dryout phenomena has been conducted by Duffey and Hughes [13]. They developed a model for the heat flux required to maintain a stable hot patch on a heated surface cooled by a falling film. Based on an analytical solution of the two-dimensional heat conduction equation and existing heat transfer correlations for the dry patch and the wet regions adjacent to the dry patch, dryout heat flux for turbulent film flow was expressed as a function of the film Reynolds number as:

$$q_d'' = 0.017\, Re_f^{0.9} \tag{4-3}$$

where

q_d'' = dryout heat flux, (kW/m^2)

Re_f = film Reynolds number, $4\Gamma/\mu$

Γ = film flow rate per unit heated perimeter $[m/(\pi d)]$, (kg/m-s)

μ = liquid viscosity, (Pa-s)

Film Reynolds numbers were computed for the INEL thermal excursion data in Tables 4.4 and 4.5 using the measured flowrate, viscosity based on the calculated fluid temperatures at level 7 (302 cm), and the test section geometry. Dryout heat fluxes were computed for the high power zone using the measured power at dryout and the heater axial peaking factor. These calculations are compared to Equation 4-3 in Figure 4.25 where the measured heat flux at thermal excursion and the flux predicted from the Duffey-Hughes model are plotted against film Reynolds number. As evidenced from Figure 4.25, the model generally under predicts the dryout flux and the slope of the flux with Reynolds number is higher than the data indicate. The model does predict the power law fit trend in the data suggested in the discussions above.

4.2.5 Facility and Operational Influence on Saturation Ratio

To examine the potential for facility hardware or operational considerations influencing excursion test results, test data can be delineated by the facility in which the data were gathered. As discussed in Section 3, two

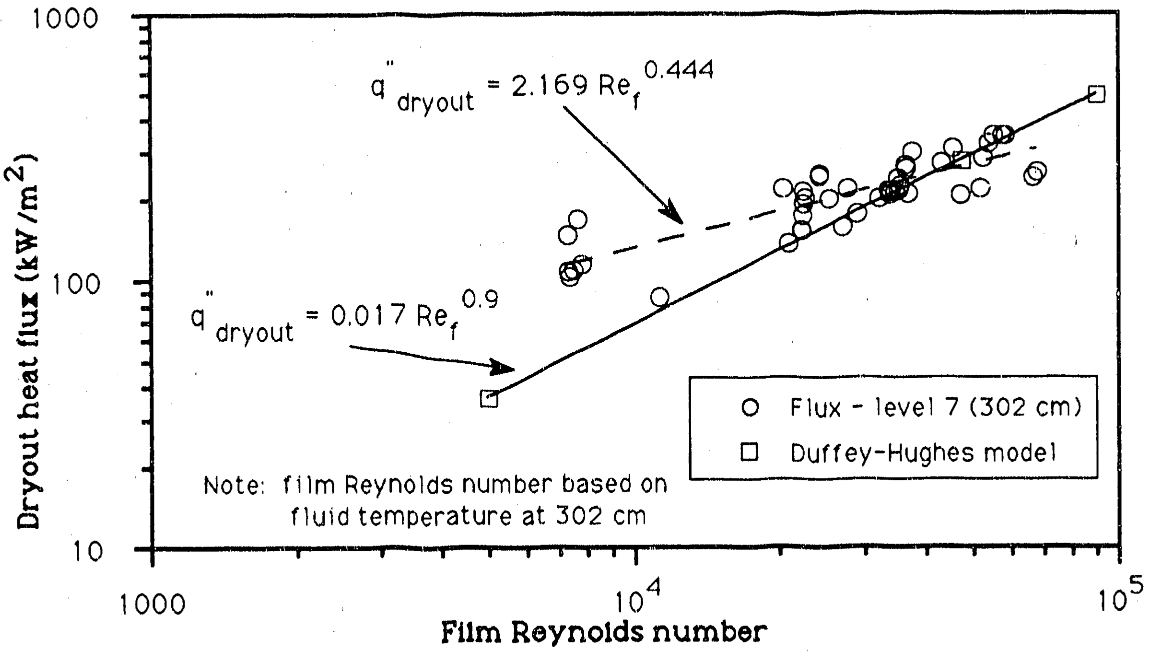


Figure 4.25. INEL thermal excursion data compared to Duffey-Hughes model

different facilities were used to conduct the excursion tests. Furthermore, there were slight intentional differences in test procedure, test completion criteria, and facility boundary conditions for the various experiments. Noteworthy differences among the various test series included:

- On the ECS-2 and WSR experiments, a cooling coil in the outlet plenum was used to maintain subcooled liquid conditions in the outlet plenum (the objective was to improve the air flow measurements by condensing the steam entrained into the outlet plenum). This cooling coil was not used in the ECS-2cE experiments.

- Sustained excursion criteria for the ECS-2 and WSR experiments were defined to be any wall temperature above approximately 620 K (350 C) whereas on the ECS-2cE experiments, a lower limit of 520 K (250 C) was used.

- On the two ECS-2FC experiments, the power was held constant while the flow was decreased in steps until excursion was achieved. On all other experiments, the flow was held constant and the power was increased until excursion was attained.

- The test procedure used to conduct the ECS-2cE experiments differed somewhat relative to the other experiments. Details of the differences are discussed in Section 3.

Figure 4.26 presents the excursion test results in the usual fashion with R factor plotted against liquid superficial velocity with test facility as a parameter. Cursory review of the data as presented in Figure 4.26 does not suggest any clear dependencies that might be attributed to facility hardware or test procedure with the possible exception of the flow coastdown experiment ECS-2FC_1. As indicated, the R value obtained from this experiment was 1.34 and occurred when the superficial velocity was 0.11 m/s. This R value is lower than the R values obtained on the ECS-2BL experiments conducted with superficial velocities of 0.07 m/s yet consistent with R values that were obtained from experiments conducted at approximately 0.2 m/s including ECS-2FC_2, the only other flow coastdown experiment. Unfortunately, since only two flow coastdown tests were run, it is not possible to determine whether ECS-2FC_1 is an outlier or represents behavior

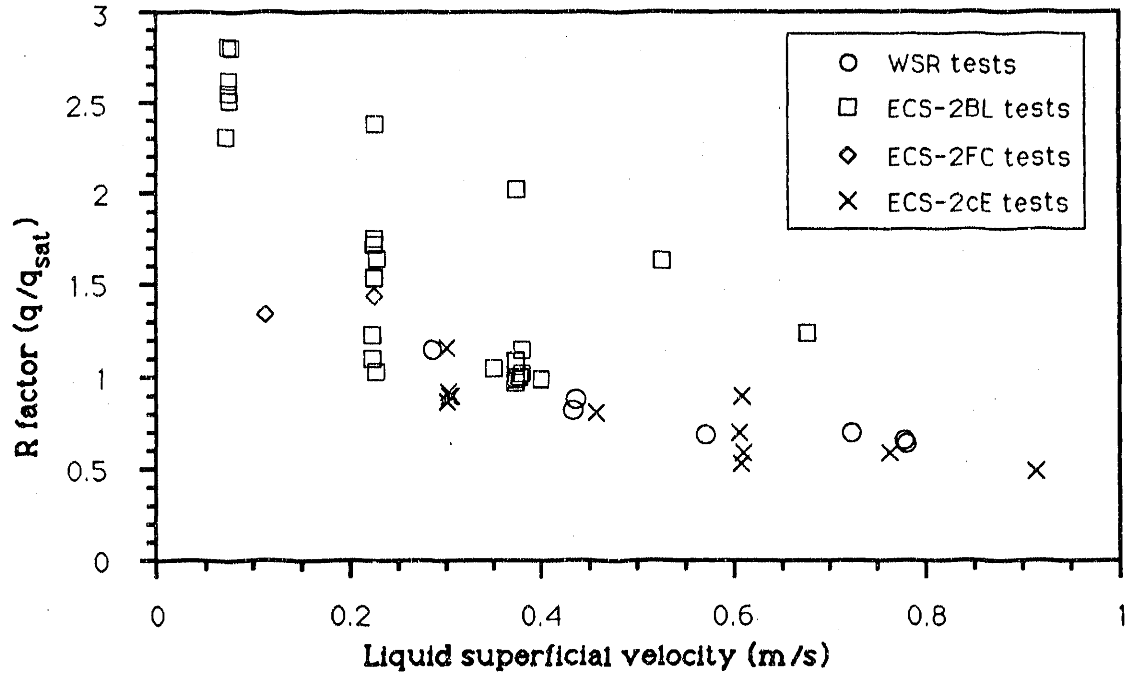


Figure 4.26. INEL thermal excursion data with test facility as a parameter

unique to flow coast down.

Review of the information in Figure 4.26 does not suggest any bias in the data due to the lower plenum cooling coil operation or the different wall temperature criteria used to define onset of excursion. However, on several of the ECS-2BL experiments, if the 520 K (rather than the 620 K) wall temperature criteria would have been used, the experiments would have been terminated sooner (thus at lower power level) due to the dry-out-rewet cycles discussed in Section 4.1. The ECS-2BL and WSR dat. points were reviewed to determine which data points could be affected by the wall temperature criteria. Table 4.7 summarizes the influence of the trip criteria on the R factor for the ECS-2BL and ECS-2WSR data sets. Results in Table 4.7 indicate that the saturation ratio for ten experiments was affected. Minor changes in R factor (< 6%) resulted in six of those cases. For four experiments, the change in the trip criterion resulted in a change in the R value by more than 10% (10% is the test repeatabiliity as shown in Appendix F).

4.3 Comparison of Excursion Criteria and Wall Saturation Criteria

One of the uses of the INEL excursion data is to provide a basis for comparison to excursion data obtained from other facilities and also to provide a relative base for data gathered using wall saturation temperature rather than excursion criteria. A comparison of data from several different sources is shown in Figure 4.27. Data on this figure include those in Figure 4.26 in addition to data from the INEL ECS-1 thermal excursion tests [10], the INEL ECS-2b wall saturation tests [11], and WSRL excursion data from rigs FA and FB [14].

Figure 4.27 indicates that there is reasonable agreement among the data from the different facilities. This comparison shows the much more conservative nature of the wall saturation criteria relative to the excursion criteria. R factors for the wall saturation criteria are generally about half of those for the excursion criteria for a given superficial velocity.

Figure 4.27 contains data gathered from test sections with flat axial power profiles and from facilities with axial cosine power profiles. With respect to the excursion data, it appears that the range in results from any given facility is as large as or larger than the data spread between any two given facilities. From this observation, one can conclude that for the global

Table 4.7 Influence of 520 K and 620 K wall temperature criteria on saturation ratio for INEL thermal excursion data points

		520 K trip criteria		620 K trip criteria		
TEST ID	Power to Saturate Outlet (kW)	Total Test Section Power (kW)	R factor (P/Psat) -	Total Test Section Power (kW)	R factor (P/Psat) -	Per cent change in R factor[1] -
ECS-2BL_1	29.54	70.80	2.34	70.80[2]	2.34	0.0
ECS-2BL_1B	31.37	68.00	2.17	78.69	2.51	13.6
ECS-2BL_2	91.88	90.00	0.98	101.48	1.10	11.3
ECS-2BL_5	19.07	50.00	2.62	53.48	2.80	6.5
ECS-2BL_5B	17.85	50.15	2.81	50.15	2.81	0.0
ECS-2BL_5C	18.78	47.96	2.55	47.96	2.55	0.0
ECS-2BL_5D	19.36	50.76	2.62	50.76	2.62	0.0
ECS-2BL_6	56.77	97.50	1.72	97.50[2]	1.72	0.0
ECS-2BL_7	101.28	99.80	0.99	99.80	0.99	0.0
ECS-2BL_7B	97.50	96.00	0.98	99.15	1.02	3.2
ECS-2BL_11[3]	29.45	50.59	-	50.59	-	-
ECS-2BL_11B	29.93	70.60	2.36	70.60[2]	2.36	0.0
ECS-2BL_12[3]	57.63	66.41	-	66.41	-	-
ECS-2BL_12B	48.00	96.94	2.02	96.94	2.02	0.0
ECS-2BL_13	62.74	101.97	1.63	101.97	1.63	0.0
ECS-2BL_14	90.85	112.43	1.24	112.43	1.24	0.0
ECS-2BL_17	61.77	63.32	1.03	63.32	1.03	0.0
ECS-2BL_18	98.76	96.00	0.97	97.50[2]	0.99	2.0
ECS-2BL_18B	103.35	98.40	0.95	98.40[2]	0.95	0.0
ECS-2BL_22	57.74	71.13	1.23	71.13	1.23	0.0
ECS-2BL_23	95.28	101.50	1.07	103.82	1.09	2.2
ECS-2BL_23B	97.58	94.00	0.96	96.61	0.99	2.7
ECS-2BL_26	57.01	93.72	1.64	93.72	1.64	0.0
ECS-2BL_26B	57.62	89.01	1.54	89.01	1.54	0.0
ECS-2BL_27	89.18	91.00	1.02	93.75[2]	1.05	2.6
ECS-2FC_1	30.15	40.35	1.34	40.35	1.34	0.0
ECS-2FC_2	55.95	80.81	1.44	80.81	1.44	0.0
ECS-2WSR0380	88.27	91.00	1.03	101.88	1.15	10.7
ECS-2WSR0580	137.18	121.22	0.88	121.22	0.88	0.0
ECS-2WSR0580C	136.03	110.88	0.82	110.88	0.82	0.0
ECS-2WSR0760	183.01	126.82	0.69	126.82	0.69	0.0
ECS-2WSR0960	230.59	162.50	0.70	162.50[2]	0.70	0.0
ECS-2WSR1040	251.70	121.00	0.48	161.39	0.64	25.0
ECS-2WSR1040B	244.82	161.25	0.66	161.25	0.66	0.0

1. Defined as the R factor calculated using the 620 K criteria minus the R factor calculated using the 520 criteria times 100 divided by the 620 K R factor.
2. Logbook recorded value due to heater voltage offset on DAS channel.
3. Dryout did not occur on this test.

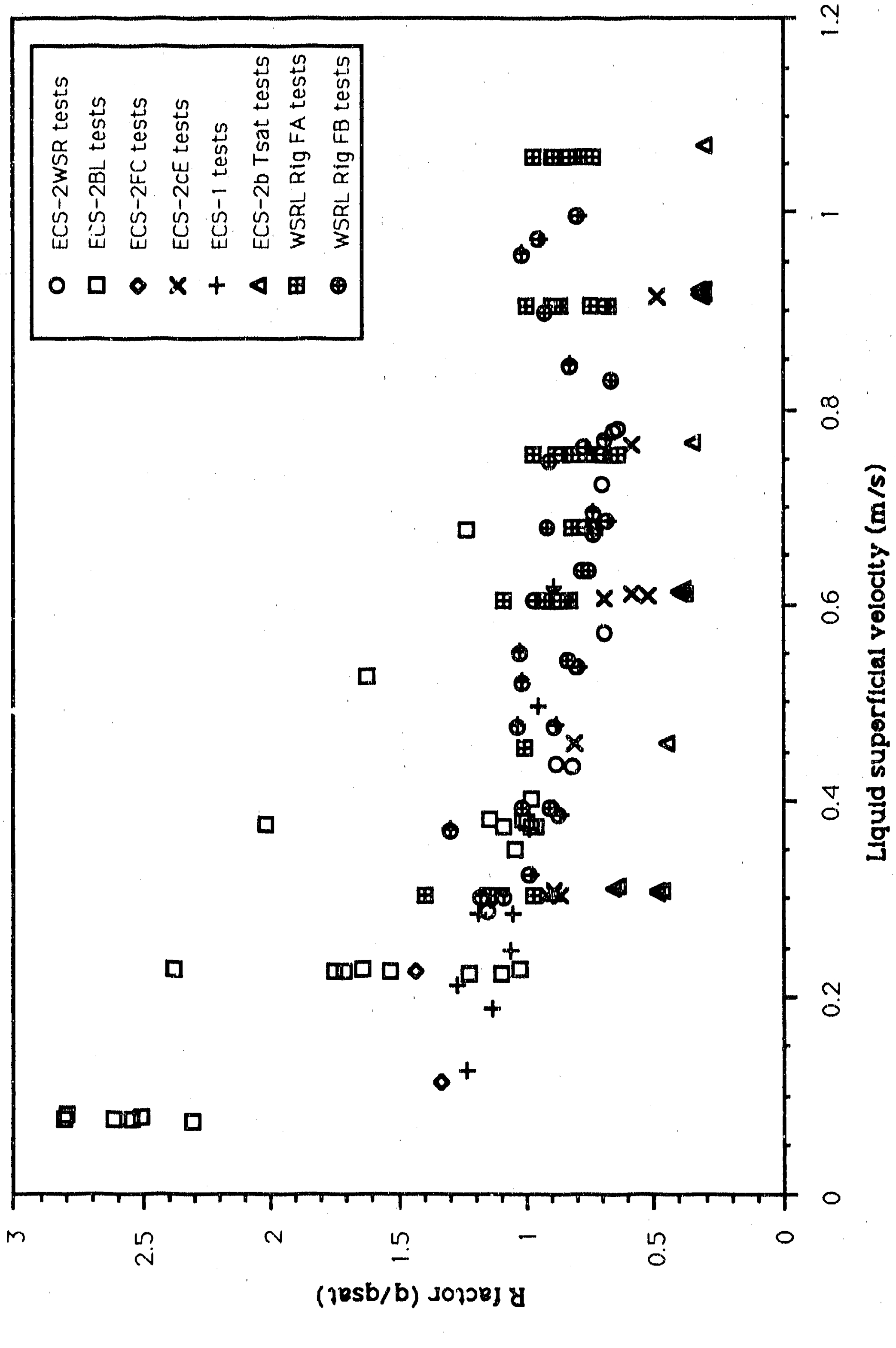


Figure 4.27. Thermal excursion data from several sources and INEL wall saturation data

saturation ratio, there does not appear to be a significant difference between the cosine profile and the flat axial power profile results. However, as argued by Duffey and Hughes, the dryout process is governed by heat flux, energy (local fluid temperature effect), and flow. Thus, for a given set of conditions, the axial power profile will influence the physical location and the total power at which dryout occurs. Close examination of the data in Figure 4.27 supports this argument. Note that the R values for the INEL ECS-2 experiments (cosine axial power profile) are approximately 10-15% lower than R values for comparable SRS Rig FA experiments (flat axial power profile). This result stems from the fact that for a given total power, the ECS-2 facility had higher heat fluxes than did the FA system.

5. CONCLUSIONS

More than 40 experiments covering a range of thermal-hydraulic conditions expected to occur during a hypothesized large break loss-of-coolant accident (LOCA) in a Savannah River Production reactor were successfully conducted at the INEL to support SRS investigation of downflow dryout in a heated annulus. These data are described and documented in this report, which will serve as a reference for use of the data in production reactor power limits setting calculations and computer code evaluations. Specific conclusions derived from evaluation of the INEL thermal excursion data include:

- Thermal excursion data represented in terms of the saturation ratio, R (power at excursion divided by power required to saturate the bulk flow) show that R varies from a maximum of 2.5 - 3 to a minimum of about 0.5 for the superficial velocity range from 0.07 to about 1 m/s, respectively.

- The saturation ratio is primarily a function of test section flow (liquid flowrate, liquid superficial velocity, or film Reynolds number). Inlet liquid temperature and facility back pressure have a weaker influence on the R value than does flow.

- Depending to some extent on inlet fluid temperature, the R factor crosses unity for a superficial velocity between 0.3 and 0.45 m/s. This observation indicates that different phenomena are causing wall thermal excursion depending on the flowrate. R factors larger than unity imply that the bulk fluid is at saturation when excursion occurs while R factors less than one indicate that excursion occurs before the bulk flow is saturated.

- Wall dryout is caused by local flooding and/or dry patch spreading depending on the flow and heat flux conditions. Flowrate plays a major role in determining which dryout conditions predominate.

- Air entrainment is a strong function of the liquid flowrate and the liquid temperature and a weaker function of the test section back pressure. Air entrainment increases with increasing flowrate and decreases with increasing inlet fluid temperature and increasing back pressure on the test section. Air entrainment rate decreases substantially at the onset of thermal excursion.

- INEL data showed that the aluminum wall of the heated test section could rewet even after temperatures in excess of 550 K had been achieved. Many experiments showed prolonged operation consisting of intermittent dryout-rewet cycles followed by a sustained thermal excursion after power increases had been effected.

- Although the processes leading to thermal excursion were quite chaotic and usually consisted of churn-turbulent types of flow regimes, the test results are very repeatable. On experiments conducted to examine repeatability, a spread of less than 10% in R value was noted.

- Hardware and test conduct differences between the various facilities used to conduct the experiments had little effect on test results.

- The present data are in general agreement with data gathered at the SRS Heat Transfer Laboratory. With respect to saturation ratio results, it appears that facilities with axial cosine power shapes produce data generally consistent with data from facilities with flat axial power profiles although there is considerable data scatter for all facilities. For comparable conditions, R values obtained with a axial cosine power profile are 10-15% lower than R values obtained with a flat axial power profile.

- Preliminary statistical examination of the excursion data suggests that flow is the dominant variable. Excursion data represented as R factor as a function of flow can be reasonably correlated with an empirical power law.

- A mechanistic approach such as that proposed by Duffey and Hughes essentially results in a power law representation of the data. Their correlation with recommended constants underpredicts the dryout heat flux.

- Two flow coastdown experiments were conducted to examine the influence of flow controlled (at constant power) experiment results relative to power controlled (at constant flow) experiment results. Although the flow coastdown results suggest the R values are lower than those obtained under constant flow-increasing power conditions, insufficient data are available to derive concrete conclusions. It appears that one of the flow coastdown points may be an outlier.

- For the INEL excursion tests, data gathered at 347 K inlet temperature shows saturation ratios nearly a factor of two larger than the saturation ratio for data from inlet liquid temperatures less than or equal to 326 K. No explanation for this difference currently exists.

- Large scatter in the saturation ratio versus liquid superficial velocity plots and the unique behavior of the 346 K data set relative to other data sets, implies our incomplete understanding of the mechanisms governing the downflow dryout process. Clearly, further work is necessary to more fully understand the dryout process and the mechanistic representation of the data trends.

6. REFERENCES

[1] J. L. Steimke, "Status of Heat Transfer Rig FA," WSRC-TR-90-44, Draft Report, January 26, 1990.

[2] J. R. Taylor, "Melting in Mark 16 Assemblies During a Loss of Coolant Accident," DPST-79-445, December 7, 1979.

[3] J. L. Steimke, "Emergency Cooling System Power Limits for Reactor Assemblies," SPST-86-815, December 1, 1986.

[4] J. L. Steimke, "Status of Heat Transfer Experiment," SPT-88-854, October 12, 1988.

[5] J. L. Steimke, "Heated Annulus Test, Rig A," Experimental Task Plan, Task 88-059-1, Rev. 0, February 8, 1989.

[6] H. N. Guerrero, "Heated Annulus Test, Rig B," Task Plan 88-064-1, March 3, 1989.

[7] A. L. Kielpinski, "Heated Channel Experiment," Task Plan 88-061-2, May 1, 1989.

[8] B. L. Johnston, "Thermal Excursions Under ECS Conditions in a Single Annulus with Azimuthal Tilt," WSRC-TR-90-45, February 1990.

[9] J. L. Steimke and C. M. Hart, "Non-Boiling Heat Transfer in Rig FA," NED-ECS-890173, November 1989.

[10] V. T. Berta, K. G. Condie, and J. A. Shroeder, "Phenomenological Scoping Studies of Downflow in a Uniformly Heated Ribbed Vertical Annulus," EGG-ES&H-8464, ES&H-SRP-3-89, August 1989.

[11] J. L. Anderson, K. G. Condie, and T. K. Larson, "Downflow Heat Transfer in a Heated Ribbed Vertical Annulus with a Cosine Power Profile (Results from Test Series ECS-2b)," Idaho National Engineering Laboratory Report, EGG-EAST-9144, July, 1990.

[12] J. L. Anderson, K. G. Condie, and T. K. Larson, "Justification and Methodology for Metal Thermocouple Corrections (ECS-2c and ECS-2b Test Series)," draft Idaho National Engineering Laboratory Report, transmitted by letter from J. L. Anderson (INEL) to J. L. Steimke (WSRC), PROPOSED ECS-2c THERMOCOUPLE CORRECTIONS, JLA-11-90, September 28, 1990.

[13] R. B. Duffey and E. D. Hughes, "Dryout Stability and Inception at Low Flowrates," Idaho National Engineering Laboratory Report, EGG-EAST-8491, November 1989.

[14] J. L. Anderson (INEL) personal communication with J. L. Steimke (WSRC), May 21, 1990.

Appendix A

Engineering Drawings for the ECS-2 Test Fixture

Appendix A

Engineering Drawings for the ECS-2 Test Fixture

Engineering drawings that document the design and construction of the ECS-2 test facility hardware are presented on the following pages. Additional information and drawings for the ECS-2c test fixture can be found in Appendix A of Anderson, et al.[Anderson, et al 1990].

Reference

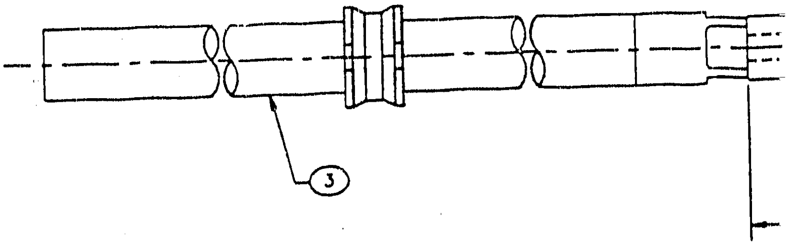
Anderson, et al 1990 J. L. Anderson, K. G. Condie, and T. K. Larson, "Downflow Heat Transfer in a Heated Ribbed Vertical Annulus with a Cosine Power Profile (Results for Test Series ECS-2b)," Idaho National Engineering Laboratory Report, EGG-EAST-9144, July, 1990.

8 7 6 5

D

NOTES.

1. PRESERVE AND PROTECT PER STD 7020, CLASS II
2. CLEANLINESS PER STD 7022, LEVEL C
3. MARK PER STD 7006-21 WITH 429993-1 ASSEMBLY
4. BRAZE PER CP DI 12.0, VISUALLY INSPECT PER CP 9.6, APPENDIX 1.



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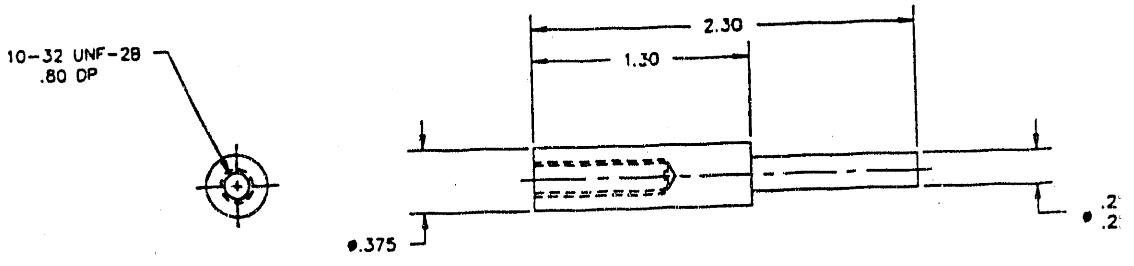

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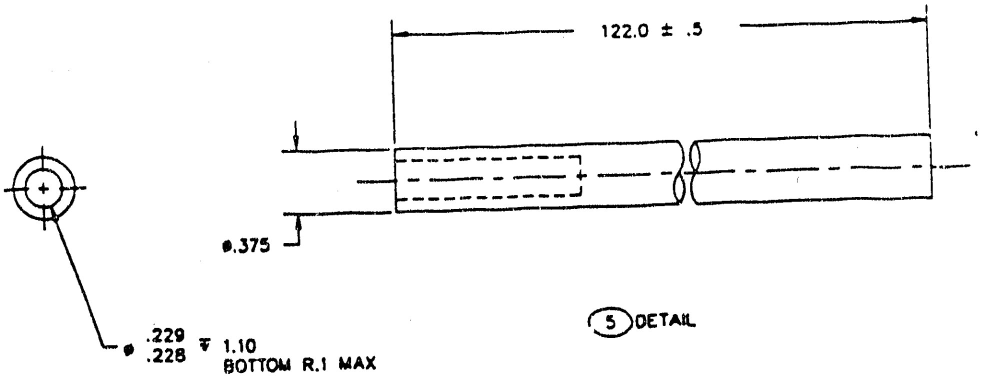

5 DETAIL

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8 7 6 5

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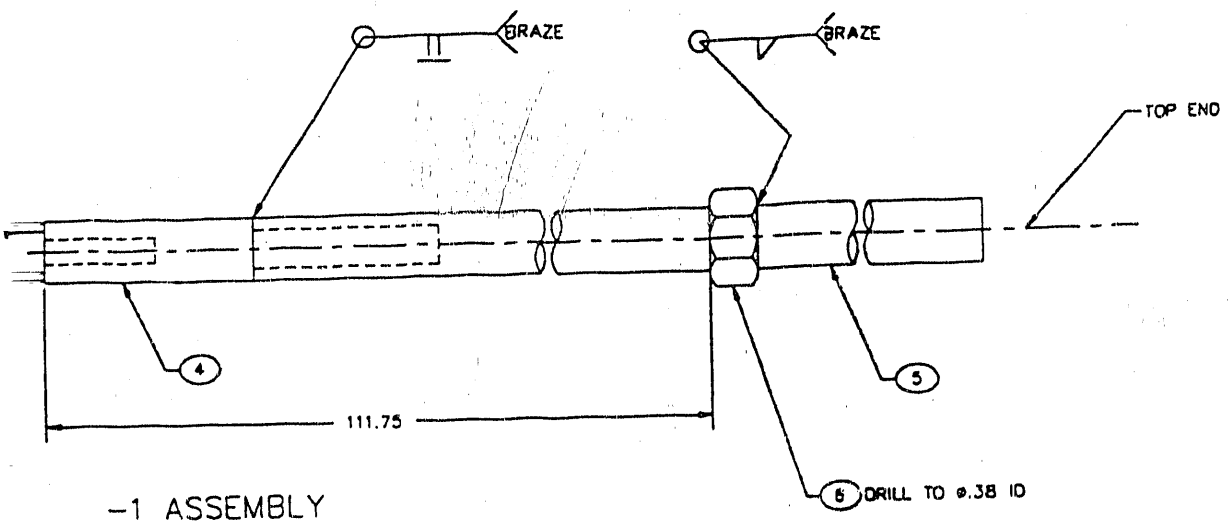

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	1	3	40P016	HEATER ROD			
							2
		8	−1	ASSEMBLY			

PARTS LIST

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SURFACE ROUGHNESS 125 ✓
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES .X = ±.1
DECIMALS .XX = ±.03
.XXX = ±.010
FRACTIONS ±1/8
ANGULAR ±1°
DO NOT SCALE DRAWING

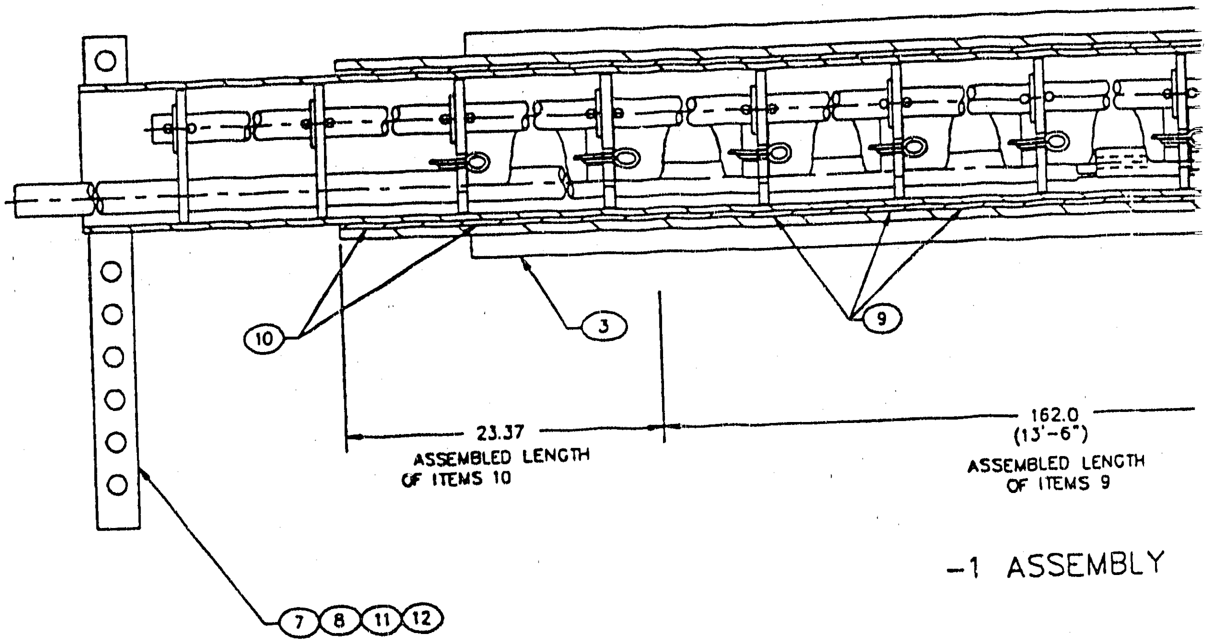
NEXT ASSY/REF DWG 429994

K L JOHNSON	9-13-89
V E BERG	9-13-89
K G CONDIE/HR	9-13-89
D STANGER	9-13-89
JON TULLIS	7/89
D STANGER	9-13-89

EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL−ECS 2 DRY OUT EXPERIMENT
INTERNAL HEATER ROD

SIZE D | 037 | 0646 | 48 | 220
DRAWING NO. 429993
SCALE 1 = 1



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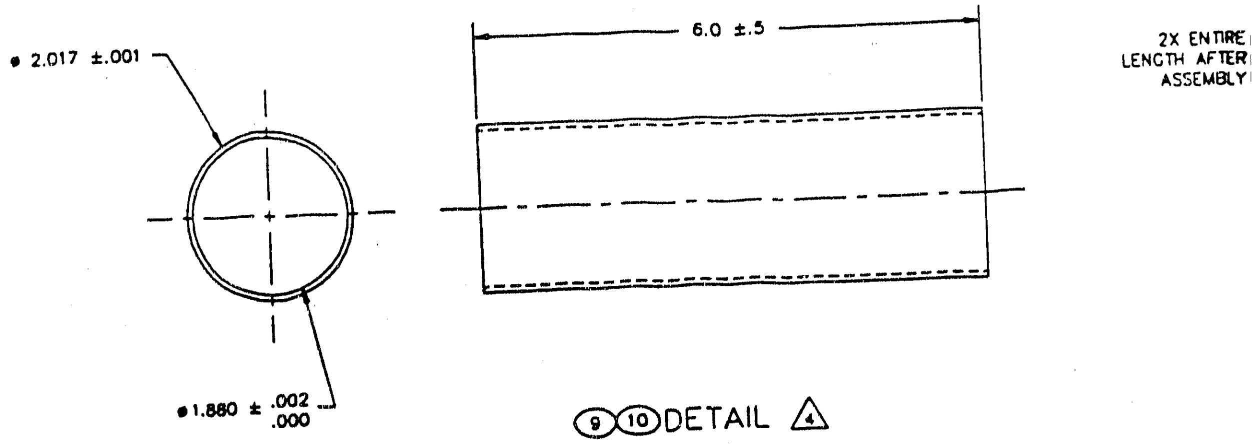
1. PRESERVE AND PROTECT PER STD 7020, CLASS II
2. CLEANLINESS PER STD 7022, LEVEL C

△3 MARK PER STD 7006-202 WITH 429994-1 ASSY ON INDICATED SURFACE

△4 MARK PER STD 7006-21 WITH 429994 AND APPROPRIATE DASH NUMBER

5. WELD PER CP A2.0, VISUALLY INSPECT PER CP 9.6, APPENDIX 1, LIQUID PENETRANT INSPECT PER CP 9.3, APPENDIX 3, PROCEDURE B-3, CRITERIA APPENDIX IV, C-1.



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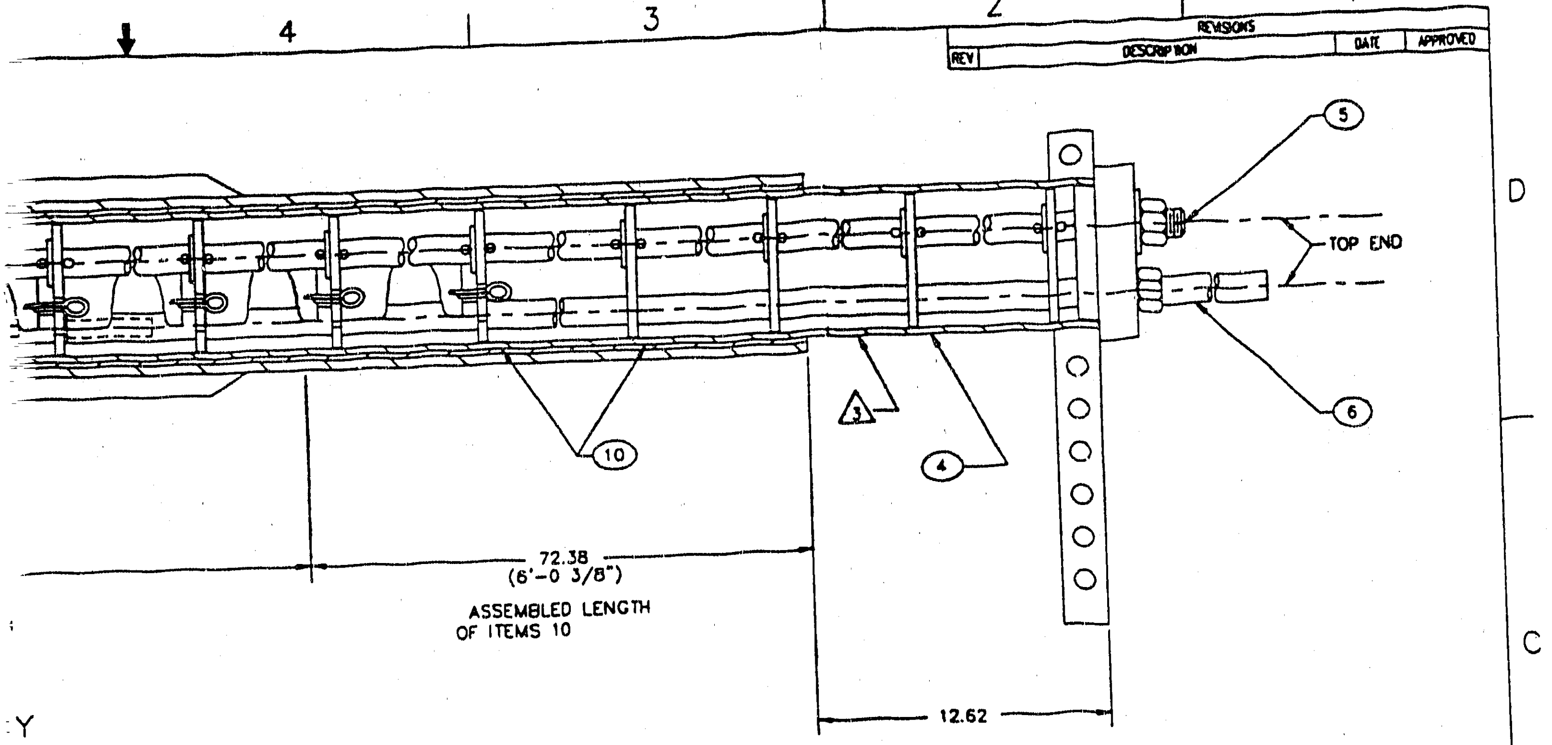

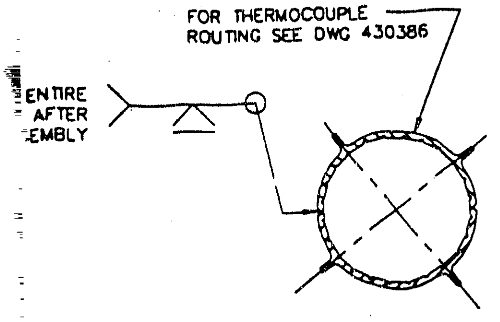

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14	B		BOLT-HEX 3/8-16-UNC-2A .75 LG			11
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27	B	-9	INSULATOR	MACOR GLASS CERAMIC ROD		9
						8
2		430055-3	BUS BAR CLAMP			7
2		430055-2	BUS BAR			6
1		429993-1	INTERNAL HEATER ROD			5
1		430056-1	SUPPORT ROD ASSEMBLY			4
1		430437-1	HEATER TUBE ASSEMBLY			3
2		430052-1	ALUMINUM HEATER TUBE			2
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EG&G Idaho, Inc.

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	V E BERG	9-13-89
	K C CONDIE/HR	9-13-89
	D STANGER	9-13-89
	JON TULLIS	7/89
	D STANGER	9-13-89

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
HEATER ASSEMBLY

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NOTES.

1. REMOVE ALL BURRS AND SHARP EDGES
2. PRESERVE AND PROTECT PER STD-7020 CLASS II
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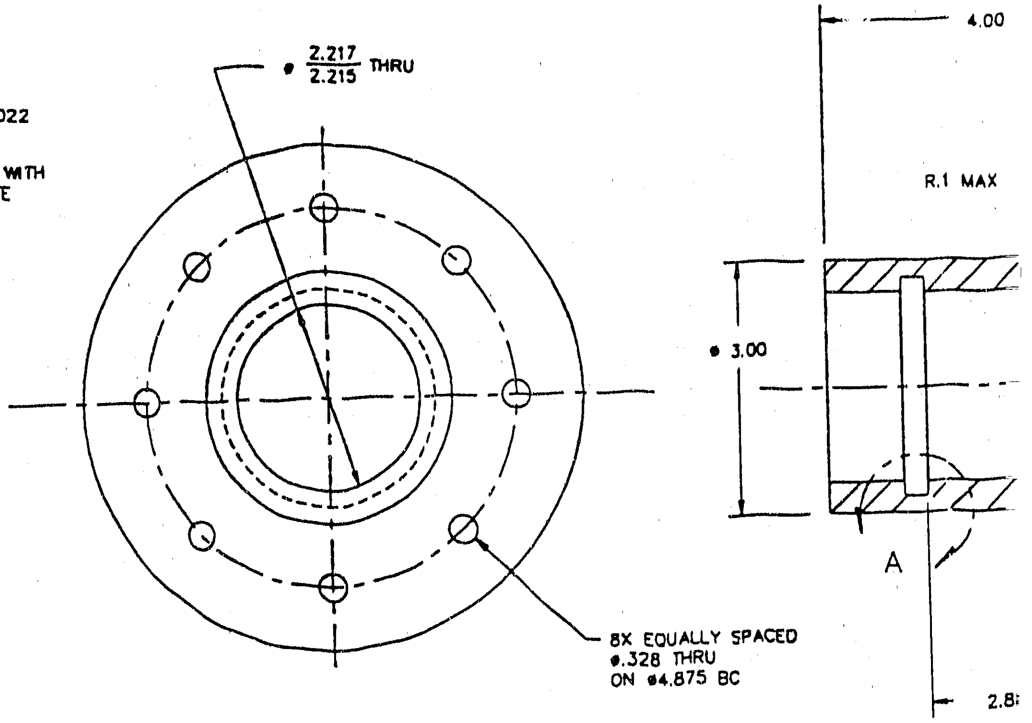
4. MARK PER STD 7006-21 WITH 430047 AND APPROPRIATE DASH NUMBER



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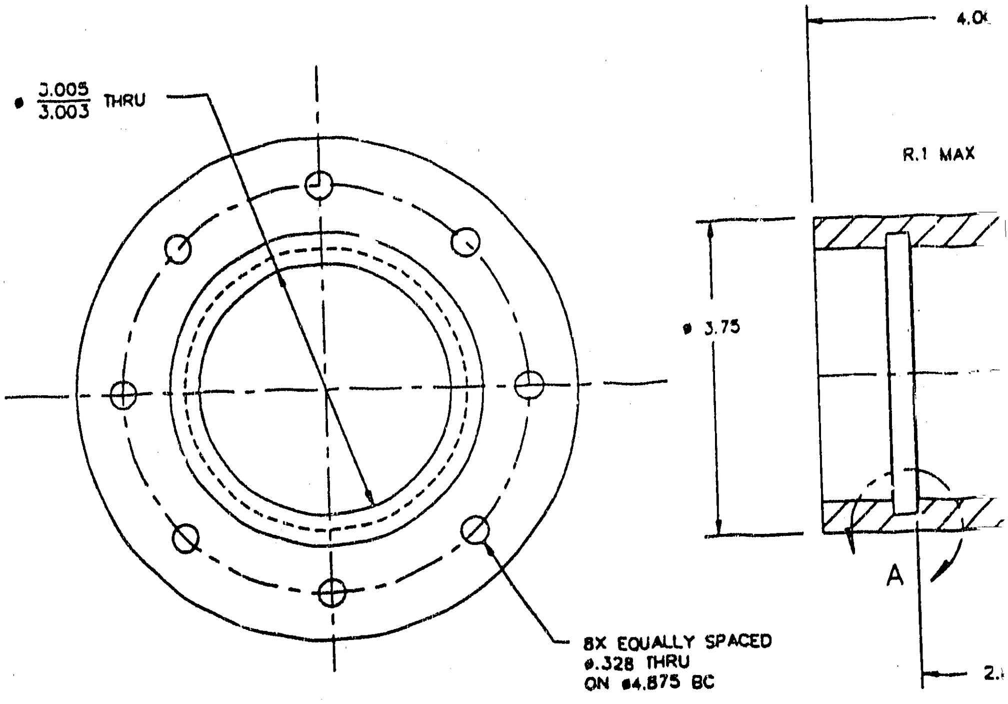

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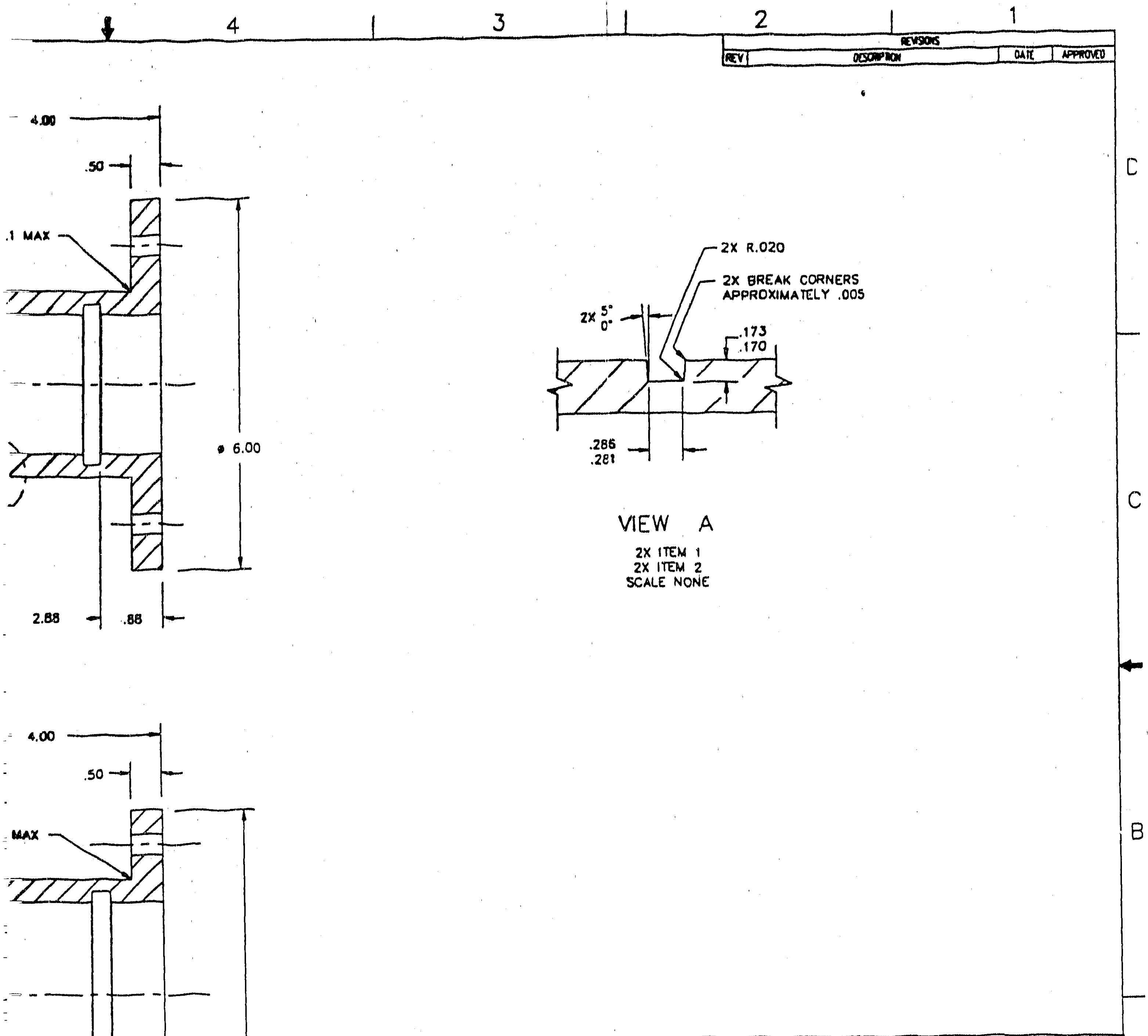

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	AR	B	−1	3.0 OD HUB			−1

430049/430436

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V E BERG		9-11-89
K G CONDIE	DATE	9-11-89
D STANGER	DATE	9-11-89
JON TULLIS	DATE	5-89
D STANGER	DATE	9-11-89

EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL−ECS 2 DRYOUT EXPERIMENT
PLENUM HUBS

D 037 0646 48 220

430047

SCALE 1/1

NOTES.

1. REMOVE ALL BURRS AND SHARP EDGES
2. CLEANLINESS PER STD-7022 LEVEL C
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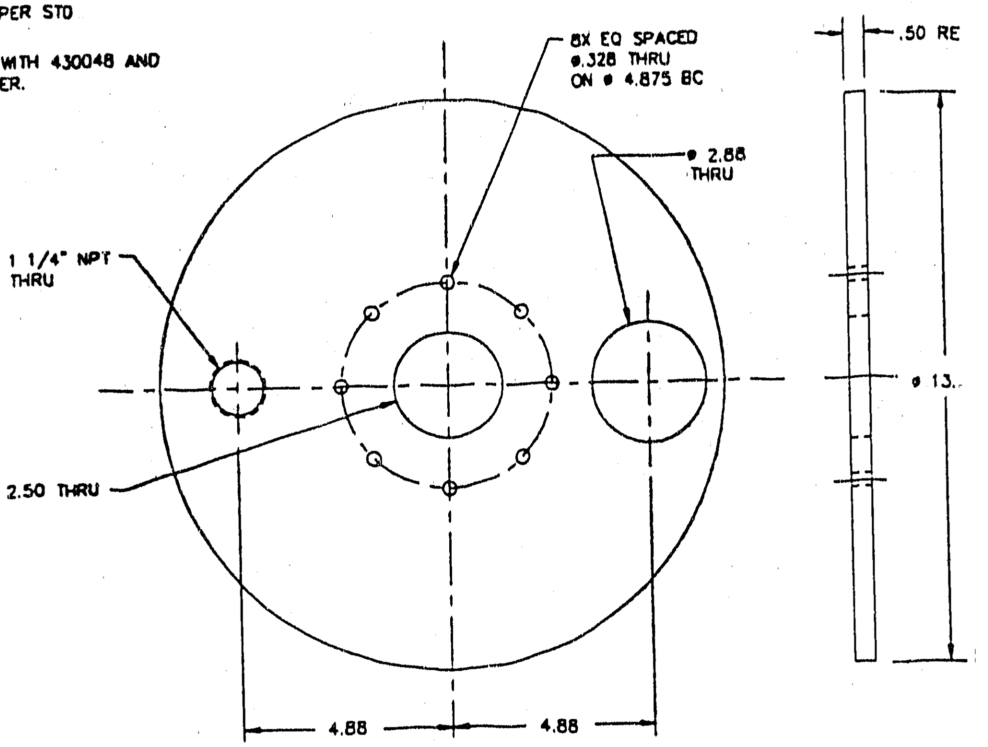

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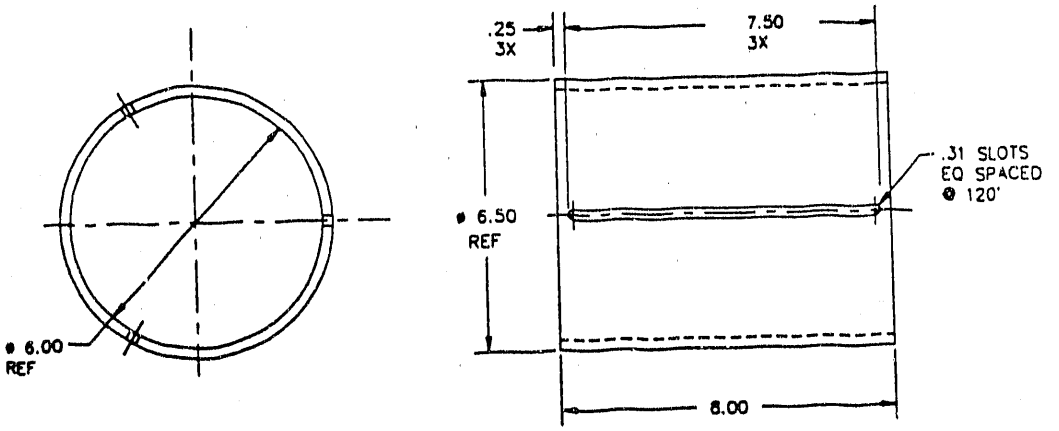

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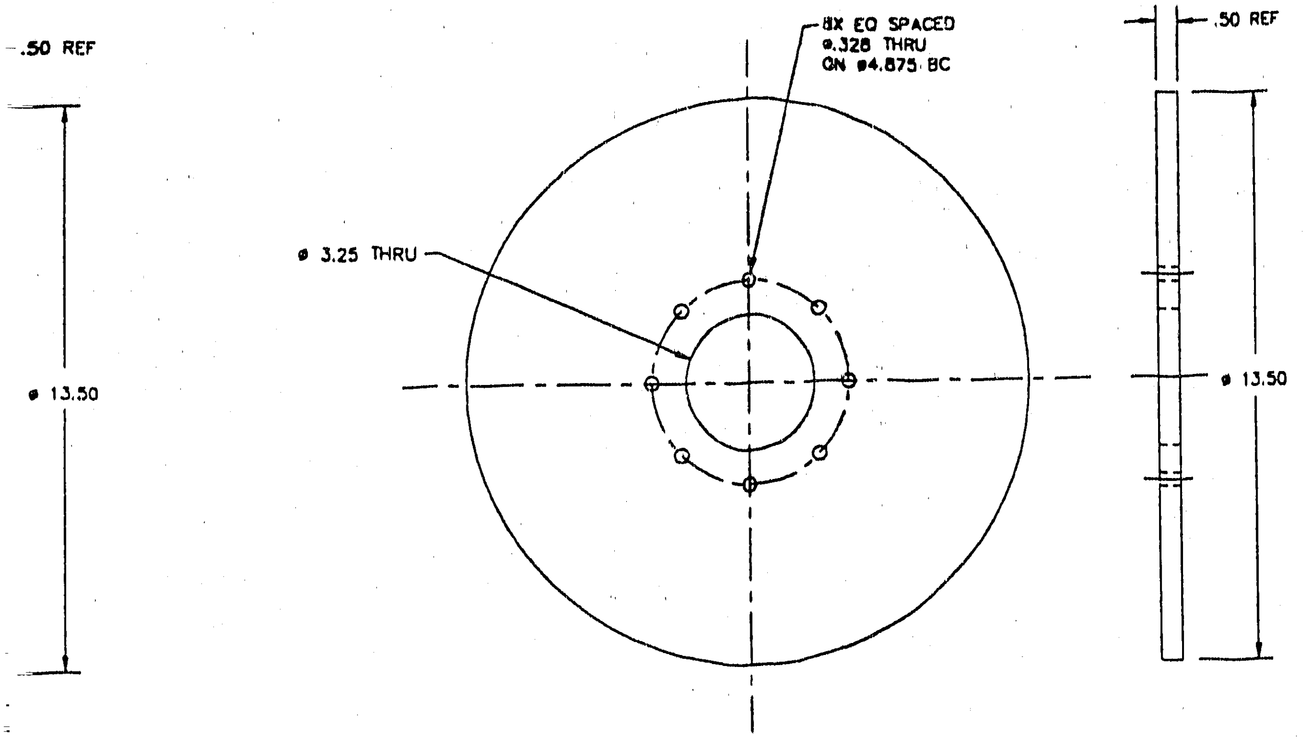

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QTY. REQD							

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K C CONDIE	9-11-89	
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JON TULLIS	3-89	SCALE 1/2
D STANGER	9-11-89	

DO NOT SCALE DRAWING

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NOTES:

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△5 ITEM 12 SUPPLIED BY OTHERS

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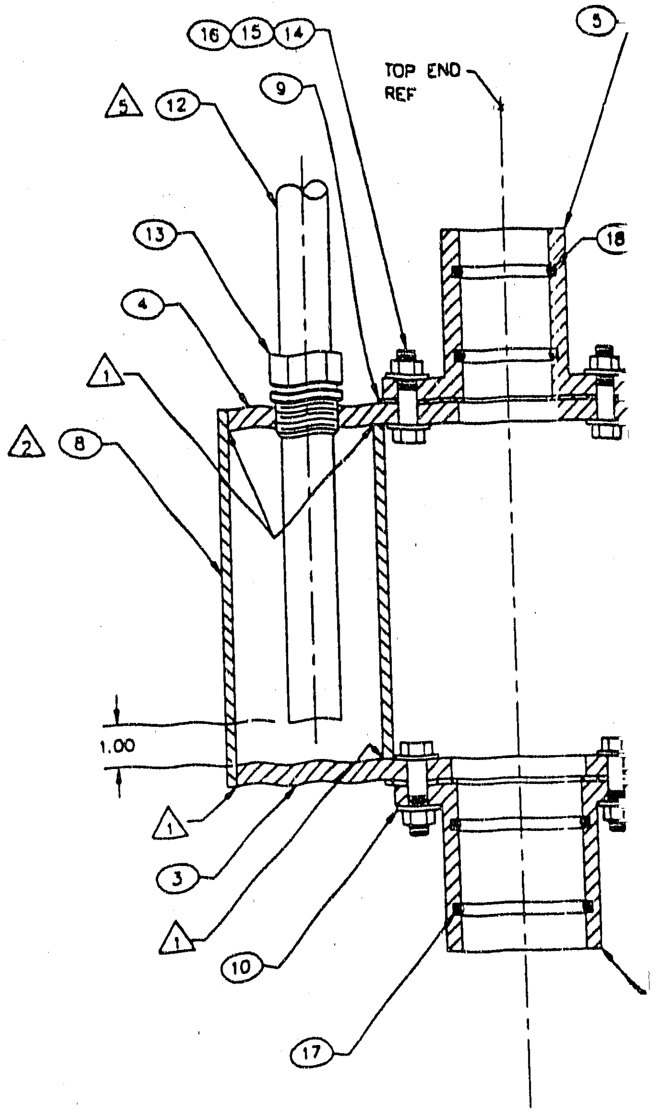

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- 1 ASSEMBLY

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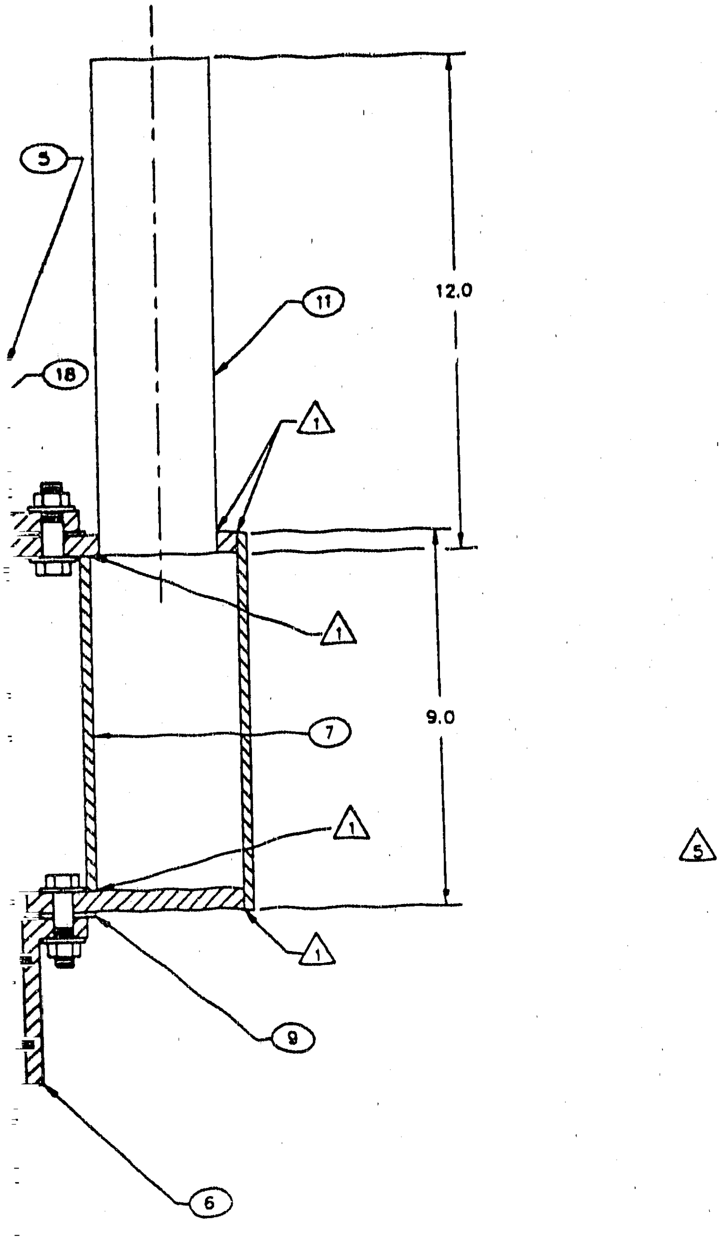

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	16	B		WASHER 5/16 X .062 THK	304 SST COML GR	16
	16	B		NUT-HEX 5/16-18-2B		15
	16	B		BOLT-HEX HEAD 5/16-18 UNC X 1 1/2" LG		14
	1	B	SS-2000-1-20	1 1/4" MALE CONNECTOR	SWAGELOK CO.	13
	AR	B		WATER INLET TUBE	TUBE 1 1/4 OD .049 WALL ASTM B210/221 AL ALLOY 6061-T6	12
	AR	B		INLET TUBE	TUBE-2 7/8" OD X 1/8" WALL CLEAR CAST ACRYLIC COML GR	11
						10
	16		430050-3	BOLT GASKET		9
	2		430050-2	HUB GASKET		8
	AR	B		OUTER HOUSING TUBE	TUBE-14" OD X 1/4" WALL CLEAR CAST ACRYLIC COML GR	7
	1		430048-3	INNER TUBE		6
	1		430047-2	3 3/4" OD HUB		5
	1		430047-1	3" OD HUB		4
	1		430048-1	TOP PLATE		3
	1		430048-2	BOTTOM PLATE		2
						1
		B	-1	ASSEMBLY		
QTY. REQ'D		QUAL LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND NO

PARTS LIST

DIMENSIONING AND TOLERANCING ARE AMERICAN NATIONAL STANDARD UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS 125 ✓
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES .X = ±.1
DECIMALS .XX = ±.03
.XXX = ±.010
FRACTIONS ± 1/8
ANGULAR ± 1°
DO NOT SCALE DRAWING

NEXT ASSY/REF DWG 430054
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QUALITY V E BERG 9-11-89
APPROVED K G CONDIE DATE 9-11-89
CHECKED D STANGER DATE 9-11-89
DRAWN JON TULLIS DATE 5-89
RELEASE D STANGER DATE 9-11-89

EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
UPPER PLENUM ASSEMBLY

SIZE D
WORK PACKAGE NUMBER 037 0646 48 220
DRAWING NO. 430049
REV
SCALE 1=1
SHEET

8 7 6 5

D

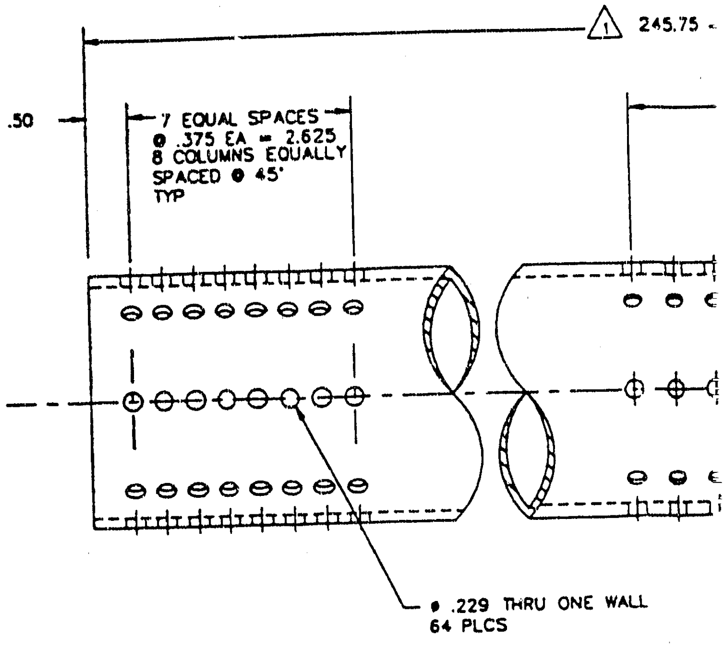
C

B

A

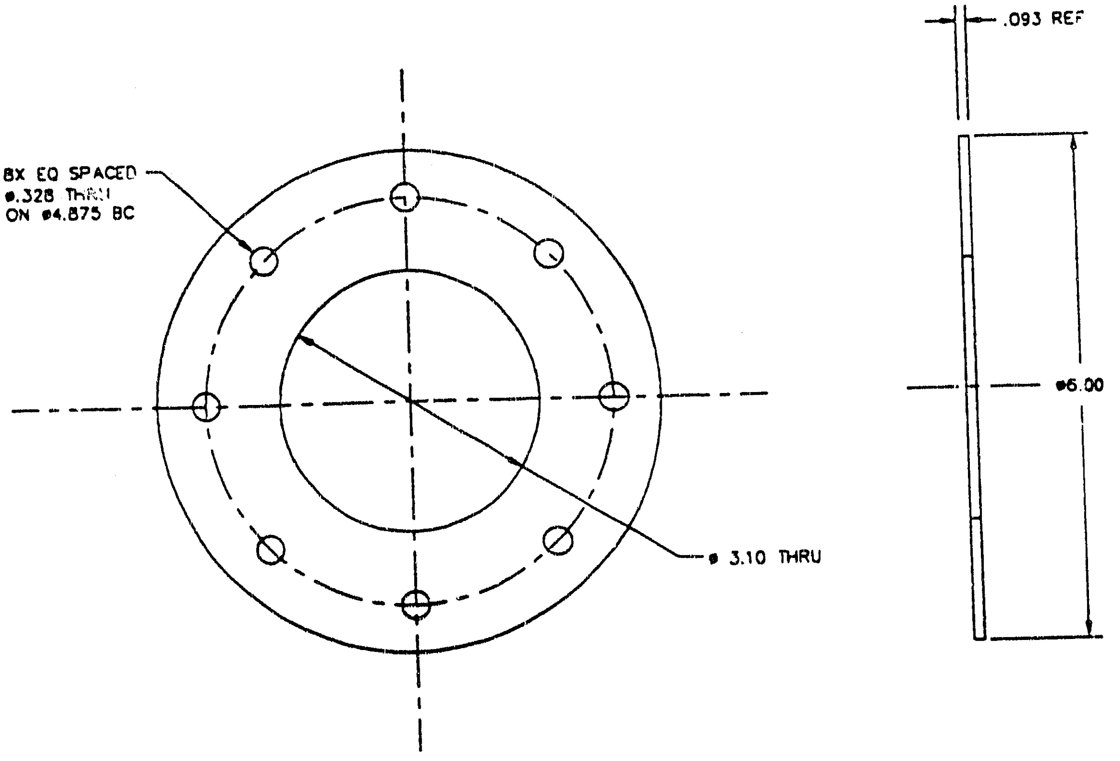
NOTES.

1. PERMISSIBLE TO OBTAIN REQUIRED LENGTH OF ITEM 1 BY USING 2 OR MORE PIECES
2. MARK PER STD-7006-21 WITH 430050 AND APPROPRIATE DASH NUMBER
3. PRESERVE AND PROTECT PER STD-7020 CLASS II
4. CLEANLINESS PER STD-7022, LEVEL C.



① DI

SCALE

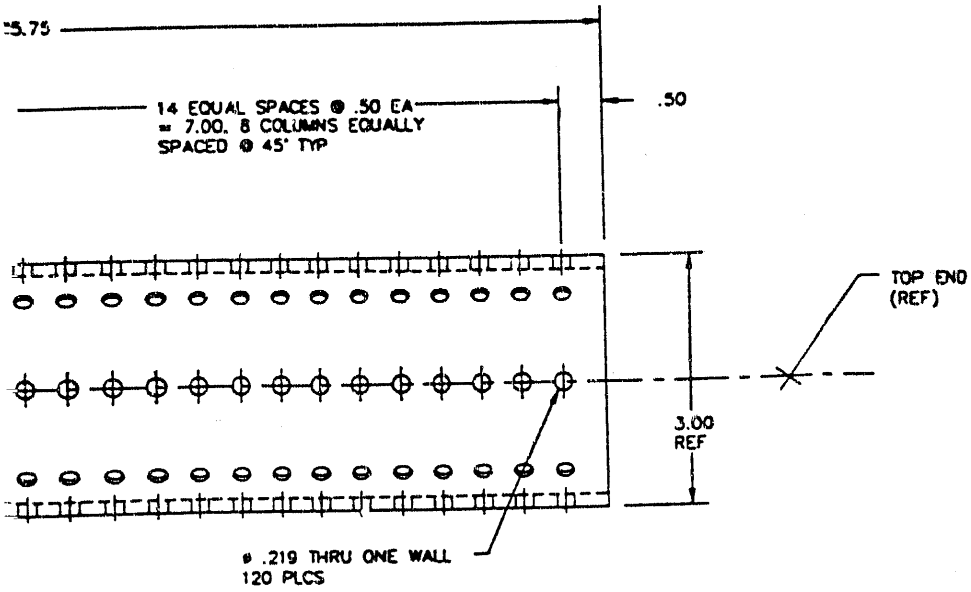


② DETAIL △2

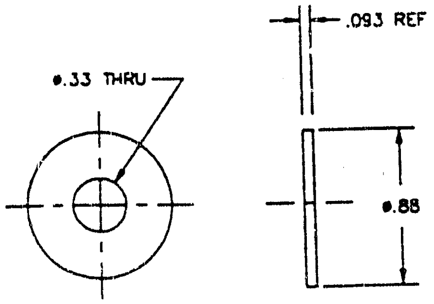
SCALE 1=1

8 7 6 5

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



① DETAIL △2
SCALE 2/1



③ DETAIL △2
SCALE 2/1

QTY. REQD		QUAL LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND
		B	-3	BOLT GASKET SILICONE RUBBER	MAKE FROM McMASTER CARR 8632K13 CAT #86	3
		B	-2	HUB GASKET SILICONE RUBBER		2
		B	-1	OUTER FLOW SHROUD	TUBE-3" OD X 1/8" WALL COML POLYCORBONATE TUBE GR	1

PARTS LIST

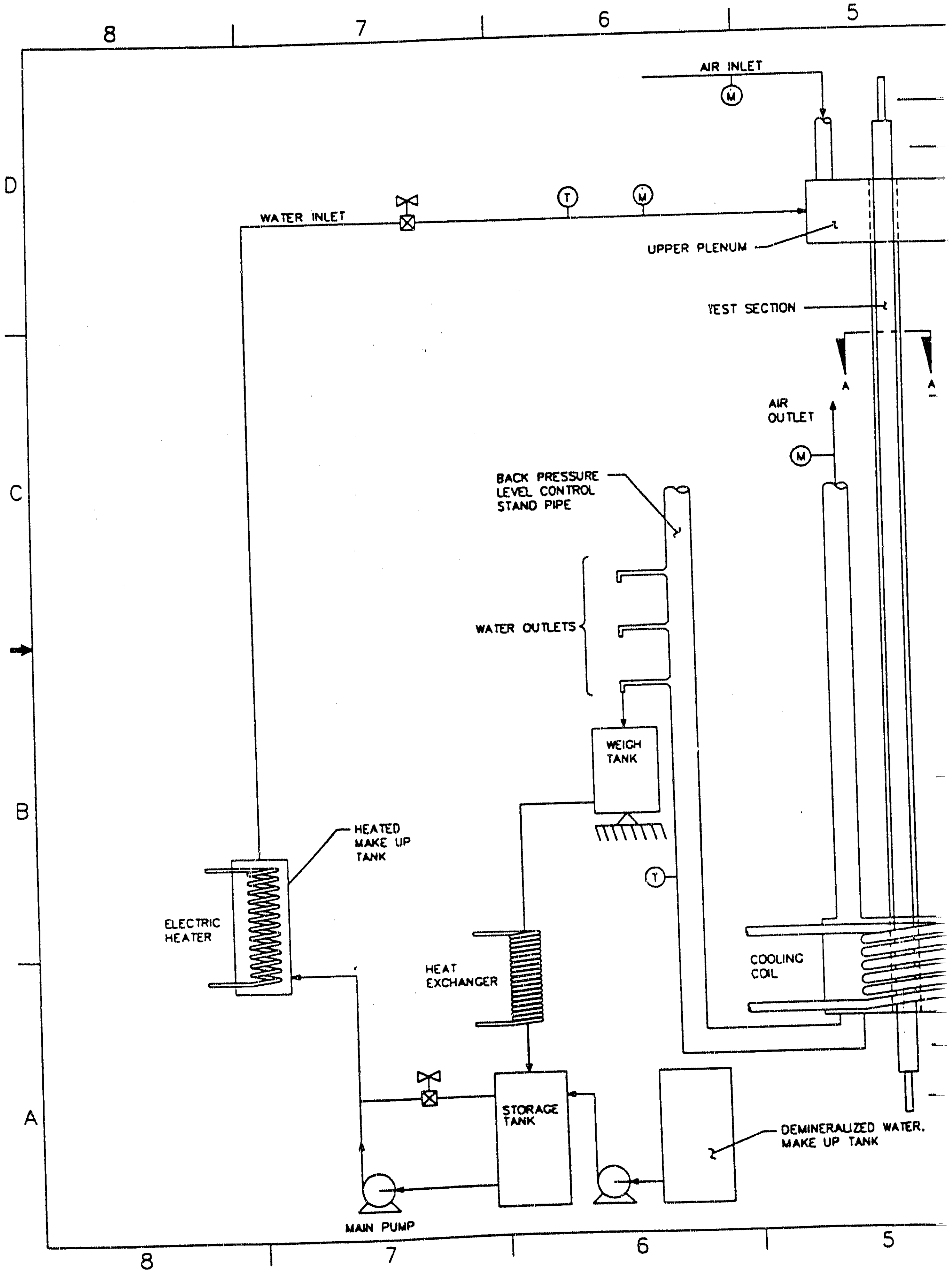
EG&G Idaho, Inc.

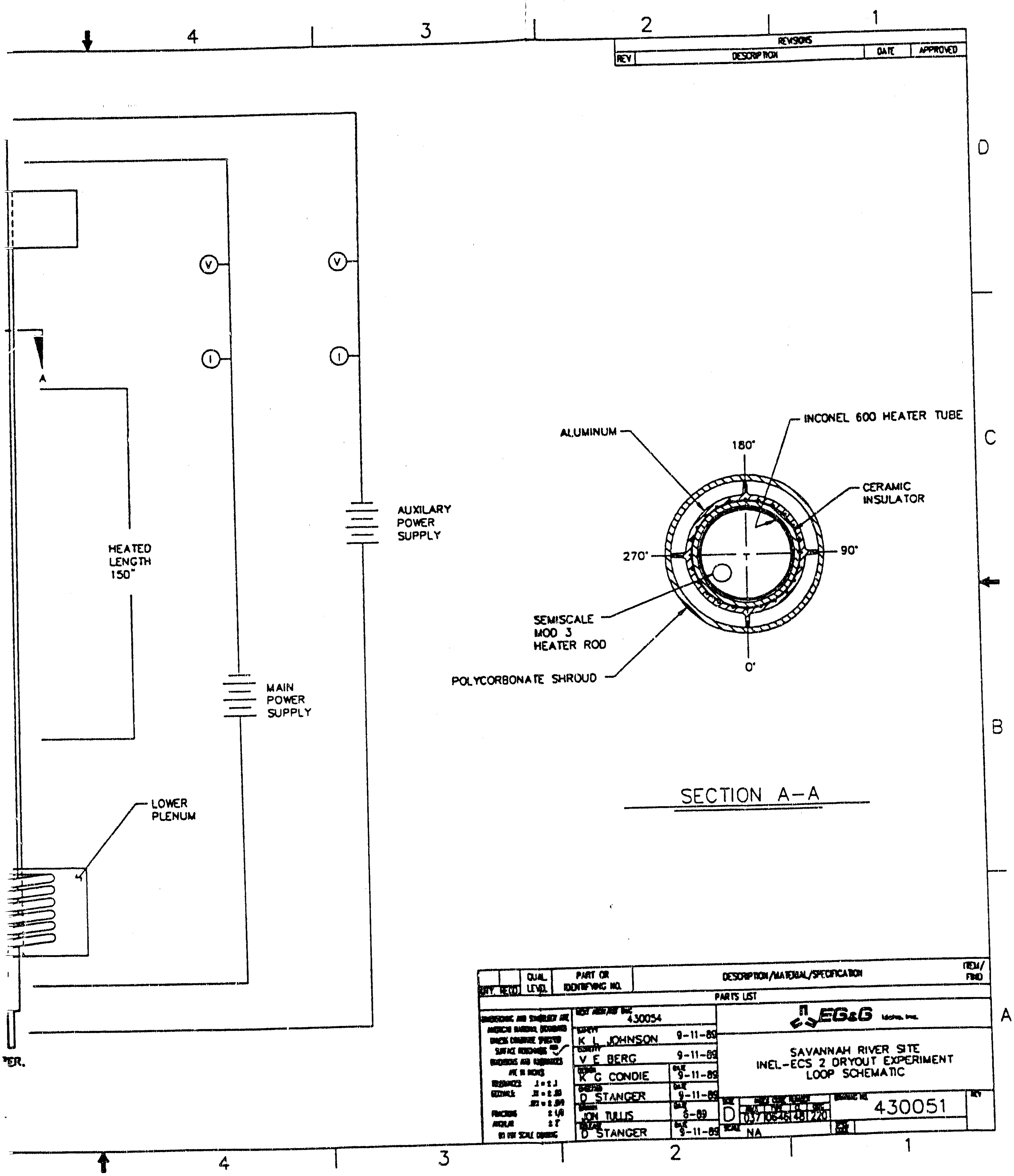
DIMENSIONS AND SYMBOLOGY ARE AMERICAN NATIONAL STANDARD UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES [illegible]
DECIMALS [illegible]
FRACTIONS [illegible]
ANGULAR [illegible]
DO NOT SCALE DRAWING

K L JOHNSON 9-11-89
V E BERG 9-11-89
K C CONDIE 9-11-89
D STANGER 9-11-89
JON TULLIS 3-89
D STANGER 9-11-89

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
OUTER FLOW SHROUD

SIZE D
037 10646 48 220
DRAWING NO. 430050
SCALE NOTED


8
7
6
5
AIR INLET
M
D
WATER INLET
T
M
UPPER PLENUM
TEST SECTION
A
A
AIR OUTLET
M
C
BACK PRESSURE LEVEL CONTROL STAND PIPE
WATER OUTLETS
WEIGH TANK
B
HEATED MAKE UP TANK
T
ELECTRIC HEATER
HEAT EXCHANGER
COOLING COIL
A
STORAGE TANK
DEMINERALIZED WATER, MAKE UP TANK
MAIN PUMP
8
7
6
5



EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
LOOP SCHEMATIC

430054

K L JOHNSON	9-11-89	
V E BERG	9-11-89	
K G CONDIE	9-11-89	
D STANGER	9-11-89	
JON TULLIS	8-89	
D STANGER	9-11-89	

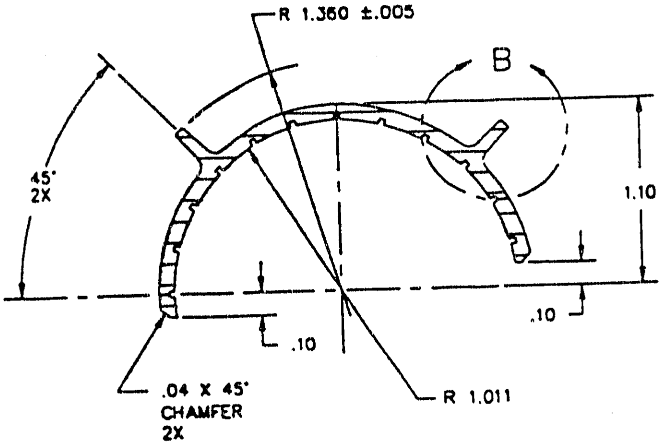
SIZE D 03710 6461 481 220

SCALE NA

DRAWING NO. 430051

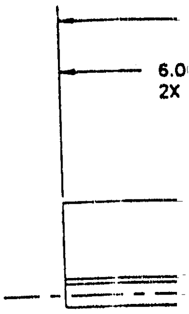
NOTES.

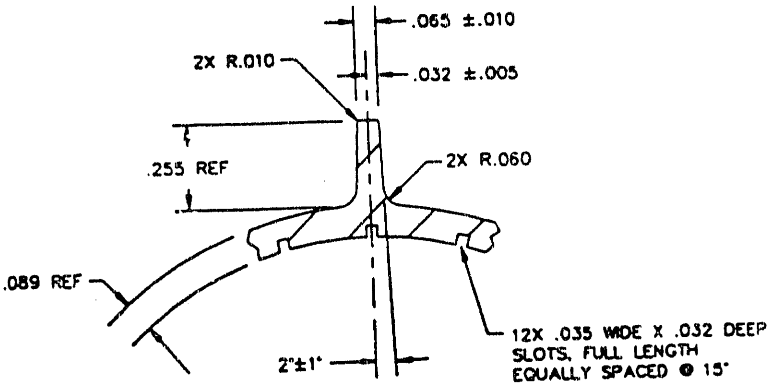
1. REMOVE ALL BURRS AND SHARP EDGES
2. PRESERVE AND PROTECT PER STD-7020 CLASS II
3. MARK PER STD 7006-21 WITH 430052-1
4. CLEANLINESS PER STD-7022, LEVEL C



SECTION A-A

SCALE 2/1

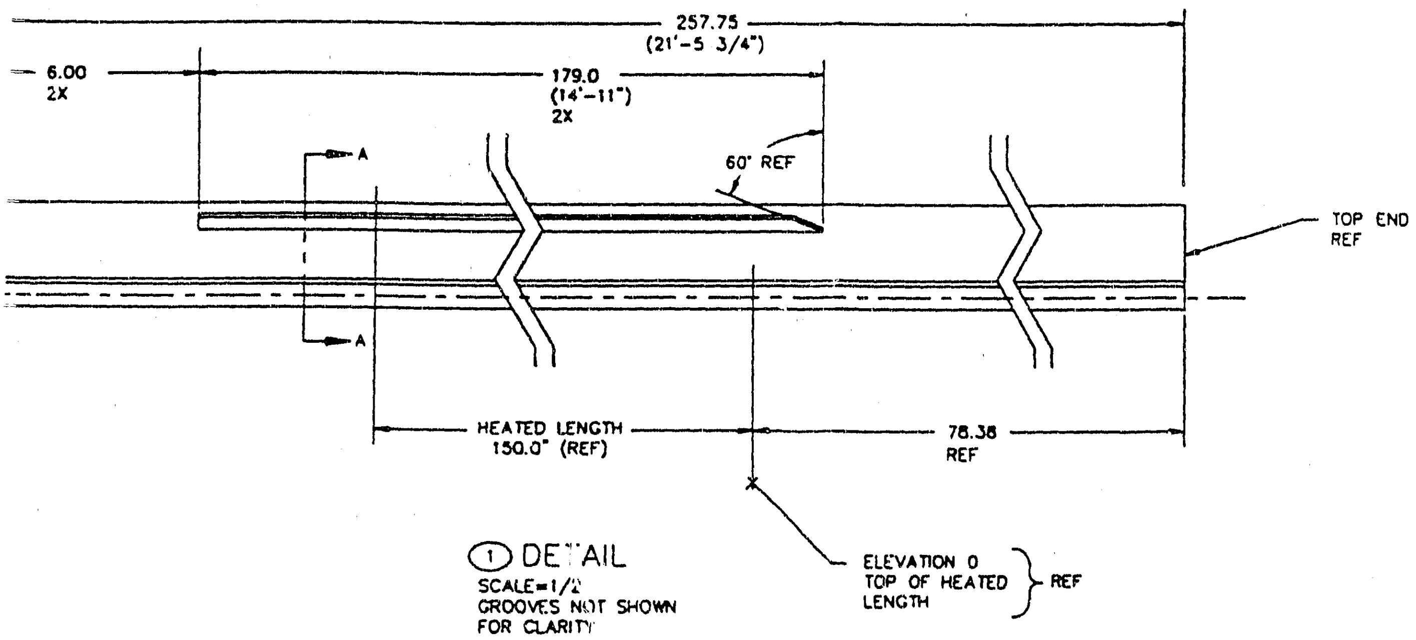




DETAIL B

SCALE 4/1

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



① DETAIL
SCALE=1/2
GROOVES NOT SHOWN
FOR CLARITY

QTY. REQD	-1	QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND
		B	-1	HEATER HOUSING	BAR OR ROUND AL ALLOY 6061-T6 ASTM B210/B221	1

PARTS LIST

K L JOHNSON	9-11-89	
V E BERG	9-11-89	
K C CONDIE	9-11-89	
D STANGER	9-11-89	
JON TULLIS	6/89	
D STANGER	9-11-89	

EG&G Idaho, Inc.

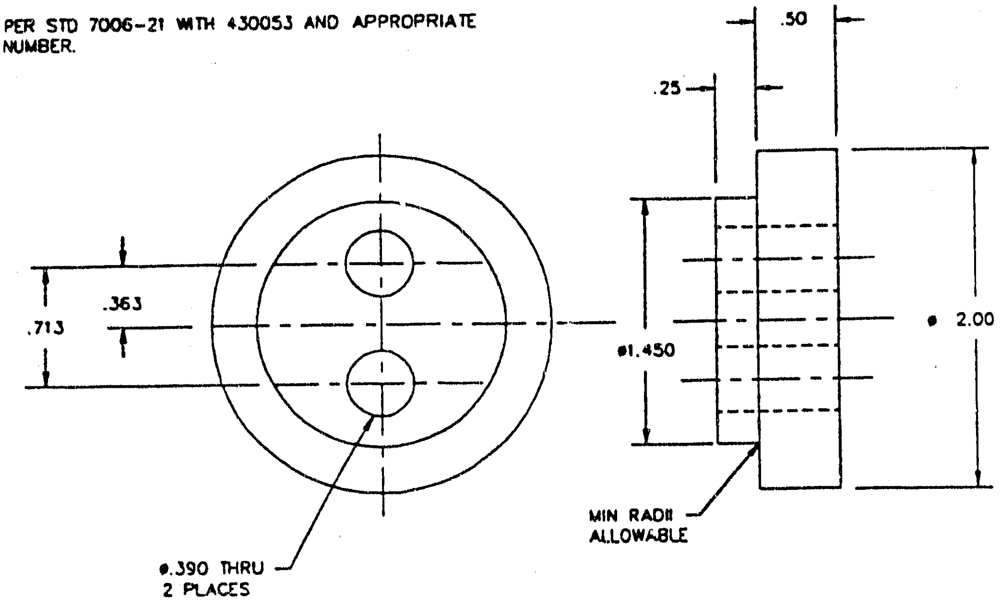
SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
ALUMINUM HEATER TUBE

D 037 10646 48 220

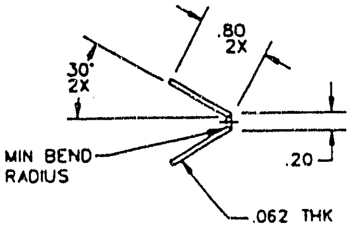
430052

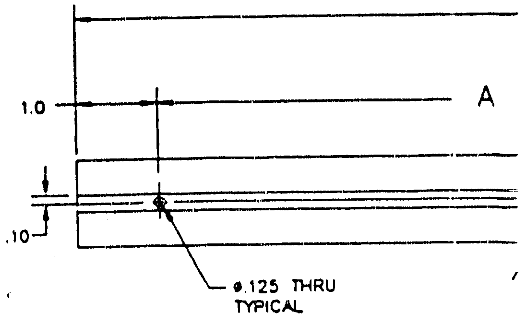
NOTED

1. PRESERVE AND PROTECT PER STD-7020 CLASS II
2. CLEANLINESS PER STD-7022, LEVEL C.
3. MARK PER STD 7006-21 WITH 430053 AND APPROPRIATE DASH NUMBER.



① DETAIL △3
SCALE 2/1

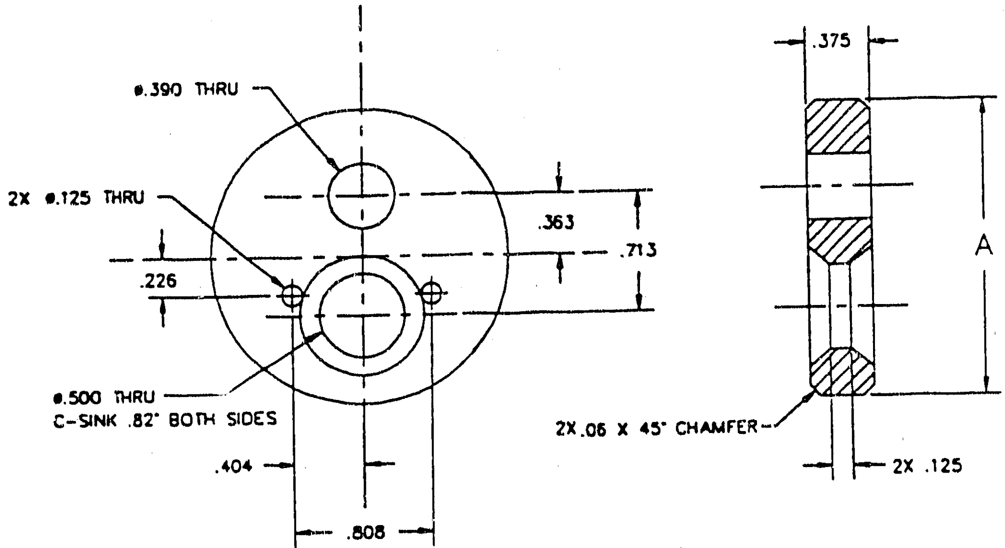




ITEM	A	B
-2	4 EQUALLY SPACED HOLES @ 4.25 EA = 12.75	14.50
-3	4 EQUALLY SPACED HOLES @ 4.92 EA = 14.75	16.50
-4	5 EQUALLY SPACED HOLES @ 3.81 EA = 15.25	17.00
-5	6 EQUALLY SPACED HOLES @ 3.75 EA = 18.75	20.50
-6	6 EQUALLY SPACED HOLES @ 4.35 EA = 21.75	23.50

② THRU ⑥

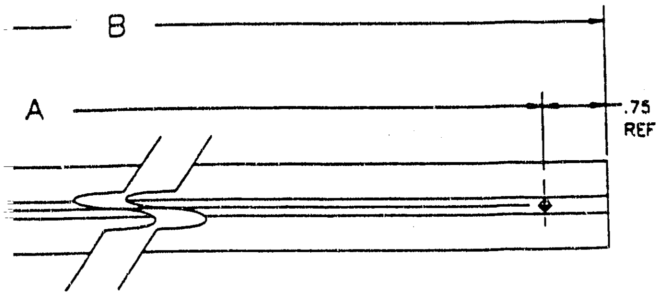
REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



⑦ THRU ⑫ DETAIL △3

SCALE: NONE

ITEM	DIM A
-7	1.450
-8	1.583
-9	1.711
-10	1.735
-11	1.748
-12	1.755



U ⑥ DETAIL △3

QTY. REQD		QUAL LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND
		B	-12	DISK	MACOR GLASS CERAMIC ROD	12
		B	-11			11
		B	-10			10
		B	-9			9
		B	-8			8
		B	-7	DISK		7
		B	-6	RADIATION SHIELD	PH 15-7MO AMS 5520 REV C	6
		B	-5			5
		B	-2			2
		B	-3			3
		B	-2	RADIATION SHIELD		2
		B	-1	END PLUG	DENSE LAMINATED HARDBOARD COML GR	1

PARTS LIST

DIMENSIONING AND TOLERANCING PER AMERICAN NATIONAL STANDARD
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS 125 ✓
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES .X ±.1
DECIMALS .XX ±.[illegible]
.XXX ±.[illegible]
FRACTIONS ±1/8
ANGULAR ±2°
DO NOT SCALE DRAWING

NEXT ASSY/REF DWG 430056
SAFETY K L JOHNSON 9-11-89
QUALITY V E BERG 9-11-89
DESIGN K C CONDIE DATE 9-11-89
CHECKED D STANGER DATE 9-11-89
DRAWN JON TULLIS DATE 6/89
RELEASE D STANGER DATE 9-11-89

EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
HEATER COMPONENTS

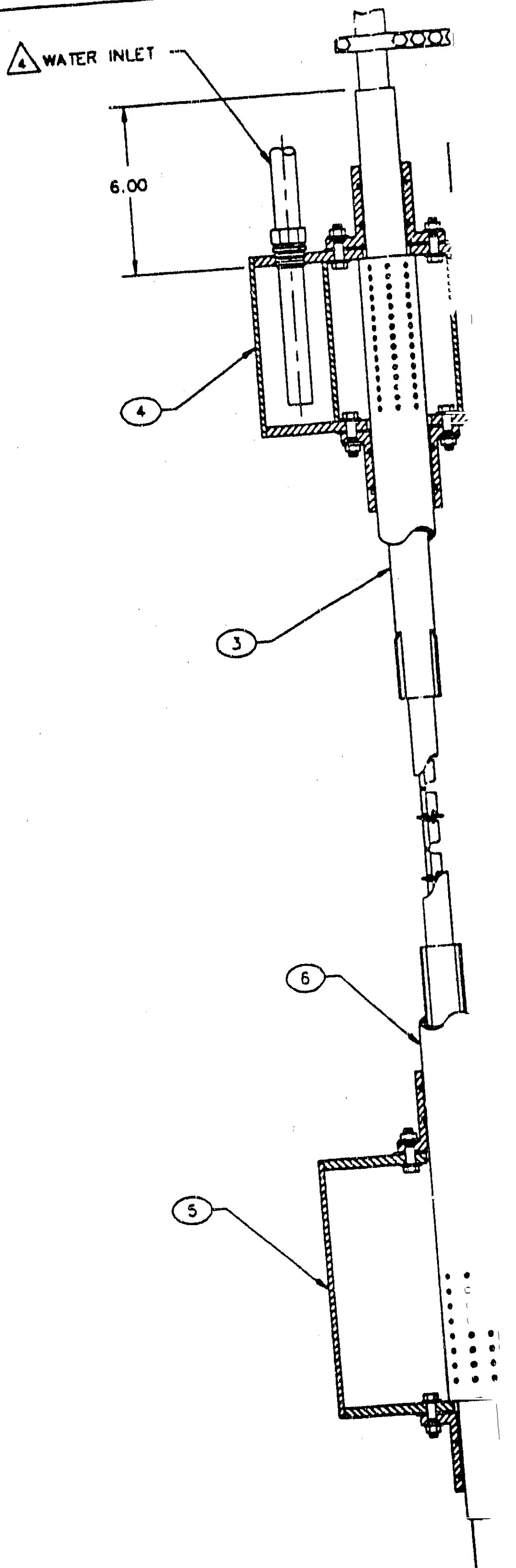
SIZE D 037 0646 481220
DRAWING NO. 430053
REV
SCALE FULL U.N.
SHEET

NOTES.

1. CLEANLINESS PER STD 7022, LEVEL C
2. PRESERVE AND PROTECT PER STD 7020, CLASS II

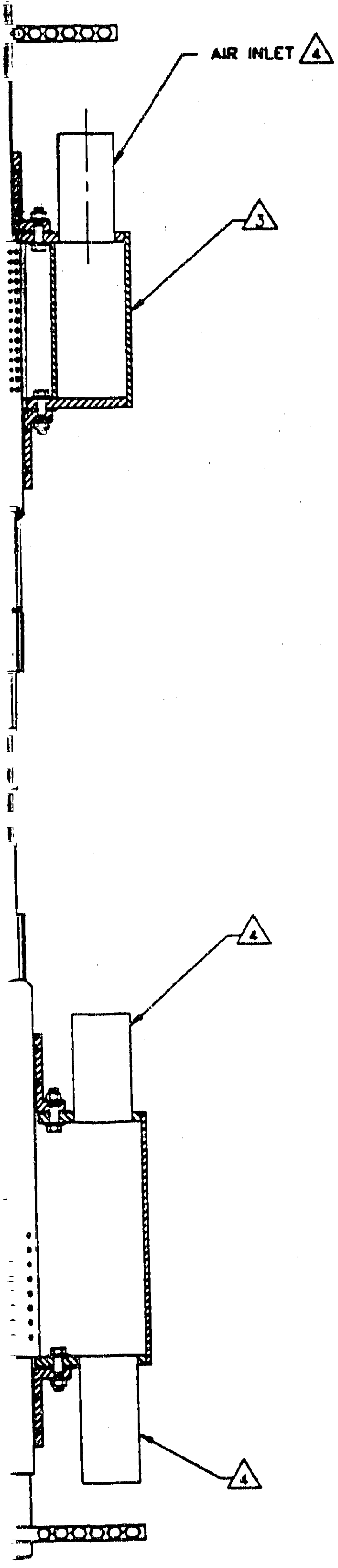
△3 MARK PER STD-7006-2D2 WITH 430054-1 ASS'Y

△4 HOOK UP BY OTHERS SEE DWG 430051



-1 ASSEMBLY

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



QTY. REQD -1	QUAL LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND
1		430050-1	OUTER FLOW SHROUD		6
1		430436-1	LOWER PLENUM ASSEMBLY		5
1		430049-1	UPPER PLENUM ASSEMBLY		4
1		429994-1	HEATER ASSEMBLY		3
					2
	B	-1	ASSEMBLY		1

PARTS LIST

DIMENSIONING AND TOLERANCING ARE AMERICAN NATIONAL STANDARD
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES .X = ±.1
DECIMALS .XX = ±.03
.XXX = ±.010
FRACTIONS ±1/8
ANGULAR ±2°
DO NOT SCALE DRAWING

SAFETY K L JOHNSON	9-11-89
QUALITY V E BERG	9-11-89
DESIGN K G CONDIE	DATE 9-11-89
CHECKED D STANGER	DATE 9-11-89
DRAWN JON TULLIS	DATE 7/89
RELEASED D STANGER	DATE 9-11-89

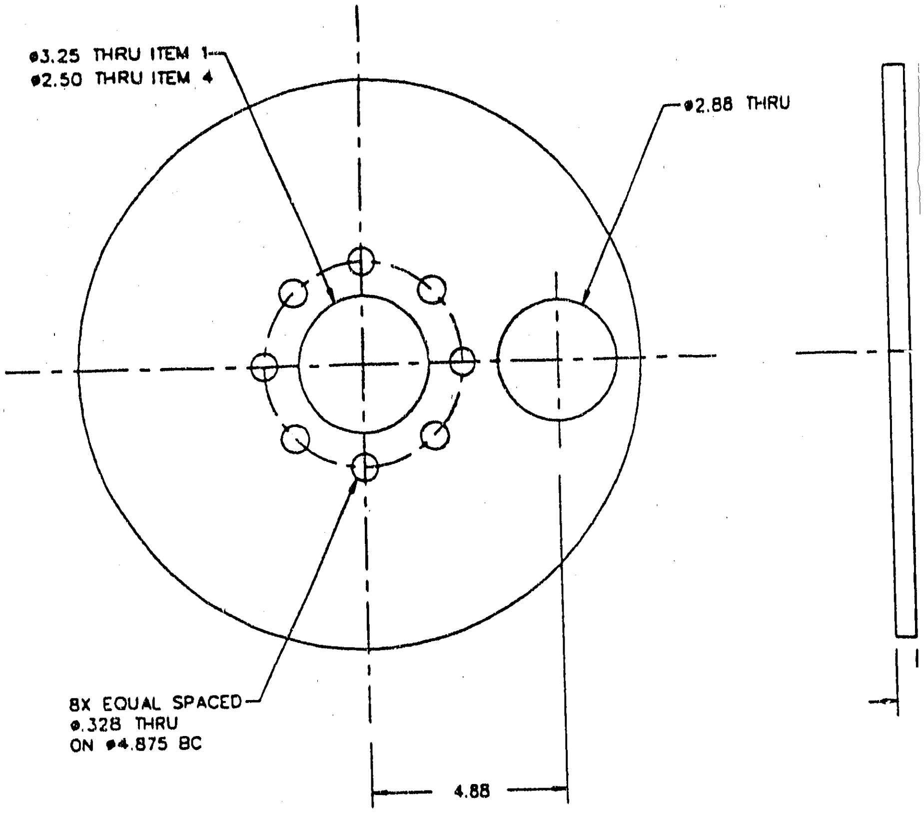
EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
TEST SECTION ASSEMBLY

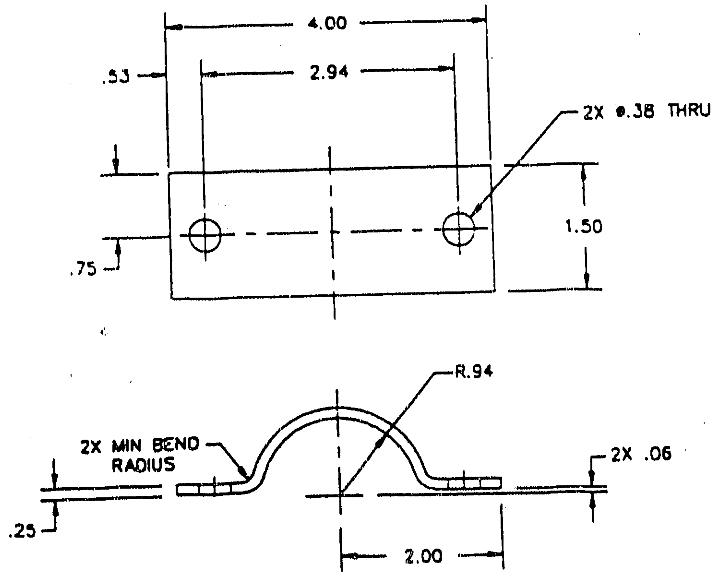
SIZE		DRAWING NO.	REV
D	037 0646 48 220	430054	
SCALE	1/2		

NOTES.

1. PRESERVE AND PROTECT PER STD 7020 CLASS II
2. CLEANLINESS PER STD 7022, LEVEL C
3. MARK PER STD 7006-21 WITH 430055 AND APPROPRIATE DASH NUMBER

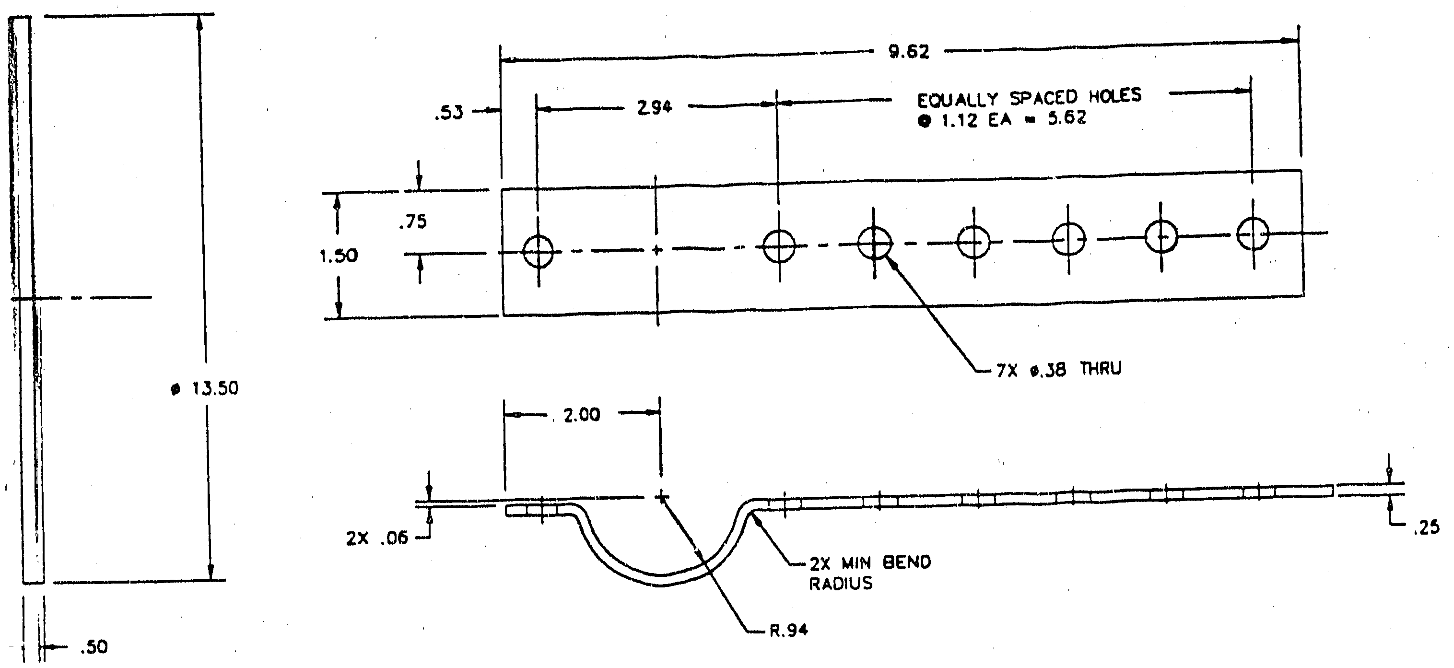


① DETAIL (SHOWN)
④ DETAIL
SCALE 1/2



③ DETAIL

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



② DETAIL

QTY. REQ'D		QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION			ITEM/FIND
		B	-4	BOTTOM PLATE	CLEAR CAST ACRYLIC	COML GR	4
		B	-3	BUS BAR CLAMP	BAR COPPER	ASTM B42	3
		B	-2	BUS BAR			2
		B	-1	PLATE	CLEAR CAST ACRYLIC	COML GR	1

PARTS LIST

DIMENSIONING AND TOLERANCING ARE
AMERICAN NATIONAL STANDARD
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS 125 ✓
DIMENSIONS AND TOLERANCES
ARE IN INCHES
TOLERANCES .X = ±.1
DECIMALS .XX = ±.03
.XXX = ±.010
FRACTIONS ±1/8
ANGULAR ±2°
DO NOT SCALE DRAWING

NEXT ASSEMBLY DWG	429994/430436	
SAFETY	K L JOHNSON	9-11-89
QUALITY	V E BERG	9-11-89
DESIGN	K G CONDIE	DATE 9-11-89
CHECKED	D STANGER	DATE 9-11-89
DRAWN	JON TULLIS	DATE 6/89
RELEASE	D STANGER	DATE 9-11-89

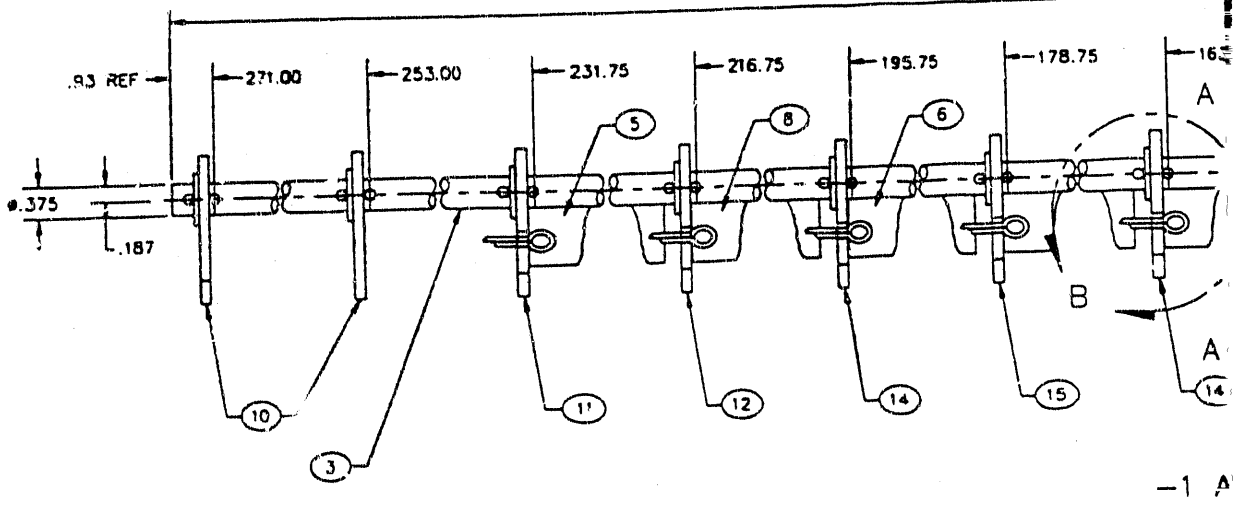
EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL--ECS 2 DRYOUT EXPERIMENT
BUS BAR,LOWER PLENUM PLATE

SIZE	CAGE CODE NUMBER	DRAWING NO.	REV
D	037 0646 48 220	430055	
SCALE 1=1 U.N.			

8 7 6 5

D

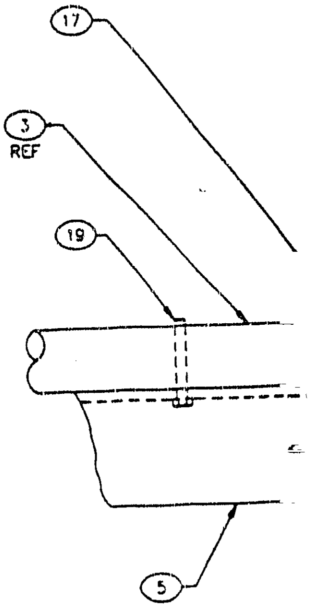


C

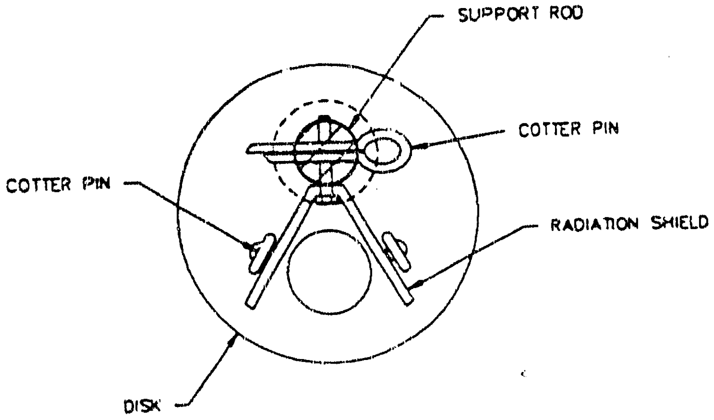
NOTES.

1. PRESERVE AND PROTECT PER STD 7020 CLASS II
2. CLEANLINESS PER STD 7022, LEVEL C

△3 MARK PER STD 7006-21 WITH 430056-1 ASSEMBLY



B



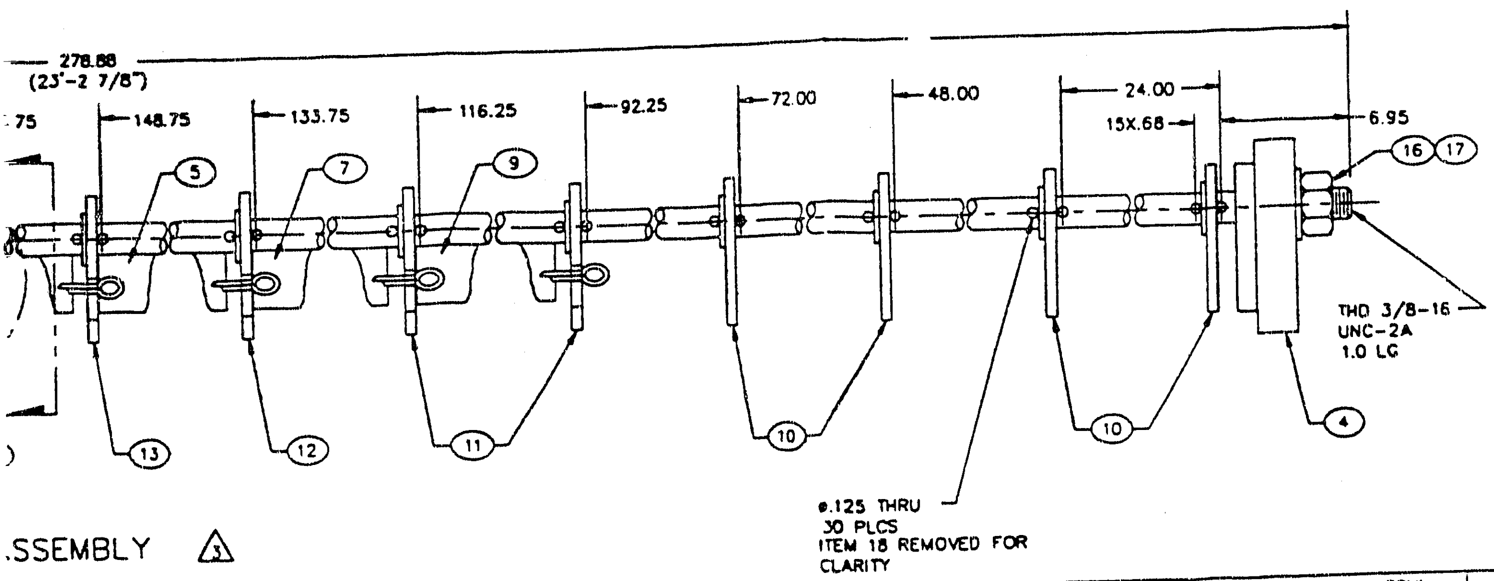
SECTION A-A

COMPONENT ASSEMBLY ORIENTATION

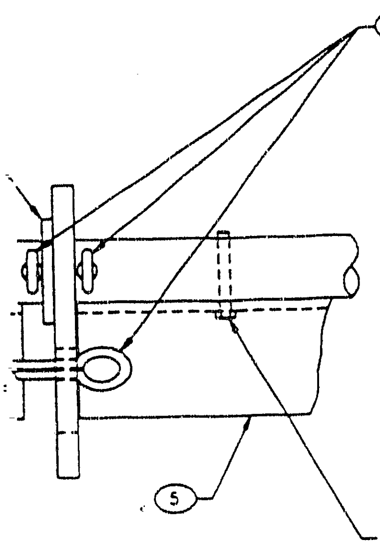
A

8 7 6 5

REV	DESCRIPTION	DATE	APPROVED



SSEMBLY △3



VIEW B

SCALE 2=1

QTY. REQD -1	QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION			ITEM/FIND
30	B		BOLT-HEX HEAD 6-32 UNC-2A 1/2" LG	304 SST	COML GR	19
48			COTTER PIN 1/8" X 3/4"	304 SST	COML GR	18
16	B	98017A200	WASHER, FLAT 3/8 X .062 THK	McMASTER CARR CATALOG #88		17
1	B		NUT-HEX HEAD 3/8-16-UNC-2B	304 SST	COML GR	16
1	B	430053-12	DISK			15
2	B	430053-11				14
2	B	430053-10				13
2	B	430053-9				12
3	B	430053-8				11
6	B	430053-7				10
1	B	430053-6	RADIATION SHIELD			9
1	B	430053-5				8
1	B	430053-4				7
1	B	430053-3				6
4	B	430053-2				5
1	B	430053-1	END PLUG			4
1	B	-3	ROD	BAR 304 SST	ASTM A276	3
						2
	B		-1 ASSEMBLY			1

PARTS LIST

429994

K L JOHNSON 9-11-89

V E BERG 9-11-89

K C CONDIE 9-11-89

D STANGER 9-11-89

TULLIS 6-89

D STANGER 9-11-89

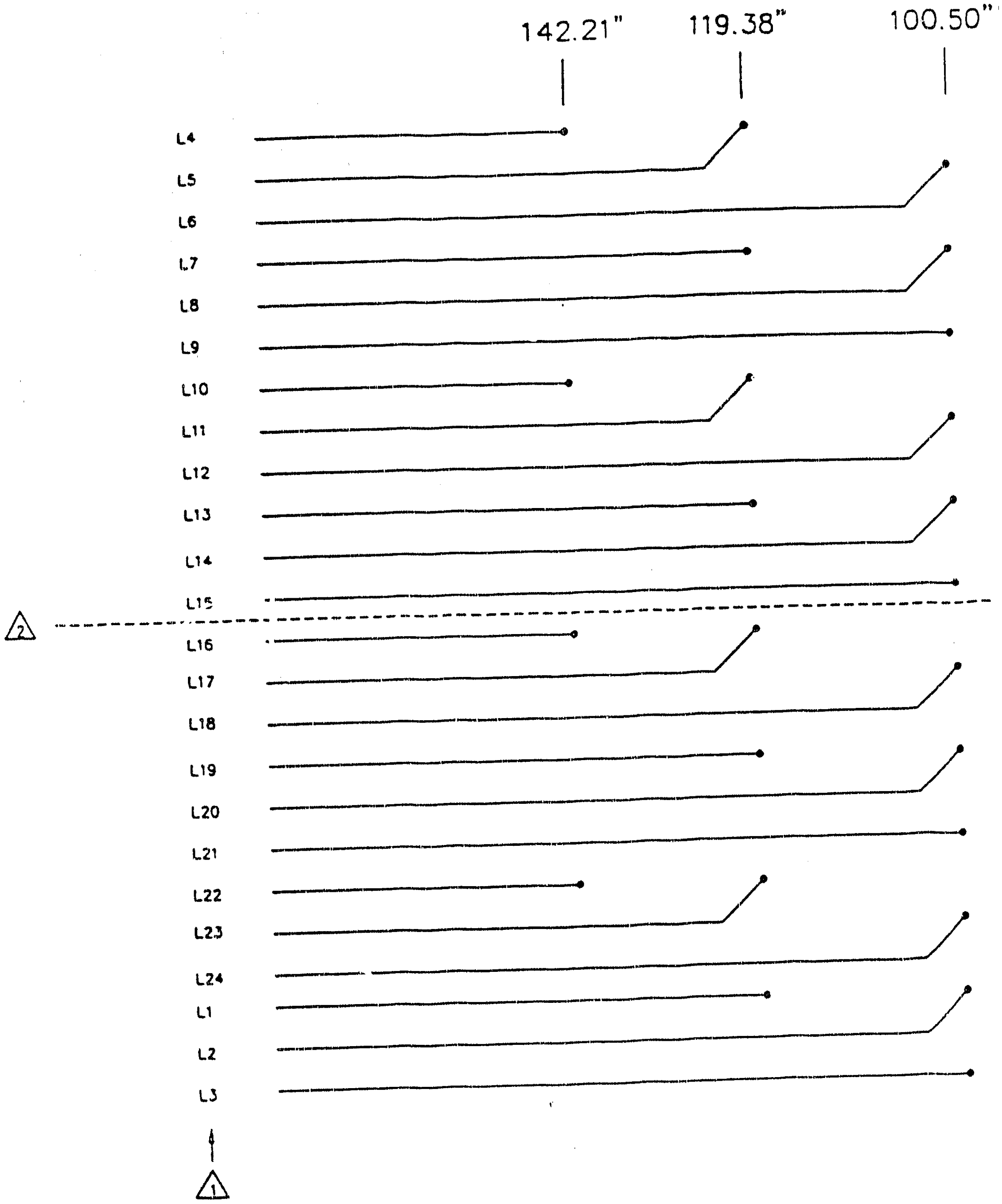
DO NOT SCALE DRAWING

EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
INSIDE HEATER ROD SUPPORT ASSEMBLY

SIZE					DRAWING NO.
D	037	10646	48	220	430056

SCALE 1=1



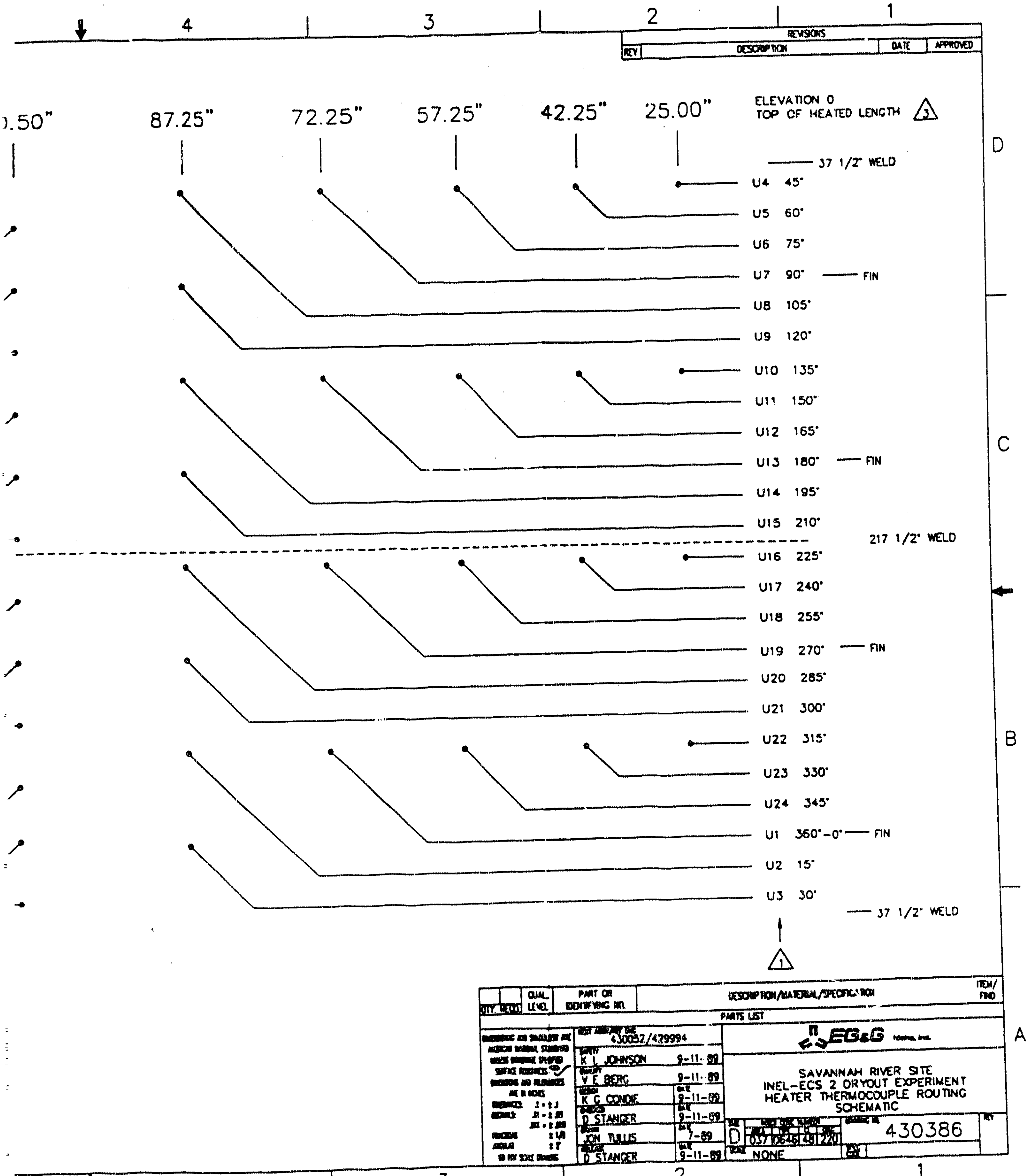
NOTES.

△1 THERMOCOUPLE LEADS TO BE MARKED AND IDENTIFIED BY THIS DESIGNATION.

△2 AS VIEWED FROM BOTTOM OF TEST SECTION GOING CLOCKWISE.

△3 SEE DWG 430052

4. INSTALL PER ASSEMBLY PROCEDURE G132



QTY. REQD		QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION	ITEM/ FIND

PARTS LIST

NEXT ASSY/ANY USE 430052/429994

SAFETY K L JOHNSON 9-11-89

QUALITY V E BERG 9-11-89

DESIGN K G CONDIE DATE 9-11-89

CHECKED D STANGER DATE 9-11-89

DRAWN JON TULLIS DATE 7-89

RELEASE D STANGER DATE 9-11-89

EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
HEATER THERMOCOUPLE ROUTING
SCHEMATIC

SIZE D

037 10646 481 220

DRAWING NO. 430386

SCALE NONE

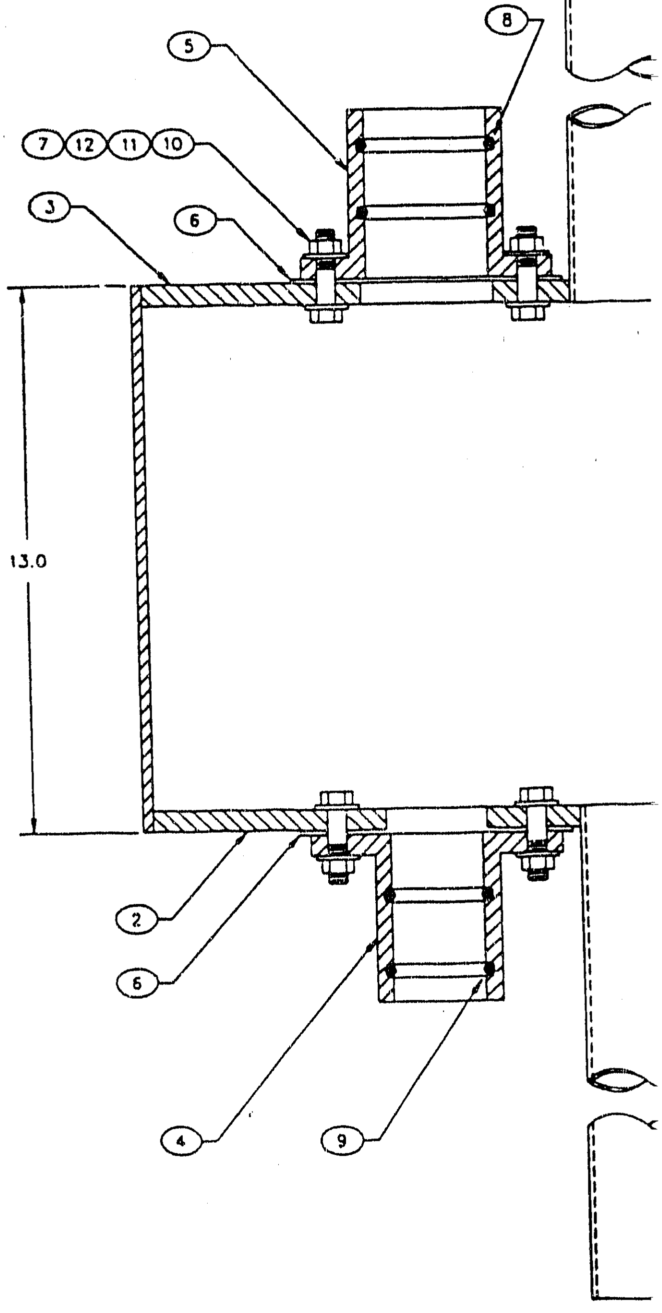
NOTES.

1. SOLVENT WELD JOINT WITH ITEM 14 OR APPROVED EQUAL PER MANUFACTURERS INSTRUCTIONS

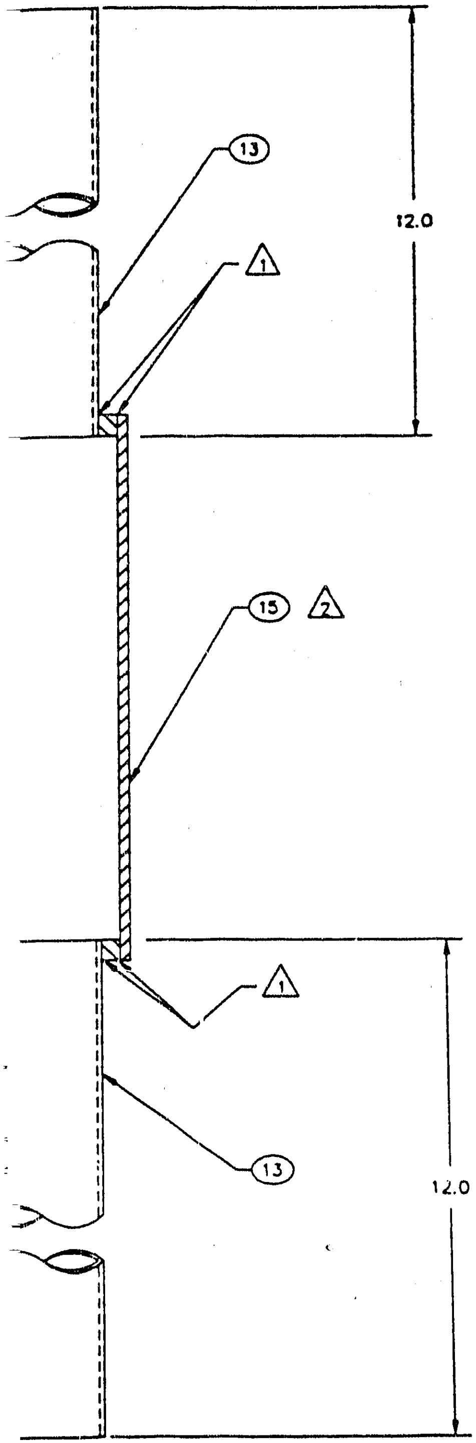
2. MARK PER STD 7006-21 WITH 430436-1 ASSEMBLY

3. PRESERVE AND PROTECT PER STD-7020, CLASS II

4. CLEANLINESS PER STD 7022, LEVEL C



REV	DESCRIPTION	DATE	APPROVED



QTY. REQD	-1	QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND
	AR	B		OUTER HOUSING	TUBE-14" OD X 1/4" WALL CLEAR CAST ACRYLIC COML GR	15
	AR	B	#16	WELD FILLER	WELDON	14
	AR	B		OUTLET TUBES	TUBE-2 7/8 OD X 1/8" WALL CLEAR CAST ACRYLIC COML GR	13
	16	B		WASHER 5/16 X .062 THK	304 SST COML GR	12
	16	B		NUT-HEX 5/16-18-2B UNC		11
	16	B		BOLT-HEX HEAD 5/16-18 UNC-2A 1 1/2 LG		10
	2	B	2-331-515-80	O-RING	PARKER CO.	9
	2	B	2-337-515-80	O-RING	PARKER CO.	8
	16		430050-3	BOLT GASKET		7
	2		430050-2	HUB GASKET		6
	1		430047-2	3 3/4" HUB		5
	1		430047-1	3" OD HUB		4
	1		430055-1	PLATE		3
	1		430055-4	BOTTOM PLATE		2
		B	-1	ASSEMBLY		1

PARTS LIST

430054
K L JOHNSON 9-11-89
V E BERG 9-11-89
K G CONDIE DATE 9-11-89
D STANGER DATE 9-11-89
JON TULLIS DATE 7/89
D STANGER DATE 9-11-89

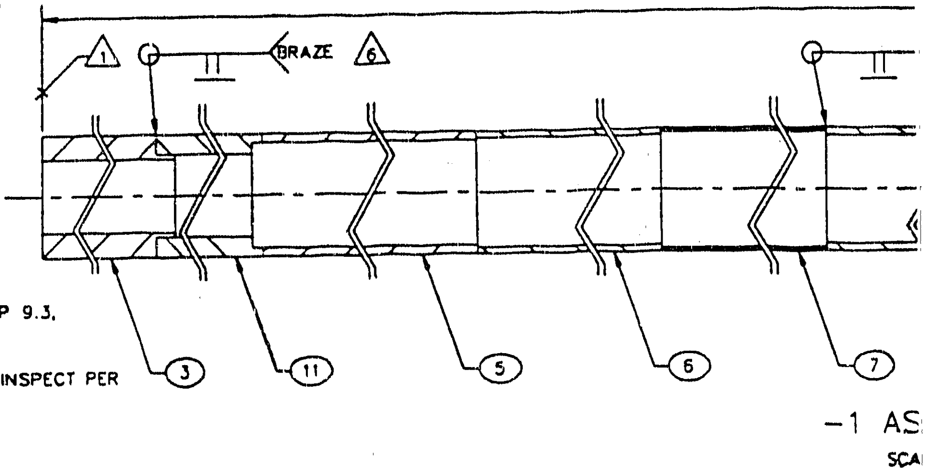
EG&G Idaho, Inc.

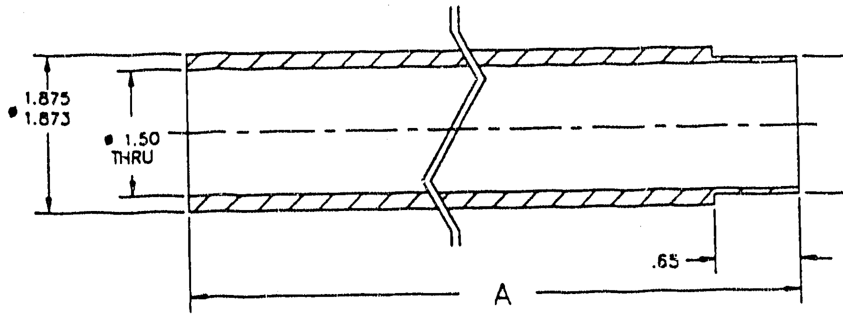
SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
LOWER PLENUM ASSEMBLY

D 037 0646 49 220
SCALE 1=1
430436

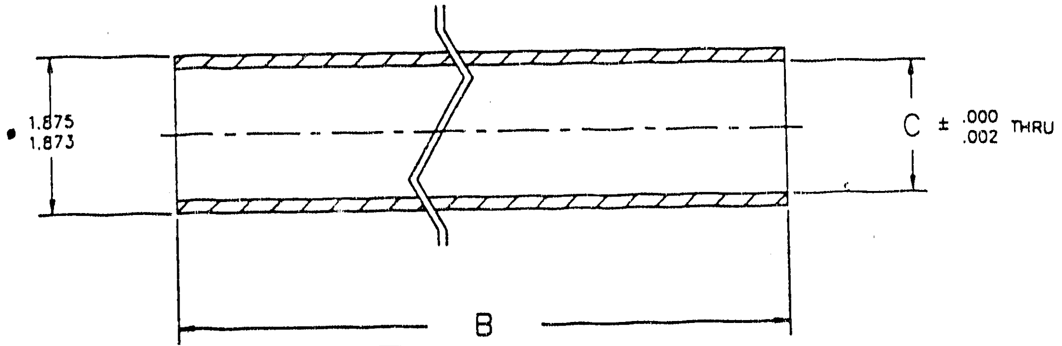
NOTES.

1. IF AFTER FINAL WELDING FABRICATION IS COMPLETED TOTAL LENGTH EXCEEDS 283.0 MACHINE APPROX EQUAL AMOUNTS FROM EACH END TO ACHIEVE 283.00 LENGTH
2. MARK PER STD-7006-21 WITH 430437 AND APPROPRIATE DASH NUMBER
3. PRESERVE AND PROTECT PER STD-7020,CLASS II
4. CLEANLINESS PER STD-7022 LEVEL C
5. WELD PER CP I 4.0, VISUALLY INSPECT PER CP 9.6, APPENDIX 1. LIQUID PENETRANT INSPECT PER CP 9.3, APPENDIX 3, PROCEDURE B-3, CRITERIA APPENDIX IV, C-1.
6. BRAZE PER CP III 12.0, VISUALLY INSPECT PER CP 9.6, APPENDIX 1.



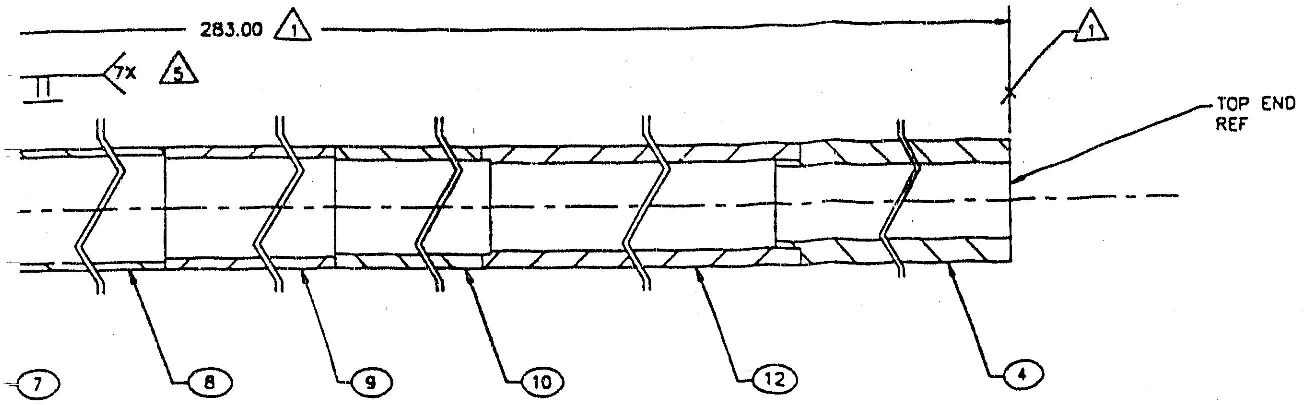


DETAIL	A
-3	42.00
-4	91.00

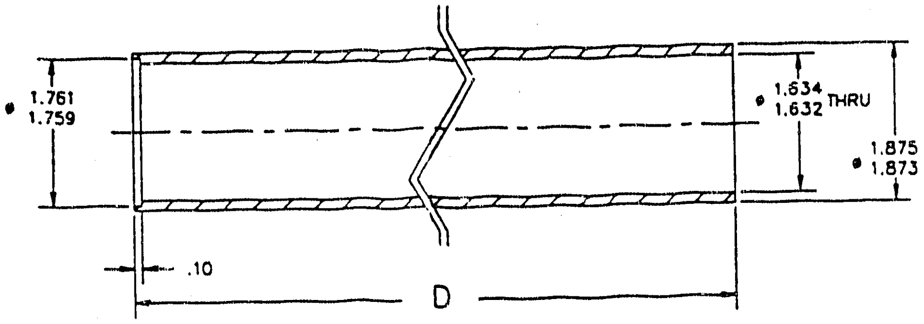


DETAIL	B	C
-5	22.73	1.761
-6	19.13	1.799
-7	15.00	1.805
-8	15.00	1.799
-9	15.00	1.785
-10	14.90	1.761

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



1 ASSEMBLY
SCALE=1/2



DETAIL	D
-11	7.54
-12	42.00

QTY. REQD		QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION			ITEM/ FIND
	1	B	-12	HEATER TUBE	INCONEL 600	ASTM B167	12
	1	B	-11				11
	1	B	-10				10
	1	B	-9				9
	1	B	-8				8
	1	B	-7				7
	1	B	-6				6
	1	B	-5	HEATER TUBE			5
	1	B	-4	CONTACT	BAR OR TUBE-COPPER	ASTM B42	4
	1	B	-3	CONTACT			3
							2
		B	-1	ASSEMBLY			1

PARTS LIST

DIMENSIONS AND TOLERANCES ARE AMERICAN NATIONAL STANDARD
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS ✓
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES .X = ±.1
DECIMALS .XX = ±.03
.XXX = ±.010
FRACTIONS ±1/8
ANGULAR ±2°
DO NOT SCALE DRAWING

429994

SAFETY K L JOHNSON 9-13-89
QUALITY V E BERG 9-13-89
DESIGN K G CONDIE/HR DATE 9-13-89
CHECKED D STANGER DATE 9-13-89
DRAWN JON TULLIS DATE 7/89
RELEASE D STANGER DATE 9-13-89

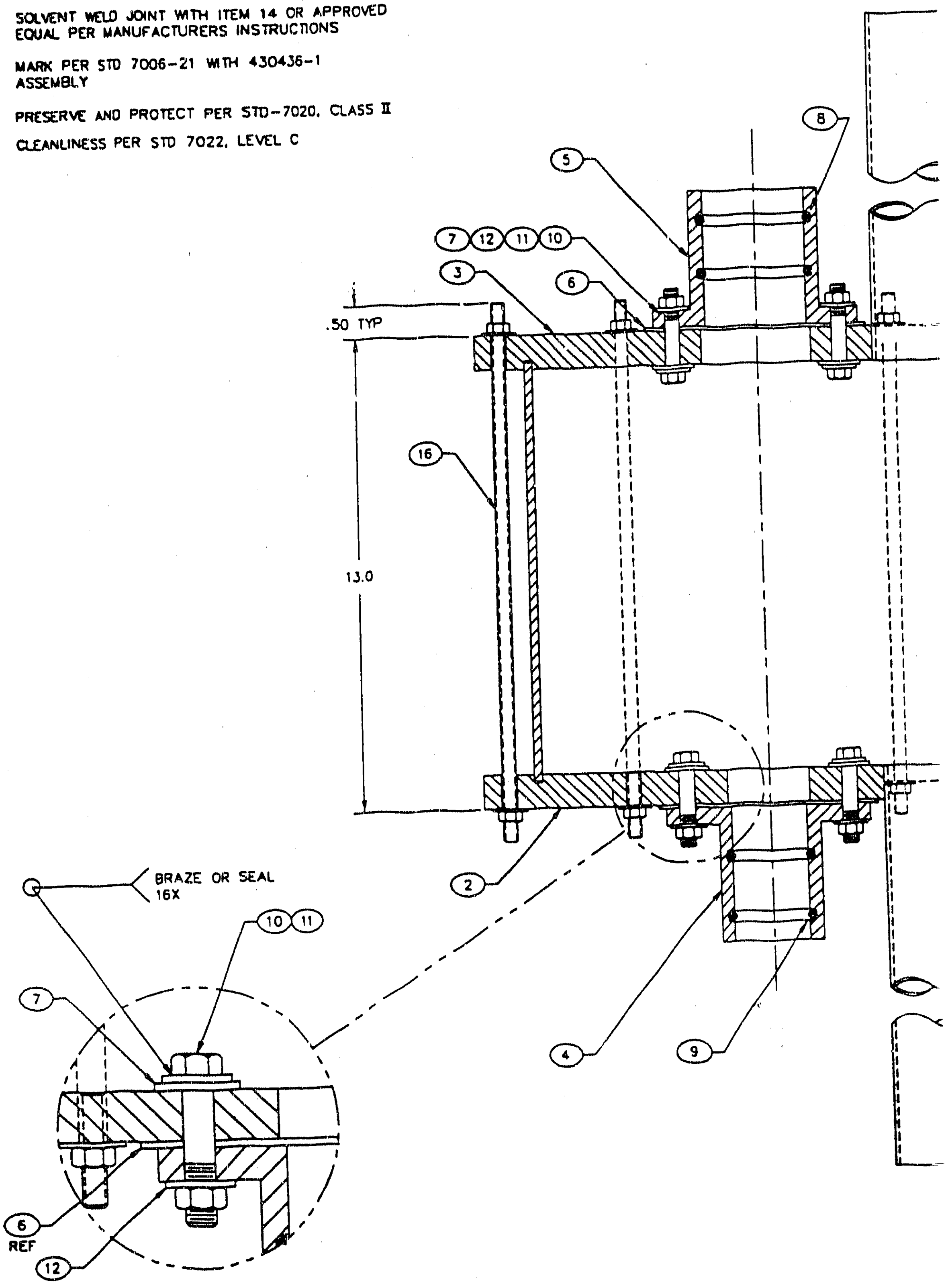
EG&G Idaho, Inc.

SAVANNAH RIVER SITE
INEL-ECS 2 DRYOUT EXPERIMENT
HEATER TUBE ASSEMBLY

SIZE D 037 0646 48 220
DRAWING NO. 430437
REV
SCALE 1=1

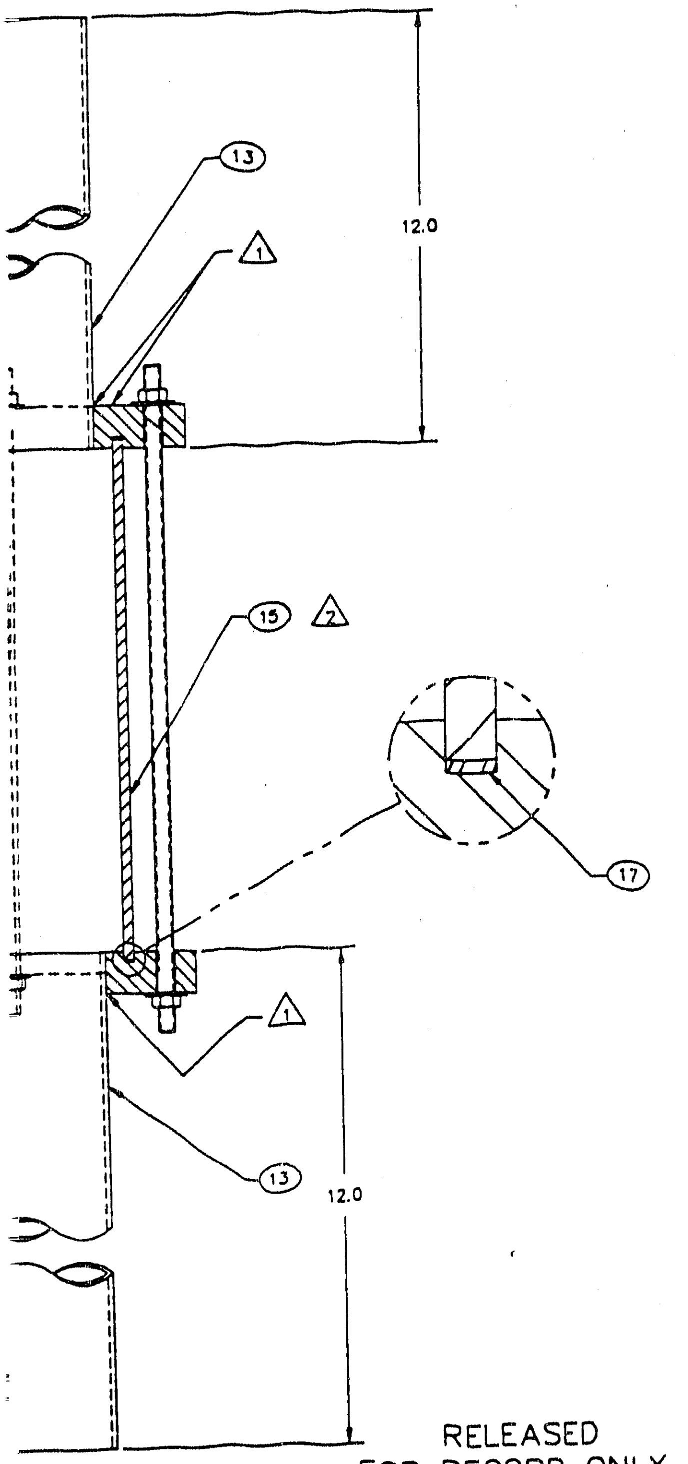
NOTES.

1. SOLVENT WELD JOINT WITH ITEM 14 OR APPROVED EQUAL PER MANUFACTURERS INSTRUCTIONS
2. MARK PER STD 7006-21 WITH 430436-1 ASSEMBLY
3. PRESERVE AND PROTECT PER STD-7020, CLASS II
4. CLEANLINESS PER STD 7022, LEVEL C



REV	DESCRIPTION	DATE	APPROVED

D



C

B

AR	B		GASKET		
AR	B		ROD-5/16-18 UNC-2A	304 SST COML GR	16
AR	B		OUTER HOUSING	TUBE-14" OD X 1/4" WALL CLEAR CAST ACRYLIC COML GR	15
AR	B	#16	WELD FILLER	WELDON	14
AR	B		OUTLET TUBES	TUBE-2 7/8 OD X 1/8" WALL CLEAR CAST ACRYLIC COML GR	13
32	B		WASHER 5/16 X .062 THK	304 SST COML GR	12
32	B		NUT-HEX 5/16-18-2B UNC		11
16	B		BOLT-HEX HEAD 5/16-18 UNC-2A 1 1/2 LG		10
2	B	2-331-515-80	O-RING	PARKER CO.	9
2	B	2-337-515-80	O-RING	PARKER CO.	8
16		430050-3	BOLT GASKET		7
2		430050-2	HUB GASKET		6
1		430047-2	3 3/4" HUB		5
1		430047-1	3" OD HUB		4
1		431748-1	PLATE		3
1		431748-1	BOTTOM PLATE		2
	B	-1	ASSEMBLY		1
-1 QTY. REQD	QUAL. LEVEL	PART OR IDENTIFYING NO.	DESCRIPTION/MATERIAL/SPECIFICATION		ITEM/FIND

PARTS LIST

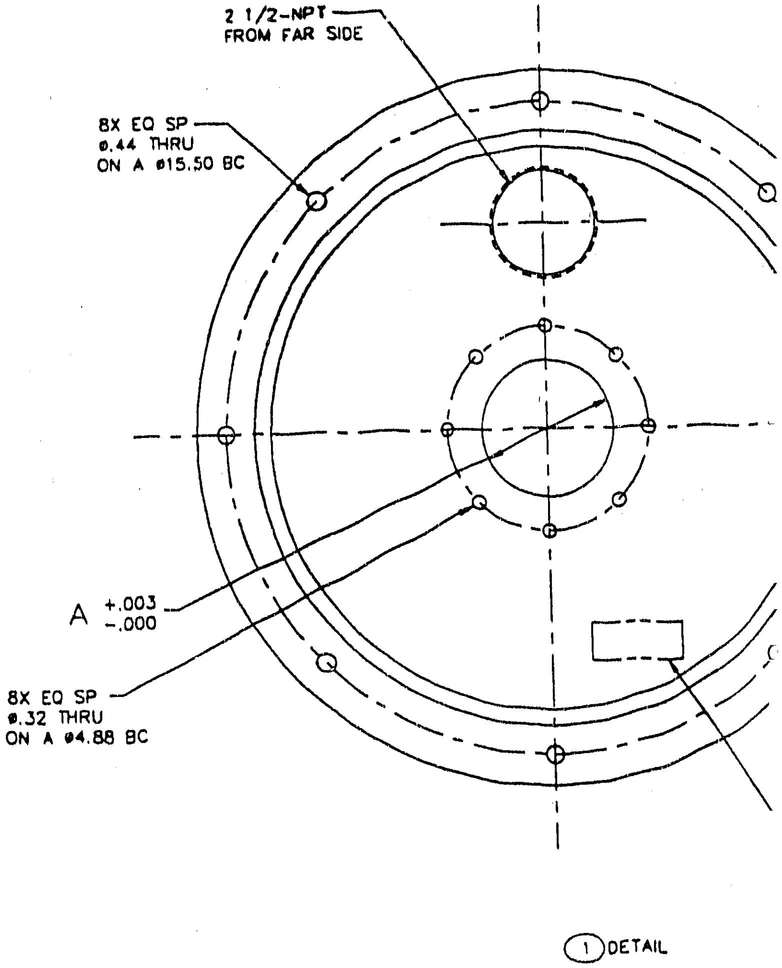
A

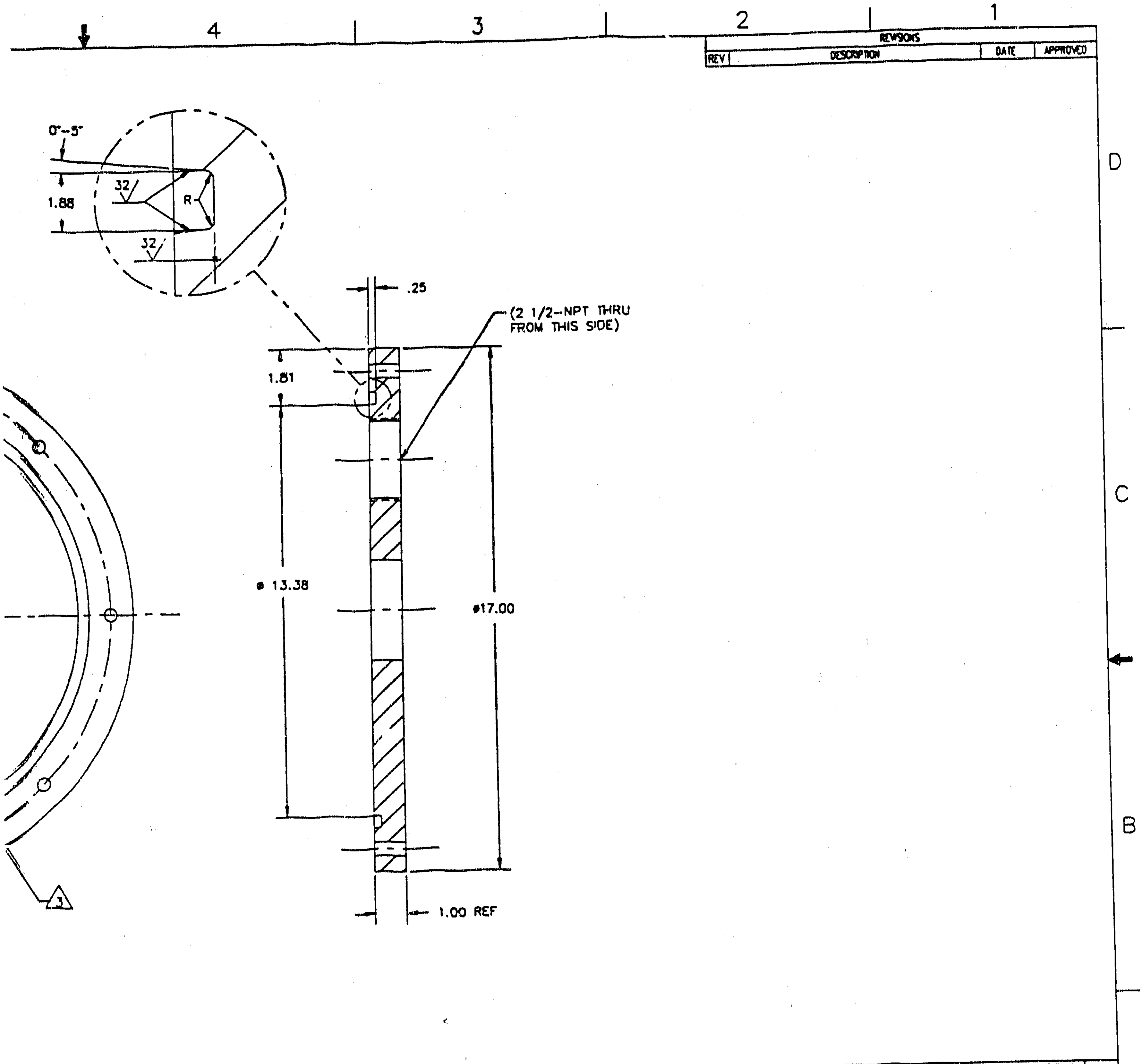
RELEASED
FOR RECORD ONLY
DO NOT FABRICATE
CHECKER J.P.BUSHMAN
DATE 6-13-90

DIMENSIONING AND TOLERANCING ARE AMERICAN NATIONAL STANDARD UNLESS OTHERWISE SPECIFIED SURFACE ROUGHNESS 125 ✓ DIMENSIONS AND TOLERANCES ARE IN INCHES TOLERANCES .X ± .1 DECIMALS .XX ± .06 .XXX ± .010 FRACTIONS ± 1/8 ANGULAR ± 1° DO NOT SCALE DRAWING	NEXT ASSY/REF DWG	EG&G Idaho, Inc.
	DESIGN / DATE	SAVANNAH RIVER SITE INEL-ECS 2 DRYOUT EXPERIMENT LOWER PLENUM ASSEMBLY
	CHECKED / DATE	
	DRAWN JON TULLIS / DATE 7/89	SIZE D / FIND CODE NUMBER 037 0646 48 220 / DRAWING NO. 431747 / REV
	RELEASE J.P.BUSHMAN / DATE 6-13-90	SCALE 1/2 / REC REL

NOTES.

1. REMOVE ALL BURRS AND SHARP EDGES
2. PRESERVE AND PROTECT PER STD 7020 CLASS II
3. MARK PER STD 7006-21 WITH 431748





	AR	B		PLATE	PLATE- 1" THK CLEAR CAST ACRYLIC	COML GR	1
QTY. REQD	QUAL. LEVEL	PART OR IDENTIFYING NO.		DESCRIPTION/MATERIAL/SPECIFICATION			ITEM/ FIND

PARTS LIST

DIMENSIONING AND TOLERANCING ARE AMERICAN NATIONAL STANDARD UNLESS OTHERWISE SPECIFIED SURFACE ROUGHNESS 125✓ DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: .X = ±.1
DECIMALS: .XX = ±.03
.XXX = ±.010
FRACTIONS ±1/
ANGULAR ±2°
DO NOT SCALE DRAWING

NEXT ASSY/REF DWG

DESIGN	DATE
CHECKED	DATE
DRAWN TULLIS	DATE 12-89
RELEASE J.P.BUSHMAN	DATE 6-13-90

EG&G Idaho, Inc.

DUAL HEATED ANNULUS TEST-
OUTER FUEL ASSEMBLY
PLENUM PLATE

SIZE	AREA	TYPE	ID	ORG	DRAWING NO.	REV
D	037	0646	48	220	431748	

SCALE 1/2
DIST CODE REC REL

A

4 3 2 1

RELEASED
FOR RECORD ONLY
DO NOT FABRICATE
CHECKER J.P.BUSHMAN
DATE 6-13-90

Appendix B

Measurements Lists for the ECS-2 and ECS-2c Thermal Excursion Experiments

Appendix B

Measurements Lists for the ECS-2 and ECS-2c Thermal Excursion Experiments

Common practice established during the INEL thermal excursion experiments was to use a shorthand notation called the "DAS tag ID" when referring to a particular measurement. Since this practice was used throughout the body of this report, reference information regarding the relationship between the measurement ID, measurement location, and so forth, is provided in this appendix.

Since excursion experiments were conducted in two different facilities with different inner heaters and instrumentation, two instrument tables are provided. Tables B-1 and B-2 apply to experiments conducted in the ECS-2 and ECS-2b facilities, respectively. Columns in these measurements lists contain the name used for measurement identification, the tag name used in the data acquisition system that is associated with the measurement identification, the type of measurement being made, the physical location of the measurement in the test section (or on the facility), the test section fluid subchannel where the measurement is located (if applicable), and the range over which the measurement was specified to operate. Note that due to instrument failures or electronics problems, not all of the measurements listed on the attached tables may be available for a particular experiment. Appendix I provides a list of known problematic instruments for the excursion tests.

Table B-1. Measurements list for the ECS-2 experiments

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
DP-A-0"-74"	DP_A_03	Differential Pressure	Across Top of Heated Length	A	0-25 kPa
DP-A-74"-150"	DP_A_10	Differential Pressure	Across Bottom of Heated Length	A	0-25 kPa
DP-B-0"-74"	DP_B_03	Differential Pressure	Across Top of Heated Length	B	0-25 kPa
DP-B-74"-150"	DP_B_10	Differential Pressure	Across Bottom of Heated Length	B	0-25 kPa
DP-C-0"-74"	DP_C_03	Differential Pressure	Across Top of Heated Length	C	0-25 kPa
DP-C-74"-150"	DP_C_10	Differential Pressure	Across Bottom of Heated Length	C	0-25 kPa
DP-D-(-65")-0"	DP_D_02	Differential Pressure	Inlet Plenum to Top of Heated Length	D	0-25 kPa
DP-D-0"-19"	DP_D_03	Differential Pressure	Heated Length, 0.0"-18.5", Subchannel D - #1	D	0-5 kPa
DP-D-19"-38"	DP_D_04	Differential Pressure	Heated Length, 18.5"-37.5", Subchannel D - #2	D	0-5 kPa
DP-D-38"-56"	DP_D_05	Differential Pressure	Heated Length, 37.5"-55.5", Subchannel D - #3	D	0-5 kPa
DP-D-56"-74"	DP_D_06	Differential Pressure	Heated Length, 55.5"-74", Subchannel D - #4	D	0-5 kPa
DP-D-74"-94"	DP_D_07	Differential Pressure	Heated Length, 74"-93.5", Subchannel D - #5	D	0-5 kPa

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
DP-D-94"-113"	DP_D_08	Differential Pressure	Heated Length, 93.5"-112.25", Subchannel D - #6	D	0-5 kPa
DP-D-113"-131"	DP_D_09	Differential Pressure	Heated Length, 112.5"-131", Subchannel D - #7	D	0-5 kPa
DP-D-131"-150"	DP_D_10	Differential Pressure	Heated Length, 131"-150", Subchannel D - #8	D	0-5 kPa
DP-D-150"-167"	DP_D_11	Differential Pressure	Heated Length to Outlet Plenum	D	0-5 kPa
DP-PL-(-72")-(-65")	DP_PL_IN	Differential Pressure	Inlet Plenum Level	A	0-5 kPa
DP-PL-161"-173"	DP_PL_OU	Differential Pressure	Outlet Plenum Liquid Level	A	0-5 kPa
DP-SP-0"-71"	DP_SP	Differential Pressure	Stand Pipe Level		0-25 kPa
I-INNER	I_INNER	Current	Inner Heater		0-2700 amps
I-SEMI	I_SEMI	Current	Semiscale Azimuthal Heater		0-2000 amps
P-ATM	P_ATM	Barometric Pressure	Atmospheric Pressure		54-108 kPa
P-A-0"	P_A_0	Absolute Pressure	Top of Heated Length	A	0-172 kPa
P-B-0"	P_B_0	Absolute Pressure	Top of Heated Length	B	0-172 kPa

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
P-C-0"	P_C_0	Absolute Pressure	Top of Heated Length	C	0-172 kPa
P-D-0"	P_D_0	Absolute Pressure	Top of Heated Length	D	0-172 kPa
P-IN-PLENUM	P_IN	Absolute Pressure	Inlet Plenum		0-172 kPa
P-OUT-PLENUM	P_OUT	Absolute Pressure	Outlet Plenum		0-345 kPa
Q-AIR-INLET	Q_A_IN	Air Flowmeter	Inlet to T/S		0-50 SLPM
Q-AIR-OUTLET	Q_A_OUT	Air Flowmeter	Outlet from T/S		0-50 SLPM
Q-H2O-CC	Q_W_CC	Water Flowmeter	Flow thru Lower Plenum Cooling Coil		0-1.5 L/s
Q-H2O-INLET-HI	Q_W_IN_H	Water Flowmeter	Inlet to T/S		0-1.5 L/s
Q-H2O-INLET-LO	Q_W_IN_L	Water Flowmeter	Inlet to T/S		0-.54 L/s
TF-A-045°-025"	TF_A_01	Fluid TC	Coolant Channel 3	A	273-821 K
TF-A-045°-072"	TF_A_02	Fluid TC	Coolant Channel 3	A	273-821 K
TF-A-045°-101"	TF_A_03	Fluid TC	Coolant Channel 3	A	273-821 K

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
TF-A-045°-155"	TF_A_04	Fluid TC	Coolant Channel 3	A	273-821 K
TF-AIR-IN	TF_A_IN	Fluid TC	Air Inlet to T/S		273-821 K
TF-AIR-OUT	TF_A_OUT	Fluid TC	Air Outlet from T/S		273-821 K
TF-B-135°-025"	TF_B_01	Fluid TC	Coolant Channel 3	B	273-821 K
TF-B-135°-072"	TF_B_02	Fluid TC	Coolant Channel 3	B	273-821 K
TF-B-135°-101"	TF_B_03	Fluid TC	Coolant Channel 3	B	273-821 K
TF-B-135°-155"	TF_B_04	Fluid TC	Coolant Channel 3	B	273-821 K
TF-H2O-IN-CC	TF_CC_IN	Fluid TC	Water Inlet to Plenum Cooling Coil		273-821 K
TF-H2O-OUT-CC	TF_CC_OU	Fluid TC	Water Outlet from Plenum Cooling Coil		273-821 K
TF-C-225°-025"	TF_C_01	Fluid TC	Coolant Channel 3	C	273-821 K
TF-C-225°-072"	TF_C_02	Fluid TC	Coolant Channel 3	C	273-821 K
TF-C-225°-101"	TF_C_03	Fluid TC	Coolant Channel 3	C	273-821 K

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
TF-C-225°-155"	TF_C_04	Fluid TC	Coolant Channel 3	C	273-821 K
TF-D-315°-025"	TF_D_01	Fluid TC	Coolant Channel 3	D	273-821 K
TF-D-315°-072"	TF_D_02	Fluid TC	Coolant Channel 3	D	273-821 K
TF-D-315°-101"	TF_D_03	Fluid TC	Coolant Channel 3	D	273-821 K
TF-D-315°-155"	TF_D_04	Fluid TC	Coolant Channel 3	D	273-821 K
TF-H2O-OUT-HX	TF_HX_OU	Fluid TC	Water Outlet from Heat Exchanger		273-821 K
TF-INLET	TF_IN	Fluid TC	Inlet Plenum		273-821 K
TF-OUTLET	TF_OUT	Fluid TC	Outlet Plenum		273-821 K
TF-H2O-IN	TF_W_IN	Fluid TC	Water Inlet to T/S		273-821 K
TF-H2O-OUT	TF_W_OUT	Fluid TC	Water Outlet from T/S		273-821 K
TMI-A-000°-087"	TI_A_a_5	Metal TC	Inner Coolant Wall	A	273-821 K
TMI-A-000°-100"	TI_A_a_6	Metal TC	Inner Coolant Wall	A	273-821 K

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
TMI-A-000°-119"	TI_A_a_7	Metal TC	Inner Coolant Wall	A	273-821 K
TMI-A-030°-100"	TI_A_c_6	Metal TC	Inner Coolant Wall	A	273-821 K
TMI-A-060°-100"	TI_A_e_6	Metal TC	Inner Coolant Wall	A	273-821 K
TMI-B-090°-087"	TI_B_g_5	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-090°-100"	TI_B_g_6	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-090°-119"	TI_B_g_7	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-120°-100"	TI_B_i_6	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-135°-025"	TI_B_j_1	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-135°-042"	TI_B_j_2	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-135°-057"	TI_B_j_3	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-135°-072"	TI_B_j_4	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-135°-087"	TI_B_j_5	Metal TC	Inner Coolant Wall	B	273-821 K

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
TMI-B-135°-119"	TI_B_j_7	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-135°-142"	TI_B_j_8	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-B-150°-100"	TI_B_k_6	Metal TC	Inner Coolant Wall	B	273-821 K
TMI-C-180°-087"	TI_C_m_5	Metal TC	Inner Coolant Wall	C	273-821 K
TMI-C-180°-100"	TI_C_m_6	Metal TC	Inner Coolant Wall	C	273-821 K
TMI-C-180°-119"	TI_C_m_7	Metal TC	Inner Coolant Wall	C	273-821 K
TMI-C-210°-100"	TI_C_o_6	Metal TC	Inner Coolant Wall	C	273-821 K
TMI-C-240°-100"	TI_C_q_6	Metal TC	Inner Coolant Wall	C	273-821 K
TMI-D-270°-087"	TI_D_s_5	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-270°-100"	TI_D_s_6	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-270°-119"	TI_D_s_7	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-300°-100"	TI_D_u_6	Metal TC	Inner Coolant Wall	D	273-821 K

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
TMI-D-315°-025"	TI_D_v_1	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-315°-042"	TI_D_v_2	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-315°-057"	TI_D_v_3	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-315°-072"	TI_D_v_4	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-315°-087"	TI_D_v_5	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-315°-119"	TI_D_v_7	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-315°-142"	TI_D_v_8	Metal TC	Inner Coolant Wall	D	273-821 K
TMI-D-330°-100"	TI_D_w_6	Metal TC	Inner Coolant Wall	D	273-821 K
TMS-040"	TMS_040	Metal TC	Semiscale Heater Rod Cladding		273-1580 K
TMS-066"	TMS_066	Metal TC	Semiscale Heater Rod Cladding		273-1580 K
TMS-094"	TMS_094	Metal TC	Semiscale Heater Rod Cladding		273-1580 K
TMS-112"	TMS_112	Metal TC	Semiscale Heater Rod Cladding		273-1580 K

Table B-1. Measurements list for the ECS-2 experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-channel	Required Measurement Range
TMS-161"	TMS_161	Metal TC	Semiscale Heater Rod Cladding		273-1580 K
V-INNER	V_INNER	Voltage	Inner Heater		0-100 V
V-SEMI	V_SEMI	Voltage	Semiscale Azimuthal Heater		0-200 V
WT-H2O-OUTLET	WT_W_OUT	Weigh Tank	Outlet from T/S		0-2224 N
TOTAL NUMBER OF CHANNELS =	114				100

Table B-2. Measurements list for the ECS-2b experiments

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
DP-A-(-64")-0"	DP_A_1	Differential Pressure	Inlet Plenum to Top of Heated Length	A	0-256 kPa
DP-A-0"-76"	DP_A_2	Differential Pressure	Top of Heated Length	A	0-304 kPa
DP-A-76"-150"	DP_A_3	Differential Pressure	Bottom of Heated Length	A	0-256 kPa
DP-A-150"-163"	DP_A_4	Differential Pressure	Bottom of Heated Length to Top of Outlet Plenum	A	0-52 kPa
DP-C-0"-76"	DP_C_2	Differential Pressure	Top of Heated Length	C	0-304 kPa
DP-C-76"-150"	DP_C_3	Differential Pressure	Bottom of Heated Length	C	0-256 kPa
DP-(-72")-(-64")-PLENUM	DP_PL_IN	Differential Pressure	Across Inlet Plenum (-72" to -64")		0-32 kPa
DP-163"-174"-PLENUM	DP_PL_OU	Differential Pressure	Across Outlet Plenum (163" to 174")		0-44 kPa
DP-SP-0"-120"	DP_SP	Differential Pressure	Across Stand Pipe		0-480 kPa
I-INNER	I_INNER	Current	Inner Heater		0-2700 amps
P-ATMOSPHERE	P_ATM	Absolute Pressure	Building		0-200 kPa
P-B-0"	P_B_0	Absolute Pressure	Top of Heated Length	B	0-200 kPa
P-B-150"	P_B_150	Absolute Pressure	Bottom of Heated Length	B	0-200 kPa

Table B-2. Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
P-B-76"	P_B_76	Absolute Pressure	76" Below Top of Heated Length	B	0-200 kPa
P_B_96"	P_B_96	Absolute Pressure	96" Below Top of Heated Length	B	0-200 kPa
P-IN-PLENUM	P_IN	Absolute Pressure	Top of Inlet Plenum		0-200 kPa
P-OUT-PLENUM	P_OUT	Absolute Pressure	Bottom of Outlet Plenum @ 174"		0-200 kPa
Q-AIR-INLET	Q_A_IN	Air Flowmeter	Inlet to T/S		0-50 SLPM
Q-AIR-OUTLET	Q_A_OUT	Air Flowmeter	Inlet to T/S		0-50 SLPM
Q_LIQ_CC	Q_W_CC	Liquid Flowmeter	Inlet to Lower Plenum Cooling Coil		0-0.3 L/s
Q-LIQ-INLET-HI	Q_W_IN_H	Liquid Flowmeter	Inlet to T/S		0.3-1.5 L/s
Q-LIQ-INLET-LO	Q_W_IN_L	Liquid Flowmeter	Inlet to T/S		0-0.3 L/s
TF-A-045°-052"	TF_A_1	Fluid TC	Coolant Channel 3 @ 52"	A	273-821 K
TF-A-045°-076"	TF_A_2	Fluid TC	Coolant Channel 3 @ 76"	A	273-821 K
TF-A-045°-096"	TF_A_3	Fluid TC	Coolant Channel 3 @ 96"	A	273-821 K
TF-A-045°-117"	TF_A_4	Fluid TC	Coolant Channel 3 @ 117"	A	273-821 K

Table B-2 Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
TF-A-045°-150"	TF_A_5	Fluid TC	Coolant Channel 3 @ 150"	A	273-821 K
TF-A-IN	TF_A_IN	Fluid TC	Inlet Air		273-821 K
TF-A-OUT	TF_A_OUT	Fluid TC	Outlet Air		273-821 K
TF-B-135°-052"	TF_B_1	Fluid TC	Coolant Channel 3 @ 52"	B	273-821 K
TF-B-135°-076"	TF_B_2	Fluid TC	Coolant Channel 3 @ 76"	B	273-821 K
TF-B-135°-096"	TF_B_3	Fluid TC	Coolant Channel 3 @ 96"	B	273-821 K
TF-B-135°-117"	TF_B_4	Fluid TC	Coolant Channel 3 @ 117"	B	273-821 K
TF-B-135°-150"	TF_B_5	Fluid TC	Coolant Channel 3 @ 150"	B	273-821 K
TF-CC-IN	TF_CC_IN	Fluid TC	Inlet to Lower Plenum Cooling Coil		273-821 K
TF-CC-OUT	TF_CC_OU	Fluid TC	Outlet to Lower Plenum Cooling Coil		273-821 K
TF-C-225°-052"	TF_C_1	Fluid TC	Coolant Channel 3 @ 52"	C	273-821 K
TF-C-225°-076"	TF_C_2	Fluid TC	Coolant Channel 3 @ 76"	C	273-821 K
TF-C-225°-096"	TF_C_3	Fluid TC	Coolant Channel 3 @ 96"	C	273-821 K

Table B-2. Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
TF-C-225°-117"	TF_C_4	Fluid TC	Coolant Channel 3 @ 117"	C	273-821 K
TF-C-225°-150"	TF_C_5	Fluid TC	Coolant Channel 3 @ 150"	C	273-821 K
TF-D-315°-052"	TF_D_1	Fluid TC	Coolant Channel 3 @ 52"	D	273-821 K
TF-D-315°-076"	TF_D_2	Fluid TC	Coolant Channel 3 @ 76"	D	273-821 K
TF-D-315°-096"	TF_D_3	Fluid TC	Coolant Channel 3 @ 96"	D	273-821 K
TF-D-315°-117"	TF_D_4	Fluid TC	Coolant Channel 3 @ 117"	D	273-821 K
TF-D-315°-150"	TF_D_5	Fluid TC	Coolant Channel 3 @ 150"	D	273-821 K
TF-HX-OUT	TF_HX_OU	Fluid TC	Outlet of the 10 coil Heat Exchanger		273-821 K
TF-INLET	TF_IN	Fluid TC	Bottom of Inlet Plenum		273-821 K
TF-OUTLET	TF_OUT	Fluid TC	Bottom of Outlet Plenum		273-821 K
TF-W-SP	TF_SP	Fluid TC	StandPipe @ 174" from top of heated length		273-821 K
TF-W-IN	TF_W_IN	Fluid TC	Inlet Water		273-821 K
TMI-A-000°-087"	TI_A_a_5	Metal TC	Inner Coolant Wall @ 87.75"	D/A	273-821 K

Table B-2. Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
TMI-A-000°-100"	TI_A_a_6	Metal TC	Inner Coolant Wall @ 99.75"	D/A	273-821 K
TMI-A-000°-119"	TI_A_a_7	Metal TC	Inner Coolant Wall @ 118.88"	D/A	273-821 K
TMI-A-030°-100"	TI_A_c_6	Metal TC	Inner Coolant Wall @ 99.75"	A	273-821 K
TMI-A-045°-025"	TI_A_d_1	Metal TC	Inner Coolant Wall @ 25"	A	273-821 K
TMI-A-045°-042"	TI_A_d_2	Metal TC	Inner Coolant Wall @ 42.75"	A	273-821 K
TMI-A-045°-057"	TI_A_d_3	Metal TC	Inner Coolant Wall @ 57.75"	A	273-821 K
TMI-A-045°-072"	TI_A_d_4	Metal TC	Inner Coolant Wall @ 72.75"	A	273-821 K
TMI-A-045°-087"	TI_A_d_5	Metal TC	Inner Coolant Wall @ 87.75"	A	273-821 K
TMI-A-045°-119"	TI_A_d_7	Metal TC	Inner Coolant Wall @ 118.88"	A	273-821 K
TMI-A-045°-142"	TI_A_d_8	Metal TC	Inner Coolant Wall @ 141.69"	A	273-821 K
TMI-A-060°-100"	TI_A_e_6	Metal TC	Inner Coolant Wall @ 99.75"	A	273-821 K
TMI-B-090°-087"	TI_B_g_5	Metal TC	Inner Coolant Wall @ 87.75"	A/B	273-821 K
TMI-B-090°-100"	TI_B_g_6	Metal TC	Inner Coolant Wall @ 99.75"	A/B	273-821 K

Table B-2. Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
TMI-B-090°-119"	TI_B_g_7	Metal TC	Inner Coolant Wall @ 118.88"	A/B	273-821 K
TMI-B-120°-072"	TI_B_i_4	Metal TC	Inner Coolant Wall @ 72.75"	B	273-821 K
TMI-B-120°-087"	TI_B_i_5	Metal TC	Inner Coolant Wall @ 87.75"	B	273-821 K
TMI-B-120°-100"	TI_B_i_6	Metal TC	Inner Coolant Wall @ 99.75"	B	273-821 K
TMI-B-150°-042"	TI_B_k_2	Metal TC	Inner Coolant Wall @ 42.75"	B	273-821 K
TMI-B-150°-057"	TI_B_k_3	Metal TC	Inner Coolant Wall @ 57.75"	B	273-821 K
TMI-B-150°-100"	TI_B_k_6	Metal TC	Inner Coolant Wall @ 99.75"	B	273-821 K
TMI-B-150°-119"	TI_B_k_7	Metal TC	Inner Coolant Wall @ 118.88"	B	273-821 K
TMI-C-180°-087"	TI_C_m_5	Metal TC	Inner Coolant Wall @ 87.75"	B/C	273-821 K
TMI-C-180°-100"	TI_C_m_6	Metal TC	Inner Coolant Wall @ 99.75"	B/C	273-821 K
TMI-C-180°-119"	TI_C_m_7	Metal TC	Inner Coolant Wall @ 118.88"	B/C	273-821 K
TMI-C-210°-100"	TI_C_o_6	Metal TC	Inner Coolant Wall @ 99.75"	C	273-821 K
TMI-C-225°-025"	TI_C_p_1	Metal TC	Inner Coolant Wall @ 25"	C	273-821 K

Table B-2. Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
TMI-C-225°-042"	TI_C_p_2	Metal TC	Inner Coolant Wall @ 42.75"	C	273-821 K
TMI-C-225°-057"	TI_C_p_3	Metal TC	Inner Coolant Wall @ 57.75"	C	273-821 K
TMI-C-225°-072"	TI_C_p_4	Metal TC	Inner Coolant Wall @ 72.75"	C	273-821 K
TMI-C-225°-087"	TI_C_p_5	Metal TC	Inner Coolant Wall @ 87.75"	C	273-821 K
TMI-C-225°-119"	TI_C_p_7	Metal TC	Inner Coolant Wall @ 118.88"	C	273-821 K
TMI-C-225°-142"	TI_C_p_8	Metal TC	Inner Coolant Wall @ 141.69"	C	273-821 K
TMI-C-240°-100"	TI_C_q_6	Metal TC	Inner Coolant Wall @ 99.75"	C	273-821 K
TMI-D-270°-087"	TI_D_s_5	Metal TC	Inner Coolant Wall @ 87.75"	C/D	273-821 K
TMI-D-270°-100"	TI_D_s_6	Metal TC	Inner Coolant Wall @ 99.75"	C/D	273-821 K
TMI-D-270°-119"	TI_D_s_7	Metal TC	Inner Coolant Wall @ 118.88"	C/D	273-821 K
TMI-D-300°-072"	TI_D_u_4	Metal TC	Inner Coolant Wall @ 72.75"	D	273-821 K
TMI-D-300°-087"	TI_D_u_5	Metal TC	Inner Coolant Wall @ 87.75"	D	273-821 K
TMI-D-300°-100"	TI_D_u_6	Metal TC	Inner Coolant Wall @ 99.75"	D	273-821 K

Table B-2. Measurements list for the ECS-2b experiments (continued)

Measurement Identification	DAS Tag ID	Measurement Type	Measurement Location	Fluid Sub-Channel	Required Measurement Range
TMI-D-330°-042"	TI_D_w_2	Metal TC	Inner Coolant Wall @ 42.75"	D	273-821 K
TMI-D-330°-057"	TI_D_w_3	Metal TC	Inner Coolant Wall @ 57.75"	D	273-821 K
TMI-D-330°-100"	TI_D_w_6	Metal TC	Inner Coolant Wall @ 99.75"	D	273-821 K
TMI-D-330°-119"	TI_D_w_7	Metal TC	Inner Coolant Wall @ 118.88"	D	273-821 K
V-INNER	V_INNER	Voltage	Inner Heater		0-50 V
Total # of Channels =	96				

Appendix C

Measurement Uncertainty for the ECS-2 Thermal Excursion Tests

Appendix C

Measurement Uncertainty for the ECS-2 Thermal Excursion Tests

An extensive measurement uncertainty analysis was conducted for the measurements and instrumentation used in the test fixture for the thermal excursion experiments. Details of this analysis are documented in Wilkins [Wilkins 1990]. Results of Wilkin's uncertainty analysis for tests conducted in the ECS-2 test fixture are equally applicable for experiments conducted in the ECS-2b fixture since the instrumentation used in the two facilities is essentially the same. A brief summary of the uncertainty analysis results is given here to provide a measure of the uncertainty associated with the data presented in this report.

Wilkins describes the potential error sources and the quantitative contribution of each to the overall uncertainty in various key measurements made during the ECS-2 test series. Those measurements include:

(a) voltage and current to the test section (used to determine the input power to the test)
(b) air and water mass flows
(c) fluid and metal temperatures in the test section
(d) mass-energy balance
(e) absolute and differential pressures at selected points in the test section
(d) contribution of the data acquisition system uncertainty to each of those measurements.

Possible error sources for the measurements were combined by the root-sum-square (RSS) method of summing bias and precision errors, and are given at the 95% (2σ) confidence level. The single exception to this is the metal thermocouple uncertainties, where bias errors were summed algebraically in order to preserve the sign of the dominant bias term. Equations appropriate for computing specific measurement uncertainties (U) are given below. Table C-1 lists low- and high-range uncertainty values for the measured parameters.

Data acquisition system:

$U_{DAS} = \pm 0.11\%$ of range

Power:

$U_{POW} = \pm[(I\,U_E)^2 + (E\,U_I)^2]^{1/2}$

where

$U_E = \pm[(0.11 \text{ volt})^2 + (0.2\%\ E)^2]^{1/2}$

$U_I = \pm[(5.16 \text{ amps})^2 + (1.02\%\ I)^2]^{1/2}$

Since E = R*I and R is approximately a constant (0.0206 ohms), the approximate total uncertainty in the power is

$U_{POW} = \pm[\ 2.34\ \% + (4.50 \times 10^{-8}\ I^2)]^{1/2}\ I$

resulting in a power uncertainty of 1.5 % at 100 kW.

Flow:

Inlet air: $U_q = \pm[(0.586 \text{ SLPM})^2 + (0.95\%\ q)^2]^{1/2}$

Outlet air: $U_q = \pm[(0.677 \text{ SLPM})^2 + (1.50\%\ q)^2]^{1/2}$

Water: $U_q = \pm[(0.0045 \text{ l/s})^2 + (0.37\%\ q)^2]^{1/2}$

where

q = volumetric flow reading (SLPM for air, l/s for water)

Fluid Temperature:

$T \leq 560K$ $U_T = \pm\{(3.33 \text{ K})^2 + [0.1\%\ (T-273) \text{ K}]^2\}^{1/2}$

T>560K $U_T = \pm\{(2.50\ K)^2 + [0.76\%\ (T-273)\ K]^2\}^{1/2}$

Metal Temperature:[1]

T≤560K Upper TCs: $U_T = \pm\{(3.33\ K)^2 + [6\%\ (T-273)\ K]^2\}^{1/2}$
$-[2.102\ K + 10.1\%\ (T-273\ K)]$

Lower TCs: $U_T = \pm\{(3.33\ K)^2 + [6\%\ (T-273\ K)]^2\}^{1/2}$
$-[-1.898\ K + 10.1\%\ (T-273\ K)]$

T>560K All TCs: $U_T = \pm\{(2.50\ K)^2 + [6.05\%\ (T-273)\ K]^2\}^{1/2}$
$-[0.102\ K + 10.1\%\ (T-273\ K)]$

Mass-energy balance:

$$U_Q = \pm[(c_p\ \Delta T\ U_m)^2 + (m\ c_p\ U_{\Delta T})^2]^{1/2}$$

where

$$U_m = \pm[(q\ U_q)^2 + (q\ U_q)^2]^{1/2}$$

$$U_{\Delta T} = \pm[(U_{Tin})^2 + (U_{Tout})^2]^{1/2}$$

Absolute Pressure:

(0-172 kPa): $U_P = \pm 0.40$ kPa

(0-345 kPa): $U_P = \pm 0.80$ kPa

(54-108 kPa): $U_P = \pm 0.126$ kPa (electronic barometer)

Differential Pressure:

---

[1] Bias terms in the metal temperature uncertainty can result in negative uncertainties, indicating the measured temperature reads high.

BLH Transducer: $U_{dP} = \pm[(0.808\%\ RG)^2 + (0.125\ kPa)^2]^{1/2}$

CEC/Genisco Transducer: $U_{dP} = \pm[(0.917\%\ RG)^2 + (0.125\ kPa)^2]^{1/2}$

where

RG = differential pressure reading

References

Wilkins 1990 S. C. Wilkins and R. A. Larson, "Savannah River Site ECS-2 Tests Uncertainty Report," Idaho National Engineering Laboratory Report, EGG-EE-9066, July 1990.

Table C-1. Summary of low- to high-range uncertainty for ECS-2 and ECS-2b measurements

Parameter	Low Range	High Range
Power	±0.15 kW	±1.7 kW
Instantaneous inlet air flow	±1.05 SLPM	±2.32 SLPM
Average inlet air flow	±0.71 gm/min	±0.99 gm/min
Instantaneous outlet air flow	±1.38 SLPM	±3.42 SLPM
Average outlet air flow	±1.15 SLPM	±2.61 SLPM
Water flow	±0.0045 l/s	±0.011 l/s
Fluid temperature	±3.37 K	±4.85 K
Metal temperature	±3.33 K	+33./-89 K
Mass-energy balance	±8.18 kW (±10.2%)	±23.6 kW (±30.3%)
Differential pressure		
BLH transducers	±0.125 kPa	±0.238 kPa
CEC transducers	±0.125 kPa	±0.332 kPa
Absolute pressure		
0 - 172 kPa range	Uniformly ±0.40 kPa	
0 - 345 kPa range	Uniformly ±0.80 kPa	
54 - 108 kPa range	Uniformly ±0.126 kPa	

Appendix D

Calculations Supporting Design/Performance of the ECS-2 Inner Heater

Appendix D

Calculations Supporting Design/Performance of the ECS-2 Inner Heater

Numerical models were used to examine the performance characteristics of the proposed inner heater design before the physical heater was built. This appendix summarizes the models constructed, discusses the performance of the inner heater relative to a production reactor fuel assembly, and presents conclusions of the conduction analysis conducted with these models. Additional analyses of the inner heater design are discussed in Appendix D of Reference [1].

Reference

[1] J. L. Anderson, K. G. Condie, and T. K. Larson, "Downflow Heat Transfer in a Heated Ribbed Vertical Annulus with a Cosine Power Profile (Results from Test Series ECS-2b)," Idaho National Engineering Laboratory Report, EGG-EAST-9144, July, 1990.

SUMMARY

A test apparatus is being designed at INEL that will simulate thermal transient behavior of a Mark 22 assembly with fuel decay heat and low coolant flow conditions. The apparatus design consists of two concentric heated tubes which model the inner and outer Mark 22 fuel rings; downward coolant flow will be introduced in the annulus between the tubes. The purpose is to obtain thermal excursion data for the range of conditions expected in the Mark 22 assemblies during the ECS addition phase of a hypothetical large-break Loss of Coolant Accident. Thermal characterization studies were performed to:

(a) compare the transient response behavior of the test apparatus heated tubes to the Mark 22 fuel rings,
(b) compare maximum temperatures of each test apparatus tube to its corresponding Mark 22 fuel ring, assuming steady-state dryout of one (90^{o}) azimuthal sector and liquid film cooling of the remaining sectors, and
(c) determine adiabatic heatup rates for the test apparatus tubes.

The thermal response characteristics of the outer tube design were determined to be nearly identical to those of the Mark 22 outer fuel ring. The test apparatus response time constant was about 10% longer, and the maximum temperature rise during sector dryout was 2% lower than for its Mark 22 counterpart. The dimensions of the outer tube design and outer fuel ring are nearly the same, and the outer tube electrical heater adds an insignificant amount of thermal mass to the system.

For the inner tube design the response time constant was about 2.4 times as long, and the maximum temperature rise about 14% higher than for the Mark 22 inner fuel ring. The slower response was attributed to the additional thermal mass required for inner tube heater design. The tube thickness design value is considered a reasonable compromise between thermal time constant and maximum temperature rise response characteristics. Increased inner tube thickness would have increased the system thermal mass, thus slowing the response time even further, while decreased thickness would have increased the maximum temperature rise

value. Thus, the selected tube thickness value represents the best match of thermal response characteristics within the constraints of the heater design requirements.

The adiabatic heatup rates represent the maximum rates obtainable with complete apparatus dryout. No credit is taken for azimuthal thermal conduction; hence, the calculated rates are significantly higher than anything expected during the thermal excursion experiments. The values were 37.4 K/s for the inner tube with a heater power of 18.7 kW/ft (44.6 K/s with heater power of 22.4 kW/ft), and 31.5 K/s for the outer tube with a heater power value of 17 kW/ft.

CONTENTS

FIGURES

1. INTRODUCTION

Heat transfer experiments are to be performed at INEL to support the safe operation of the Savannah River Site production reactors. One safety concern is the thermal response of the Mark 22 fuel assemblies during the ECS addition phase of a hypothetical large-break Loss of Coolant Accident (LOCA). The assemblies consist of a series of concentric target and fuel rings that are separated by annular coolant channels, each divided by ribs into four azimuthal sectors, as shown in Figure 1. The phenomenon of interest involves the dryout of one or more (90°) sectors. Uncertainties exist in the prediction of dryout incipience and the requirements for successful rewet of a dry surface, given the assembly boundary conditions of inlet coolant flow and fuel decay heat. Experimental studies are desired to obtain thermal excursion data for the range of conditions expected in the Mark 22 assemblies during the ECS addition phase of the hypothetical LOCA.

A test apparatus is being designed at INEL that will simulate the thermal transient behavior of the inner and outer fuel rings and the enclosed coolant annulus (designated as Channel 3 of Figure 1).[1] It will have the capability to heat both the inner and outer walls of the coolant annulus. Additionally, it is to be constructed of reactor "typical" materials, i.e., aluminum. It will use an existing design for the inner heated tube that simulates a Mark 22 inner fuel; an outer heated tube is being added to simulate the outer fuel. Figure 2 shows the proposed configuration of the test apparatus.

Calculations were performed to characterize the expected thermal behavior of the test apparatus heated tubes, and to compare the transient response characteristics to those of Mark 22 assembly fuel rings. The purposes of the analyses were: (a) to ensure that the test apparatus inner and outer fuel rings will exhibit prototypical transient thermal behavior during thermal excursion tests, and (b) to provide maximum heatup rate and temperature information to be used as guidance for termination criteria for the thermal excursion experiments. Details of the studies are described in the following paragraphs.

2. SCOPE OF THERMAL STUDIES

The thermal calculations included in the present document are outlined below:

1. Transient thermal time constants were estimated for two-dimensional (r-θ) finite difference models of the test apparatus outer heated tube and the Mark 22 outer fuel ring. These models will be collectively designated "outer tube models." The calculations were performed using the ABAQUS computer code. The results[2] indicated the desirability for a thinner-walled outer tube than was provided in the initial design. Following the incorporation of this modification into the design, the calculation was repeated. Results of the final calculations are presented.

2. Similar calculations were also performed for r-θ models of the test apparatus inner tube and the Mark 22 inner fuel, collectively designated as "inner tube models." This characterization was for information only, because an existing inner heated tube design will be used for the experiments.

3. Steady-state temperatures were calculated for the inner and outer tube models, with heat source values representative of maximum test apparatus power and coolant convection boundary conditions representing dryout of one (90°) sector.

4. Adiabatic heatup rates were estimated for the test apparatus heated tubes.

Items 1, 2, and 3 were accomplished using the ABAQUS three-dimensional, finite element computer code, with a two-dimensional thermal mesh created using PATRAN. Item 4 used simple hand calculations. The details of the thermal calculations, the results, and the conclusions of the effort are contained in the following sections.

3. TWO-DIMENSIONAL THERMAL CALCULATIONS

3.1 Computer Codes

3.1.1 ABAQUS Finite Element Code

The two-dimensional transient thermal response calculations were performed using the ABAQUS[3] computer code, using a finite element mesh generated using PATRAN Plus.[4] ABAQUS is a general purpose, production oriented, finite element code. It is simple to use and has capabilities for a wide range of nonlinear applications, one of which is the solution of three-dimensional, transient heat conduction, or thermal diffusion, problems. Steady-state solutions are obtained by direct integration of the spatial partial differential equation. Transient solutions are obtained by integrating the temporal/spatial equation with the backward difference operator (modified Crank-Nicholson method).

3.1.2 PATRAN Computer-Aided Engineering System

PATRAN Plus is an open-ended, general purpose, three-dimensional computer aided engineering software system. It includes the capabilities for generating finite element meshes in cartesian, cylindrical, or spherical coordinate systems, using automated command sequences. Element material properties, volumetric heat generation rates for elements, and surface heat flux values and convection heat transfer coefficients for edges can all be specified. Translation of files from PATRAN to ABAQUS and back are done with PATABA and ABAPAT, respectively, which are supplied with the PATRAN Plus software. The ABAQUS and PATRAN Plus software packages used for the calculations comply with EG&G Quality Manual Section QP-21, Computer Software Configuration Management.[5] In addition, Hawkes performed verification and benchmark calculations using these software packages.[6] Results showed that ABAQUS and PATRAN produced the correct solutions to heat transfer problems when installed on INEL computers.

3.1.3 Calculational Sequence

The sequence of calculational steps is shown in Figure 3. PATRAN was used to generate the model finite difference mesh, using input values for major dimensional values (i.e. radii of inner and outer surfaces and rib corner coordinates). The command sequence used to create the desired model is stored in the ( ).ses file; the ( ).dat file contains the binary representation of the current model plus a number of flags which control various display options. The completed model was written to a "neutral," or interface, file, the format of which is described in Chapter 29 of the PATRAN Plus User Manual.[3] The neutral file was input to a translator (PATABA) that converted the model into the format required for ABAQUS. Present translator capabilities are limited to conversion of node coordinates, making node/element associations, and assigning material/property information to element groups. This information forms the dimensional structure of the ABAQUS input deck.

Model boundary conditions, material property tables, and transient control information were entered manually into the ABAQUS [( ).inp] deck, as shown in Figure 3. The boundary conditions (film heat transfer coefficients and heat sources) are specified by: (a) input cards specifying the boundary location and type, and (b) subroutines assigning the value. The input cards were generated by the simple Fortran programs CONTRAN2, SHEAT, AND VHEAT. CONTRAN2 is used for surfaces with film heat transfer coefficient boundary conditions, and is maintained as a controlled document in the E&ST Software Index per E&ST Group Standard Practice 4.0. SHEAT and VHEAT are versions of CONTRAN2 slightly modified to generate appropriate cards that specify distributed heat sources for element surfaces or volumes. Listings for SHEAT and VHEAT are contained in Appendix A; these two programs are not controlled versions, but were shown to produce the correct boundary conditions via spot checks and card-to-card consistency checks. The subroutines which assign values to the boundaries are named FILM and DFLUX, and specify convection and heat source values, respectively, as a function of azimuthal angle and transient time. These values are applied to the model elements as specified by the input cards described above. Material property tables and time step control parameters were added to the ABAQUS input deck. The final step was to change the element designations from the type supplied by PATRAN (S4R5) to diffusion-continuum, 2-dimensional, 4-node (DC2D4), which is recognized by ABAQUS as a heat transfer element. The ABAQUS finite element code was then used to obtain the transient thermal solutions.

As shown in Figure 3, three methods are available for obtaining plots. The mesh representation can be plotted directly, as can any variable written to ( ).fil. For the present application, the most useful directly-plotted information was the temperature response.

The method for obtaining color fringe plots required translating the ( ).fil information back to PATRAN-compatible form. Again, the translation between the two major software items is not complete, and manual steps were required to supplement the translation. The ABAQUS results file is written using internal data management routines in order to minimize computer I/O cost and disk storage requirements. The ABAQUS documentation offers sample coding, the purpose of which is to convert the results file into ASCII format: i.e., to the ( ).fin file. The implementation of this coding is the CONVERT program. The ABAPAT translator was then used to obtain a PATRAN-compatible file containing the nodal temperature information required for the color fringe plots.

The third plotting method used the Lotus 1-2-3 PC software package, which is capable of performing mathematical manipulations (e.g., logarithms and least-squares linear fitting) of nodal temperature history data. The translation was performed using TREAD, another implementation of ABAQUS sample coding. The data were then downloaded to the PC and input to the 1-2-3 spreadsheet program. The thermal time constants were obtained using this procedure.

3.2 Test Apparatus Heated Tube and Mark 22 Fuel Ring Models

Two-dimensional (r-θ) transient thermal response calculations were made to compare the thermal responses of the test apparatus outer heated tubes and the Mark 22 assembly fuel rings. For each calculation, models of the test apparatus tube and the corresponding Mark 22 fuel ring were included on the same input deck so the results of the calculation could easily be compared. Figure 4 shows the finite difference mesh models used for the calculation; the top 90° section represents the test apparatus inner and outer tubes, and the bottom 90° section represents the fuel rings of Mark 22 assembly. Note there is no thermal connection between the two model sections.

3.2.1 Outer Tube Models

The Test Apparatus outer tube is T6061 aluminum tubing with vertical thermocouple grooves every 15° around the outer circumference. A heat flux boundary condition is applied to the outer surface using etched foil heaters, which consist of a thin (0.005-in.) Inconel strip sandwiched between two 0.010-in.-thick mica sheets. An aluminum sheet, surrounding the tube, forms a bridge across the thermocouple grooves to prevent local overheating of the Inconel. The original design specified a 1.375-inch tube inside radius, a wall thickness of 0.125 in., and a 0.032-in. aluminum sheet. This design was modified based on results of a preliminary thermal response calculation that indicated the need for a thinner tube. The final dimensions, based on the 1.375-in. inside radius, were a wall thickness of 0.074 in. and an aluminum sheet thickness of 0.016 in. The foil heaters were assumed to contribute a negligible amount to the thermal mass of the outer tube, and were omitted from the model. The Mark 22 outer fuel model was based on the dimensions in the Hydraulics Manual,[7] and consists of the fuel tube portion from the log mean radius inward.

The derivations of dimensional values for nodalization, heat flux boundary conditions, etc., required to support the PATRAN and ABAQUS input values are in Appendix B. The PATRAN "session" files to create the inner tube models are in Appendix C. Heat addition rate for the test apparatus outer tube was 240 kW/m^2, based on maximum heater power of 22.4 kW. This was an early design value; the present maximum heater power is 18.7 kW.[1] The Mark 22 model had a symmetry boundary at the log mean radius and included a uniformly distributed heat source value of 225.2 MW/m^3; this produces the same steady-state heat flux at the inside surface as the 240 kW/m^2 heat flux value; thus, the two heat sources were equivalent.

3.2.2 Inner Tube Models

The test apparatus inner tube design is the same one to be used for the ECS-2 thermal excursion experiment. It has a heated T6061 aluminum tube with a 2.211-in. outside diameter and a 0.095-in. wall thickness. Four ribs are affixed to the outer surface (at 90° intervals) and vertical thermocouple grooves are machined into the inner circumference, spaced 15° apart. The cross-section drawing, which shows the above details, is in the EOS.[1] Details of the rib dimensions and arrangement are in drawing 430052.[8] Inside the tube is a MACOR ceramic insulator surrounding an Inconel tube heater, which has an axially-varying wall thickness to simulate a non-uniform axial flux profile. The Inconel heater dimensions are taken from drawing 430437[9] and correspond to axial location 5, the location of maximum heat flux. The corresponding Mark 22 inner fuel model was again based on the dimensions in the Hydraulics Manual, and consists of the portion from the log mean radius outward.

As with the outer tube models, the derivation of the values used to generate the inner tube models is in Appendix B, and the PATRAN "session" files that create the outer tube models are in Appendix C. The heat generation rate for the test apparatus inner tube was 427.3 MW/m^3, based on a maximum linear heat generation rate of 17 kW/ft. The corresponding value for the Mark 22 inner fuel ring was 207.8 MW/m^3.

3.2.3 Initial and Boundary Conditions

The initial condition for the coolant channel surface of each model was a heat transfer coefficient representative of forced convection to a liquid falling film at 10 gpm flowrate (assumed typical of annulus low-flow ECS conditions), and 311K. The calculation of this heat transfer coefficient is in Appendix B of Reference 2; the value was 8800 W/m^2-K. A steady-state solution was obtained for this "wetted" condition. A transient condition was then initiated by setting the convection heat transfer coefficient on half (45°) of each section to a low value (7.6 W/m^2) to represent dryout of one annular sector. The calculations were continued until a new steady-state condition was achieved.

3.3 Results of Outer Tube Comparison

The thermal transient behavior of the test apparatus outer and inner tube models were compared to the corresponding models for the Mark 22 fuel rings for conditions simulating dryout of one annular sector. Because of the dryout boundary condition, the behavior of the two models is dominated by azimuthal heat conduction. The one-dimensional, transient heat conduction equation provides an approximate description of the response:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

where

T is temperature,
x is location along the azimuthal direction,
t is time, and
α is the thermal diffusivity of the material.

Assume a solution of the form:

$$T = f(t) \cdot g(x) \tag{2}$$

Substituting (2) into (1) gives:

$$f(t) \cdot g''(x) = \frac{1}{\alpha} f'(t) \cdot g(x)$$

or

$$\frac{g''(x)}{g(x)} = \frac{1}{\alpha}\frac{f'(t)}{f(t)} \tag{3}$$

If x and t are independent, the only way to satisfy the equation is for each function to be constant:

$$\frac{f'(t)}{f(t)} = \alpha \cdot \frac{g''(x)}{g(x)} = \alpha \cdot \beta^2. \tag{4}$$

where the form of Eqn. (3) suggests that the constant is some multiple of α. For any fixed location on the models, the thermal response is approximately described by:

$$f = C_1 \; e^{\alpha\beta^2 t}.$$

Using the initial and final conditions of the problem gives:

$$\frac{T_f - T(t)}{T_f - T_i} = e^{-t/\tau} \qquad (5)$$

where

$T(t)$ is the transient thermal response,

T_i is the initial temperature,

T_f is the final temperature, and

τ is the thermal time constant.

The linear form of this equation is

$$\ln\,[T_f - T(t)] = t/\tau + \ln\,[T_f - T_i] \qquad (6)$$

Figures 5 and 6 show the thermal responses of the outer tube models for the location at the center of the dryout patch (the symmetry boundary at the 0° azimuthal position). Figure 5 is temperature versus time, and Figure 6 shows $\ln\,(T_f - T)$ versus time and the corresponding least-squares fitted lines for calculated temperatures at the center of the dryout patch (0°).

The regression results were, at the center of the dryout region:

Test Apparatus : $\ln\,(722.51 - T) = -t\,/\,7.69 + \ln\,(416.98)$

Mark 22: $\ln\,(731.07 - T) = -t\,/\,7.02 + \ln\,(414.45)$

Hence, the thermal time constants were:

Test Apparatus	7.7 s
Mark 22	7.0 s

The results of the calculation for steady-state maximum temperature with dryout conditions were:

Test Apparatus	722 K
Mark 22	731 K

The steady-state temperatures of the test apparatus with the dryout boundary condition were nearly identical to those calculated for the Mark 22 outer fuel ring; the temperature rise of the test apparatus model was 98% of that calculated for the Mark 22 model. The thermal time constants also agreed closely; the test apparatus response was slower because of the larger thermal mass and lower thermal conductivity of the T6061 test apparatus tube compared to U-Al (fuel) and aluminum (cladding) used in the Mark 22 model.

3.4 Results of Inner Tube Comparison

Figures 7 and 8 show the thermal responses of the inner tube models for the location at the center of the dryout patch (the symmetry boundary at the 0° azimuthal position). Figure 7 shows temperature versus time, and Figure 8 shows ln (T_f - T) versus time. The corresponding linear least-squares fitted equations are:

Test Apparatus : $\ln(517.74 - T) = -t / 10.04 + \ln(141.25)$

Mark 22: $\ln(497.22 - T) = -t / 4.14 + \ln(155.19)$

Hence, the thermal time constants were:

Test Apparatus	10.0 s
Mark 22	4.1 s

The results of the calculation for steady-state maximum temperature with dryout conditions were:

Test Apparatus	594 K
Mark 22	566 K

The steady-state temperatures of the test apparatus with the dryout boundary condition are slightly higher than for the Mark 22 inner fuel ring. (Total transient temperature rise is about 14% higher for the test apparatus.) However, the thermal response of the test apparatus is significantly slower. The difference in temperature rise is due to the difference in thermal conductivity of T6061 aluminum and that of the Mark 22 fuel and clad materials. The slower response is because of the mass of the Inconel heater and the MACOR insulating tube; wall thicknesses of the test apparatus tube itself and the Mark 22 fuel ring are comparable.

4. TEST APPARATUS ADIABATIC HEATUP RATES

Adiabatic heatup rates were determined for the inner and outer tubes of the test apparatus. These are the heatup rates for the theoretical case of complete dryout of the apparatus. The calculation provides an estimate of the maximum heatup rates attainable, for use in design of test apparatus protection systems. Details of the calculations are in Appendix B. Outer tube calculations were done for maximum heater power values of 22.4 kW and 18.7 kW. The results were heatup rates of 44.6 and 37.4 K/s, respectively. For the inner tube, a maximum heater power value of 17 kW/ft was used; the calculated heatup rate was 31.5 K/s.

5. DISCUSSION AND CONCLUSIONS

The calculated thermal response characteristics of the test apparatus outer tube were nearly identical to those of the Mark 22 outer fuel tube model. Transient temperature rise was 2% lower than for the Mark 22 model and the estimated thermal time constant was about 10% slower. Based on the similarity of response of the thermal models, the test apparatus outer tube should be nearly indistinguishable from a Mark 22 outer fuel ring for equal sets of boundary conditions. Calculations for the inner tube thermal models also showed responses very similar to the Mark 22 inner fuel ring. The differences are due to the lower value of test apparatus azimuthal conduction and the heater, which adds a significant amount of thermal mass to the system. The original thermal studies, performed by Schroeder,[10] were done to provide response similarity for transient times of up to about 30 seconds. The tube thickness final design value was a reasonable compromise between overall transient response temperature rise and the thermal time constant. A thicker tube would increase the thermal mass, thus slowing the response time even further. A thinner tube would have further reduced the azimuthal conduction of the system. Thus, the selected value for tube thickness represented the best compromise between heater design requirements and fidelity to prototypical thermal behavior. These results, i.e. the demonstration of closely matched thermal characteristics for both test apparatus tubes, indicates that the thermal behavior of the entire apparatus, including the enclosed coolant annulus, should provide the best prototypical behavior attainable for the given design constraints.

The adiabatic heatup rates represent the maximum rates attainable for the given heat input values. The calculated rates are significantly higher than the results of the transient calculations (Figures 5 and 7), which indicate average heatup rate values of ~25K/s. The azimuthal conduction characteristics of the system, and the assumption of one (90°) dry sector, significantly reduces the rate to far below the adiabatic rate.

6. REFERENCES

1. J.L. Anderson, T.K. Larson, H.N. Romero, Experimental Operating Specifications, Dual Heated ECS Heat Transfer Experiments (draft), July 5, 1989.

2. J.E. Fisher ltr to J.R. Wolf, "Results of Thermal Response Calculations for SRL Dual Heated ECS Heat Transfer Experiment Outer Tube," EG&G Interoffice Correspondence JEF-03-89, August 7, 1989.

3. ABAQUS Users Manual, Version 4.7, Hibbitt, Karlsson & Sorensen, Inc., 1988.

4. PATRAN Plus User Manual Volumes I and II, Release 2.3, PDA Engineering, Costa Mesa, California, July 1988.

5. EG&G Idaho, Inc. Quality Manual, Issue 14, March 17, 1989, Document No. QP-21.

6. G.L. Hawkes, Verification and Benchmarking of ABAQUS and PATRAN for Heat Transfer Applications, EGG-EAST-8680, to be published.

7. Hydraulics and Heat Transfer of Mark 22 Fuel Assemblies, DPSTM-22(H), Revised November 1974.

8. Savannah River Site INEL-ECS 2 Dryout Experiment Aluminum Heater Tube, EG&G Idaho Dwg. 430052, June 1989.

9. Savannah River Site INEL-ECS 2 Dryout Experiment Heater Tube Assembly, EG&G Idaho Dwg. 430437, July 1989.

10. J.A. Schroeder, private communication, 9-21-1989.

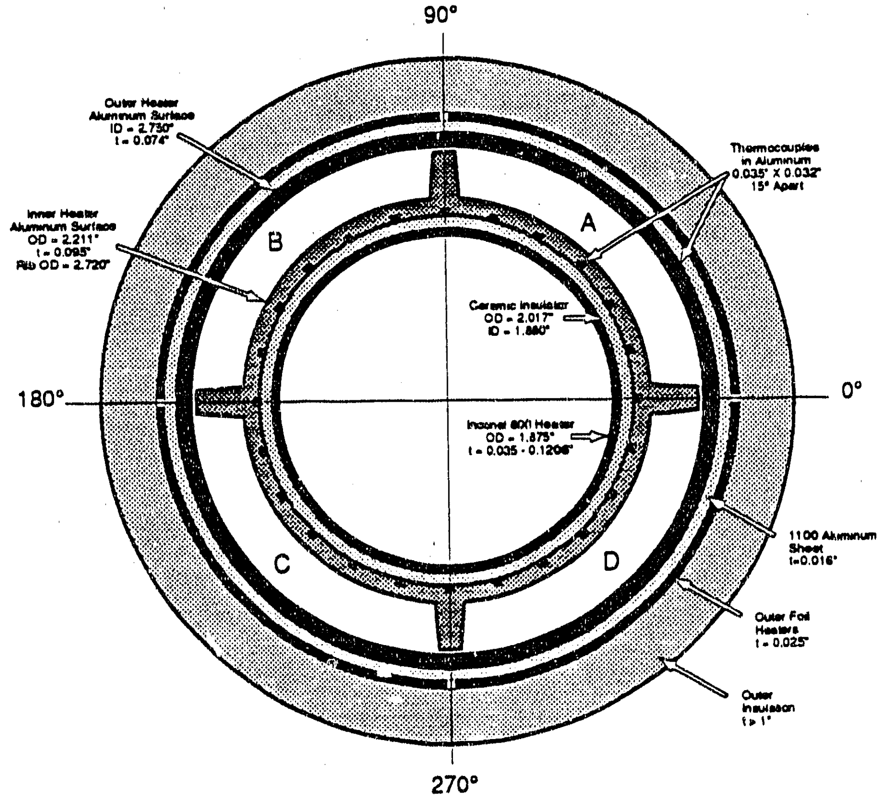


Figure 2. Proposed configuration for the dual heated dryout heat transfer experiments.

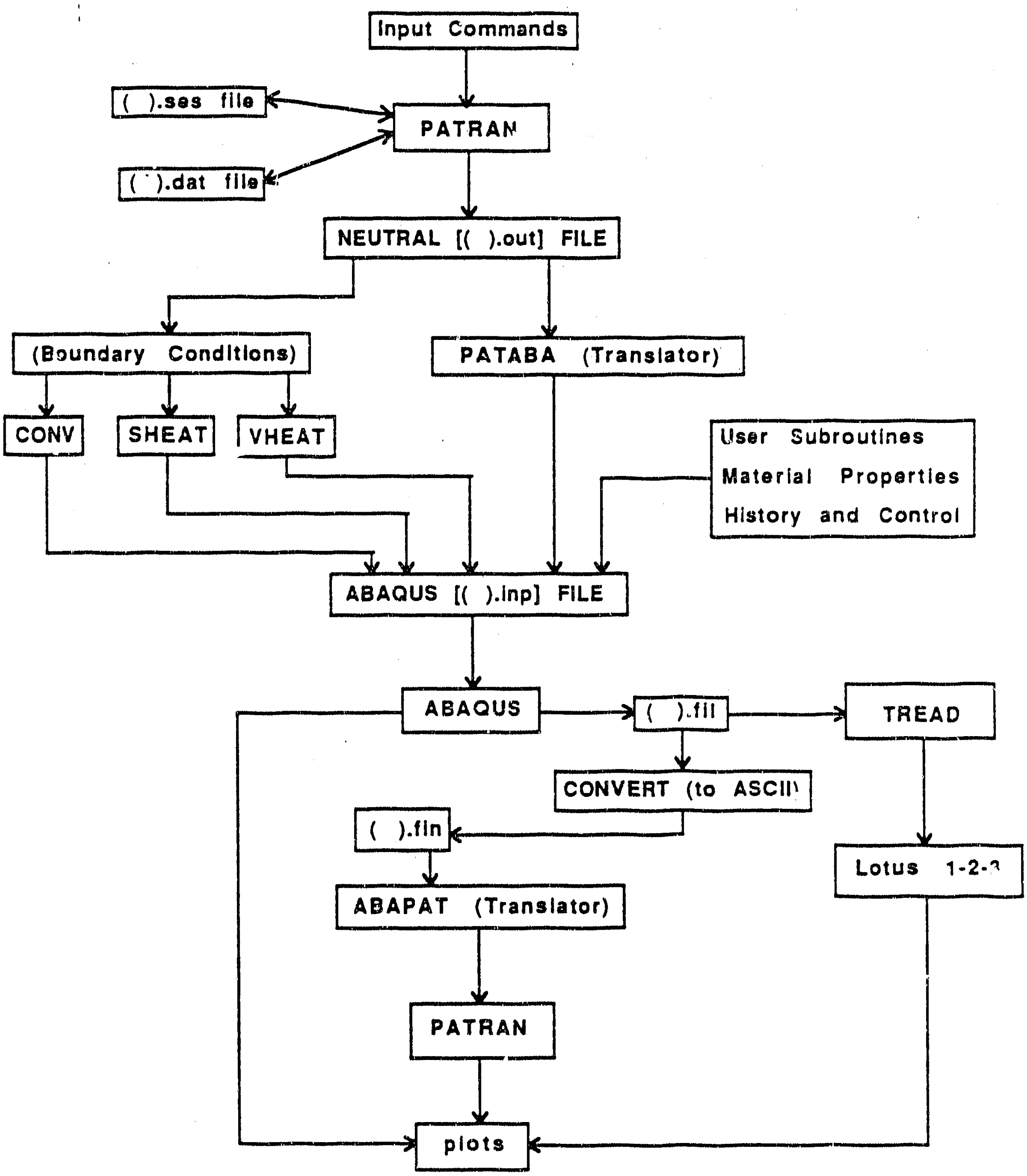


Figure 3. PATRAN / ABAQUS Calculation Flowchart

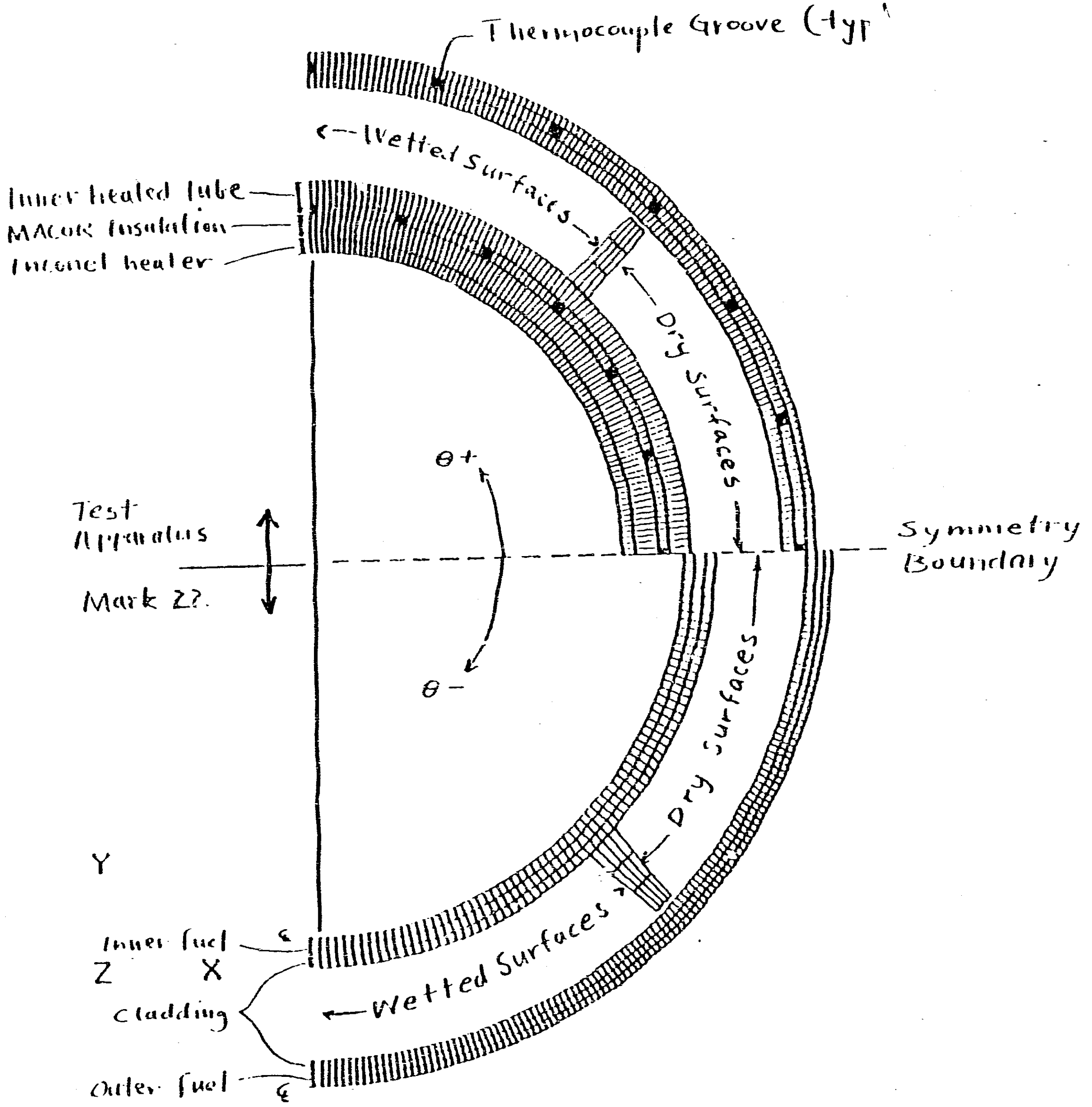


Figure 4. Test apparatus and Mark 22 finite difference mesh models.

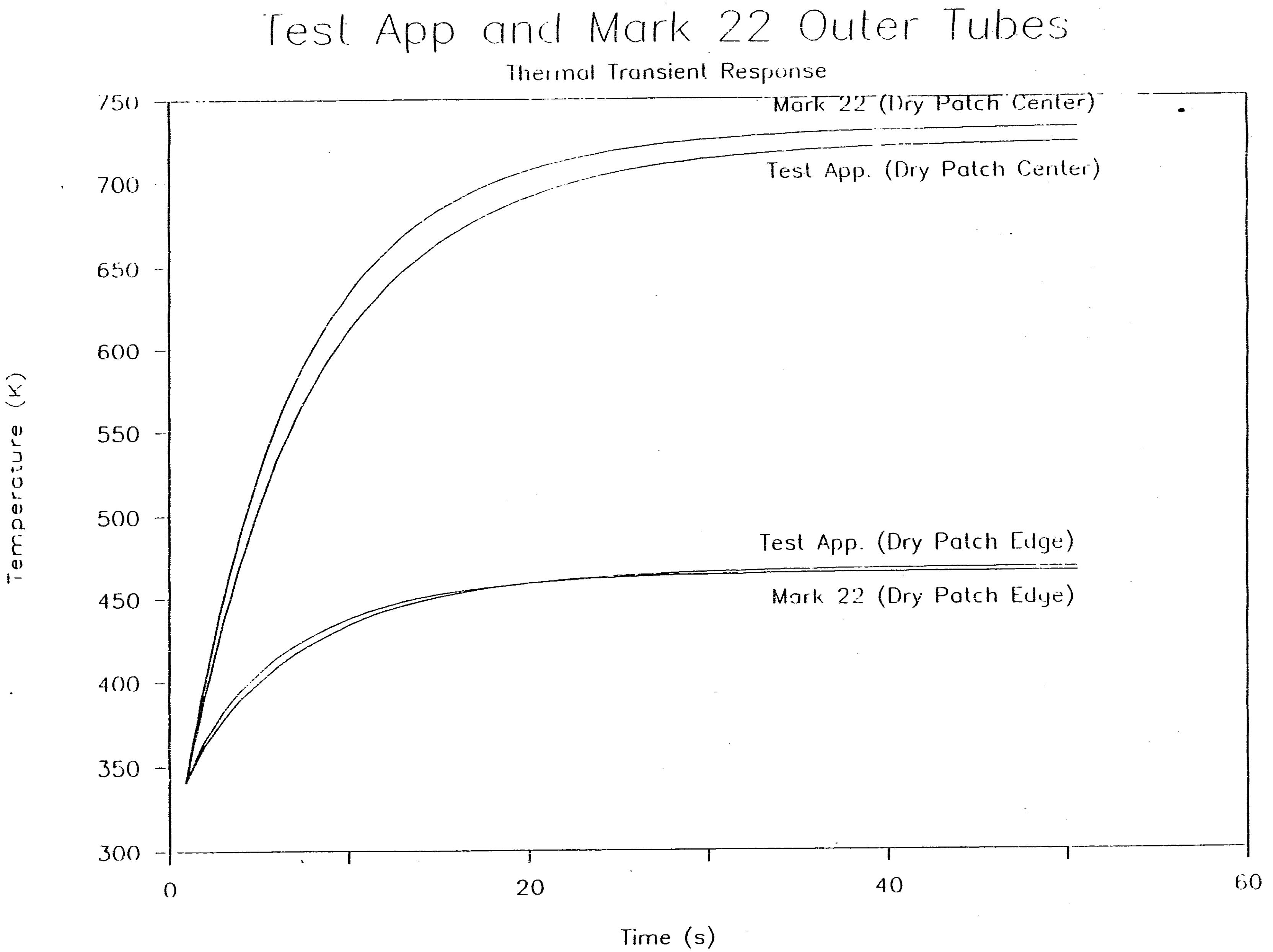


Figure 5. Test apparatus and Mark 22 outer tube thermal transient responses.

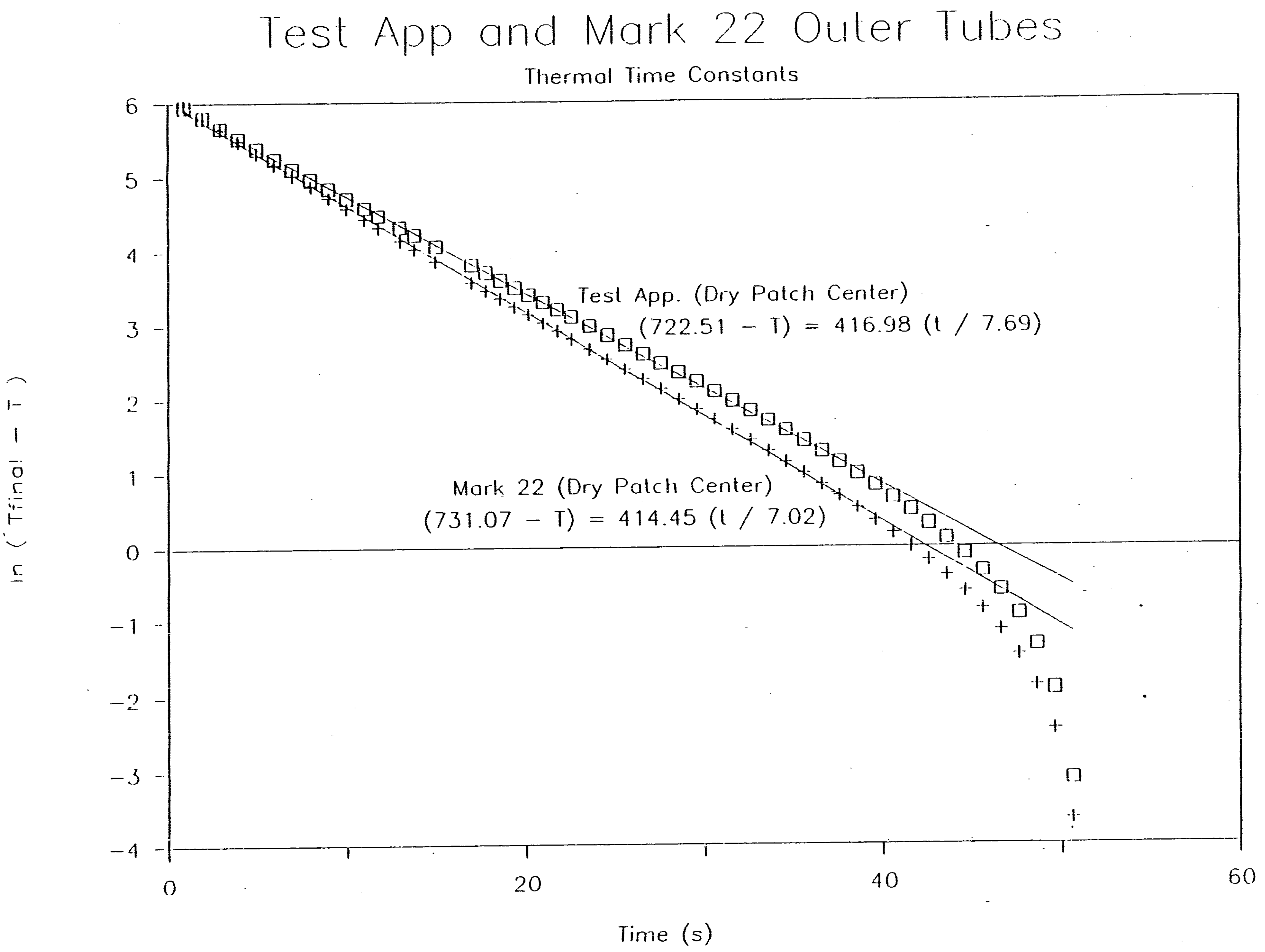


Figure 6. Test apparatus and Mark 22 outer tube thermal time constants.

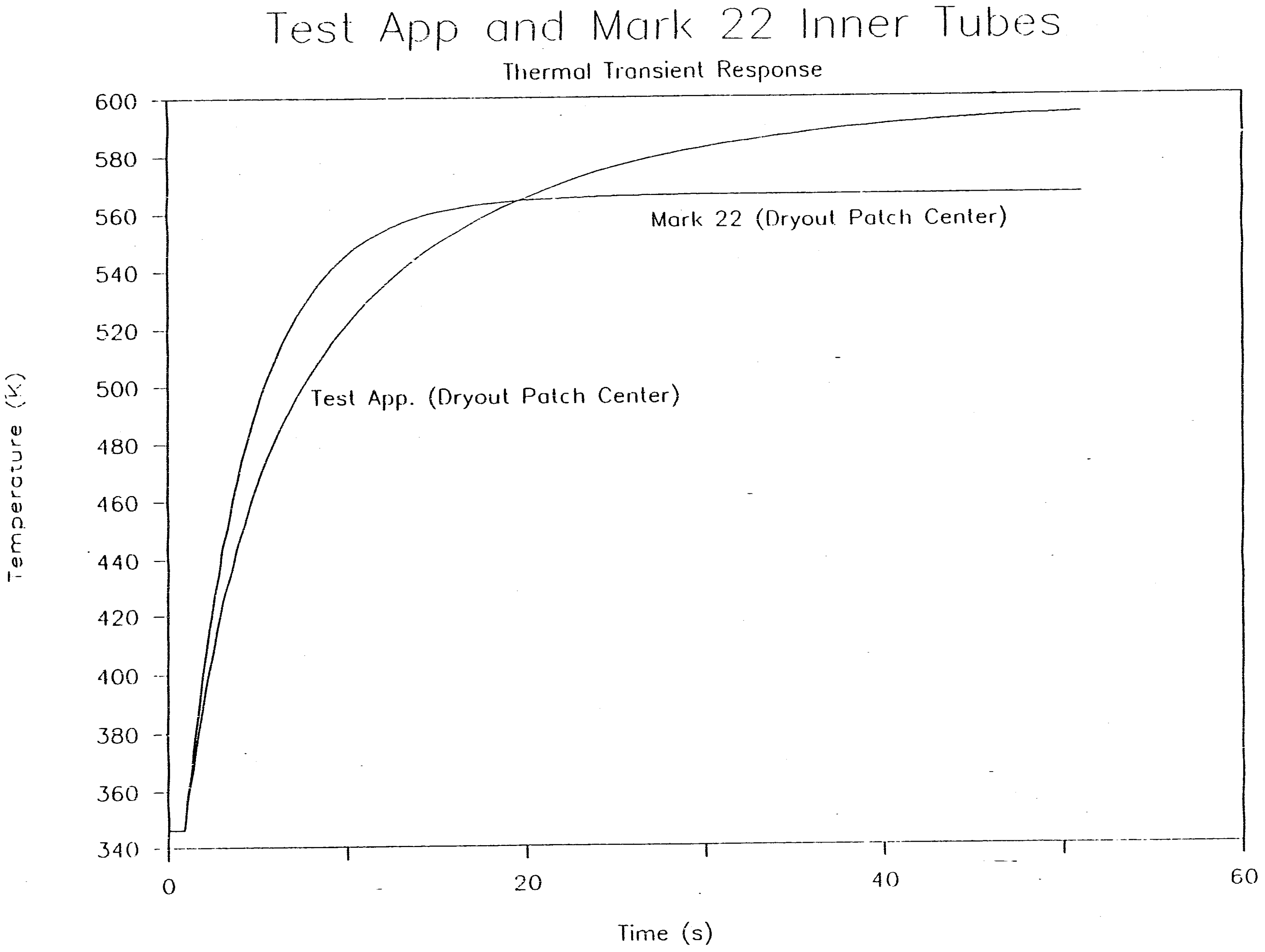


Figure 7. Test apparatus and Mark 22 inner tube thermal transient responses.

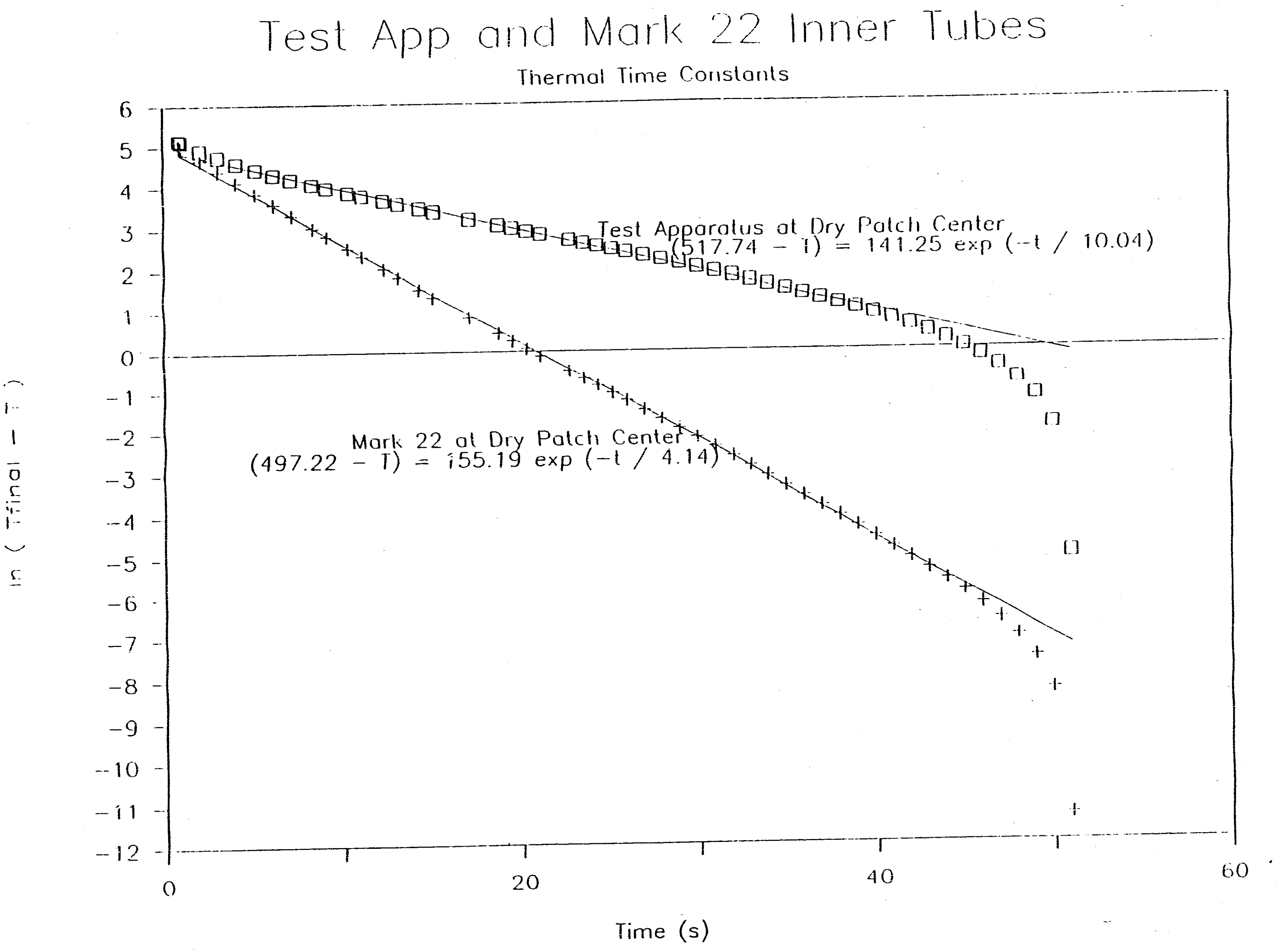


Figure 8. Test apparatus and Mark 22 inner tube thermal time constants.

APPENDIX A

Listings of FORTRAN Programs that Transform PATRAN Model Boundary Conditions into ABAQUS Input Cards

```
        program sheat
c*******************************************************************
c  Program Written by Grant Hawkes Jan. 31, 1989
c  -This program translates the distributed heat sources
c   from the patran neutral file.
c  -Element faces, HTC's, and corresponding fluid temperature are
c   translated to be used in an Abaqus input deck.
c  -File heat.dat needs to be created by extracting only the HTC's
c   from the patran neutral file.  An example of a HTC applied to
c   an element face in the patran neutral file is as follows:
c  16      6      1      2      1      0      0      0      0
c  0 11110000
c   0.500000000e+03
c  -See Patran User's Manual for explanation in chapter 29.
c  -File heat.out will be created to be input in an Abaqus input deck.
c  -While creating the HTC's in patran a different load id needs to
c   be created for each separate load.
c  -The highest load id should not exceed 10
c*******************************************************************
        dimension ftemp(10)
        dimension quest(10)
        integer i, id, iv, kc, nl, n2, n3, nflag, node(8)
        integer ptype
        real data
        open(7,file='sheat.dat')
        open(8,file='sheat.out')
        write(6,*)'input number of loads'
        read(5,*)loads
        do 20 i=1,loads
        write(6,510)i
510     format(//,' for load ',i2,' :',/)
        write(6,500)
500    format(' input  1  to translate the distributed heat sources from
     & patran as constant',/,' input  2  to calculate the heat source va
     & lues with a user subroutine')
        read(5,*)quest(i)
20      continue
        write(8,*)'*DFLUX'
10      continue
            read(7, '(i2,8i8)', end=999) ptype, id, iv, kc, nl, n2, n3
            read(7, '(il, 1x, 8il)') nflag, (node(i), i=1, 8)
            read(7, '(5el6.9)') data
        if (quest(iv).eq.1.0) then
          if((node(1) .eq. 1) .and. (node(2) .eq. 1)) then
        write(8,'(i4,a4,e12.4)')id,',S1,',data
          else if ((node(2) .eq. 1) .and. (node(3) .eq. 1)) then
        write(8,'(i4,a4,e12.4)')id,',S2,',data
          else if ((node(3) .eq. 1) .and. (node(4) .eq. 1)) then
        write(8,'(i4,a4,e12.4)')id,',S3,',data
          else if ((node(4) .eq. 1) .and. (node(1) .eq. 1)) then
        write(8,'(i4,a4,e12.4)')id,',S4,',data
          endif
        elseif (quest(iv).eq.2.0) then
          if((node(1) .eq. 1) .and. (node(2) .eq. 1)) then
        write(8,'(i4,a5)')id,',S1NU'
```

```
          else if ((node(2) .eq. 1) .and. (node(3) .eq. 1)) then
        write(8,'(i4,a5)')id,',S2NU'
          else if ((node(3) .eq. 1) .and. (node(4) .eq. 1)) then
        write(8,'(i4,a5)')id,',S3NU'
          else if ((node(4) .eq. 1) .and. (node(1) .eq. 1)) then
        write(8,'(i4,a5)')id,',S4NU'
          endif
        endif
        go to 10
999     continue
        close(7)
        close(8)
        stop
        end
```

```
      program vheat
c*******************************************************************
c  Program Written by Grant Hawkes Jan. 31, 1989
c   Modified by J. E. Fisher July 1989
c  -This program translates the distributed heat sources
c   from the patran neutral file.
c  -Element faces, HTC's, and corresponding fluid temperature are
c   translated to be used in an Abaqus input deck.
c  -File heat.dat needs to be created by extracting only the HTC's
c   from the patran neutral file.  An example of a HTC applied to
c   an element face in the patran neutral file is as follows:
c  16       6       1       2       1       0       0       0       0
c  0 11110000
c   0.500000000e+03
c  -See Patran User's Manual for explanation in chapter 29.
c  -File heat.out will be created to be input in an Abaqus input deck.
c  -While creating the HTC's in patran a different load id needs to
c   be created for each separate load.
c  -The highest load id should not exceed 10
c*******************************************************************
      dimension ftemp(10)
      dimension quest(10)
      integer i, id, iv, kc, nl, n2, nflag, node(8)
      integer ptype
      real data
      open(7,file='vheat.dat')
      open(8,file='vheat.out')
      write(6,*)'input number of loads'
      read(5,*)loads
      do 20 i=1,loads
      write(6,510)i
510   format(//,' for load ',i2,' :',/)
      write(6,500)
500  format(' input  1  to translate the distributed heat sources from
     & patran as constant',/,' input  2  to calculate the heat source va
     & lues with a user subroutine')
      read(5,*)quest(i)
20    continue
      write(8,*)'*DFLUX'
10    continue
          read(7, '(i2,8i8)', end=999) ptype, id, iv, kc, nl, n2
          read(7, '(il, lx, 8il)') nflag, (node(i), i=1, 8)
          read(7, '(5el6.9)') data
    if          (quest(iv).eq.1.0) then
      write(8,'(i4,a4,el2.4,al,el2.4)')id,',BF,',data
    else
      write(8,'(i4,a5)')id,',BFNU'
    endif
      go to 10
999   continue
      close(7)
      close(8)
      stop
      end
```

APPENDIX B

Supporting Calculations for SRL Test Apparatus and Mark 22 Fuel Assembly Thermal Models

EG&G Idaho, Inc.

FORM EG&G-1592
(Rev. 5-77)

CALCULATION WORK SHEET

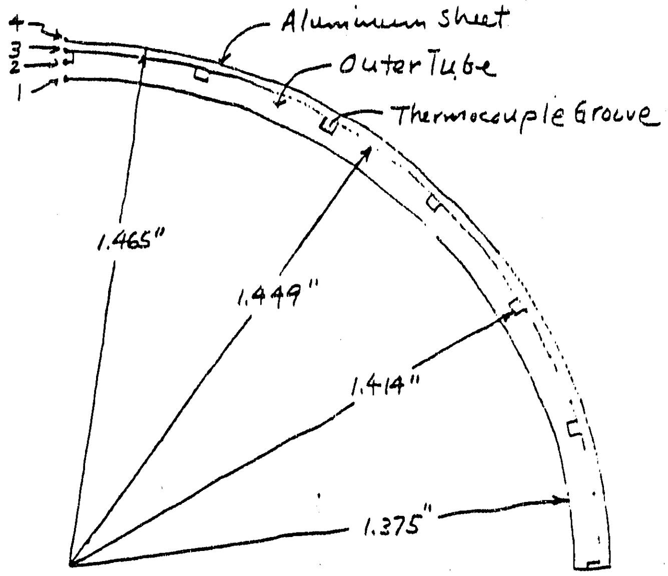
Page 1 of 13 Pages

Subject SRL Test Apparatus Outer Tube Model Date 25 Sept 89

Prepared By Fisher Checked GLH Work Request

The outer heated tube dimensions are 2.75" ID x 0.074" wall thickness. Axial thermocouple grooves will be machined into the outer surface, 0.035" wide x 0.035" deep, spaced at 15° intervals.

An Aluminum sheet, 0.016" thick, surrounds the tube and forms a thermal bridge across the thermocouple grooves. A heat flux boundary condition will be imposed at the outer surface, equivalent to 22.4 kW per 15-inch axial section (maximum value).



Input values for reference radial points 1, 2, 3, and 4 are:

point	rad (in)	rad (m)
1	1.375	0.03492250
2	1.414	0.0359156
3	1.449	0.0368046
4	1.465	0.0372110

For model simplicity, the computational mesh should approximately overlay the thermocouple grooves. Assume 20 nodes per 15° sector. Thermocouple groove is 2 nodes wide:

$$ds = r\,d\theta = (1.449)(2)\left(\frac{15}{20}\right)\frac{\pi}{180} = 0.0379''$$

Heat flux:

$$\frac{22.4 \times 10^3\ W}{(2\pi)(1.465)(15)\ in^2}\ \frac{in^2}{(.0254)^2\ m^2} = 251460.\ W/m^2$$

$$\sim \boxed{250\ kW/m^2}$$

EG&G Idaho, Inc.

FORM EG&G-1592
(Rev 5-77)

CALCULATION WORK SHEET

Page 4 of 13 Pages

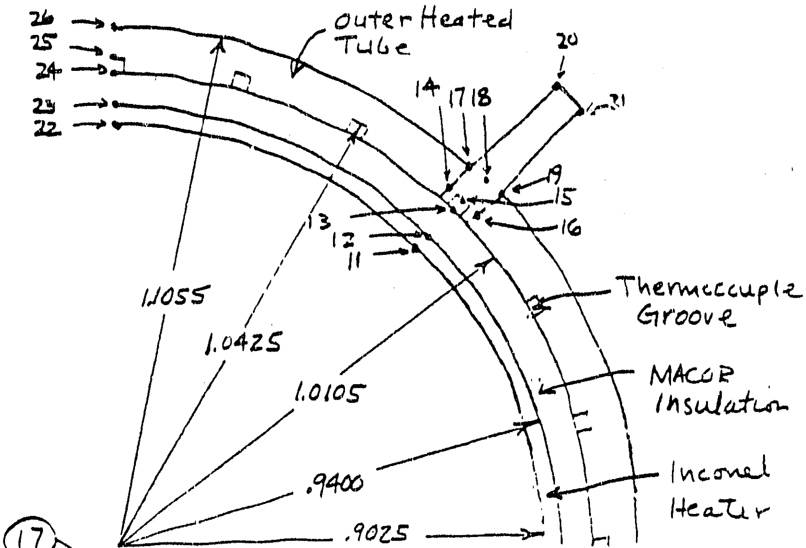
Subject SRL Test Apparatus Inner Heated Tube Model Date 11 Sept 89

Prepared By Fisher Checked G.-F. Work Request

The test apparatus inner tube is 2.211" od x 0.095" wall thickness. Thermocouple wells in the inner surface are 0.034" wide x 0.032" deep, and are spaced at 15° intervals. The geometry is complicated by the presence of ribs on the outer surface, which are spaced at 90° intervals, the same as their counterparts on the Mark 22 inner fuel ring. An Inconel heater imposes a heat flux boundary condition on the inside tube surface. A MACOR tube separates the inner heated tube and the heater.

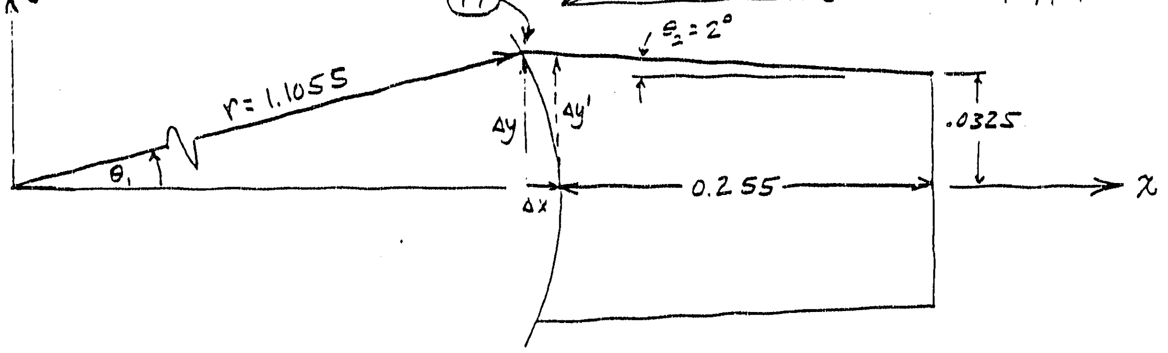
The computational mesh for the two-dimensional ABAQUS calculation was generated using PATRAN. The following calculations are the derivation of the reference points for the PATRAN mesh. These points (11 through 26) are indicated on the sketch.

Details are presented for points 17 and 14. Remaining points can be readily obtained from the given dimensions.



Point #17:

1. $\Delta y = (0.255 + \Delta x)\tan(\theta_2) + 0.0325$
2. $\Delta y = r\sin(\theta_1)$
3. $\Delta x = r - r\cos(\theta_1)$



CALCULATION WORK SHEET

Page 5 of 13 Pages

Subject SRL Test Apparatus Inner Heated Tube Model Date 11 Sept 89

Prepared By Fisher Checked GLH Work Request

$\Delta y \simeq \Delta y' = 0.255 \tan(2°) + 0.0325 = 0.0414048$

$\theta_1 = \sin^{-1}\left(\frac{\Delta y}{r}\right) = \sin\left(\frac{.0414048}{1.1055}\right) = 2.1464°$

$\Delta x = r\,[1-\cos(\theta_1)] = 1.1055[1-\cos(2.1464)] = 0.00077565$

$\Delta y = (0.255 + 0.00077565)\tan(2°) + 0.0325 = 0.04143188$

$\theta_1 = \sin^{-1}\left(\frac{0.04143188}{1.1055}\right) = 2.1478$

$\Delta x = 0.0077666$

$\Delta y = 0.04143192$

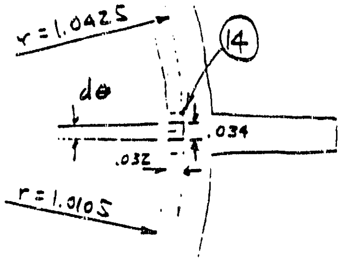
$\theta_1 = 2.1478$

Point #17 $(r,\theta) = (1.1055, 2.1478°)$, $(x,y) = (1.104723, 0.041431)$

Point #14:

$d\theta = \frac{ds}{r} = \frac{.034}{1.0425} = 0.032614$

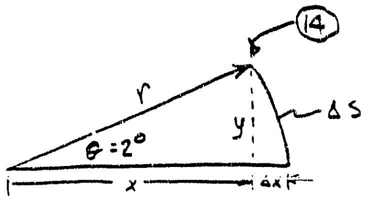
$\times \frac{180}{\pi} = 1.87°$



⇒ use azimuthal node spacing of 1°. Each thermocouple occupies two element widths.

$x = r\cos\theta = (1.0425)\cos(2) = 1.04186$

$y = r\sin\theta = (1.0425)\sin(2) = 0.03638$



EG&G Idaho, Inc.

FORM EG&G-1592
(Rev 5-77)

CALCULATION WORK SHEET

Page 6 of 13 Pages

Subject SRL Test Apparatus Inner Heated Tube Model Date 11 Sept 89

Prepared By Fisher Checked GLH Work Request

The actual coordinates used for points 14 (and 16) were slightly different from the [illegible]. The original calculation used the more obscure approximations:

$$x = r - \Delta s \sin(\theta) \qquad y = r\theta \cos(\theta)$$
$$= r - r\theta \sin(\theta)$$

and the calculations contained a mistake:

$$x = 1.0425 - \frac{(1.0405)(2)\pi}{180} \sin(2°) = 1.041232$$

$$y = \frac{(1.0405)(2)\pi}{180} \cos(2°) = 0.036298$$

However, these results differ only slightly from the correct values, i.

$$\frac{1.041232}{1.04186} = 0.9994 \quad \text{and} \quad \frac{0.036298}{0.03638} = 0.9977$$. Also, points 14 and 16 only affect the position of the thermocouple well within the model. Therefore, the calculation was not repeated with the corrected values.

The remaining points required no calculation. Points 11 through 21 were rotated to the correct orientation. The values were transformed to polar coordinates, rotated -45°, then transformed back to rectangular coordinates. The attached table shows the results of a LOTUS 1-2-3 spreadsheet which performs the reference point calculation and converts the results to metric units.

GCH

Test Apparatus Inner Heated Tube Reference Points
21 August 89 with Final Numbering System

Grid	X	Y	R	Theta (rel)	Theta
11	0.90250000	0.00000000	0.90250000	0.00000000	45.00000000
12	0.94000000	0.00000000	0.94000000	0.00000000	45.00000000
13	1.01050000	0.00000000	1.01050000	0.00000000	45.00000000
14	1.04123244	0.03629818	1.04186494	1.99656711	46.99656711
15	1.04250000	0.00000000	1.04250000	0.00000000	45.00000000
16	1.04123244	-0.03629818	1.04186494	-1.99656711	43.00343289
17			1.10550000	2.14780000	47.14780000
18			1.10550000	0.00000000	45.00000000
19			1.10550000	-2.14780000	42.85220000
20	1.36050000	0.03250000	1.36088813	1.36843716	46.36843716
21	1.36050000	-0.03250000	1.36088813	-1.36843716	43.63156284
22	0.00000000	0.90250000			
23	0.00000000	0.94000000			
24	0.00000000	1.01050000			
25	0.00000000	1.04250000			
26	0.00000000	1.10550000			

DS (14,16) 0.03632030

Points Rotated +45 Degrees

Grid	X (in.)	Y (in.)	X (m)	Y (m)
11	0.63816387	0.63816387	0.01620936	0.01620936
12	0.66468037	0.66468037	0.01688288	0.01688288
13	0.71453140	0.71453140	0.01814910	0.01814910
14	0.71059583	0.76192921	0.01804913	0.01935300
15	0.73715882	0.73715882	0.01872383	0.01872383
16	0.76192921	0.71059583	0.01935300	0.01804913
17	0.75186105	0.81045371	0.01909727	0.02058552
18	0.78170655	0.78170655	0.01985535	0.01985535
19	0.81045371	0.75186105	0.02058552	0.01909727
20	0.93903781	0.98499975	0.02385156	0.02501899
21	0.98499975	0.93903781	0.02501899	0.02385156
22			0.00000000	0.02292350
23			0.00000000	0.02387600
24			0.00000000	0.02566670
25			0.00000000	0.02647950
26			0.00000000	0.02807970

CALCULATION WORK SHEET

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Subject Test Apparatus Adiabatic Heating Rate Date 23 Sep-89

Prepared By Fisher Checked GLH Work Request

Heat addition to a system in the absence of a removal mechanism results in:

$$q = \rho C_p V \frac{dT}{dt}$$

Outer tube: Maximum heater power is 18.7 kW for a 15-inch section.

$$\frac{q}{A} = \frac{18.7 \times 10^3 \ W}{(2\pi)(1.465)(15) \ in^2} \ \frac{in^2}{(.0254)^2 m^2} = 209\,926 \ W/m^2$$

$$V_{6061} = \pi \left[(1.449)^2 - (1.375)^2\right] (.0254)^2 \ h = 4.2356 \times 10^{-4} \ h \ m^3$$

$$V_{1100} = \pi \left[(1.465)^2 - (1.449)^2\right] (.0254)^2 \ h = 9.4499 \times 10^{-5} \ h \ m^3$$

$$\rho_{6061} \sim 2700 \ kg/m^3$$

$$C_{p_{6061}} \sim 942.14 \ J/kg\text{-}K$$

$$\rho_{1100} \sim 2708.53 \ kg/m^3$$

$$C_{p_{1100}} \sim 913.57 \ J/kg\text{-}K$$

$$\frac{dT}{dt} = \frac{209{,}926 \ (2\pi)(1.465)(.0254) \ h}{\left[(4.2356 \times 10^{-4})(2700)(942.14) + (9.4499 \times 10^{-5})(2708.53)(913.57)\right] h} = \boxed{37.43} \ K/s$$

$$\frac{(W/m^2) \ (m)(m)}{(m^2)(kg/m^3)(J/kg\text{-}K)(m)} = \frac{K}{s}$$

For the original value of maximum heater power, 22.4 kW (250 kW/m²):

$$\frac{(250 \times 10^3)(2\pi)(1.465)(.0254)}{(4.2356 \times 10^{-4})(2700)(942.14) + (9.4499 \times 10^{-5})(2708.53)(913.57)} = \boxed{[illegible]} \ K/s$$

CALCULATION WORK SHEET

Page 13 of 13 Pages

Subject Test Apparatus Adiabatic Heatup Rate Date 28 Sept 89

Prepared By Fisher Checked GLH Work Request

Inner Tube : Maximum heater power is 17 kW/ft

$$\forall_{6061} = \pi\left[(1.1055)^2-(1.0105)^2\right](.0254)^2 h + \frac{2}{2}(.0325+.0414)(.0255)(.0254)^2(4)h$$
$$= 4.1230\times10^{-4} h$$

$$\forall_{MACOR} : \pi\left[(1.0105)^2-(.9400)^2\right](.0254)^2 h = 8.8716\times10^{-5} h$$

$$\forall_{inconel} = \pi\left[(.9400)^2-(.9025)^2\right](.0254)^2 h = 1.4004\times10^{-4} h$$

$\rho_{MACOR} = 2514.9$ kg/m^3

$C_{p\,MACOR} = 836.8$ J/kg-K

$\rho_{inconel} : 8331.41$ kg/m^3

$C_{p\,inconel} = 460.46$ J/kg-K

$$\frac{dT}{dt} = \frac{(17000)/.3048}{\underset{1048.80}{(4.1230\times10^{-4})(2700)(942.14)} + \underset{186.7}{(8.8716\times10^{-5})(2514.9)(836.8)} + \underset{537.23}{(1.4004\times10^{-4})(8331.41)(460.46)}}$$

$$\frac{W/m}{(m^2)(kg/m^3)(J/kg\text{-}K)} \qquad = \boxed{31.46}\ \frac{K}{s}$$

APPENDIX C

PATRAN "Session" Files for Generating Inner and Outer Tube Finite Difference Models

Outer Tube Models

Inner Tube Models

Appendix E

Calculated Parameters for the ECS-2 and ECS-2c Thermal Excursion Experiments

Appendix E

Calculated Parameters for the ECS-2 and ECS-2c Thermal Excursion Experiments

Throughout the main body of this report and in the data tabulations contained in Appendix J, reference is made to calculated parameters. Information in this appendix documents the calculation of the computed parameters.

Saturation Temperature Calculation

Saturation temperature was calculated from local pressure measurements using an Antoine equation curve fit for water. This equation as used for the ECS-2 and ECS-2c experiments was

$$T = \left[\frac{a}{b - \log_{10}(P/c)}\right]\frac{1}{1.8} \qquad \text{(E-1)}$$

where

T = fluid saturation temperature in K
P = pressure in kPa
a = 4044.17692
b = 7.186012
c = 6.894

This equation is valid for pressures between 1.76 and 124 kPa.

Liquid Level Calculation

Liquid levels were computed from select differential pressure measurements. All of the differential pressure cells were connected so that the high side of the cell was attached to the standing leg (filled with cold water) of the sense line connected to the test section and the low side of the cell was connected to the test section. The differential pressure is

$$\Delta P_{meas} = P_H - P_L \tag{E-2}$$

where

ΔP_{meas} = measured differential pressure

P_H = hydrostatic pressure on the high side of the cell

P_L = hydrostatic pressure on the low side of the cell

Each hydrostatic pressure can be represented as

$$P_i = \rho_i g h_i + P_{ref} \tag{E-3}$$

where

P_i = hydrostatic pressure in leg i

P_{ref} = pressure at the reference tap location

ρ_i = density in leg i

g = acceleration due to gravity

h_i = vertical height of leg i

With the measured differential pressure and known sense line vertical distances and pressure tap locations, the effective level can be calculated as

$$h = h_c - \frac{\Delta P_{meas}}{\rho_{meas} g} + h_{ref} \tag{E-4}$$

where

h_c = reference component height

ΔP_{meas} = measured differential pressure

ρ_{meas} = fluid density in the test section

g = acceleration due to gravity

h_{ref} = reference height for the level measurement

Table E-1 lists the relevant parameters used in the calculation of levels for the thermal excursion tests.

Table E-1. Parameters used for level calculations for the thermal excursion experiments[1]

For ECS-2 experiments

Level ID	h_c	ΔP_{meas}	ρ_{meas}	h_{ref}
L_SP	1.803	DP_SP	RHOW_SP	0
L_PL_OUT	0.279	DP_PL_OUT	RHOW_OUT	0
L_PL_IN	0.213	DP_PL_IN	RHOW_IN	0
L_TS_TOT	5.74	DP_D_ALL	RHOW_TS	L_PL_OUT

For ECS-2cE experiments

Level ID	h_c	ΔP_{meas}	ρ_{meas}	h_{ref}
L_SP	2.064	DP_SP	RHOW_SP	0
L_PL_OUT	0.279	DP_PL_OUT	RHOW_OUT	0
L_PL_IN	0.208	DP_PL_IN	RHOW_IN	0
L_TS_TOT	5.734	DP_D_ALL	RHOW_TS	L_PL_OUT

---

[1] The physical geometry was different for the ECS-2 and ECS-2c facilities. Therefore, the component heights used in the level calculations are slightly different.

Superficial Velocity Calculation

Liquid and vapor superficial velocities were calculated on line in the DAS and are listed in the data tabulations for the ECS-2cE experiments. Superficial velocities were computed in British units and are presented in the data tabulations in ft/s. Superficial velocity was calculated as

$$j_i = \frac{Q_i}{A_{ts}} \qquad \text{(E-5)}$$

where

j_i = superficial velocity of component i

Q_i = volumetric flowrate of component i

A_{ts} = test section flow area (13.31 cm^2)

and the appropriate units conversions were made to obtain British units.

Liquid Density

Liquid density as a function of temperature was computed using a second order fit to water properties from the 1967 ASME Steam Tables. The following equation

$$\rho_l = a + bT + cT^2 \qquad \text{(E-6)}$$

where

$a = 760.48$
$b = 1.837$
$c = -3.503 \times 10^{-3}$
T = measured liquid temperature in K

produces a maximum error of 0.9 kg/m^3 (0.1%) at the low end (273 K) of the temperature range. Over the temperature and pressure range of interest for the ECS-2 experiments (85.6 kPa and $292\ K < T < 373\ K$), the maximum error is 0.56 kg/m^3 or 0.06%.

Local Heat Flux

The local power generation rate at an axial location on the heater can be defined as

$$q_i = \frac{q_T}{L} p_f l_i \qquad \text{(E-7)}$$

where

q_T = heater total power
L = heater total length
p_f = peaking factor for the zone i
l_i = length of the zone i

The local heat flux can be calculated from knowledge of the local power and the surface area for heat transfer. In conjunction with Equation E-7, the local flux for power step i is

$$q_i'' = \frac{q_T}{L}\,\frac{p_f\, l_i}{A_i} = \frac{q_T}{L}\,\frac{p_f}{\pi\, d_i} \qquad \text{(E-8)}$$

where

Ai = heat transfer area for power zone i

di = diameter of zone i

Table E-2 lists relevant dimensions and power factors for the inner heater. Note that the denominator of Equation E-8 is a constant equal to 0.669 m^2 for the ECS-2 and ECS-2c heaters.

Table E-2. Geometric parameters for inner heater

		Inconel		Macor		Aluminum		
Heater zone	Length (cm)	ID (cm)	OD (cm)	ID (cm)	OD (cm)	ID (cm)	OD (cm)	Power Factor
1	104.775	4.1478	4.7600	4.7600	5.1359	5.1359	5.5880	0.47
2	38.100	4.4729	4.7600	4.7600	5.1359	5.1359	5.5880	0.97
3	38.100	4.5339	4.7600	4.7600	5.1359	5.1359	5.5880	1.22
4	38.100	4.5695	4.7600	4.7600	5.1359	5.1359	5.5880	1.43
5	38.100	4.5847	4.7600	4.7600	5.1359	5.1359	5.5880	1.56
6	48.590	4.5695	4.7600	4.7600	5.1359	5.1359	5.5880	1.43
7	57.912	4.4729	4.7600	4.7600	5.1359	5.1359	5.5880	0.97
8	17.247	4.1478	4.7600	4.7600	5.1359	5.1359	5.5880	0.47

Saturation Ratio Calculation (R Factor)

Researchers at WSRL commonly use the so-called R factor or saturation power ratio for the presentation of power limits data. The R factor is defined simply as the ratio of the power at the defined limiting criteria (for example, electrical power applied to the test section when a sustained thermal excursion occurred) divided by the power required to saturate the fluid at the outlet of the heated length. For the thermal excursion experiments, this definition of the R factor is

$$R = \frac{q_{ts}}{\dot{m}\, C_p\, (T_{sat} - T_{in})} \qquad \text{(E-9)}$$

where

q_{ts} = power applied at the limiting criteria

m = test section inlet mass flowrate

C_p = test section inlet liquid specific heat

T_{sat} = saturation temperature at outlet plenum

T_{in} = test section inlet liquid temperature

An R factor can be computed in a similar fashion for experiments conducted using wall saturation temperature as the power limiting criteria. For the INEL ECS-2b experiments described in Anderson [Anderson, et al 1990], the R factor was defined as

$$R = \frac{h\, (T_{sat} - T_f)\, A_{surface} / P}{\dot{m}\, C_p\, (T_{sat} - T_{in})} \qquad \text{(E-10)}$$

where

h = heat transfer coefficient

T_{sat} = saturation temperature

T_f = local bulk fluid temperature

$A_{surface}$ = surface area of the heater

P = axial peaking factor

m = test section inlet liquid mass flowrate

C_p = liquid specific heat

T_{in} = test section inlet fluid temperature

The numerator of Equation E-10 was defined in terms of the computed heat transfer coefficient to account for variations in the wall temperature from the saturation temperature.

Integrated Thermal and Electrical Powers

To compare thermal and electrical powers, the integrated power from the inlet to the axial locations of the fluid thermocouples was computed and i presented in the tables in Appendix J. The total thermal power was calculated as

$$q_t = \dot{m}\, C_p\, (T_{out} - T_{in}) \qquad \text{(E-11)}$$

where

T_{out} = test section outlet fluid temperature
T_{in} = test section inlet fluid temperature
m = mass flowrate
C_p = specific heat

The integrated thermal power up to each fluid thermocouple location was computed using Equation E-11 with T_{out} replaced by the average fluid temperature at that location. Note that Equation E-11 is accurate only until saturation conditions are reached.

Total electrical power was calculated as the product of the measured total voltage and current in the heater. Knowledge of the axial positions of the fluid thermocouples and the axial power profile for the heater allowed computation of the electrical power integrated from the inlet up to the fluid thermocouple location. For each facility, the location of the fluid thermocouples was constant as was the axial power profile. Therefore, the integrated electrical power is simply a constant that is a function of axial position times the total electrical power. Table E-3 lists the constants used for the ECS-2 and ECS-2c programs.

Average Fluid and Wall Temperatures

Average fluid temperature was computed as the arithmetic average of all the fluid temperatures at a given location. For example, the average fluid temperature at the 253 cm elevation for the ECS-2 facility experiments (TF_03_AV) was computed as

TF_03_AV = (TF_A_03 + TF_B_03 + TF_C_03 + TF_D_03) / 4 (E-12)

Average wall temperatures were computed in a like fashion using an equation similar to Equation E-12 with fluid temperature replaced with wall thermocouple measurements at a specific axial location and on a specific power step.

Table E-3. Integrated electrical power constants for thermal excursion tests.

ECS-2 and ECS-2WSR tests		ECS-2cE tests	
axial position (cm)	constant	axial position (cm)	constant
63.5	0.079	132	0.2
183.0	0.357	193	0.4
257.0	0.646	244	0.6
381.0	1.0	297	0.8
-	-	381	1.0

In the data tables, the computed average fluid and wall temperatures all have an "AV" suffix in their measurement identification. The average of the wall thermocouples at the 253 cm elevation, for example, would be labeled TI_6_AV. The test section average fluid temperature was computed as the average of the average fluid temperatures at each fluid temperature measurement location.

Heater Electrical Resistance

For some of the experiments, the electrical resistance of the inner heater was computed and stored in the data tables. The resistance was computed using the measured heater voltage and current, ie.,

R_INNER = V_INNER / I_INNER (E-13)

Reference

Anderson, et al 1990 J. L. Anderson, K. G. Condie, and T. K. Larson, "Downflow Heat Transfer in a heated Ribbed Vertical Annulus with a Cosine Power Profile (Results from Test Series ECS-2b)," Idaho National Engineering Laboratory Report, EGG-EAST-9144, July 1990.

Appendix F

Data Repeatability for Onset of Thermal Excursion Experiments

Appendix F

Data Repeatability for Onset of Thermal Excursion Experiments

Data repeatability was investigated during the course of the thermal excursion test program conducted in the ECS-2 and ECS-2b facilities by performing essentially the same experiment multiple times. By design, the same experiment was conducted on numerous occasions to support facility checkout procedures, investigate changes in the facility hardware, and provide experiment/facility demonstrations for the customer, visiting dignitaries, and other interested personnel. A comparison of the data from the experiments is presented in this appendix to demonstrate the high degree of repeatability observed in the test results.

Thermal excursion experiment ECS-2BL_5 was conducted on four different occasions for the reasons cited above. This test was conducted with nominal conditions of 324 K inlet temperature, an inlet flowrate of 0.1 l/s, and with a standpipe level of 43 cm relative to the bottom of the lower plenum. In addition to the base case test, the experiment was also conducted as ECS-2BL_5B, ECS-2BL_5C, and ECS-2BL_5D with the actual conditions and on the dates shown in Table F-1.

Conduct dates for the repeatability tests are shown in the second column of Table F-1. It is noteworthy that these experiments were not all conducted on the same date and that the elapsed time between performance of the individual tests was nearly a calendar week in all cases. Also, between the conduct of the base case test and ECS-2BL_5B, the bottom 1.8 m of the Lexan™ shroud[1] was replaced with 1.8 m of aluminum shroud of the same inner diameter.

Examination of the values in Table F-1 shows that the variation in flowrate and inlet temperature between the tests was less than 6% and 1%, respectively. Such small differences influence the energy balance so that the power required to saturate the fluid in the lower plenum (the eighth

---

[1] During testing, the heater and shroud came in contact resulting in deformation and partial melting of the lower part of the shroud. To preclude further problems, the decision was made to replace the lower part of the shroud with aluminum.

Table F-1. Conduct dates and actual conditions for repeatability tests.

TEST[1]	Test Conduct Date	Test Section Superficial Velocity	Water Inlet Temp.	Air Ent. Rate	Stand Pipe Height	Test Section Power	Power to Saturate Outlet	R (P/Psat)
	-	(m/s)[2]	(K)	(SLPM)	(cm)[3]	(kW)	(kW)	-
BL_5	12/15/89	0.078	325.96	0.01	408.70	53.48	19.07	2.80
BL_5B	12/19/89	0.074	326.08	10.01	399.37	50.15	17.85	2.81
BL_5C	12/29/89	0.074	324.04	see 4.	400.76	47.96	18.78	2.55
BL_5D	1/10/90	0.075	323.96	8.01	401.40	50.76	19.36	2.62

---

1. For clarity, the ECS-2 prefix on the test names has been dropped.
2. Superficial velocity based on test section flow area of 13.31 cm^2.
3. Reference is top of heated length, increasing downward.
4. Air meters not functioning properly.

column) varies between the tests by as much as 1.5 kW.

The R factor, which is the power at the occurrence of thermal excursion (the seventh column) divided by the power required to saturate the fluid in the lower plenum (calculated by the test section energy balance) for each test is shown in the last column of Table F-1. The spread in the R values is approximately 9%.

The rather small spread in the R factors for the repeatability tests is quite interesting in light of the random nature of the hydraulic and heat transfer processes leading to the thermal excursion. Furthermore, these four tests were not conducted in exactly the same fashion. For instance, Test BL_5 was one of the first excursion experiments conducted and the excursion condition was conservatively approached with a series of many small increases in total test section power over the course of about 2400 s. As experience was gained with the operation of the system and the phenomena under investigation, the conduct of the test was accelerated by using larger power steps. These differences in test conduct are demonstrated in Figure F-1, a comparison of the test section electrical power for the four experiments. As shown, Tests BL_5B, BL_5C, and BL_5D were conducted in approximately 1500 s by using somewhat larger power steps relative to the base case experiment. As evidenced from the comparisons in Table F-1, difference in test conduct or test section hardware apparently had little effect on the power at which thermal excursion occurred.

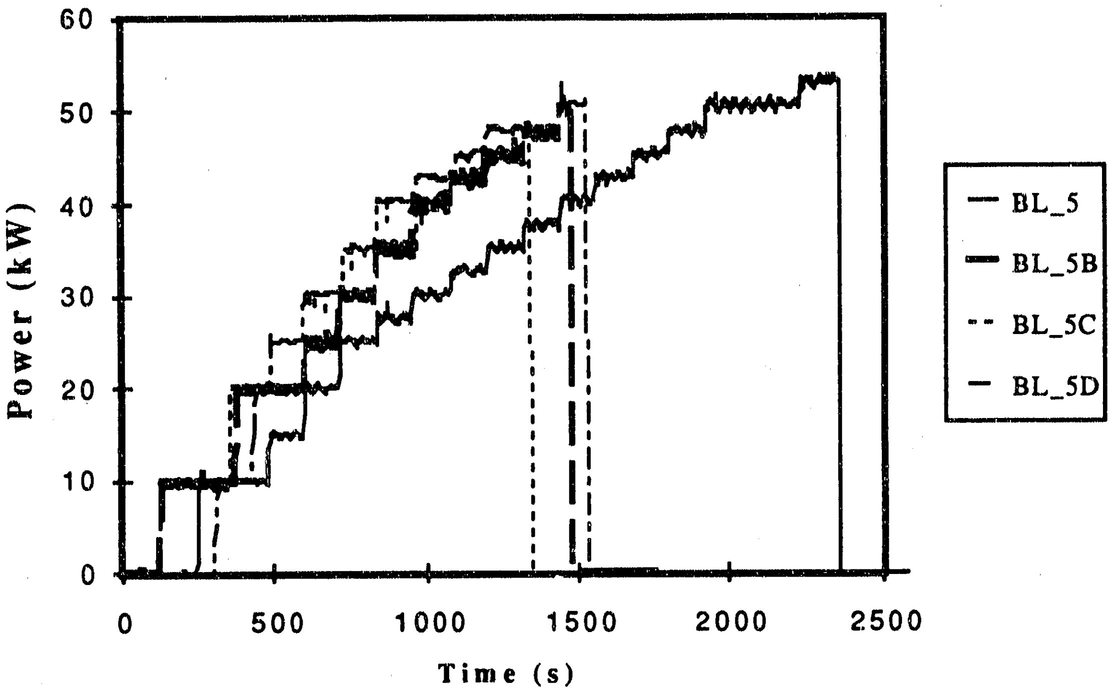

Figure F-1. Comparison of electrical power for repeatability tests.

As was discussed previously, in the excursion tests the power to the test section was terminated when any wall thermocouples attained a temperature of 600 K. Table F-2 lists for each of the repeatability tests, the wall thermocouples that initiated the power trip, the time at which the trip occurred, and the peak temperature and time that the peak temperature was recorded after the power was tripped.

From the data in Table F-2, it is obvious that the location of the dryout was not always the same in the repeatability tests. For example, in three of the tests, the thermocouples at level 7 were the first to dry out and reach the 600 K trip criterion, whereas on Test BL_5C, the level 6 thermocouples dried out first. It is noteworthy that the thermocouples initiating the trip on the BL_5x repeatability tests were generally at 302 cm (level 7) below the top of the heated length rather than at the high power zone. One may have expected that the highest power location would dryout first.

Table F-2. Thermocouples initiating power trip for repeatability tests

Test ID[1] --	Time of Trip (s)	TC Initiating Trip --	TC Reading at Trip (K)	Peak TC Reading[2] (K)	Time of Peak Reading (s)
BL_5	2360	TI_B_j_7	603.6	627.76	2373
	2360	TI_D_s_7	599.5	631.85	2373
	2360	TI_C_m_7	602.2	629.56	2372.5
BL_5B	1482	TI_A_a_7	566	588	1490
	1482	TI_B_g_7	563.8	587.8	1490
	1482	TI_B_j_7	565.2	593.74	1492
BL_5C	1344	TI_C_q_6	566	609	1358
	1344	TI_D_w_6	593.3	629	1356
BL_5D	1529	TI_C_q_6	468	603.7	1512
	1529	TI_D_w_6	425	588.7	1512
	1529	TI_B_j_7	601.7	647.1	1552.4
	1529	TI_D_v_7	613.74	640.2	1550

---

1. For clarity, the ECS-2 prefix on the test names has been dropped.
2. The thermocouples continue to heatup after power trip due to stored energy in the heater.

Appendix G

ECS-2 Air Ingress Test Results

Appendix G

ECS-2 Air Ingress Test Results

INTRODUCTION

Twelve experiments were conducted in the ECS-2 facility to examine the functional relationship between the rate at which air was entrained into the test section and other test section boundary conditions. These experiments were termed the air ingress (AI) tests. Inlet liquid temperature and flowrate and back pressure on the lower plenum (the standpipe setting) were the major variables in the AI tests.

The procedure used to conduct the AI tests was somewhat different than the procedure used to conduct the excursion tests. Since the major objective of the AI tests was to determine the parameters influencing entrainment of air into the test section, the heater was not energized. For a given standpipe setting and inlet fluid temperature, experiment conduct entailed injecting water into the upper plenum in the normal manner, allowing the test section to stabilize, printing a data scan (an average of approximately 25 seconds of data) on the DAS, and then changing the inlet liquid flowrate and repeating the data scan. For the AI tests, the inlet liquid flowrate was increased in 0.2 l/s increments between 0.1 and 1.5 l/s. After a change in inlet flowrate, the test section was allowed to stabilize for at least 2 minutes before taking a data scan.

Tests were conducted with three different inlet temperatures and four different standpipe settings. Table G-1 is the test matrix for the AI test group.

RESULTS

Data collected during the AI test series shows that, for a given standpipe level[1] and inlet liquid temperature, the rate at which air is entrained into the top of the test section increases with increasing liquid flowrate. Figures G-1, G-2, and G-3 graphically present the data collected during the

---

[1] For the purposes of this discussion, the standpipe level is referenced to the bottom of the lower plenum.

Table G-1. Matrix of Air Ingress Tests Conducted

Test Name	Inlet Subcooling (K)	Inlet Temp (K)	Volumetric Flow (l/s)	Liq. Superficial Velocity (m/s)	Standpipe[c] (cm)
ECS-2AI_1	72.5	296	[a]	[b]	171
ECS-2AI_2	72.5	296	[a]	[b]	112
ECS-2AI_3	72.5	296	[a]	[b]	80
ECS-2AI_4	72.5	296	[a]	[b]	43
ECS-2AI_5	44.5	324	[a]	[b]	171
ECS-2AI_6	44.5	324	[a]	[b]	112
ECS-2AI_7	44.5	324	[a]	[b]	80
ECS-2AI_8	44.5	324	[a]	[b]	43
ECS-2AI_9	22.5	346	[a]	[b]	171
ECS-2AI_10	22.5	346	[a]	[b]	112
ECS-2AI_11	22.5	346	[a]	[b]	80
ECS-2AI_12	22.5	346	[a]	[b]	43

---

a. Data taken for flowrates from 0.1 to 1.5 l/s in 0.2 l/s steps
b. Superficial velocity ranged from 0.75 m/s to 1.127 m/s
c. Standpipe referenced to bottom of lower plenum

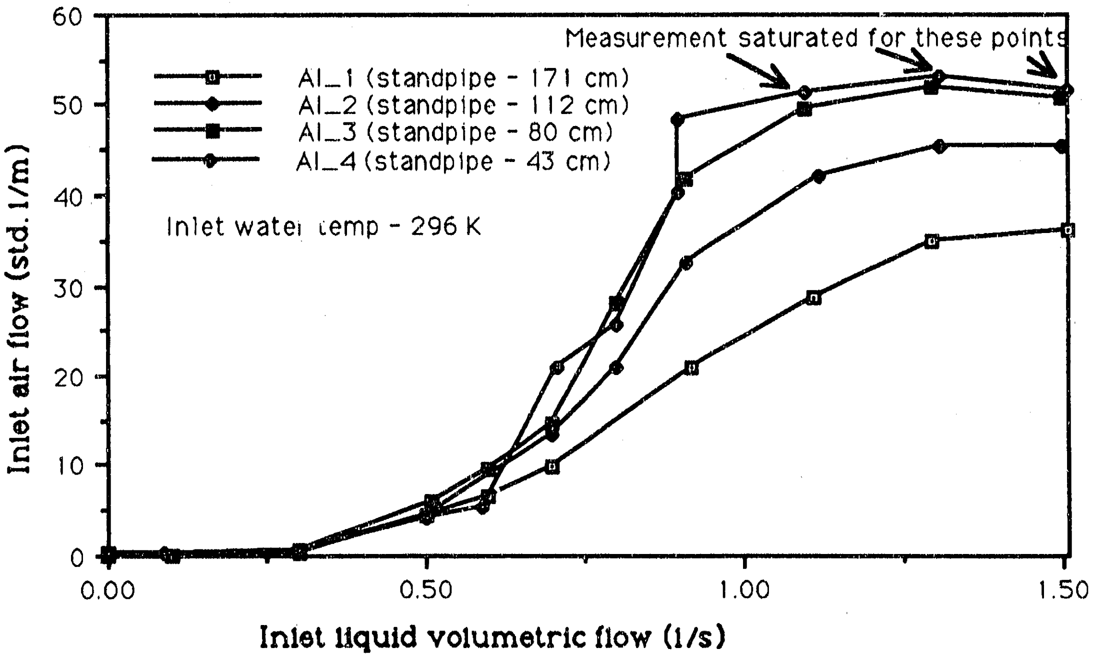

Figure G-1. Air ingress rate for 296 K inlet liquid temperature.

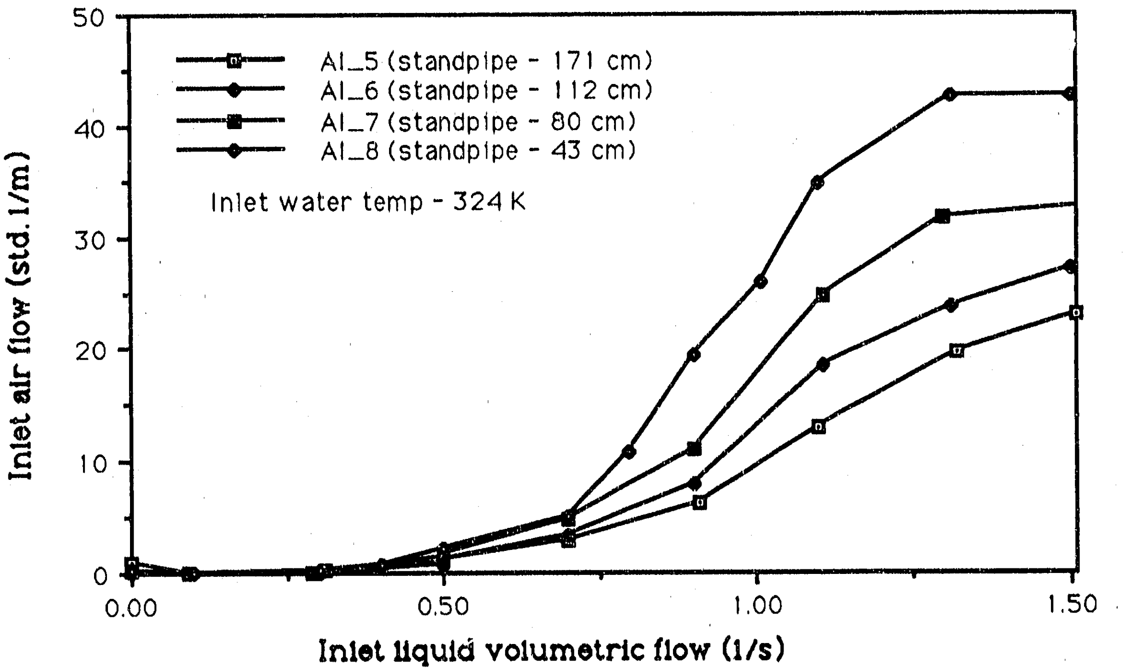

Figure G-2. Air ingress rate for 324 K inlet liquid temperature.

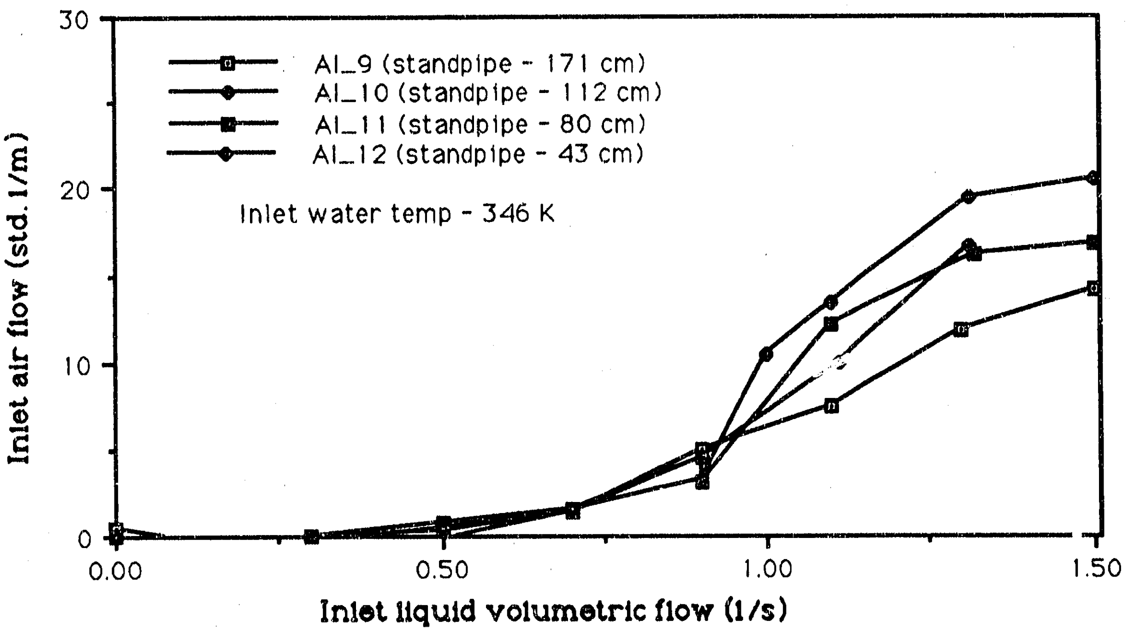

Figure G-3. Air ingress rate for 346 K inlet fluid temperature.

AI tests in terms of the measured air flowrate at the test section inlet as a function of the liquid volumetric flowrate. Each of the figures presents the data taken for a specific inlet fluid temperature and for all of the standpipe level settings.

Figures G-1, G-2, and G-3 clearly show the effects of standpipe level (back pressure) on the air ingress rate. The trend is what one would expect in that as the imposed pressure differential on the test section is decreased, the air flowrate should decrease if all other parameters remain constant. Considering a pressure balance on the simple schematic shown in Figure G-4, the test section flowrate is proportional to the test section and standpipe head difference. If h_1 is constant then as the value of h_2 increases, the driving potential for the air flow decreases. For simplicity, if we assume that all other factors are equal (interfacial drag, wall drag, viscosity effects, etc.) then the air flowrate would be expected to decrease with increasing standpipe levels. Data shown in Figures G-1, G-2, and G-3 is consistent with this expectation. As shown on Figure G-2, runs at a liquid flowrate of 1.5 l/s showed measured air flowrates of 43-, 33-, 27-, and 23 std. l/m for the 43-, 80-, 112-, and 171 cm standpipe levels,

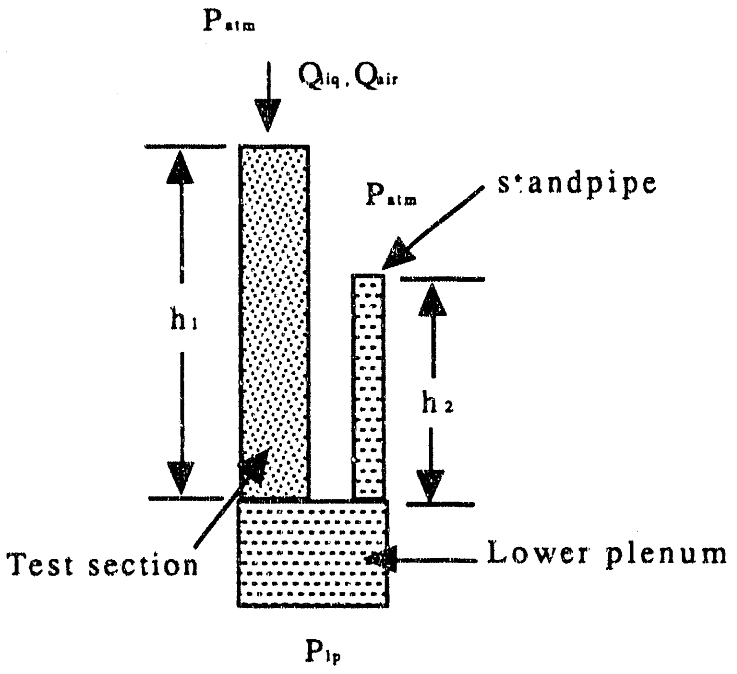

Figure G-4. Test section schematic for simplified pressure balance.

respectively. This same trend is evident in the other figures as well.[2]

Inlet liquid temperature had a significant effect on the air entrainment rate. As expected, the cooler the inlet liquid temperature, the higher the air entrainment rate. Figures G-5, G-6, G-7, and G-8 present the AI data for each standpipe setting with inlet temperature as a parameter. Data in Figure G-8 (171 cm standpipe setting) for the highest liquid flowrate (1.5 l/s) show that the air entrainment rate decreased by a factor of 2 (from about 36 std. l/m to 15 std. l/m) as the inlet liquid temperature increased from 296 K to 346 K. Since the liquid viscosity decreases by a factor of 2 over this range of temperature, it is likely that viscosity is a predominant factor influencing the air entrainment. As shown on the other figures, the other standpipe level settings showed the same general trends.

Tabular values for the data collected during the AI test series runs is given in Table G-2. The values listed represent time averages of

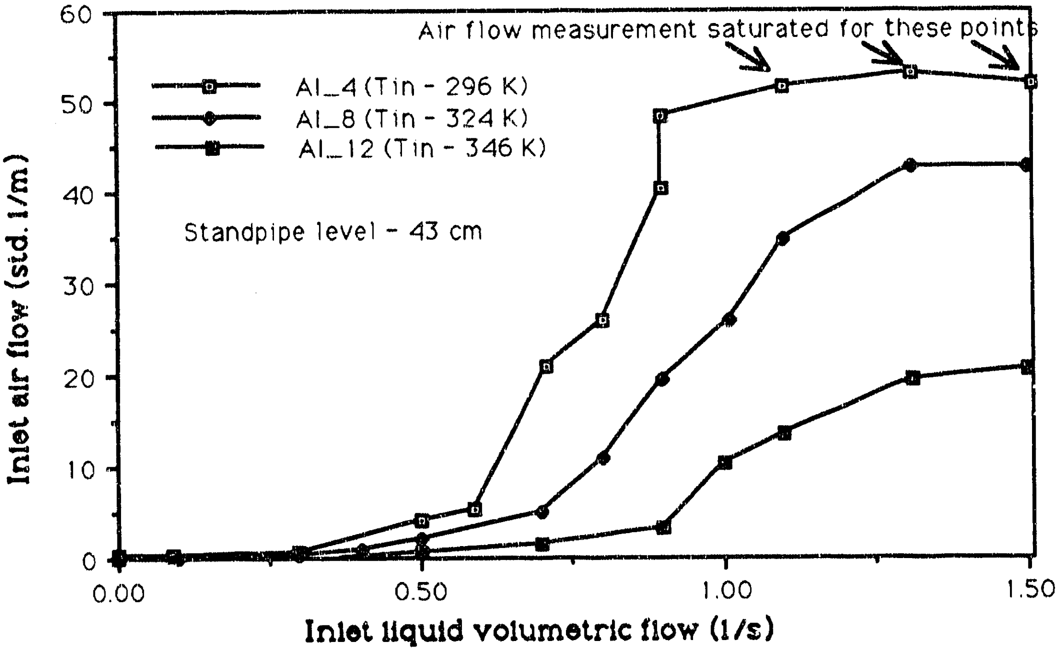

Figure G-5. Air ingress rate for 43 cm standpipe setting.

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[2] The inlet air flowrate measurement for the 296 K inlet water temperature case with 43 cm and 80 cm standpipe levels was near saturation (the measurement range maximum was ~50 std. l/m).

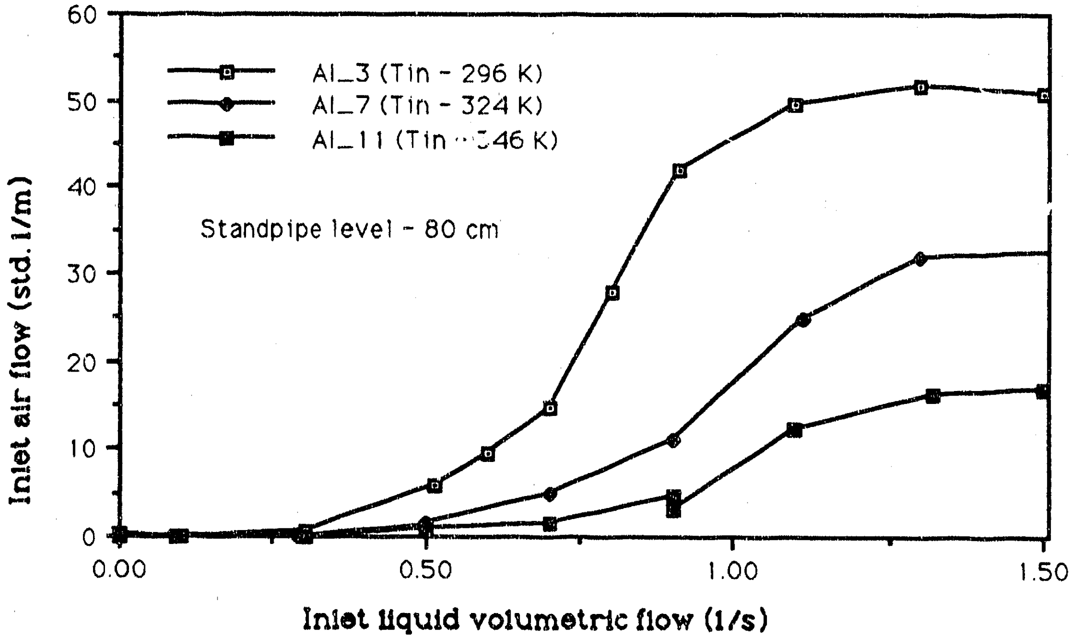

Figure G-6. Air ingress rate for 80 cm standpipe setting.

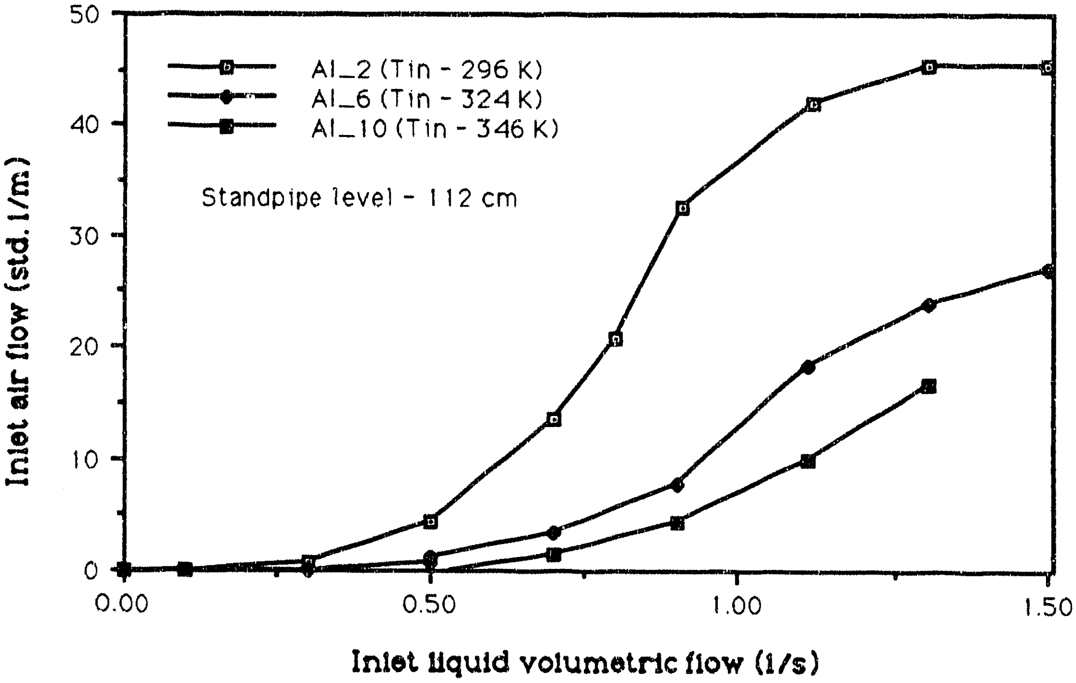

Figure G-7. Air ingress results for 112 cm standpipe setting.

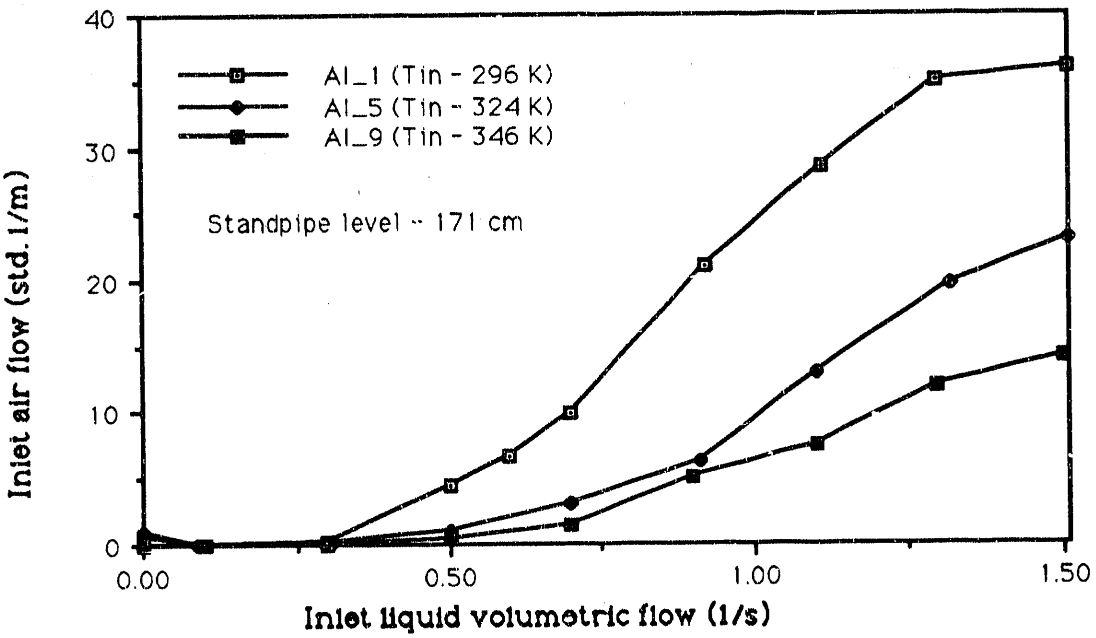

Figure G-8. Air ingress results for 171 cm standpipe setting.

approximately 20 data points.

CONCLUSIONS

Data was gathered in the ECS-2 facility to examine the rate at which air was entrained into the top of the test section. The data shows that the air entrainment rate is a function of the liquid flowrate, liquid inlet temperature, and back pressure imposed on the facility.

Analysis of the data indicates the following relationships:

- air entrainment rate increases with increasing liquid flowrate
- air entrainment rate decreases with increasing inlet fluid temperature
- air entrainment rate decreases as the back pressure on the facility is increased (the standpipe height is increased).

Table G-2. Air Ingress Test Results Summary

Test ID	*********** Air Ingress General Test Parameters ***********					
	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [1.]	Water Inlet Temp. (K)	Air Entrainment Rate (std. l/m) [2.]	Stand Pipe Height (m) [3.]	Air Inlet Temperature (K)
ECS-2AI_1	0.00	0.00	298.97	-0.01	1.71	309.13
ECS-2AI_1	0.10	0.08	298.66	0.05	1.73	309.06
ECS-2AI_1	0.30	0.23	296.95	0.29	1.74	309.09
ECS-2AI_1	0.50	0.38	295.49	4.41	1.76	308.86
ECS-2AI_1	0.70	0.52	298.11	9.85	1.78	307.48
ECS-2AI_1	0.92	0.69	293.50	20.97	1.78	304.72
ECS-2AI_1	1.11	0.83	295.30	28.56	1.81	302.50
ECS-2AI_1	1.30	0.98	296.33	34.88	1.82	301.87
ECS-2AI_1	1.51	1.13	295.84	36.02	1.86	301.47
ECS-2AI_1	0.60	0.45	296.90	6.59	1.75	303.52
ECS-2AI_1	0.00	0.00	297.41	0.00	1.72	304.81
ECS-2AI_2	0.00	0.00	305.96	0.03	1.05	308.77
ECS-2AI_2	0.10	0.08	297.38	0.08	1.12	309.13
ECS-2AI_2	0.30	0.22	295.93	0.69	1.13	309.05
ECS-2AI_2	0.50	0.38	299.37	4.44	1.15	308.75
ECS-2AI_2	0.70	0.53	294.19	13.45	1.16	306.74
ECS-2AI_2	0.91	0.68	295.79	32.61	1.17	305.55
ECS-2AI_2	1.12	0.84	295.91	42.03	1.22	305.84
ECS-2AI_2	1.31	0.98	296.51	45.33	1.24	305.95
ECS-2AI_2	1.50	1.13	296.01	45.39	1.24	305.60
ECS-2AI_2	0.80	0.60	295.74	20.78	1.16	304.65
ECS-2AI_2	0.00	0.00	296.33	0.07	1.11	305.38
ECS-2AI_3	0.00	0.00	304.08	0.04	0.77	308.98
ECS-2AI_3	0.10	0.07	295.82	0.14	0.81	309.26
ECS-2AI_3	0.30	0.22	296.87	0.71	0.83	309.27
ECS-2AI_3	0.51	0.38	294.86	5.95	0.84	308.78
ECS-2AI_3	0.70	0.53	296.47	14.73	0.86	307.88
ECS-2AI_3	0.91	0.68	297.50	41.92	0.88	306.93
ECS-2AI_3	1.10	0.83	296.17	49.46	0.96	306.97
ECS-2AI_3	1.30	0.98	295.77	51.80	0.89	306.61
ECS-2AI_3	1.50	1.13	295.17	50.82	0.94	306.60
ECS-2AI_3	0.80	0.60	297.56	27.93	0.86	306.06
ECS-2AI_3	0.60	0.45	298.15	9.41	0.85	305.11
ECS-2AI_3	0.00	0.00	298.17	0.19	0.80	305.60

Table G-2. Air Ingress Test Results Summary (Cont'd)

Test ID	*********** Air Ingress General Test Parameters ***********					
	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [1.]	Water Inlet Temp. (K)	Air Entrainment Rate (std. l/m) [2.]	Stand Pipe Height (m) [3.]	Air Inlet Temperature (K)
ECS-2AI_4	0.00	0.00	295.72	0.07	0.44	302.23
ECS-2AI_4	0.09	0.07	299.20	0.22	0.46	302.58
ECS-2AI_4	0.30	0.22	297.69	0.65	0.47	302.65
ECS-2AI_4	0.50	0.38	294.70	4.21	0.49	302.63
ECS-2AI_4	0.71	0.53	296.01	20.78	0.48	301.63
ECS-2AI_4	0.90	0.68	295.65	48.23	0.47	301.85
ECS-2AI_4	1.10	0.83	296.24	51.36	0.53	301.76
ECS-2AI_4	1.31	0.98	295.02	53.07	0.61	301.57
ECS-2AI_4	1.51	1.13	294.34	51.71	0.57	301.91
ECS-2AI_4	0.80	0.60	297.03	25.77	0.51	301.99
ECS-2AI_4	0.90	0.68	295.19	40.17	0.54	301.87
ECS-2AI_4	0.59	0.45	297.87	5.41	0.49	302.69
ECS-2AI_4	0.00	0.00	297.82	0.22	0.45	302.98
ECS-2AI_5	0.00	0.00	322.86	0.18	1.70	309.90
ECS-2AI_5	0.09	0.07	325.72	-0.01	1.71	309.87
ECS-2AI_5	0.31	0.23	324.85	0.22	1.73	309.70
ECS-2AI_5	0.50	0.37	324.80	1.11	1.74	309.83
ECS-2AI_5	0.70	0.53	324.92	2.93	1.76	309.56
ECS-2AI_5	0.91	0.68	323.97	6.30	1.78	309.48
ECS-2AI_5	1.10	0.83	324.48	12.91	1.81	308.13
ECS-2AI_5	1.32	0.99	325.54	19.54	1.84	306.43
ECS-2AI_5	1.51	1.14	324.89	23.03	1.89	305.45
ECS-2AI_5	0.50	0.38	325.42	0.94	1.74	307.04
ECS-2AI_5	0.00	0.00	323.81	0.97	1.70	307.96
ECS-2AI_6	0.00	0.00	323.24	0.10	1.09	310.25
ECS-2AI_6	0.10	0.07	324.74	-0.10	1.10	310.48
ECS-2AI_6	0.30	0.22	325.12	0.08	1.12	310.45
ECS-2AI_6	0.50	0.38	324.91	1.09	1.13	310.52
ECS-2AI_6	0.70	0.52	324.66	3.34	1.15	310.43
ECS-2AI_6	0.90	0.68	324.48	7.84	1.16	309.60
ECS-2AI_6	1.11	0.83	324.39	18.34	1.18	308.45
ECS-2AI_6	1.31	0.98	325.05	23.80	1.21	307.66
ECS-2AI_6	1.50	1.13	325.34	26.95	1.23	307.28
ECS-2AI_6	0.50	0.37	327.92	0.70	1.13	307.97

Table G-2. Air Ingress Test Results Summary (Cont'd)						
	*********** Air Ingress General Test Parameters ***********					
Test ID	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [1.]	Water Inlet Temp. (K)	Air Entrainment Rate (std. l/m) [2.]	Stand Pipe Height (m) [3.]	Air Inlet Temperature (K)
ECS-2AI_6	0.00	0.00	320.67	0.00	1.72	320.63
ECS-2AI_7	0.00	0.00	317.22	-0.35	0.79	306.01
ECS-2AI_7	0.09	0.07	322.56	-0.27	0.80	305.81
ECS-2AI_7	0.29	0.22	325.33	0.08	0.81	305.93
ECS-2AI_7	0.50	0.38	323.04	1.57	0.83	305.87
ECS-2AI_7	0.70	0.53	322.98	4.88	0.84	305.65
ECS-2AI_7	0.90	0.68	323.79	10.99	0.85	305.21
ECS-2AI_7	1.11	0.83	323.95	24.65	0.88	304.43
ECS-2AI_7	1.30	0.98	324.24	31.69	0.91	303.89
ECS-2AI_7	1.53	1.15	323.78	32.57	0.99	303.21
ECS-2AI_7	0.50	0.37	324.02	1.35	0.83	303.07
ECS-2AI_7	0.00	0.00	323.20	0.14	0.78	303.34
ECS-2AI_8	0.00	0.00	322.69	-0.36	0.41	305.74
ECS-2AI_8	0.10	0.07	323.69	-0.07	0.43	305.76
ECS-2AI_8	0.30	0.22	324.05	0.29	0.44	306.00
ECS-2AI_8	0.50	0.38	323.54	2.18	0.45	305.96
ECS-2AI_8	0.70	0.53	323.79	5.10	0.46	305.95
ECS-2AI_8	0.90	0.68	323.88	19.31	0.49	305.18
ECS-2AI_8	1.10	0.83	323.97	34.77	0.50	304.58
ECS-2AI_8	1.31	0.98	323.81	42.53	0.53	304.18
ECS-2AI_8	1.50	1.13	324.45	42.66	0.56	304.22
ECS-2AI_8	1.01	0.76	325.97	25.74	0.48	303.93
ECS-2AI_8	0.80	0.60	324.04	10.80	0.49	303.87
ECS-2AI_8	0.40	0.30	325.14	0.78	0.44	304.10
ECS-2AI_8	0.00	0.00	323.92	0.16	0.41	304.37
ECS-2AI_9	0.00	0.00	320.13	-1.66	1.07	308.80
ECS-2AI_9	0.10	0.07	349.40	-0.10	1.70	308.74
ECS-2AI_9	0.30	0.22	350.72	-0.02	1.70	308.97
ECS-2AI_9	0.50	0.38	346.91	0.34	1.72	309.17
ECS-2AI_9	0.70	0.53	347.27	1.38	1.73	308.86
ECS-2AI_9	0.90	0.68	345.18	5.03	1.75	309.06
ECS-2AI_9	1.10	0.83	345.18	7.44	1.79	308.61
ECS-2AI_9	1.30	0.98	345.13	11.82	1.82	307.60

Table G-2. Air Ingress Test Results Summary (Cont'd)

	************ Air Ingress General Test Parameters ************					
Test ID	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [1.]	Water Inlet Temp. (K)	Air Entrainment Rate (std. l/m) [2.]	Stand Pipe Height (m) [3.]	Air Inlet Temperature (K)
ECS-2AI_9	1.50	1.13	345.52	14.12	1.81	306.60
ECS-2AI_9	0.00	0.00	341.52	0.54	1.68	308.24
ECS-2AI_10	0.00	0.00	337.97	-0.31	1.07	314.71
ECS-2AI_10	0.10	0.07	349.82	-0.41	1.08	312.94
ECS-2AI_10	0.30	0.22	346.71	-0.13	1.09	312.28
ECS-2AI_10	0.50	0.37	347.90	-0.15	1.10	312.03
ECS-2AI_10	0.70	0.53	344.70	1.35	1.13	311.31
ECS-2AI_10	0.90	0.68	343.48	4.44	1.15	311.03
ECS-2AI_10	1.11	0.83	342.66	9.98	1.16	310.89
ECS-2AI_10	1.31	0.98	342.42	16.64	1.18	310.14
ECS-2AI_11	0.00	0.00	327.54	-1.42	0.41	306.47
ECS-2AI_11	0.09	0.07	346.03	-0.14	0.78	307.07
ECS-2AI_11	0.30	0.23	347.35	0.06	0.79	307.31
ECS-2AI_11	0.50	0.38	345.61	0.82	0.80	307.04
ECS-2AI_11	0.70	0.53	346.12	1.60	0.82	306.71
ECS-2AI_11	0.90	0.68	343.91	4.54	0.84	305.91
ECS-2AI_11	1.10	0.83	346.25	12.15	0.87	305.56
ECS-2AI_11	1.32	0.99	347.03	16.11	0.87	305.65
ECS-2AI_11	1.50	1.13	346.38	16.74	0.89	305.27
ECS-2AI_11	0.90	0.68	348.01	3.10	0.85	305.36
ECS-2AI_11	0.00	0.00	320.67	0.00	1.72	320.63
ECS-2AI_12	0.00	0.00	340.81	-0.21	0.39	306.10
ECS-2AI_12	0.10	0.07	349.33	-1.24	0.40	306.99
ECS-2AI_12	0.30	0.23	351.19	-0.35	0.41	307.47
ECS-2AI_12	0.50	0.38	349.49	0.47	0.42	307.09
ECS-2AI_12	0.70	0.53	346.78	1.57	0.44	306.72
ECS-2AI_12	0.90	0.68	346.24	3.34	0.46	305.65
ECS-2AI_12	1.10	0.83	346.21	13.44	0.50	305.51
ECS-2AI_12	1.31	0.98	346.37	19.49	0.51	305.43
ECS-2AI_12	1.50	1.13	347.43	20.49	0.51	305.14
ECS-2AI_12	1.00	0.75	346.00	10.34	0.49	305.13
ECS-2AI_12	0.00	0.00	343.55	0.01	0.39	305.12

Table G-2. Air Ingress Test Results Summary (Cont'd)

[1.] Superficial velocity based on test section flow area of 13.31 m^2.
[2.] Air ingress rate based on inlet air flow measurement (Q_A_IN).
[3.] Standpipe height referenced to bottom of the lower plenum.

Location	Elevation (cm)
Top of upper plenum	-182.2
Bottom of upper plenum	-161.9
Top of heated length	0
Bottom of heated length	380.9
Top of lower plenum	410.2
Bottom of lower plenum	438.2

Appendix H

Video System Used During the ECS-2 Thermal Excursion Tests

Appendix H

Video System Used During the ECS-2 Thermal Excursion Tests

A video recording system was used on many of the thermal excursion experiments to record phenomena of interest. Figure H-1 shows a schematic of the video equipment. Video system hardware and control software was supplied by Mark Heyer of Heyer Tech, Inc., Palo Alto, CA.

The video system consisted of three video cameras, three monitors, three video decks equipped with optical disc recorders (12" optical discs), and other associated hardware and software components. The entire system was synchronized to the data acquisition system for timing purposes. Control of the video system was accomplished using Hypercard software on a

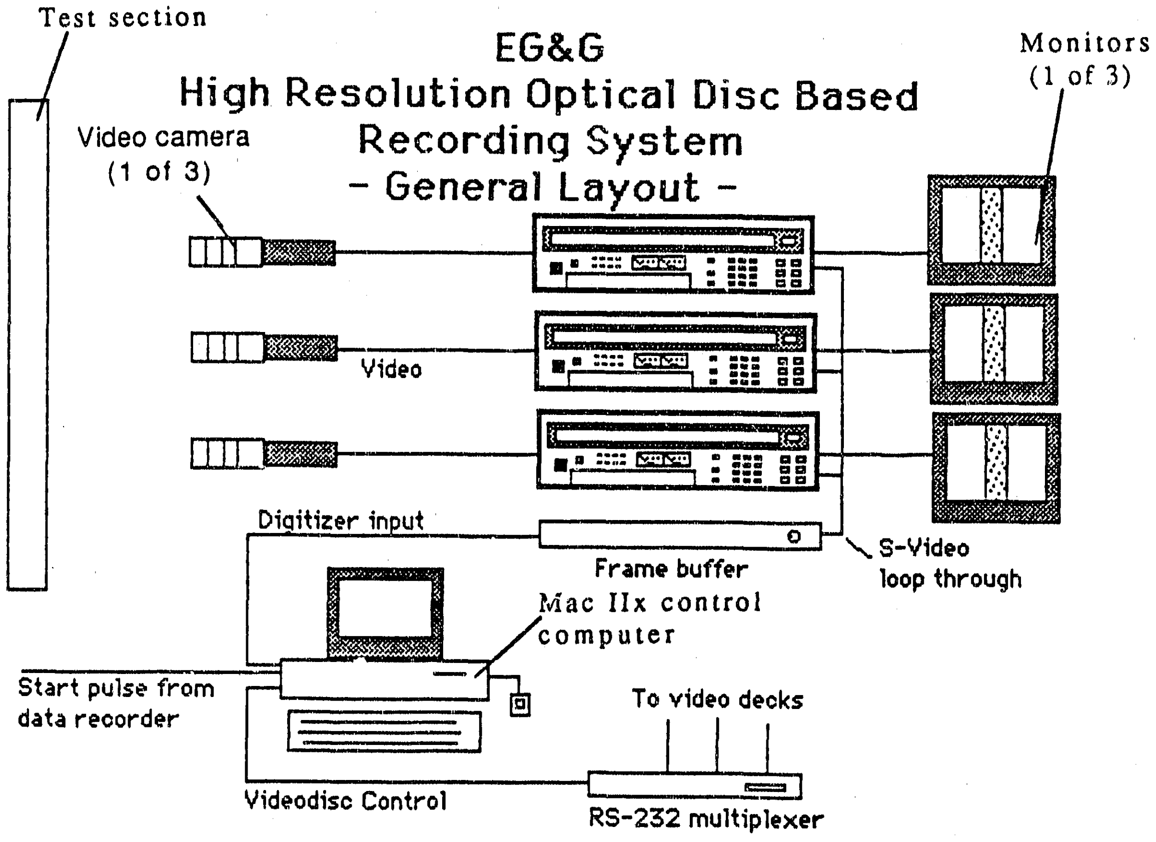

Figure H-1. Video system used on ECS-2 thermal excursion tests

Macintosh IIx computer. Table H-1 lists the components in the video system.

The video system was capable of recording up to approximately 30 frames per second from each of the cameras. The signal was displayed on the monitors and/or written to optical disc for archival. Information regarding the archived recordings is stored in a Hypercard stack for post-test retrieval/display and analysis. At the highest recording rate, each video disc could hold approximately 30 minutes of video data.

For the ECS-2 and WSR tests, the top and middle camera were generally trained on the test section high power zone (between 200- and 302 cm) and the bottom camera was trained on the outlet plenum. Cameras were set up to provide a 20-40 cm field of view. The system was used to monitor the test section on nearly all of the experiments although, due to the large volume of data generated by video, video data was not archived for all tests nor was data archived for the whole duration of any single test.

Analysis and review of the video data is a time consuming operation. Useful and informative insights can be obtained from analysis of the video data. However, due to time constraints, video results are not presented here.

Table H-1. Video recording system components

Component	Manufacturer	Model Number
Hardware		
Camera (3)	CCD	TK-66
Monitor (3)	Sony	PVM-122
Optical Disc Recorder (3)	Panasonic	TQ-3031F
Optical Disc	Panasonic	TQ-FH331/TQ-FH332[1]
Video Distribution Amp.	Sigma Electronics	VDA-100A
Data Broadcast Unit	Black Box	DB 8/25
Digital Time Base Corrector	FOR-A	FA300
Hardware/software control		
Computer	Apple	Mac IIx
Controller	IoTech	Mac/IEEE488
I/O	National Inst.	NB-D10-24
Image capture	SCION	Image Capture 2

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1. Single-sided and double-sided discs respectively.

Appendix I

Questionable or Failed Measurements for the ECS-2 and ECS-2c Thermal Excursion Experiments

Appendix I

Questionable or Failed Measurements for the ECS-2 and ECS-2c Thermal Excursion Experiments

During the INEL thermal excursion experiment program, a detailed written log was maintained to document various aspects of the experiment including instrumentation/measurement problems. After review of quick look plots (data comparisons compiled immediately after the conduct of an experiment) and more thorough analyses of the experimental data, additional measurements known or suspected of being bad have been identified.

For historical documentation, the measurements known to be questionable for each thermal excursion experiment are listed in Table I-1. The table lists the experiment name, the date the experiment was conducted, and the measurements identified by "DAS Tag ID" (see Appendix B for a description of the measurement) deemed or known to be questionable. An entry of a particular measurement on a given test does not necessarily imply that the measurement was unusable for the whole experiment and does not imply that the measurement was unusable for experiments conducted chronologically after that point in time. Generally, measurements problems were electrical or electronic in nature (bad connectors, problems with analog-to-digital conversion cards, broken wires, reference oven problems, etc.) and were readily corrected once identified.

The information in Table I-1 provides a quick indication of measurements that obviously experienced some problem during the excursion tests and does not constitute an extensive data quality review. Furthermore, the fact that an instrument is not listed in the table does not guarantee that the measurement performed flawlessly during the experiments.

Table I-1. List of questionable or failed instruments for thermal excursion tests

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2BL_1	12/27/89	TI_D_s_7			DP_D_05, DP_D_06	WT_W_OUT
ECS-2BL_1B	12/29/89	TI_D_s_7, TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_2	12/29/89	TI_D_s_7, TI_C_o_6, TI_D_u_6				WT_W_OUT
ECS-2BL_5	12/15/89	TI_D_u_6, TI_D_s_7, TI_C_o_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_5B	12/19/89	TI_D_u_6, TI_C_o_6				WT_W_OUT
ECS-2BL_5C	12/29/89	TI_D_u_6, TI_C_o_6, TI_D_s_7		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2BL_5D	01/10/90	TI_D_u_6, TI_C_o_6, TI_A_a_7		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_6	12/16/89	TI_C_o_6				WT_W_OUT
ECS-2BL_7	12/19/89	TI_C_o_6				WT_W_OUT
ECS-2BL_7B	12/29/89	TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_11	12/14/89	TI_A_d_5				WT_W_OUT
ECS-2BL_11B	12/29/89	TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2BL_12	12/15/89	TI_C_o_6				WT_W_OUT
ECS-2BL_12B	12/29/89	TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_13	12/15/89	TI_C_o_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_14	12/15/89	TI_C_o_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_17	12/20/89	TI_D_s_7				WT_W_OUT
ECS-2BL_18	12/20/89	TI_D_s_7				WT_W_OUT

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2BL_18B	01/10/90	TI_D_s_7, TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
ECS-2BL_22	12/19/89	TI_D_s_7				WT_W_OUT
ECS-2BL_23	12/20/89					WT_W_OUT
ECS-2BL_23B	12/21/89	TI_D_s_7				WT_W_OUT
ECS-2BL_26	12/19/89					WT_W_OUT
ECS-2BL_26B	12/29/89	TI_D_s_7, TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2BL_27	12/19/89	TI_D_s_7				WT_W_OUT
FC_1	12/29/89	TI_D_s_7, TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
FC_2	12/29/89	TI_C_o_6, TI_D_u_6		P_A_0, P_B_0, P_C_0, P_D_0		WT_W_OUT
WSR0380	01/15/90	TI_C_q_6, TI_C_o_6, TI_D_u_6				WT_W_OUT
WSR0580	01/16/90	TI_C_q_6, TI_C_o_6, TI_D_u_6, TI_D_s_7				WT_W_OUT
WSR0580B	01/16/90			lost all data		

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
WSR0580C	01/16/90	TI_C_q_6, TI_C_o_6, TI_D_u_6, TI_D_v_7				WT_W_OUT
WSR0760	01/16/90	TI_C_q_6, TI_C_o_6, TI_D_u_6				WT_W_OUT
WSR0960	01/17/90	TI_C_q_6, TI_C_o_6, TI_D_u_6				Q_A_IN, WT_W_OUT
WSR1040	01/17/90	TI_D_v_7, TI_C_q_6, TI_C_o_6, TI_D_u_6				WT_W_OUT
WSR1040B	01/17/90	TI_D_v_7, TI_C_q_6, TI_C_o_6, TI_D_u_6				Q_A_IN, WT_W_OUT
WSR1340	01/17/90	TI_D_v_7, TI_C_q_6, TI_C_o_6, TI_D_u_6				WT_W_OUT

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2cE11	06/28/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE12	06/28/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE13	06/28/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE14	07/03/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE21	06/27/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4	TF_D_1			
ECS-2cE22	06/27/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				

Table I-1. List of questionable or failed instruments for thermal excursion tests (continued)

Test ID	Date Conducted	Wall Thermocouples	Fluid Thermocouples	Pressures	Differential pressures	Flow Meters
ECS-2cE23	07/03/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE24	07/03/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE31	06/27/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE32	06/28/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				Q_A_IN, Q_A_OUT
ECS-2cE34	07/04/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				
ECS-2cE42	06/28/90	TI_A_d_5, TI_D_u_4, TI_D_w_2, TI_B_i_4				

Appendix J

Experimental Data Summary for INEL Thermal Excursion Tests (ECS-2, WSR, and ECS-2cE tests)

Appendix J

Experimental Data Summary for INEL Thermal Excursion Tests (ECS-2, WSR, and ECS-2cE tests)

The manner in which the INEL thermal excursion tests were conducted constituted a series of steady-state steps during which the power and flowrate were constant. Data averages during these constant power steps were calculated in order to facilitate data interpretation. Averages were necessary due to fluctuations in the data - especially as saturation conditions were achieved in the test section and/or the dryout point was approached. This appendix presents data averages calculated for each parameter recorded on the DAS for each of the thermal excursion experiments conducted. Averages computed for the power step immediately preceding the power step on which excursion occurred and for the power step on which excursion occurred are presented on the following tables. Since the time frame for averaging on each experiment was different, the starting and ending time for the computation of the averages is given in the tables. Every effort was made to ensure that averages were computed during time frames when all wall thermocouples were in a wetted state, although this was not always possible.

Note that in the attached data tables, questionable or failed measurement values are highlighted. Note also that due to the chaotic flooding processes occuring during the excursion power step, the air flow measurements may not be valid.

Attached tables contain the following information:

Table J-1	General test parameters for the ECS-2BL experiments
Table J-2	ECS-2BL test pre-excursion and excursion power step data averages
Table J-3	General test parameters for the WSR experiments
Table J-4	WSR test pre-excursion and excursion power step data averages

Table J-5 General test parameters for the ECS-2cE experiments

Table J-6 ECS-2cE tests pre-excursion and excursion power step data averages.

Table J-1. ECS-2 test results summary

TEST ID [1.]	***************** ECS-2 General Test Parameters ********************							
	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [2.]	Water Inlet Temp. (K)	Air Entrainment Rate [6.] (Std. L/min.)	Stand Pipe Height (cm) [3.]	Total Test Section Power (kW)	Power to Saturate Outlet (kW)	R factor (P / Psat) -
ECS-2BL_1 - Pre	0.097	0.073	296.5	1.0	400	65.93	29.72	2.22
ECS-2BL_1 - Ex	0.096	0.072	296.7	1.3	394	70.8 [7.]	29.54	2.38
ECS-2BL_1B - Pre	0.102	0.077	296.1	0.4	400	76.05	31.69	2.40
ECS-2BL_1B - Ex	0.101	0.076	296.1	0.3	402	78.69	31.37	2.51
ECS-2BL_2 - Pre	0.297	0.223	296.2	3.1	395	98.53	92.14	1.07
ECS-2BL_2 - Ex	0.297	0.223	296.4	2.6	394	101.48	91.88	1.10
ECS-2BL_5 - Pre	0.104	0.078	325.9	4.8	403	50.91	19.20	2.65
ECS-2BL_5 - Ex	0.104	0.078	326.0	0.0	409	53.48	19.07	2.80
ECS-2BL_5B - Pre	0.098	0.074	326.0	0.6	404	47.37	18.04	2.63
ECS-2BL_5B - Ex	0.098	0.074	326.1	10.0	399	50.15	17.85	2.81
ECS-2BL_5C - Pre	0.099	0.074	323.9	1.5	399	45.76	18.95	2.41
ECS-2BL_5C - Ex	0.098	0.074	324.0	[4.]	401	47.96	18.78	2.55
ECS-2BL_5D - Pre	0.100	0.075	324.1	1.3	400	47.55	19.15	2.48
ECS-2BL_5D - Ex	0.100	0.075	324.0	8.0	401	50.76	19.36	2.62
ECS-2BL_6 - Pre	0.300	0.226	324.5	5.5	400	96.48	57.12	1.69
ECS-2BL_6 - Ex	0.300	0.225	324.7	5.8	403	97.49 [7.]	56.77	1.72
ECS-2BL_7 - Pre	0.481	0.361	324.8	0.2	394	80.80	90.54	0.89
ECS-2BL_7 - Ex	0.532	0.400	324.4	3.4	393	99.80	101.28	0.99
ECS-2BL_7B - Pre	0.506	0.380	324.3	1.8	395	96.43	96.67	1.00
ECS-2BL_7B - Ex	0.504	0.379	323.8	2.6	395	99.15	97.50	1.02
ECS-2BL_11 - Pre[5.]	0.299	0.225	346.6	0.1	395	47.04	29.22	1.61
ECS-2BL_11 - Ex[5.]	0.300	0.225	346.5	0.6	400	50.59	29.45	1.72
ECS-2BL_11B - Pre	0.304	0.229	345.8	[4.]	400	68.70	30.65	2.24
ECS-2BL_11B - Ex	0.301	0.226	345.9	[4.]	406	70.60 [7.]	29.93	2.36

Table J-1. ECS-2 test results summary (continued)

TEST ID [1.]	**************** ECS-2 General Test Parameters *******************							
	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [2.]	Water Inlet Temp. (K)	Air Entrainment Rate (Std. L/min.)	Stand Pipe Height (cm) [3.]	Total Test Section Power (kW)	Power to Saturate Outlet (kW)	R factor (P / Psat) -
ECS-2BL_12 - Pre[5.]	0.505	0.379	343.3	2.1	398	64.15	56.25	1.14
ECS-2BL_12 - Ex[5.]	0.505	0.379	342.7	2.2	399	66.41	57.63	1.15
ECS-2BL_12B - Pre	0.499	0.375	346.8	0.5	393	93.94	48.58	1.93
ECS-2BL_12B - Ex	0.498	0.374	346.5	0.2	419	96.94	48.00	2.02
ECS-2BL_13 - Pre	0.701	0.527	348.7	2.8	395	95.95	62.38	1.54
ECS-2BL_13 - Ex	0.700	0.526	348.6	1.9	404	101.97	62.74	1.63
ECS-2BL_14 - Pre	0.899	0.675	346.4	7.1	394	106.85	89.17	1.20
ECS-2BL_14 - Ex	0.899	0.676	345.9	2.6	395	112.43	90.85	1.24
ECS-2BL_17 - Pre	0.305	0.229	323.9	2.2	267	60.38	62.79	0.96
ECS-2BL_17 - Ex	0.302	0.227	323.7	2.5	282	63.32	61.77	1.03
ECS-2BL_18 - Pre	0.502	0.378	325.8	3.4	281	95.83	99.40	0.96
ECS-2BL_18 - Ex	0.502	0.377	326.0	2.3	292	97.5 [7.]	98.76	0.99
ECS-2BL_18B - Pre	0.497	0.373	323.5	2.4	284	96.07	102.97	0.93
ECS-2BL_18B - Ex	0.497	0.373	323.4	1.5	293	98.46 [7.]	103.35	0.95
ECS-2BL_22 - Pre	0.297	0.223	325.0	0.4	332	65.64	57.82	1.14
ECS-2BL_22 - Ex	0.297	0.223	325.3	4.0	312	71.13	57.74	1.23
ECS-2BL_23 - Pre	0.496	0.373	325.9	3.3	304	101.71	95.96	1.06
ECS-2BL_23 - Ex	0.497	0.373	326.2	3.5	315	103.82	95.28	1.09
ECS-2BL_23B - Pre	0.497	0.373	324.5	3.3	348	94.09	98.00	0.96
ECS-2BL_23B - Ex	0.497	0.373	325.1	3.4	321	96.61	97.58	0.99
ECS-2BL_26 - Pre	0.303	0.228	325.7	0.4	352	91.02	57.20	1.59
ECS-2BL_26 - Ex	0.303	0.228	325.8	0.2	365	93.72	57.01	1.64
ECS-2BL_26B - Pre	0.300	0.225	324.4	1.1	330	85.89	58.44	1.47
ECS-2BL_26B - Ex	0.300	0.225	324.5	0.7	399	89.01	57.62	1.54

Table J-1. ECS-2 test results summary (continued)

TEST ID [1.]	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [2.]	Water Inlet Temp. (K)	Air Entrainment Rate (Std. L/min.)	Stand Pipe Height (cm) [3.]	Total Test Section Power (kW)	Power to Saturate Outlet (kW)	R factor (P / Psat) -
	******************* ECS-2 General Test Parameters **********************							
ECS-2BL_27 - Pre	0.496	0.372	324.9	1.8	354	90.69	95.32	0.95
ECS-2BL_27 - Ex	0.466	0.350	325.2	2.4	356	93.75 [7.]	89.18	1.05
ECS-2FC_1 - Pre	0.175	0.132	323.7	0.1	355	40.08	34.57	1.16
ECS-2FC_1 - Ex	0.151	0.113	323.0	0.8	363	40.35	30.15	1.34
ECS-2FC_2 - Pre	0.323	0.242	325.5	0.6	386	80.53	61.18	1.32
ECS-2FC_2 - Ex	0.299	0.225	325.9	0.8	398	80.81	55.95	1.44

[1.] Two values for each test are given - "Pre" implies conditions at the power step just before the excursion and "Ex" represents conditions at the excursion.

[2.] Superficial velocity based on test section flow area fof 13.31 cm^2.

[3.] Reference is top of heated length, increasing downward.

[4.] Air meters not functioning properly.

[5.] No dryout occurred on these tests.

[6.] Air entrainment rates during the excursion step may not be valid because of flooding

[7.] Log book recorded value due to heater voltage offset on DAS channel.

Location	Elevation (cm)
Top of upper plenum	-182.2
Bottom of upper plenum	-161.9
Top of heated length	0
Bottom of heated length	380.9
Top of lower plenum	410.2
Bottom of lower plenum	438.2

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_A_03 kPa	DP_A_10 kPa	DP_B_03 kPa	DP_B_10 kPa	DP_C_03 kPa	DP_C_10 kPa	DP_D_02 kPa	DP_D_03 kPa
ECS-2BL_1 - Pre	3252	3272	15.757	19.678	15.112	18.854	15.607	19.357	14.035	4.248
ECS-2BL_1 - Ex	3348	3368	16.484	19.839	16.385	19.507	16.508	19.626	12.411	4.355
ECS-2BL_1B - Pre	1900	1920	15.720	20.336	15.788	20.349	15.575	20.060	12.697	4.412
ECS-2BL_1B - Ex	1960	1980	16.286	19.909	16.424	19.344	16.222	19.675	13.891	4.195
ECS-2BL_2 - Pre	1480	1500	15.542	17.613	15.706	17.585	15.779	17.333	16.532	4.842
ECS-2BL_2 - Ex	1528	1548	15.825	17.956	15.483	18.034	15.637	17.838	16.538	4.771
ECS-2BL_5 - Pre	2210	2230	17.312	20.047	17.099	19.288	17.100	19.785	12.336	4.735
ECS-2BL_5 - Ex	2340	2360	17.701	19.506	17.232	18.692	17.540	19.458	13.663	4.456
ECS-2BL_5B - Pre	1422	1442	16.690	19.357	16.786	19.302	16.594	19.220	13.731	4.112
ECS-2BL_5B - Ex	1462	1482	17.772	19.837	17.281	19.784	17.141	19.136	11.782	4.473
ECS-2BL_5C - Pre	1180	1200	16.620	19.446	16.958	19.278	16.705	19.256	13.377	4.387
ECS-2BL_5C - Ex	1324	1344	17.997	18.860	17.722	18.863	17.822	18.832	14.944	4.675
ECS-2BL_5D - Pre	1428	1438	18.171	19.874	17.612	19.665	16.706	19.609	11.639	5.361
ECS-2BL_5D - Ex	1521	1531	16.903	20.065	17.667	19.335	17.099	19.546	12.745	5.218
ECS-2BL_6 - Pre	2265	2285	12.769	20.847	13.091	20.711	12.965	20.678	15.523	4.289
ECS-2BL_6 - Ex	2345	2365	14.232	20.718	14.507	20.681	14.791	20.747	14.878	2.958
ECS-2BL_7 - Pre	820	840	18.172	18.591	18.142	18.423	18.108	18.348	16.737	4.953
ECS-2BL_7 - Ex	937	957	14.327	18.602	14.399	18.276	14.408	18.264	16.804	4.881
ECS-2BL_7B - Pre	1664	1684	14.361	18.396	14.323	17.902	13.918	18.140	16.721	4.746
ECS-2BL_7B - Ex	1722	1742	15.425	18.122	14.540	18.452	14.509	18.447	16.697	4.611
ECS-2BL_11 - Pre	2803	2823	14.599	18.898	14.877	19.416	14.736	18.733	15.974	3.706
ECS-2BL_11 - Ex[a]	3019	3039	13.825	19.479	13.623	19.736	13.854	19.218	16.452	3.969
ECS-2BL_11B - Pre	1894	1914	15.316	21.081	14.665	20.659	14.372	20.481	12.254	4.254
ECS-2BL_11B - Ex	1954	1974	17.419	20.188	17.181	19.719	17.115	19.970	13.842	4.913
ECS-2BL_12 - Pre	1885	1905	14.947	18.284	14.752	17.642	14.640	18.062	16.698	4.623
ECS-2BL_12 - Ex[a]	2027	2047	14.782	18.446	14.410	17.904	14.526	18.349	16.624	4.518
ECS-2BL_12B - Pre	2442	2462	12.402	23.285	13.129	22.295	12.980	23.076	10.735	3.540
ECS-2BL_12B - Ex	2547	2567	16.340	22.164	16.388	21.455	15.670	21.475	11.716	4.315
ECS-2BL_13 - Pre	2137	2157	14.437	21.570	14.409	20.802	14.999	21.160	11.247	3.943
ECS-2BL_13 - Ex	2200	2220	15.569	22.680	15.676	21.395	15.514	22.411	11.789	3.897
ECS-2BL_14 - Pre	2856	2876	14.418	21.846	14.360	20.327	14.379	21.782	11.598	3.384
ECS-2BL_14 - Ex	2886	2906	15.048	22.122	14.276	21.825	14.385	21.675	10.539	3.551

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_A_03 kPa	DP_A_10 kPa	DP_B_03 kPa	DP_B_10 kPa	DP_C_03 kPa	DP_C_10 kPa	DP_D_02 kPa	DP_D_03 kPa
ECS-2BL_17 - Pre	706	726	12.292	12.833	12.019	13.254	11.583	13.311	16.133	3.313
ECS-2BL_17 - Ex	892	912	17.361	16.646	17.270	16.665	17.206	16.723	12.241	4.781
ECS-2BL_18 - Pre	1606	1626	11.681	17.985	10.532	18.310	10.788	17.321	10.830	1.914
ECS-2BL_18 - Ex	1646	1666	13.165	17.642	13.651	17.514	12.498	16.655	10.955	2.831
ECS-2BL_18B - Pre	2104	2114	11.697	17.172	10.961	15.833	10.369	15.907	13.919	3.688
ECS-2BL_18B - Ex	2172	2182	14.181	20.264	13.793	20.348	13.439	20.114	7.597	4.096
ECS-2BL_22 - Pre	934	954	11.267	16.998	11.340	17.214	10.905	16.877	15.966	3.880
ECS-2BL_22 - Ex	1157	1177	13.496	17.836	14.174	18.412	13.481	18.208	12.845	3.811
ECS-2BL_23 - Pre	1660	1680	9.544	17.115	10.154	17.092	9.815	17.776	15.306	1.933
ECS-2BL_23 - Ex	1712	1732	11.348	18.414	11.124	18.259	12.065	18.626	13.418	2.961
ECS-2BL_23B - Pre	1296	1316	11.594	18.302	11.194	17.773	10.861	17.313	16.506	3.574
ECS-2BL_23B - Ex	1378	1398	10.677	18.260	10.576	18.644	10.902	18.181	15.199	2.538
ECS-2BL_26 - Pre	2022	2042	10.424	19.531	11.184	19.340	10.482	19.400	14.861	3.887
ECS-2BL_26 - Ex	2072	2092	14.350	19.222	15.074	19.150	14.253	19.147	12.999	4.176
ECS-2BL_26B - Pre	1421	1441	9.854	17.409	10.817	18.947	10.343	17.314	14.544	3.299
ECS-2BL_26B - Ex	1498	1518	15.792	22.103	15.241	20.524	15.272	20.693	12.014	4.335
ECS-2BL_27 - Pre	1061	1081	13.332	17.280	13.232	17.209	12.899	17.235	16.832	4.440
ECS-2BL_27 - Ex	1168	1188	12.652	16.946	12.570	17.491	12.263	17.130	16.650	4.179
ECS-2FC_1 - Pre	1170	1190	12.335	18.118	12.771	17.816	12.109	18.207	16.372	3.981
ECS-2FC_1 - Ex	1360	1380	16.075	19.096	15.418	18.508	15.391	18.848	12.939	4.773
ECS-2FC_2 - Pre	1602	1622	12.499	19.446	11.581	18.538	11.684	19.302	16.469	4.235
ECS-2FC_2 - Ex	1775	1795	12.332	20.031	11.131	19.186	11.361	19.056	15.711	3.234

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_D_04 kPa	DP_D_05 kPa	DP_D_06 kPa	DP_D_07 kPa	DP_D_08 kPa	DP_D_09 kPa	DP_D_10 kPa	DP_D_11 kPa
ECS-2BL_1 - Pre	3252	3272	4.100	3.054	4.412	4.657	4.717	4.967	5.011	6.006
ECS-2BL_1 - Ex	3348	3368	4.288	3.463	4.453	4.781	4.748	4.961	4.974	6.009
ECS-2BL_1B - Pre	1900	1920	3.447	3.432	4.640	4.971	4.765	5.296	5.158	6.148
ECS-2BL_1B - Ex	1960	1980	4.032	3.696	4.750	5.103	4.660	4.941	4.932	5.524
ECS-2BL_2 - Pre	1480	1500	4.590	3.435	3.175	4.099	3.857	4.553	4.551	5.585
ECS-2BL_2 - Ex	1528	1548	4.619	3.028	3.948	4.265	4.252	4.347	4.438	5.169
ECS-2BL_5 - Pre	2210	2230	4.256	3.963	4.846	4.941	4.466	5.023	5.213	6.001
ECS-2BL_5 - Ex	2340	2360	4.464	4.070	4.730	4.958	4.488	4.851	4.912	5.347
ECS-2BL_5B - Pre	1422	1442	4.228	3.909	4.796	4.870	4.628	4.830	4.901	5.763
ECS-2BL_5B - Ex	1462	1482	4.830	4.151	4.587	4.952	4.704	4.940	4.723	5.516
ECS-2BL_5C - Pre	1180	1200	4.047	3.848	4.702	5.035	4.581	5.195	4.642	5.833
ECS-2BL_5C - Ex	1324	1344	4.621	4.008	4.926	5.016	4.503	4.484	4.517	3.849
ECS-2BL_5D - Pre	1428	1438	4.661	4.123	4.951	5.059	4.744	4.927	4.881	5.994
ECS-2BL_5D - Ex	1521	1531	4.502	3.886	4.650	4.864	4.819	4.890	4.944	5.970
ECS-2BL_6 - Pre	2265	2285	2.619	2.824	4.012	4.713	4.664	5.178	5.954	6.337
ECS-2BL_6 - Ex	2345	2365	3.121	3.277	4.604	4.796	4.717	5.204	5.668	6.279
ECS-2BL_7 - Pre	820	840	4.645	4.267	4.730	4.826	4.372	4.540	4.610	1.958
ECS-2BL_7 - Ex	937	957	4.402	2.739	2.936	4.493	4.372	4.760	4.427	5.725
ECS-2BL_7B - Pre	1664	1684	4.272	2.413	3.393	4.352	4.388	4.392	4.702	5.907
ECS-2BL_7B - Ex	1722	1742	3.474	2.787	4.275	4.743	4.412	4.799	4.498	5.443
ECS-2BL_11 - Pre	2803	2823	3.752	3.455	4.136	4.609	4.480	4.713	4.923	5.576
ECS-2BL_11 - Ex[a]	3019	3039	2.891	2.974	3.971	4.762	4.560	4.834	5.080	5.721
ECS-2BL_11B - Pre	1894	1914	3.615	2.716	4.358	5.008	4.771	5.342	5.384	6.387
ECS-2BL_11B - Ex	1954	1974	4.477	3.791	4.846	5.167	4.571	5.276	5.029	4.757
ECS-2BL_12 - Pre	1885	1905	3.811	3.101	4.011	4.108	4.237	4.683	4.876	5.394
ECS-2BL_12 - Ex[a]	2027	2047	3.665	3.333	3.722	4.261	4.261	4.654	4.878	5.538
ECS-2BL_12B - Pre	2442	2462	3.123	2.344	4.278	4.737	4.969	6.271	6.892	6.490
ECS-2BL_12B - Ex	2547	2567	4.241	3.650	4.782	5.162	4.726	5.520	6.097	5.735
ECS-2BL_13 - Pre	2137	2157	2.634	3.490	4.850	5.023	4.465	5.174	6.194	6.543
ECS-2BL_13 - Ex	2200	2220	3.358	3.715	4.867	5.181	4.770	5.616	6.901	6.070
ECS-2BL_14 - Pre	2856	2876	3.195	3.514	4.313	4.808	4.753	5.564	6.593	6.329
ECS-2BL_14 - Ex	2886	2906	3.783	3.446	4.397	4.923	4.754	5.660	6.314	6.124

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_D_04 kPa	DP_D_05 kPa	DP_D_06 kPa	DP_D_07 kPa	DP_D_08 kPa	DP_D_09 kPa	DP_D_10 kPa	DP_D_11 kPa
ECS-2BL_17 - Pre	706	726	3.816	1.436	2.563	3.505	4.002	2.853	2.446	1.732
ECS-2BL_17 - Ex	892	912	4.375	4.109	4.702	4.723	4.353	4.353	3.166	1.546
ECS-2BL_18 - Pre	1606	1626	2.746	3.354	3.522	4.223	4.099	4.750	4.684	2.830
ECS-2BL_18 - Ex	1646	1666	3.571	3.186	3.520	4.245	4.054	4.825	4.376	2.766
ECS-2BL_18B - Pre	2104	2114	2.250	2.573	4.143	4.510	4.038	4.562	2.891	2.504
ECS-2BL_18B - Ex	2172	2182	2.661	3.132	4.999	4.911	4.557	4.976	5.496	3.930
ECS-2BL_22 - Pre	934	954	1.947	2.588	3.728	3.738	3.983	4.618	4.628	4.308
ECS-2BL_22 - Ex	1157	1177	2.779	2.888	4.558	4.605	4.433	4.720	3.925	3.648
ECS-2BL_23 - Pre	1660	1680	1.970	1.722	3.583	4.024	4.451	4.067	4.421	5.701
ECS-2BL_23 - Ex	1712	1732	3.147	2.534	4.111	4.017	4.605	4.483	4.601	4.747
ECS-2BL_23B - Pre	1296	1316	2.904	2.093	2.858	4.222	4.070	4.782	5.057	4.265
ECS-2BL_23B - Ex	1378	1398	2.220	2.499	4.443	4.502	4.356	4.699	4.255	4.442
ECS-2BL_26 - Pre	2022	2042	2.525	1.874	2.685	4.538	4.630	4.964	5.153	5.939
ECS-2BL_26 - Ex	2072	2092	3.168	3.358	4.066	4.799	4.461	4.888	4.867	5.431
ECS-2BL_26B - Pre	1421	1441	2.475	1.721	3.294	3.586	4.066	6.162	4.532	6.087
ECS-2BL_26B - Ex	1498	1518	4.057	3.625	4.517	5.250	4.619	6.165	5.984	4.582
ECS-2BL_27 - Pre	1061	1081	3.418	2.654	3.361	4.228	3.885	4.470	4.624	4.647
ECS-2BL_27 - Ex	1168	1188	3.218	2.671	3.535	3.942	4.095	4.583	4.537	5.178
ECS-2FC_1 - Pre	1170	1190	2.795	1.859	3.884	4.612	4.234	4.190	4.453	4.730
ECS-2FC_1 - Ex	1360	1380	3.840	3.580	4.700	4.994	4.394	4.901	4.616	3.984
ECS-2FC_2 - Pre	1602	1622	2.963	1.772	4.066	4.334	4.335	4.842	5.265	5.871
ECS-2FC_2 - Ex	1775	1795	2.066	3.172	4.307	4.500	4.228	5.592	5.628	5.858

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_D_ALL kPa	DP_D_S1 kPa	DP_D_S2 kPa	DP_D_TOT kPa	DP_PL_IN kPa	DP_PL_OU kPa	DP_SP kPa	I_INNER Amps
ECS-2BL_1 - Pre	3252	3272	49.470	15.814	19.353	35.167	1.884	0.040	13.496	1819.430
ECS-2BL_1 - Ex	3348	3368	48.734	16.559	19.465	36.024	1.884	0.029	12.909	1850.930
ECS-2BL_1B - Pre	1900	1920	48.753	15.931	20.190	36.121	1.895	0.039	13.508	1918.370
ECS-2BL_1B - Ex	1960	1980	50.087	16.673	19.635	36.308	1.853	0.050	13.698	1948.020
ECS-2BL_2 - Pre	1480	1500	49.688	16.042	17.060	33.101	1.674	0.012	13.106	2180.600
ECS-2BL_2 - Ex	1528	1548	50.319	16.365	17.302	33.667	1.676	-0.002	12.994	2210.570
ECS-2BL_5 - Pre	2210	2230	49.695	17.800	19.642	37.442	1.882	-0.114	13.715	1558.210
ECS-2BL_5 - Ex	2340	2360	50.869	17.720	19.209	36.929	1.826	-0.061	14.235	1594.970
ECS-2BL_5B - Pre	1422	1442	49.778	17.044	19.229	36.273	1.851	0.111	13.797	1514.980
ECS-2BL_5B - Ex	1462	1482	49.392	18.040	19.319	37.359	1.704	0.062	13.373	1555.790
ECS-2BL_5C - Pre	1180	1200	49.442	16.984	19.453	36.437	1.897	0.053	13.446	1483.910
ECS-2BL_5C - Ex	1324	1344	51.801	18.230	18.520	36.750	1.709	-0.006	13.618	1523.910
ECS-2BL_5D - Pre	1428	1438	49.684	19.097	19.611	38.708	1.758	0.001	13.567	1522.970
ECS-2BL_5D - Ex	1521	1531	49.712	18.256	19.516	37.772	1.734	0.108	13.687	1563.160
ECS-2BL_6 - Pre	2265	2285	49.140	13.743	20.509	34.252	1.669	-0.157	13.346	2145.930
ECS-2BL_6 - Ex	2345	2365	49.828	13.960	20.386	34.346	1.683	-0.054	13.693	2178.610
ECS-2BL_7 - Pre	820	840	53.500	18.595	18.349	36.944	1.393	0.042	12.987	1970.240
ECS-2BL_7 - Ex	937	957	49.733	14.958	18.052	33.010	1.363	0.074	12.835	2189.900
ECS-2BL_7B - Pre	1664	1684	49.478	14.824	17.835	32.659	1.404	0.005	13.042	2155.860
ECS-2BL_7B - Ex	1722	1742	50.243	15.146	18.452	33.599	1.407	-0.014	13.032	2181.250
ECS-2BL_11 - Pre	2803	2823	56.475	15.049	18.725	33.775	1.475	-0.046	12.984	1508.090
ECS-2BL_11 - Ex[a]	3019	3039	56.887	13.804	19.236	33.040	1.471	-0.062	13.427	1564.490
ECS-2BL_11B - Pre	1894	1914	48.652	14.943	20.505	35.447	1.606	0.043	13.402	1821.000
ECS-2BL_11B - Ex	1954	1974	51.449	18.026	20.044	38.070	1.111	0.029	14.018	1848.140
ECS-2BL_12 - Pre	1885	1905	56.602	15.546	17.903	33.449	1.293	-0.015	13.267	1760.400
ECS-2BL_12 - Ex[a]	2027	2047	56.658	15.239	18.055	33.294	1.287	-0.019	13.331	1788.570
ECS-2BL_12B - Pre	2442	2462	46.422	13.285	22.870	36.156	1.389	0.037	12.806	2126.370
ECS-2BL_12B - Ex	2547	2567	50.219	16.988	21.505	38.494	0.984	0.159	15.220	2156.680
ECS-2BL_13 - Pre	2137	2157	54.838	14.919	20.856	35.775	1.065	-0.024	12.940	2146.420
ECS-2BL_13 - Ex	2200	2220	56.829	15.837	22.468	38.306	0.738	-0.017	13.817	2203.640
ECS-2BL_14 - Pre	2856	2876	47.861	14.406	21.719	36.125	0.799	0.129	12.856	2259.260
ECS-2BL_14 - Ex	2886	2906	47.709	15.177	21.651	36.828	0.580	0.129	12.935	2314.090

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_D_ALL kPa	DP_D_S1 kPa	DP_D_S2 kPa	DP_D_TOT kPa	DP_PL_IN kPa	DP_PL_OU kPa	DP_SP kPa	I_INNER Amps
ECS-2BL_17 - Pre	706	726	41.258	11.129	12.806	23.935	1.602	-0.011	0.878	1705.750
ECS-2BL_17 - Ex	892	912	46.248	17.967	16.596	34.563	0.267	-0.004	2.340	1742.670
ECS-2BL_18 - Pre	1606	1626	40.495	11.535	17.756	29.291	1.342	-0.004	2.154	2141.740
ECS-2BL_18 - Ex	1646	1666	41.761	13.106	17.499	30.606	1.231	0.068	3.275	2172.560
ECS-2BL_18B - Pre	2104	2114	42.789	12.654	16.002	28.655	1.220	0.060	2.442	2155.720
ECS-2BL_18B - Ex	2172	2182	42.042	14.887	19.939	34.826	0.056	0.124	3.385	2182.540
ECS-2BL_22 - Pre	934	954	44.231	12.143	16.967	29.110	1.594	-0.021	7.081	1778.080
ECS-2BL_22 - Ex	1157	1177	44.178	14.035	17.683	31.718	1.346	-0.083	5.178	1843.480
ECS-2BL_23 - Pre	1660	1680	41.965	9.208	16.964	26.171	1.395	-0.046	4.396	2203.730
ECS-2BL_23 - Ex	1712	1732	43.180	12.753	17.707	30.460	1.386	-0.076	5.408	2229.440
ECS-2BL_23B - Pre	1296	1316	46.401	11.430	18.130	29.560	1.338	0.047	8.617	2127.440
ECS-2BL_23B - Ex	1378	1398	44.135	11.701	17.811	29.511	1.336	-0.051	6.011	2154.560
ECS-2BL_26 - Pre	2022	2042	44.816	10.970	19.284	30.255	1.580	0.030	8.842	2090.220
ECS-2BL_26 - Ex	2072	2092	46.571	14.769	19.016	33.785	1.481	0.031	10.100	2119.850
ECS-2BL_26B - Pre	1421	1441	41.807	10.789	18.346	29.135	1.612	-0.123	6.846	2030.900
ECS-2BL_26B - Ex	1498	1518	49.908	16.534	22.019	38.553	1.381	0.153	13.410	2067.030
ECS-2BL_27 - Pre	1061	1081	47.445	13.874	17.208	31.081	1.375	0.000	9.144	2089.220
ECS-2BL_27 - Ex	1168	1188	46.248	13.603	17.158	30.760	1.368	0.015	9.343	2118.710
ECS-2FC_1 - Pre	1170	1190	46.825	12.519	17.490	30.009	1.772	-0.017	9.275	1394.520
ECS-2FC_1 - Ex	1360	1380	48.110	16.893	18.906	35.799	1.798	0.041	10.036	1395.420
ECS-2FC_2 - Pre	1602	1622	48.415	13.037	18.776	31.813	1.609	0.089	12.125	1970.900
ECS-2FC_2 - Ex	1775	1795	48.074	12.779	19.947	32.727	1.636	0.134	13.259	1971.600

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	L_PL_IN m	L_PL_OUT m	L_SP m	L_TS_TOT m	MDOT_W kg/s	P_ATM kPa	P_A_0 kPa	P_B_0 kPa
ECS-2BL_1 - Pre	3252	3272	0.020	0.275	0.384	0.752	0.097	84.934	87.792	88.066
ECS-2BL_1 - Ex	3348	3368	0.020	0.276	0.444	0.831	0.096	84.943	88.770	88.940
ECS-2BL_1B - Pre	1900	1920	0.019	0.275	0.378	0.827	0.102	85.324	121.526	120.265
ECS-2BL_1B - Ex	1960	1980	0.023	0.274	0.358	0.682	0.101	85.343	120.894	119.735
ECS-2BL_2 - Pre	1480	1500	0.041	0.278	0.427	0.791	0.297	84.786	86.329	86.358
ECS-2BL_2 - Ex	1528	1548	0.041	0.279	0.439	0.726	0.297	84.794	86.297	86.333
ECS-2BL_5 - Pre	2210	2230	0.008	0.291	0.349	0.738	0.103	85.105	123.010	121.533
ECS-2BL_5 - Ex	2340	2360	0.014	0.286	0.295	0.611	0.103	85.088	122.124	120.877
ECS-2BL_5B - Pre	1422	1442	0.037	0.267	0.344	0.707	0.097	85.184	88.342	88.730
ECS-2BL_5B - Ex	1462	1482	0.052	0.272	0.388	0.753	0.096	85.189	89.688	90.027
ECS-2BL_5C - Pre	1180	1200	0.017	0.273	0.394	0.751	0.097	85.265	121.608	120.501
ECS-2BL_5C - Ex	1324	1344	0.036	0.280	0.374	0.508	0.097	85.260	120.546	119.329
ECS-2BL_5D - Pre	1428	1438	0.031	0.279	0.379	0.727	0.099	85.039	122.334	121.038
ECS-2BL_5D - Ex	1521	1531	0.033	0.267	0.368	0.715	0.099	85.081	122.170	120.811
ECS-2BL_6 - Pre	2265	2285	0.030	0.296	0.387	0.812	0.297	85.134	87.431	87.644
ECS-2BL_6 - Ex	2345	2365	0.029	0.285	0.352	0.728	0.296	85.134	88.245	88.797
ECS-2BL_7 - Pre	820	840	0.085	0.275	0.442	0.406	0.475	85.061	85.678	85.973
ECS-2BL_7 - Ex	937	957	0.088	0.271	0.456	0.768	0.526	85.086	85.780	86.022
ECS-2BL_7B - Pre	1664	1684	0.068	0.278	0.432	0.802	0.500	85.309	119.152	118.385
ECS-2BL_7B - Ex	1722	1742	0.067	0.280	0.433	0.721	0.498	85.311	119.100	118.261
ECS-2BL_11 - Pre	2803	2823	0.049	-0.005	0.430	0.238	0.292	85.285	86.156	86.452
ECS-2BL_11 - Ex[a]	3019	3039	0.049	-0.018	0.381	0.194	0.293	85.287	85.713	85.924
ECS-2BL_11B - Pre	1894	1914	0.045	0.274	0.387	0.837	0.297	85.142	123.620	122.601
ECS-2BL_11B - Ex	1954	1974	0.097	0.276	0.322	0.540	0.294	85.141	123.309	122.044
ECS-2BL_12 - Pre	1885	1905	0.068	0.012	0.403	0.246	0.494	84.690	86.044	86.136
ECS-2BL_12 - Ex[a]	2027	2047	0.068	-0.003	0.397	0.236	0.494	84.704	86.052	86.172
ECS-2BL_12B - Pre	2442	2462	0.068	0.275	0.449	1.076	0.487	85.151	125.203	124.240
ECS-2BL_12B - Ex	2547	2567	0.110	0.262	0.195	0.655	0.486	85.164	124.704	123.454
ECS-2BL_13 - Pre	2137	2157	0.091	-0.110	0.434	0.416	0.684	85.287	123.470	121.981
ECS-2BL_13 - Ex	2200	2220	0.126	-0.060	0.341	0.200	0.683	85.269	123.591	122.185
ECS-2BL_14 - Pre	2856	2876	0.119	0.265	0.446	0.933	0.878	85.128	123.867	122.601
ECS-2BL_14 - Ex	2886	2906	0.142	0.265	0.437	0.937	0.879	85.139	124.536	123.112

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	L_PL_IN m	L_PL_OUT m	L_SP m	L_TS_TOT m	MDOT_W kg/s	P_ATM kPa	P_A_0 kPa	P_B_0 kPa
ECS-2BL_17 - Pre	706	726	0.063	0.280	1.711	1.658	0.301	85.470	86.516	86.722
ECS-2BL_17 - Ex	892	912	0.201	0.279	1.558	1.102	0.298	85.472	93.685	93.941
ECS-2BL_18 - Pre	1606	1626	0.090	0.279	1.576	1.725	0.496	85.442	91.119	91.450
ECS-2BL_18 - Ex	1646	1666	0.101	0.272	1.458	1.579	0.496	85.443	91.810	92.127
ECS-2BL_18B - Pre	2104	2114	0.087	0.273	1.546	1.493	0.491	84.920	121.236	120.156
ECS-2BL_18B - Ex	2172	2182	0.207	0.266	1.447	1.529	0.490	85.011	126.208	124.887
ECS-2BL_22 - Pre	934	954	0.064	0.281	1.059	1.327	0.294	85.135	86.256	86.449
ECS-2BL_22 - Ex	1157	1177	0.089	0.288	1.258	1.339	0.293	85.124	90.167	90.630
ECS-2BL_23 - Pre	1660	1680	0.085	0.284	1.340	1.574	0.490	85.411	87.954	88.308
ECS-2BL_23 - Ex	1712	1732	0.085	0.287	1.233	1.447	0.491	85.419	89.135	89.292
ECS-2BL_23B - Pre	1296	1316	0.091	0.274	0.898	1.120	0.491	85.685	86.559	86.819
ECS-2BL_23B - Ex	1378	1398	0.091	0.284	1.171	1.357	0.491	85.698	87.961	88.089
ECS-2BL_26 - Pre	2022	2042	0.065	0.276	0.867	1.253	0.299	85.084	87.578	87.964
ECS-2BL_26 - Ex	2072	2092	0.076	0.276	0.734	1.057	0.299	85.090	89.913	90.178
ECS-2BL_26B - Pre	1421	1441	0.046	0.292	1.081	1.589	0.296	85.210	122.198	121.252
ECS-2BL_26B - Ex	1498	1518	0.070	0.263	0.388	0.690	0.296	85.196	123.588	122.424
ECS-2BL_27 - Pre	1061	1081	0.087	0.279	0.842	1.005	0.489	85.116	85.746	86.000
ECS-2BL_27 - Ex	1168	1188	0.087	0.277	0.820	1.126	0.460	85.116	85.834	86.162
ECS-2FC_1 - Pre	1170	1190	0.030	0.281	0.834	1.042	0.173	85.179	121.120	119.934
ECS-2FC_1 - Ex	1360	1380	0.027	0.275	0.754	0.901	0.149	85.167	122.679	121.631
ECS-2FC_2 - Pre	1602	1622	0.046	0.269	0.526	0.873	0.318	85.177	121.042	119.853
ECS-2FC_2 - Ex	1775	1795	0.044	0.265	0.406	0.855	0.295	85.179	121.275	120.182

Note: Shadowed areas indicate failed or questionable measurements.

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	P_C_0 kPa	P_D_0 kPa	P_IN kPa	P_OUT kPa	Q_A_IN SLPM	Q_A_OUT SLPM	Q_CC kW	Q_DIFF %
ECS-2BL_1 - Pre	3252	3272	88.103	87.229	84.779	89.860	0.334	0.969	44.216	-55.223
ECS-2BL_1 - Ex	3348	3368	89.018	88.130	84.766	90.056	0.276	1.313	44.826	-57.073
ECS-2BL_1B - Pre	1900	1920	117.701	116.314	85.326	91.132	0.356	0.353	49.734	-58.605
ECS-2BL_1B - Ex	1960	1980	117.087	115.369	85.305	90.602	-3.457	0.313	45.842	-60.489
ECS-2BL_2 - Pre	1480	1500	86.457	85.868	85.282	91.007	2.424	3.058	32.308	-7.790
ECS-2BL_2 - Ex	1528	1548	86.416	85.800	85.289	91.139	2.044	2.561	30.046	-11.125
ECS-2BL_5 - Pre	2210	2230	120.064	114.263	85.146	91.230	4.763	1.354	31.186	-62.945
ECS-2BL_5 - Ex	2340	2360	119.292	113.607	85.183	90.547	-2.071	0.010	30.635	-64.950
ECS-2BL_5B - Pre	1422	1442	88.854	87.852	85.007	90.745	0.631	0.527	29.140	-61.904
ECS-2BL_5B - Ex	1462	1482	89.970	89.034	85.010	90.559	10.009	0.705	26.064	-64.442
ECS-2BL_5C - Pre	1180	1200	118.396	114.874	85.247	90.918	0.385	1.522	33.358	-59.421
ECS-2BL_5C - Ex	1324	1344	116.536	113.423	85.241	90.610	-21.168	-0.086	24.790	-62.079
ECS-2BL_5D - Pre	1428	1438	118.922	116.820	85.054	90.837	0.818	1.294	35.762	-60.449
ECS-2BL_5D - Ex	1521	1531	118.645	116.410	85.083	92.266	8.006	1.300	33.754	-62.920
ECS-2BL_6 - Pre	2265	2285	87.746	86.336	84.941	91.275	5.482	5.405	43.061	-41.285
ECS-2BL_6 - Ex	2345	2365	88.730	87.500	84.970	91.117	5.769	5.691	43.288	-43.738
ECS-2BL_7 - Pre	820	840	85.988	85.135	84.888	90.783	0.017	0.164	29.388	-2.621
ECS-2BL_7 - Ex	937	957	86.084	85.178	84.900	90.902	3.355	2.345	38.905	-3.229
ECS-2BL_7B - Pre	1664	1684	115.302	112.959	85.303	91.392	1.650	1.811	37.537	-3.816
ECS-2BL_7B - Ex	1722	1742	115.152	112.908	85.302	91.333	1.293	2.559	36.005	-8.492
ECS-2BL_11 - Pre	2803	2823	86.775	85.888	85.123	91.209	0.135	0.140	82.541	-39.205
ECS-2BL_11 - Ex[a]	3019	3039	86.235	85.322	85.119	91.330	0.587	-0.253	86.791	-42.914
ECS-2BL_11B - Pre	1894	1914	121.243	115.743	85.157	90.991	-0.038	-0.264	49.322	-56.915
ECS-2BL_11B - Ex	1954	1974	120.430	115.251	85.195	90.399	-26.077	-0.101	41.987	-60.174
ECS-2BL_12 - Pre	1885	1905	86.436	86.235	85.275	91.494	1.883	2.122	31.102	-15.752
ECS-2BL_12 - Ex[a]	2027	2047	86.509	86.251	85.278	91.621	1.880	2.184	33.912	-16.974
ECS-2BL_12B - Pre	2442	2462	123.041	116.982	85.146	91.892	0.141	0.475	60.297	-49.502
ECS-2BL_12B - Ex	2547	2567	122.192	116.599	85.156	89.961	0.152	-0.421	58.058	-51.741
ECS-2BL_13 - Pre	2137	2157	121.043	115.841	85.299	91.348	1.901	2.791	55.978	-35.741
ECS-2BL_13 - Ex	2200	2220	120.671	116.224	85.800	91.467	-6.404	1.853	57.694	-40.297
ECS-2BL_14 - Pre	2856	2876	121.630	116.277	85.202	91.913	7.084	5.986	59.053	-22.724
ECS-2BL_14 - Ex	2886	2906	122.069	116.634	85.305	91.515	-3.700	2.638	57.574	-23.007

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	P_C_0 kPa	P_D_0 kPa	P_IN kPa	P_OUT kPa	Q_A_IN SLPM	Q_A_OUT SLPM	Q_CC kW	Q_DIFF %
ECS-2BL_17 - Pre	706	726	86.859	85.936	85.297	103.175	1.190	2.160	24.715	-2.270
ECS-2BL_17 - Ex	892	912	94.033	93.078	87.326	101.357	-6.416	2.481	19.926	-28.375
ECS-2BL_18 - Pre	1606	1626	91.548	90.835	85.279	102.646	3.350	2.750	32.703	-3.364
ECS-2BL_18 - Ex	1646	1666	92.097	91.195	85.278	102.434	-2.688	2.338	33.018	-9.707
ECS-2BL_18B - Pre	2104	2114	▨ 117.565	▨ 116.246	84.966	102.615	2.410	0.859	0.001	-6.432
ECS-2BL_18B - Ex	2172	2182	▨ 123.561	▨ 121.289	86.825	103.280	-6.492	1.473	0.005	-7.356
ECS-2BL_22 - Pre	934	954	86.560	85.590	84.976	96.729	0.389	0.256	29.350	-12.473
ECS-2BL_22 - Ex	1157	1177	90.550	89.534	84.969	97.859	4.016	0.715	30.475	-24.913
ECS-2BL_23 - Pre	1660	1680	88.238	87.376	85.223	99.266	3.327	3.257	36.625	-7.378
ECS-2BL_23 - Ex	1712	1732	89.487	88.518	85.230	98.838	3.512	3.171	35.371	-14.031
ECS-2BL_23B - Pre	1296	1316	86.794	85.987	85.470	97.338	2.824	3.314	35.731	-2.402
ECS-2BL_23B - Ex	1378	1398	88.098	87.290	85.486	98.679	3.408	3.379	35.470	-6.530
ECS-2BL_26 - Pre	2022	2042	87.870	86.738	84.917	94.403	0.410	0.271	44.005	-37.072
ECS-2BL_26 - Ex	2072	2092	90.421	89.339	84.895	94.014	-4.139	0.249	43.265	-39.479
ECS-2BL_26B - Pre	1421	1441	▨ 118.881	▨ 114.847	85.196	94.878	-0.439	1.126	44.367	-33.202
ECS-2BL_26B - Ex	1498	1518	▨ 120.676	▨ 116.595	85.223	92.872	-8.717	0.694	42.584	-37.776
ECS-2BL_27 - Pre	1061	1081	86.096	85.149	84.924	94.655	1.785	1.107	30.270	-0.336
ECS-2BL_27 - Ex	1168	1188	86.190	85.339	84.926	94.802	2.429	1.300	31.541	-10.331
ECS-2FC_1 - Pre	1170	1190	▨ 117.514	▨ 113.332	85.192	94.583	-0.444	0.132	24.571	-16.032
ECS-2FC_1 - Ex	1360	1380	▨ 119.576	▨ 115.223	85.177	94.228	0.806	0.357	26.163	-28.520
ECS-2FC_2 - Pre	1602	1622	▨ 117.738	▨ 113.132	85.203	94.345	0.169	0.605	39.360	-25.719
ECS-2FC_2 - Ex	1775	1795	▨ 118.058	▨ 113.352	85.198	93.390	0.137	0.786	41.691	-31.625

Note: Shadowed areas represent failed or questionable measurements.

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	Q_E_1 kW	Q_E_3 kW	Q_E_5 kW	Q_E_TOT kW	Q_T_1 kW	Q_T_3 kW	Q_T_5 kW	Q_T_TOT kW
ECS-2BL_1 - Pre	3252	3272	5.208	23.537	42.591	65.930	28.039	29.962	29.968	29.521
ECS-2BL_1 - Ex	3348	3368	5.394	24.377	44.111	68.283	27.911	29.688	29.751	29.310
ECS-2BL_1B - Pre	1900	1920	6.008	27.150	49.129	76.051	29.943	31.890	32.051	31.481
ECS-2BL_1B - Ex	1960	1980	6.216	28.091	50.831	78.685	30.231	30.923	30.867	31.089
ECS-2BL_2 - Pre	1480	1500	7.784	35.175	63.651	98.530	23.816	81.200	89.125	90.851
ECS-2BL_2 - Ex	1528	1548	8.017	36.227	65.554	101.477	23.578	82.447	89.187	90.188
ECS-2BL_5 - Pre	2210	2230	4.022	18.174	32.886	50.906	18.360	18.692	18.556	18.863
ECS-2BL_5 - Ex	2340	2360	4.225	19.093	34.549	53.481	17.847	17.907	17.761	18.745
ECS-2BL_5B - Pre	1422	1442	3.742	16.912	30.603	47.373	17.854	18.334	18.479	18.046
ECS-2BL_5B - Ex	1462	1482	3.962	17.902	32.394	50.146	16.277	16.612	16.763	17.830
ECS-2BL_5C - Pre	1180	1200	3.615	16.335	29.559	45.757	18.691	18.648	18.990	18.568
ECS-2BL_5C - Ex	1324	1344	3.789	17.122	30.983	47.961	16.758	16.575	16.668	18.187
ECS-2BL_5D - Pre	1428	1438	3.756	16.975	30.716	47.549	19.453	19.424	19.414	18.806
ECS-2BL_5D - Ex	1521	1531	4.010	18.121	32.790	50.758	17.701	17.932	17.943	18.819
ECS-2BL_6 - Pre	2265	2285	7.622	34.444	62.327	96.481	46.266	57.196	57.961	56.648
ECS-2BL_6 - Ex	2345	2365	7.857	35.504	64.245	99.450	47.014	55.660	57.054	55.952
ECS-2BL_7 - Pre	820	840	6.383	28.844	52.194	80.796	16.147	30.143	62.883	78.671
ECS-2BL_7 - Ex	937	957	7.884	35.627	64.469	99.797	18.020	80.964	93.783	96.574
ECS-2BL_7B - Pre	1664	1684	7.618	34.424	62.291	96.425	19.460	69.428	89.776	92.744
ECS-2BL_7B - Ex	1722	1742	7.833	35.398	64.053	99.154	20.652	81.052	87.625	90.725
ECS-2BL_11 - Pre	2803	2823	3.716	16.792	30.386	47.036	26.008	29.696	30.165	28.594
ECS-2BL_11 - Ex[a]	3019	3039	3.997	18.061	32.683	50.592	24.789	30.595	30.557	28.880
ECS-2BL_11B - Pre	1894	1914	5.427	24.525	44.378	68.697	27.199	30.022	31.971	29.598
ECS-2BL_11B - Ex	1954	1974	5.626	25.423	46.004	71.213	28.315	27.654	28.127	28.361
ECS-2BL_12 - Pre	1885	1905	5.068	22.903	41.443	64.153	25.541	48.138	53.685	54.046
ECS-2BL_12 - Ex[a]	2027	2047	5.247	23.710	42.904	66.414	30.823	49.974	54.793	55.134
ECS-2BL_12B - Pre	2442	2462	7.421	33.536	60.684	93.938	38.086	48.606	53.094	47.437
ECS-2BL_12B - Ex	2547	2567	7.658	34.606	62.620	96.935	46.523	47.286	49.374	46.778
ECS-2BL_13 - Pre	2137	2157	7.580	34.255	61.986	95.953	46.870	60.350	62.024	61.656
ECS-2BL_13 - Ex	2200	2220	8.055	36.402	65.870	101.967	53.851	65.356	64.312	60.875
ECS-2BL_14 - Pre	2856	2876	8.441	38.147	69.027	106.853	35.168	63.767	76.793	82.581
ECS-2BL_14 - Ex	2886	2906	8.882	40.135	72.626	112.425	60.235	81.933	88.485	86.562

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	Q_E_1 kW	Q_E_3 kW	Q_E_5 kW	Q_E_TOT kW	Q_T_1 kW	Q_T_3 kW	Q_T_5 kW	Q_T_TOT kW
ECS-2BL_17 - Pre	706	726	4.770	21.554	39.003	60.375	17.282	54.181	58.617	59.012
ECS-2BL_17 - Ex	892	912	5.003	22.606	40.907	63.323	50.397	51.049	51.096	45.349
ECS-2BL_18 - Pre	1606	1626	7.570	34.210	61.904	95.827	55.301	87.260	92.338	92.593
ECS-2BL_18 - Ex	1646	1666	7.816	35.319	63.911	98.933	65.705	86.915	92.927	89.316
ECS-2BL_18B - Pre	2104	2114	7.589	34.296	62.059	96.066	26.963	80.716	88.861	89.898
ECS-2BL_18B - Ex	2172	2182	7.888	35.645	64.501	99.846	76.220	87.979	89.741	92.484
ECS-2BL_22 - Pre	934	954	5.185	23.432	42.400	65.635	37.094	52.898	57.360	57.444
ECS-2BL_22 - Ex	1157	1177	5.619	25.392	45.947	71.126	37.152	51.536	52.817	53.410
ECS-2BL_23 - Pre	1660	1680	8.035	36.310	65.703	101.707	53.226	83.722	91.473	94.199
ECS-2BL_23 - Ex	1712	1732	8.201	37.062	67.065	103.816	57.673	84.365	92.270	89.238
ECS-2BL_23B - Pre	1296	1316	7.433	33.589	60.781	94.088	12.734	78.745	89.682	91.834
ECS-2BL_23B - Ex	1378	1398	7.632	34.490	62.411	96.611	33.627	84.951	89.655	90.296
ECS-2BL_26 - Pre	2022	2042	7.191	32.496	58.802	91.025	41.714	55.156	58.291	57.280
ECS-2BL_26 - Ex	2072	2092	7.404	33.457	60.542	93.718	49.465	55.498	61.826	56.720
ECS-2BL_26B - Pre	1421	1441	6.785	30.663	55.406	85.891	44.135	54.970	58.794	57.368
ECS-2BL_26B - Ex	1498	1518	7.032	31.776	57.500	89.009	54.219	56.576	57.782	55.386
ECS-2BL_27 - Pre	1061	1081	7.164	32.375	58.584	90.687	38.098	75.128	88.161	90.372
ECS-2BL_27 - Ex	1168	1188	7.383	33.362	60.370	93.452	38.599	73.942	83.113	83.795
ECS-2FC_1 - Pre	1170	1190	3.167	14.310	25.894	40.083	28.025	33.467	34.394	33.655
ECS-2FC_1 - Ex	1360	1380	3.187	14.404	26.063	40.346	24.990	29.465	29.667	28.837
ECS-2FC_2 - Pre	1602	1622	6.362	28.749	52.022	80.530	37.595	54.648	59.706	59.818
ECS-2FC_2 - Ex	1775	1795	6.384	28.848	52.201	80.807	39.829	52.841	57.134	55.251

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	Q_W_CC L/s	Q_W_IN L/s	Q_W_IN_H L/s	Q_W_IN_L L/s	RHOW_CC kg/m	RHOW_IN kg/m	RHOW_OUT kg/m	RHOW_SP kg/m
ECS-2BL_1 - Pre	3252	3272	0.213	0.097	-0.004	0.097	999.79	997.19	960.92	972.23
ECS-2BL_1 - Ex	3348	3368	0.214	0.096	-0.004	0.096	999.77	997.14	960.94	971.55
ECS-2BL_1B - Pre	1900	1920	0.204	0.102	0.100	0.102	999.74	997.29	960.64	969.26
ECS-2BL_1B - Ex	1960	1980	0.203	0.101	0.100	0.101	999.74	996.90	960.87	969.06
ECS-2BL_2 - Pre	1480	1500	0.199	0.297	0.292	0.297	999.77	997.21	961.09	974.04
ECS-2BL_2 - Ex	1528	1548	0.199	0.297	0.291	0.297	999.77	997.26	961.25	974.23
ECS-2BL_5 - Pre	2210	2230	0.093	0.104	-0.002	0.104	999.61	986.14	960.84	964.40
ECS-2BL_5 - Ex	2340	2360	0.093	0.104	-0.001	0.104	999.59	985.83	960.95	965.14
ECS-2BL_5B - Pre	1422	1442	0.093	0.098	-0.004	0.098	999.63	987.18	960.35	966.63
ECS-2BL_5B - Ex	1462	1482	0.091	0.098	-0.004	0.098	999.63	985.37	960.43	966.50
ECS-2BL_5C - Pre	1180	1200	0.195	0.099	0.081	0.099	999.63	987.91	961.02	975.61
ECS-2BL_5C - Ex	1324	1344	0.194	0.098	0.087	0.098	999.61	985.81	961.48	974.67
ECS-2BL_5D - Pre	1428	1438	0.189	0.100	0.084	0.100	999.75	987.86	960.96	974.36
ECS-2BL_5D - Ex	1521	1531	0.189	0.100	0.083	0.100	999.78	986.44	961.01	975.30
ECS-2BL_6 - Pre	2265	2285	0.131	0.300	0.296	0.300	999.69	987.74	960.49	963.43
ECS-2BL_6 - Ex	2345	2365	0.131	0.300	0.296	0.300	999.67	987.62	960.76	964.69
ECS-2BL_7 - Pre	820	840	0.260	0.481	0.481	0.000	999.78	987.59	964.73	975.59
ECS-2BL_7 - Ex	937	957	0.263	0.532	0.532	0.000	999.79	987.97	961.90	974.40
ECS-2BL_7B - Pre	1664	1684	0.208	0.506	0.506	0.000	999.73	987.72	961.61	972.53
ECS-2BL_7B - Ex	1722	1742	0.207	0.504	0.504	0.000	999.73	987.89	962.62	972.59
ECS-2BL_11 - Pre	2803	2823	0.274	0.299	0.292	0.299	999.58	976.58	960.63	966.67
ECS-2BL_11 - Ex[a]	3019	3039	0.274	0.300	0.293	0.300	999.57	976.59	960.57	965.31
ECS-2BL_11B - Pre	1894	1914	0.195	0.304	0.277	0.304	999.64	976.76	960.94	967.43
ECS-2BL_11B - Ex	1954	1974	0.195	0.301	0.279	0.301	999.63	975.86	961.37	967.59
ECS-2BL_12 - Pre	1885	1905	0.131	0.505	0.505	0.000	999.77	978.36	960.99	969.12
ECS-2BL_12 - Ex[a]	2027	2047	0.153	0.505	0.505	0.000	999.79	978.58	961.07	969.41
ECS-2BL_12B - Pre	2442	2462	0.262	0.499	0.499	0.000	999.69	976.47	960.52	966.74
ECS-2BL_12B - Ex	2547	2567	0.262	0.498	0.498	0.000	999.69	976.00	960.95	967.86
ECS-2BL_13 - Pre	2137	2157	0.251	0.701	0.701	0.000	999.76	975.14	960.41	966.66
ECS-2BL_13 - Ex	2200	2220	0.251	0.700	0.700	0.000	999.76	975.21	960.66	966.51
ECS-2BL_14 - Pre	2856	2876	0.268	0.899	0.899	0.000	999.76	976.28	961.42	968.36
ECS-2BL_14 - Ex	2886	2906	0.268	0.899	0.899	0.000	999.76	976.80	961.07	968.21

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	Q_W_CC L/s	Q_W_IN L/s	Q_W_IN_H L/s	Q_W_IN_L L/s	RHOW_CC kg/m	RHOW_IN kg/m	RHOW_OUT kg/m	RHOW_SP kg/m
ECS-2BL_17 - Pre	706	726	0.163	0.305	0.307	0.305	999.77	988.13	959.97	976.41
ECS-2BL_17 - Ex	892	912	0.163	0.302	0.307	0.302	999.77	984.77	967.83	975.08
ECS-2BL_18 - Pre	1606	1626	0.163	0.502	0.502	0.000	999.77	987.30	960.26	971.39
ECS-2BL_18 - Ex	1646	1666	0.163	0.502	0.502	0.000	999.75	987.22	961.00	971.68
ECS-2BL_18B - Pre	2104	2114	0.000	0.497	0.497	0.000	999.92	988.02	962.34	972.82
ECS-2BL_18B - Ex	2172	2182	0.000	0.497	0.497	0.001	999.90	985.31	961.76	973.08
ECS-2BL_22 - Pre	934	954	0.151	0.297	0.290	0.297	999.75	987.67	959.28	973.53
ECS-2BL_22 - Ex	1157	1177	0.151	0.297	0.270	0.297	999.75	986.54	961.55	971.84
ECS-2BL_23 - Pre	1660	1680	0.165	0.496	0.496	0.000	999.70	987.24	959.17	970.15
ECS-2BL_23 - Ex	1712	1732	0.165	0.497	0.497	0.000	999.72	987.09	960.79	969.48
ECS-2BL_23B - Pre	1296	1316	0.211	0.497	0.497	0.000	999.71	987.81	961.32	973.45
ECS-2BL_23B - Ex	1378	1398	0.211	0.497	0.497	0.000	999.71	987.52	961.25	972.85
ECS-2BL_26 - Pre	2022	2042	0.152	0.303	0.300	0.305	999.72	987.26	959.49	965.86
ECS-2BL_26 - Ex	2072	2092	0.152	0.303	0.300	0.305	999.72	987.15	959.80	965.71
ECS-2BL_26B - Pre	1421	1441	0.195	0.300	0.271	0.300	999.63	987.70	960.08	969.74
ECS-2BL_26B - Ex	1498	1518	0.196	0.300	0.271	0.300	999.61	987.49	961.22	969.25
ECS-2BL_27 - Pre	1061	1081	0.151	0.496	0.496	0.000	999.75	987.66	961.30	973.37
ECS-2BL_27 - Ex	1168	1188	0.152	0.466	0.466	0.000	999.74	987.52	961.57	972.06
ECS-2FC_1 - Pre	1170	1190	0.193	0.175	0.161	0.175	999.60	988.01	960.47	978.66
ECS-2FC_1 - Ex	1360	1380	0.193	0.151	0.144	0.151	999.64	988.32	961.11	978.33
ECS-2FC_2 - Pre	1602	1622	0.193	0.323	0.323	0.328	999.66	986.91	960.33	970.62
ECS-2FC_2 - Ex	1775	1795	0.193	0.299	0.293	0.299	999.66	987.30	960.20	970.32

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	RHOW_TS kg/m	TF_01_AV K	TF_02_AV K	TF_03_AV K	TF_04_AV K	TF_A_01 K	TF_A_02 K	TF_A_03 K
ECS-2BL_1 - Pre	3252	3272	961.18	365.91	370.67	370.69	369.59	363.53	370.43	370.78
ECS-2BL_1 - Ex	3348	3368	961.16	366.16	370.57	370.72	369.57	361.90	369.72	370.69
ECS-2BL_1B - Pre	1900	1920	960.83	366.38	370.95	371.33	369.96	367.05	371.76	371.41
ECS-2BL_1B - Ex	1960	1980	960.52	369.18	370.81	370.68	369.65	368.52	371.03	370.78
ECS-2BL_2 - Pre	1480	1500	971.97	315.63	361.86	368.24	369.39	300.89	368.72	370.55
ECS-2BL_2 - Ex	1528	1548	971.97	315.21	362.64	368.07	369.10	301.85	369.06	370.34
ECS-2BL_5 - Pre	2210	2230	960.06	370.72	371.49	371.17	369.71	370.34	370.96	370.87
ECS-2BL_5 - Ex	2340	2360	960.60	370.18	370.32	369.98	369.54	368.89	369.58	369.61
ECS-2BL_5B - Pre	1422	1442	960.25	369.59	370.77	371.12	370.36	368.65	370.81	370.59
ECS-2BL_5B - Ex	1462	1482	960.21	369.97	370.81	371.18	370.25	368.82	370.65	370.56
ECS-2BL_5C - Pre	1180	1200	960.66	369.88	369.77	370.61	369.46	369.73	369.86	370.72
ECS-2BL_5C - Ex	1324	1344	960.97	369.98	369.53	369.76	368.85	369.48	369.59	369.98
ECS-2BL_5D - Pre	1428	1438	960.03	371.16	371.09	371.07	369.53	370.36	371.24	370.93
ECS-2BL_5D - Ex	1521	1531	960.45	370.17	370.73	370.75	369.48	370.13	371.04	370.86
ECS-2BL_6 - Pre	2265	2285	961.80	361.71	370.51	371.13	370.12	358.30	371.32	371.28
ECS-2BL_6 - Ex	2345	2365	961.94	362.62	369.59	370.71	369.80	360.82	370.22	370.89
ECS-2BL_7 - Pre	820	840	975.28	332.91	339.96	356.41	364.39	325.46	333.13	346.61
ECS-2BL_7 - Ex	937	957	969.91	332.11	360.71	366.54	368.26	324.84	360.54	364.06
ECS-2BL_7B - Pre	1664	1684	969.81	333.80	357.69	367.42	368.66	326.24	352.11	364.91
ECS-2BL_7B - Ex	1722	1742	969.47	334.02	362.98	366.13	367.27	327.58	344.48	353.31
ECS-2BL_11 - Pre	2803	2823	960.83	367.49	370.51	370.89	369.97	363.33	369.42	370.35
ECS-2BL_11 - Ex[a]	3019	3039	960.83	366.45	371.18	371.15	370.05	363.40	370.14	370.49
ECS-2BL_11B - Pre	1894	1914	960.78	367.80	370.07	371.64	369.57	368.05	370.43	371.17
ECS-2BL_11B - Ex	1954	1974	960.66	370.47	369.93	370.32	368.97	370.04	370.09	370.50
ECS-2BL_12 - Pre	1885	1905	964.19	355.52	366.45	369.13	369.50	348.46	365.42	368.97
ECS-2BL_12 - Ex[a]	2027	2047	963.65	357.67	366.93	369.26	369.39	352.04	366.83	369.58
ECS-2BL_12B - Pre	2442	2462	960.95	365.11	370.27	372.47	370.12	365.61	370.35	372.55
ECS-2BL_12B - Ex	2547	2567	960.36	370.05	370.43	371.45	369.52	368.94	370.71	371.60
ECS-2BL_13 - Pre	2137	2157	961.52	365.03	369.74	370.33	370.27	364.91	371.96	372.03
ECS-2BL_13 - Ex	2200	2220	960.75	367.37	371.39	371.03	369.90	366.22	371.75	371.78
ECS-2BL_14 - Pre	2856	2876	964.68	356.32	364.10	367.65	368.89	353.80	363.16	367.63
ECS-2BL_14 - Ex	2886	2906	962.45	362.24	368.14	369.92	369.41	360.74	367.76	369.77

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	RHOW_TS kg/m	TF_01_AV K	TF_02_AV K	TF_03_AV K	TF_04_AV K	TF_A_01 K	TF_A_02 K	TF_A_03 K
ECS-2BL_17 - Pre	706	726	966.90	337.27	366.56	370.08	370.78	337.26	371.33	369.24
ECS-2BL_17 - Ex	892	912	961.57	371.22	371.75	371.79	360.13	370.13	372.20	371.87
ECS-2BL_18 - Pre	1606	1626	964.26	352.10	367.48	369.93	370.37	335.20	358.79	363.80
ECS-2BL_18 - Ex	1646	1666	963.45	357.30	367.52	370.42	369.03	349.92	359.31	364.34
ECS-2BL_18B - Pre	2104	2114	968.07	336.93	363.09	367.05	367.27	335.01	365.43	358.95
ECS-2BL_18B - Ex	2172	2182	960.21	366.91	372.65	373.52	368.52	370.57	374.21	373.96
ECS-2BL_22 - Pre	934	954	963.36	354.77	367.62	371.25	371.74	348.73	364.80	370.14
ECS-2BL_22 - Ex	1157	1177	963.20	357.39	369.10	370.15	368.83	354.79	370.60	371.11
ECS-2BL_23 - Pre	1660	1680	964.28	351.56	366.43	370.22	371.88	337.65	368.07	370.61
ECS-2BL_23 - Ex	1712	1732	964.04	354.01	367.01	370.86	369.68	343.27	370.70	371.85
ECS-2BL_23B - Pre	1296	1316	969.51	330.50	362.62	367.94	369.22	326.55	354.74	365.45
ECS-2BL_23B - Ex	1378	1398	966.89	341.32	366.30	368.59	369.04	339.70	371.03	371.84
ECS-2BL_26 - Pre	2022	2042	962.08	358.86	369.59	372.09	371.46	355.35	368.09	370.80
ECS-2BL_26 - Ex	2072	2092	960.25	365.27	370.08	375.13	371.05	364.82	368.59	370.34
ECS-2BL_26B - Pre	1421	1441	962.12	360.13	368.86	371.95	370.67	354.64	366.34	370.67
ECS-2BL_26B - Ex	1498	1518	960.63	368.75	370.65	371.62	369.16	368.79	370.93	371.58
ECS-2BL_27 - Pre	1061	1081	967.48	343.35	361.29	367.64	369.04	335.95	352.43	360.63
ECS-2BL_27 - Ex	1168	1188	966.82	345.01	363.37	368.14	368.71	333.94	364.19	369.55
ECS-2FC_1 - Pre	1170	1190	961.72	362.53	370.04	371.32	370.19	363.25	370.09	371.18
ECS-2FC_1 - Ex	1360	1380	961.75	363.15	370.32	370.65	369.24	361.22	370.19	369.98
ECS-2FC_2 - Pre	1602	1622	963.67	354.54	367.33	371.12	370.36	351.29	367.77	370.94
ECS-2FC_2 - Ex	1775	1795	962.80	357.66	368.18	371.65	370.55	358.09	369.65	371.65

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_A_04 K	TF_A_IN K	TF_A_OUT K	TF_B_01 K	TF_B_02 K	TF_B_03 K	TF_B_04 K	TF_CC_IN K
ECS-2BL_1 - Pre	3252	3272	369.54	304.51	310.07	368.23	370.49	370.73	369.60	283.08
ECS-2BL_1 - Ex	3348	3368	369.64	304.61	310.30	367.71	370.64	370.87	369.57	283.22
ECS-2BL_1B - Pre	1900	1920	369.88	302.03	306.73	369.45	371.06	371.13	370.02	283.40
ECS-2BL_1B - Ex	1960	1980	369.74	302.09	306.83	370.62	370.65	370.69	369.60	283.43
ECS-2BL_2 - Pre	1480	1500	369.38	300.91	303.96	340.07	368.65	368.65	369.66	283.23
ECS-2BL_2 - Ex	1528	1548	368.95	300.98	304.05	339.22	369.46	369.94	369.62	283.20
ECS-2BL_5 - Pre	2210	2230	369.82	325.11	318.76	371.37	373.20	370.89	369.46	284.28
ECS-2BL_5 - Ex	2340	2360	369.48	332.11	348.17	370.52	371.53	369.93	369.34	284.38
ECS-2BL_5B - Pre	1422	1442	370.31	308.16	310.57	369.52	370.19	370.43	370.36	284.15
ECS-2BL_5B - Ex	1462	1482	370.39	333.23	310.71	370.17	370.34	370.43	370.22	284.15
ECS-2BL_5C - Pre	1180	1200	369.54	306.65	309.17	369.93	369.45	370.64	369.39	284.12
ECS-2BL_5C - Ex	1324	1344	368.87	345.01	309.39	369.96	369.16	369.79	368.82	284.24
ECS-2BL_5D - Pre	1428	1438	369.43	304.09	307.79	371.44	370.75	370.80	369.42	283.31
ECS-2BL_5D - Ex	1521	1531	369.31	317.92	307.60	370.49	370.04	370.62	369.46	283.11
ECS-2BL_6 - Pre	2265	2285	370.02	305.70	314.04	369.79	372.29	371.23	370.01	283.76
ECS-2BL_6 - Ex	2345	2365	370.06	306.00	327.42	370.01	371.62	371.12	369.65	283.86
ECS-2BL_7 - Pre	820	840	360.94	308.31	309.83	343.64	339.60	357.43	366.20	283.11
ECS-2BL_7 - Ex	937	957	368.19	308.38	309.34	343.26	369.57	370.34	369.90	283.07
ECS-2BL_7B - Pre	1664	1684	366.85	304.70	307.76	338.87	352.94	363.06	367.80	283.47
ECS-2BL_7B - Ex	1722	1742	360.51	304.80	307.86	340.69	369.07	370.22	369.22	283.47
ECS-2BL_11 - Pre	2803	2823	369.92	305.44	312.44	370.16	372.00	370.48	369.80	284.48
ECS-2BL_11 - Ex[a]	3019	3039	370.00	305.50	312.86	370.11	373.19	370.69	369.86	284.51
ECS-2BL_11B - Pre	1894	1914	369.52	315.31	312.26	370.28	370.00	371.28	369.57	284.06
ECS-2BL_11B - Ex	1954	1974	368.98	356.61	312.35	370.59	369.71	370.31	368.97	284.10
ECS-2BL_12 - Pre	1885	1905	369.81	308.93	312.56	363.64	370.95	370.42	369.63	283.20
ECS-2BL_12 - Ex[a]	2027	2047	369.85	308.80	312.72	366.03	371.07	370.48	369.45	283.04
ECS-2BL_12B - Pre	2442	2462	370.36	314.66	314.61	369.59	371.50	372.70	370.08	283.71
ECS-2BL_12B - Ex	2547	2567	369.61	324.32	314.24	371.43	370.38	371.44	369.40	283.76
ECS-2BL_13 - Pre	2137	2157	370.60	308.83	318.58	371.73	373.46	372.19	370.30	283.29
ECS-2BL_13 - Ex	2200	2220	370.09	317.94	318.64	369.93	374.80	371.82	369.85	283.26
ECS-2BL_14 - Pre	2856	2876	368.88	316.73	349.01	358.80	367.05	367.35	369.11	283.24
ECS-2BL_14 - Ex	2886	2906	369.58	321.03	347.79	365.33	371.86	370.40	369.63	283.25

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_A_04 K	TF_A_IN K	TF_A_OUT K	TF_B_01 K	TF_B_02 K	TF_B_03 K	TF_B_04 K	TF_CC_IN K
ECS-2BL_17 - Pre	706	726	370.18	308.05	309.18	346.61	362.12	368.74	370.72	283.17
ECS-2BL_17 - Ex	892	912	359.88	321.68	309.58	373.56	371.59	371.71	360.45	283.24
ECS-2BL_18 - Pre	1606	1626	368.75	309.99	319.43	355.24	368.88	370.96	370.36	283.21
ECS-2BL_18 - Ex	1646	1666	367.91	311.05	319.93	366.09	372.26	373.16	369.08	283.32
ECS-2BL_18B - Pre	2104	2114	363.86	303.44	316.82	343.46	371.83	372.37	369.27	282.16
ECS-2BL_18B - Ex	2172	2182	368.21	308.66	318.10	370.48	373.71	374.49	368.56	282.29
ECS-2BL_22 - Pre	934	954	371.87	310.11	310.23	365.10	371.02	371.74	371.93	283.37
ECS-2BL_22 - Ex	1157	1177	369.16	314.54	310.58	360.37	371.35	372.07	369.82	283.35
ECS-2BL_23 - Pre	1660	1680	372.33	307.51	310.55	360.80	371.68	371.98	372.64	283.65
ECS-2BL_23 - Ex	1712	1732	370.13	307.50	310.10	364.34	371.56	371.95	371.11	283.51
ECS-2BL_23B - Pre	1296	1316	367.86	305.51	309.03	333.68	358.08	365.55	368.39	283.58
ECS-2BL_23B - Ex	1378	1398	370.09	305.56	309.20	349.35	371.64	371.84	371.00	283.63
ECS-2BL_26 - Pre	2022	2042	371.57	309.82	311.59	368.07	371.78	372.02	371.47	283.54
ECS-2BL_26 - Ex	2072	2092	371.21	311.53	311.97	371.00	371.55	371.44	371.03	283.56
ECS-2BL_26B - Pre	1421	1441	370.48	308.48	310.18	367.89	370.50	372.17	370.65	284.14
ECS-2BL_26B - Ex	1498	1518	369.11	312.56	310.28	371.28	370.50	371.62	369.06	284.24
ECS-2BL_27 - Pre	1061	1081	367.23	309.34	309.75	356.90	370.21	370.20	370.40	283.32
ECS-2BL_27 - Ex	1168	1188	369.56	309.54	309.86	355.38	370.44	370.96	370.18	283.43
ECS-2FC_1 - Pre	1170	1190	370.17	308.36	310.88	369.38	370.59	371.20	370.20	284.34
ECS-2FC_1 - Ex	1360	1380	369.21	308.94	310.97	364.04	369.24	370.05	369.05	284.06
ECS-2FC_2 - Pre	1602	1622	370.43	311.00	311.64	367.28	370.05	371.51	370.41	283.95
ECS-2FC_2 - Ex	1775	1795	370.70	311.08	312.33	367.94	370.33	371.79	370.56	283.96

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_CC_OU K	TF_C_01 K	TF_C_02 K	TF_C_03 K	TF_C_04 K	TF_D_01 K	TF_D_02 K	TF_D_03 K
ECS-2BL_1 - Pre	3252	3272	332.58	366.51	370.97	370.53	369.56	365.39	370.80	370.70
ECS-2BL_1 - Ex	3348	3368	333.35	367.02	370.65	370.65	369.56	368.03	371.25	370.67
ECS-2BL_1B - Pre	1900	1920	341.77	367.53	370.63	371.29	369.99	361.49	370.36	371.49
ECS-2BL_1B - Ex	1960	1980	337.34	370.77	370.84	370.36	369.62	366.80	370.74	370.90
ECS-2BL_2 - Pre	1480	1500	321.95	316.51	361.44	366.67	369.34	305.04	348.63	367.10
ECS-2BL_2 - Ex	1528	1548	319.31	314.59	363.09	367.66	369.36	305.20	348.94	364.33
ECS-2BL_5 - Pre	2210	2230	364.52	370.65	370.86	372.08	369.74	370.51	370.95	370.86
ECS-2BL_5 - Ex	2340	2360	363.27	370.92	370.03	370.28	369.65	370.40	370.14	370.11
ECS-2BL_5B - Pre	1422	1442	359.25	370.06	371.08	372.58	370.31	370.10	370.98	370.89
ECS-2BL_5B - Ex	1462	1482	352.39	370.35	371.31	372.99	370.17	370.55	370.92	370.73
ECS-2BL_5C - Pre	1180	1200	325.07	370.11	369.88	370.39	369.41	369.75	369.90	370.69
ECS-2BL_5C - Ex	1324	1344	314.84	370.29	369.64	369.28	368.84	370.19	369.73	369.98
ECS-2BL_5D - Pre	1428	1438	328.43	371.82	371.05	371.47	369.57	371.03	371.34	371.09
ECS-2BL_5D - Ex	1521	1531	325.75	369.96	370.68	370.57	369.46	370.10	371.16	370.96
ECS-2BL_6 - Pre	2265	2285	362.16	370.36	371.49	372.76	370.20	348.41	366.97	369.26
ECS-2BL_6 - Ex	2345	2365	362.72	370.01	370.81	372.23	369.60	349.63	365.70	368.61
ECS-2BL_7 - Pre	820	840	310.07	335.13	348.83	367.93	366.41	327.40	338.27	353.66
ECS-2BL_7 - Ex	937	957	318.43	333.33	368.00	371.63	369.54	327.00	344.73	360.12
ECS-2BL_7B - Pre	1664	1684	326.68	340.67	363.82	370.52	370.01	329.41	361.90	371.19
ECS-2BL_7B - Ex	1722	1742	325.02	338.59	369.77	370.35	369.69	329.20	368.58	370.62
ECS-2BL_11 - Pre	2803	2823	356.36	370.71	370.79	372.05	370.03	365.78	369.84	370.70
ECS-2BL_11 - Ex[a]	3019	3039	360.19	370.69	371.20	372.49	370.10	361.59	370.22	370.94
ECS-2BL_11B - Pre	1894	1914	344.40	368.62	370.33	372.64	369.56	364.26	369.53	371.47
ECS-2BL_11B - Ex	1954	1974	335.65	370.83	369.82	369.93	368.93	370.42	370.10	370.53
ECS-2BL_12 - Pre	1885	1905	339.99	364.06	370.10	371.17	369.55	345.90	359.32	365.97
ECS-2BL_12 - Ex[a]	2027	2047	335.98	366.42	370.06	371.33	369.45	346.20	359.76	365.65
ECS-2BL_12B - Pre	2442	2462	338.71	367.03	370.62	372.42	370.00	358.20	368.60	372.21
ECS-2BL_12B - Ex	2547	2567	336.75	371.41	370.43	371.24	369.53	368.42	370.19	371.53
ECS-2BL_13 - Pre	2137	2157	336.57	370.97	372.29	372.07	370.30	352.51	361.25	365.01
ECS-2BL_13 - Ex	2200	2220	338.13	369.40	371.89	371.98	370.01	363.92	367.12	368.52
ECS-2BL_14 - Pre	2856	2876	335.91	358.12	363.77	370.59	369.08	354.56	362.43	365.02
ECS-2BL_14 - Ex	2886	2906	334.66	364.62	368.30	371.64	369.33	358.27	364.63	367.88

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_CC_OU K	TF_C_01 K	TF_C_02 K	TF_C_03 K	TF_C_04 K	TF_D_01 K	TF_D_02 K	TF_D_03 K
ECS-2BL_17 - Pre	706	726	319.37	335.83	364.12	370.48	371.08	329.39	368.67	371.88
ECS-2BL_17 - Ex	892	912	312.49	370.90	371.53	371.72	360.13	370.32	371.69	371.85
ECS-2BL_18 - Pre	1606	1626	331.05	363.44	372.66	372.93	371.30	354.51	369.61	372.03
ECS-2BL_18 - Ex	1646	1666	331.58	365.11	371.87	372.62	369.61	348.07	366.62	371.54
ECS-2BL_18B - Pre	2104	2114	322.15	339.54	370.11	371.34	368.56	329.71	344.99	365.56
ECS-2BL_18B - Ex	2172	2182	317.53	362.83	372.30	372.89	368.51	363.74	370.39	372.72
ECS-2BL_22 - Pre	934	954	329.77	366.43	370.96	373.25	371.63	338.82	363.73	369.89
ECS-2BL_22 - Ex	1157	1177	331.48	360.52	371.47	371.29	368.89	353.86	362.99	366.11
ECS-2BL_23 - Pre	1660	1680	336.75	366.72	370.68	371.71	372.04	341.07	355.31	366.56
ECS-2BL_23 - Ex	1712	1732	334.86	365.86	372.06	377.42	369.97	342.54	353.71	362.21
ECS-2BL_23B - Pre	1296	1316	324.10	332.81	371.48	370.86	370.24	328.96	366.17	369.90
ECS-2BL_23B - Ex	1378	1398	323.88	347.46	370.71	371.86	369.83	328.78	351.84	358.83
ECS-2BL_26 - Pre	2022	2042	352.65	366.79	371.30	374.07	371.41	345.21	367.19	371.50
ECS-2BL_26 - Ex	2072	2092	351.52	370.43	371.20	387.54	371.00	354.82	368.99	371.18
ECS-2BL_26B - Pre	1421	1441	338.39	367.72	370.65	372.74	370.76	350.27	367.96	372.19
ECS-2BL_26B - Ex	1498	1518	336.27	370.63	370.70	371.48	369.28	364.30	370.47	371.81
ECS-2BL_27 - Pre	1061	1081	331.06	352.39	368.57	374.36	369.72	328.18	353.95	365.38
ECS-2BL_27 - Ex	1168	1188	333.14	358.72	368.57	371.02	368.87	332.02	350.29	361.04
ECS-2FC_1 - Pre	1170	1190	314.76	367.23	369.66	371.34	370.13	350.24	369.82	371.56
ECS-2FC_1 - Ex	1360	1380	316.44	365.28	370.81	371.30	369.28	362.08	371.05	371.26
ECS-2FC_2 - Pre	1602	1622	333.52	361.93	367.02	370.81	370.24	337.65	364.50	371.22
ECS-2FC_2 - Ex	1775	1795	335.68	363.41	367.73	371.95	370.43	341.18	365.02	371.23

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_D_04 K	TF_HX_OU K	TF_IN K	TF_OUT K	TF_TS_AV K	TF_W_IN K	TF_W_OUT K	TI_A_a_5 K
ECS-2BL_1 - Pre	3252	3272	369.64	287.79	296.52	353.64	369.22	296.52	353.32	410.86
ECS-2BL_1 - Ex	3348	3368	369.53	288.06	296.74	354.01	369.25	296.68	354.38	411.34
ECS-2BL_1B - Pre	1900	1920	369.96	287.61	296.09	358.58	369.66	296.06	357.86	411.95
ECS-2BL_1B - Ex	1960	1980	369.63	287.69	297.68	358.39	370.08	296.12	358.17	448.19
ECS-2BL_2 - Pre	1480	1500	369.16	289.57	296.44	346.80	353.78	296.19	350.43	408.56
ECS-2BL_2 - Ex	1528	1548	368.47	289.49	296.22	347.24	353.75	296.45	350.13	408.02
ECS-2BL_5 - Pre	2210	2230	369.82	321.55	328.03	366.74	370.77	325.85	364.86	409.01
ECS-2BL_5 - Ex	2340	2360	369.69	319.43	328.69	366.97	370.00	325.96	363.78	412.86
ECS-2BL_5B - Pre	1422	1442	370.45	329.77	325.71	362.83	370.46	326.01	361.71	402.35
ECS-2BL_5B - Ex	1462	1482	370.24	329.56	329.65	360.38	370.55	326.08	361.89	428.91
ECS-2BL_5C - Pre	1180	1200	369.50	304.18	324.05	349.28	369.93	323.94	347.87	405.39
ECS-2BL_5C - Ex	1324	1344	368.85	303.68	328.70	347.85	369.53	324.04	349.42	433.37
ECS-2BL_5D - Pre	1428	1438	369.71	319.21	324.18	349.60	370.72	324.11	349.92	397.84
ECS-2BL_5D - Ex	1521	1531	369.67	320.24	327.36	349.23	370.28	323.96	348.38	400.27
ECS-2BL_6 - Pre	2265	2285	370.26	342.21	324.46	367.28	368.37	324.51	366.20	413.28
ECS-2BL_6 - Ex	2345	2365	369.88	338.27	324.73	367.82	368.18	324.71	364.34	412.54
ECS-2BL_7 - Pre	820	840	364.02	328.49	324.79	348.45	348.42	324.83	347.90	389.78
ECS-2BL_7 - Ex	937	957	365.39	332.04	323.92	347.72	356.90	324.37	349.84	391.97
ECS-2BL_7B - Pre	1664	1684	369.97	292.40	324.49	352.54	356.89	324.31	352.86	406.68
ECS-2BL_7B - Ex	1722	1742	369.66	299.47	324.12	351.47	357.60	323.78	352.75	401.51
ECS-2BL_11 - Pre	2803	2823	370.13	345.79	346.22	361.58	369.72	346.59	361.65	396.59
ECS-2BL_11 - Ex[a]	3019	3039	370.25	337.35	346.21	363.61	369.71	346.48	363.58	398.97
ECS-2BL_11B - Pre	1894	1914	369.64	344.75	345.93	360.32	369.77	345.78	360.56	406.58
ECS-2BL_11B - Ex	1954	1974	369.00	345.11	347.45	358.86	369.92	345.91	360.33	468.51
ECS-2BL_12 - Pre	1885	1905	368.99	299.10	343.16	355.63	365.15	343.35	358.07	407.25
ECS-2BL_12 - Ex[a]	2027	2047	368.82	326.92	342.77	354.71	365.81	342.74	357.65	408.43
ECS-2BL_12B - Pre	2442	2462	370.03	335.84	346.43	360.68	369.49	346.85	361.55	410.97
ECS-2BL_12B - Ex	2547	2567	369.53	331.78	347.21	361.43	370.36	346.55	359.85	449.67
ECS-2BL_13 - Pre	2137	2157	369.87	304.62	348.65	361.06	368.84	348.73	361.66	411.81
ECS-2BL_13 - Ex	2200	2220	369.66	320.88	348.53	361.59	369.92	348.61	361.89	430.00
ECS-2BL_14 - Pre	2856	2876	368.51	315.60	346.75	360.28	364.24	346.42	359.19	411.49
ECS-2BL_14 - Ex	2886	2906	369.08	309.81	345.86	359.78	367.43	345.87	359.41	424.31

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_D_04 K	TF_HX_OU K	TF_IN K	TF_OUT K	TF_TS_AV K	TF_W_IN K	TF_W_OUT K	TI_A_a_5 K
ECS-2BL_17 - Pre	706	726	371.15	328.71	323.56	347.01	361.17	323.94	346.52	412.60
ECS-2BL_17 - Ex	892	912	360.07	319.95	330.79	341.74	368.72	323.73	348.74	573.57
ECS-2BL_18 - Pre	1606	1626	371.05	348.48	325.47	356.43	364.97	325.78	354.62	413.79
ECS-2BL_18 - Ex	1646	1666	369.54	348.91	325.63	356.59	366.07	325.99	354.18	416.99
ECS-2BL_18B - Pre	2104	2114	367.39	293.89	323.81	354.77	358.59	323.52	352.39	388.58
ECS-2BL_18B - Ex	2172	2182	368.78	294.06	329.75	348.40	370.40	323.40	351.98	594.98
ECS-2BL_22 - Pre	934	954	371.55	336.07	324.61	353.29	366.35	325.03	351.26	408.29
ECS-2BL_22 - Ex	1157	1177	367.45	337.45	327.13	354.13	366.37	325.33	353.93	423.70
ECS-2BL_23 - Pre	1660	1680	370.51	335.73	325.60	357.02	365.02	325.94	356.53	408.43
ECS-2BL_23 - Ex	1712	1732	367.52	344.62	325.92	355.99	365.39	326.22	357.53	409.02
ECS-2BL_23B - Pre	1296	1316	370.38	344.25	324.30	353.56	357.57	324.53	351.40	409.60
ECS-2BL_23B - Ex	1378	1398	365.22	340.47	324.96	352.79	361.31	325.09	352.34	411.56
ECS-2BL_26 - Pre	2022	2042	371.37	340.58	325.54	362.90	368.00	325.71	362.81	412.88
ECS-2BL_26 - Ex	2072	2092	370.96	338.94	325.78	362.91	370.38	325.78	363.03	435.23
ECS-2BL_26B - Pre	1421	1441	370.77	340.94	324.56	357.54	367.90	324.43	357.15	408.29
ECS-2BL_26B - Ex	1498	1518	369.18	341.05	325.02	358.11	370.04	324.49	357.88	461.40
ECS-2BL_27 - Pre	1061	1081	368.80	338.30	324.64	353.68	360.33	324.95	351.53	398.84
ECS-2BL_27 - Ex	1168	1188	366.23	334.60	324.95	352.97	361.31	325.17	353.58	403.66
ECS-2FC_1 - Pre	1170	1190	370.23	326.01	323.84	343.68	368.52	323.73	342.63	399.36
ECS-2FC_1 - Ex	1360	1380	369.42	322.33	323.10	344.08	368.34	323.02	343.21	400.44
ECS-2FC_2 - Pre	1602	1622	370.37	327.08	326.33	355.49	365.84	325.49	355.81	405.09
ECS-2FC_2 - Ex	1775	1795	370.49	306.95	325.45	356.79	367.01	325.86	356.27	405.12

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_A_a_6 K	TI_A_a_7 K	TI_A_c_6 K	TI_A_e_6 K	TI_B_g_5 K	TI_B_g_6 K	TI_B_g_7 K	TI B_i_6 K
ECS-2BL_1 - Pre	3252	3272	392.92	389.45	408.56	403.67	416.66	401.24	393.94	415.26
ECS-2BL_1 - Ex	3348	3368	393.70	417.16	407.60	403.98	417.52	401.10	477.86	421.25
ECS-2BL_1B - Pre	1900	1920	396.72	395.35	416.61	412.27	425.52	402.08	393.44	413.80
ECS-2BL_1B - Ex	1960	1980	440.41	431.24	459.11	457.61	449.88	446.09	427.69	456.48
ECS-2BL_2 - Pre	1480	1500	400.20	399.05	435.81	423.76	420.97	402.88	394.74	412.84
ECS-2BL_2 - Ex	1528	1548	415.73	405.70	519.43	566.92	425.42	564.87	533.09	554.72
ECS-2BL_5 - Pre	2210	2230	386.04	457.13	394.99	391.83	403.94	393.90	403.37	395.91
ECS-2BL_5 - Ex	2340	2360	403.58	492.87	411.85	411.31	412.64	409.53	545.58	410.38
ECS-2BL_5B - Pre	1422	1442	386.24	389.05	391.26	393.02	402.40	394.14	381.82	396.32
ECS-2BL_5B - Ex	1462	1482	473.11	515.35	494.43	524.00	460.20	512.19	509.86	497.78
ECS-2BL_5C - Pre	1180	1200	390.88	385.04	397.45	394.93	403.93	393.39	381.39	398.83
ECS-2BL_5C - Ex	1324	1344	482.21	450.73	491.04	487.18	461.97	488.99	444.79	487.67
ECS-2BL_5D - Pre	1428	1438	395.10	465.00	399.66	398.50	396.07	389.11	380.04	394.74
ECS-2BL_5D - Ex	1521	1531	418.99	476.83	418.11	417.96	399.37	396.66	582.50	402.18
ECS-2BL_6 - Pre	2265	2285	396.35	400.73	400.06	405.53	423.70	409.77	390.74	431.89
ECS-2BL_6 - Ex	2345	2365	395.14	400.31	401.06	406.87	424.56	415.84	416.83	473.11
ECS-2BL_7 - Pre	820	840	380.13	387.54	388.97	392.98	369.08	388.63	379.08	402.35
ECS-2BL_7 - Ex	937	957	382.79	394.79	392.17	404.29	419.84	416.21	429.76	485.54
ECS-2BL_7B - Pre	1664	1684	399.78	395.58	408.82	400.06	375.31	390.11	382.29	401.79
ECS-2BL_7B - Ex	1722	1742	397.33	394.72	400.46	390.10	384.77	401.38	383.51	461.90
ECS-2BL_11 - Pre	2803	2823	385.17	387.32	393.36	391.92	398.17	391.94	380.84	393.41
ECS-2BL_11 - Ex[a]	3019	3039	386.45	388.91	394.97	394.13	400.38	393.71	382.06	394.32
ECS-2BL_11B - Pre	1894	1914	403.48	389.54	410.96	404.40	415.05	396.15	387.17	409.35
ECS-2BL_11B - Ex	1954	1974	473.04	422.29	488.09	490.67	456.31	484.76	440.72	494.14
ECS-2BL_12 - Pre	1885	1905	383.51	389.86	395.61	398.78	409.14	398.38	383.75	398.93
ECS-2BL_12 - Ex[a]	2027	2047	384.69	391.74	397.73	399.99	410.92	399.59	384.39	399.92
ECS-2BL_12B - Pre	2442	2462	409.26	392.55	410.87	413.50	424.15	403.33	391.81	412.79
ECS-2BL_12B - Ex	2547	2567	442.12	410.44	450.39	456.71	453.62	447.59	416.32	461.84
ECS-2BL_13 - Pre	2137	2157	394.24	401.09	406.48	405.80	424.16	409.14	389.49	413.54
ECS-2BL_13 - Ex	2200	2220	408.96	409.88	429.79	428.89	442.48	426.98	396.39	431.84
ECS-2BL_14 - Pre	2856	2876	393.60	398.46	410.88	402.19	421.97	405.22	387.25	411.10
ECS-2BL_14 - Ex	2886	2906	404.13	409.49	422.93	417.77	438.98	421.08	402.13	428.86

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_A_a_6 K	TI_A_a_7 K	TI_A_c_6 K	TI_A_e_6 K	TI_B_g_5 K	TI_B_g_6 K	TI_B_g_7 K	TI_B_i_6 K
ECS-2BL_17 - Pre	706	726	390.10	391.38	398.94	393.85	403.51	396.23	383.82	400.07
ECS-2BL_17 - Ex	892	912	427.41	399.02	439.04	438.77	482.13	454.97	397.49	496.39
ECS-2BL_18 - Pre	1606	1626	397.70	397.73	410.29	394.82	414.92	402.69	386.15	416.25
ECS-2BL_18 - Ex	1646	1666	399.84	401.49	411.19	409.07	428.05	432.02	391.11	512.09
ECS-2BL_18B - Pre	2104	2114	398.60	356.74	401.91	408.72	411.82	403.78	386.20	448.93
ECS-2BL_18B - Ex	2172	2182	478.99	368.98	496.17	504.38	570.11	518.37	422.12	542.13
ECS-2BL_22 - Pre	934	954	388.39	392.52	395.31	399.14	411.08	402.30	387.14	400.83
ECS-2BL_22 - Ex	1157	1177	446.79	442.91	43.85	520.96	460.04	525.66	482.07	529.43
ECS-2BL_23 - Pre	1660	1680	393.44	396.67	408.45	402.69	423.36	408.09	391.04	416.07
ECS-2BL_23 - Ex	1712	1732	396.06	401.49	411.07	416.13	427.35	423.29	452.43	470.47
ECS-2BL_23B - Pre	1296	1316	399.10	401.62	422.55	402.92	413.50	403.17	386.20	410.59
ECS-2BL_23B - Ex	1378	1398	401.63	411.03	453.08	484.84	432.07	496.87	540.45	532.84
ECS-2BL_26 - Pre	2022	2042	394.27	398.09	59.58	404.43	420.84	406.04	390.25	412.10
ECS-2BL_26 - Ex	2072	2092	433.66	412.13	107.02	444.63	431.54	445.76	423.43	451.24
ECS-2BL_26B - Pre	1421	1441	401.19	393.43	404.56	405.35	420.05	402.36	390.90	412.94
ECS-2BL_26B - Ex	1498	1518	451.49	416.17	460.04	454.73	444.52	453.65	428.08	459.85
ECS-2BL_27 - Pre	1061	1081	386.19	390.17	388.87	396.00	413.22	399.70	386.82	404.95
ECS-2BL_27 - Ex	1168	1188	389.78	396.32	395.24	405.45	419.49	405.85	415.54	411.05
ECS-2FC_1 - Pre	1170	1190	392.00	383.89	395.05	391.28	397.75	389.74	380.85	394.77
ECS-2FC_1 - Ex	1360	1380	392.26	382.24	393.22	390.29	395.85	388.39	378.93	392.52
ECS-2FC_2 - Pre	1602	1622	396.86	391.08	410.69	406.77	417.26	398.35	388.10	407.20
ECS-2FC_2 - Ex	1775	1795	396.36	390.86	410.59	406.16	418.40	398.70	388.56	407.38

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_B_j_1 K	TI_B_j_2 K	TI_B_j_3 K	TI_B_j_4 K	TI_B_j_5 K	TI_B_j_7 K	TI_B_j_8 K	TI_B_k_6 K
ECS-2BL_1 - Pre	3252	3272	375.67	388.84	392.66	400.81	424.11	414.34	388.56	409.05
ECS-2BL_1 - Ex	3348	3368	375.15	388.39	391.18	398.61	423.65	503.22	398.94	418.68
ECS-2BL_1B - Pre	1900	1920	378.32	390.61	392.32	396.62	429.25	412.13	385.12	405.10
ECS-2BL_1B - Ex	1960	1980	379.05	395.23	398.52	415.70	457.45	442.10	404.12	443.12
ECS-2BL_2 - Pre	1480	1500	356.10	361.31	390.18	398.12	430.98	406.03	384.31	401.81
ECS-2BL_2 - Ex	1528	1548	357.27	364.12	391.58	398.70	468.57	504.13	396.32	478.18
ECS-2BL_5 - Pre	2210	2230	377.48	385.51	386.36	389.77	413.85	405.68	391.70	392.56
ECS-2BL_5 - Ex	2340	2360	378.11	387.62	390.30	395.48	429.67	565.43	416.91	408.16
ECS-2BL_5B - Pre	1422	1442	375.12	383.10	384.34	387.76	413.98	399.27	381.41	393.14
ECS-2BL_5B - Ex	1462	1482	377.95	388.04	390.12	394.70	440.76	513.12	448.41	472.56
ECS-2BL_5C - Pre	1180	1200	376.43	384.23	385.16	390.20	415.58	402.93	378.08	393.42
ECS-2BL_5C - Ex	1324	1344	377.02	391.12	393.62	404.74	453.36	460.67	416.07	479.48
ECS-2BL_5D - Pre	1428	1438	378.71	386.19	387.42	392.41	401.80	389.02	378.67	390.95
ECS-2BL_5D - Ex	1521	1531	377.97	386.23	386.53	389.84	404.56	584.47	391.70	395.27
ECS-2BL_6 - Pre	2265	2285	377.47	390.55	391.86	397.11	445.79	425.77	385.29	435.45
ECS-2BL_6 - Ex	2345	2365	378.24	393.40	393.84	400.47	472.68	521.04	385.25	483.17
ECS-2BL_7 - Pre	820	840	353.34	366.42	373.52	384.93	420.91	403.75	381.53	394.88
ECS-2BL_7 - Ex	937	957	354.23	364.23	388.69	394.97	444.24	591.43	507.03	490.84
ECS-2BL_7B - Pre	1664	1684	350.44	357.60	365.88	374.88	412.92	408.97	384.09	401.12
ECS-2BL_7B - Ex	1722	1742	347.62	380.46	390.71	402.53	433.84	457.68	391.68	485.65
ECS-2BL_11 - Pre	2803	2823	374.54	382.76	383.66	385.77	407.73	397.34	381.10	386.25
ECS-2BL_11 - Ex[a]	3019	3039	375.05	383.05	384.48	386.70	409.52	399.07	381.67	387.33
ECS-2BL_11B - Pre	1894	1914	378.92	389.70	391.74	396.28	418.68	408.08	379.56	399.11
ECS-2BL_11B - Ex	1954	1974	380.03	400.35	415.49	442.82	482.89	459.26	392.80	482.57
ECS-2BL_12 - Pre	1885	1905	366.52	385.15	387.04	389.52	415.87	404.74	383.44	390.02
ECS-2BL_12 - Ex[a]	2027	2047	371.65	385.43	387.83	389.80	416.83	405.05	383.72	390.76
ECS-2BL_12B - Pre	2442	2462	378.24	395.00	396.15	402.48	430.86	412.14	381.29	405.60
ECS-2BL_12B - Ex	2547	2567	383.41	403.57	423.48	435.19	464.83	438.36	393.86	451.79
ECS-2BL_13 - Pre	2137	2157	380.39	395.62	395.48	396.74	435.59	425.90	384.72	415.71
ECS-2BL_13 - Ex	2200	2220	380.19	400.50	406.60	418.81	461.12	423.37	388.93	418.16
ECS-2BL_14 - Pre	2856	2876	368.30	385.18	389.14	392.99	427.31	410.69	384.45	396.39
ECS-2BL_14 - Ex	2886	2906	375.26	397.22	405.69	409.72	448.96	426.56	390.48	415.56

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_B_j_1 K	TI_B_j_2 K	TI_B_j_3 K	TI_B_j_4 K	TI_B_j_5 K	TI_B_j_7 K	TI_B_j_8 K	TI_B_k_6 K
ECS-2BL_17 - Pre	706	726	353.16	368.68	371.89	375.80	414.13	400.72	382.33	393.32
ECS-2BL_17 - Ex	892	912	416.30	490.46	489.35	529.52	482.43	417.86	387.20	527.25
ECS-2BL_18 - Pre	1606	1626	363.16	385.29	388.92	398.32	424.80	409.68	385.01	419.55
ECS-2BL_18 - Ex	1646	1666	375.07	398.29	400.90	409.47	444.18	419.31	386.14	569.62
ECS-2BL_18B - Pre	2104	2114	353.64	384.30	392.59	398.88	435.23	415.63	383.39	453.11
ECS-2BL_18B - Ex	2172	2182	387.54	486.85	562.82	557.36	583.58	451.12	386.98	536.23
ECS-2BL_22 - Pre	934	954	370.46	385.37	386.59	388.91	419.99	403.67	383.92	398.00
ECS-2BL_22 - Ex	1157	1177	370.59	390.74	402.12	428.42	481.06	505.87	384.76	519.01
ECS-2BL_23 - Pre	1660	1680	369.28	392.40	393.45	396.64	427.26	408.62	386.22	401.99
ECS-2BL_23 - Ex	1712	1732	372.27	394.62	394.43	397.64	490.10	475.39	416.46	468.44
ECS-2BL_23B - Pre	1296	1316	344.47	362.19	374.59	388.84	415.95	407.88	382.72	400.42
ECS-2BL_23B - Ex	1378	1398	357.26	391.38	394.88	404.35	459.06	554.67	454.09	517.26
ECS-2BL_26 - Pre	2022	2042	376.16	391.48	392.01	395.20	430.69	407.69	384.41	401.63
ECS-2BL_26 - Ex	2072	2092	380.02	395.29	400.55	413.99	449.79	442.50	391.47	443.52
ECS-2BL_26B - Pre	1421	1441	374.23	390.26	391.93	398.26	425.88	409.99	383.16	403.41
ECS-2BL_26B - Ex	1498	1518	377.11	397.85	412.15	428.13	453.95	447.55	391.91	449.00
ECS-2BL_27 - Pre	1061	1081	363.16	389.00	390.97	393.44	442.49	408.55	384.93	400.60
ECS-2BL_27 - Ex	1168	1188	361.17	390.73	390.98	393.59	431.50	557.00	467.00	409.09
ECS-2FC_1 - Pre	1170	1190	369.85	379.70	381.70	385.10	408.23	397.19	378.30	390.79
ECS-2FC_1 - Ex	1360	1380	367.08	378.43	380.39	384.20	405.88	395.86	377.20	389.45
ECS-2FC_2 - Pre	1602	1622	370.54	387.73	390.77	396.14	426.90	408.46	383.16	399.65
ECS-2FC_2 - Ex	1775	1795	374.69	388.98	391.13	396.66	427.48	408.84	382.75	399.92

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_C_m_5 K	TI_C_m_6 K	TI_C_m_7 K	TI_C_o_6 K	TI_C_q_6 K	TI_D_s_5 K	TI_D_s_6 K	TI_D_s_7 K
ECS-2BL_1 - Pre	3252	3272	403.47	425.48	387.21	189.06	458.99	411.61	385.73	538.74
ECS-2BL_1 - Ex	3348	3368	405.80	429.29	442.63	183.08	469.91	411.87	390.74	528.73
ECS-2BL_1B - Pre	1900	1920	408.82	422.97	389.53	171.93	480.16	413.36	389.56	587.29
ECS-2BL_1B - Ex	1960	1980	428.36	462.31	422.04	129.56	511.67	426.91	425.06	567.21
ECS-2BL_2 - Pre	1480	1500	402.88	431.02	388.56	177.64	485.62	406.75	385.00	541.70
ECS-2BL_2 - Ex	1528	1548	409.47	439.26	392.89	170.47	490.38	403.85	383.25	541.40
ECS-2BL_5 - Pre	2210	2230	400.58	407.04	384.19	405.77	414.87	404.39	395.47	528.53
ECS-2BL_5 - Ex	2340	2360	413.26	423.36	556.49	426.63	431.05	420.58	411.95	570.26
ECS-2BL_5B - Pre	1422	1442	399.42	406.62	385.10	418.04	417.59	401.92	393.73	394.47
ECS-2BL_5B - Ex	1462	1482	409.28	465.74	493.45	462.57	462.17	410.91	420.67	502.73
ECS-2BL_5C - Pre	1180	1200	396.69	415.76	383.16	185.73	445.17	404.88	387.67	495.02
ECS-2BL_5C - Ex	1324	1344	414.13	494.97	443.46	111.91	508.73	419.54	446.22	534.54
ECS-2BL_5D - Pre	1428	1438	399.91	404.13	381.17	188.07	443.90	397.86	389.09	387.03
ECS-2BL_5D - Ex	1521	1531	401.72	408.40	558.33	181.49	473.40	397.99	393.03	569.64
ECS-2BL_6 - Pre	2265	2285	411.96	433.04	390.23	422.97	427.43	414.24	404.55	427.53
ECS-2BL_6 - Ex	2345	2365	429.69	443.70	505.98	430.37	438.59	415.97	404.77	429.36
ECS-2BL_7 - Pre	820	840	398.50	420.94	385.87	415.34	433.48	402.67	394.94	406.26
ECS-2BL_7 - Ex	937	957	410.34	453.88	595.33	419.48	447.23	408.85	399.53	435.39
ECS-2BL_7B - Pre	1664	1684	402.50	427.72	399.32	176.65	496.83	417.82	392.93	509.33
ECS-2BL_7B - Ex	1722	1742	409.85	511.33	469.97	76.19	558.94	420.50	410.20	518.32
ECS-2BL_11 - Pre	2803	2823	397.90	409.09	382.20	412.61	405.64	402.95	392.87	390.16
ECS-2BL_11 - Ex[a]	3019	3039	399.44	411.28	383.13	414.33	406.87	404.20	393.94	391.01
ECS-2BL_11B - Pre	1894	1914	404.60	421.88	387.34	184.24	474.08	422.28	392.13	414.24
ECS-2BL_11B - Ex	1954	1974	457.54	500.91	429.07	97.47	537.65	497.05	454.01	434.77
ECS-2BL_12 - Pre	1885	1905	405.35	421.70	385.90	425.17	414.24	404.72	394.76	392.36
ECS-2BL_12 - Ex[a]	2027	2047	406.05	422.84	386.48	425.11	415.45	405.44	395.85	393.56
ECS-2BL_12B - Pre	2442	2462	410.56	419.20	391.38	182.76	472.96	423.38	395.89	431.54
ECS-2BL_12B - Ex	2547	2567	441.43	464.21	412.68	131.77	513.15	457.31	429.64	441.12
ECS-2BL_13 - Pre	2137	2157	414.07	438.50	390.75	425.00	427.47	413.70	402.91	408.29
ECS-2BL_13 - Ex	2200	2220	433.10	445.32	398.26	444.51	447.83	428.09	419.11	420.13
ECS-2BL_14 - Pre	2856	2876	413.19	430.53	388.95	420.73	432.52	412.47	405.10	411.16
ECS-2BL_14 - Ex	2886	2906	432.84	447.66	401.61	437.89	446.13	420.43	412.98	423.01

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_C_m_5 K	TI_C_m_6 K	TI_C_m_7 K	TI_C_o_6 K	TI_C_q_6 K	TI_D_s_5 K	TI_D_s_6 K	TI_D_s_7 K
ECS-2BL_17 - Pre	706	726	401.66	418.28	387.05	412.32	430.19	408.18	402.33	460.32
ECS-2BL_17 - Ex	892	912	446.69	546.54	397.83	511.73	472.63	470.84	434.07	459.69
ECS-2BL_18 - Pre	1606	1626	415.34	438.88	404.58	468.81	491.63	422.01	433.65	483.07
ECS-2BL_18 - Ex	1646	1666	425.49	579.65	426.98	584.99	548.29	427.18	442.01	538.90
ECS-2BL_18B - Pre	2104	2114	409.25	426.17	392.62	177.04	474.68	404.50	392.07	931.11
ECS-2BL_18B - Ex	2172	2182	575.97	533.86	408.70	61.40	559.77	577.17	442.06	931.11
ECS-2BL_22 - Pre	934	954	407.47	430.49	390.32	416.81	436.79	409.43	401.09	405.70
ECS-2BL_22 - Ex	1157	1177	427.21	512.28	490.84	489.48	483.42	416.73	425.75	467.14
ECS-2BL_23 - Pre	1660	1680	411.83	442.03	391.98	415.29	450.95	413.18	399.96	449.55
ECS-2BL_23 - Ex	1712	1732	423.42	478.89	441.39	443.13	455.76	413.02	398.33	448.37
ECS-2BL_23B - Pre	1296	1316	404.41	433.69	388.80	421.22	491.13	416.49	392.50	460.04
ECS-2BL_23B - Ex	1378	1398	417.11	495.87	467.35	467.66	504.16	405.97	386.35	453.29
ECS-2BL_26 - Pre	2022	2042	414.25	425.24	393.60	416.28	433.82	415.33	401.94	418.37
ECS-2BL_26 - Ex	2072	2092	423.10	463.20	410.53	472.30	479.85	440.58	444.30	453.18
ECS-2BL_26B - Pre	1421	1441	408.17	430.04	390.22	183.98	505.14	417.31	391.59	931.11
ECS-2BL_26B - Ex	1498	1518	424.76	478.53	430.06	126.94	544.42	445.03	429.93	905.29
ECS-2BL_27 - Pre	1061	1081	413.26	446.73	405.60	440.45	468.81	412.86	402.32	532.32
ECS-2BL_27 - Ex	1168	1188	411.60	444.36	563.03	419.63	443.05	407.99	396.30	526.33
ECS-2FC_1 - Pre	1170	1190	392.89	408.50	382.01	193.44	451.65	400.53	387.56	434.63
ECS-2FC_1 - Ex	1360	1380	393.32	408.39	381.79	192.96	452.35	400.91	388.27	428.53
ECS-2FC_2 - Pre	1602	1622	406.66	422.02	388.79	188.64	462.07	415.47	388.58	426.76
ECS-2FC_2 - Ex	1775	1795	407.95	422.65	389.30	188.18	463.86	417.14	389.64	427.55

Note: Shadowed areas represent failed or questionable measurements.

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_D_u_6 K	TI_D_v_1 K	TI_D_v_2 K	TI_D_v_3 K	TI_D_v_4 K	TI_D_v_5 K	TI_D_v_7 K	TI_D_v_8 K
ECS-2BL_1 - Pre	3252	3272	301.65	371.58	388.35	393.22	405.12	406.28	420.05	382.88
ECS-2BL_1 - Ex	3348	3368	301.60	374.77	392.32	396.66	410.80	409.60	443.29	387.43
ECS-2BL_1B - Pre	1900	1920	931.32	368.63	389.55	394.08	409.92	411.90	426.26	385.63
ECS-2BL_1B - Ex	1960	1980	931.32	373.61	399.45	399.60	422.54	445.07	452.90	404.84
ECS-2BL_2 - Pre	1480	1500	931.32	321.38	348.15	358.12	368.03	406.83	426.24	384.16
ECS-2BL_2 - Ex	1528	1548	931.32	321.48	345.20	362.46	367.21	404.24	425.13	383.78
ECS-2BL_5 - Pre	2210	2230	398.82	375.00	385.14	387.97	396.01	399.52	443.59	422.25
ECS-2BL_5 - Ex	2340	2360	416.49	375.91	389.20	393.77	408.39	415.18	549.66	406.27
ECS-2BL_5B - Pre	1422	1442	931.32	374.72	383.55	387.75	395.10	398.30	408.49	379.37
ECS-2BL_5B - Ex	1462	1482	931.32	375.85	388.45	391.02	399.34	410.98	515.59	452.07
ECS-2BL_5C - Pre	1180	1200	931.32	373.21	382.46	386.31	397.19	402.93	409.14	378.19
ECS-2BL_5C - Ex	1324	1344	931.32	375.72	397.08	399.52	414.34	439.70	474.74	421.49
ECS-2BL_5D - Pre	1428	1438	93.92	376.13	385.39	389.29	401.10	397.43	408.05	377.67
ECS-2BL_5D - Ex	1521	1531	91.65	374.70	385.85	390.17	403.51	397.20	600.32	399.57
ECS-2BL_6 - Pre	2265	2285	399.07	357.31	378.28	390.87	406.59	405.06	426.68	382.89
ECS-2BL_6 - Ex	2345	2365	401.21	359.60	382.56	392.18	406.82	405.10	429.29	382.43
ECS-2BL_7 - Pre	820	840	391.51	343.39	365.43	381.79	397.42	397.89	419.64	380.76
ECS-2BL_7 - Ex	937	957	392.91	344.68	363.81	371.83	390.34	395.09	425.14	378.24
ECS-2BL_7B - Pre	1664	1684	931.32	341.69	354.73	375.52	405.06	406.45	453.58	397.48
ECS-2BL_7B - Ex	1722	1742	931.32	339.85	361.09	384.63	407.96	409.84	479.80	407.95
ECS-2BL_11 - Pre	2803	2823	405.24	368.80	379.11	383.89	389.32	395.85	404.46	379.85
ECS-2BL_11 - Ex[a]	3019	3039	406.33	365.92	378.37	384.19	390.44	396.32	406.46	380.19
ECS-2BL_11B - Pre	1894	1914	931.32	369.80	384.75	391.20	404.56	409.22	418.85	380.56
ECS-2BL_11B - Ex	1954	1974	931.32	376.24	399.13	404.80	426.35	493.77	456.38	392.25
ECS-2BL_12 - Pre	1885	1905	433.66	354.00	363.02	367.72	383.45	392.83	410.41	377.80
ECS-2BL_12 - Ex[a]	2027	2047	435.47	353.46	363.71	368.28	384.54	393.47	411.35	378.44
ECS-2BL_12B - Pre	2442	2462	931.32	365.44	373.79	393.73	407.93	409.56	422.62	381.89
ECS-2BL_12B - Ex	2547	2567	931.32	376.53	399.44	413.13	442.19	461.01	443.75	393.54
ECS-2BL_13 - Pre	2137	2157	391.24	359.70	367.19	382.56	397.17	399.45	419.15	380.03
ECS-2BL_13 - Ex	2200	2220	420.84	371.71	393.08	399.87	415.52	428.53	436.40	384.47
ECS-2BL_14 - Pre	2856	2876	436.65	364.49	385.13	392.31	405.83	406.80	427.05	381.72
ECS-2BL_14 - Ex	2886	2906	453.28	367.74	390.11	397.66	412.52	420.28	440.58	387.17

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_D_u_6 K	TI_D_v_1 K	TI_D_v_2 K	TI_D_v_3 K	TI_D_v_4 K	TI_D_v_5 K	TI_D_v_7 K	TI_D_v_8 K
ECS-2BL_17 - Pre	706	726	393.07	342.15	360.31	375.28	396.87	401.44	418.01	381.97
ECS-2BL_17 - Ex	892	912	425.00	385.94	441.94	482.33	529.07	529.82	431.91	387.16
ECS-2BL_18 - Pre	1606	1626	402.51	360.24	383.06	392.24	410.59	420.92	443.37	387.61
ECS-2BL_18 - Ex	1646	1666	418.51	355.33	381.54	391.49	409.83	421.90	493.05	387.62
ECS-2BL_18B - Pre	2104	2114	931.32	337.79	355.92	359.47	372.89	394.63	423.50	382.60
ECS-2BL_18B - Ex	2172	2182	931.32	375.63	437.35	503.05	546.64	596.72	440.96	388.10
ECS-2BL_22 - Pre	934	954	397.82	347.21	359.57	373.07	392.64	398.12	416.73	382.19
ECS-2BL_22 - Ex	1157	1177	436.85	361.55	378.55	384.45	401.21	408.19	464.59	378.12
ECS-2BL_23 - Pre	1660	1680	395.89	348.93	360.83	366.67	394.64	401.28	425.40	383.23
ECS-2BL_23 - Ex	1712	1732	391.29	349.99	362.57	366.25	390.95	398.71	423.73	380.21
ECS-2BL_23B - Pre	1296	1316	410.39	342.35	361.52	388.88	408.12	412.09	452.40	394.46
ECS-2BL_23B - Ex	1378	1398	379.89	339.54	354.43	361.66	375.21	397.50	422.79	376.49
ECS-2BL_26 - Pre	2022	2042	397.97	354.10	372.64	386.70	406.10	406.27	426.41	384.07
ECS-2BL_26 - Ex	2072	2092	442.51	363.70	386.41	397.53	421.21	440.34	455.58	389.49
ECS-2BL_26B - Pre	1421	1441	931.32	358.00	370.25	385.15	406.63	406.51	422.33	384.05
ECS-2BL_26B - Ex	1498	1518	931.32	370.49	384.86	399.90	425.34	455.68	452.38	390.74
ECS-2BL_27 - Pre	1061	1081	394.56	337.83	352.79	366.69	391.96	399.65	421.21	383.29
ECS-2BL_27 - Ex	1168	1188	388.58	341.19	356.34	362.14	388.63	394.18	423.53	378.10
ECS-2FC_1 - Pre	1170	1190	931.32	353.58	367.09	373.91	392.11	399.85	404.63	379.75
ECS-2FC_1 - Ex	1360	1380	931.32	368.62	376.98	383.84	393.73	399.39	403.69	378.15
ECS-2FC_2 - Pre	1602	1622	931.32	346.17	360.92	374.14	400.26	403.75	425.67	383.88
ECS-2FC_2 - Ex	1775	1795	931.32	349.98	363.66	379.91	401.71	403.90	425.62	383.34

Note: Shadowed areas represent failed or questionable measurements.

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_D_w_6 K	V_INNER V	WT_W_OUT N
ECS-2BL_1 - Pre	3252	3272	427.87	36.237	1482.100
ECS-2BL_1 - Ex	3348	3368	431.12	36.891	1466.330
ECS-2BL_1B - Pre	1900	1920	444.49	39.644	780.985
ECS-2BL_1B - Ex	1960	1980	480.27	40.393	898.442
ECS-2BL_2 - Pre	1480	1500	437.70	45.185	1006.250
ECS-2BL_2 - Ex	1528	1548	445.07	45.905	1290.690
ECS-2BL_5 - Pre	2210	2230	404.94	32.670	778.957
ECS-2BL_5 - Ex	2340	2360	423.13	33.531	1048.290
ECS-2BL_5B - Pre	1422	1442	405.26	31.269	36.404
ECS-2BL_5B - Ex	1462	1482	482.52	32.232	30.658
ECS-2BL_5C - Pre	1180	1200	421.50	30.836	1482.100
ECS-2BL_5C - Ex	1324	1344	515.79	31.472	1482.100
ECS-2BL_5D - Pre	1428	1438	418.28	31.221	-41.528
ECS-2BL_5D - Ex	1521	1531	437.39	32.472	-32.872
ECS-2BL_6 - Pre	2265	2285	423.66	44.960	909.606
ECS-2BL_6 - Ex	2345	2365	426.05	45.648	1401.500
ECS-2BL_7 - Pre	820	840	413.84	41.008	868.601
ECS-2BL_7 - Ex	937	957	412.48	45.571	110.059
ECS-2BL_7B - Pre	1664	1684	440.74	44.727	1482.100
ECS-2BL_7B - Ex	1722	1742	438.77	45.458	87.620
ECS-2BL_11 - Pre	2803	2823	389.22	31.189	47.604
ECS-2BL_11 - Ex[a]	3019	3039	390.60	32.338	1122.950
ECS-2BL_11B - Pre	1894	1914	419.88	37.725	46.350
ECS-2BL_11B - Ex	1954	1974	503.17	38.533	19.947
ECS-2BL_12 - Pre	1885	1905	386.59	36.442	1228.720
ECS-2BL_12 - Ex[a]	2027	2047	387.32	37.133	1074.910
ECS-2BL_12B - Pre	2442	2462	431.32	44.178	1482.100
ECS-2BL_12B - Ex	2547	2567	473.63	44.947	1482.100
ECS-2BL_13 - Pre	2137	2157	394.37	44.704	1484.600
ECS-2BL_13 - Ex	2200	2220	420.31	46.272	211.186
ECS-2BL_14 - Pre	2856	2876	401.90	47.296	1484.600
ECS-2BL_14 - Ex	2886	2906	415.21	48.582	406.555

Table J-2. ECS-2 test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_D_w_6 K	V_INNER V	WT_W_OUT N
ECS-2BL_17 - Pre	706	726	420.99	35.395	196.945
ECS-2BL_17 - Ex	892	912	446.11	36.337	1159.060
ECS-2BL_18 - Pre	1606	1626	426.78	44.743	88.083
ECS-2BL_18 - Ex	1646	1666	435.54	45.538	88.313
ECS-2BL_18B - Pre	2104	2114	432.10	44.563	-3.090
ECS-2BL_18B - Ex	2172	2182	502.47	45.748	-47.802
ECS-2BL_22 - Pre	934	954	420.69	36.914	378.814
ECS-2BL_22 - Ex	1157	1177	473.91	38.583	54.760
ECS-2BL_23 - Pre	1660	1680	414.22	46.152	1491.900
ECS-2BL_23 - Ex	1712	1732	412.77	46.566	87.935
ECS-2BL_23B - Pre	1296	1316	449.84	44.226	367.677
ECS-2BL_23B - Ex	1378	1398	436.23	44.840	1182.000
ECS-2BL_26 - Pre	2022	2042	425.99	43.548	584.282
ECS-2BL_26 - Ex	2072	2092	462.21	44.210	882.491
ECS-2BL_26B - Pre	1421	1441	436.65	42.293	44.401
ECS-2BL_26B - Ex	1498	1518	482.08	43.061	32.785
ECS-2BL_27 - Pre	1061	1081	414.89	43.407	914.974
ECS-2BL_27 - Ex	1168	1188	412.36	44.108	666.193
ECS-2FC_1 - Pre	1170	1190	417.30	28.743	889.669
ECS-2FC_1 - Ex	1360	1380	416.88	28.913	1461.780
ECS-2FC_2 - Pre	1602	1622	427.21	40.860	53.028
ECS-2FC_2 - Ex	1775	1795	426.88	40.985	520.361

Note: Shadowed areas represent failed or questionable measurements.

Table J-3. ECS-2WSR test results summary

TEST ID [1.]	***************** WSR General Test Parameters ********************							
	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [2.]	Water Inlet Temp. (K)	Air Entrainment Rate (Std. L/min.)	Stand Pipe Height (cm) [3.]	Total Test Section Power (kW)	Power to Saturate Outlet (kW)	R factor (P / Psat) -
ECS-2WSR0380 - Pre	0.381	0.286	315.4	3.1	416	96.94	88.23	1.10
ECS-2WSR0380 - Ex	0.380	0.286	315.8	3.4	366	101.88	88.27	1.15
ECS-2WSR0580 - Pre	0.581	0.437	314.7	2.0	329	100.47	138.22	0.73
ECS-2WSR0580 - Ex	0.582	0.437	315.2	3.7	329	121.22	137.18	0.88
ECS-2WSR0580C - Pre	0.578	0.434	314.7	5.4	329	102.89	137.69	0.75
ECS-2WSR0580C - Ex	0.578	0.434	315.4	7.4	325	110.88	136.03	0.82
ECS-2WSR0760 - Pre	0.761	0.571	315.5	7.1	328	119.80	178.80	0.67
ECS-2WSR0760 - Ex	0.761	0.571	314.1	8.2	330	126.82	183.01	0.69
ECS-2WSR0960 - Pre	0.963	0.723	314.5	17.6	322	153.33	230.60	0.66
ECS-2WSR0960 - Ex	0.963	0.723	314.5	11.3	340	162.50 [5.]	230.59	0.70
ECS-2WSR1040 - Pre	1.039	0.780	313.5	16.1	329	149.93	253.20	0.59
ECS-2WSR1040 - Ex	1.039	0.780	313.9	15.4	323	161.39	251.70	0.64
ECS-2WSR1040B - Pre	1.037	0.779	316.4	13.6	328	151.60	240.31	0.63
ECS-2WSR1040B - Ex	1.036	0.778	315.4	3.9	316	161.25	244.82	0.66
ECS-2WSR1340 - Pre	1.342	1.008	315.4	32.5	324	172.72	317.45	0.54
ECS-2WSR1340 - Ex [4.	1.343	1.009	315.8	35.6	338	171.21	316.68	0.54

[1.] Two values for each test are given - "Pre" implies conditions at the power step just before the excursion and "Ex" represents conditions at the excursion.

[2.] Superficial velocity based on test section flow area fof 13.31 cm^2.

[3.] Reference is top of heated length, increasing downward.

[4.] Test section failure, dryout did not occur.

[5.] Log book recorded value due to heater voltage offset on DAS channel.

Location	Elevation (cm)
Top of upper plenum	-182.2
Bot. of upper plenum	-161.9
Top of heated length	0
Bot. of heated length	380.9
Top of lower plenum	410.2
Bot. of lower plenum	438.2

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_A_03 kPa	DP_A_10 kPa	DP_B_03 kPa	DP_B_10 kPa	DP_C_03 kPa	DP_C_10 kPa	DP_D_02 kPa	DP_D_03 kPa
ECS-2WSR0380 - Pre	4915	4925	11.614	24.368	9.542	20.082	9.382	22.879	15.744	4.784
ECS-2WSR0380 - Ex	5205	5215	11.509	20.301	10.234	18.196	10.231	19.435	15.830	2.764
ECS-2WSR0580 - Pre	1011	1021	18.131	13.186	18.082	13.349	17.942	13.109	16.692	5.665
ECS-2WSR0580 - Ex	1071	1081	11.342	17.439	11.218	16.901	11.306	17.254	16.839	4.517
ECS-2WSR0580C - Pre	2210	2220	18.025	13.777	18.020	13.905	17.854	13.415	16.605	5.850
ECS-2WSR0580C - Ex	2502	2512	13.109	17.149	11.700	18.135	12.171	17.701	16.667	5.250
ECS-2WSR0760 - Pre	1330	1340	17.147	14.867	16.681	15.175	16.506	14.873	15.706	5.630
ECS-2WSR0760 - Ex	1612	1622	14.633	15.784	14.292	17.598	13.835	15.882	14.909	5.372
ECS-2WSR0960 - Pre	5918	5928	14.897	16.043	14.858	17.618	14.829	16.032	12.644	4.182
ECS-2WSR0960 - Ex	6044	6054	10.761	22.987	12.940	24.645	9.936	23.651	5.889	2.969
ECS-2WSR1040 - Pre	1668	1678	15.364	16.758	14.642	17.384	14.609	16.638	12.908	4.673
ECS-2WSR1040 - Ex	1872	1882	14.797	17.523	14.234	17.933	14.384	17.534	12.365	4.269
ECS-2WSR1040B - Pre	1067	1077	14.316	17.374	14.798	17.625	14.499	16.334	13.630	4.438
ECS-2WSR1040B - Ex	1275	1285	11.383	28.964	8.782	27.576	13.217	28.185	1.720	2.812
ECS-2WSR1340 - Pre	1346	1356	13.424	16.869	14.091	17.414	13.677	16.068	13.963	3.816
ECS-2WSR1340 - Ex	1574	1584	15.514	16.230	12.620	15.061	13.806	14.269	16.756	5.828

Test ID	Start Time(s)	End Time(s)	DP_D_04 kPa	DP_D_05 kPa	DP_D_06 kPa	DP_D_07 kPa	DP_D_08 kPa	DP_D_09 kPa	DP_D_10 kPa	DP_D_11 kPa
ECS-2WSR0380 - Pre	4915	4925	2.676	2.123	4.308	5.066	5.044	5.715	7.091	5.967
ECS-2WSR0380 - Ex	5205	5215	2.215	2.356	3.588	4.678	4.556	5.015	5.592	4.892
ECS-2WSR0580 - Pre	1011	1021	4.556	4.025	4.678	4.891	4.436	1.968	1.360	1.201
ECS-2WSR0580 - Ex	1071	1081	2.480	1.945	3.454	4.348	4.353	4.482	4.140	3.610
ECS-2WSR0580C - Pre	2210	2220	4.557	4.029	4.631	4.853	4.311	2.640	1.281	1.070
ECS-2WSR0580C - Ex	2502	2512	2.387	2.124	4.232	4.267	4.445	4.625	4.165	2.423
ECS-2WSR0760 - Pre	1330	1340	4.610	3.791	4.614	3.540	3.861	4.204	2.551	2.589
ECS-2WSR0760 - Ex	1612	1622	4.150	2.850	3.075	3.461	3.417	4.553	4.022	4.251
ECS-2WSR0960 - Pre	5918	5928	3.818	3.618	3.950	4.703	3.389	3.545	3.460	5.074
ECS-2WSR0960 - Ex	6044	6054	2.031	2.436	4.034	4.733	4.315	6.027	7.313	6.535
ECS-2WSR1040 - Pre	1668	1678	4.108	3.228	3.707	4.041	3.608	4.045	3.924	5.162
ECS-2WSR1040 - Ex	1872	1882	4.014	3.460	3.873	4.180	3.938	4.622	3.812	5.031
ECS-2WSR1040B - Pre	1067	1077	4.313	3.462	3.940	4.069	3.628	4.418	3.824	4.952
ECS-2WSR1040B - Ex	1275	1285	2.514	2.257	4.330	5.366	7.242	7.841	8.815	6.544

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR1340 - Pre	1346	1356	3.614	3.269	3.419	4.297	3.591	4.309	3.190	5.570
ECS-2WSR1340 - Ex	1574	1584	5.115	2.383	4.075	4.692	3.533	2.078	4.523	4.933

Test ID	Start Time(s)	End Time(s)	DP_D_ALL kPa	DP_D_S1 kPa	DP_D_S2 kPa	DP_D_TOT kPa	DP_PL_IN kPa	DP_PL_OU kPa	DP_SP kPa	I_INNER Amps
ECS-2WSR0380 - Pre	4915	4925	51.726	13.891	22.915	36.806	1.584	0.487	14.987	2188.910
ECS-2WSR0380 - Ex	5205	5215	47.640	10.923	19.841	30.764	1.582	0.220	10.235	2211.370
ECS-2WSR0580 - Pre	1011	1021	48.010	18.925	12.655	31.579	1.388	-0.011	6.761	2215.750
ECS-2WSR0580 - Ex	1071	1081	45.619	12.396	17.324	29.721	1.389	-0.025	6.798	2424.950
ECS-2WSR0580C - Pre	2210	2220	48.406	19.067	13.085	32.152	1.370	0.008	6.736	2295.710
ECS-2WSR0580C - Ex	2502	2512	46.925	13.994	17.501	31.495	1.367	-0.010	6.427	2322.870
ECS-2WSR0760 - Pre	1330	1340	47.720	18.644	14.156	32.800	1.007	-0.010	6.698	2451.780
ECS-2WSR0760 - Ex	1612	1622	45.326	15.447	15.452	30.899	1.042	0.000	6.915	2476.530
ECS-2WSR0960 - Pre	5918	5928	43.584	15.569	15.097	30.666	0.983	0.090	6.146	2751.190
ECS-2WSR0960 - Ex	6044	6054	39.637	11.469	22.388	33.857	0.465	0.105	7.815	2805.140
ECS-2WSR1040 - Pre	1668	1678	45.029	15.716	15.619	31.335	0.954	0.031	6.827	2705.630
ECS-2WSR1040 - Ex	1872	1882	44.686	15.615	16.551	32.167	0.957	-0.010	6.240	2804.470
ECS-2WSR1040B - Pre	1067	1077	45.319	16.154	15.939	32.094	0.966	0.016	6.717	2705.930
ECS-2WSR1040B - Ex	1275	1285	42.066	11.913	29.264	41.178	0.186	-0.058	5.592	2787.830
ECS-2WSR1340 - Pre	1346	1356	44.255	14.119	15.387	29.506	0.744	0.080	6.292	2893.720
ECS-2WSR1340 - Ex	1574	1584	48.500	17.401	14.826	32.228	0.735	-0.090	7.654	2889.500

Test ID	Start Time(s)	End Time(s)	L_PL_IN m	L_PL_OUT m	L_SP m	L_TS_TOT m	MDOT_W kg/s	P_ATM kPa	P_A_0 kPa	P_B_0 kPa
ECS-2WSR0380 - Pre	4915	4925	0.050	0.227	0.223	0.497	0.377	84.565	86.279	86.464
ECS-2WSR0380 - Ex	5205	5215	0.050	0.256	0.724	0.966	0.377	84.513	85.939	86.048
ECS-2WSR0580 - Pre	1011	1021	0.070	0.280	1.095	1.013	0.577	84.517	85.295	85.569
ECS-2WSR0580 - Ex	1071	1081	0.070	0.282	1.091	1.227	0.577	84.495	85.199	85.461
ECS-2WSR0580C - Pre	2210	2220	0.072	0.278	1.097	0.964	0.573	84.604	85.336	85.650
ECS-2WSR0580C - Ex	2502	2512	0.072	0.280	1.129	1.090	0.573	84.592	85.407	85.625
ECS-2WSR0760 - Pre	1330	1340	0.109	0.280	1.103	1.027	0.754	84.592	86.744	87.044
ECS-2WSR0760 - Ex	1612	1622	0.106	0.279	1.080	1.264	0.754	84.527	86.999	87.252
ECS-2WSR0960 - Pre	5918	5928	0.112	0.270	1.160	1.460	0.955	84.613	89.935	90.217
ECS-2WSR0960 - Ex	6044	6054	0.165	0.268	0.985	1.794	0.955	84.666	99.176	99.719
ECS-2WSR1040 - Pre	1668	1678	0.115	0.276	1.090	1.330	1.031	85.054	89.850	90.056
ECS-2WSR1040 - Ex	1872	1882	0.114	0.280	1.151	1.361	1.030	85.039	90.282	90.611

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR1040 - Pre	1668	1678	11.845	53.525	96.855	149.930	27.079	67.979	130.765	149.006
ECS-2WSR1040 - Ex	1872	1882	12.750	57.617	104.260	161.393	27.609	82.890	149.771	173.889
ECS-2WSR1040B - Pre	1067	1077	11.976	54.122	97.934	151.602	31.500	78.766	137.021	162.480
ECS-2WSR1040B - Ex	1275	1285	12.739	57.568	104.170	161.253	220.241	261.744	261.359	245.250
ECS-2WSR1340 - Pre	1346	1356	13.645	61.660	111.576	172.719	29.031	83.056	156.423	179.045
ECS-2WSR1340 - Ex	1574	1584	13.525	61.120	110.600	171.210	37.889	102.770	114.300	156.060

Test ID	Start Time(s)	End Time(s)	Q_W_CC L/s	Q_W_IN L/s	Q_W_IN_H L/s	Q_W_IN_L L/s	RHOW_CC kg/m	RHOW_IN kg/m	RHOW_OUT kg/m	RHOW_SP kg/m
ECS-2WSR0380 - Pre	4915	4925	0.146	0.381	0.381	0.000	999.737	991.378	960.096	970.107
ECS-2WSR0380 - Ex	5205	5215	0.146	0.380	0.380	0.000	999.749	991.182	960.456	969.803
ECS-2WSR0580 - Pre	1011	1021	0.190	0.581	0.581	0.000	999.781	991.757	970.733	977.132
ECS-2WSR0580 - Ex	1071	1081	0.191	0.582	0.582	0.000	999.790	991.509	964.178	976.133
ECS-2WSR0580C - Pre	2210	2220	0.193	0.578	0.578	0.000	999.794	991.628	968.091	975.340
ECS-2WSR0580C - Ex	2502	2512	0.194	0.578	0.578	0.000	999.814	991.434	966.620	975.562
ECS-2WSR0760 - Pre	1330	1340	0.193	0.761	0.761	0.000	999.785	991.458	966.767	978.525
ECS-2WSR0760 - Ex	1612	1622	0.193	0.761	0.761	0.000	999.778	991.873	968.115	977.404
ECS-2WSR0960 - Pre	5918	5928	0.190	0.963	0.963	0.000	999.794	991.696	970.014	977.422
ECS-2WSR0960 - Ex	6044	6054	0.191	0.963	0.963	0.000	999.837	991.711	959.714	977.404
ECS-2WSR1040 - Pre	1668	1678	0.174	1.039	1.039	0.000	999.799	992.134	975.461	979.506
ECS-2WSR1040 - Ex	1872	1882	0.181	1.039	1.039	0.000	999.820	991.922	971.743	978.194
ECS-2WSR1040B - Pre	1067	1077	0.205	1.037	1.037	0.000	999.814	991.147	971.449	979.169
ECS-2WSR1040B - Ex	1275	1285	0.206	1.036	1.036	0.000	999.799	991.302	958.789	976.639
ECS-2WSR1340 - Pre	1346	1356	0.135	1.342	1.342	0.000	999.667	991.406	975.822	979.327
ECS-2WSR1340 - Ex	1574	1584	0.139	1.343	1.343	0.000	999.680	991.220	978.010	979.580

Test ID	Start Time(s)	End Time(s)	RHOW_TS kg/m	TF_01_AV K	TF_02_AV K	TF_03_AV K	TF_04_AV K	TF_A_01 K	TF_A_02 K	TF_A_03 K
ECS-2WSR0380 - Pre	4915	4925	967.110	332.609	367.429	371.212	370.711	330.357	370.562	372.627
ECS-2WSR0380 - Ex	5205	5215	968.440	332.565	364.491	369.216	370.007	336.619	357.751	365.061
ECS-2WSR0580 - Pre	1011	1021	980.318	326.048	330.734	346.180	355.626	316.516	330.584	343.756
ECS-2WSR0580 - Ex	1071	1081	972.829	321.975	358.238	364.184	364.881	318.497	337.618	363.602
ECS-2WSR0580C - Pre	2210	2220	979.215	326.273	331.393	349.343	359.589	316.457	332.981	347.713
ECS-2WSR0580C - Ex	2502	2512	973.173	323.771	358.453	363.183	361.129	318.499	331.222	341.014
ECS-2WSR0760 - Pre	1330	1340	977.282	327.018	335.653	355.175	361.630	317.321	329.942	347.774
ECS-2WSR0760 - Ex	1612	1622	974.760	328.850	347.453	361.933	360.219	316.824	331.652	356.115

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR1040B - Pre	1067	1077	0.113	0.277	1.102	1.289	1.027	85.084	89.600	89.981
ECS-2WSR1040B - Ex	1275	1285	0.194	0.285	1.218	1.537	1.027	85.095	107.032	107.572
ECS-2WSR1340 - Pre	1346	1356	0.136	0.271	1.146	1.405	1.331	85.173	89.571	89.836
ECS-2WSR1340 - Ex	1574	1584	0.137	0.288	1.004	0.984	1.332	85.169	86.283	86.412

Test ID	Start Time(s)	End Time(s)	P_C_0 kPa	P_D_0 kPa	P_IN kPa	P_OUT kPa	Q_A_IN SLPM	Q_A_OUT SLPM	Q_CC kW	Q_DIFF %
ECS-2WSR0380 - Pre	4915	4925	86.203	85.668	84.324	93.933	1.948	3.109	34.314	-9.718
ECS-2WSR0380 - Ex	5205	5215	85.862	85.179	84.331	95.495	3.013	3.403	36.230	-15.962
ECS-2WSR0580 - Pre	1011	1021	85.366	84.695	84.319	96.428	1.807	1.983	26.343	-1.648
ECS-2WSR0580 - Ex	1071	1081	85.232	84.574	84.323	96.531	2.140	3.741	32.170	-0.975
ECS-2WSR0580C - Pre	2210	2220	85.465	84.832	84.401	96.746	5.073	5.416	28.106	4.985
ECS-2WSR0580C - Ex	2502	2512	85.422	84.741	84.390	96.900	6.683	7.425	31.992	-1.016
ECS-2WSR0760 - Pre	1330	1340	86.800	86.134	84.378	96.947	3.221	7.100	27.719	21.828
ECS-2WSR0760 - Ex	1612	1622	87.068	86.432	84.347	96.741	2.533	8.166	30.699	14.932
ECS-2WSR0960 - Pre	5918	5928	90.005	89.405	84.438	97.268	14.185	17.632	35.041	9.535
ECS-2WSR0960 - Ex	6044	6054	99.262	98.370	84.898	97.344	-10.562	11.261	35.013	41.617
ECS-2WSR1040 - Pre	1668	1678	89.878	89.157	84.842	97.337	15.594	16.102	31.157	-0.596
ECS-2WSR1040 - Ex	1872	1882	90.388	89.708	84.837	97.690	14.035	15.405	33.421	7.740
ECS-2WSR1040B - Pre	1067	1077	89.772	88.941	84.877	97.535	12.222	13.611	34.795	7.173
ECS-2WSR1040B - Ex	1275	1285	107.043	106.649	91.603	97.942	-25.177	3.855	40.763	52.108
ECS-2WSR1340 - Pre	1346	1356	89.724	88.988	85.013	97.886	32.452	19.837	27.158	3.669
ECS-2WSR1340 - Ex	1574	1584	86.108	85.313	85.007	98.731	35.577	20.112	27.509	-8.848

Test ID	Start Time(s)	End Time(s)	Q_E_1 kW	Q_E_3 kW	Q_E_5 kW	Q_E_TOT kW	Q_T_1 kW	Q_T_3 kW	Q_T_5 kW	Q_T_TOT kW
ECS-2WSR0380 - Pre	4915	4925	7.658	34.608	62.624	96.940	27.070	82.061	88.037	87.380
ECS-2WSR0380 - Ex	5205	5215	8.048	36.369	65.811	101.875	26.177	76.574	84.037	85.616
ECS-2WSR0580 - Pre	1011	1021	7.937	35.867	64.902	100.467	28.028	39.340	76.631	98.810
ECS-2WSR0580 - Ex	1071	1081	9.577	43.277	78.310	121.223	16.585	104.153	118.504	120.041
ECS-2WSR0580C - Pre	2210	2220	8.128	36.731	66.466	102.888	27.565	39.852	82.927	107.810
ECS-2WSR0580C - Ex	2502	2512	8.760	39.585	71.629	110.882	20.299	103.522	114.869	109.755
ECS-2WSR0760 - Pre	1330	1340	9.464	42.768	77.389	119.798	37.163	64.412	126.045	145.753
ECS-2WSR0760 - Ex	1612	1622	10.019	45.276	81.927	126.820	46.521	105.263	150.995	145.684
ECS-2WSR0960 - Pre	5918	5928	12.113	54.739	99.052	153.331	29.408	89.881	138.107	167.834
ECS-2WSR0960 - Ex	6044	6054	12.723	57.493	104.035	161.045	182.686	230.214	237.149	228.056

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR0960 - Pre	5918	5928	979.473	321.958	337.082	349.141	356.486	317.599	335.411	349.511
ECS-2WSR0960 - Ex	6044	6054	961.648	360.272	372.160	373.897	371.569	363.535	368.533	373.490
ECS-2WSR1040 - Pre	1668	1678	982.651	319.671	329.148	343.698	348.057	317.205	333.374	340.729
ECS-2WSR1040 - Ex	1872	1882	980.557	320.389	333.208	348.717	354.255	316.720	327.322	340.325
ECS-2WSR1040B - Pre	1067	1077	980.138	323.401	334.390	347.934	354.161	319.184	336.017	350.378
ECS-2WSR1040B - Ex	1275	1285	958.483	366.898	376.548	376.458	372.468	370.338	377.421	376.614
ECS-2WSR1340 - Pre	1346	1356	982.455	320.601	330.299	343.471	347.502	317.440	326.010	336.450
ECS-2WSR1340 - Ex	1574	1584	983.110	322.680	334.320	336.390	343.770	318.080	355.710	340.780

Test ID	Start Time(s)	End Time(s)	TF_A_04 K	TF_A_IN K	TF_A_OUT K	TF_B_01 K	TF_B_02 K	TF_B_03 K	TF_B_04 K	TF_CC_IN K
ECS-2WSR0380 - Pre	4915	4925	370.868	303.036	313.974	342.472	371.505	372.357	370.775	283.422
ECS-2WSR0380 - Ex	5205	5215	368.297	303.054	315.064	341.650	364.195	367.511	369.406	283.341
ECS-2WSR0580 - Pre	1011	1021	355.044	303.355	306.581	336.471	336.781	353.760	358.738	283.123
ECS-2WSR0580 - Ex	1071	1081	368.451	303.291	306.547	325.278	359.313	350.907	357.418	283.070
ECS-2WSR0580C - Pre	2210	2220	359.368	305.130	309.948	334.579	335.048	355.588	361.267	283.035
ECS-2WSR0580C - Ex	2502	2512	352.148	305.072	310.281	329.854	365.885	370.200	364.404	282.896
ECS-2WSR0760 - Pre	1330	1340	359.575	306.130	314.792	332.750	341.423	356.979	362.858	283.095
ECS-2WSR0760 - Ex	1612	1622	355.487	305.902	318.349	340.417	355.255	369.709	363.527	283.152
ECS-2WSR0960 - Pre	5918	5928	358.633	307.036	337.608	329.129	350.167	357.143	360.541	283.035
ECS-2WSR0960 - Ex	6044	6054	371.531	307.471	335.568	372.191	374.563	374.395	371.718	282.735
ECS-2WSR1040 - Pre	1668	1678	346.757	302.917	331.630	326.215	331.896	349.810	353.412	283.001
ECS-2WSR1040 - Ex	1872	1882	348.531	302.863	333.976	325.646	345.108	359.341	362.244	282.845
ECS-2WSR1040B - Pre	1067	1077	356.867	302.848	329.361	332.069	345.863	361.659	364.090	282.900
ECS-2WSR1040B - Ex	1275	1285	372.601	309.132	329.352	374.060	376.793	376.714	372.238	282.994
ECS-2WSR1340 - Pre	1346	1356	345.773	299.591	334.199	325.025	338.658	355.973	356.204	283.886
ECS-2WSR1340 - Ex	1574	1584	345.200	299.940	332.980	331.530	332.250	336.630	344.220	283.800

Test ID	Start Time(s)	End Time(s)	TF_CC_OU K	TF_C_01 K	TF_C_02 K	TF_C_03 K	TF_C_04 K	TF_D_01 K	TF_D_02 K	TF_D_03 K
ECS-2WSR0380 - Pre	4915	4925	339.602	334.333	362.250	368.893	370.325	323.277	365.397	370.971
ECS-2WSR0380 - Ex	5205	5215	342.725	328.877	369.349	371.893	371.124	323.116	366.671	372.402
ECS-2WSR0580 - Pre	1011	1021	316.270	334.360	333.314	351.455	354.898	316.847	322.255	335.751
ECS-2WSR0580 - Ex	1071	1081	323.410	324.949	369.601	371.118	364.591	319.176	366.423	371.106
ECS-2WSR0580C - Pre	2210	2220	317.800	336.274	333.971	355.644	360.094	317.783	323.574	338.425
ECS-2WSR0580C - Ex	2502	2512	322.350	327.963	370.441	370.685	366.081	318.771	366.266	370.832

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR0760 - Pre	1330	1340	317.394	336.890	342.367	362.501	362.817	321.113	328.875	353.445
ECS-2WSR0760 - Ex	1612	1622	321.193	338.651	358.290	370.221	365.205	319.508	344.615	351.682
ECS-2WSR0960 - Pre	5918	5928	327.035	324.101	337.983	351.177	353.212	317.001	324.765	338.731
ECS-2WSR0960 - Ex	6044	6054	326.639	364.247	374.719	374.404	371.852	341.113	370.827	373.293
ECS-2WSR1040 - Pre	1668	1678	325.715	319.646	327.265	348.540	347.832	315.619	324.058	335.714
ECS-2WSR1040 - Ex	1872	1882	326.914	322.499	337.101	360.767	360.741	316.689	323.299	334.439
ECS-2WSR1040B - Pre	1067	1077	323.384	324.481	332.255	346.821	349.710	317.869	323.426	332.878
ECS-2WSR1040B - Ex	1275	1285	330.249	368.246	376.400	376.223	372.516	354.945	375.575	376.277
ECS-2WSR1340 - Pre	1346	1356	331.935	322.008	333.251	349.324	345.815	317.930	323.277	332.140
ECS-2WSR1340 - Ex	1574	1584	330.970	323.910	323.920	334.550	341.490	317.200	325.400	333.590

Test ID	Start Time(s)	End Time(s)	TF_D_04 K	TF_HX_OU K	TF_IN K	TF_OUT K	TF_TS_AV K	TF_W_IN K	TF_W_OUT K	TI_A_a_5 K
ECS-2WSR0380 - Pre	4915	4925	370.880	307.920	315.465	357.148	360.490	315.382	356.589	408.220
ECS-2WSR0380 - Ex	5205	5215	371.203	308.531	315.983	358.095	359.070	315.773	357.049	405.632
ECS-2WSR0580 - Pre	1011	1021	353.820	300.861	314.436	346.049	339.646	314.694	345.289	359.311
ECS-2WSR0580 - Ex	1071	1081	369.063	301.270	315.107	349.041	352.319	315.169	346.988	411.532
ECS-2WSR0580C - Pre	2210	2220	357.617	306.681	314.789	348.759	341.648	314.666	348.314	362.438
ECS-2WSR0580C - Ex	2502	2512	361.881	306.585	315.312	348.551	351.634	315.391	347.943	403.463
ECS-2WSR0760 - Pre	1330	1340	361.264	314.896	315.247	343.624	344.869	315.456	342.861	365.507
ECS-2WSR0760 - Ex	1612	1622	356.657	314.412	314.117	345.515	349.614	314.087	344.821	364.047
ECS-2WSR0960 - Pre	5918	5928	353.555	311.380	314.603	346.973	341.166	314.515	344.788	376.476
ECS-2WSR0960 - Ex	6044	6054	371.171	310.828	314.559	348.468	369.474	314.508	344.820	414.569
ECS-2WSR1040 - Pre	1668	1678	344.224	300.836	313.395	342.537	335.144	313.528	341.107	358.665
ECS-2WSR1040 - Ex	1872	1882	345.503	301.821	313.987	344.836	339.142	313.930	343.440	353.113
ECS-2WSR1040B - Pre	1067	1077	345.979	309.524	316.077	343.898	339.972	316.383	341.710	355.036
ECS-2WSR1040B - Ex	1275	1285	372.513	310.764	315.662	351.316	373.093	315.420	346.131	433.929
ECS-2WSR1340 - Pre	1346	1356	342.218	320.139	315.388	342.235	335.469	315.360	341.429	353.531
ECS-2WSR1340 - Ex	1574	1584	344.170	337.260	315.880	342.830	334.290	315.770	340.970	362.520

Test ID	Start Time(s)	End Time(s)	TI_A_a_6 K	TI_A_a_7 K	TI_A_c_6 K	TI_A_e_6 K	TI_B_g_5 K	TI_B_g_6 K	TI_B_g_7 K	TI_B_i_6 K
ECS-2WSR0380 - Pre	4915	4925	406.884	362.282	413.473	425.298	412.100	405.325	390.016	414.939
ECS-2WSR0380 - Ex	5205	5215	420.905	366.842	423.032	430.931	405.048	401.205	385.688	407.373
ECS-2WSR0580 - Pre	1011	1021	375.147	358.256	404.109	423.426	391.240	395.130	377.590	406.829
ECS-2WSR0580 - Ex	1071	1081	405.525	462.296	411.035	432.128	364.846	383.322	379.483	390.900

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR0580C - Pre	2210	2220	392.048	350.647	414.124	434.215	393.579	393.227	380.987	405.854
ECS-2WSR0580C - Ex	2502	2512	397.587	365.046	380.963	401.803	364.338	382.940	376.431	409.495
ECS-2WSR0760 - Pre	1330	1340	383.479	356.087	402.793	431.829	366.146	383.816	379.873	401.963
ECS-2WSR0760 - Ex	1612	1622	379.690	353.370	396.279	433.897	380.902	393.517	386.714	407.927
ECS-2WSR0960 - Pre	5918	5928	396.135	361.346	412.682	453.758	400.136	392.116	386.640	408.811
ECS-2WSR0960 - Ex	6044	6054	410.136	369.508	425.596	461.870	430.701	409.509	398.220	449.902
ECS-2WSR1040 - Pre	1668	1678	378.635	350.804	405.422	444.191	369.534	387.890	380.500	415.066
ECS-2WSR1040 - Ex	1872	1882	378.313	349.697	412.629	448.225	387.255	400.242	384.765	418.718
ECS-2WSR1040B - Pre	1067	1077	380.427	351.246	424.152	450.935	399.431	414.123	390.259	425.907
ECS-2WSR1040B - Ex	1275	1285	418.729	374.085	447.495	483.350	439.585	442.890	399.018	517.280
ECS-2WSR1340 - Pre	1346	1356	379.043	348.421	418.263	454.254	400.554	407.812	384.220	427.579
ECS-2WSR1340 - Ex	1574	1584	383.680	351.850	420.770	450.420	378.830	389.370	376.120	418.750

Test ID	Start Time(s)	End Time(s)	TI_B_j_1 K	TI_B_j_2 K	TI_B_j_3 K	TI_B_j_4 K	TI_B_j_5 K	TI_B_j_7 K	TI_B_j_8 K	TI_B_k_6 K
ECS-2WSR0380 - Pre	4915	4925	351.329	390.494	390.342	400.310	418.356	424.256	383.865	409.897
ECS-2WSR0380 - Ex	5205	5215	347.715	376.995	384.342	395.200	411.380	415.264	382.129	403.609
ECS-2WSR0580 - Pre	1011	1021	350.231	361.442	378.220	393.905	412.032	408.413	374.308	404.907
ECS-2WSR0580 - Ex	1071	1081	336.577	354.135	366.948	383.416	410.346	388.168	373.029	403.173
ECS-2WSR0580C - Pre	2210	2220	347.549	359.710	375.596	395.744	418.373	416.027	378.086	413.012
ECS-2WSR0580C - Ex	2502	2512	338.923	362.222	375.222	396.945	419.272	435.638	385.928	422.671
ECS-2WSR0760 - Pre	1330	1340	345.134	361.002	375.860	388.828	416.290	425.066	380.963	418.897
ECS-2WSR0760 - Ex	1612	1622	353.068	368.280	372.803	392.557	418.733	452.609	390.304	423.035
ECS-2WSR0960 - Pre	5918	5928	343.275	367.539	384.988	399.919	430.910	430.017	383.160	429.659
ECS-2WSR0960 - Ex	6044	6054	376.491	398.319	403.963	428.164	487.894	467.881	387.776	508.884
ECS-2WSR1040 - Pre	1668	1678	340.260	359.538	366.516	391.111	426.154	426.086	380.572	429.061
ECS-2WSR1040 - Ex	1872	1882	341.570	365.580	382.656	402.610	430.108	430.590	388.203	432.601
ECS-2WSR1040B - Pre	1067	1077	346.791	366.974	378.350	400.391	430.288	427.588	387.481	423.635
ECS-2WSR1040B - Ex	1275	1285	380.413	396.267	409.551	425.363	475.578	458.692	387.408	551.511
ECS-2WSR1340 - Pre	1346	1356	339.376	366.353	388.285	403.590	436.054	428.989	383.811	433.584
ECS-2WSR1340 - Ex	1574	1584	345.320	359.830	366.450	365.750	425.880	399.840	369.140	424.780

Test ID	Start Time(s)	End Time(s)	TI_C_m_5 K	TI_C_m_6 K	TI_C_m_7 K	TI_C_o_6 K	TI_C_q_6 K	TI_D_s_5 K	TI_D_s_6 K	TI_D_s_7 K
ECS-2WSR0380 - Pre	4915	4925	408.562	424.371	394.419	170.145	497.990	408.339	395.735	416.131
ECS-2WSR0380 - Ex	5205	5215	408.840	423.661	392.874	179.493	485.262	410.446	397.154	514.372

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

ECS-2WSR0580 - Pre	1011	1021	396.460	410.862	379.110	176.200	478.310	362.789	367.696	375.514
ECS-2WSR0580 - Ex	1071	1081	410.398	432.164	396.693	117.262	531.553	415.427	421.201	485.956
ECS-2WSR0580C - Pre	2210	2220	395.655	408.559	381.526	176.873	501.804	371.089	368.850	399.517
ECS-2WSR0580C - Ex	2502	2512	411.168	429.106	482.342	87.499	595.841	413.666	420.244	591.423
ECS-2WSR0760 - Pre	1330	1340	399.481	413.994	389.467	174.065	540.657	384.866	377.604	421.318
ECS-2WSR0760 - Ex	1612	1622	407.728	420.341	418.782	153.413	562.346	400.090	389.842	423.665
ECS-2WSR0960 - Pre	5918	5928	390.124	410.713	386.064	177.114	570.799	369.700	371.015	432.317
ECS-2WSR0960 - Ex	6044	6054	443.059	459.313	400.948	75.417	647.952	437.832	421.124	445.305
ECS-2WSR1040 - Pre	1668	1678	391.734	410.330	382.869	167.101	577.365	361.138	367.078	379.817
ECS-2WSR1040 - Ex	1872	1882	406.376	419.474	393.140	160.392	589.830	390.441	376.973	417.632
ECS-2WSR1040B - Pre	1067	1077	397.253	417.168	388.258	162.182	571.463	363.208	367.303	391.604
ECS-2WSR1040B - Ex	1275	1285	430.051	503.391	412.108	29.274	675.079	434.959	439.092	448.251
ECS-2WSR1340 - Pre	1346	1356	385.838	425.653	383.214	149.255	571.460	378.620	377.474	379.231
ECS-2WSR1340 - Ex	1574	1584	369.170	415.280	373.180	156.240	571.780	379.240	370.520	380.330
Test ID	Start Time(s)	End Time(s)	TI_D_u_6 K	TI_D_v_1 K	TI_D_v_2 K	TI_D_v_3 K	TI_D_v_4 K	TI_D_v_5 K	TI_D_v_7 K	TI_D_v_8 K
ECS-2WSR0380 - Pre	4915	4925	-27.551	334.473	356.725	372.545	415.686	406.840	425.650	384.430
ECS-2WSR0380 - Ex	5205	5215	-34.873	334.141	357.351	369.255	417.147	411.473	521.600	386.879
ECS-2WSR0580 - Pre	1011	1021	-242.400	327.671	344.786	348.591	360.153	369.800	395.522	371.188
ECS-2WSR0580 - Ex	1071	1081	-242.400	332.643	352.862	378.987	421.493	411.935	560.265	459.700
ECS-2WSR0580C - Pre	2210	2220	263.065	329.710	347.562	353.090	362.686	391.372	408.767	374.756
ECS-2WSR0580C - Ex	2502	2512	250.414	331.352	350.636	377.667	415.204	409.673	535.985	443.042
ECS-2WSR0760 - Pre	1330	1340	137.113	336.349	354.430	357.726	366.402	384.969	415.910	378.262
ECS-2WSR0760 - Ex	1612	1622	126.488	334.779	355.616	361.490	371.353	376.380	414.919	378.220
ECS-2WSR0960 - Pre	5918	5928	-104.646	324.722	353.081	355.564	360.170	395.599	424.028	376.368
ECS-2WSR0960 - Ex	6044	6054	-107.935	343.869	379.414	386.118	390.907	417.524	460.796	384.589
ECS-2WSR1040 - Pre	1668	1678	-242.400	327.047	350.986	355.974	359.832	366.807	424.503	369.990
ECS-2WSR1040 - Ex	1872	1882	-242.400	330.337	350.196	353.460	359.182	380.650	411.048	370.483
ECS-2WSR1040B - Pre	1067	1077	-242.400	330.382	346.216	348.506	355.489	365.557	931.120	367.643
ECS-2WSR1040B - Ex	1275	1285	-242.400	366.403	383.533	396.079	432.707	432.666	814.558	385.170
ECS-2WSR1340 - Pre	1346	1356	-242.400	332.897	350.436	351.400	355.436	382.199	931.120	364.714
ECS-2WSR1340 - Ex	1574	1584	-242.400	327.980	344.570	349.100	352.260	404.720	931.120	365.190

Table J-4. ECS-2WSR test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_D_w_6 K	V_INNER V
ECS-2WSR0380 - Pre	4915	4925	435.312	44.284
ECS-2WSR0380 - Ex	5205	5215	484.171	46.069
ECS-2WSR0580 - Pre	1011	1021	418.502	45.343
ECS-2WSR0580 - Ex	1071	1081	476.977	49.990
ECS-2WSR0580C - Pre	2210	2220	429.183	44.818
ECS-2WSR0580C - Ex	2502	2512	442.912	47.735
ECS-2WSR0760 - Pre	1330	1340	432.740	48.861
ECS-2WSR0760 - Ex	1612	1622	427.346	51.210
ECS-2WSR0960 - Pre	5918	5928	440.379	55.732
ECS-2WSR0960 - Ex	6044	6054	452.975	57.410
ECS-2WSR1040 - Pre	1668	1678	437.225	55.413
ECS-2WSR1040 - Ex	1872	1882	439.051	57.549
ECS-2WSR1040B - Pre	1067	1077	432.260	56.026
ECS-2WSR1040B - Ex	1275	1285	461.259	57.842
ECS-2WSR1340 - Pre	1346	1356	436.485	59.687
ECS-2WSR1340 - Ex	1574	1584	439.900	59.251

Note: Shadowed areas indicate failed or questionable measurements.

Table J-5. ECS-2cE test results summary

TEST ID[1.]	Water Inlet Flowrate (l/s)	Test Section Superficial Velocity (m/s) [2.]	Water Inlet Temp. (K)	Stand Pipe Height (cm) [3.]	Air Entrainment Rate (Std. L/min.)	Total Test Section Power (kW)	Power to Saturate Plenum (kW)	R factor (P/Psat) -
	*************** ECS2cE General Test Parameters ******************							
ECS2cE11 - P	0.405	0.305	311.7	340	[4.]	90.5	101.7	0.89
ECS2cE11 - E	0.405	0.304	310.7	336	[4.]	93.4	103.3	0.90
ECS2cE12 - P	0.608	0.457	310.8	335	[4.]	121.5	154.9	0.78
ECS2cE12 - E	0.608	0.457	311.2	332	[4.]	124.5	153.8	0.81
ECS2cE13 - P	0.807	0.606	311.8	331	04.5	141.1	202.4	0.70
ECS2cE13 - E	0.807	0.606	311.4	335	02.5	143.7	204.0	0.70
ECS2cE14 - P	1.015	0.762	311.6	328	12.9	146.7	255.0	0.58
ECS2cE14 - E	1.015	0.763	312.0	331	13.9	150.0	253.2	0.59
ECS2cE21 - P	0.401	0.301	326.9	388	00.6	78.4	72.6	1.08
ECS2cE21 - E	0.400	0.301	328.3	389	00.5	81.8	70.3	1.16
ECS2cE22 - P	0.400	0.300	326.4	246	00.1	70.3	79.4	0.88
ECS2cE22 - E	0.404	0.303	326.7	248	00.1	73.2	79.5	0.92
ECS2cE23 - P	0.408	0.306	295.1	385	00.4	112.6	128.6	0.88
ECS2cE23 - E	0.408	0.306	295.2	385	00.4	115.7	128.5	0.90
ECS2cE24 - P	0.402	0.302	296.5	247	00.6	111.0	130.5	0.85
ECS2cE24 - E	0.402	0.302	296.6	229	00.9	113.6	130.2	0.87
ECS2cE31 - P	0.810	0.608	327.2	382	00.6	129.4	146.1	0.89
ECS2cE31 - E	0.811	0.609	326.8	376	00.6	132.8	147.6	0.90
ECS2cE32 - P	0.811	0.610	326.2	241	[4.]	93.2	162.0	0.58
ECS2cE32 - E	0.811	0.610	325.9	232	[4.]	96.1	162.9	0.59
ECS2cE34 - P	0.810	0.609	295.7	239	03.7	135.8	265.9	0.51
ECS2cE34 - E	0.810	0.608	297.2	240	03.3	139.4	260.7	0.53
ECS2cE42 - P	1.215	0.913	327.0	237	23.5	114.1	239.5	0.48
ECS2cE42 - E	1.216	0.914	326.8	236	37.4	117.2	240.4	0.49

[1.] Two values for each test are given - "Pre" implies conditions at the power step just before the excursion and "Ex" represents conditions at the excursion.
[2.] Superficial velocity is based upon a test section flow area of 13.31 cm^2.
[3.] Elevation 0.0 is defined as top of heated length, increasing downward.
[4.] The air flowrate meters were inoperable during this test point.

Location	Elevation (cm)
Top of upper Plenum	-182.2
Bottom of upper plenum	-161.9
Top of heated length	0.0
Bottom of Heated Length	381.0
Top of lower plenum	410.2
Bottom of lower plenum	438.2

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_A_1 kPa	DP_A_2 kPa	DP_A_3 kPa	DP_A_4 kPa	DP_A_ALL kPa	DP_C_2 kPa	DP_C_3 kPa	DP_PL_IN kPa	DP_PL_OU kPa
ECS2cE11 - Pre	50	150	16.502	13.501	16.715	2.301	49.018	13.526	16.611	1.586	-0.061
ECS2cE11 - Ex	210	250	16.234	12.216	17.440	2.736	48.626	12.331	17.305	1.582	-0.042
ECS2cE12 - Pre	50	150	16.692	18.236	13.284	1.016	49.228	18.354	13.125	1.375	-0.047
ECS2cE12 - Ex	200	230	16.580	14.915	14.906	2.142	48.543	14.970	14.953	1.355	-0.033
ECS2cE13 - Pre	650	750	12.975	15.170	16.505	3.752	48.403	15.021	16.436	1.108	-0.043
ECS2cE13 - Ex	840	890	14.366	13.549	17.165	4.040	49.120	13.772	16.850	1.038	-0.033
ECS2cE14 - Pre	50	150	12.014	15.255	16.932	4.479	48.679	15.035	16.799	1.058	-0.057
ECS2cE14 - Ex	320	370	12.814	14.652	16.763	4.600	48.829	14.411	16.714	1.064	-0.057
ECS2cE21 - Pre	50	150	16.635	14.184	17.622	4.957	53.398	14.254	17.625	1.375	0.193
ECS2cE21 - Ex	320	370	16.525	13.869	18.053	5.024	53.471	13.913	17.999	1.380	0.342
ECS2cE22 - Pre	50	150	16.277	14.213	9.257	0.742	40.488	14.247	9.280	1.542	-0.049
ECS2cE22 - Ex	250	300	14.669	12.070	12.667	1.135	40.541	12.121	12.734	1.499	-0.034
ECS2cE23 - Pre	50	150	16.596	18.569	17.863	0.701	53.729	18.623	17.801	1.658	-0.121
ECS2cE23 - Ex	410	460	16.600	18.604	17.738	0.749	53.691	18.611	17.600	1.658	-0.120
ECS2cE24 - Pre	50	150	15.192	12.820	11.412	1.314	40.737	12.837	11.330	1.652	-0.119
ECS2cE24 - Ex	200	215	14.824	10.231	12.374	1.870	39.299	10.395	12.377	1.654	-0.048
ECS2cE31 - Pre	50	150	15.045	15.394	17.710	5.329	53.478	15.521	17.508	0.839	0.018
ECS2cE31 - Ex	210	260	14.816	14.989	18.084	5.515	53.404	15.044	18.044	0.818	0.046
ECS2cE32 - Pre	50	150	8.324	17.298	14.239	1.821	41.681	17.152	14.181	0.777	-0.030
ECS2cE32 - Ex	510	560	13.154	14.800	10.477	1.676	40.107	15.041	10.403	0.961	-0.012
ECS2cE34 - Pre	50	150	5.689	18.010	14.655	1.763	40.117	17.811	14.610	1.227	-0.101
ECS2cE34 - Ex	570	620	7.005	17.624	14.416	1.564	40.609	17.651	14.200	1.131	-0.111
ECS2cE42 - Pre	50	150	8.891	13.412	14.717	4.240	41.260	13.544	14.469	0.661	-0.010
ECS2cE42 - Ex	380	430	8.373	13.066	14.472	3.992	39.902	12.737	14.346	0.782	0.004

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	DP_SP kPa	I_INNER Amps	JF_FPS ft/s	JG_FPS ft/s	L_PL_IN m	L_PL_OUT m	L_SP m	L_TS_TOT m	MDOT_W kg/s
ECS2cE11 - Pre	50	150	10.173	2092.880	0.999	0.016	0.040	0.285	0.985	0.826	0.402
ECS2cE11 - Ex	210	250	9.816	2124.790	0.998	0.016	0.040	0.283	1.023	0.863	0.402
ECS2cE12 - Pre	50	150	9.790	2414.610	1.499	0.016	0.061	0.284	1.030	0.882	0.604
ECS2cE12 - Ex	200	230	9.514	2443.610	1.499	0.015	0.063	0.282	1.059	0.924	0.604
ECS2cE13 - Pre	650	750	9.469	2600.060	1.990	0.016	0.089	0.284	1.068	0.952	0.801
ECS2cE13 - Ex	840	890	9.775	2624.920	1.990	0.016	0.096	0.283	1.035	0.867	0.801
ECS2cE14 - Pre	50	150	9.183	2667.550	2.502	0.001	0.094	0.285	1.102	0.951	1.008
ECS2cE14 - Ex	320	370	9.482	2695.860	2.502	0.001	0.093	0.285	1.070	0.931	1.007
ECS2cE21 - Pre	50	150	14.723	1939.380	0.988	0.026	0.061	0.258	0.498	0.325	0.395
ECS2cE21 - Ex	320	370	14.788	1980.650	0.987	0.033	0.060	0.243	0.491	0.299	0.395
ECS2cE22 - Pre	50	150	1.339	1838.850	0.985	0.017	0.043	0.284	1.922	1.731	0.394
ECS2cE22 - Ex	250	300	1.491	1876.020	0.995	0.006	0.048	0.283	1.906	1.709	0.398
ECS2cE23 - Pre	50	150	14.483	2336.310	1.006	0.000	0.033	0.292	0.532	0.423	0.407
ECS2cE23 - Ex	410	460	14.484	2366.260	1.005	-0.002	0.033	0.292	0.530	0.422	0.407
ECS2cE24 - Pre	50	150	1.426	2315.280	0.991	0.004	0.034	0.292	1.913	1.720	0.401
ECS2cE24 - Ex	200	215	-0.265	2341.890	0.991	0.004	0.033	0.284	2.092	1.861	0.401
ECS2cE31 - Pre	50	150	14.135	2479.290	1.995	0.248	0.116	0.277	0.566	0.378	0.799
ECS2cE31 - Ex	210	260	13.587	2511.590	1.998	0.190	0.118	0.274	0.623	0.376	0.800
ECS2cE32 - Pre	50	150	0.902	2116.160	2.000	-0.396	0.123	0.282	1.969	1.646	0.801
ECS2cE32 - Ex	510	560	0.046	2148.520	2.000	0.018	0.104	0.280	2.059	1.808	0.801
ECS2cE34 - Pre	50	150	0.670	2561.600	1.997	0.001	0.077	0.290	1.994	1.875	0.808
ECS2cE34 - Ex	570	620	0.788	2595.850	1.996	0.002	0.087	0.291	1.982	1.812	0.807
ECS2cE42 - Pre	50	150	0.461	2334.980	2.996	0.966	0.134	0.280	2.016	1.690	1.199
ECS2cE42 - Ex	380	430	0.399	2368.930	2.997	1.538	0.122	0.279	2.022	1.837	1.200

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	P_ATM kPa	P_B_0 kPa	P_B_150 kPa	P_B_76 kPa	P_B_96 kPa	P_IN kPa	P_OUT kPa	Q_A_IN SLPM	Q_A_OUT SLPM
ECS2cE11 - Pre	50	150	84.833	85.421	93.339	91.013	92.101	84.648	96.919	0.401	0.001
ECS2cE11 - Ex	210	250	84.828	85.560	93.836	91.897	93.026	84.649	96.727	0.394	-0.016
ECS2cE12 - Pre	50	150	84.790	85.434	91.999	85.894	86.458	84.605	97.036	0.380	0.199
ECS2cE12 - Ex	200	230	84.792	85.545	93.313	88.976	90.293	84.618	96.800	0.373	0.825
ECS2cE13 - Pre	650	750	84.761	89.155	95.439	92.480	94.194	84.575	97.240	0.396	4.528
ECS2cE13 - Ex	840	890	84.757	88.041	95.595	93.143	94.720	84.568	97.280	0.398	2.548
ECS2cE14 - Pre	50	150	84.854	90.120	95.705	93.997	94.553	84.788	96.703	0.032	12.893
ECS2cE14 - Ex	320	370	84.853	89.407	95.670	93.752	94.583	84.787	96.641	0.026	13.870
ECS2cE21 - Pre	50	150	84.935	85.276	91.633	89.651	90.797	84.765	92.223	0.627	0.600
ECS2cE21 - Ex	320	370	84.929	85.421	91.830	90.336	91.263	84.759	92.289	0.794	0.542
ECS2cE22 - Pre	50	150	84.962	85.691	100.353	90.378	92.233	84.789	105.836	0.406	0.070
ECS2cE22 - Ex	250	300	84.963	87.340	100.570	93.753	95.410	84.782	105.573	0.146	0.062
ECS2cE23 - Pre	50	150	84.975	85.085	86.485	85.440	85.619	84.903	91.635	-0.008	0.412
ECS2cE23 - Ex	410	460	84.966	85.100	86.535	85.504	85.830	84.905	91.662	-0.047	0.392
ECS2cE24 - Pre	50	150	84.779	86.372	100.044	93.001	94.024	84.707	104.951	0.091	0.649
ECS2cE24 - Ex	200	215	84.781	86.939	100.283	94.735	95.669	84.707	104.605	0.092	0.915
ECS2cE31 - Pre	50	150	84.810	87.522	92.373	90.505	91.738	84.627	92.706	6.043	0.620
ECS2cE31 - Ex	210	260	84.805	87.649	92.628	91.068	92.068	84.617	92.642	4.628	0.592
ECS2cE32 - Pre	50	150	84.977	95.309	102.104	96.761	97.476	85.592	106.222	-9.636	0.034
ECS2cE32 - Ex	510	560	84.980	89.607	101.870	92.731	94.822	84.798	105.973	0.442	-0.009
ECS2cE34 - Pre	50	150	84.775	95.792	101.054	97.187	97.574	84.728	105.220	0.031	3.744
ECS2cE34 - Ex	570	620	84.770	94.851	100.880	96.397	96.877	84.706	105.151	0.058	3.337
ECS2cE42 - Pre	50	150	84.993	94.865	105.154	100.319	101.645	85.668	106.646	23.510	0.071
ECS2cE42 - Ex	380	430	84.990	94.242	104.924	100.010	101.939	84.797	106.559	37.441	-0.028

Note: Shadowed areas indicate failed or questionable measurements.

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	Q_CC kW	Q_DIFF %	Q_E_1 kW	Q_E_2 kW	Q_E_3 kW	Q_E_4 kW	Q_E_5 kW	Q_E_TOT kW	Q_T_1 kW
ECS2cE11 - Pre	50	150	-0.023	4.900	18.109	36.217	54.326	72.435	90.543	90.543	68.028
ECS2cE11 - Ex	210	250	-0.024	4.512	18.676	37.353	56.029	74.705	93.382	93.382	73.122
ECS2cE12 - Pre	50	150	-0.005	1.723	24.307	48.614	72.921	97.228	121.535	121.535	27.924
ECS2cE12 - Ex	200	230	-0.006	8.802	24.899	49.798	74.698	99.597	124.496	124.496	34.760
ECS2cE13 - Pre	650	750	-0.012	11.815	28.212	56.424	84.636	112.848	141.060	141.060	48.286
ECS2cE13 - Ex	840	890	-0.009	13.173	28.734	57.468	86.202	114.936	143.670	143.670	59.862
ECS2cE14 - Pre	50	150	-0.002	7.092	29.340	58.680	88.020	117.360	146.700	146.700	36.198
ECS2cE14 - Ex	320	370	-0.001	7.029	30.001	60.002	90.003	120.003	150.006	150.006	38.108
ECS2cE21 - Pre	50	150	-0.028	-7.035	15.685	31.371	47.056	62.741	78.427	78.427	45.692
ECS2cE21 - Ex	320	370	-0.019	-13.320	16.356	32.713	49.069	65.425	81.781	81.781	44.754
ECS2cE22 - Pre	50	150	-0.019	-2.916	14.057	28.113	42.170	56.227	70.283	70.283	39.035
ECS2cE22 - Ex	250	300	-0.012	-1.497	14.644	29.288	43.932	58.576	73.220	73.220	55.751
ECS2cE23 - Pre	50	150	-0.025	4.510	22.523	45.046	57.568	90.091	112.614	112.614	21.558
ECS2cE23 - Ex	410	460	-0.033	5.355	23.148	46.296	69.443	92.591	115.739	115.739	22.148
ECS2cE24 - Pre	50	150	-0.013	3.369	22.203	44.406	66.609	88.812	111.014	111.014	77.809
ECS2cE24 - Ex	200	215	-0.017	1.174	22.715	45.429	68.144	90.858	113.573	113.573	87.321
ECS2cE31 - Pre	50	150	-0.029	0.608	25.877	51.753	77.630	103.507	129.383	129.383	46.719
ECS2cE31 - Ex	210	260	-0.020	-0.298	26.553	53.105	79.658	106.211	132.764	132.764	56.781
ECS2cE32 - Pre	50	150	-0.013	12.014	18.646	37.293	55.939	74.585	93.232	93.232	35.539
ECS2cE32 - Ex	510	560	-0.003	11.130	19.227	38.453	57.679	76.906	96.132	96.132	39.463
ECS2cE34 - Pre	50	150	-0.011	1.796	27.164	54.328	81.492	108.655	135.819	135.819	36.286
ECS2cE34 - Ex	570	620	-0.009	8.959	27.870	55.741	83.611	111.482	139.352	139.352	50.650
ECS2cE42 - Pre	50	150	-0.018	18.145	22.813	45.626	68.440	91.253	114.066	114.066	54.704
ECS2cE42 - Ex	380	430	-0.013	14.922	23.443	46.885	70.328	93.771	117.213	117.213	38.971

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	Q_T_2 kW	Q_T_3 kW	Q_T_4 kW	Q_T_5 kW	Q_T_TOT kW	Q_W_CC L/s	Q_W_IN L/s	Q_W_IN_H L/s	Q_W_IN_L L/s
ECS2cE11 - Pre	50	150	86.726	92.282	96.736	94.939	94.979	0.000	0.405	0.405	0.001
ECS2cE11 - Ex	210	250	89.558	94.856	98.799	97.711	97.597	0.000	0.405	0.405	0.001
ECS2cE12 - Pre	50	150	43.291	68.428	106.210	123.850	123.629	0.000	0.608	0.608	0.001
ECS2cE12 - Ex	200	230	76.799	105.137	130.920	135.772	135.460	0.000	0.608	0.608	0.001
ECS2cE13 - Pre	650	750	82.089	116.567	154.031	157.426	157.724	0.000	0.807	0.807	0.001
ECS2cE13 - Ex	840	890	99.698	124.786	154.093	162.138	162.617	0.000	0.807	0.807	0.001
ECS2cE14 - Pre	50	150	71.824	103.143	147.783	157.088	157.114	0.000	1.015	1.015	0.000
ECS2cE14 - Ex	320	370	79.778	108.841	153.284	160.737	160.554	0.000	1.015	1.015	0.000
ECS2cE21 - Pre	50	150	66.128	69.433	72.784	73.300	72.909	0.000	0.401	0.401	0.001
ECS2cE21 - Ex	320	370	64.812	67.703	70.746	71.182	70.888	0.000	0.400	0.400	0.001
ECS2cE22 - Pre	50	150	60.662	66.167	69.762	68.161	68.232	0.000	0.400	0.400	0.000
ECS2cE22 - Ex	250	300	66.693	71.086	74.526	72.210	72.124	0.000	0.404	0.404	0.000
ECS2cE23 - Pre	50	150	48.528	77.369	110.280	117.882	117.692	0.000	0.408	0.408	0.000
ECS2cE23 - Ex	410	460	51.455	80.368	114.379	122.142	121.936	0.000	0.408	0.408	0.000
ECS2cE24 - Pre	50	150	109.485	115.400	118.472	115.074	114.751	0.000	0.402	0.402	0.000
ECS2cE24 - Ex	200	215	111.795	116.814	118.877	115.333	114.916	0.000	0.402	0.402	0.000
ECS2cE31 - Pre	50	150	74.643	97.949	123.897	130.906	130.171	0.000	0.810	0.810	0.001
ECS2cE31 - Ex	210	260	85.666	104.825	127.094	132.397	132.363	0.000	0.811	0.811	0.001
ECS2cE32 - Pre	50	150	52.493	70.850	96.309	104.526	104.440	0.000	0.811	0.811	0.001
ECS2cE32 - Ex	510	560	58.067	76.962	101.972	106.795	106.813	0.000	0.811	0.811	0.001
ECS2cE34 - Pre	50	150	65.916	88.506	121.631	138.930	138.259	0.000	0.810	0.810	0.001
ECS2cE34 - Ex	570	620	82.163	105.965	141.548	151.979	151.854	0.000	0.810	0.810	0.000
ECS2cE42 - Pre	50	150	77.746	101.314	131.876	135.165	134.825	0.000	1.215	1.215	0.001
ECS2cE42 - Ex	380	430	66.028	89.308	128.436	134.193	134.703	0.000	1.216	1.216	0.001

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	RHOW_CC kg/m	RHOW_IN kg/m	RHOW_OUT kg/m	RHOW_SP kg/m	RHOW_TS kg/m	R_INNER Ohms	TF_1_AV K	TF_2_AV K	TF_3_AV K
ECS2cE11 - Pre	50	150	995.438	992.724	962.025	964.280	965.108	0.021	352.103	363.202	366.500
ECS2cE11 - Ex	210	250	995.323	993.099	961.582	964.125	964.588	0.021	354.069	363.835	366.982
ECS2cE12 - Pre	50	150	994.795	993.057	967.982	968.531	980.108	0.021	321.796	327.877	337.823
ECS2cE12 - Ex	200	230	994.646	992.942	964.491	967.980	974.715	0.021	324.840	341.476	352.689
ECS2cE13 - Pre	650	750	993.196	992.652	968.402	971.740	976.920	0.021	326.324	336.402	346.682
ECS2cE13 - Ex	840	890	993.159	992.798	967.497	971.337	975.419	0.021	329.350	341.226	348.706
ECS2cE14 - Pre	50	150	994.524	992.767	974.959	976.277	982.166	0.021	320.173	328.620	336.045
ECS2cE14 - Ex	320	370	994.318	992.648	974.214	975.807	981.365	0.021	320.974	330.856	337.747
ECS2cE21 - Pre	50	150	993.614	986.741	959.862	961.414	963.391	0.021	354.302	366.648	368.645
ECS2cE21 - Ex	320	370	993.487	985.114	959.732	961.481	963.058	0.021	355.160	367.300	369.049
ECS2cE22 - Pre	50	150	996.333	986.876	962.337	963.585	965.549	0.021	350.035	363.139	366.473
ECS2cE22 - Ex	250	300	996.110	986.745	960.592	963.104	962.488	0.021	360.118	366.676	369.308
ECS2cE23 - Pre	50	150	997.602	997.542	964.855	966.525	980.593	0.021	307.664	323.498	340.428
ECS2cE23 - Ex	410	460	997.036	997.534	963.023	965.226	979.627	0.021	308.047	325.258	342.236
ECS2cE24 - Pre	50	150	997.258	997.235	964.250	965.986	967.517	0.021	342.676	361.549	365.073
ECS2cE24 - Ex	200	215	997.118	997.232	964.128	965.510	966.413	0.021	348.354	362.938	365.929
ECS2cE31 - Pre	50	150	993.122	986.612	963.425	964.662	970.788	0.021	340.958	349.311	356.282
ECS2cE31 - Ex	210	260	992.974	986.699	963.167	963.861	969.539	0.021	343.756	352.381	358.101
ECS2cE32 - Pre	50	150	994.784	986.960	969.366	971.411	975.535	0.021	336.821	341.879	347.356
ECS2cE32 - Ex	510	560	994.587	987.095	969.144	972.230	974.846	0.021	337.682	343.230	348.865
ECS2cE34 - Pre	50	150	998.348	997.432	981.903	982.440	988.695	0.021	306.212	314.973	321.652
ECS2cE34 - Ex	570	620	997.394	997.040	978.919	981.092	985.797	0.021	312.115	321.439	328.483
ECS2cE42 - Pre	50	150	994.900	986.653	971.709	974.555	975.963	0.021	337.790	342.380	347.076
ECS2cE42 - Ex	380	430	994.941	986.658	971.939	974.074	977.135	0.021	334.643	340.032	344.667

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_4_AV K	TF_5_AV K	TF_A_1 K	TF_A_2 K	TF_A_3 K	TF_A_4 K	TF_A_5 K	TF_A_IN K	TF_A_OUT K
ECS2cE11 - Pre	50	150	369.145	368.078	352.246	363.331	368.504	369.896	368.330	300.340	301.997
ECS2cE11 - Ex	210	250	369.324	368.678	355.830	363.526	368.980	370.230	369.680	300.445	303.990
ECS2cE12 - Pre	50	150	352.774	359.755	315.718	321.412	330.911	347.845	358.478	301.718	303.692
ECS2cE12 - Ex	200	230	362.892	364.813	322.664	331.207	345.847	358.658	362.352	301.695	303.855
ECS2cE13 - Pre	650	750	357.852	358.864	326.180	338.241	348.958	360.039	360.835	302.042	335.507
ECS2cE13 - Ex	840	890	357.444	359.841	327.143	339.483	346.683	355.931	359.377	302.514	333.244
ECS2cE14 - Pre	50	150	346.630	348.836	323.335	332.989	340.870	355.619	356.109	299.112	339.538
ECS2cE14 - Ex	320	370	348.285	350.053	323.257	333.231	340.759	353.274	355.181	299.080	340.162
ECS2cE21 - Pre	50	150	370.668	370.981	358.222	364.430	368.422	369.788	370.151	303.264	369.417
ECS2cE21 - Ex	320	370	370.891	371.156	358.921	365.735	368.947	369.911	370.133	303.254	369.299
ECS2cE22 - Pre	50	150	368.652	367.683	349.317	363.707	368.722	367.974	366.155	305.323	311.150
ECS2cE22 - Ex	250	300	371.370	369.980	359.469	366.418	370.079	370.545	368.580	306.078	316.115
ECS2cE23 - Pre	50	150	359.749	364.212	305.272	326.656	347.876	366.384	365.807	299.356	298.883
ECS2cE23 - Ex	410	460	362.208	366.767	309.939	332.997	352.441	367.024	368.438	299.293	298.848
ECS2cE24 - Pre	50	150	366.903	364.879	341.690	361.191	365.915	367.842	364.352	297.684	303.281
ECS2cE24 - Ex	200	215	367.157	365.044	360.349	368.275	372.016	367.761	364.082	297.741	306.595
ECS2cE31 - Pre	50	150	364.043	366.139	341.138	346.798	355.785	363.908	367.830	304.853	363.017
ECS2cE31 - Ex	210	260	364.751	366.335	346.395	348.968	356.307	363.068	367.415	305.136	364.143
ECS2cE32 - Pre	50	150	354.951	357.400	337.761	341.567	347.359	354.970	357.969	309.342	344.350
ECS2cE32 - Ex	510	560	356.325	357.763	333.321	338.073	344.795	352.602	357.180	308.055	345.636
ECS2cE34 - Pre	50	150	331.445	336.560	308.287	316.205	324.612	339.340	337.327	298.037	321.121
ECS2cE34 - Ex	570	620	339.013	342.099	313.312	319.488	327.537	341.217	342.148	298.257	329.899
ECS2cE42 - Pre	50	150	353.164	353.819	342.372	344.097	348.286	353.343	354.702	316.601	345.114
ECS2cE42 - Ex	380	430	352.458	353.604	341.589	345.670	349.940	357.265	357.878	315.737	346.150

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_B_1 K	TF_B_2 K	TF_B_3 K	TF_B_4 K	TF_B_5 K	TF_CC_IN K	TF_CC_OU K	TF_C_1 K	TF_C_2 K
ECS2cE11 - Pre	50	150	362.201	370.753	371.207	372.433	370.062	303.162	336.864	359.872	366.838
ECS2cE11 - Ex	210	250	366.809	371.310	371.588	372.689	370.808	303.560	335.483	363.510	368.857
ECS2cE12 - Pre	50	150	318.938	328.955	341.365	352.417	360.457	305.342	315.686	336.169	338.989
ECS2cE12 - Ex	200	230	320.563	343.601	356.900	365.353	366.326	305.831	315.491	335.914	353.696
ECS2cE13 - Pre	650	750	330.077	336.338	348.609	358.620	359.342	310.345	329.191	325.186	336.963
ECS2cE13 - Ex	840	890	331.306	344.034	351.988	359.261	361.829	310.453	330.855	331.990	343.296
ECS2cE14 - Pre	50	150	317.914	329.355	337.304	345.991	348.939	306.231	308.986	319.629	326.175
ECS2cE14 - Ex	320	370	320.492	336.445	344.245	352.562	354.382	306.895	308.833	321.122	328.857
ECS2cE21 - Pre	50	150	368.429	370.736	370.930	371.954	371.810	309.088	369.449	370.045	370.584
ECS2cE21 - Ex	320	370	368.369	370.616	371.104	372.162	371.969	309.472	370.021	370.973	370.967
ECS2cE22 - Pre	50	150	357.854	369.952	371.283	372.049	368.753	299.916	342.659	356.471	366.679
ECS2cE22 - Ex	250	300	368.150	371.937	372.438	373.606	371.055	300.745	337.272	368.160	369.965
ECS2cE23 - Pre	50	150	303.096	324.728	338.253	355.476	366.089	294.756	336.944	320.056	325.804
ECS2cE23 - Ex	410	460	302.455	324.023	339.112	359.821	368.791	297.148	349.432	315.949	323.119
ECS2cE24 - Pre	50	150	354.688	371.205	371.441	368.213	365.656	296.233	340.619	345.875	354.934
ECS2cE24 - Ex	200	215	361.930	372.979	373.071	373.519	367.260	296.815	349.836	347.788	367.016
ECS2cE31 - Pre	50	150	340.772	351.531	359.124	365.854	367.788	310.564	348.553	345.617	353.570
ECS2cE31 - Ex	210	260	345.378	356.287	362.190	366.921	367.812	311.000	350.827	346.962	355.575
ECS2cE32 - Pre	50	150	335.564	343.093	349.334	355.479	358.270	305.380	338.432	338.203	342.653
ECS2cE32 - Ex	510	560	336.409	345.177	351.771	359.079	358.758	306.025	336.828	346.053	349.496
ECS2cE34 - Pre	50	150	303.362	315.489	320.951	327.217	337.004	291.305	305.611	307.274	315.284
ECS2cE34 - Ex	570	620	307.595	322.259	329.546	337.160	342.956	295.656	306.268	310.402	321.757
ECS2cE42 - Pre	50	150	334.304	341.860	347.490	353.112	355.004	304.996	324.202	336.252	341.893
ECS2cE42 - Ex	380	430	331.936	341.074	347.548	355.385	356.585	304.859	323.592	332.010	336.758

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_C_3 K	TF_C_4 K	TF_C_5 K	TF_D_1 K	TF_D_2 K	TF_D_3 K	TF_D_4 K	TF_D_5 K	TF_HX_OU K
ECS2cE11 - Pre	50	150	368.835	371.497	368.380	334.091	351.888	357.455	362.752	365.538	349.754
ECS2cE11 - Ex	210	250	370.490	372.326	369.032	330.128	351.647	356.869	362.054	365.193	350.376
ECS2cE12 - Pre	50	150	344.392	358.845	360.803	316.360	322.154	334.626	351.989	359.282	300.547
ECS2cE12 - Ex	200	230	359.302	367.737	367.054	320.220	337.400	348.708	359.822	363.520	300.718
ECS2cE13 - Pre	650	750	342.840	356.055	357.554	323.849	334.064	346.318	356.693	357.726	304.876
ECS2cE13 - Ex	840	890	348.991	359.074	360.098	326.961	338.093	347.163	355.506	358.060	305.000
ECS2cE14 - Pre	50	150	329.668	339.121	342.192	319.813	325.962	336.341	345.789	348.104	306.307
ECS2cE14 - Ex	320	370	332.705	344.641	344.518	319.026	324.888	333.279	342.666	346.134	306.131
ECS2cE21 - Pre	50	150	370.648	372.259	371.684	320.513	360.843	364.579	368.675	370.277	302.228
ECS2cE21 - Ex	320	370	370.961	372.360	371.883	322.378	361.882	365.186	369.131	370.639	297.797
ECS2cE22 - Pre	50	150	369.550	372.651	368.867	336.497	352.218	356.338	361.932	366.956	319.474
ECS2cE22 - Ex	250	300	371.541	374.123	370.828	344.693	358.386	363.174	367.204	369.458	319.355
ECS2cE23 - Pre	50	150	333.092	355.086	359.925	302.233	316.802	342.493	362.049	365.024	296.432
ECS2cE23 - Ex	410	460	332.736	357.661	362.031	303.848	320.889	344.653	364.325	367.806	296.405
ECS2cE24 - Pre	50	150	359.331	365.229	365.171	328.454	358.867	363.605	366.329	364.336	297.679
ECS2cE24 - Ex	200	215	369.650	370.974	365.936	323.346	343.480	348.973	356.372	362.898	297.569
ECS2cE31 - Pre	50	150	357.887	365.848	365.767	336.306	345.347	352.331	360.562	363.171	329.282
ECS2cE31 - Ex	210	260	358.804	366.634	366.485	336.290	348.695	355.107	362.383	363.626	329.635
ECS2cE32 - Pre	50	150	345.455	355.120	356.621	335.758	340.203	347.275	354.233	356.741	325.920
ECS2cE32 - Ex	510	560	352.127	360.643	359.712	334.941	340.175	346.769	352.976	355.403	327.375
ECS2cE34 - Pre	50	150	318.084	327.860	334.931	305.925	312.913	322.960	331.366	336.979	300.623
ECS2cE34 - Ex	570	620	325.718	340.172	341.961	317.154	322.255	331.131	337.501	341.328	301.030
ECS2cE42 - Pre	50	150	346.361	355.347	353.605	338.233	341.673	346.164	350.855	351.965	326.907
ECS2cE42 - Ex	380	430	339.524	348.381	349.163	333.040	336.625	341.657	348.802	350.790	313.625

Note: Shadowed areas indicate failed or questionable measurements.

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TF_IN K	TF_OUT K	TF_SP K	TF_TS_AV K	TF_W_IN K	TI_5_AV K	TI_6_AV K	TI_7_AV K	TI_A_a_5 K
ECS2cE11 - Pre	50	150	311.718	365.887	365.024	363.805	311.694	389.704	411.180	414.701	371.723
ECS2cE11 - Ex	210	250	310.623	366.151	365.238	364.578	310.690	391.122	412.323	414.950	371.039
ECS2cE12 - Pre	50	150	310.747	359.705	358.943	340.005	310.835	384.867	412.945	401.580	361.140
ECS2cE12 - Ex	200	230	311.084	360.972	359.753	349.342	311.209	389.326	414.760	406.402	362.764
ECS2cE13 - Pre	650	750	311.927	354.522	354.083	345.224	311.838	383.909	418.741	408.694	369.238
ECS2cE13 - Ex	840	890	311.504	354.996	354.706	347.313	311.361	387.865	421.287	409.144	367.870
ECS2cE14 - Pre	50	150	311.591	347.408	346.744	336.061	311.584	378.623	415.944	401.654	365.525
ECS2cE14 - Ex	320	370	311.938	347.953	347.533	337.583	311.981	380.683	416.944	403.038	361.595
ECS2cE21 - Pre	50	150	326.699	370.688	368.925	366.249	326.935	389.777	404.418	397.543	373.623
ECS2cE21 - Ex	320	370	328.074	370.895	368.823	366.711	328.251	390.941	405.871	400.113	375.453
ECS2cE22 - Pre	50	150	326.401	366.904	365.984	363.196	326.357	385.309	399.459	391.612	369.764
ECS2cE22 - Ex	250	300	326.690	367.729	366.643	367.491	326.741	390.383	404.937	396.590	375.067
ECS2cE23 - Pre	50	150	295.009	362.499	361.860	339.110	295.121	385.313	413.673	403.541	363.129
ECS2cE23 - Ex	410	460	295.042	364.408	363.702	340.903	295.163	385.803	414.925	404.473	365.306
ECS2cE24 - Pre	50	150	296.321	363.462	362.628	360.216	296.514	392.001	420.423	407.439	378.318
ECS2cE24 - Ex	200	215	296.331	363.923	363.305	361.884	296.578	395.109	420.583	413.011	373.878
ECS2cE31 - Pre	50	150	326.984	364.212	364.488	355.347	327.204	389.491	416.601	405.382	370.112
ECS2cE31 - Ex	210	260	326.793	365.647	365.600	357.065	326.803	390.993	416.319	407.658	370.387
ECS2cE32 - Pre	50	150	326.214	355.474	354.573	347.681	326.239	378.269	400.022	390.107	365.845
ECS2cE32 - Ex	510	560	325.910	354.207	353.317	348.773	325.905	379.293	398.799	390.296	361.444
ECS2cE34 - Pre	50	150	295.484	336.149	335.605	322.168	295.682	372.320	406.924	393.334	356.538
ECS2cE34 - Ex	570	620	297.128	339.276	338.179	328.630	297.165	378.200	411.748	398.551	358.858
ECS2cE42 - Pre	50	150	326.892	350.531	349.593	346.846	326.960	378.184	404.487	392.688	364.413
ECS2cE42 - Ex	380	430	326.882	350.797	350.386	345.081	326.782	377.024	404.854	394.243	366.346

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	*Start* Time(s)	*End* Time(s)	*TI_A_a_6* K	*TI_A_a_7* K	*TI_A_c_6* K	*TI_A_d_1* K	*TI_A_d_2* K	*TI_A_d_3* K	*TI_A_d_4* K	*TI_A_d_7* K	*TI_A_d_8* K
ECS2cE11 - Pre	50	150	401.864	406.418	420.799	329.906	359.805	373.829	383.082	426.129	386.070
ECS2cE11 - Ex	210	250	403.363	406.662	416.829	333.088	362.572	376.415	384.121	410.082	387.524
ECS2cE12 - Pre	50	150	407.511	415.815	421.852	326.293	344.195	355.946	376.562	408.404	381.300
ECS2cE12 - Ex	200	230	407.907	416.840	421.768	328.266	348.015	360.344	373.946	407.292	383.803
ECS2cE13 - Pre	650	750	419.813	434.975	433.152	334.969	358.237	368.421	380.997	422.941	394.102
ECS2cE13 - Ex	840	890	417.477	431.328	432.911	331.612	354.576	366.331	379.696	416.051	387.694
ECS2cE14 - Pre	50	150	414.183	427.406	436.005	333.815	357.338	366.357	384.754	415.748	387.301
ECS2cE14 - Ex	320	370	411.619	426.087	433.503	332.717	356.011	366.774	382.273	414.129	386.025
ECS2cE21 - Pre	50	150	396.663	398.489	417.183	344.410	367.036	373.597	381.743	399.709	385.852
ECS2cE21 - Ex	320	370	398.976	400.576	419.238	349.553	368.903	375.093	383.331	400.706	386.441
ECS2cE22 - Pre	50	150	394.440	392.168	412.277	339.732	356.580	367.537	378.633	397.340	380.101
ECS2cE22 - Ex	250	300	400.328	397.324	416.051	348.480	367.293	375.422	382.303	402.814	383.157
ECS2cE23 - Pre	50	150	397.779	426.515	423.174	316.918	339.667	361.001	388.873	412.515	388.262
ECS2cE23 - Ex	410	460	401.964	430.905	423.432	317.783	342.632	366.526	390.489	411.478	389.073
ECS2cE24 - Pre	50	150	415.819	424.620	422.917	320.786	349.183	370.472	383.290	414.340	385.519
ECS2cE24 - Ex	200	215	406.982	420.304	432.957	335.630	371.139	378.332	390.955	411.123	386.080
ECS2cE31 - Pre	50	150	412.398	413.992	431.919	345.267	362.716	370.249	380.468	410.106	388.811
ECS2cE31 - Ex	210	260	406.954	414.967	431.602	346.544	366.747	373.459	380.282	408.085	387.919
ECS2cE32 - Pre	50	150	391.451	395.905	411.796	345.771	359.731	366.428	375.721	398.114	376.545
ECS2cE32 - Ex	510	560	387.543	392.376	405.318	339.728	352.443	359.346	368.467	393.134	374.263
ECS2cE34 - Pre	50	150	393 098	416.664	423.418	325.506	349.795	363.181	378.525	406.731	367.316
ECS2cE34 - Ex	570	620	396.448	420.768	424.114	328.134	352.946	364.818	377.785	407.091	372.370
ECS2cE42 - Pre	50	150	401.251	401.272	412.360	344.375	360.709	367.739	374.339	400.332	378.306
ECS2cE42 - Ex	380	430	404.290	406.042	419.273	345.978	364.589	371.938	379.198	406.070	384.135

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_A_e_6 K	TI_B_g_6 K	TI_B_g_7 K	TI_B_i_5 K	TI_B_i_6 K	TI_B_k_2 K	TI_B_k_3 K	TI_B_k_6 K	TI_B_k_7 K
ECS2cE11 - Pre	50	150	426.395	393.411	415.988	403.669	429.146	377.979	391.471	414.312	452.321
ECS2cE11 - Ex	210	250	417.115	395.077	400.760	407.430	434.414	382.242	393.496	417.294	444.160
ECS2cE12 - Pre	50	150	416.494	384.714	390.044	404.329	424.472	361.577	379.910	414.320	413.159
ECS2cE12 - Ex	200	230	415.657	388.879	393.643	405.840	424.096	360.410	380.556	416.369	417.350
ECS2cE13 - Pre	650	750	426.206	391.380	395.161	404.240	432.018	363.081	379.152	415.339	414.605
ECS2cE13 - Ex	840	890	423.072	393.798	396.939	410.448	442.266	368.286	383.034	424.044	418.993
ECS2cE14 - Pre	50	150	421.970	389.464	392.420	404.966	433.647	351.942	373.072	417.333	411.235
ECS2cE14 - Ex	320	370	420.456	391.275	394.632	408.636	439.328	355.254	381.148	422.799	415.258
ECS2cE21 - Pre	50	150	410.309	389.090	390.654	399.056	418.890	385.379	390.139	403.904	406.259
ECS2cE21 - Ex	320	370	411.161	389.936	392.123	399.596	421.501	386.669	390.790	406.259	414.483
ECS2cE22 - Pre	50	150	406.157	387.422	387.691	397.266	417.362	369.370	383.450	402.171	399.030
ECS2cE22 - Ex	250	300	408.462	389.503	391.686	402.776	422.732	382.175	389.297	408.036	405.574
ECS2cE23 - Pre	50	150	419.852	383.512	389.104	403.631	428.630	362.702	384.366	416.620	411.202
ECS2cE23 - Ex	410	460	421.024	386.294	392.362	404.611	429.556	361.436	384.655	417.499	412.996
ECS2cE24 - Pre	50	150	420.215	395.418	395.661	409.530	430.142	366.789	391.393	423.234	415.798
ECS2cE24 - Ex	200	215	431.416	404.153	402.386	414.058	449.596	376.398	395.115	429.901	442.069
ECS2cE31 - Pre	50	150	420.208	392.815	395.595	404.095	436.338	375.903	386.641	412.701	418.350
ECS2cE31 - Ex	210	260	415.755	393.059	396.357	405.950	436.692	379.055	390.472	413.632	417.827
ECS2cE32 - Pre	50	150	404.869	380.019	384.375	392.237	419.396	366.484	374.852	399.382	397.966
ECS2cE32 - Ex	510	560	399.309	377.765	383.031	390.313	417.917	367.214	375.481	399.751	399.932
ECS2cE34 - Pre	50	150	416.134	377.273	380.514	390.569	419.899	346.854	363.790	402.452	397.046
ECS2cE34 - Ex	570	620	416.834	380.204	384.342	397.974	426.822	354.169	370.550	411.389	405.140
ECS2cE42 - Pre	50	150	406.308	381.924	379.377	390.848	423.100	364.581	374.295	400.650	401.943
ECS2cE42 - Ex	380	430	412.206	385.447	389.222	395.654	424.880	362.936	375.224	402.860	406.437

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_C_m_5 K	TI_C_m_7 K	TI_C_o_6 K	TI_C_p_1 K	TI_C_p_2 K	TI_C_p_3 K	TI_C_p_4 K	TI_C_p_5 K	TI_C_p_7 K
ECS2cE11 - Pre	50	150	385.021	403.103	410.022	350.013	366.306	385.814	386.939	406.160	416.606
ECS2cE11 - Ex	210	250	386.084	405.794	415.061	346.681	369.004	388.907	389.316	407.279	451.719
ECS2cE12 - Pre	50	150	372.461	385.995	414.799	360.029	375.766	392.105	389.574	406.740	398.280
ECS2cE12 - Ex	200	230	380.883	393.650	419.509	355.051	366.607	389.099	391.748	410.152	416.640
ECS2cE13 - Pre	650	750	368.037	387.767	410.176	344.962	356.545	377.924	379.777	398.712	400.357
ECS2cE13 - Ex	840	890	374.199	391.206	417.228	348.388	362.364	383.621	384.159	403.700	406.783
ECS2cE14 - Pre	50	150	359.532	378.053	400.921	336.968	349.857	369.979	372.229	392.780	388.747
ECS2cE14 - Ex	320	370	364.806	384.042	405.418	338.888	350.570	374.277	375.237	397.059	394.038
ECS2cE21 - Pre	50	150	384.118	391.298	394.792	370.232	381.031	391.907	389.741	405.576	403.266
ECS2cE21 - Ex	320	370	384.731	393.364	395.043	375.702	382.737	393.426	390.885	407.476	406.735
ECS2cE22 - Pre	50	150	383.061	386.245	394.926	355.739	361.465	378.742	382.567	398.741	392.156
ECS2cE22 - Ex	250	300	385.507	389.352	402.455	363.009	375.052	387.671	388.544	404.924	397.016
ECS2cE23 - Pre	50	150	371.871	384.427	410.599	352.025	372.758	389.896	388.085	409.716	397.855
ECS2cE23 - Ex	410	460	371.461	383.756	411.165	349.320	369.974	390.064	388.803	409.504	397.548
ECS2cE24 - Pre	50	150	382.449	391.670	426.697	339.682	354.318	380.871	379.309	405.045	405.682
ECS2cE24 - Ex	200	215	390.363	404.388	425.603	333.314	352.206	381.561	389.955	416.145	424.563
ECS2cE31 - Pre	50	150	378.180	392.606	415.950	361.992	373.281	390.011	388.293	408.989	407.491
ECS2cE31 - Ex	210	260	380.814	394.734	421.435	359.005	370.711	389.004	389.714	409.262	419.162
ECS2cE32 - Pre	50	150	368.350	379.528	397.794	352.159	359.664	374.554	375.683	391.315	387.192
ECS2cE32 - Ex	510	560	371.749	383.702	399.765	356.017	366.181	380.580	380.695	395.969	391.626
ECS2cE34 - Pre	50	150	353.280	369.609	399.106	333.114	347.438	373.655	376.353	394.709	385.565
ECS2cE34 - Ex	570	620	359.562	378.611	406.257	334.544	348.595	377.952	381.444	401.731	393.474
ECS2cE42 - Pre	50	150	366.553	379.622	405.249	349.761	357.836	375.124	377.259	393.538	392.710
ECS2cE42 - Ex	380	430	364.549	378.887	399.781	345.850	352.204	368.763	370.667	388.424	384.827

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_C_p_8 K	TI_C_q_6 K	TI_D_s_5 K	TI_D_s_6 K	TI_D_s_7 K	TI_D_u_4 K	TI_D_u_6 K	TI_D_w_2 K	TI_D_w_3 K
ECS2cE11 - Pre	50	150	392.977	414.943	381.944	383.994	387.111	300.091	426.247	300.085	376.767
ECS2cE11 - Ex	210	250	405.901	418.531	383.777	385.853	390.948	300.214	428.333	300.215	368.142
ECS2cE12 - Pre	50	150	383.371	419.556	379.664	381.563	384.593	300.734	440.614	300.719	384.831
ECS2cE12 - Ex	200	230	392.574	423.023	386.995	388.750	391.827	300.628	441.011	300.632	386.268
ECS2cE13 - Pre	650	750	386.949	420.812	379.320	381.581	385.182	301.630	450.370	301.625	396.492
ECS2cE13 - Ex	840	890	387.310	424.816	383.109	384.903	387.071	301.856	450.916	301.798	395.385
ECS2cE14 - Pre	50	150	370.927	417.849	370.315	375.018	377.276	299.589	443.859	299.535	393.917
ECS2cE14 - Ex	320	370	374.294	422.638	371.320	375.345	377.013	299.668	442.110	299.630	390.582
ECS2cE21 - Pre	50	150	387.717	410.587	386.510	386.552	387.639	304.717	422.196	302.635	384.581
ECS2cE21 - Ex	320	370	386.336	411.192	387.450	387.242	388.112	304.912	424.004	302.574	388.320
ECS2cE22 - Pre	50	150	383.820	401.689	377.713	378.330	380.988	298.100	411.175	298.096	373.749
ECS2cE22 - Ex	250	300	385.254	407.952	383.645	383.245	384.722	298.237	418.990	298.234	379.852
ECS2cE23 - Pre	50	150	385.393	424.151	378.214	381.672	383.915	298.493	445.536	298.448	389.391
ECS2cE23 - Ex	410	460	384.822	425.009	378.131	381.101	384.047	298.595	447.212	298.417	392.654
ECS2cE24 - Pre	50	150	385.479	429.416	384.663	389.762	389.629	297.537	447.026	297.724	381.801
ECS2cE24 - Ex	200	215	387.492	429.089	381.100	384.024	387.304	297.616	428.865	297.827	377.729
ECS2cE31 - Pre	50	150	388.788	419.775	386.080	386.536	387.860	303.873	440.747	303.835	395.900
ECS2cE31 - Ex	210	260	388.154	423.041	388.555	388.531	390.547	304.115	434.019	304.087	397.897
ECS2cE32 - Pre	50	150	375.580	397.914	373.600	374.000	376.395	298.944	424.432	298.926	386.468
ECS2cE32 - Ex	510	560	379.546	402.465	376.993	376.865	379.178	298.953	423.067	298.987	384.077
ECS2cE34 - Pre	50	150	362.063	416.011	356.505	369.953	371.566	297.476	442.026	297.438	388.208
ECS2cE34 - Ex	570	620	371.235	424.684	372.873	375.903	376.837	297.917	446.285	297.819	394.455
ECS2cE42 - Pre	50	150	376.568	407.181	375.568	376.698	377.913	299.718	430.496	299.547	387.715
ECS2cE42 - Ex	380	430	370.473	399.189	370.145	370.927	372.856	299.975	429.979	299.790	386.911

Note: Shadowed areas indicate failed or questionable measurements.

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TI_D_w_6 K	TI_D_w_7 K	TSAT_0 K	TSAT_150 K	TSAT_76 K	TSAT_96 K
ECS2cE11 - Pre	50	150	401.839	409.930	368.750	371.090	370.415	370.731
ECS2cE11 - Ex	210	250	403.688	409.470	368.792	371.229	370.671	370.997
ECS2cE12 - Pre	50	150	416.501	416.354	368.754	370.710	368.895	369.067
ECS2cE12 - Ex	200	230	415.389	413.976	368.788	371.083	369.808	370.193
ECS2cE13 - Pre	650	750	425.308	428.569	369.865	371.683	370.835	371.327
ECS2cE13 - Ex	840	890	422.732	424.784	369.538	371.724	371.019	371.469
ECS2cE14 - Pre	50	150	425.130	422.344	370.150	371.762	371.276	371.435
ECS2cE14 - Ex	320	370	421.891	419.105	369.936	371.751	371.207	371.444
ECS2cE21 - Pre	50	150	398.435	403.029	368.706	370.605	370.023	370.360
ECS2cE21 - Ex	320	370	400.025	404.809	368.750	370.662	370.224	370.496
ECS2cE22 - Pre	50	150	388.097	397.277	368.829	373.034	370.225	370.767
ECS2cE22 - Ex	250	300	396.549	404.234	369.314	373.087	371.187	371.659
ECS2cE23 - Pre	50	150	418.880	422.797	368.647	369.076	368.755	368.811
ECS2cE23 - Ex	410	460	419.922	422.693	368.651	369.092	368.776	368.875
ECS2cE24 - Pre	50	150	424.004	422.112	369.024	372.942	370.962	371.255
ECS2cE24 - Ex	200	215	403.833	411.953	369.198	373.006	371.445	371.712
ECS2cE31 - Pre	50	150	413.225	417.055	369.381	370.815	370.263	370.625
ECS2cE31 - Ex	210	260	414.784	419.581	369.418	370.889	370.431	370.723
ECS2cE32 - Pre	50	150	399.187	401.380	371.632	373.495	372.040	372.374
ECS2cE32 - Ex	510	560	397.027	399.391	369.996	373.432	370.894	371.489
ECS2cE34 - Pre	50	150	416.790	418.981	371.783	373.220	372.170	372.276
ECS2cE34 - Ex	570	620	420.285	422.141	371.514	373.173	371.943	372.076
ECS2cE42 - Pre	50	150	404.137	408.329	371.497	374.288	373.006	373.494
ECS2cE42 - Ex	380	430	404.562	409.600	371.315	374.233	372.925	373.444

Table J-6. ECS-2cE test pre-excursion and excursion power step data averages

Test ID	Start Time(s)	End Time(s)	TSAT_ATM K	TSAT_IN K	TSAT_OUT K	V_INNER V
ECS2cE11 - Pre	50	150	368.570	368.511	372.097	43.263
ECS2cE11 - Ex	210	250	368.570	368.511	372.042	43.949
ECS2cE12 - Pre	50	150	368.556	368.497	372.131	50.334
ECS2cE12 - Ex	200	230	368.556	368.502	372.063	50.948
ECS2cE13 - Pre	650	750	368.548	368.488	372.186	54.253
ECS2cE13 - Ex	840	890	368.546	368.486	372.190	54.733
ECS2cE14 - Pre	50	150	358.576	368.555	372.039	54.994
ECS2cE14 - Ex	320	370	368.575	368.555	372.022	55.643
ECS2cE21 - Pre	50	150	368.601	368.547	370.774	40.439
ECS2cE21 - Ex	320	370	368.600	368.546	370.794	41.290
ECS2cE22 - Pre	50	150	368.610	368.555	374.469	38.221
ECS2cE22 - Ex	250	300	368.610	368.553	374.400	39.029
ECS2cE23 - Pre	50	150	368.610	368.591	370.605	48.202
ECS2cE23 - Ex	410	460	368.610	368.591	370.613	48.912
ECS2cE24 - Pre	50	150	368.550	368.530	374.238	47.949
ECS2cE24 - Ex	200	215	368.550	368.530	374.152	48.496
ECS2cE31 - Pre	50	150	368.560	368.505	370.912	52.186
ECS2cE31 - Ex	210	260	368.560	368.501	370.894	52.860
ECS2cE32 - Pre	50	150	368.611	368.796	374.568	44.057
ECS2cE32 - Ex	510	560	368.613	368.558	374.501	44.744
ECS2cE34 - Pre	50	150	368.550	368.535	374.311	53.021
ECS2cE34 - Ex	570	620	368.550	368.528	374.294	53.682
ECS2cE42 - Pre	50	150	368.620	368.817	374.674	48.851
ECS2cE42 - Ex	380	430	368.620	368.558	374.654	49.480

END

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