

Heat Transfer Above the Two-Phase Mixture
Level Under Core Uncovery Conditions in a
336-Rod Bundle
Volume 1

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Pittsburgh, Pennsylvania

EPRI PERSPECTIVE

PROJECT DESCRIPTION

The nuclear accident which occurred on March 28, 1979, at the Three Mile Island Unit-2 plant is believed to have resulted in fuel damage. The fuel damage was caused by the partial uncovering of the reactor core as the water inventory was gradually drained from a stuck-open valve. During the core uncovering transient, the extent of damage depends on the effectiveness of heat transfer in the region where the core is exposed to the steam. RP1760-1, which is entitled Heat Transfer Above the Two-Phase Mixture Level Under Core Uncovering Conditions, is a part of EPRI's program to develop realistic heat transfer models for small-break loss-of-coolant accidents.

PROJECT OBJECTIVE

The objective of this project is to study the data obtained from a 336-rod bundle of typical PWR geometry under the conditions of a simulated small-break loss-of-coolant accident. The data were provided to EPRI by the Nuclear Technology Division of the Westinghouse Electric Corporation as a donation to this project. Their contribution is hereby acknowledged. The data will be used to describe the thermal-hydraulic phenomenon and to develop a heat transfer model for the core uncovering conditions.

PROJECT RESULTS

This report documents in detail the test facility function, the instrumentation, the test procedure, and the test result in data form. The report should be useful to those who are interested in model development and computer code qualification in the area of small-break loss-of-coolant accident. The detailed test data, which run to about 650 pages, are published as Volume 2 of this report and will be available separately on request from the Research Reports Center.

Bill K. H. Sun, Program Manager
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ABSTRACT

Twenty-two constant pressure boiloff, or core uncover, tests were performed in the G-2 Loop test facility using a bundle of 336 heater rods. The parameters tested were vessel pressure and bundle power.

For each test, temperatures at various axial positions within selected heater rods in the bundle and temperatures, pressures, differential pressures, and water levels at various locations around the facility were taken and recorded. From the recorded data were calculated heater rod heat fluxes, steam flows, liquid carryover from the bundle, and rates of boiloff or core uncover. These calculated data were used to evaluate the heat transfer process above the bundle two-phase mixture level under core uncover conditions.

ACKNOWLEDGMENTS

The 22 core uncover tests documented in this report were performed in 1975 with Westinghouse funds at its Forest Hills, PA, laboratory. The test parameters and method of testing were specified by J. P. Cunningham and L. L. Overton of the Thermal Hydraulics Development group, K. L. Rieke, manager. The tests were performed under the direction of R. R. Fayfich of the Test Engineering group, H. J. Fix, manager. The original data reduction computer programs were written during the period of 1974 through 1975 by J. P. Cunningham, R. W. Steer, and T. S. Andreychek.

B. A. McIntyre of the Safeguards Analysis II group provided much-appreciated assistance in locating and accessing test data, letters, and test facility drawings pertaining to the core uncover tests. The support and direction of R. P. Vijuk, manager, Safeguards Development, is gratefully acknowledged. Project management was performed by I. M. Keyfitz.

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SUMMARY

Twenty-two core uncover tests were performed by Westinghouse Electric Corporation in its G-2 Loop facility. The parameters varied were bundle power and system pressure.

Data recorded and included in this report are as follows:

- A representative sample of internal heater rod temperatures
- Bundle steam probe temperatures
- Bundle, baffle, and vessel differential pressures
- Vessel total pressure
- Liquid level in exhaust line steam/water separator
- Power supplied to the bundle

Also included in the current report are the following calculated data:

- Bundle mixture levels as a function of time, as derived from heater rod temperature measurements
- A representative sample of heater rod heat fluxes, as calculated using both power and internal heater rod temperature measurements

The data included in this report form the basis for the following:

- Assessing parameter effects on heat transfer above the two-phase level of the 336-rod bundle of G-2 Loop under core uncover conditions
- Establishing a recommended model for the heat transfer above the two-phase level in a rod bundle under core uncover conditions, by comparison of G-2 Loop facility data with existing correlations and other available data

These assessments, comparisons, and recommendations are presented in Volume II of this report.

Section 1

INTRODUCTION

The drying out of a reactor core by boiling off of coolant inventory is known as a core uncover event. Such an event occurred on March 28, 1979, at the Three Mile Island (TMI) Unit 2 nuclear generating station (1). Subsequent analyses of the accident have shown the need for both the qualification of existing models and, in some cases, the development of new and specifically applicable models to describe the thermal-hydraulic behavior of coolant within the reactor core during a core uncover event. A model describing thermal-hydraulic behavior within a flow channel below the two-phase level during core uncover conditions has been proposed by Sun, et al. (2). The current study focuses on quantifying the thermal-hydraulic behavior within a flow channel above the two-phase level during core uncover conditions.

The basis of the study is 22 core uncover tests performed by Westinghouse in 1975 at its Forest Hills site using the G-2 Loop facility, a high-pressure, high-temperature flow loop having 336 electrically heated fuel rod simulators arranged in a 17x17 array fuel assembly. Core uncover testing was accomplished by pressurizing the facility to a predetermined value, filling the test section (rod bundle) with saturated water, and then boiling off the water in the test section by applying power to the heater rod bundle. Constant total pressure, and consequently saturation temperature, was maintained within the facility during each test.

The current study is presented in two phases. This report presents the data collected from the 22 tests identified in the preceding paragraph. The next report contains the analysis of the data from the 22 tests, a comparison and evaluation of existing correlations with the test data, and a recommended correlation to be used in describing thermal-hydraulic behavior in a flow channel in a reactor core during a core uncover event.

Section 2

TEST DESCRIPTION

TEST FACILITY DESCRIPTION

A schematic diagram of the G-2 Loop test facility configured to accomplish core uncover testing is given in Figure 2-1. The primary system for the current series of tests consisted of the following components:

- Test vessel (including test section)
- Two steam-water separators
- Associated piping, valves, and orifices

The primary loop was a closed piping system which could simulate thermal and hydraulic conditions representative of the environment in the core of a PWR after a hypothetical LOCA, based on safety analysis design calculations. For the core uncover tests, the test loop was initially heated and pressurized with saturated steam generated in steam-water separator 1 to obtain the desired initial test conditions for a given test run. The test vessel, which housed the test section (Figure 2-2), consisted primarily of the vessel shell, a spool piece, and two end closures.

The vessel shell was a 17 ft (5.2 m) length of 24 in. (0.61 m) schedule 140 seamless carbon steel pipe with a standard 24 in. (0.61 m) 1500 lb (10.3 MPa) welding neck flange welded to each end. Two radial penetrations through the top end of the vessel shell for the hot leg discharge piping (see piping discussion below) and an unused nozzle were located 26.5 in. (0.67 m) from the face of the top welding neck flange. These penetrations were 5.189 in. (13.18 cm) diameter holes [6 in. (15 cm) schedule 160 bore] in the vessel wall 180 degrees opposed. The piping connection to these penetrations was accomplished with a 6 in. (15 cm), 150 lb (10.3 MPa) long welding neck flange welded to the vessel shell. Two identical penetrations, located 9.5 in. (24 cm) below and 90 degrees from the aforementioned penetrations, were used for rod power neutral leads and instrumentation ports.

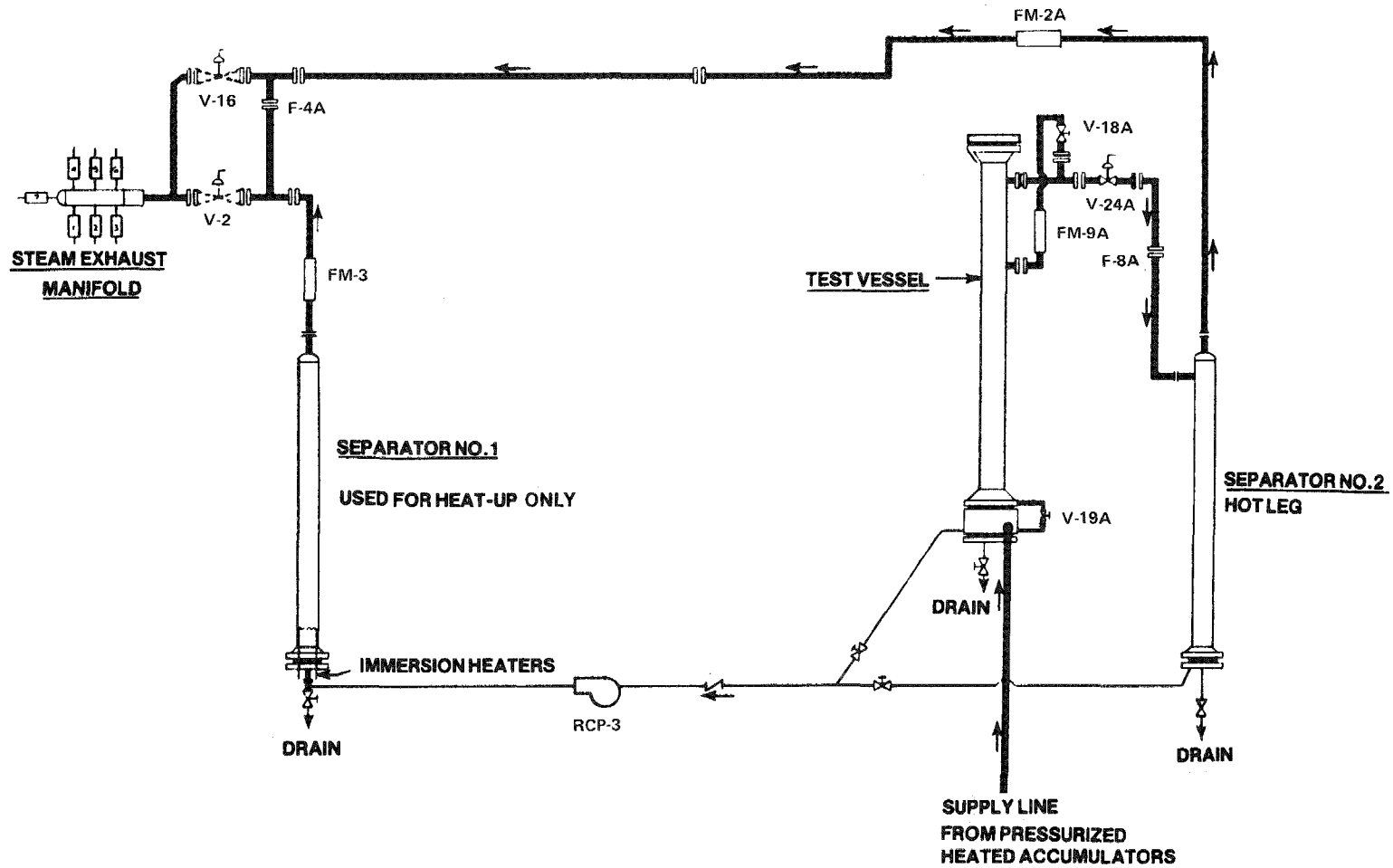


Figure 2-1. G-2 Loop Test Facility Core Uncovery Flow Diagram

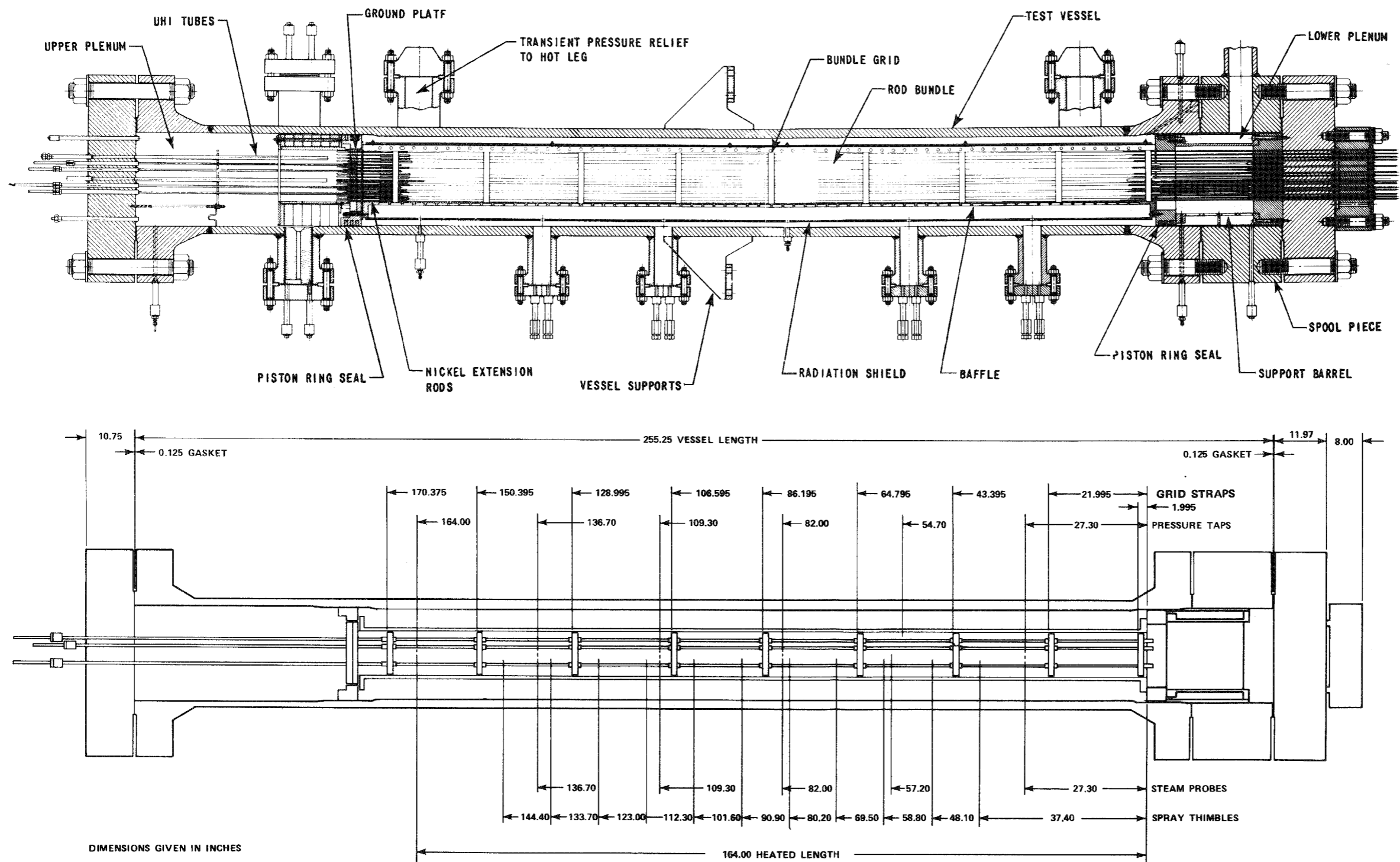


Figure 2-2. G-2 Loop Test Vessel and Test Section



A fifth penetration, located 62.5 in. (1.59 m) from the face of the top welding neck flange, was used to connect to a 4 in. (10 cm) schedule 160 pipe from a tee on the hot leg discharge pipe. This line, which included a 4 in. (10 cm), 1500 lb (10.3 MPa) orifice flange and a 4 in. (10 cm), 1500 lb (10.3 MPa) gate valve, allowed pressure communication from the annulus between the flow baffle and the test vessel shell to the test vessel upper plenum. This was done to avoid excessive pressure drops across the baffle, which could cause structural failure. A sixth penetration, located 26.5 in. (0.67 m) from the face of the bottom welding neck flange, was not used.

Four 3.438 in. (8.733 cm) radial penetrations [4 in. (10 cm) schedule 160 bore] were located at 37.3, 64.7, 119.3, and 146.7 in. (0.95, 1.64, 3.03, and 3.73 m) from the face of the bottom welding neck flange on the same side of the test vessel. These penetrations consisted of four 4 in. (10 cm), 1500 lb (10.3 MPa) long welding neck flanges, which were welded to the test vessel shell and used as instrumentation ports.

The 24 in. (0.61 m), 1500 lb (10.3 MPa) welding neck flange on the bottom of the test vessel shell contained four 0.813 in. (2.07 cm) diameter penetrations. Two of these penetrations, at 4.25 in. (10.8 cm) from the face of the flange, were radial and were used for lower plenum instrumentation. The other two flange penetrations did not extend through to the inside of the flange, but intersected a similar bore made at a 30-degree angle to the radial bore, permitting access to the bottom of the annulus between the baffle and the test vessel shell. These last two penetrations were used for baffle/vessel annulus filling, draining, and water level measurement and were also located at 4.25 in. (10.8 cm) from the face of the flange.

The spool piece (Figure 2-2) was a 46 in. OD by 20.75 in. ID by 18 in. long (1.17 m OD by 0.53 m ID by 0.46 m long) carbon steel forging attached to the 24 in. (0.61 m), 1500 lb (10.3 MPa) welding neck flange at the bottom of the test vessel shell. The spool piece had four 5.313 in. (13.50 cm) diameter penetrations 90 degrees apart and four 0.815 in. (2.07 cm) diameter penetrations at 45 degrees from the latter. The spool piece simulated a portion of the volume of the reactor lower plenum.

The upper and lower vessel closures were 24 in. (0.61 m), 1500 lb (10.3 MPa) carbon steel blind flanges. The top closure was 10.75 in. (0.2730 m) thick with 13 0.62 in. (1.6 cm) diameter and 24 0.855 in. (2.17 cm) diameter axial penetrations.

All of the 0.62 in. (1.6 cm) penetrations were used to install tubes for a later test program, and 16 of the 0.855 in. (2.17 cm) penetrations were used for removable simulated control thimbles, some of which were instrumented. The remaining penetrations were used for various types of instrumentation, pressure taps, safety heads, vents, and the like. The bottom closure was 12 in. (0.30 m) thick with 336 multidiameter [0.391 x 0.384 x 0.462 in. (0.993 x 0.975 x 1.17 cm)] axial penetrations through which the bottom end of heater rods containing the power lead protruded. Three O-ring seals were used on each rod to prevent flow through the heater rod penetrations. A 23 in. (0.58 m) diameter 8 in. (20 cm) thick seal flange was bolted to the bottom of the bottom closure, which also contained 336 multidiameter axial penetrations with O-ring seals for the heater rod power leads. A cavity between the bottom closure and the bottom seal flanges served as a heat exchanger to keep the heater rod power leads and O-ring seals cooled. Additional penetrations in the seal flange were used to circulate the cooling water required for the cooling cavity.

The steam separators (Figures 2-1, 2-3, and 2-4) consisted of two 300 gal (1.14 m³) tanks. Separator 2 (Figure 2-4) was located in the hot leg piping and separated the steam-water mixtures flowing through the exhaust line. The liquid phase remained in the tank, where its level was measured. Separator 1 (Figure 2-3) was located near the system exhaust valves and was used to generate steam to heat and pressurize the primary system piping, separator 2, and test vessel. Water was supplied to separator 1 by recirculating condensate from low points in the system.

The two separators, which were identical except for the bottom closures, consisted of approximately 19 ft (5.8 m) of 24 in. (0.61 m) schedule 120 carbon steel pipe, a 24 in. (0.61 m) elliptical dished head, and a 24 in. (0.61 m), 1500 lb (10.3 MPa) welding neck flange. The bottom closure of both separators was a standard 24 in. (0.61 m), 1500 lb (10.3 MPa) blind flange. The bottom flange for separator 1 was drilled and tapped for installation of eighteen 18 kW immersion heaters, which protruded 2 ft (0.61 m) into the bottom of the vessel.

The hot leg discharge from the test vessel was connected to separator 2 using a 6 in. (15 cm) Grayloc nozzle welded to the separator vessel wall 1 ft (0.30 m) below the circumferential weld to the elliptical head. The flow which entered the vessel impinged on a deflector plate which was mounted at an angle of 15 degrees from the normal to the direction of flow. This plate imparted a circular motion to the flow, which helped separate the steam and water phases. The water was allowed

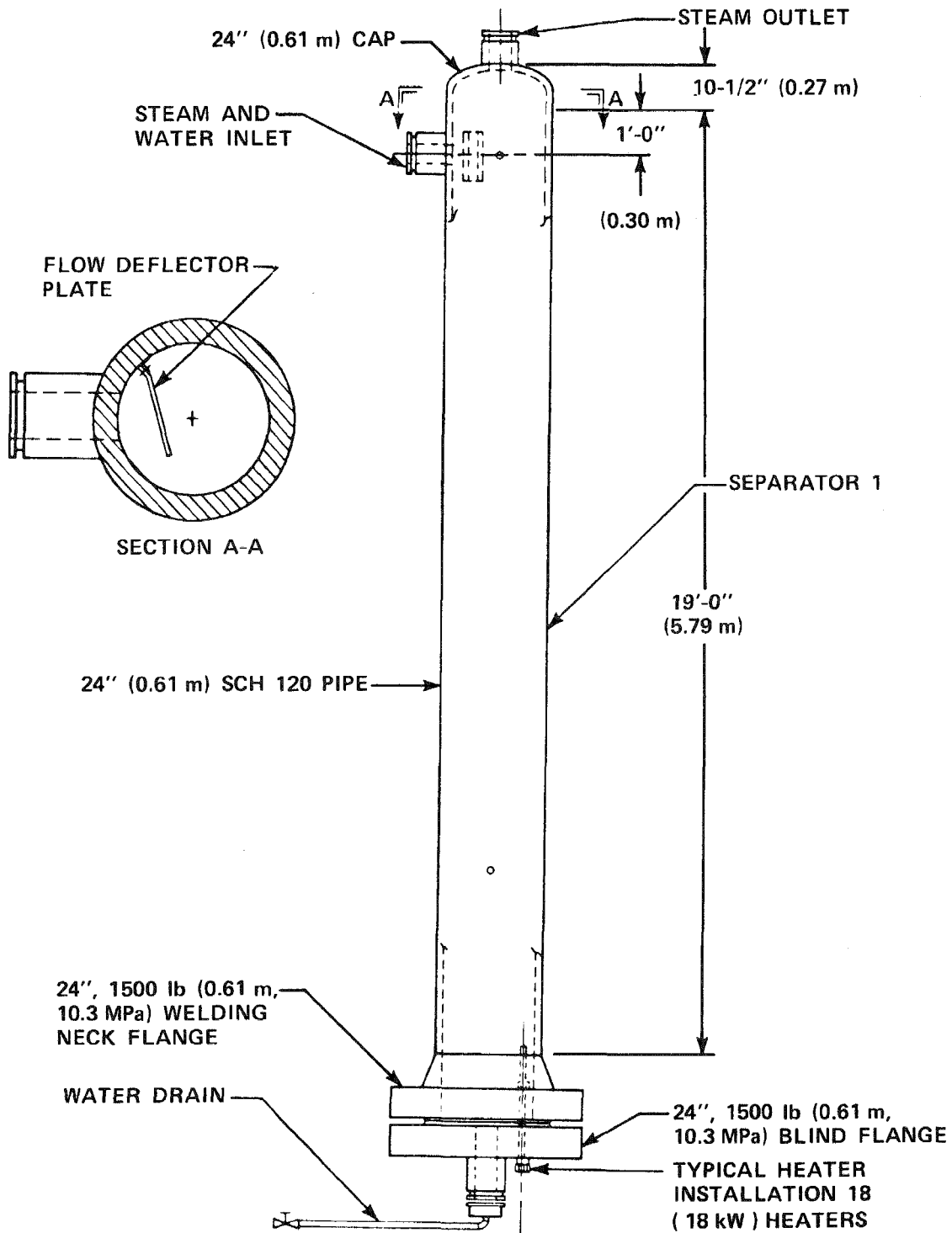


Figure 2-3. Steam Separator 1

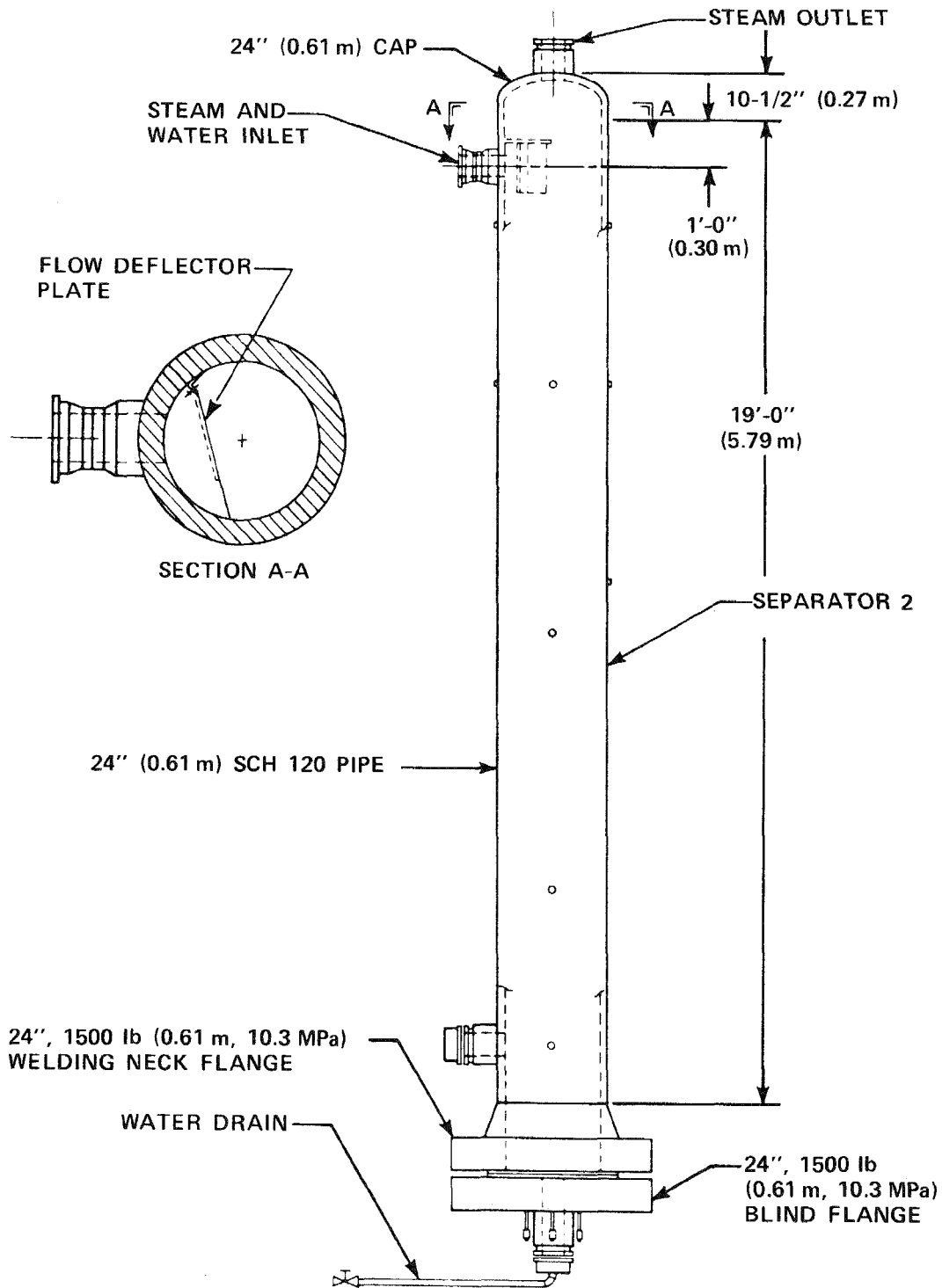


Figure 2-4. Steam Separator 2

to fall to the bottom, while the steam was discharged from the vessel through a 6 in. (15 cm) schedule 160 Grayloc nozzle welded to the top of the elliptical head. The steam was then directed to the exhaust valves, V-2 and V-16, through a run of 6 in. (15 cm) schedule 160 pipe.

All interconnecting primary loop piping was 6 in. (15 cm) schedule 160 carbon steel pipe except for the pipe connecting the test vessel baffle annulus region to the hot leg discharge from the test vessel, which was 4 in. (10 cm) schedule 160 carbon steel.

All primary system valves were 6 in. (15 cm), 1500 lb (10.3 MPa) pressure-class carbon steel valves with the exception of V-18A. Valve V-18A was a 4 in. (10 cm), 1500 lb (10.3 MPa) manually operated valve. Valve V-24A was a computer-operated gate valve located in the hot leg downstream of the test vessel. This valve, which had been used for other test programs, was in the full open position for core uncover testing. Valves V-2 and V-16 were the primary system pressure control valves. The valves were operated in unison either manually or by computer demand. Each valve had a controller enabling controlled constant pressure to be obtained by computer demand from input computer tables or using a manual setpoint.

Flange tap orifice installations were used in the primary system for flow measurement. Blank orifice plates were used to direct flow paths for a desired test or to isolate piping sections.

In the series of tests reported in this document, orifice plates at F-4A and F-8A were full orifices; that is, pipe inside diameter = orifice diameter = 5.189 in. (13.18 cm) . The orifice plate at FM-2A was used for flow measurement.

A list of the orifices used in each test is given in Appendix A, and the locations of the orifices within the loop are identified in Figure 2-1.

Test Section Geometry

The test section, consisting of a bundle of electrical resistance heater rods surrounded by a flow guide baffle, was contained within the test vessel, which had a 19.87 in. (0.5047 m) inside diameter and a 249.5 in. (6.337 m) inside length. Saturated coolant was introduced at one of the 6 in. (15 cm) nozzles in the lower plenum of the vessel until the desired initial water level for start of test was achieved. The steam or steam-water mixture generated in the bundle flowed past

the heater rods up through the ground plate into the upper plenum and exited radially through a 6 in. (15 cm) nozzle. The test section is illustrated in Figures 2-2 and 2-5.

The rod bundle contained 336 heater rods. The overall length of the heater rods was 226 in. (5.74 m), with a heated length of 164 in. (4.17 m). A schematic

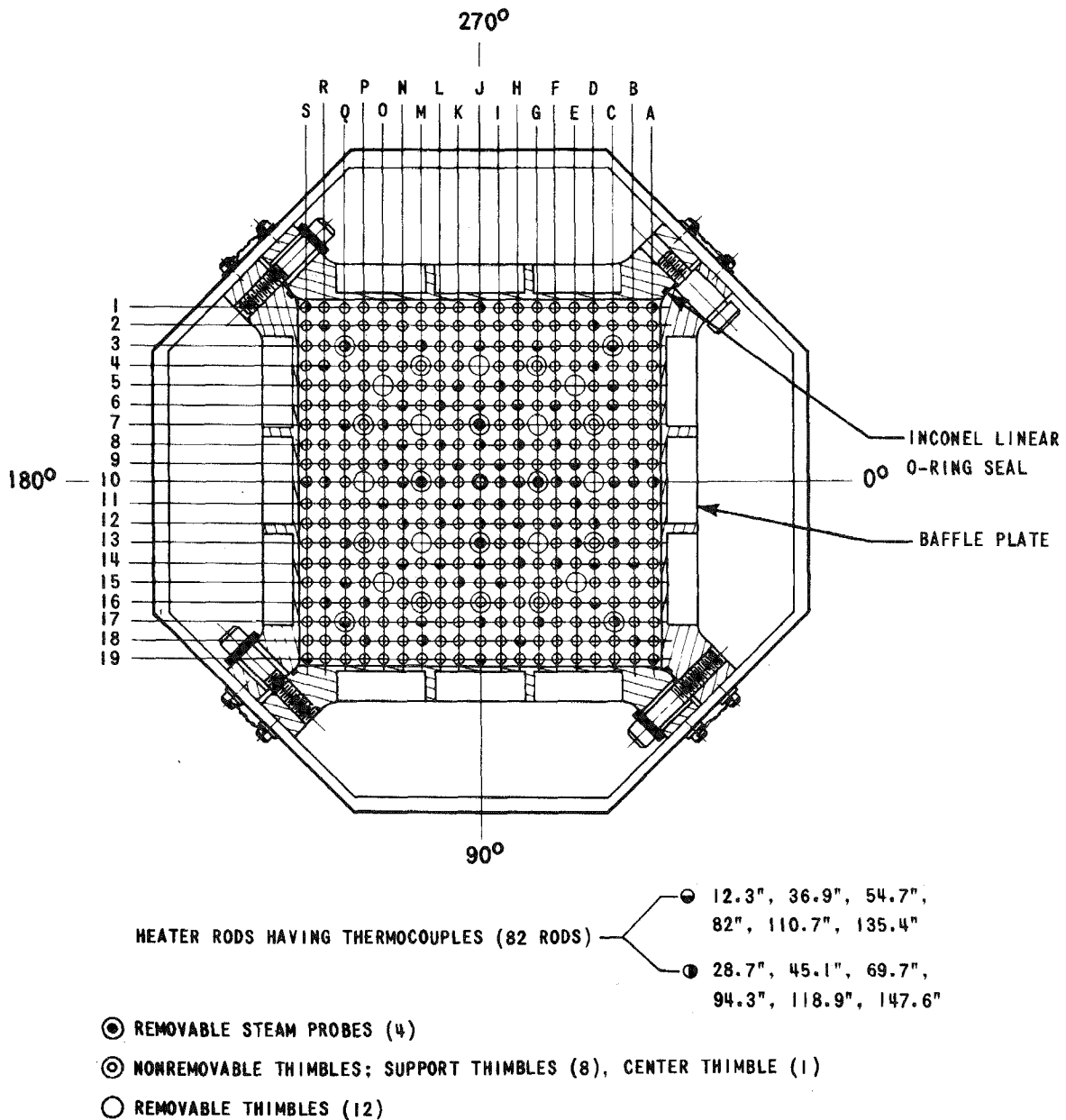


Figure 2-5. G-2 Loop Rod Bundle, Baffle Cross Section, and Bundle Instrumentation

diagram of a typical heater rod is shown in Figure 2-6 and the normalized axial power distribution produced by the rods is shown in Figure 2-7. Nine grids were placed along the length of the bundle (seven mixing vane grids and two end grids), as in an actual 17 x 17-XL PWR fuel assembly (Figure 2-2). These were made from standard 17 x 17 grids and were spotwelded to eight support thimbles. This structure positioned the heater rods laterally and allowed them to expand vertically upward during heatup. The heater rods [0.374 in. (0.950 cm) OD], the nine nonremovable thimbles [0.484 in. (1.23 cm) OD -- eight support thimbles and 1 center instrument thimble], and 16 removable thimbles [0.465 in. (1.18 cm) OD -- 12 thimbles and 4 steam probes] were arranged as shown in Figure 2-5 with a 0.496 in. (1.26 cm) square pitch.

Four plates bolted along their edges formed the baffle which provided a flow boundary around the rod bundle. The enclosed cross-sectional area was 49.5 in² (0.0319 m²). The vessel side of the baffle plates had a honeycomb design obtained by electrochemical machining to provide a low-mass baffle. Figure 2-5 shows the baffle cross section and Figure 2-8 shows the honeycomb design. At the bottom end, the baffle was bolted to the lower seal ring, which in turn was bolted to the support barrel (Figure 2-2). During heatup the baffle expanded upward because of thermal expansion. Sliding piston ring seals at the lower and upper end of the baffle and Inconel linear O-rings along the vertical baffle edges limited leakage to the region behind the baffle.

The cross-sectional area in the cavity between the baffle and the test vessel was approximately 190 in² (0.123 m²). The volume of nozzles on the vessel, averaged over the rod heated length, provided for an average cross section of 194 in² (0.125 m²).

A summary of the flow areas associated with the test bundle, the spacer grids, and the flow baffle/test vessel annulus is given in Table 2-1.

The rod bundle was supported by the bottom flange of the test vessel. The bottom end of each heater rod extended through the bottom flange of the test vessel, where the above-ground electrical connections and thermocouple hookups were made. The top end was connected to a copper ground plate with a nickel extension rod and a flexible copper braid. The ground plate conducted the phase-to-phase currents between the heater rods. (A three-phase Y-connection with a neutral to ground powered the rods.) The unbalanced current was carried to penetrations in the vessel by copper braids.

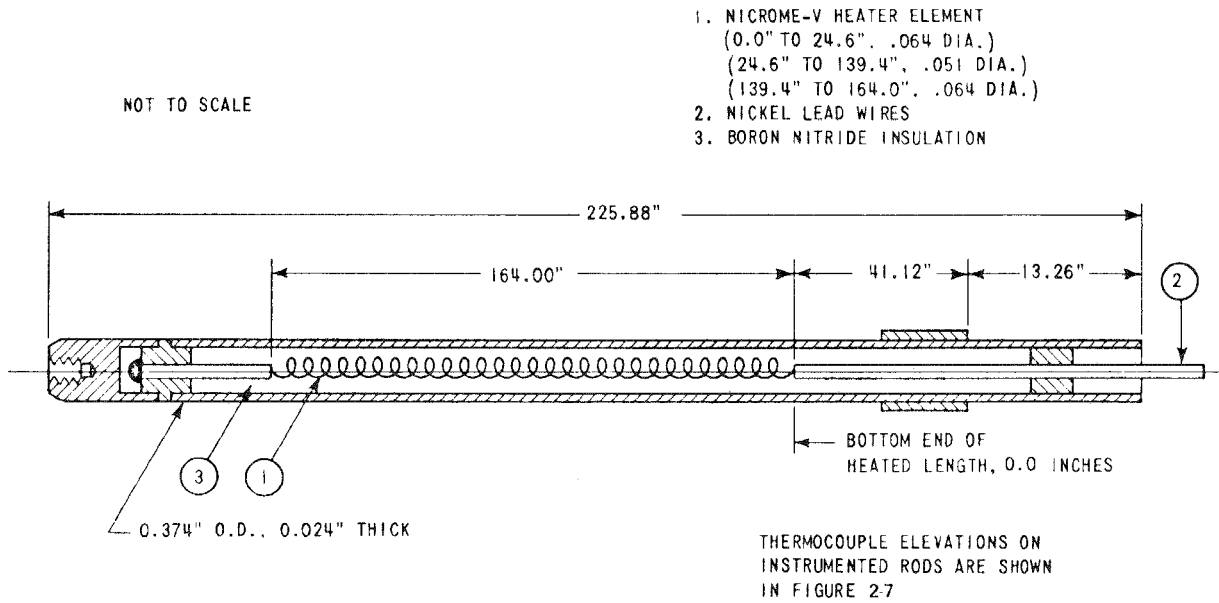


Figure 2-6. G-2 Loop Heater Rod

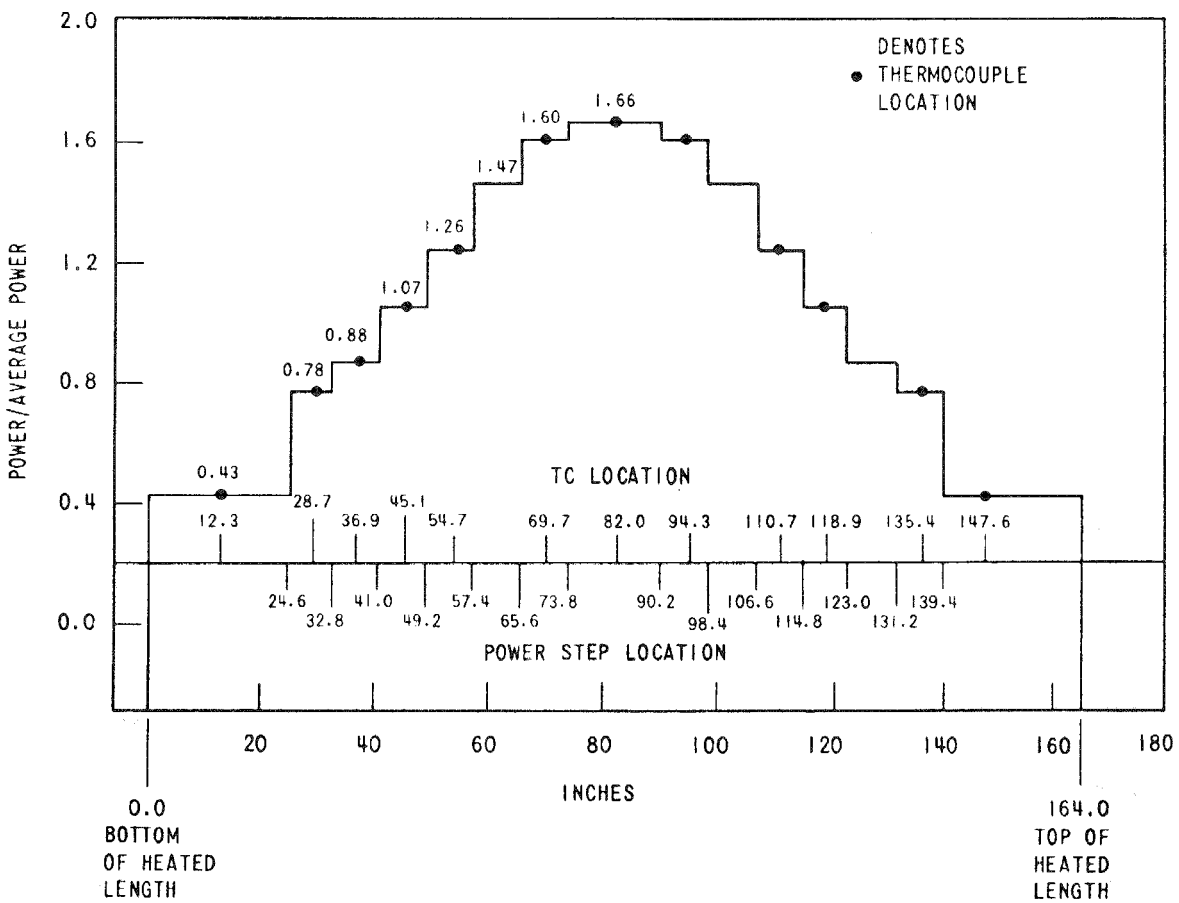


Figure 2-7. G-2 Loop Heater Rod Axial Power Profile

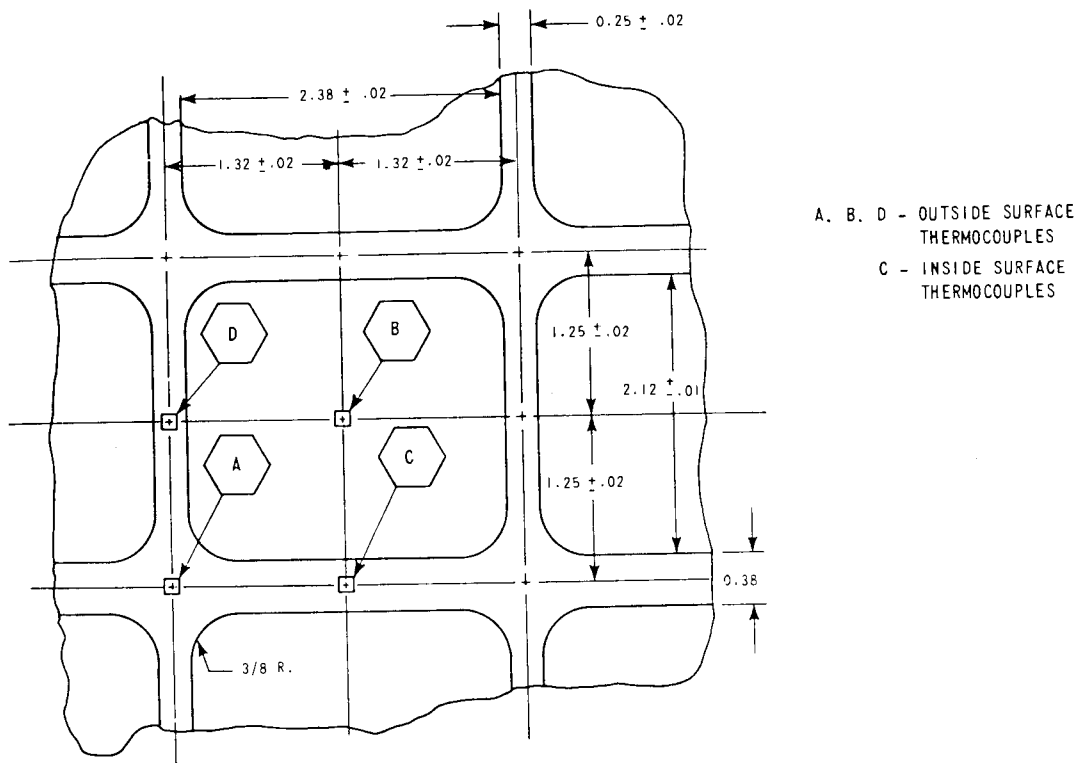


Figure 2-8. G-2 Loop Mass Baffle and Location of Thermocouples at 270° Angular Orientation

Table 2-1
G-2 LOOP CORE UNCOVERY TEST VESSEL FLOW AREAS

Location	Flow Area [in ² (m ²)]
Test bundle	49.30 (0.03181)
Spacer grid	29.80 (0.01923)
Flow baffle/test vessel annulus	194 ^(a) (0.125)

a. This is an average cross-sectional area that accounts for volumes of nozzles welded to the vessel. This average area was used to calculate liquid height and mass in that annulus.

Most of the components in the test section were made of austenitic stainless steel. The exceptions were as follows:

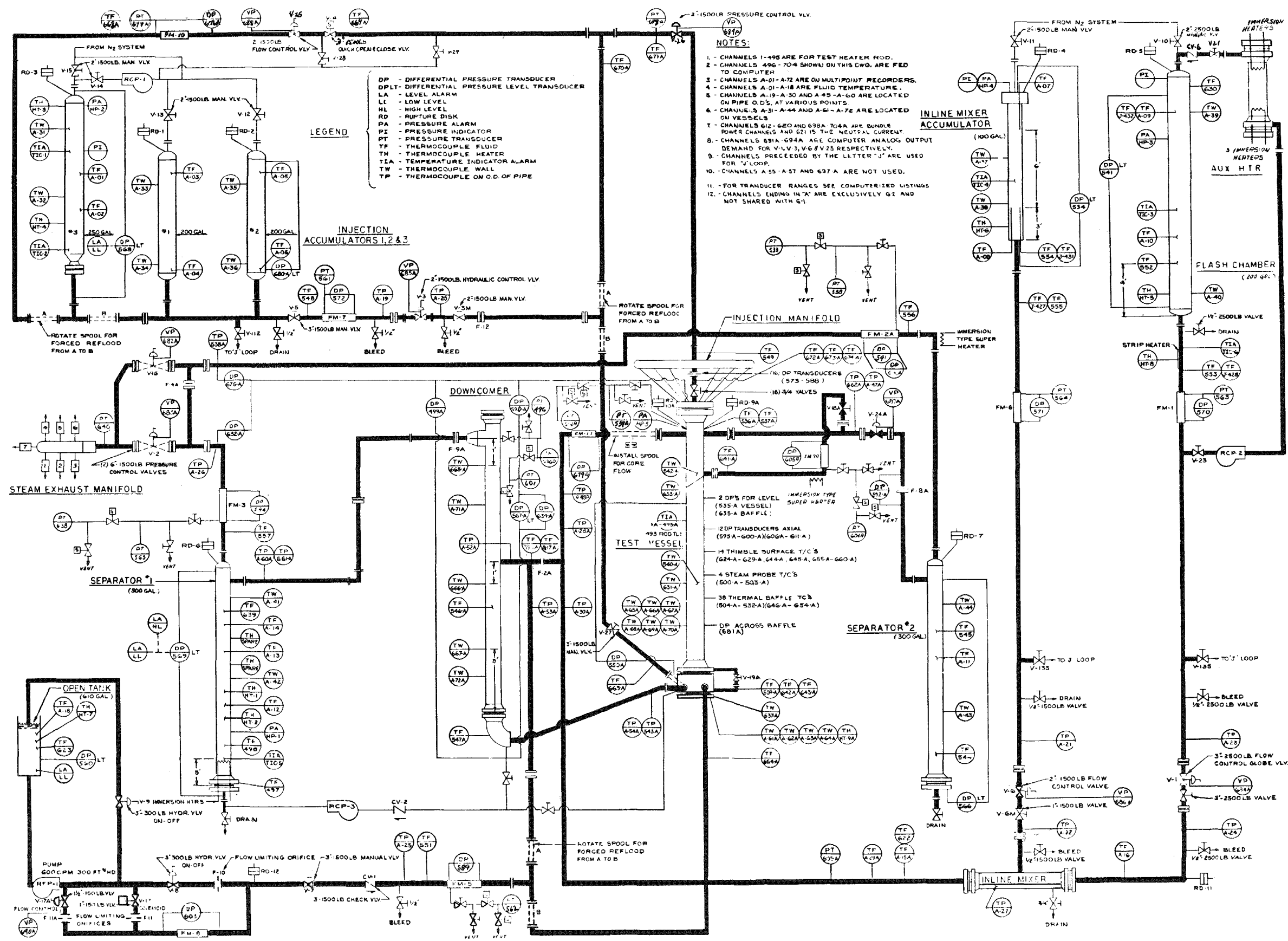
- Copper and nickel were used for the ground assembly.
- Inconel was used for the rod bundle grids and the linear O-ring seals.

Instrumentation

Instrumentation used in the core uncover tests is described in the following paragraphs.

Rod Bundle. The G-2 Loop test section contained 82 instrumented heater rods, each with six thermocouples. Half of the instrumented rods (41 rods) had thermocouple junctions at the 12.3, 36.9, 54.7, 82.0, 110.7, and 135.4 in. (0.31, 0.94, 1.39, 2.08, 2.81, and 3.44 m) elevations and the other half had junctions at the 28.7, 45.1, 69.7, 94.3, 118.9, and 147.6 in. (0.73, 1.15, 1.77, 2.40, 3.02, and 3.75 m) elevations from the bottom of the heated length (Figures 2-5 and 2-7). The thermocouples were contained within the boron nitride heater element insulation, with the junction located 0.020 in. (0.050 cm) from the inside wall of the heater rod tubing (clad). The thermocouples were ungrounded chromel-alumel (type K), premium grade, 0.006 in. (0.015 cm) diameter wire with a 0.040 in. (0.10 cm) diameter 304 stainless steel sheath. The junction was insulated from the sheath by high-purity magnesium oxide insulation with a resistance of 100 megohms at ± 50 volts dc for each specified length. The entire length of each thermocouple had been annealed to maintain a premium grade accuracy of $\pm 6^{\circ}\text{F}$ (3.3°C) during heater rod manufacturing. All test section heater rod thermocouples utilized a 150°F (65.6°C) reference junction for computer readout.

Primary Loop and Auxiliary Systems. The instrumentation used on the G-2 Loop test facility consisted of thermocouples, absolute pressure transducers, bidirectional differential pressure transducers, and differential pressure transducers in vessels and piping. Differential pressure transducers measured pressure drops throughout the system and across orifices for flow measurement, level transmitters determined vessel water levels, and thermocouples measured fluid or wall surface temperatures. The facility had sufficient instrumentation for making a mass balance check on the system. Figure 2-9 and Table B-1 (Appendix B) show the location of all facility instrumentation.



LEGEND

- DP - DIFFERENTIAL PRESSURE TRANSDUCER
- DPLT - DIFFERENTIAL PRESSURE LEVEL TRANSDUCER
- LA - LEVEL ALARM
- LL - LOW LEVEL
- HL - HIGH LEVEL
- RD - RUPTURE DISK
- PA - PRESSURE ALARM
- PI - PRESSURE INDICATOR
- PT - PRESSURE TRANSDUCER
- TF - THERMOCOUPLE FLUID
- TH - THERMOCOUPLE HEATER
- TIA - TEMPERATURE INDICATOR ALARM
- TW - THERMOCOUPLE WALL
- TP - THERMOCOUPLE ON O.D. OF PIPE

NOTES:

- 1 - CHANNELS 1-495 ARE FOR TEST HEATER ROD.
- 2 - CHANNELS 496-704 SHOW ON THIS DWG. ARE FED TO COMPUTER.
- 3 - CHANNELS A-01-A-72 ARE ON MULTIPoint RECORDERS.
- 4 - CHANNELS A-01-A-18 ARE FLUID TEMPERATURE.
- 5 - CHANNELS A-19-A-30 AND A-45-A-60 ARE LOCATED ON PIPE O.D.S. AT VARIOUS POINTS.
- 6 - CHANNELS A-31-A-44 AND A-61-A-72 ARE LOCATED ON VESSELS.
- 7 - CHANNELS 612-620 AND 639A-704A ARE BUNDLE POWER CHANNELS AND 621 IS THE NEUTRAL CURRENT DEMAND FOR V-LV-3, V-6 & V-25 RESPECTIVELY.
- 8 - CHANNELS 691A-694A ARE COMPUTER ANALOG OUTPUT FOR 'J' LOOP.
- 9 - CHANNELS PRECEDED BY THE LETTER 'J' ARE USED FOR 'J' LOOP.
- 10 - CHANNELS A-55-A-57 AND 637A ARE NOT USED.
- 11 - FOR TRANSDUCER RANGES SEE COMPUTERIZED LISTINGS.
- 12 - CHANNELS ENDING IN 'A' ARE EXCLUSIVELY G2 AND NOT SHARED WITH G-1.

Figure 2-9. G-2 Loop Instrumentation

Ungrounded, 0.125 in. (0.318 cm) diameter sheathed thermocouples were used extensively throughout the facility to measure fluid, steam, pipe, and vessel wall temperatures. Chromel-alumel (type K) ungrounded thermocouples utilizing a 150°F (65.6°C) reference junction provided data for all channels using computer readout. In addition, type K thermocouples were used as heater sheath temperature limit sensors for auxiliary system heater controllers. Iron-constantan (type J) ungrounded thermocouples were used as control temperature sensors for the heater controllers, and read temperatures recorded on non-computer-readout equipment. No external reference junction was used for type J thermocouples, since the heater controllers and multipoint temperature recorders used to read type J thermocouples contained a built-in 32°F (0°C) reference junction in their input circuitry.

Test Facility Design Logic

For core uncover testing, it was only necessary to scale that portion of the facility which was within the flow boundary in the test section, that is, the rod bundle. In addition, the ground plate and the upper plenum (Figure 2-2) were designed to give hydraulic resistance and/or flow velocities which are representative of the reactor. These components are discussed in the following paragraphs.

Rod Bundle. The diameters of the test bundle heater rods, thimbles, and instrumentation tube, and the square pitch arrangement of the rods were the same or nearly the same as those in a 17x17 or 17x17XL PWR assembly, as shown in Table 2-2. Although in the 17x17 PWR assembly, all thimbles and the instrumentation tube have the same diameter, two different thimble diameters were used in the test bundle. The test bundle was designed to permit the removal of 16 thimbles; this design required that these thimbles be built to a slightly smaller than prototypical diameter. The reactor to test bundle flow area ratio was 153. The mixing vane grid and end grid designs used were prototypical. The axial locations of the grids were the same as in the preliminary 17x17XL PWR design at the time of the G-2 Loop facility design, except that the sixth grid was at 106.6 in. (2.71 m) rather than at 107.6 in. (2.73 m) from the beginning of the heated length. [The 107.6 in. (2.73 m) location would have interfered with pressure taps in the vessel.]

Ground Plate. The flow holes in the ground plate (Figure 2-10) were sized to give approximately the same hydraulic resistance to upward flow as would be provided in the PWR by the upper fuel nozzle and the upper core plate during reflood. The reactor core inlet loss coefficient of 2.82 for the 17x17 fuel assembly was matched in the test bundle ground plate by the use of 324 0.315 in. (0.800 cm) diameter holes

Table 2-2

COMPARISON OF 17x17XL PWR ROD AND TEST ROD BUNDLE

Item	PWR Rods	Test Rods
Diameter	0.374 in. (0.950 cm)	0.374 in. (0.950 cm)
Thimble outside diameter		
Support thimbles (9)	0.484 in. (0.431 in. dashpot) [1.23 cm (1.09 cm dashpot)]	0.484 in. (0.431 in. dashpot) [1.23 cm (1.09 cm dashpot)]
Removable thimbles (16)	---	0.465 in. (0.431 in. dashpot) [1.18 cm (1.09 cm dashpot)]
Instrumentation tube outside diameter	0.484 in. (0.431 in. dashpot) [1.23 cm (1.09 cm dashpot)]	0.484 in. (0.431 in. dashpot) [1.23 cm (1.09 cm dashpot)]
Rod pitch	0.496 in. (1.26 cm) square pitch	0.496 (1.26 cm) square pitch
Clad thickness	0.0225 in. (0.057 cm)	0.020 - 0.024 in. (0.05 - 0.06 cm)
Clad material	Zircaloy-4	Type 347 stainless steel
Heated length	168 in. (4.27 m)	164 in. (4.17 cm) ^(a)
Filler material	UO ₂	Boron nitride
Flow grid characteristics		
Flow area ^(b)	29.7258 in ² (0.19179 m ²)	29.80 in ² (0.1923 m ²)
K-factor for standard (non-mixing vane) grid ^(c)		
Reynolds number = 10 ³	1.4 ± 30%	1.4 ± 30%
Reynolds number = 10 ⁴	1.2 ± 30%	1.2 ± 30%
K factor for mixing vane grid ^(d)		
Reynolds number = 10 ³	1.8 ± 20%	1.8 ± 20%
Reynolds number = 10 ⁴	1.5 ± 20%	1.5 ± 20%

- a. The original 17x17XL fuel length was 164 in. (4.17 m) at the time the facility heater rods were purchased. Since that time the PWR fuel length has been increased to 168 in. (4.27 m).
- b. The flow area given is applicable to both mixing vane and non-mixing-vane grids.
- c. There are two standard grids in the test bundle, one each at the beginning of heated length and at the end of heated length.
- d. There are seven mixing vane grids in the test bundle, located between the two standard grids (Figure 2-2).

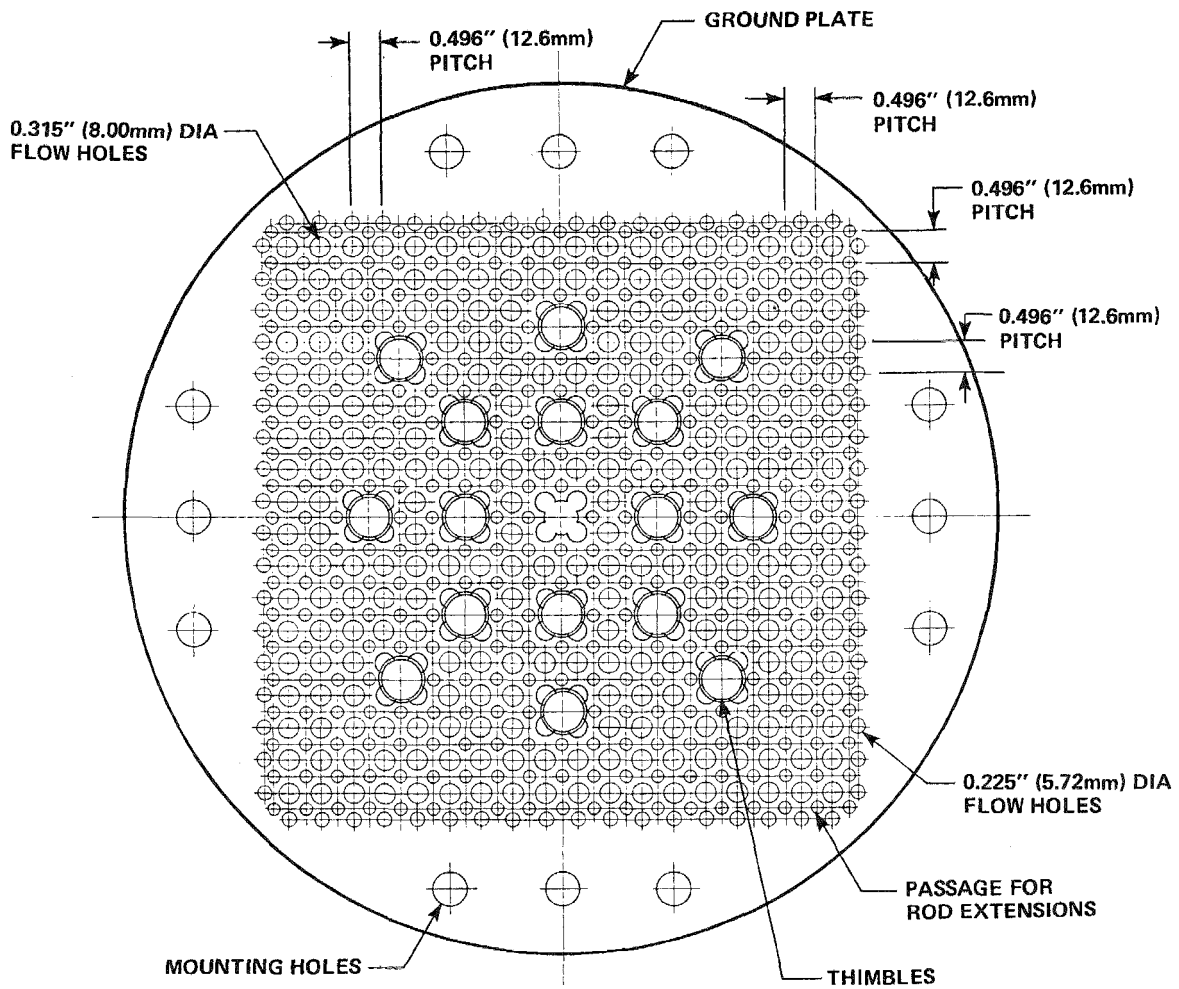


Figure 2-10. G-2 Loop Ground Plate

with a 0.02 (+0.01, -0.00) in. [0.05 (+0.02, -0.00) cm] radius at the inlet (bottom) side and 72 0.225 in. (0.572 cm) diameter holes without radius at the bottom edge.

Upper Plenum. The cross-sectional flow area in the upper plenum was scaled to model the PWR axial velocity above the ground plate. To attain this, the PWR ratio (of 1.65) of upper plenum flow cross-section area just above the ground plate to reactor core flow cross-section area was maintained in the G-2 Loop test vessel.

Power Supply and Control

The test section heater rod power was supplied by a power transformer and passed through switchgear for test section protection, silicon-controlled rectifier (SCR) units with integral disconnect switches for zone regulation, and a circuit breaker cabinet for individual heater rod protection. The specified power profile was demanded by analog signals from the computer using a digital input table. A high-temperature trip, which opened the switchgear, was incorporated in the system to ensure test section high-temperature protection.

Method of Power Supply and Control. Test section heater rod power was supplied by a three-phase 1500 kVA 23,000 Vac primary (delta-connected), and a 480 Vac line-to-line secondary (grounded Y-connected) oil-cooled transformer. The power was delivered through a three-phase 600 Vac 2500-A/phase motor-operated circuit breaker, and was distributed to seven single-phase phase-fired full-wave SCR units. Each SCR was rated as follows:

<u>SCR</u>	<u>Maximum Power (kW)</u>	<u>Maximum Continuous Current (A)</u>	<u>Number of Rods</u>
1	400	1600	24
2	600	2400	40
3	480	1800	20
4A	1200	4500	72
4B	1200	4500	56
5	800	3200	68
6	600	2400	56

Figure A-1 (Appendix A) and Table B-2 (Appendix B) identify the heater rods assigned to each SCR.

The maximum desired power and current limit was preset for each SCR by front panel digital controls. The SCR units were operational in three modes and two

types of control. The individual mode allowed each SCR to be operated independently, the master mode permitted all SCR units to be controlled simultaneously using one front panel digital control setting, and the automatic mode enabled all SCR units to be controlled simultaneously by one common 0 to 10 Vdc input signal (such as from the computer). Constant power control would interpret the input signal as a power demand; constant current control would interpret the input signal as a current demand. The power from the SCRs was delivered to the test section heater rods, which were individually protected by circuit breakers.

Method of Operation. The individual heater rod circuit breakers were closed according to the table in the facility preparation and heatup procedure (Appendix C), and the SCR disconnect switches were closed. The SCR system was started by turning the console power key switch to the ON position and depressing the START button. The main circuit breaker would close and the SCRs would supply power to the test section heater rods according to the mode/control settings and the computer demand, provided that all system safety interlocks are satisfied.

For G-2 Loop test runs, the power level supplied to the test section heater rods was controlled by computer demand using a linearly interpolated demand table. Although each heater rod provided less than 0.33 percent of the total bundle power, the power demand to a given SCR was decreased when a heater rod became inoperative such that the peak power on the powered rods remained as specified for the test. Five heater rods were inoperative during the core uncover test series. The SCRs were operated in automatic mode with constant power control, which operated all SCRs simultaneously using one 0 to 10 Vdc input signal from the computer demand table POWER. The tests were initiated with a zero or no power demand. At about 10 seconds after initiation of test, the power demand was increased in step change form to the desired power level, and held constant at that level until the test was terminated. Thus, once applied, bundle power was held constant. The power input from the SCRs to the heater rods was a direct proportion of the power settings preset on the front panel digital controls; that is, 10 Vdc input from the computer equaled full power preset on the digital controls, 5 Vdc equaled half power, and so forth. At the conclusion of the test run, the main circuit breaker was opened by computer demand, removing the power supply to the SCRs. The SCR STOP button was then pushed, and the power key-switch was turned to the OFF position.

Alternate methods of terminating power included the following:

- Depressing the STOP pushbutton to remove the demand signals to all SCRs, thus shutting off output, and causing the main circuit breaker to open 2 seconds later

- Depressing the SCRAM pushbutton to open the main circuit breaker immediately
- Loss of any safety interlock, which opened the main circuit breaker immediately
- Excessive current in any SCR unit, which had the following effects:
 - Shut down power to that SCR if current exceeded the current limit setpoint on the front panel digital control
 - Opened the main circuit breaker if any SCR exceeded any internally set current trip, thus protecting the SCR semiconductor

Power Measurement. The SCR voltage and current outputs were transmitted by instrument transformers to a Hall-effect watt transducer. The transducer was calibrated to output 0 to 50 millivolts dc for 0 kilowatts to SCR full-scale output kilowatts. This signal was operated by signal conditioning circuitry which converted the instantaneous power signal to true rms values. The rms values were transmitted to both the computer and a summing network to calculate total power to the bundle.

Control Panels

Two separate control panels were used to monitor and operate the G-2 Loop test facility: the G-2 Loop operator's panel located at the facility, and the test director's console located in an adjacent control room.

Operator's Control Panel. The G-2 Loop operator's control panel (Figure 2-11) was used by the facility operators to control and monitor facility heatup. All primary system and auxiliary system heater controls and test section heater rod power SCR controls were located on this control panel. Facility fluid and wall temperatures were monitored using three continuously operating 24-channel multipoint recorders. Pressures and vessel water levels were also monitored during heatup. As a safety precaution, an audiovisual alarm panel was used to warn the operators if unsafe conditions occurred, such as high temperature or pressure, or low hydraulic fluid pressure. Other controls located on the panel included the recirculating pump ON-OFF buttons, switches to open or close all remote by operated valves, and a separate switch to change from manual to computer control.

In addition to the control and monitor systems, there were three continuous strip chart recorders, which were mounted in the control panel used for recording test data. These recorders were used to record the total power supplied to each test

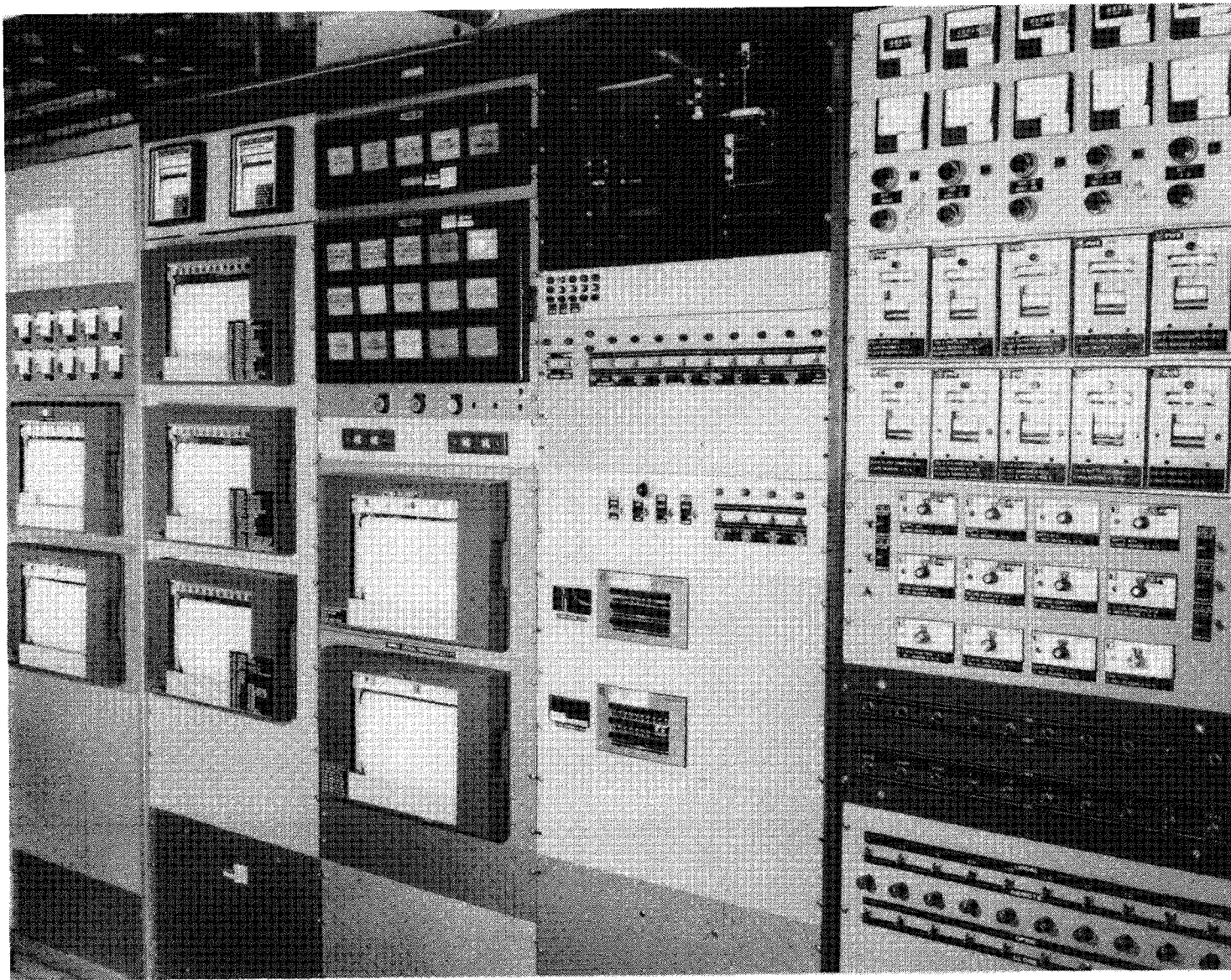


Figure 2-11. G-2 Loop Operator's Control Panel

section heater rod zone and the temperature of six preselected clad thermocouples during test section preheating and the test run.

Test Director's Console. The test director's console (Figure 2-12) was used by the cognizant test engineer to monitor facility conditions and operation prior to and during the test. Indicating meters showed vessel temperatures, pressures, and water levels; selected heater rod clad thermocouple readings; total test section heater rod bundle power; and flow rates from auxiliary systems. A row of indicating lights allowed the test director to check valve positions and valve operation. The actual run time was displayed on a digital timer, which was started by the computer at the initiation of the test run. The test director's console enabled the test director to monitor facility operation, to check if all pretest requirements had been established, and to check if all test events occurred as demanded.

DATA ACQUISITION SYSTEM

The computerized data acquisition system used for the G-2 Loop tests was designed to monitor and record output from most of the facility instrumentation during a test; the exceptions were nine strip chart and multipoint recorders used to record auxiliary data.

Description of Equipment

The data acquisition equipment is described in the following paragraphs.

Main Frame Components. With the exception of the line printer and the cathode ray tube (CRT) at the operator's terminal, all main frame components were manufactured by Digital Equipment Corporation. These components were as follows:

- PDP-11/20 computer
- 24 K of MM11 900-nanosecond memory
- RK11 1.2-million-word-capacity moving head disk
- TU10/TM11 magnetic tape controller and drive
- PC11 paper tape reader and punch

The line printer, manufactured by Data Printer with a Diva, Inc., interface, was capable of printing 600 80-column lines per minute. All messages displayed on the CRT at the operator's terminal were echoed to the line printer so that a permanent record of them could be kept.

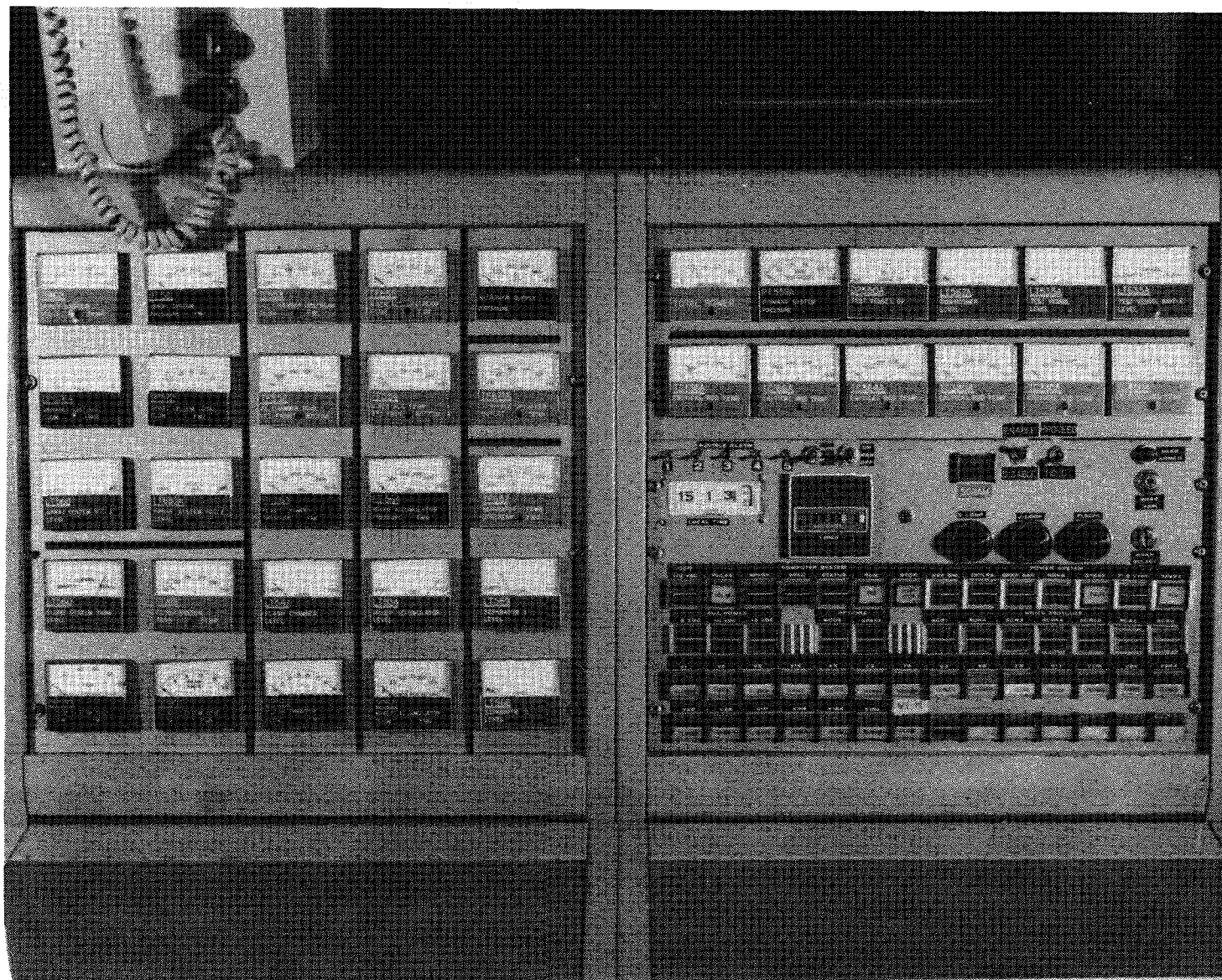


Figure 2-12. Test Director's Console

Peripheral Equipment. The interface to the test floor controls and instrumentation sensors was provided by a real time peripheral (RTP) system manufactured by Computer Products, Inc. This system consisted of the following:

- 704 channels of 12-bit low-level analog-to-digital converters
- 16 contact closure output channels for control of alarms, solenoid valves, and the like
- 16 contact closure input channels for sensing of control push-buttons, limit switches, and the like
- Six channels of bipolar digital-to-analog converters

The RTP system incorporated the following characteristics:

- The capability to reject 120 dB of ac noise from dc thermocouple signals. In actual practice, the guaranteed 120 dB was closer to an actual value of about 135 dB average.
- Negligible amounts of channel cross-talk
- A very small temporal drift of channel calibration (two bits out of 2047 in 6 months), together with an easy calibration procedure
- The ability to acquire data at a very fast rate. Each multiplexer communicated with 64 channels and ran at a constant 8 kHz rate. With the ability to overlap the operation of the 11 multiplexers on the system, a theoretical data rate of 88,000 channels per second was possible; an actual rate of 22,000 channels per second was achieved. The difference was due to the software necessary for addressing and gathering data from the multiplexers.

Description of Software

The software used during a test was known as the Data Acquisition and Control Program (DACP). The DACP recorded thermocouple, pressure, pressure differential, and power measurements on the disk during the execution of a test. It simultaneously issued setpoint values from tabular input to several valve controllers, checked for operator intervention, and checked various values of temperature. Several optional actions could be chosen, depending on the status of the sensor readings.

Computer System Requirements. The DACP operated on the DEC PDP-11/20 computer system using version 8 of the DEC disk operating system monitor. The program occupied approximately 10 K of core. Peripheral equipment requirements for the DACP included the Computer Products' RTP system, the RK11/RK05 disk, and the Tektronix 4010 keyboard printer.

Program Loading and Initialization. The DACP was loaded into core by placing the monitor in command mode and issuing the RUN DACP (CR) command. The program was then read from disk, loaded into core, and started. During the initialization part of the program, it read appropriate tables (used for temperature conversions, valve setpoint curves, and so forth) from the disk and reset the contact closure outputs. A dialog phase was then entered, in which the program asked the operator for run variables such as run title, length of run, and critical temperature levels. This phase also permitted the operator to edit the tables originally read from disk. In the event that the tables were edited, the edited version was rewritten back to disk for later use. At the end of the dialog, the operator could cancel the test, enter a test preconditioning routine, or proceed directly with the test. If the preconditioning phase was entered, the operator could cancel the test, reenter the preconditioning routine, or proceed with the test when that phase was completed. The operator could optionally display the current reading of any channel, in millivolts or degrees, on the display terminal.

Main Program Operation. The basic time cycle of the DACP determined the rate at which its various repetitive functions were performed. One-tenth of a second was used as the basic cycle; the necessary timing information came from the KW11-P programmable real-time clock. The repetitive data acquisition and control functions were performed at 0.1-, 0.5-, and 3-second intervals. The DACP focused on the 0.1-second interval and apportioned the processing time in 0.1-second periods. During each 0.1-second period, the program performed the 0.1-second functions as well as a selected portion of the 0.5- or 3-second functions. The program repetitively sequenced through five 0.1-second periods, each with its specific functions, as shown in Figure 2-13. The following paragraphs describe the specific characteristics of these functions.

The following 0.1-second functions were performed repeatedly by the DACP at the basic cycle rate:

- The power control signal was output to the appropriate digital-to-analog control point. This signal was determined as a function of run time by a linear interpolation of the POWER versus TIME tables, unless an overtemperature condition had been reached. After an overtemperature condition had been reached, the power control value was always set to zero.
- The control value was output to five analog valve controllers and optionally to a sixth. For core uncover testing, control values were output to V-24A, V-2, and V-16 valves (see Figure 2-1). These values were again derived from a linear interpolation of the

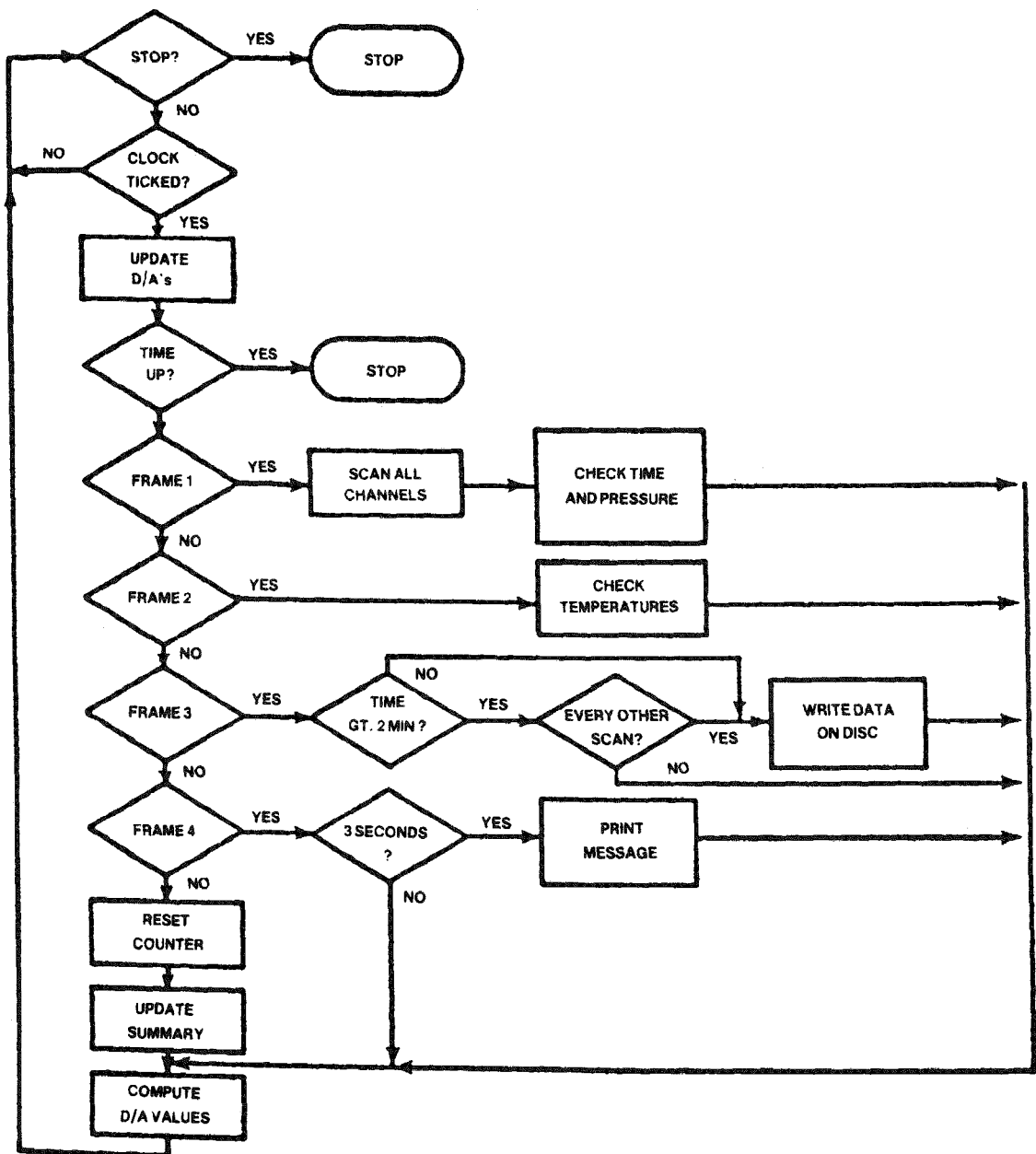


Figure 2-13. DACP Test Control Flow Chart

appropriate input tables, except that all valve control signals were inhibited for the first 2 seconds of the run. The control signals were inhibited in this manner to permit changeover from manual to automatic valve control early in the test.

The following 0.5-second functions were performed:

- All 704 channels were scanned and the data were saved in memory.
- The input values for all heater rod bundle thermocouples were searched for defective thermocouples, overtemperature thermocouples, and the hottest channel thermocouple.

A thermocouple reading was considered defective if it was either less than -2.66 mV or higher than a preset value (the defect temperature limit). If a reading was found to be defective, its value was cleared to zero.

All thermocouples that were not defective were checked to find the hottest channel. The hottest channel value was then checked for an overtemperature condition. A thermocouple was considered to be over temperature if its value was greater than the maximum acceptable temperature but less than the defective temperature limit for two successive readings.

When the first overtemperature channel had been detected, the search shifted to look for the second highest temperature. When the second hottest channel was detected to be overtemperature, the DACP set the power to zero, set overtemperature indicator CCOs to their proper states, and informed the operator that the overtemperature had occurred.

Other functions of the DACP were continued, but further testing for the hottest channel and for overtemperature was discontinued.

- For the core uncover tests, the data values for the 704 channels and the corresponding relative times were recorded on disk throughout the test run at the frequency specified in the Core Uncovery Test Prospectus (Appendix D) for the power and pressure conditions being tested.
- The record containing the run number, the operating time for the sixth (optional) valve, the overtemperature time, and the number of scans of data on disk was updated.

The 3-second function consisted of printing the latest value of the hottest channel of the rod bundle thermocouples, converted to degrees Fahrenheit, in the following form:

Time	Temp	CH
xxx	YYYY.Y	zzz

The heading was output only once at the beginning of the run. This output was discontinued whenever an overtemperature condition was detected. The 3-second function was performed to keep the test director abreast of the status of the test article. As shown below, the test director could terminate the test manually if he wished to do so.

There were six ways in which the running program could be terminated:

- Pressing the STOP pushbutton on the floor
- CTRL/S input through the typewriter
- Reaching maximum test duration time
- Software-detected error
- Multiplexer failure
- Power failure

When the stop condition was reached, scanning was stopped and the six digital-to-analog converters for valve position and the one digital-to-analog converter for power were all reset to zero. This was done so that the test hardware assumed a failsafe condition. The operator was informed of the reason for the stop and was given the option of keeping or ignoring any data collected at the time the stop condition was detected. If he chose to ignore the data, the program restarted; conversely, if the data was to be kept, the program terminated.

On computer power failure, the scanning stopped and the six digital-to-analog converters for the valve position controllers and the one-digital-to-analog converter for the power controller were all set to zero. On power recovery and restart, the DACP printed a message indicating that a power failure had occurred and then reset all input/output devices and halted. The operator then had to load the monitor back into core using the computer console switch register. The operator could optionally process the data acquired before the power failure or restart the DACP and acquire new data.

Description of Other Recorders

The G-2 Loop test facility utilized six null-balance strip chart recorders to provide a continuous recording of critical test section heatup and selected test data. Three recorders were mounted in the G-2 Loop operator's control panel and provided a continuous trace of power supplied to each test section heater rod zone, and the

temperature of six test section clad thermocouples at the 82 in. (2.08 m) elevation. The remaining three recorders, located in the control room, were wired to a patch panel which permitted quick recorder input changes. In particular, two of these recorders were used to provide traces of any facility pressure or differential pressure transducer or vessel level transmitter desired. The third recorder was a high-impedance input, high-frequency response recorder with eight analog channels used primarily to obtain control valve performance data by recording valve positions and pressure drops across flow orifices.

BAFFLE SEAL LEAKAGE

After initial blowdown testing in the facility and prior to running the core uncover tests, baffle seal leakage checks were made and forced flooding tests were run to check out the facility. These tests indicated that the rate at which coolant could leak from the rod bundle into the cavity behind the baffle was substantially greater than expected. Therefore, a number of tests were performed to determine the magnitude of the leakage and its variation along the axial length of the baffle flange joints. A detailed account of these tests is given in Appendix E. The results of all leakage tests (including tests run after the reflood test series was completed) indicated consistently low leakage below the 70 in. (1.78 m) level. Since a leakage path in the upper half of the baffle would result in an accumulation of entrainment in the baffle/vessel cavity behind the more leaktight lower portion of the baffle, and thus would invalidate the entrainment (carryover) and heat transfer data, the core uncover tests were run with the baffle/vessel cavity prefilled with water to the same height as the water in the test section.

METHOD OF CORE UNCOVERY

Test Prospectus

The test prospectus is a document which states the purpose of the test and specifies for the test engineer all of the test conditions (such as temperature, pressure, initial water elevation, and power) and data as well as data accuracy requirements of the test. Each of the runs in Table 2-3 was specified in a test prospectus which was reviewed by cognizant personnel prior to final issue. A sample test prospectus is presented in Appendix D.

The rationale for selection of the various initial bundle water levels specified in the data of Table 2-3 is not addressed in the test prospectus of Appendix D; it is therefore appropriate to do so here. The initial bundle water levels listed in

Table 2-3
G-2 LOOP CORE UNCOVERY
TEST PARAMETERS

<u>Run Number</u>	<u>Pressure [psia (kPa)]</u>	<u>Bundle Power (Mw)</u>	<u>Initial Bundle Water Level [in. (m)]</u>
715	779 (5371)	0.603	114 (2.90)
716	775 (5344)	0.252	138 (3.51)
717	796 (5488)	0.905	102 (2.59)
718	799 (5509)	1.258	90 (2.29)
719	394 (2717)	0.267	138 (3.51)
720	395 (2724)	0.615	114 (2.90)
721	394 (2717)	0.914	102 (2.59)
722	395 (2724)	1.264	84 (2.13)
723	395 (2724)	0.614	114 (2.90)
724	96 (662)	0.252	126 (3.20)
725	96 (662)	0.599	96 (2.44)
726	96 (662)	0.857	84 (2.13)
727	97 (669)	1.247	78 (1.98)
728	50 (345)	0.596	84 (2.13)
729	50 (345)	0.250	114 (2.90)
730	50 (345)	0.894	66 (1.68)
731	50 (345)	1.244	54 (1.37)
732	15.1 (104)	0.254	102 (2.59)
733	15.8 (109)	0.600	72 (1.83)
734	16.1 (111)	0.900	60 (1.52)
735	16.7 (115)	1.249	54 (1.37)
736	15.3 (105)	0.253	102 (2.59)

Table 2-3 are those levels that were calculated to cover the axial length of the bundle when power was first applied to the bundle. The calculations were made using the Yeh void fraction correlation (3) to compute the void fraction distribution in the bundle at given pressures and powers, and hence the net liquid height (that is, the collapsed liquid level), when the froth level is at the top of the bundle heated length. A small height of water, amounting to several inches (centimeters) was added to each of the calculated heights to ensure that the bundle was initially covered by the froth level.

Pretest Operations

Pretest operations are detailed below.

Facility Preparations. Following the receipt of a test prospectus, a detailed loop preparation and heatup procedure was prepared by the cognizant test engineer for the loop technicians. The procedure specified the desired test conditions for the primary and auxiliary systems, valve positions, bundle power SCR settings, and instrumentation preparation for pretest zero checks. Appendix C contains a sample procedure.

The procedure consisted of separate sections for each loop component or loop system, with the individual steps arranged in a checklist format. Each step was initialed after it was completed. A general checklist preceded the individual sections, outlining the order in which the sections were to be completed.

After the facility was heated as specified by the procedure, all loop conditions were reviewed by the cognizant test engineer prior to the initiation of instrumentation zero readings.

Zero Readings. When all facility conditions were within specification, a pretest instrumentation check was performed by the computer. The computer scanned all data channels. Defective bundle thermocouples were identified and intentionally shorted to avoid interference with testing. Transducer zero readings were recorded and automatically entered into the calibration file. The calibration file, stored in the computer, consisted of the millivolt versus psi calibration in the form of the slope and intercept of a least-squares fit to the data and the transducer zero at time of calibration for each pressure transducer and level transmitter. The calibration curve was automatically corrected for zero shift by entering the new zero reading, which it compared to the original zero when calibrated. The file was used during test data printout and reduction to convert raw millivolt signals from the instrument to engineering units.

Inputs to Computer. Following completion of pretest transducer zero checks, the Data Acquisition and Control Program was entered into the computer. Manual inputs to the DACP specified the run number, run duration, and maximum allowable temperature. A sample input form is shown in Appendix C. At this time, the test parameter control tables were entered into the computer. Sample tables are shown in Appendix C. Power demand was controlled by computer-supplied analog demands in accordance with the input tables. Each demand table used an individual time table to allow flexibility in sequencing of events.

The computer then remained in a ready condition until the test was started.

Pretest Procedures. After zero readings and computer inputs were completed, the final phase of facility preparation was implemented using the pretest procedures. Sample procedures, shown in Appendix C, consisted of a checklist used by the cognizant test engineer to specify valve positions, power settings, and circuit breaker positions; to verify completion of key sections of the setup procedures and computer inputs; and to ensure that computer control of the facility was established.

Following the completion of the pretest procedures, the facility was ready for test initiation.

Testing

A typical core uncover test was divided into three distinct operations:

- System heatup
- Bundle and baffle prefill
- Core uncover (power applied to bundle)

System Heatup. Separator 1 was used to heat up and pressurize the facility. The desired test pressure was maintained for at least 1 hour prior to initiation of the test run. During the heatup period, noncondensable gases were vented from the facility. The test vessel lower plenum and baffle-vessel annulus were kept empty by continual draining.

Bundle and Baffle Region Filling. After the test vessel and lower plenum were at or approached the saturation temperature of the pressure at which the test was to be conducted, saturated water was pumped into the test section and baffle regions (baffle/vessel cavity) through the test vessel lower plenum. Valves V-19A and V-18A (Figure 2-1) were opened during the filling operation, allowing the fluid levels in the two

regions to equalize. When the test vessel/baffle region had been filled to the desired level, flow into the lower plenum was terminated and valve V-18A was closed.

This filling procedure was initiated just prior to the start of test.

Core Uncovery. With the facility pressurized and heated, and fluid in the test section/baffle region at the specified level, the test was begun by initiating the acquisition of data. Power was applied to the bundle at about 10.0 to 12.0 seconds after initiation of test, as controlled by the computer. At that time, the power was stepped from zero to the specified power required for the test, and held at that value for the time duration specified in the test prospectus.

The pressure in the test vessel was held constant during the test by use of valve V-16. The pressure demand was set manually and pressure control was accomplished by means of an analog control system.

Test termination was determined by several conditions:

- Run duration limit reached, test stopped by computer
- Maximum allowable clad temperature exceeded by second thermocouple, test stopped by computer
- SCRAM, test stopped by loop operator or test director

Posttest Procedures

After the test run had been conducted, the facility operators and the computer operator had specific functions to complete, as described below.

Instrument Reading and Data Reduction. The computer operator performed a posttest data channel scan immediately after the test run was terminated. The readings obtained in this scan were used to cross-check the instrumentation against the pre-test readings, to verify instrument reliability during the test.

Following the posttest channel scan, the computer operator ran the data reduction program (DRP), which transferred the test data from disk storage to magnetic tape. This magnetic tape was used for further data reduction programs.

The final operation performed by the computer operator was a data printout (in engineering units) of selected instrumentation channels. A quick evaluation of

test results was made using this printout. The data could also be used to review instrumentation performance for that test and to identify defective instrumentation prior to the next test.

Facility Standby Conditions. Immediately following the test run, the loop technicians completed a posttest procedure to secure the test facility. The test data from the continuous data recorders was collected and placed into a test run information package along with the facility preparation and heatup procedures.

At this time, the facility could be either prepared for further testing or shutdown. For system shutdown, the primary loop was drained and filled with dry nitrogen at a positive pressure for corrosion protection. The auxiliary systems were depressurized and refilled. If additional testing was planned, a new set of loop preparation and heatup procedures was issued to the facility operators.

Test Validation

The requirements established for the control of the test parameters are listed in Table 2-3. The purpose of these requirements was to aid in obtaining test runs in which all of the test parameters were held at or near their reference value. These requirements were also used as guidelines for test acceptance or rejection. Each test was formally evaluated against the requirements of Table 2-4.

Generally, most of the test parameters were within their specified control band. The out-of-specification conditions that did occur were of short duration and/or minor character. A test was accepted as valid if it could be judged that the basic objective of the experiment was achieved.

Table 2-4
TEST CONTROL REQUIREMENTS

<u>Parameter</u>	<u>Control Band</u>
Initial condition ^(a)	
Vessel pressure (PT602A)	$\pm 10\%$ ^(b)
Water level	± 10 in. (0.25 m) ^(b)
During test	
Vessel pressure (PT602A)	$\pm 2\%$ ^(c)
Power (per SCR zone)	$\pm 1.5\%$ (within 1 second after initiation of power to bundle)

- a. Prior to initiation of test
- b. About demand values specified in test prospectus
- c. Variation from initial condition

Section 3

DATA REDUCTION

GENERAL

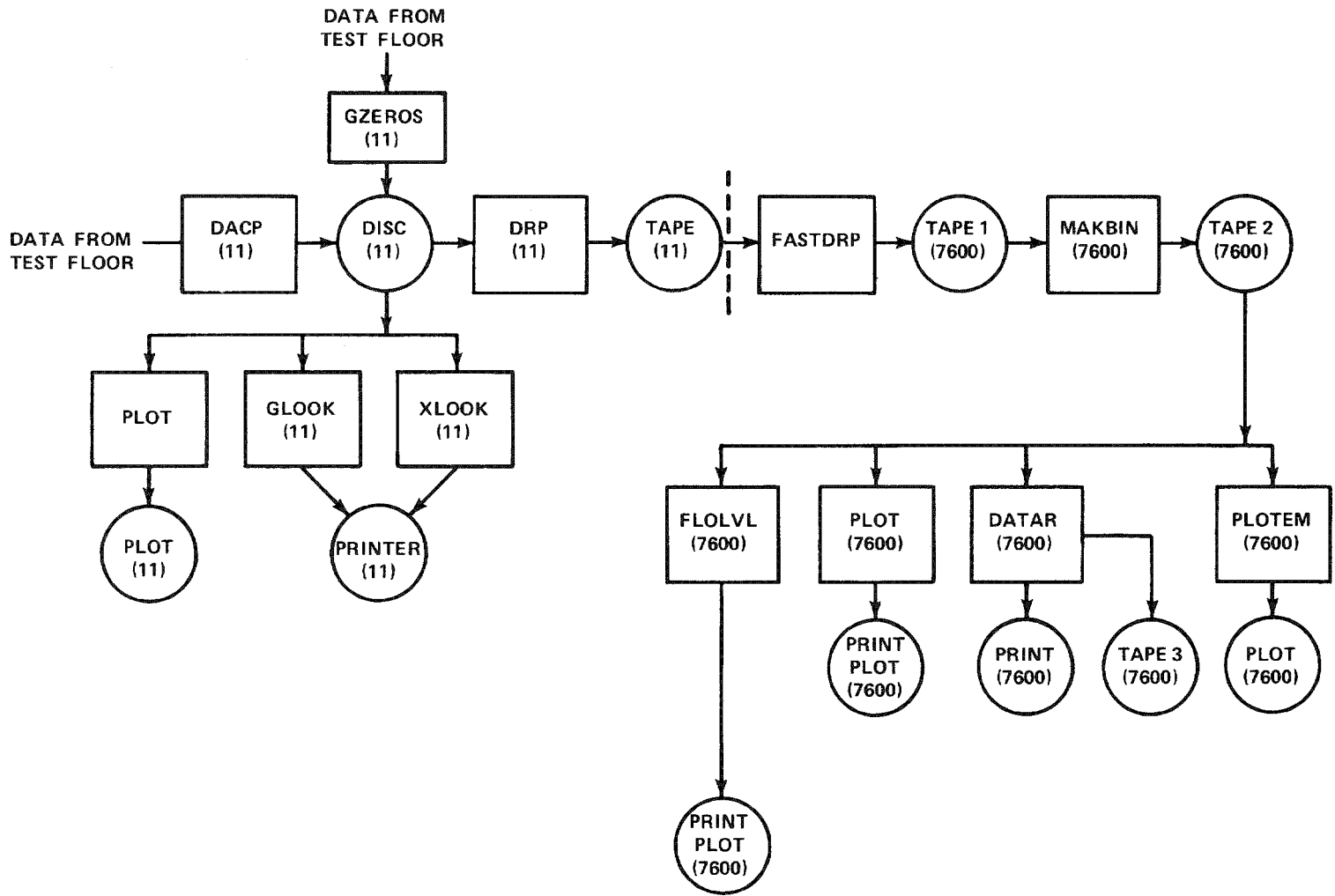
Experimental data acquired during a test were reduced to useful forms through a series of digital computer programs that provided for manual intervention at various points. Manual intervention was kept to a minimum, allowing the data flow to be as systematic as possible. Some of the final forms of reduced data are the graphs presented in Section 4 and Appendix F of this report, others were tables and graphs used in the analyses of the tests, and still others were magnetic tape records suitable for use with thermal-hydraulic and heat transfer calculations, with correlation programs, and for permanent storage.

AUTOMATED INFORMATION FLOW

The processing of the data proceeded from the location of the test facility in Forest Hills, Pennsylvania, to the Nuclear Center in Monroeville, Pennsylvania, where test planning and any subsequent analyses were performed. Two computers were involved in the data processing: a PDP-11 at Forest Hills and a CDC-7600 at Monroeville. The general flow and processing of data is shown in the schematic diagram of Figure 3-1. The following paragraphs describe the basic elements of the data reduction.

Calibration and Orifice Files (PDP-11)

A file of calibration constants for each instrument in the G-2 Loop (except for thermocouples) was kept on the PDP-11 magnetic disk storage for use in converting measured millivolt signals to engineering units such as psi. Since all of these instruments were nominally linear, this file contained three values for each instrument: a slope (engineering units per millivolt) and an offset (engineering units at a zero millivolt signal) that had been derived by least-squares fits from several manually measured calibration points, and a zero value, which was the millivolt reading obtained during calibration with zero engineering units (for instance, with zero pressure differential for a pressure cell). A similar file contained the diameter of each flow measurement orifice in the loop. These



3-2

Figure 3-1. Data Flow Diagram

files were modified to reflect replacement or recalibration of instruments or orifice replacement by keyboard entry on the PDP-11.

GZEROS (PDP-11) Program

The purpose of the GZEROS program was to record pretest zero readings for all loop instrumentation just prior to execution of a test. The program was run for as short a time as was practical before a test run and after as many as practical of the loop instruments had been set to a zero condition. To reduce the effects of system noise, the pretest zero reading of each transducer channel was taken as the mean of 100 rapid readings from that channel. This pretest or new zero reading was placed in the calibration file for later use in determining how much an instrument had drifted from its original calibration curve before the test run and to correct the pressure transducers for any H₂O legs in the individual instrument installation arrangements.

DACP (PDP-11) Program

The Data Acquisition and Control Program (DACP) was the program run during the actual test. Its purpose was to acquire and store test data, and to control several functions during both the pretest bundle and flow baffle heatup and the test. DACP stored data from all channels at intervals of 0.5 second or longer, starting at the beginning of the test (zero time), and continuing for up to 720 time points. The data were stored on the computer's disk memory.

DRP (PDP-11) Program

The Data Reduction Program (DRP) was run after a test. The purpose of the program was to operate on the raw data stored on disk, arrange it into a suitable format, and write it onto a nine-track magnetic tape for use by the CDC-7600. Also written to the magnetic tape were the orifice file and the calibration file with new zero data.

GLOOK and PLOT (PDP-11) Programs

These programs read the raw test data stored on the computer disk memory, converted it to engineering units, and displayed it on the PDP-11 line printer or the Tektronix 4010 graphic display terminal (which had hard-copy capability).

FASTDRP (CDC-7600) Program

This program utilized the system record manager available under the CDC SCOPE 2 operating system to read the nine-track tape and load it on the CDC Permanent

File Manager (PFM) system. The program converted the coded data to millivolts, and thermocouple millivolt data to temperatures. A list of known defective channels was also input to FASTDRP. This list, supplemented by other thermocouple channel numbers determined to be bad by the program, became a part of the subsequent data tape. The data were stored on magnetic tape in UPDATE format for further access within the CDC-7600 system.

MAKBIN (CDC-7600) Program

This program converted the UPDATE format of the data output from FASTDRP to a binary record format. Also, the millivolt signals of all data acquisition channels that were not connected to thermocouples (pressure cells, levels transducers, and the like) were converted to engineering units. The resulting binary tape from MAKBIN provided a more efficient form for multiple accessing of the data by succeeding data reduction programs. Each binary data file contained the data of up to 10 tests.

PLOT (CDC-7600) Program

The PLOT code was used to generate plots of test data versus time for a given test run. Input to the program consisted of a list of desired groups of data acquisition channels to be plotted.

FLQLVL (CDC-7600) Programs

The FLQLVL program calculated the following parameters as functions of time:

- Flow rates and mass storage at various locations around the G-2 Loop
- A fluid mass balance on the G-2 Loop

All flow rates were calculated using the correlations for ASME sharp-edge orifices with flange taps. The correlations were taken from the sixth edition of Fluid Meters, published by the ASME. Orifice sizes used were taken from the orifice size record on the data tape. Upstream pipe diameters used were nominal inside diameters for the appropriate size and schedule of pipe. The data channels used in calculating flows of major interest are listed in Table 3-1.

Table 3-1

DATA CHANNELS USED BY FLOLVL
FOR CORE UNCOVERY TEST FLOW CALCULATIONS

<u>Flow Calculated</u>	<u>ΔP Channel</u>	<u>Pressure Channel</u>	<u>Temperature Channel</u>	<u>Alternate Pressure Channel(a)</u>
FM-2A (steam flow exiting separator 2)	591	558	556	533

- a. There were two pressure transducers on flowmeter FM-2A: a high-range transducer [channel 558, 0-1500 psig (0.10-10.44 MPa)] and a low-range transducer [channel 533, 0-300 psig (0.10-2.17 MPa)]. Data from the high-range transducer were used in flow calculations when the measured pressure was in excess of 200 psia (1.38 MPa); data from the low-range transducer were used when the measured pressure was less than 200 psia (1.38 MPa).

All mass storages in the test vessel and separator 2 (see Figure 2-1) were calculated using ΔP level transmitters installed to measure liquid level in the storage volumes of the loop. The storage volumes were calibrated for cross-sectional area versus elevation. The data channels used to determine mass storage values as a function of time are given in Table 3-2.

The mass balance determination was made by comparing the initial system mass and the total mass stored in the system plus the mass of steam leaving the system at each time. The following equations represent the mass of interest:

- Integrated steam outlet mass (FM2FLO)

$$FM2FLO|_t = \int_{t=0}^{t=t} W_{FM2A} dt \quad (3-1)$$

- Mass stored at time t:

-- In test section

$$TSM|_t = \Delta P_{535} \times \text{bundle flow area} \quad (3-2)$$

Table 3-2

DATA CHANNELS USED BY FLOLVL
FOR CORE UNCOVERY TEST
MASS STORAGE CALCULATIONS

<u>Mass Storage Calculated</u>	<u>ΔP-Level Transmitter Channel</u>	<u>Pressure Channel (high/low)^(a)</u>	<u>Temperature Channel</u>
Test section mass (TSM)	535	559/602	539
Baffle cavity mass (BAFMAS)	635	559/602	T _{sat} at P559/P602 ^(b)
Separator 2 mass (SP2M)	566	558/333	544

- a. The term high/low indicates that a high-range pressure transducer (such as 559) and a low-range pressure transducer (such as 602) were available for density calculation. Data from the sensor that was most accurate at the pressure level being tested were used in the calculations.
- b. There were no fluid temperature monitoring thermocouples within the baffle cavity region; thus, a temperature equal to the saturation temperature within the test vessel was assumed for baffle cavity mass calculations.

-- In baffle cavity

$$\text{BAFMAS}|_t = \frac{\Delta P_{635} \times \text{baffle cavity}}{\text{cross-section area}} \quad (3-3)$$

-- In separator 2

$$\text{SP2M}|_t = \frac{\Delta P_{566} \times \text{separator 2}}{\text{cross-section area}} \quad (3-4)$$

where

W = flow rate (lb/sec)
 ΔP_{xxx} = level transmitter reading (lb/in²)
t = time after initiation of power to bundle

The initial system mass was calculated as

$$\text{SYSINM} = \text{TSM}|_{t=0} + \text{BAFMAS}|_{t=0} + \text{SP2M}|_{t=0} \quad (3-5)$$

The mass defect at time t was then calculated as

$$\text{MSDFT (lb)}|_t = \text{SYSINM} - \text{FM2FLO}|_t - \text{TSM}|_t - \text{BAFMAS}|_t - \text{SP2M}|_t \quad (3-6)$$

The results of the mass balance as calculated above showed the mass defect to be generally less than 5 percent of the total initial mass at any time during test duration.

In addition to calculating values for the parameters identified above, FLOLVL also plotted those values as a function of time. Typical plots generated by FLOLVL are presented in Section 4.

DATAR (CDC-7600) Program

The DATAR program used heater rod thermocouple data and bundle zone power histories from the binary data tape (generated by the MAKBIN program) with a built-in model of the heater rod to calculate heat flux at and temperature on the clad outer surface at each thermocouple location. With this information and using the appropriate sink temperature, the program then calculated heat transfer coefficients at each thermocouple location as a function of time. The results were both tabulated and written to magnetic tape for subsequent use. The DATAR program used for G-2 Loop was essentially the same as that used in FLECHT-SET data reduction (4).

The finite difference method employed for the heat transfer calculation was a modified form of the method originally proposed by Beck (5). In this method, the criterion for calculation of surface heat flux for a given time is a least-squares

fit to the measured temperatures at that time and at the next two sample times. During sharp transient changes, the matching at future times is waived. Before the heat transfer calculation, the recorded temperatures are smoothed to eliminate the effect of spurious single-time deviations by more than 5⁰F (3⁰C) from the average of the previous and the next future temperatures equal to that average. The value of 5⁰F (3⁰C) was chosen because it was slightly greater than the 3-bit accuracy of about 3⁰F (2⁰C) of the data acquisition system.

A more detailed description of the DATAR code is presented in Appendix G.

PLOTR (CDC-7600) Program

The PLOTR program plotted heat transfer coefficients, temperatures, or heat flux versus time for selected channels directly from the tape files produced by the DATARH program.

PLOTEM (CDC-7600) Program

The PLOTEM program was used to plot test results from more than one test as read from the binary data tape files (generated by the MAKBIN program) on the same graph as a function of time. Typical plots generated by PLOTEM are given in Section 4.

INVALID ROD THERMOCOUPLE TREATMENT

During the course of these tests and prior testing, some of the 492 heater rod thermocouples became inoperative. The process of eliminating bad thermocouple data from subsequent data reduction and presentation consisted of four steps:

- Elimination of nonrepresentative thermocouple locations
- Review of data taken at near-isothermal conditions before each test and disabling of false-reading channels
- Automatic elimination of unvarying temperature histories
- Review of pretest initial temperature readings as a check on inadvertent wiring changes to the data channels

These four steps, which provided the basis for the development of the bad channel list carried on the data tapes generated by FASTDRP and MAKBIN, are described in more detail in subsequent paragraphs.

Nonrepresentative Thermocouple Locations

Nonrepresentative locations included thermocouples on unpowered rods, thermocouples mislocated axially, and in some cases thermocouples on rods adjacent to the baffle.

Pretest Data Check

Before applying power to the heater rods for each test, when the rod bundle was at near-isothermal conditions, the voltage of each rod thermocouple was scanned and printed out by the PDP-11 computer. This printout was manually checked, and any channel reading which was unreasonably different from the others was noted. For each such channel, accessible electrical connections were checked and, if the reading remained out of line, the channel was permanently electrically shorted at the analog input to the data acquisition system such that the analog output signal was a constant zero millivolt reading. The channel number was added to a cumulative list of such channels and the current list of bad channels was sent with the test data tape to Monroeville. This list was written on the UPDATE data tape generated by FASTDRP.

Automatic Screening by FASTDRP

The FASTDRP program for data conversion contained six tests for all data channels; passing any one of them would cause the complete record of a data channel for a given test run to be labeled as bad. They were as follows:

- If the out-of-range indicator had been set by the program DRP (PDP-11)
- If the indicated temperature was ever equal to zero or greater than 2382°F (1306°C)
- If the indicated temperature ever increased by more than 200°F (111°C) in one time step
- If temperatures at all times were equal to 150°F (66°C) (short circuit value)
- If all reading were equal to +50 mV (for nonthermocouple channels)
- If the channel was one of an input list of known bad channels

Misconnected Channels

A review of data from tests prior to run 715, the first core uncover test, revealed that two data channels had apparently been connected to incorrect thermocouple leads. These channels were treated as failed and added to the list of known bad channels.

PERMANENT DATA STORAGE

Provisions were made for immediate and later referral of the test data using two forms:

- Magnetic tape files
- Microfiche

The availability and accessibility of these forms is discussed below.

Magnetic Tape Files

Magnetic tape files were cataloged through the Westinghouse Power Systems Computer Center located at Monroeville. The tapes were created to be read directly under the CDC-7600 SCOPE 2.0 operating system. The tape files generated by the data acquisition and data reduction programs include the following:

- Basic data tape in UPDATE form for each test run, from program FASTDRP; permanent file name FSXXXG2, where XXX is the run number. This formed the basic data tape for permanent storage.
- Binary data tape for each test run, 10 runs per tape, from program MAKBIN; permanent file name FSG2XXXTOYYYBINARY, where YYY is a run number exactly divisible by 10 and XXX = YYY-9. This file was used for day-to-day processing.
- DATAR program output tape for each run; permanent file name G2XXX DATAR OUTPUT, where XXX is the run number. This tape file was permanently stored.

Microfilm

The output of the various data reduction programs, both printed and graphic, was stored in microfiche form. Two files were maintained in parallel, one for permanent storage and one for day-to-day use. The permanent microfiche file contained the following for each test run:

- Catalog output - This record contained, in printed tabular form, the same information contained in output by programs FASTDRP and MAKBIN, including the calibration file, temperature histories for thermocouple channels, and histories for other channel outputs in both millivolts and engineering units.
- PLOTEM program output - This record contained graphs of selected channels versus time, including pertinent fluid temperatures, pressures, and differential pressures in the bundle and the loop.
- DATAR program output - This record contained, for each valid rod thermocouple, the measured temperature and calculated surface temperature, heat flux, and heat transfer coefficient based on an appropriate heat sink temperature tabulated versus time.

Section 4

CORE UNCOVERY TEST DATA

GENERAL

Within this section are presented typical data from a core uncovery test performed using the G-2 Loop facility. More complete data packages for each of the 22 core uncovery tests are presented in Appendix F.

The data presented in this report fall into two categories: measured or primary data, and calculated or secondary data. The measured or primary data reported are as follows:

- Heater rod internal temperatures
- Bundle steam probe temperatures
- Test vessel pressure
- Bundle, baffle, and test vessel pressure differences
- Bundle power

The following calculated or secondary data are reported:

- Exhaust line steam mass flow
- Coolant mass in test section
- Coolant mass in separator 2 (exhaust line separator)
- Bundle mixture level
- Heater rod heat flux

All data, measured or calculated, are presented in graphic form as a function of test time.

SAMPLE DATA

Typical data from run 718 were arbitrarily selected for presentation in this section. Run 718 was a high-pressure high-power test (see Table 2-2) that was terminated 272

seconds after initiation of testing when the maximum heater rod temperature limit was exceeded.

Heater Rod Internal Temperatures

Heater rod internal temperatures were recorded at 12 elevations within the bundle, as follows: 12.3, 28.7, 36.9, 45.1, 54.7, 69.7, 82.0, 94.3, 110.7, 118.9, 135.4, and 147.6 in. (0.31, 0.73, 0.94, 1.15, 1.39, 1.77, 2.08, 2.40, 2.81, 3.02, 3.44, and 3.75 m). To allow for both compact presentation of data and a visual evaluation of the uniformity of the heat transfer process in a plane, temperature histories of eight thermocouples located at the same elevation were plotted on a single graph. Typical plots for the uppermost seven planes of instrumentation starting at the 147.6 in. (3.75 m) elevation and decreasing to the 69.7 in. (1.77 m) elevation are presented in Figures 4-1 through 4-7. The data presented in these figures indicate the following:

- The core uncover process generally occurred uniformly in a horizontal plane.
- The test was terminated before the 69.7 in. (1.77 m) elevation was uncovered.

To provide for a visual evaluation of the heat transfer process in the axial direction, temperature histories of seven thermocouples, one located at each of the seven elevations identified in the previous paragraph, are plotted on the same graph (Figure 4-8). These data indicate the following:

- The peak heater rod temperatures occurred at the 118.9 in. (3.02 m) elevation.
- About 85 seconds were required to uncover 12 in. (0.30 m) of core length [94.3 to 82.0 in. (2.40 to 2.08 m)].

Bundle Steam Probes

Steam probes were located at four locations within the bundle. The time-temperature histories of the four thermocouples are plotted on the same graph (Figure 4-9).

These data indicate that dry steam begins to occur as follows:

- At the 136.7 in. (3.47 m) elevation about 40 seconds after initiation of test
- At the 109.3 in. (2.78 m) elevation about 75 seconds after initiation of test
- At the 82.0 in. (2.08 m) elevation about 220 seconds after initiation of test.

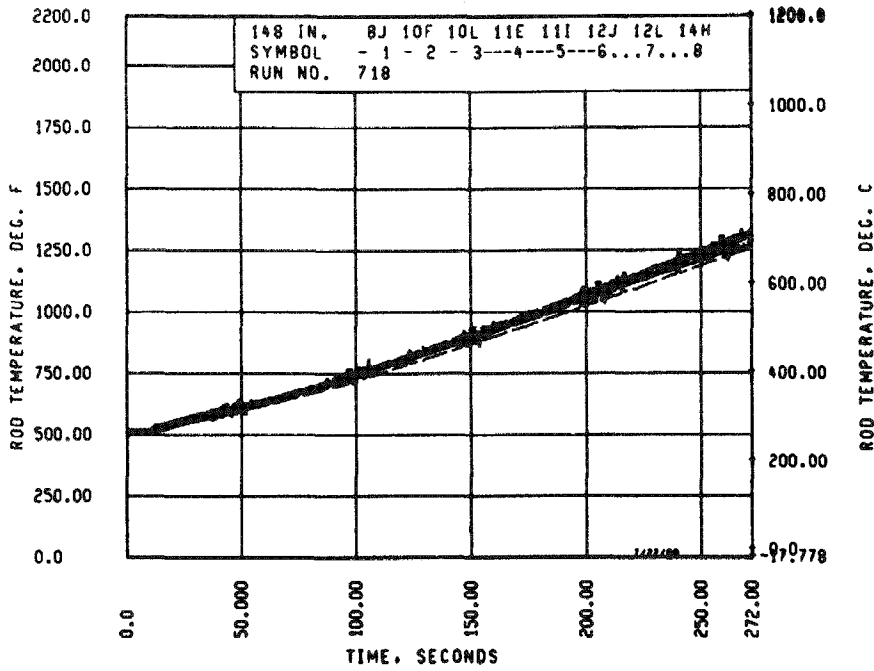


Figure 4-1. Typical Heater Rod Internal Temperatures, Test 718, 147.6 in. (3.75 m) Elevation

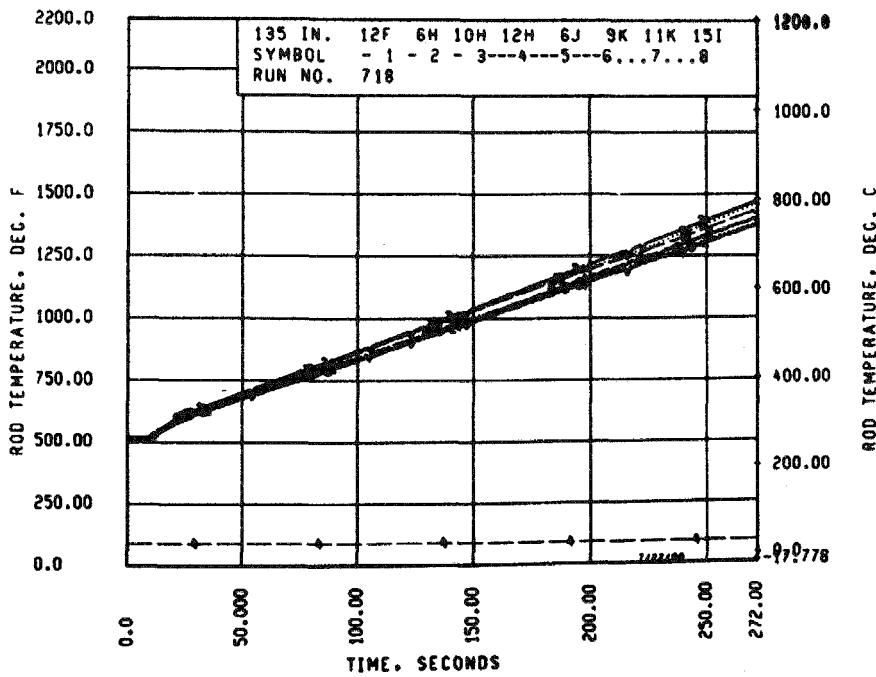


Figure 4-2. Typical Heater Rod Internal Temperatures, Test 718, 135.4 (3.44 m) Elevation

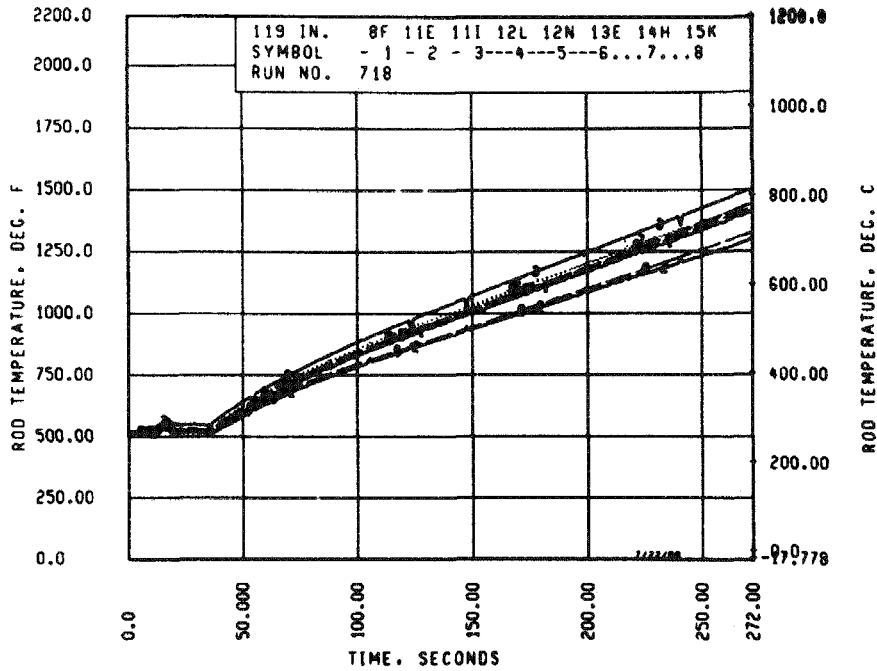


Figure 4-3. Typical Heater Rod Internal Temperatures, Test 718, 118.9 in. (3.02 m) Elevation

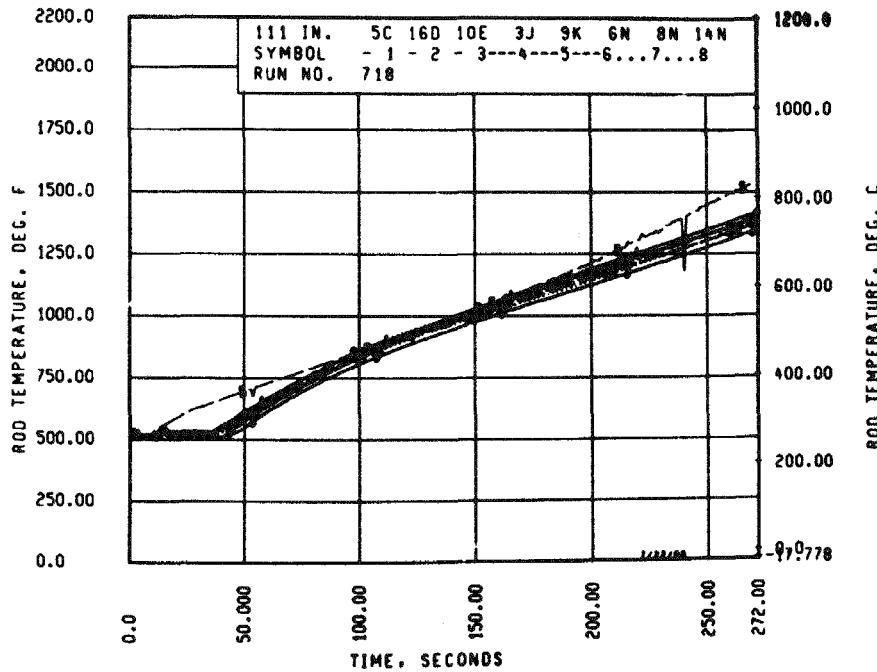


Figure 4-4. Typical Heater Rod Internal Temperatures, Test 718, 110.7 (2.81 m) Elevation

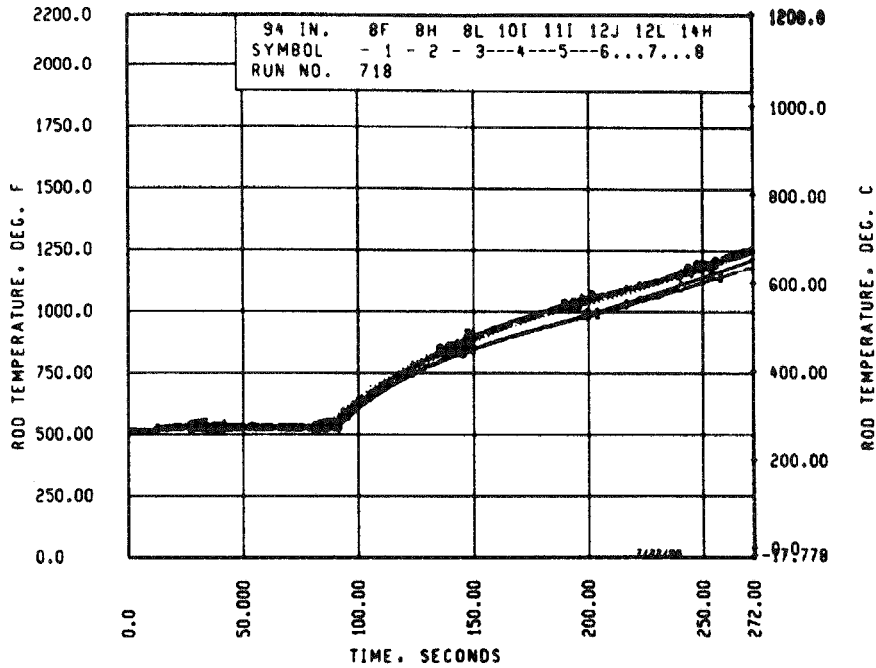


Figure 4-5. Typical Heater Rod Internal Temperatures, Test 718, 94.3 in. (2.40 m) Elevation

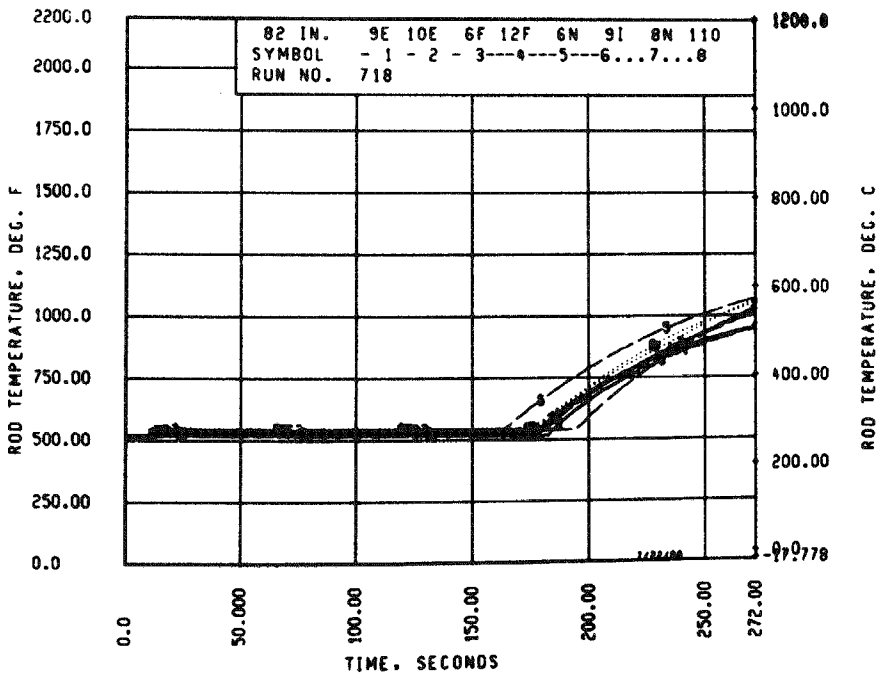


Figure 4-6. Typical Heater Rod Internal Temperatures, Test 718, 82.0 in. (2.08 m) Elevation

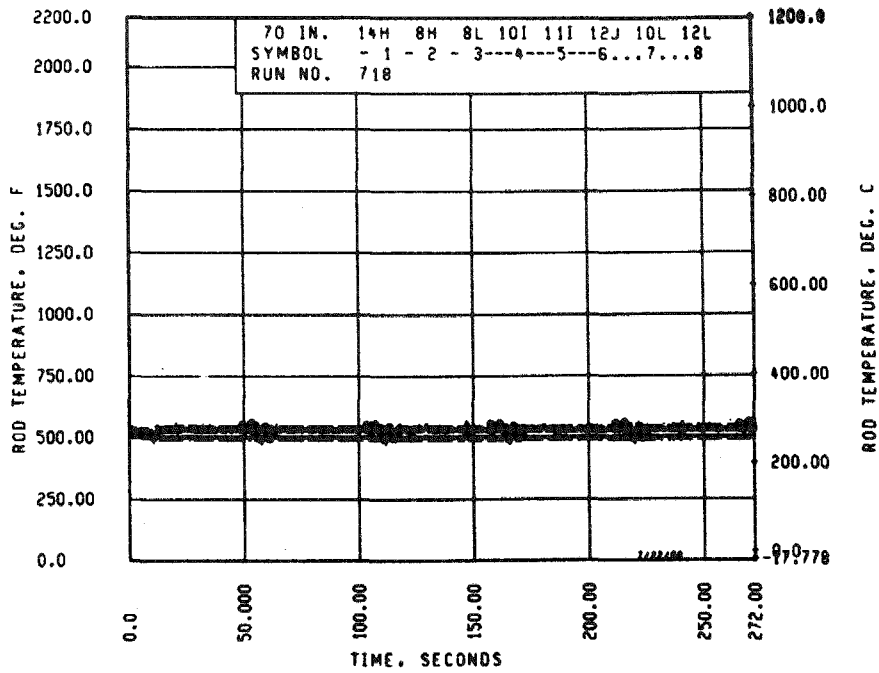


Figure 4-7. Typical Heater Rod Internal Temperatures, Test 718, 69.7 in. (1.77 m) Elevation

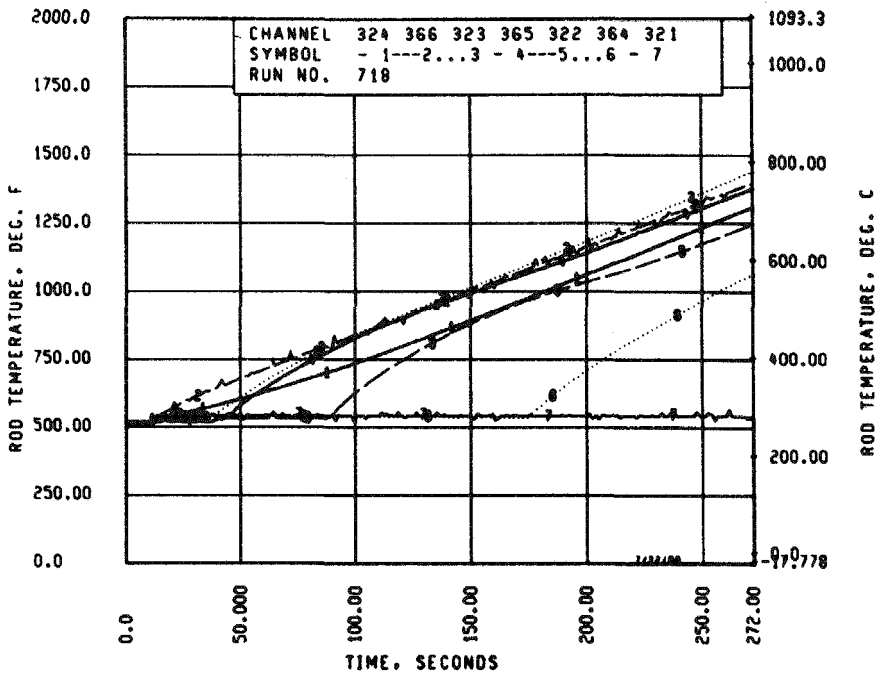
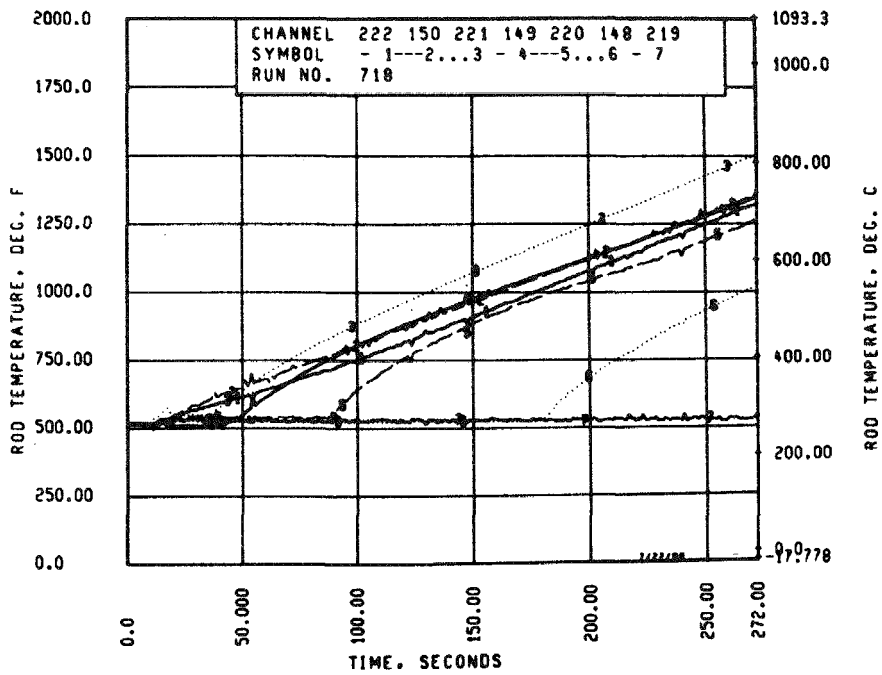


Figure 4-8. Heater Rod Internal Temperatures, Test 718, Selected Successive Axial Locations

Test Vessel Pressure

The test vessel pressure was monitored in the test vessel upper plenum. The time history of the test vessel pressure for run 718 is plotted in Figure 4-10. The data indicate that, except for a small variation during the first 30 seconds of test, the vessel pressure remained constant at 791 psia (5.45 MPa) during the test.

Bundle and Vessel Pressure Drop

Axial pressure drops occurring along the heated length of the test bundle were recorded by two sets of differential pressure (DP) transducers:

- A single instrument extending from -5.88 in. (-0.149 m) below the beginning of heated length to 164 in. (4.17 m) or the end of heated length of the bundle
- Six transducers, connected in series and each extending over about a 28 in. (0.71 m) elevation, covering the same total axial height as the single instrument previously identified

Because of the construction of the test vessel, the reference leg of the bundle DP transducers was located at -5.88 in. (-0.149 m) below the beginning of heated length. A schematic diagram showing the hookup of the DP transducers along the heated length, and the computer channels monitoring those transducers, is given in Figure 4-11.

A composite plot of the output from the six DP transducers located in series along the heated length (Figure 4-12) shows the reduction in water level in the bundle as a function of time. The outputs of those six transducers were summed and plotted with that from the transducer monitored by computer channel DP550 (Figure 4-13). For the purpose of identification, the summed DP transducer data have been assigned a computer channel number of 800. From Figure 4-13, the total pressure drop through the bundle as measured by the six DP cells in series is shown to be the same as that measured by the single, larger-range DP transducer.

The total pressure drop from the bottom of the lower plenum to the top of the upper plenum of the test vessel was measured by two instruments: a DP transducer and a level transducer (LT). A schematic diagram showing the hookup of the two transducers to the vessel and the computer channels assigned to monitor them is given in Figure 4-11. The outputs from the two transducers are plotted in Figure 4-14. The outputs from the two transducers are shown to vary by about 0.3 psi (2 kPa) throughout the test, thus indicating a constant error between the outputs of the two transducers.

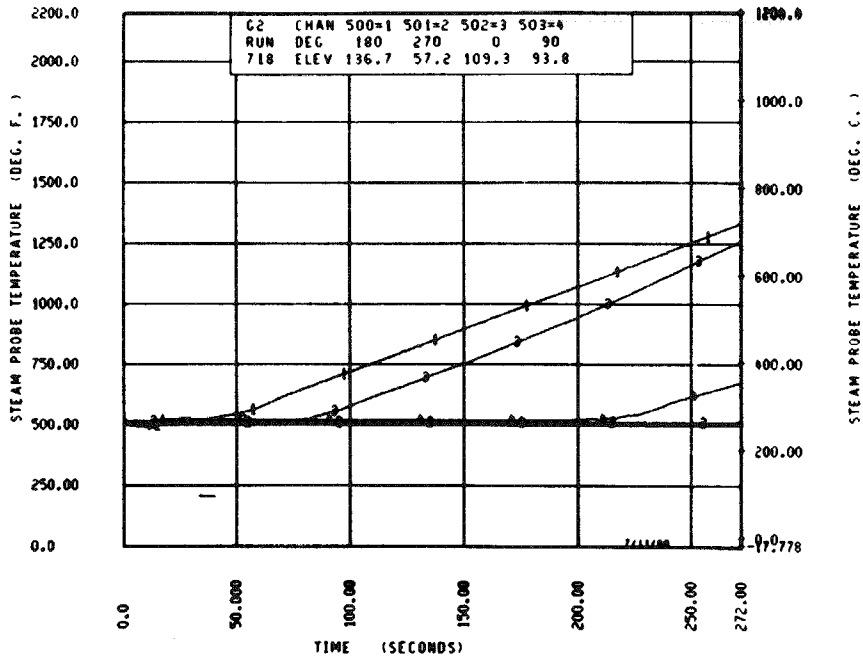


Figure 4-9. Bundle Steam Probe Temperatures, Test 718

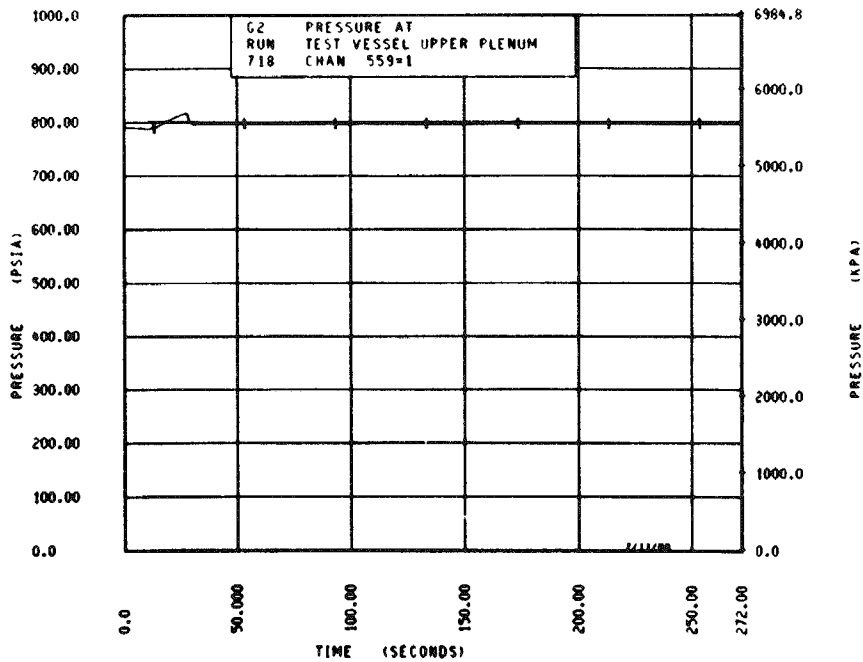
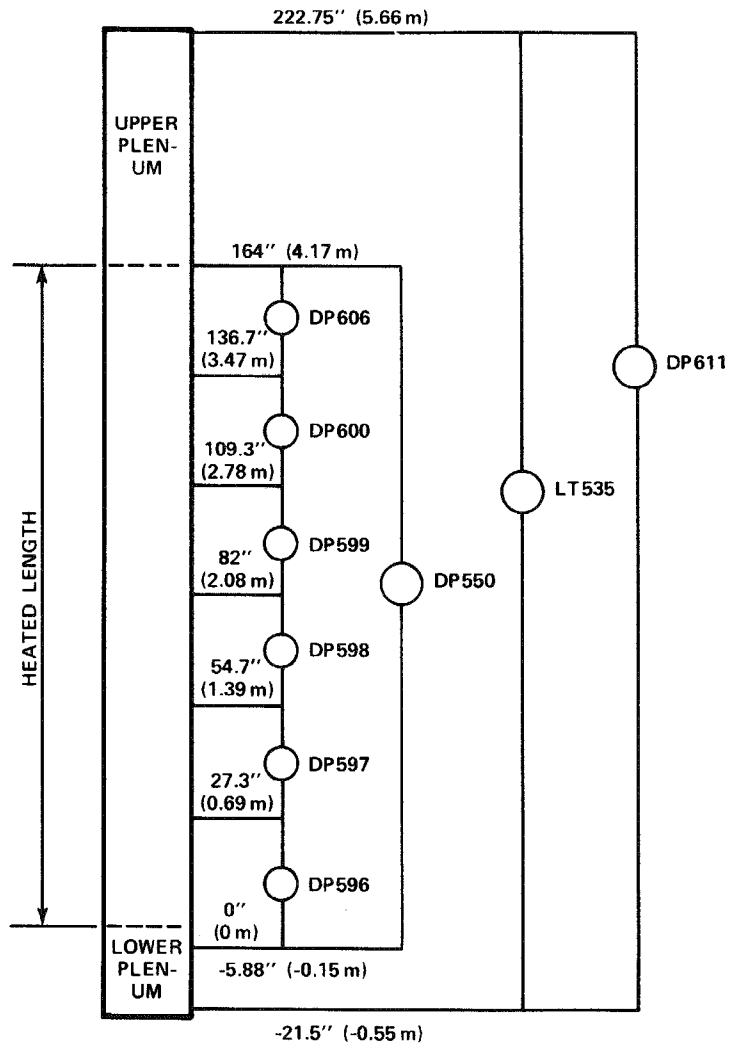


Figure 4-10. Test Vessel Pressure, Test 718

DP – DIFFERENTIAL PRESSURE
LT – LEVEL TRANSDUCER

COMPUTER CHANNEL	RANGE
DP596	± 1 PSID (0.11 MPa)
DP597	± 1 PSID (0.11 MPa)
DP598	+ 1 PSID (0.11 MPa)
DP599	± 1 PSID (0.11 MPa)
DP600	+ 1 PSID (0.11 MPa)
DP606	± 1 PSID (0.11 MPa)
DP550	± 10 PSID (0.17 MPa)
DP611	± 10 PSID (0.17 MPa)
LT535	0 - 244.3" (0 - 6.21 m)



NOTE: FICTITIOUS CHANNEL DP800 = DP596 + DP597 + DP598 + DP599 + DP600 + DP606

Figure 4-11. Schematic Diagram of Test Section, Showing Locations of DP Cells

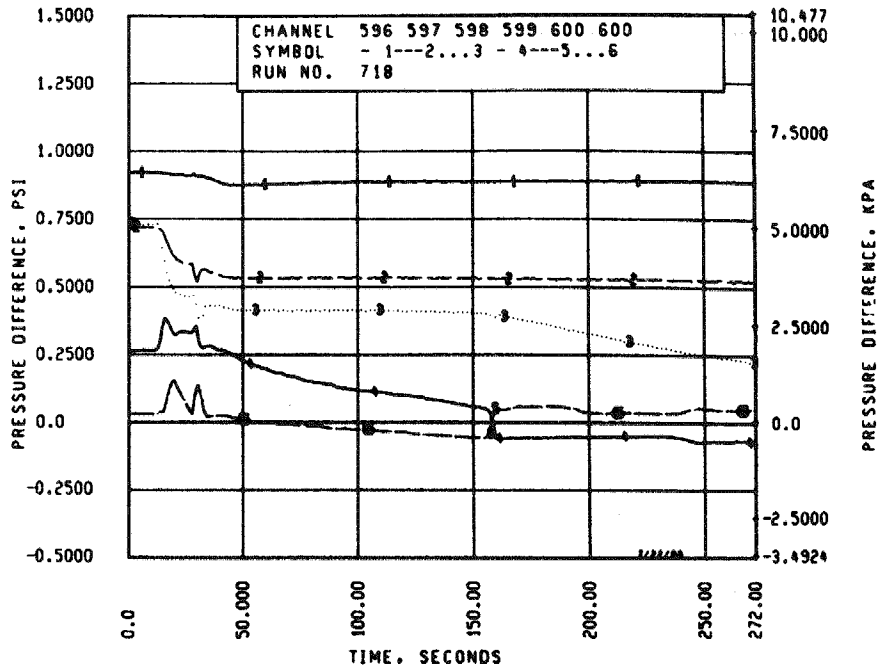


Figure 4-12. DP Cell Readings Along Heated Length, Test 718

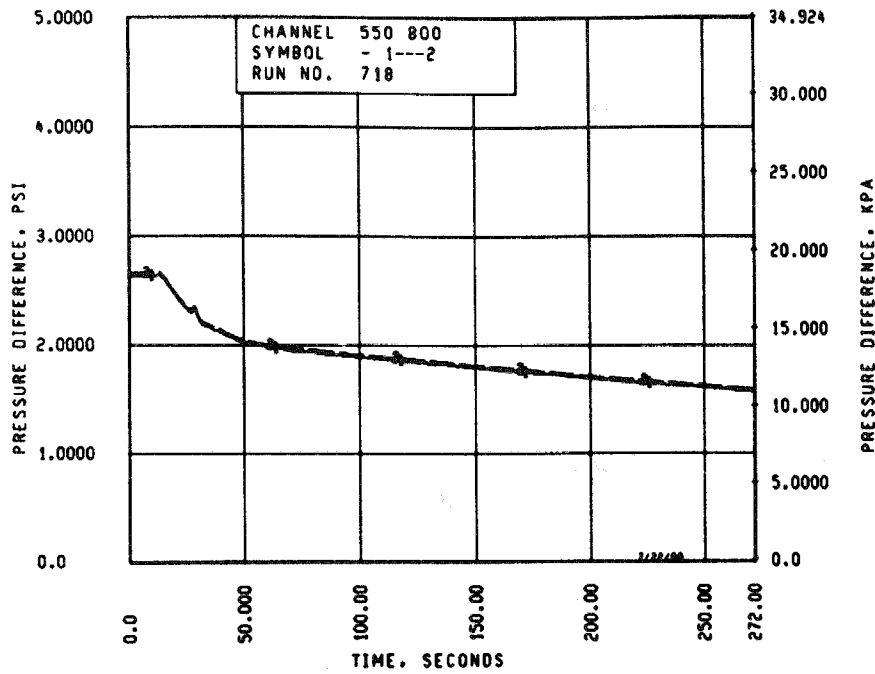


Figure 4-13. Comparison of Sum of DP Cell Readings Along Heated Length With Channel DP550 Reading, Test 718

The pressure drop across the flow baffle is plotted in Figure 4-15.

Bundle Power

Seven SCRs were used to power the bundle during a test. The output histories of the seven SCRs are plotted on a single graph (Figure 4-16). These data indicate the following:

- Power to the bundle was initiated at about 10 seconds after initiation of test.
- Initiation of power occurred at the same time for all seven SCRs.
- Once initiated, the power output of each SCR was constant for the duration of the test.

The summation of the seven SCRs' output is plotted in Figure 4-17. The data indicate that the total power to the bundle, after initiation of power, was slightly more than 1.25 MW.

Exhaust Line Steam Mass Flow

The facility exhaust line steam mass flow was calculated using the instrumentation associated with flowmeter FM-2. The flow rate history of FM-2 for run 718 is plotted in Figure 4-18. A momentary flow spike of about 4.5 lb/sec (2.0 kg/sec) was recorded at about 25 seconds after initiation of test (most likely due to application of power to the bundle). The flow decreased immediately to 1.1 lb/sec (0.50 kg/sec) and continued to decrease at a steady rate for the duration of the test. The total steam mass passing through the exhaust line was calculated by integrating, with respect to time, the data plotted in Figure 4-18. The total steam mass exhausted as a function of time is plotted in Figure 4-19.

Mass in Test Vessel

The mass storage histories for the test section and the test vessel (lower plenum, test section, and baffle cavity) for run 718 are plotted in Figures 4-20 and 4-21, respectively. The two curves indicate that, because of the core uncover process, the mass of water in the test section decreased by about 55 lb (25 kg) during the test, and the mass of water in the test section as a whole decreased by about 225 lb (102 kg) during the test.

Mass in Separator 2

The mass storage history of separator 2, the exhaust line steam-water separator, is given in Figure 4-22. These data indicate that about 4 lb (2 kg) of coolant were

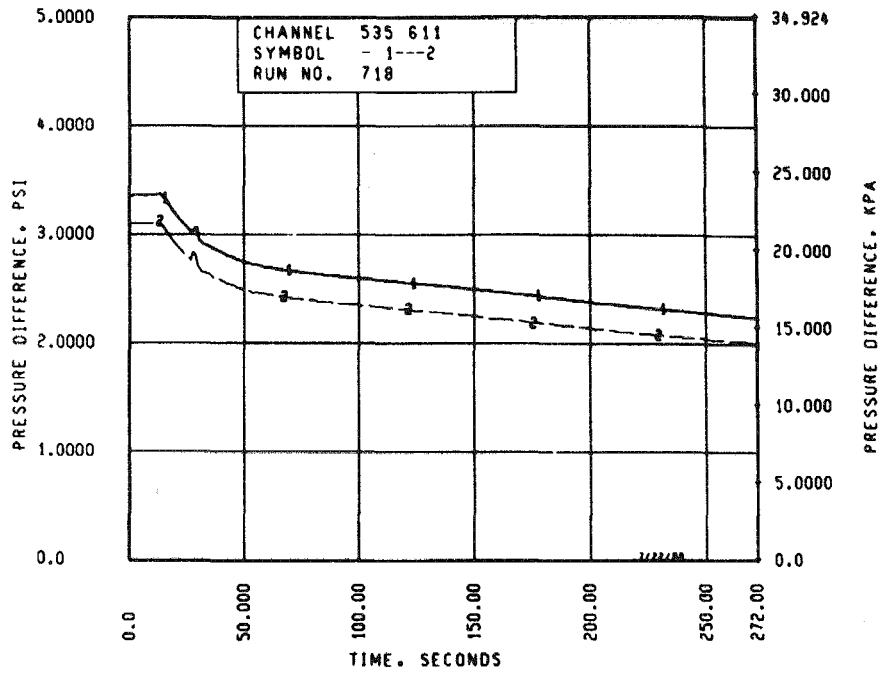


Figure 4-14. Comparison of Vessel Level Transducer and DP Cell Readings, Test 718

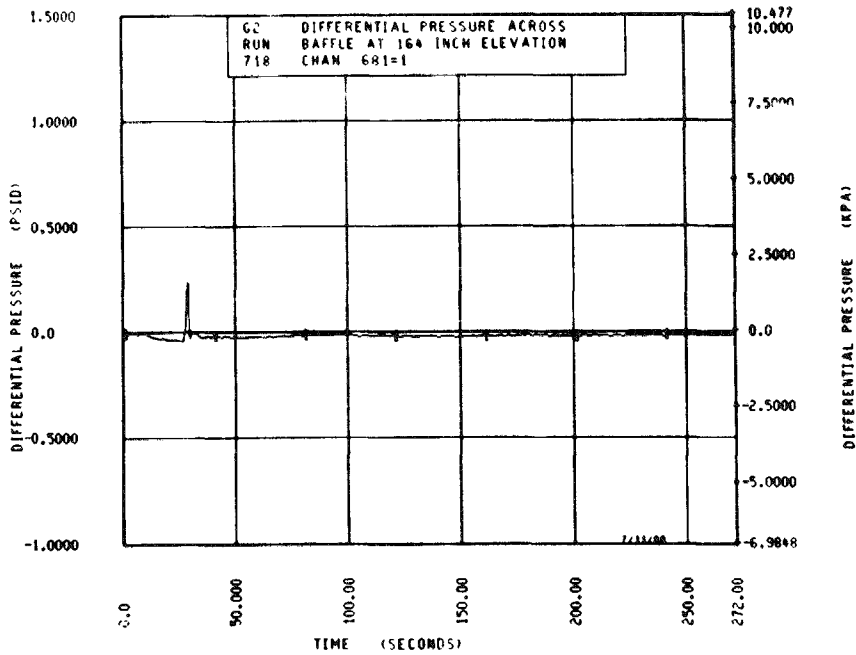


Figure 4-15. Pressure Drop Across Flow Baffle, Test 718

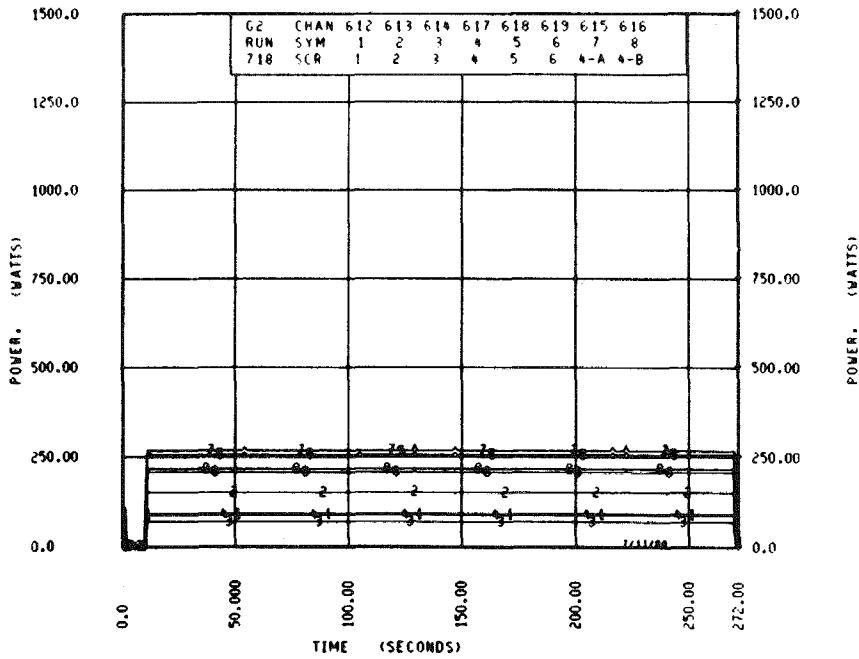


Figure 4-16. Individual SCR Output Histories, Test 718

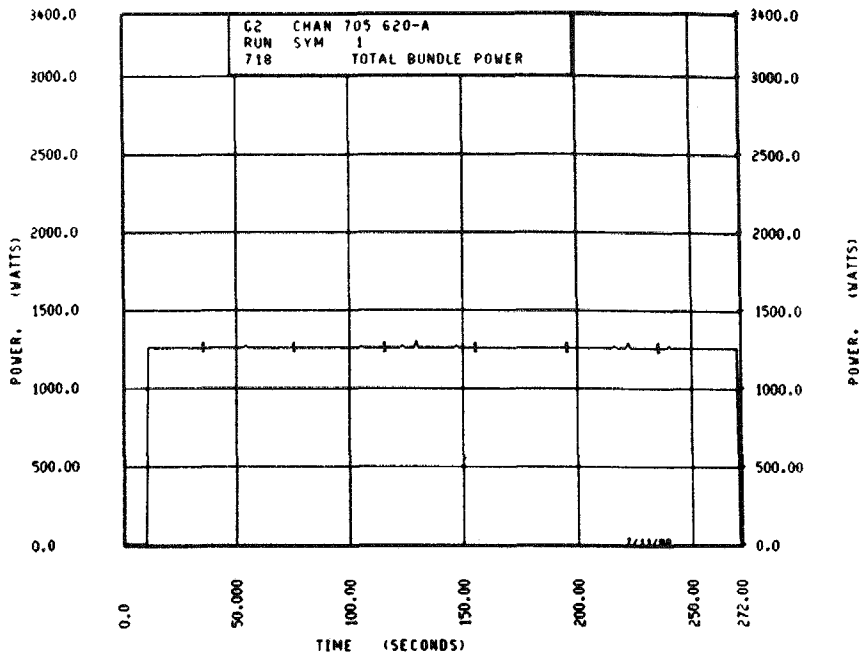


Figure 4-17. Summation of Individual SCR Output Histories, Test 718

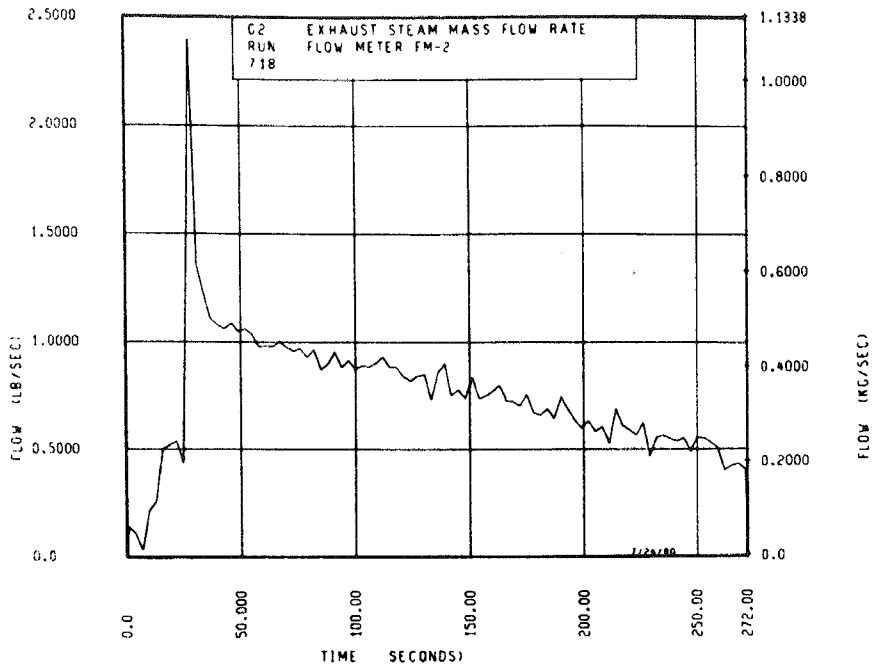


Figure 4-18. Exhaust Line Steam Mass Flow Rates, Test 718

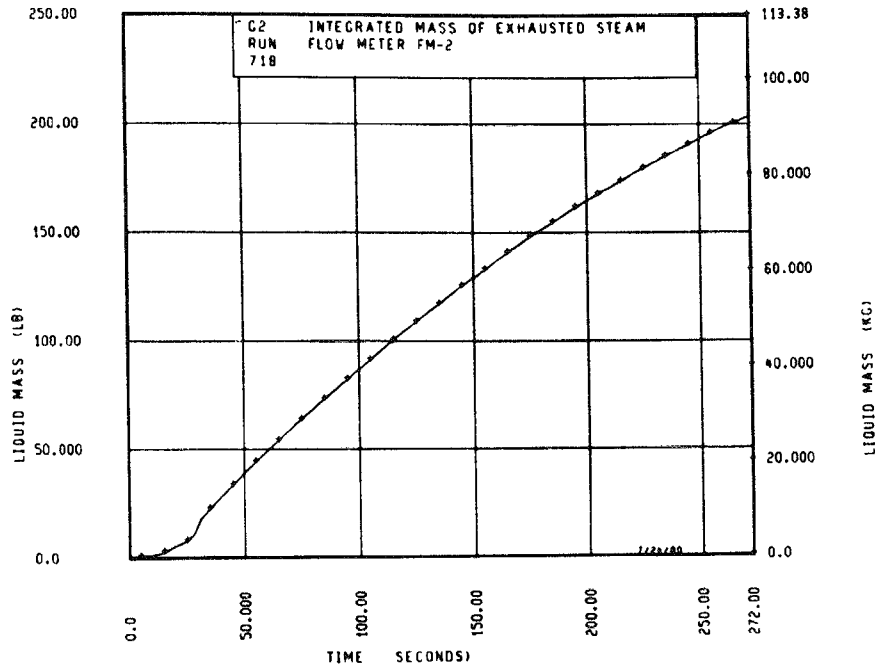


Figure 4-19. Integrated Exhaust Line Steam Mass, Test 718

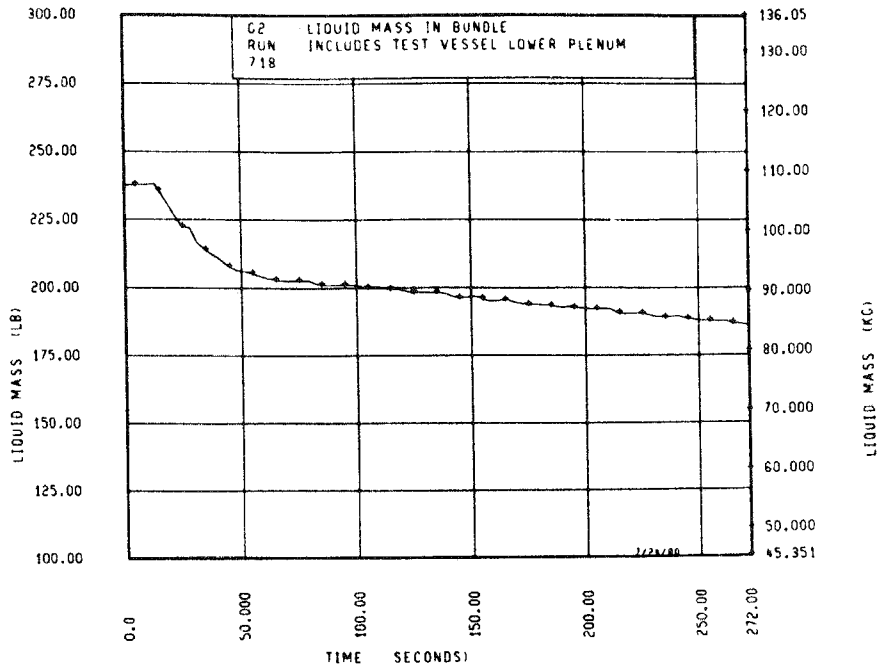


Figure 4-20. Mass Storage History of Bundle, Test 718

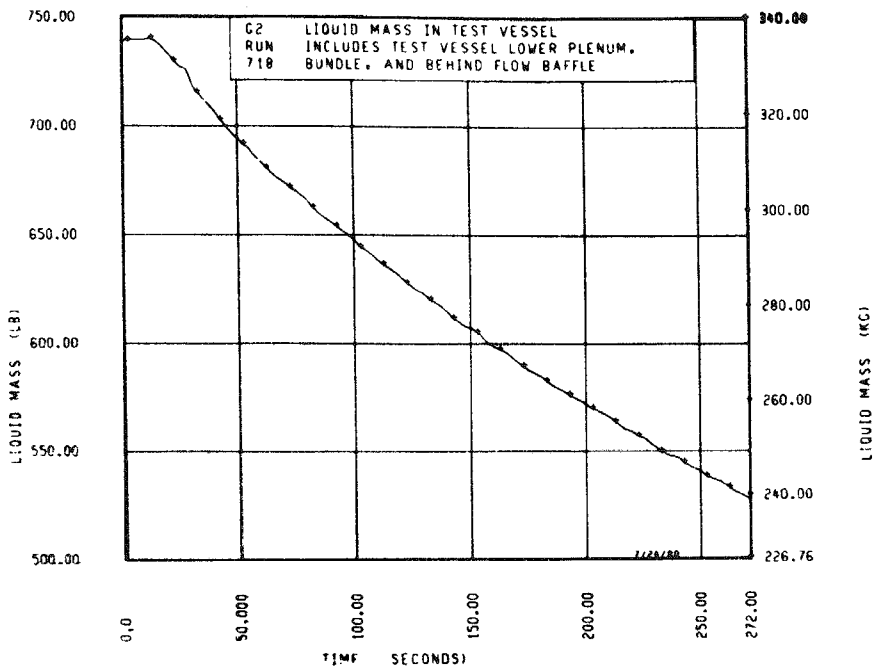


Figure 4-21. Mass Storage History of Test Vessel, Test 718

carried over from the test vessel in the first 40 seconds after initiation of power. During the final 200 seconds of test, the coolant mass in separator 2 increased by about 1 lb (0.5 kg). These data indicate that a short time after the initiation of power, there was very little water carryover from the test vessel into separator 2.

Bundle Mixture Level

The bundle mixture level was determined from heater rod thermocouple data by noting when the thermocouples at a given elevation within the bundle began to rise above the saturation temperature for that test. It was noted from the data of Figures 4-1 through 4-7 that the core uncover process occurred relatively uniformly in a horizontal plane. Using heater rod thermocouple plots similar to those of Figures 4-1 through 4-7 for all core uncover tests, the bundle mixture height as a function of time for each test was evaluated.

The calculated bundle mixture heights for the core uncover tests performed at 800 psia (5.52 MPa) are shown in Figure 4-23. As expected, the time required to uncover the bundle at a given elevation decreased with increasing power. Bundle mixture heights as a function of time for all 22 core uncover tests are given in Appendix F.

Heat Flux From Heater Rods

The DATAR computer program (2) used heater rod thermocouple data to calculate heat fluxes as a function of time for valid heater rod thermocouples. Typical time-history heat flux plots at the 147.6, 135.4, 118.9, 94.3, 82.0 and 69.7 in. (3.75, 3.44, 3.02, 2.40, 2.08 and 1.77 m) elevations for run 718 are presented in Figures 4-24 through 4-29. The heat flux data presented here are calculated from heater rods powered by SCR 1. There were no valid thermocouples at the 110.7 in. (2.81 m) elevation on any of the heater rods powered by SCR 1; this accounts for the absence of heat flux data at that elevation.

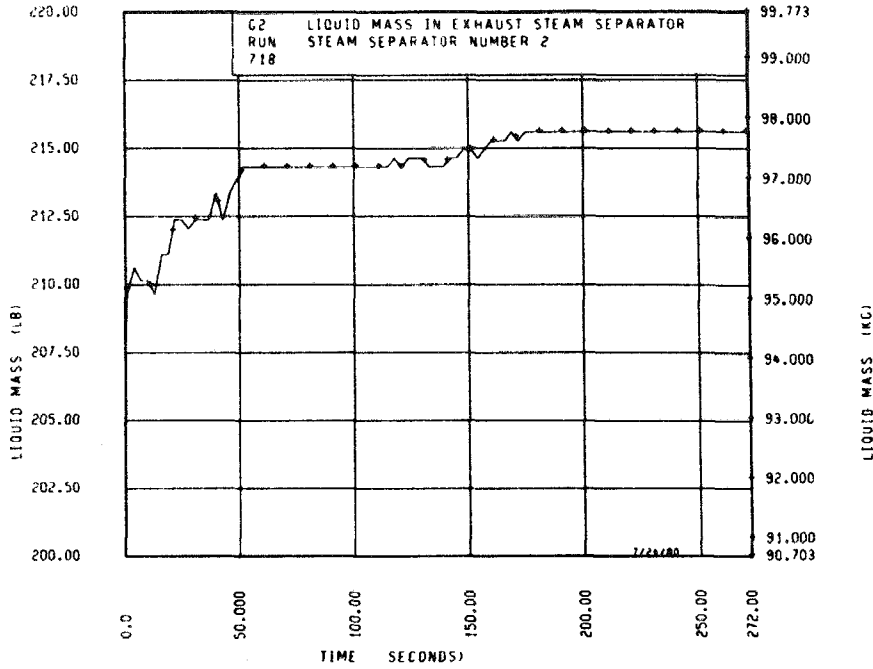


Figure 4-22. Mass Storage History of Separator 2, Test 718

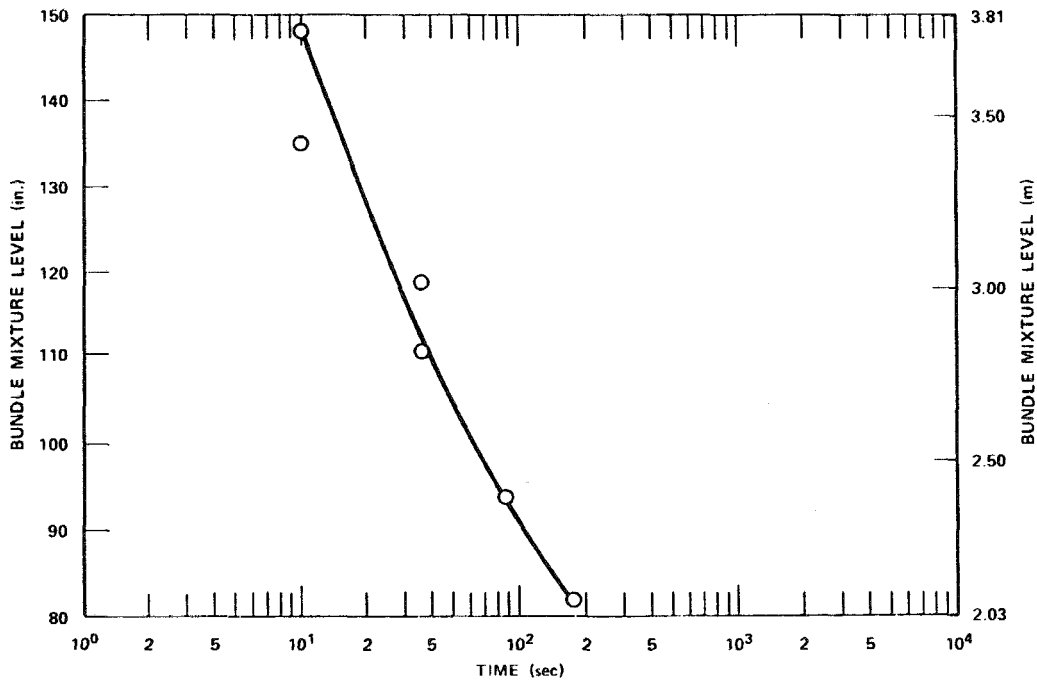


Figure 4-23. Bundle Mixture Level History, Test 718

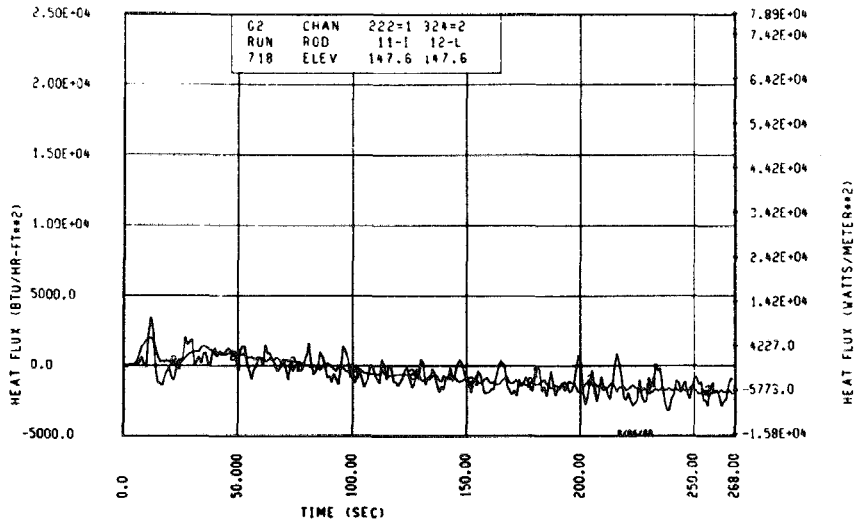


Figure 4-24. Typical Calculated Heater Rod Heat Flux History, Test 718, 147.6 in. (3.75 m) Elevation

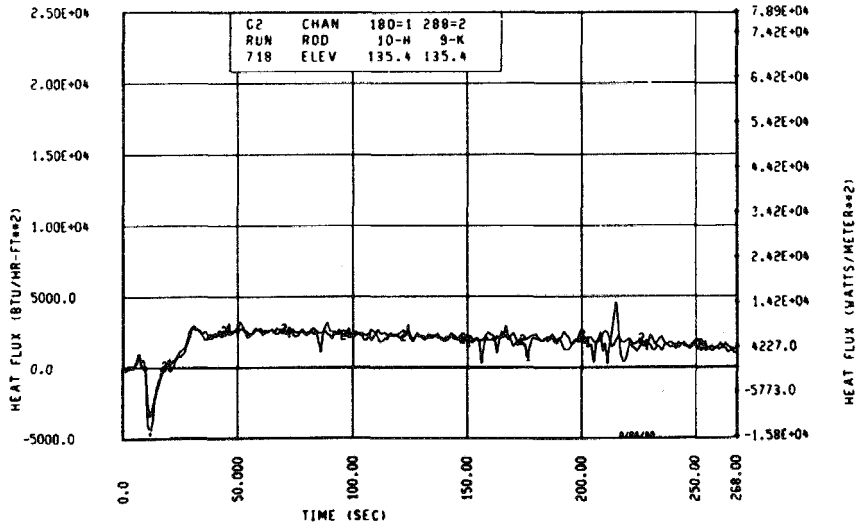


Figure 4-25. Typical Calculated Heater Rod Heat Flux History, Test 718, 135.4 in. (3.44 m) Elevation

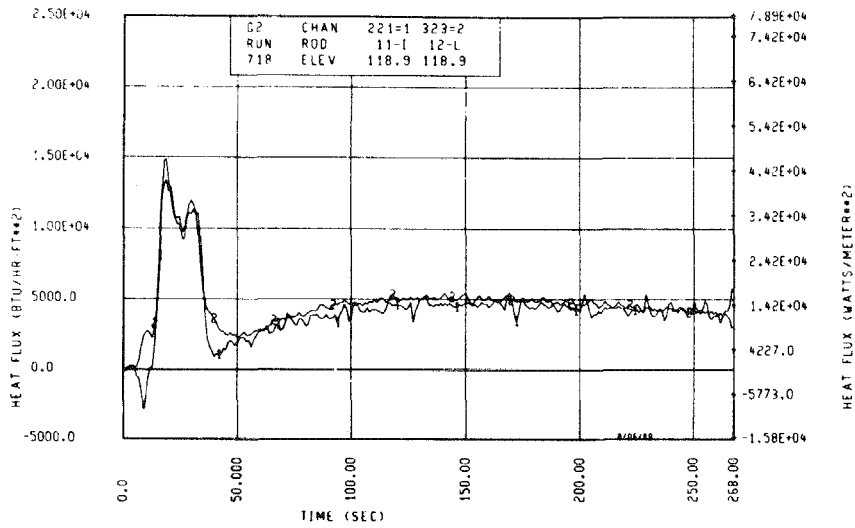


Figure 4-26. Typical Calculated Heater Rod Heat Flux History, Test 718, 118.9 in. (3.02 m) Elevation

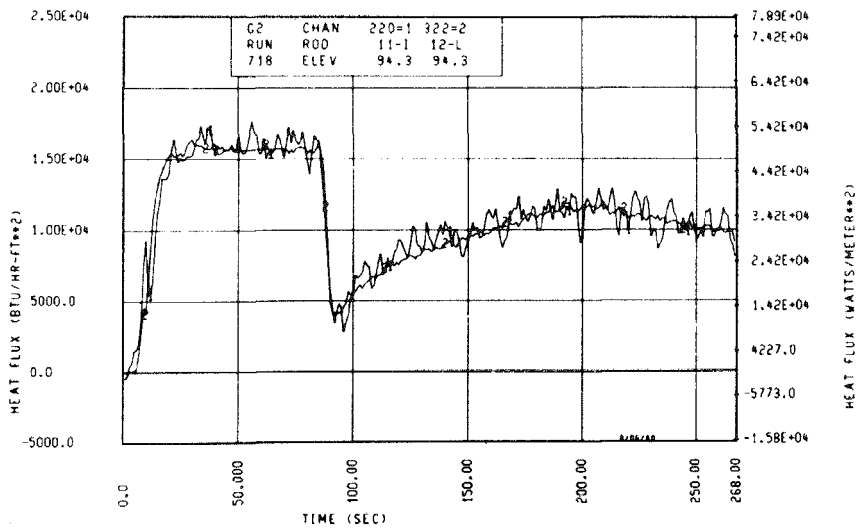


Figure 4-27. Typical Calculated Heater Rod Heat Flux History, Test 718, 94.3 in. (2.40 m) Elevation

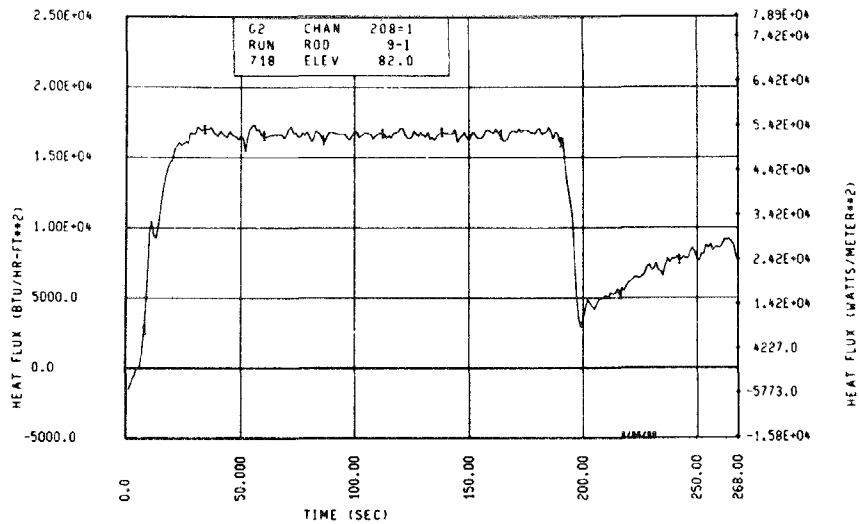


Figure 4-28. Typical Calculated Heater Rod Heat Flux History, Test 718, 82.0 in. (2.08 m) Elevation

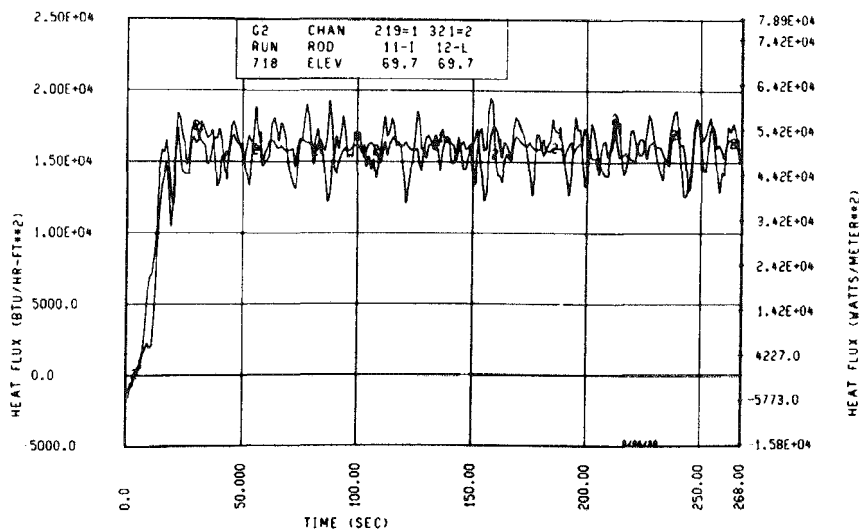


Figure 4-29. Typical Calculated Heater Rod Heat Flux History, Test 718, 69.7 in. (1.77 m) Elevation

Section 5

REFERENCES

1. Nuclear Safety Analysis Center. "Analysis of Three Mile Island - Unit 2 Accident." NSAC-1, July 1979.
2. K. H. Sun, R. B. Duffy, and C. M. Peng. "A Thermal-Hydraulic Analysis of Core Uncovery." Presented at the 1980 National Heat Transfer Conference, ASME, Orlando, Florida, July 29-31, 1980.
3. J. P. Cunningham and H. C. Yeh. "Experiments and Void Correlation for PWR Small Break LOCA Conditions." Trans. Am. Nucl. Soc. 17, p. 369 (1973).
4. J. P. Waring, E. R. Rosal, and L. E. Hochreiter. "PWR FLECHT-SET Phase B1 Data Report." WCAP-8431, Appendix A, December 1974.
5. J. V. Beck. "Nonlinear Estimation Applied to the Nonlinear Inverse Heat Conduction Problem." Int. J. Heat and Mass Transfer 13, pp. 703-716 (1970).

Appendix A
FACILITY RECORDS

Table A-1 traces the orifice diameters installed for every test in the G-2 Loop core uncover series at the various metering and flow impedance locations. FM-XX indicates a flowmeter, F-XX designates a flow impedance. The physical locations of these orifices are shown in the facility sketches in Section 2.

Figure A-1 schematically shows the SCR power unit assignment to each heater rod in the bundle.

Seven SCR power units were used to provide power to the G-2 Loop test bundle, designated as units 1, 2, 3, 4A, 4B, 5, and 6.

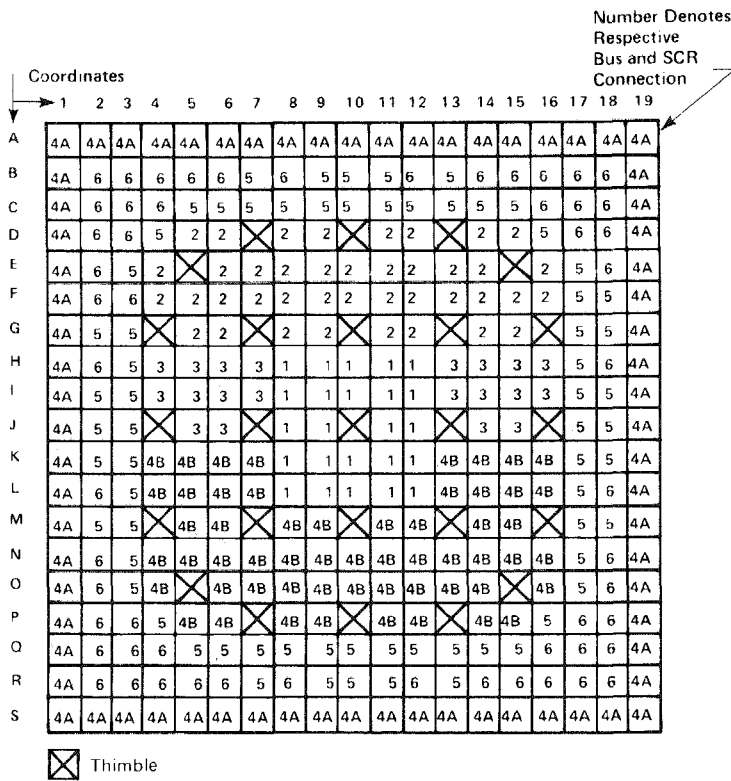


Figure A-1. SCR/Heater Rod Assignments

Table A-1
G-2 LOOP ORIFICES

<u>Orifice^(a)</u>	<u>Diameter</u> <u>[in. (cm)]</u>	<u>Pipe ID</u> <u>[in. (cm)]</u>	<u>Pipe</u>	<u>Run Numbers</u>
FM-2A	2.407 (6.114)	5.189 (13.18)	6 in. (15 cm) sch 160	All runs
FM-3 ^(b)	4.151 (10.54)	5.189 (13.18)	6 in. (15 cm) sch 160	All runs
FM-9A ^(c)	--	--	--	All runs
F-4A	5.189 (13.18)	5.189 (13.18)	6 in. (15 cm) sch 160	All runs
F-8A	5.189 (13.18)	5.189 (13.18)	6 in. (15 cm) sch 160	All runs

- a. The orifice locations are shown in the facility sketches in Section 2.
- b. FM-3 was not used during testing as it was not directly in the exhaust flow path.
- c. FM-9A was not used; all tests were run with V-18A closed.

Appendix B
INSTRUMENTATION

Table B-1 lists the G-2 Loop instrumentation. An asterisk identifies those instrument channels whose signals were recorded by the computer data acquisition system during the forced flooding tests. The table also identifies the installed pressure transducer or level transmitter range and the type of thermocouple material (Type K) used for the listed channel. The location of instrumentation on or within the test vessel is also given.

Table B-2 summarizes all pertinent information necessary to fully determine the location (column and row) and elevation of a thermocouple within the test bundle and the SCR power unit hookup to the rods. All temperature measurements within the bundle were recorded by the computer data acquisition system.

Table B-3 lists temperature instrumentation on the loop recorded on multipoint recorders. This temperature instrumentation and recording system was primarily used to establish system heatup to test conditions and record the system temperature status prior to initiation of the test. It was also used during test facility preparation for a subsequent test, or for securing the facility in a safe shutdown temperature condition after a test.

Table B-1

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

Channel	Type	Description	Elevation [in. (m)]	Azimuth (%)	Range or Material
496	PT	Pressure at top of downcomer			0-1500 psig (0.10-10.44 MPa)
497*(a)	TC	Separator 1 at bottom			K
498*	TC	Separator 1 1' (0.3 m) from bottom			K
499A	DP	Bottom of downcomer to vessel upper plenum			+50 psid (+0.34 MPa)
500A*	TC	Steam probe	136.7 (3.47)	270	K
501A*	TC	Steam probe	57.2 (1.45)	180	K
502A*	TC	Steam probe	82 (2.08)	90	K
503A*	TC	Steam probe	109.3 (2.78)	0	K
504A*	TC	Baffle outside flange surface	1 (0.03)	270	K
505A*	TC	Baffle outside flange surface	3 (0.08)	270	K
506A*	TC	Baffle outside flange surface	7 (0.18)	270	K
507A*	TC	Baffle outside surface type A	26 (0.66)	270	K
508A*	TC	Baffle outside surface type B	27.25 (0.69)	270	K
509A*	TC	Baffle outside surface type A	136 (3.45)	180	K
510A*	TC	Baffle outside surface type B	137.25 (3.49)	180	K
511A*	TC	Baffle outside surface type A	108.5 (2.76)	270	K
512A*	TC	Baffle outside surface type B	109.75 (2.79)	270	K
513A*	TC	Baffle outside surface type A	136 (3.45)	270	K
514A	TC	Unassigned thermocouple channel			K
515A*	TC	Baffle outside surface type A	26 (0.66)	0	K
516A*	TC	Baffle outside surface type B	27.25 (0.69)	0	K
517A*	TC	Baffle outside surface type A	26 (0.66)	90	K
518A*	TC	Baffle outside surface type B	27.25 (0.69)	90	K
519A*	TC	Baffle outside surface type A	81 (2.06)	90	K
520A*	TC	Baffle outside surface type B	82.25 (2.09)	90	K
521A*	TC	Baffle outside surface type A	81 (2.06)	180	K
522A*	TC	Baffle outside surface type B	82.25 (2.09)	180	K
523A*	TC	Baffle outside surface type A	108.5 (2.76)	90	K
524A*	TC	Baffle outside surface type B	109.75 (2.79)	90	K
525A*	TC	Baffle outside surface type A	136 (3.45)	90	K
526A*	TC	Baffle outside surface type B	137.25 (3.49)	90	K
527A*	TC	Baffle flange surface R=7.00" (18 cm)	82.25 (2.09)	315	K
528A*	TC	Baffle flange surface R=7.75" (20 cm)	82.25 (2.09)	315	K
529A*	TC	Baffle outside surface type A	81 (2.06)	270	K
530A*	TC	Baffle outside surface type C	81 (2.06)	270	K
531A*	TC	Baffle outside surface type B	82.25 (2.09)	270	K
532A*	TC	Baffle outside surface type D	82.25 (2.09)	270	K
533*	PT	Separator 2 pressure (on FM-2)			0-300 psig (0.10-2.17 MPa)
534	LT	In-line mixer accumulator level			+5.64 psid (+0.0389 MPa)

a. An asterisk indicates that channel signals were recorded by CDAS.

Table B-1 (cont)

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

Channel	Type	Description	Elevation [in. (m)]	Azimuth (%)	Range or Material
535A*	LT	Vessel level -21.5" to 222.75" (-0.55 to 5.66 m)			+8.83 psid (+0.0609 MPa)
536A*	TC	Upper plenum fluid temperature R=0.6" (1.5 cm)	200.5 (5.09)	270	K
537A*	TC	Upper plenum fluid temperature R=3.58" (9.09 cm)	200.5 (5.09)	0	K
538A*	TC	Hot leg wall at V-16 inlet			K
539A*	TC	Lower plenum fluid temperature R=7.0" (18 cm)	-5.88 (-0.15)	135	K
540A	TC	Unassigned thermocouple channel			K
541	LT	Flash chamber DP for level			+4.77 psid (+0.0329 MPa)
542A*	TC	Vessel inside wall temperature	109.3 (2.77)	225	K
543A	TC	Pipe wall between bottom of downcomer and vessel			K
544*	TC	Separator 2 bottom fluid temperature			K
545*	TC	Separator 2 top fluid temperature			K
546A	TC	Downcomer center fluid temperature			K
547A	TC	Downcomer bottom fluid temperature			K
548	TC	Spray system TC for flow (upstream of FM-7)			K
549	TC	Spray TC on spray manifold			K
550A*	DP	Vessel DP -5.88" to 164.0" (-0.15 to 4.17 m)			+50 psid (+0.34 MPa)
551	TC	Flood system fluid temperature (upstream of FM-5)			K
552	TC	Flash chamber 1' (0.3 m) from bottom			K
553	TC	Flash chamber (upstream of FM-1)			K
554	TC	Mixer accumulator 3' (0.91 m) from bottom			K
555	TC	Mixer accumulator (upstream of FM-6)			K
556*	TC	Separator 2 outlet temperature (upstream of FM-2)			K
557*	TC	Separator 1 TC for flow (upstream of FM-3)			K
558*	PT	Separator 2 pressure (on FM-2)			0-1500 psig (0.10-10.44 MPa)
559A*	PT	Test vessel upper plenum pressure			0-1500 psig (0.10-10.44 MPa)
560	LT	Reflood tank level			+2.6 psid (+0.018 MPa)

Table B-1 (cont)

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

Channel	Type	Description	Elevation [in. (m)]	Azimuth (%)	Range or Material
561	PT	Spray system pressure on FM-7			0-2500 psig (0.10-17.34 MPa)
562	PT	Flood system pressure on FM-5			0-300 psig (0.10-2.17 MPa)
563	PT	Flash chamber pressure on FM-1			0-3500 psig (0.10-24.23 MPa)
564	PT	Mixer accumulator pressure on FM-6			0-2500 psig (0.10-17.34 MPa)
565*	PT	Separator 1 pressure on FM-3			0-1500 psig (0.10-10.44 MPa)
566*	LT	Separator 2 DP for level			+7.85 psid (+0.0541 MPa)
567A	LT	Downcomer level			+8.84 psid (+0.0610 MPa)
568	LT	Spray accumulator 3 DP for level			+6.94 psid (+0.0479 MPa)
569*	LT	Separator 1 DP for level			8.31 psid (+0.0573 MPa)
570	DP	Flash chamber DP for flow on FM-1			+20 psid (+0.14 MPa)
571	DP	Mixer accumulator DP for flow on FM-6			+20 psid (+0.14 MPa)
572	DP	Spray system main DP for total flow on FM-7			+20 psid (+0.14 MPa)
573	DP	Spray system DP for thimble flow on SMF-01			+20 psid (+0.14 MPa)
574	DP	Spray system DP for thimble flow on SMF-04			+20 psid (+0.14 MPa)
575	DP	Spray system DP for thimble flow on SMF-07			+20 psid (+0.14 MPa)
576	DP	Spray system DP for thimble flow on SMF-10			+20 psid (+0.14 MPa)
577	DP	Spray system DP for thimble flow on SMF-13			+20 psid (+0.14 MPa)
578	DP	Spray system DP for thimble flow on SMF-16			+20 psid (+0.14 MPa)
579	DP	Spray system DP for thimble flow on SMF-02			+20 psid (+0.14 MPa)
580	DP	Spray system DP for thimble flow on SMF-05			+20 psid (+0.14 MPa)
581	DP	Spray system DP for thimble flow on SMF-08			+20 psid (+0.14 MPa)
582	DP	Spray system DP for thimble flow on SMF-11			+20 psid (+0.14 MPa)
583	DP	Spray system DP for thimble flow on SMF-14			+20 psid (+0.14 MPa)

Table B-1 (cont)

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

Channel	Type	Description	Elevation [in. (m)]	Azimuth (%)	Range or Material
584	DP	Spray system DP for thimble flow on SMF-03			+20 psid (+0.14 MPa)
585	DP	Spray system DP for thimble flow on SMF-06			+20 psid (+0.14 MPa)
586	DP	Spray system DP for thimble flow on SMF-09			+20 psid (+0.14 MPa)
587	DP	Spray system DP for thimble flow on SMF-12			+20 psid (+0.14 MPa)
588	DP	Spray system DP for thimble flow on SMF-15			+20 psid (+0.14 MPa)
589	DP	Flood system DP for flow on FM-5 for high flow			+50 psid (+0.34 MPa)
590A	DP	Top of vessel to top of downcomer			+20 psid (+0.14 MPa)
591*	DP	Separator 2 DP for flow (on FM-2)			+50 psid (+0.34 MPa)
592A*	DP	Separator 2 inlet DP for flow (on F-8)			+20 psid (+0.14 MPa)
593A	TC	Reflood inlet to downcomer fluid temperature			K
594*	DP	Separator 1 DP for flow on FM-3			+20 psid (+0.14 MPa)
595A*	DP	Axial DP -21.50" to -5.88" (-0.55 to -0.15 m)			+5 psid (+0.03 MPa)
596A*	DP	Axial DP -5.88" to 27.30" (-0.15 to 0.69 m)			+5 psid (+0.03 MPa)
597A*	DP	Axial DP 27.3" to 54.7" (0.69 to 1.39 m)			+5 psid (+0.03 MPa)
598A*	DP	Axial DP 54.7" to 82" (1.39 to 2.08 m)			+5 psid (+0.03 MPa)
599A*	DP	Axial DP 82" to 109.3" (2.08 to 2.78 m)			+5 psid (+0.03 MPa)
600A*	DP	Axial DP 109.3" to 136.7" (2.78 to 3.47 m)			+5 psid (+0.03 MPa)
601	PT	Pressure at top of downcomer			0-100 psig (0.10-0.79 MPa)
602A*	PT	Test vessel upper plenum pressure			0-100 psig (0.10-0.79 MPa)
603	DP	Flood system DP for low flood (on FM-6)			+20 psid (+0.14 MPa)
604A*	PT	Pressure on FM-9			0-100 psig (0.10-0.79 MPa)
605A*	DP	Pressure drop across FM-9			+5 psid (+0.03 MPa)
606A*	DP	Axial DP 136.7" to 164" (3.47 to 4.17 m)			+5 psid (+0.03 MPa)
607A*	DP	Axial DP 164" to 190" (4.17 to 4.83 m)			+5 psid (+0.03 MPa)

Table B-1 (cont)

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

Channel	Type	Description	Elevation [in. (m)]	Azimuth (%)	Range or Material
608A*	DP	Axial DP 182.5" to 190" (4.64 to 4.83 m)			+5 psid (+0.03 MPa)
609A*	DP	Axial DP 190" to 200.5" (4.83 to 5.09 m)			+5 psid (+0.03 MPa)
610A*	DP	Axial DP 190" to 222.75" (4.83 to 5.66 m)			+5 psid (+0.03 MPa)
611A*	DP	Axial DP -21.5" to 222.75" (-0.55 to 5.66 m)			+5 psid (+0.03 MPa)
612*	WT	Power zone 1			+50 psid (+0.34 MPa)
613*	WT	Power zone 2			
614*	WT	Power zone 3			
615*	WT	Power zone 4A			
616*	WT	Power zone 4B			
617*	WT	Power zone 4			
618*	WT	Power zone 5			
619*	WT	Power zone 6			
620*	WT	Total bundle power			
621*	CT	Neutral current			
622	TC	In-line mixer outlet fluid temperature			K
623	TC	Reflow tank fluid temperature			K
624A*	TC	Center thimble surface temperature	-4.0 (-0.10)		K
625A*	TC	Center thimble surface temperature	0 (0)		K
626A*	TC	Center thimble surface temperature	27.3 (0.69)		K
627A*	TC	Center thimble surface temperature	36.9 (0.94)		K
628A*	TC	Center thimble surface temperature	45.1 (1.15)		K
629A*	TC	Center thimble surface temperature	54.7 (1.39)		K
630	TC	Flash chamber top fluid TC			K
631A*	TC	Test vessel outside wall	54.7 (1.39)	225	K
632A*	DP	Test vessel upper plenum to V-2 inlet			+25 psid (+0.17 MPa)
633A*	TC	Test vessel outside wall	109.3 (2.78)	225	K
634A	DP	DP bottom to top of downcomer parallel to 567			+20 psid (+0.14 MPa)
635A*	LT	Vessel baffle level 0" to 164" (0 to 4.17 m)			+5.94 psid (+0.410 MPa)
636A	TC	Downcomer top fluid temperature			K
637A*	TC	OD surface temperature of vessel bottom flange			K

Table B-1 (cont)

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

Channel	Type	Description	Elevation [in. (m)]	Azimuth (%)	Range or Material
638*	PT	Separator 1 pressure (on FM-3)			0-100 psig (0.10-0.79 MPa)
639*	TC	Separator 1 top fluid temperature			K
640*	PT	V-2/V-16 outlet pressure			0-100 psig (0.10-0.70 MPa)
641A*	TC	FM-9 thermocouple			K
642A*	TC	Fluid TC in bottom plenum	-21.5 (-0.55)	90	K
643A	TC	Unassigned thermocouple channel			K
644A*	TC	Center thimble surface temperature	82 (2.08)		K
645A*	TC	Center thimble surface temperature	109.3 (2.78)		K
646A*	TC	Baffle outside surface type A	53.5 (1.36)	270	K
647A*	TC	Baffle inside surface type C	53.5 (1.36)	270	K
648A*	TC	Baffle outside surface type B	54.75 (1.39)	270	K
649A*	TC	Baffle outside surface type D	54.75 (1.39)	270	K
650A*	TC	Baffle outside surface type A	53.5 (1.36)	0	K
651A*	TC	Baffle outside surface type B	54.75 (1.39)	0	K
652A*	TC	Baffle outside surface type A	53.5 (1.36)	90	K
653A*	TC	Baffle outside surface type B	54.75 (1.36)	90	K
654A*	TC	Baffle outside surface type A	108.5 (2.76)	0	K
655A	TC	Thimble M7 surface temperature	27.3 (0.69)		K
656A	TC	Thimble M7 surface temperature	36.9 (0.94)		K
657A	TC	Thimble M7 surface temperature	45.1 (1.15)		K
658A	TC	Thimble M7 surface temperature	54.7 (1.39)		K
659A	TC	Thimble M7 surface temperature	82.0 (2.08)		K
660A	TC	Thimble M7 surface temperature	109.3 (2.78)		K
661A*	TC	Pipe wall temperature at separator 1 inlet			K
662A*	TC	Pipe wall temperature upstream of V-24			K
663A	TC	Forced reflood inlet tem- perature to lower plenum from spray system			K
664A	TC	Forced reflood inlet tem- perature to lower plenum from reflood pump			K
665A	TC	Downcomer wall TC 1' (0.3 m) below overflow		225	K
666A	TC	Downcomer wall TC 1' (0.3 m) below reflood inlet		225	K
667A	TC	Downcomer wall TC 5' (1.5 m) from bottom		225	K
668A	TC	Variable UHI hot flow temperature (upstream of FM-10)			K

Table B-1 (cont)

LOCATIONS AND RANGES OF G-2 LOOP TRANSDUCERS AND THERMOCOUPLES
FOR CORE UNCOVERY TESTING

<u>Channel</u>	<u>Type</u>	<u>Description</u>	<u>Elevation</u> <u>[in. (m)]</u>	<u>Azimuth</u> <u>(%)</u>	<u>Range or</u> <u>Material</u>
669A	TC	Variable UHI mixer hot inlet temperature			K
670A	TC	Variable UHI mixer cold inlet temperature			K
671A	TC	Variable UHI mixer outlet temperature			K
672A	TC	Spray system temperature for thimble flow (on SMF-01)			K
673A	TC	Spray system temperature for thimble flow (on SMF-02)			K
674A	TC	Spray system temperature for thimble flow (on SMF-03)			K
675A*	DP	Test vessel upper plenum to V-16 inlet			+50 psid (0.34 MPa)
676A	DP	Variable UHI hot flow DP (on FM-10)			+20 psid (+0.14 MPa)
677A	PT	Variable UHI hot flow PT (on FM-10)			0-2500 psig (0.10-17.34 MPa)
678A	PT	Variable UHI downstream of mixer			0-2500 psig (0.10-17.34 MPa)
679A	DP	Core flow DP at vessel inlet (on FM-11)			+20 psid (+0.14 MPa)
680A	LT	Spray accumulator 2 DP for level			+4.34 psid (+0.099 MPa)
681A*	DP	DP across baffle at 164" (4.17 m) elevation			+5 psid (+0.03 MPa)

Table B-2

CLAD TEMPERATURE INSTRUMENTATION AND SCR/ROD SUMMARY

Channel	Rod Location(a)	Thermocouple(b)	SCR	Channel	Rod Location(a)	Thermocouple(b)	SCR
001	A1	2	4A	034	B14	7	6
002	A1	4	4A	035	B14	9	6
003	A1	6	4A	036	B14	11	6
004	A1	8	4A	037	D12	2	2
005	A1	10	4A	038	D12	4	2
006	A1	12	4A	039	D12	6	2
007	A10	2	4A	040	D12	8	2
008	A10	4	4A	041	D12	10	2
009	A10	6	4A	042	D12	12	2
010	A10	8	4A	043	C3	1	6
011	A10	10	4A	044	C3	3	6
012	A10	12	4A	045	C3	5	6
013	A19	1	4A	046	C3	7	6
014	A19	3	4A	047	C3	9	6
015	A19	5	4A	048	C3	11	6
016	A19	7	4A	049	C5	1	5
017	A19	9	4A	050	C5	3	5
018	A19	11	4A	051	C5	5	5
019	B18	2	6	052	C5	7	5
020	B18	4	6	053	C5	9	5
021	B18	6	6	054	C5	11	5
022	B18	8	6	055	C10	1	5
023	B18	10	6	056	C10	3	5
024	B18	12	6	057	C10	5	5
025	B9	2	5	058	C10	7	5
026	B9	4	5	059	C10	9	5
027	B9	6	5	060	C10	11	5
028	B9	8	5	061	C13	2	5
029	B9	10	5	062	C13	4	5
030	B9	12	5	063	C13	6	5
031	B14	1	6	064	C13	8	5
032	B14	3	6	065	C13	10	5
033	B14	5	6	066	C13	12	5

a. See Figure 2-9 for column/row designation.

- b.
- 1 indicates 12.3 in. (0.31 m) elevation thermocouple
 - 2 indicates 28.7 in. (0.73 m) elevation thermocouple
 - 3 indicates 36.9 in. (0.94 m) elevation thermocouple
 - 4 indicates 45.1 in. (1.15 m) elevation thermocouple
 - 5 indicates 54.7 in. (1.89 m) elevation thermocouple
 - 6 indicates 69.7 in. (1.77 m) elevation thermocouple
 - 7 indicates 82.0 in. (2.08 m) elevation thermocouple
 - 8 indicates 94.3 in. (2.40 m) elevation thermocouple
 - 9 indicates 110.7 in. (2.81 m) elevation thermocouple
 - 10 indicates 118.9 in. (3.02 m) elevation thermocouple
 - 11 indicates 135.4 in. (3.44 m) elevation thermocouple
 - 12 indicates 147.6 in. (3.75 m) elevation thermocouple

Table B-2 (cont)

CLAD TEMPERATURE INSTRUMENTATION AND SCR/ROD SUMMARY

<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>	<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>
067	C17	2	6	115	F6	1	2
068	C17	4	6	116	F6	3	2
069	C17	6	6	117	F6	5	2
070	C17	8	6	118	F6	7	2
071	C17	10	6	119	F6	9	2
072	C17	12	6	120	F6	11	2
073	D2	2	6	121	F8	2	2
074	D2	4	6	122	F8	4	2
075	D2	6	6	123	F8	6	2
076	D2	8	6	124	F8	8	2
077	D2	10	6	125	F8	10	2
078	D2	12	6	126	F8	12	2
079	D4	2	5	127	F10	2	2
080	D4	4	5	128	F10	4	2
081	D4	6	5	129	F10	6	2
082	D4	8	5	130	F10	8	2
083	D4	10	5	131	F10	10	2
084	D4	12	5	132	F10	12	2
085	D6	1	2	133	F12	1	2
086	D6	3	2	134	F12	3	2
087	D6	5	2	135	F12	5	2
088	D6	7	2	136	F12	7	2
089	D6	9	2	137	F12	9	2
090	D6	11	2	138	F12	11	2
091	D14	1	2	139	F14	2	2
092	D14	3	2	140	F14	4	2
093	D14	5	2	141	F14	6	2
094	D14	7	2	142	F14	8	2
095	D14	9	2	143	F14	10	2
096	D14	11	2	144	F14	12	2
097	D16	1	5	145	E10	1	2
098	D16	3	5	146	E10	3	2
099	D16	5	5	147	E10	5	2
100	D16	7	5	148	E10	7	2
101	D16	9	5	149	E10	9	2
102	D16	11	5	150	E10	11	2
103	E9	1	2	151	G3	1	5
104	E9	3	2	152	G3	3	5
105	E9	5	2	153	G3	5	5
106	E9	7	2	154	G3	7	5
107	E9	9	2	155	G3	9	5
108	E9	11	2	156	G3	11	5
109	E11	2	2	157	G17	2	5
110	E11	4	2	158	G17	4	5
111	E11	6	2	159	G17	6	5
112	E11	8	2	160	G17	8	5
113	E11	10	2	161	G17	10	5
114	E11	12	2	162	G17	12	5

Table B-2 (cont)

CLAD TEMPERATURE INSTRUMENTATION AND SCR/ROD SUMMARY

<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>	<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>
163	H6	1	3	211	I10	2	1
164	H6	3	3	212	I10	4	1
165	H6	5	3	213	I10	6	1
166	H6	7	3	214	I10	8	1
167	H6	9	3	215	I10	10	1
168	H6	11	3	216	I10	12	1
169	H8	2	1	217	I11	2	1
170	H8	4	1	218	I11	4	1
171	H8	6	1	219	I11	6	1
172	H8	8	1	220	I11	8	1
173	H8	10	1	221	I11	10	1
174	H8	12	1	222	I11	12	1
175	H10	1	1	223	I15	1	3
176	H10	3	1	224	I15	3	3
177	H10	5	1	225	I15	5	3
178	H10	7	1	226	I15	7	3
179	H10	9	1	227	I15	9	3
180	H10	11	1	228	I15	11	3
181	H12	1	1	229	J1	2	4A
182	H12	3	1	230	J1	4	4A
183	H12	5	1	231	J1	6	4A
184	H12	7	1	232	J1	8	4A
185	H12	9	1	233	J1	10	4A
186	H12	11	1	234	J1	12	4A
187	H14	2	3	235	J3	1	5
188	H14	4	3	236	J3	3	5
189	H14	6	3	237	J3	5	5
190	H14	8	3	238	J3	7	5
191	H14	10	3	239	J3	9	5
192	H14	12	3	240	J3	11	5
193	H18	1	6	241	J6	1	3
194	H18	3	6	242	J6	3	3
195	H18	5	6	243	J6	5	3
196	H18	7	6	244	J6	7	3
197	H18	9	6	245	J6	9	3
198	H18	11	6	246	J6	11	3
199	I5	2	3	247	J8	2	1
200	I5	4	3	248	J8	4	1
201	I5	6	3	249	J8	6	1
202	I5	8	3	250	J8	8	1
203	I5	10	3	251	J8	10	1
204	I5	12	3	252	J8	12	1
205	I9	1	1	253	J12	2	1
206	I9	3	1	254	J12	4	1
207	I9	5	1	255	J12	6	1
208	I9	7	1	256	J12	8	1
209	I9	9	1	257	J12	10	1
210	I9	11	1	258	J12	12	1

Table B-2 (cont)

CLAD TEMPERATURE INSTRUMENTATION AND SCR/ROD SUMMARY

<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>	<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>
259	J14	1	3	307	L8	2	1
260	J14	3	3	308	L8	4	1
261	J14	5	3	309	L8	6	1
262	J14	7	3	310	L8	8	1
263	J14	9	3	311	L8	10	1
264	J14	11	3	312	L8	12	1
265	J17	2	5	313	L10	2	1
266	J17	4	5	314	L10	4	1
267	J17	6	5	315	L10	6	1
268	J17	8	5	316	L10	8	1
269	J17	10	5	317	L10	10	1
270	J17	12	5	318	L10	12	1
271	J19	1	4A	319	L12	2	1
272	J19	3	4A	320	L12	4	1
273	J19	5	4A	321	L12	6	1
274	J19	7	4A	322	L12	8	1
275	J19	9	4A	232	L12	10	1
276	J19	11	4A	324	L12	12	1
277	K5	1	4B	325	L14	1	4B
278	K5	3	4B	326	L14	3	4B
279	K5	5	4B	327	L14	5	4B
280	K5	7	4B	328	L14	7	4B
281	K5	9	4B	329	L14	9	4B
282	K5	11	4B	330	L14	11	4B
283	K9	1	1	331	M3	2	5
284	K9	3	1	332	M3	4	5
285	K9	5	1	333	M3	6	5
286	K9	7	1	334	M3	8	5
287	K9	9	1	335	M3	10	5
288	K9	11	1	336	M3	12	5
289	K11	1	1	337	M17	1	5
290	K11	3	1	338	M17	3	5
291	K11	5	1	339	M17	5	5
292	K11	7	1	340	M17	7	5
293	K11	9	1	341	M17	9	5
294	K11	11	1	342	M17	11	5
295	K15	2	4B	343	M18	2	5
296	K15	4	4B	344	M18	4	5
297	K15	6	4B	345	M18	6	5
298	K15	8	4B	346	M18	8	5
299	K15	10	4B	347	M18	10	5
300	K15	12	4B	348	M18	12	5
301	L6	2	4B	349	B10	1	5
302	L6	4	4B	350	B10	3	5
303	L6	6	4B	351	B10	5	5
304	L6	8	4B	352	B10	7	5
305	L6	10	4B	353	B10	9	5
306	L6	12	4B	354	B10	11	5

Table B-2 (cont)

CLAD TEMPERATURE INSTRUMENTATION AND SCR/ROD SUMMARY

<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>	<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>
355	N6	1	4B	403	P16	2	5
356	N6	3	4B	404	P16	4	5
357	N6	5	4B	405	P16	6	5
358	N6	7	4B	406	P16	8	5
359	N6	9	4B	407	P16	10	5
360	N6	11	4B	408	P16	12	5
361	N8	1	4B	409	P18	2	6
362	N8	3	4B	410	P18	4	6
363	N8	5	4B	411	P18	6	6
364	N8	7	4B	412	P18	8	6
365	N8	9	4B	413	P18	10	6
366	N8	11	4B	414	P18	12	6
367	N10	1	4B	415	Q3	2	6
368	N10	3	4B	416	Q3	4	6
369	N10	5	4B	417	Q3	6	6
370	N10	7	4B	418	Q3	8	6
371	N10	9	4B	419	Q3	10	6
372	N10	11	4B	420	Q3	12	6
373	N12	2	4B	421	Q7	1	5
374	N12	4	4B	422	Q7	3	5
375	N12	6	4B	423	Q7	5	5
376	N12	8	4B	424	Q7	7	5
377	N12	10	4B	425	Q7	9	5
378	N12	12	4B	426	Q7	11	5
379	N14	1	4B	427	Q13	2	5
380	N14	3	4B	428	Q13	4	5
381	N14	5	4B	429	Q13	6	5
382	N14	7	4B	430	Q13	8	5
383	N14	9	4B	431	Q13	10	5
384	N14	11	4B	432	Q13	12	5
385	07	2	4B	433	Q15	1	5
386	07	4	4B	434	Q15	3	5
387	07	6	4B	435	Q15	5	5
388	07	8	4B	436	Q15	7	5
389	07	10	4B	437	Q15	9	5
390	07	12	4B	438	Q15	11	5
391	09	2	4B	439	Q17	1	6
392	09	4	4B	440	Q17	3	6
393	09	6	4B	441	Q17	5	6
394	09	8	4B	442	Q17	7	6
395	09	10	4B	443	Q17	9	6
396	09	12	4B	444	Q17	11	6
397	011	1	4B	445	R2	1	6
398	011	3	4B	446	R2	3	6
399	011	5	4B	447	R2	5	6
400	011	7	4B	448	R2	7	6
401	011	9	4B	449	R2	9	6
402	011	11	4B	450	R2	11	6

Table B-2 (cont)

CLAD TEMPERATURE INSTRUMENTATION AND SCR/ROD SUMMARY

<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>	<u>Channel</u>	<u>Rod Location(a)</u>	<u>Thermocouple(b)</u>	<u>SCR</u>
451	R4	1	6	472	R16	8	6
452	R4	3	6	473	R16	10	6
453	R4	5	6	474	R16	12	6
454	R4	7	6	475	S1	2	4A
455	R4	9	6	476	S1	4	4A
456	R4	11	6	477	S1	6	4A
457	E13	2	2	478	S1	8	4A
458	E13	4	2	479	S1	10	4A
459	E13	6	2	480	S1	12	4A
460	E13	8	2	481	S10	1	4A
461	E13	10	2	482	S10	3	4A
462	E13	12	2	483	S10	5	4A
463	R10	2	5	484	S10	7	4A
464	R10	4	5	485	S10	9	4A
465	R10	6	5	486	S10	11	4A
466	R10	8	5	487	S19	1	4A
467	R10	10	5	488	S19	3	4A
468	R10	12	5	489	S19	5	4A
469	R16	2	6	490	S19	7	4A
470	R16	4	6	491	S19	9	4A
471	R16	6	6	492	S19	11	4A

Table B-3

LOOP TEMPERATURE RECORDING SYSTEM

<u>Channel</u>	<u>Instrument(a)</u>	<u>Description</u>	<u>Vessel</u>
RECORDER A			
1	A01	Top fluid	UHI accumulator 3
2	A02	Bottom fluid	UHI accumulator 3
3	A03	Top fluid	UHI accumulator 1
4	A04	Top fluid	UHI accumulator 1
5	A05	Top fluid	UHI accumulator 2
6	A06	Bottom fluid	UHI accumulator 2
7	A07	Top well	In-line mixer accumulator
8	A08	Bottom well	In-line mixer accumulator
9	A09	Top fluid	Flash chamber
10	A10	Bottom fluid	Flash chamber
11	A11	Fluid	Separator 2
12	A12	Bottom fluid	Separator 1
13	A13	Middle fluid	Separator 1
14	A14	Top fluid	Separator 1
15	A15A	Discharge fluid	In-line mixer
16	A16	Inlet fluid	In-line mixer
17	A17	Discharge fluid	Flowmeter 5
18	A18	Fluid	Open tank
19	A19	Fluid	UHI system control valve (V-3)
20	A20	Outlet pipe	UHI system control valve (V-3)
21	A21	Inlet pipe	Mixer flow control valve (V-6)
22	A22	Outlet pipe	Mixer flow control valve (V-6)
23	A23	Inlet pipe	Flash chamber flow control valve (V-1)
24	A24	Outlet pipe	Flash chamber flow control valve (V-1)

a. See Figure 2-9.

Table B-3 (cont)
 LOOP TEMPERATURE RECORDING SYSTEM

<u>Channel</u>	<u>Instrument(a)</u>	<u>Description</u>	<u>Vessel</u>
RECORDER B			
1	A25	Outlet pipe	Reflood check valve
2	A26	Inlet pipe	Pressure control valve (V-2)
3	A27	Middle pipe	In-line mixer
4	A28A	Outlet pipe	In-line mixer
5	A29A	Outlet pipe	In-line mixer
6	A30A	Outlet pipe	In-line mixer
7	A31	Top wall	UHI accumulator 3
8	A32	Bottom wall	UHI accumulator 3
9	A33	Top wall	UHI accumulator 1
10	A34	Bottom wall	UHI accumulator 1
11	A35	Top wall	UHI accumulator 2
12	A36	Bottom wall	UHI accumulator 2
13	A37	Top wall	In-line mixer accumulator
14	A38	Bottom wall	In-line mixer accumulator
15	A39	Top wall	Flash chamber
16	A40	Bottom wall	Flash chamber
17	A41	Top wall	Separator 1
18	A42	Middle wall	Separator 1
19	A43	Outlet wall	Separator 2
20	A44	Inlet wall	Separator 2
21	A45	Inlet pipe	UHI system test vessel
22	A46	Inlet pipe	UHI system test vessel
23	A47A	Outlet pipe	Test vessel pipe
24	A48A	Inlet pipe	Test vessel pipe

a. See Figure 2-9.

Table B-3 (cont)
 LOOP TEMPERATURE RECORDING SYSTEM

<u>Channel</u>	<u>Instrument(a)</u>	<u>Description</u>	<u>Vessel</u>
RECORDER C			
1	A49	Outlet pipe	Downcomer
2	A50	Outlet pipe	Flow orifice (F-4A)
3	A51	Unassigned	
4	A52A	Outlet pipe	Flow orifice (F-2A)
5	A53A	Outlet pipe	Flowmeter (FM-5)
6	A54A	Pipe	Test vessel to downcomer crossover
7	A55	Unassigned	
8	A56	Unassigned	
9	A57	Unassigned	
10	A58	Unassigned	
11	A59	Unassigned	
12	A60A	Inlet pipe	Separator 1
13	A61A	Head	Test vessel bottom flange
14	A62A	Head	Test vessel bottom flange
15	A63A	Head	Test vessel bottom flange
16	A64A	Head	Test vessel bottom flange
17	A65A	Wall	Test vessel
18	A66A	Wall	Test vessel
19	A67A	Wall	Test vessel
20	A68A	Wall	Test vessel
21	A69A	Wall	Test vessel
22	A70A	Wall	Test vessel
23	A71A	Wall	Top of downcomer
24	A72A	Wall	Bottom of downcomer

a. See Figure 2-9.

Appendix C
SAMPLE TEST PROSPECTUS

A test prospectus is a document which defines the proposed test and the data to be obtained from that test in sufficient detail to permit preparation of facility operating procedures by the responsible test engineer for the facility technicians. This appendix contains the following:

- The Core Uncovering Test Prospectus, as originally issued
- Addendum 1 to the Core Uncovering Test Prospectus

The 22 tests reported in this report were performed using the original Core Uncovering Test Prospectus as amended by Addendum 1.





EO-T&H-T-69

WRD - PWRSD Engineering
From Engineering Operations
WIN 249-4988
Date March 24, 1975
Subject Core Uncovering Test Prospectus (EO-T&H-T-69)

SEE ADD. 1

WATER REACTOR DIVISIONS

to R: R. Fayfich
H. J. Fix
A. D. Gray
D. L. McKown
B. A. McIntyre
R. P. Vijuk

cc: C. L. Caso
L. E. Hochreiter
J. L. Koetting
P. G. Kozlowski
A. Y. Lee
O. J. Mendler
K. L. Rieke
R. W. Steer
D. E. Thorn
G-2 File
Test Programs File

The attached test prospectus for core uncovering tests in the G-2 loop is submitted for your review. Prior to development of a firm test plan, this prospectus is based on a preliminary plan/confirmed by Messrs. Vijuk and McIntyre in a meeting on March 14, 1975.

J. P. Cunningham
Thermal & Hydraulic Development

JPC/sb

Attachment



TEST NO. EO-T&H-T-69

TO: Test Engineering Section (3)

PRELIMINARY DISCUSSION DATE March 14, 1975

PROSPECTUS INITIATION DATE March 17, 1975

COMPLETION DATE _____

1. Test Name:

CORE UNCOVERING TESTS

2. Responsible Engineer(s):
 MNC: J. P. Cunningham
 FH: A. D. Gray / R. R. Fayfich

3. Charge No.:
 YYHC-201

4. Test Data Requested and their Accuracy Requirements:

<u>DATA</u>	<u>ACCURACY</u> (Data Path Error)
Temperature	<u>+ 5°F</u>
Differential Pressure	<u>+ 1.5%</u>
Power	<u>+ 1%</u>
Output from G-LOOK and Data Tape	

5. Test Piece or Model Sketch No.

G-2 Loop

6. Date of Completion of Test Piece Fabrication:

15 July 1974

7. Requested Completion Date (Listed in order of preference):

TEST ITEMS

COMPLETION DATE

8. Requested date of information from Test Engineering regarding a description of general test arrangement, the proposed test engineering schedule and the expected accuracy of the test data:



PROSPECTUS INITIATION DATE March 17, 1975

Test Name:

CORE UNCOVERING TESTS

9 Objectives and Description of Test: (specify test conditions, specific data, location of measurements and purpose of obtaining and specified data, literature references if available)

OBJECTIVES

1. To determine the mass of water required to cool an initially-cool rod bundle with 17x17-XL geometry to various levels under near-steady state conditions at elevated pressures.
2. To determine void fraction distributions under the same conditions.

These data will be used to confirm or develop void-fraction calculation methods used in predicting reactor conditions in the case of slow loss of coolant through a small break in the primary coolant system.

DESCRIPTION

1. Facility Configuration

- A. The test facility shall be configured basically as for forced flooding tests, with the test vessel lower plenum isolated from the downcomer and crossover pipe, V-24A open, and separator number 1 available to pressurize the system. However, FM-5 and the open tank will not be used. Also, valves V-18A and V-19A will be open during the heat up ~~and testing~~, **BUT V-18A CLOSED FOR TEST**
- B. Three injection accumulators shall be available for UHI injection at constant temperature. RCP-1 should be valved to permit maximum recirculation through the UHI lines to maintain temperature. All thirteen UHI tube valves shall be open for equal flow through all UHI ports.

2. Preparation for Test

A. ~~Prior Baffle Leakage Tests~~

~~Before the first core uncovering test at each pressure, and after the last prior blowdown test, a hot baffle-leakage test shall be performed and recorded with the test vessel heated to saturation at the pressure of the uncovering test, nitrogen overpressure applied, and leakage of hot water (at the uncovering test pressure saturation temperature, Table 1, Column B, + 10°F) from the baffle-vessel annulus into an empty bundle.~~

RESPONSIBLE ENGINEERS

[Signature]

APPROVED BY

[Signature]

Test Name:

CORE UNCOVERING TESTS

9. Objectives and Description of Test: (specify test conditions, specific data, location of measurements and purpose of obtaining and specified data, literature references if available)

B. Heater Rod Power Distribution

The rod power SCR's shall be set up for equal power to each rod, with the maximum total bundle power of 1.25 megawatts (equivalent to demand power of 1.0).

C. Injection Accumulators and Flash Chamber

Fill the injection accumulators and UHI piping and the flash chamber with water and heat the water up to or above the temperature indicated in Table 1, Column B for the test. RCP-1 and RCP-2 shall be operating.

D. Facility Heat Up

Using Separator number 1 as a pressurizer, heat up and pressurize the test facility to the pressure specified for the test in Table 1, Column A, with V-18A and V-19A open. Vent all noncondensable gasses from the facility and hold it at pressure for at least one hour. During this heating period the test vessel lower plenum and baffle-vessel annulus shall be kept empty by continual draining.

E. Instrumentation

All facility instrumentation is to be operational with the exception of those associated with the in-line mixer accumulator, reflood system, downcomer, and crossover pipe. Particular care must be taken with the purging and zeroing, at test pressure, of all of the test-vessel vertical differential pressure channels.

3. Test Execution

- A. When the facility has been prepared, fill the test vessel to the level indicated for the test in Table 1, Columns D and E, with water from the accumulators or the flash chamber (the in-line mixer must be drained immediately before using the flash Chamber water). If the bundle has been heated immediately prior to this test, the UHI system should be used to assure cooling of the rods to saturation temperature. If during or after

RESPONSIBLE ENGINEERS

James P. Cunningham

APPROVED BY

R. J. ...

TEST NO. CO-TAH-T-10

PROSPECTUS INITIATION DATE March 17, 1970

Test Name:

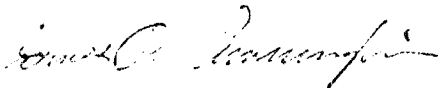
CORE UNCOVERING TESTS

9. Objectives and Description of Test: (specify test conditions, specific data, location of measurements and purpose of obtaining and specified data, literature references if available)

the fill process the lower plenum fluid temperature is more than 10°F below the saturation temperature indicated in Table 1, Column B, the water should be drained from the lower plenum (preferably from the bottom of the plenum) and replaced until the temperature rises to within 10°F of saturation.

- B. Pressure shall be constant throughout the tests at the value given for the test in Table 1, Column A, + 2%. In particular sudden changes in pressure must be avoided.
- C. The maximum permissible rod temperature shall be ~~1500°F~~. **1500°F**
- D. The start of data acquisition shall be at time t=0. The data acquisition sampling period, run duration, and power transient input shall be as indicated in Table 2. These sequences are designed to provide a record of an initial equilibrium period, a period in which the water is boiled away and the rods are slowly uncovered and start to heat up from the top down to below the 69-inch level, and a final no-power equilibrium period for each test. The power duration and maximum allowed temperature are selected to prevent the heater rods from exceeding 2000°F.
- E. If during the test, before power is turned on, the maximum rod temperature is more than 15°F above the saturation temperature given for the test in Table 1, Column B, then the test should be aborted, the rods further cooled with the UHI system, the level adjusted by draining from the lower plenum, and the test restarted.
- F. If there is no period within 10 to 20 seconds after power is turned on in which the maximum rod temperature is less than 15°F above saturation temperature, then the test should be aborted, the water level raised and rods cooled with the UHI system, and the test restarted.
- G. If rod power is turned off because the rod temperature reaches the maximum allowable temperature, data taking should continue for at least 30 seconds, then the test may be terminated.
- H. Following a test, before another test begins, use the UHI system to cool the rods to saturation temperature. The program TCSST can be used to find and monitor the hottest thermocouple between tests.

RESPONSIBLE ENGINEERS



APPROVED BY



TEST NO. EO-TFH-T-10

PROSPECTUS INITIATION DATE March 17, 1974

Test Name:

CORE UNCOVERING TESTS

9 Objectives and Description of Test: (specify test conditions, specific data, location of measurements and purpose of obtaining and specified data, literature references if available)

TABLE 1
 TEST INITIAL CONDITIONS

Column	A	B	C	D	E
Test No.	Test Vessel Pressure, psia	Saturation Temperature °F	Total Bundle Power, MW	Estimated Initial Water Level Feet Above B.O.H.L.	Equivalent ΔP , Ch 550, psid
1	800	518	0.25	11	3.82
2	800	518	0.50	10	3.49
3	800	518	0.75	9	3.16
4	800	518	1.00	8.5	2.99
5	800	518	1.25	8.5	2.99
6	800	518	0.75	9	3.16
7	400	445	0.25	11	4.13
8	400	445	0.50	9.5	3.59
9	400	445	0.75	8.5	3.23
10	400	445	1.00	8	3.05
11	400	445	1.25	7.5	2.87
12	400	445	0.75	8.5	3.23

RESPONSIBLE ENGINEER:

[Handwritten Signature]

APPROVED BY:

[Handwritten Signature]

TEST NO. CO-74H Test 1

PROSPECTUS INITIATION DATE March 17, 1961

Test Name:

CORE UNCOVERING TESTS

9 Objectives and Description of Test: (specify test conditions, specific data, location of measurements and purpose of obtaining and specified data, literature references if available)

TABLE 2
COMPUTER DEMAND

Full Power = 1.25 MW, Maximum Temperature = 1580°F

Test Numbers	1, 7	2, 8	3, 6, 9, 12	4, 10	5, 11
Bundle Power, MW	0.25	0.5	0.75	1.0	1.25
Run Duration, Sec.	2880	1440	1080	720	720
Sampling Period, Sec.	4	2	1.5	1	1

Power vs. Time	Time	Power	Time	Power	Time	Power	Time	Power	Time	Power
	0	0	0	0	0	0	0	0	0	0
	12	0	10	0	10.5	0	10	0	10	0
	12	.2	10	.4	10.5	.6	10	.8	10	1
	2752	.2	1380	.4	921	.6	700	.8	560	1
	2752	0	1380	0	921	0	700	0	560	0
	2800	0	1440	0	1080	0	720	0	600	0

RESPONSIBLE ENGINEERS

James P. [Signature]

APPROVED BY

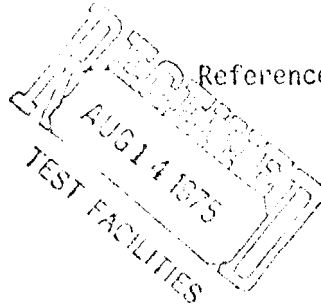
[Signature]

C-12

EO-T&H-T-69
Addendum 1

WRD - PWRSD Engineering
Engineering Operations
249-4989
August 12, 1975
Core Uncovering Test Prospectus
Addendum 1

Reference: SE-SA/II-233,
SE-SD-788



to WATER REACTOR DIVISIONS

R. R. Fayfich

H. J. Fix

A. D. Gray

D. L. McKown

B. A. McIntyre

R. P. Vijuk

cc: J. O. Cermak

L. E. Hochreiter

J. L. Koetting

J. M. Krampe

D. C. Garner

T. A. Meyer

K. L. Rieke

D. E. Thorn

G-2 File

Test Programs File

In order to accomplish core uncovering (small break) testing as presented in the referenced test plan, the following modifications must be made to the preliminary test prospectus (EO-T&H-T-69).

1. The charge number is to be changed to FTLP-1264 from YYHC-201.
2. The last sentence of paragraph 1.A of the Description is to be changed to read as follows:

Also, valves V-19A and V-18A will be open during heatup but valve V-18A will be closed before testing.

3. Paragraph 2.A of the Description is to be deleted because the baffle-leakage tests are run under a separate prospectus (EO-T&H-T-72).
4. Tables I and 2 are to be replaced by the attached Tables I and II.

L. L. Overton
Thermal & Hydraulic Development

APPROVED:

K. L. Rieke, Manager
Thermal & Hydraulic Development

/pdc
attachment

TABLE I
Test Initial Conditions

Column	A	B	C	D	E	
Test No.	Test Vessel Pressure (psia)	Saturation Temperature (°F)	Total Bundle Power MW	Estimated Initial Water Level Feet Above B.O.H.L.	Equivalent ΔP, Ch 550, psid	
715 ✓	1	800	518	.6	9.5	3.32
719 ✓	2	400	445	.25	11.5	4.30
720 ✓	3	400	445	.6	9.5	3.58
721 ✓	4	400	445	.9	8.5	3.22
722 ✓	5	400	445	1.25	7	2.69
724 ✓	6	100	328	.25	10.5	4.30
725 ✓	7	100	328	.6	8	3.32
728 ✓	8	50	281	.6	7	3.01
732 ✓	9	14.7	212	.25	8.5	3.73
733 ✓	10	14.7	212	.6	6	2.69
734 ✓	11	800	518	.25	11.5	3.99
717 ✓	12	800	518	.9	8.5	2.99
718 ✓	13	800	518	1.25	7.5	2.65
723 ✓	14	400	445	.6	9.5	3.58
726 ✓	15	100	328	.9	7	2.93
727 ✓	16	100	328	1.25	6.5	2.73
729 ✓	17	50	281	.25	9.5	4.01
730 ✓	18	50	281	.9	5.5	2.40
731 ✓	19	50	281	1.25	4.5	2.00
736 ✓	20	14.7	212	.25	8.5	3.73
734 ✓	21	14.7	212	.9	5	2.28
735 ✓	22	14.7	212	1.25	4.5	2.07

TABLE II

Computer Demand

Full Power = 1.25 MW, Maximum Temperature = 1500°F

Test Numbers	2,6,9,11,17,20		1,3,7,8,10,14		4,12,15,18,21		5,13,16,19,22	
Bundle Power, MW	0.25		0.6		0.9		1.25	
Run Duration, Sec.	2880		1200		820		600	
Sampling Period, Sec.	4		2		1.5		1	
SMALL BREAK	8		4		3		2	
Power vs. Time	Time	Power	Time	Power	Time	Power	Time	Power
	0	0	0	0	0	0	0	0
	12	0	10	0	10.5	0	10	0
	12	.2	10	.48	10.5	.72	10	1
	2752	.2	1160	.48	771	.72	560	1
	2752	0	1160	0	771	0	560	0
	2800	0	1200	0	820	0	600	0

Appendix D
SAMPLE TEST PROCEDURE

A test procedure is a document that provides for the orderly execution of a test by defining the sequence of events that the facility technicians and test engineer must perform prior to, during, and after a test. The sequential performance of the events is acknowledged by initialing the appropriate locations on the test procedure. A sample test procedure is presented on the following pages.



G-2 LOOP
CORE UNCOVERING TESTS
TEST PROCEDURE

APPROVED FOR USE ON RUN _____ ON _____ BY _____
(DATE) (SIGNATURE)

LOOP OPERATOR _____ TEST DIRECTOR _____

ASSISTANT L.O. _____ INSTRUMENT TECH. _____

ASSISTANT L.O. _____ COMPUTER OPERATOR _____

TEST PROSPECTUS _____ TEST NUMBER _____

REVISION	0	1	2	3	4	5
DATE						
PREPARED						
APPROVED						

D-4

BEFORE STARTING THIS PROCEDURE, TURN TAPE RECORDER ON AND RECORD TAPE METER POSITION AT _____.

STEPS 1 THROUGH 8 ARE TO BE COMPLETED BY THE COMPUTER OPERATOR.

1. VERIFY DACP _____ RUN TABLES HAVE BEEN INPUT INTO COMPUTER _____
2. VERIFY THAT A/D, D/A, CCØ, AND CCI CONNECTORS ARE PLUGGED INTO COMPUTER:
 - a. ANALOG OUTPUTS: POWER _____
 - b. CCØ CONNECTOR PLUGGED INTO COMPUTER _____
 - c. CCI CONNECTOR PLUGGED INTO COMPUTER _____
 - d. CCØ, CCI, AND AK RELAY SWITCHES ON MAINTENANCE PANEL IN OFF (LEFT) POSITION. _____
 - e. ALL DATA CHANNELS PLUGGED INTO COMPUTER. _____
3. VERIFY CCO 110 VAC SWITCH ON. _____
4. VERIFY THAT ALL OUTPUT CONNECTORS ARE PLUGGED INTO REFERENCE JUNCTIONS. _____
5. VERIFY REFERENCE JUNSTION POWER ON. _____
6. VERIFY ALL 6 REFERENCE JUNSTIONS ON. _____
7. VERIFY 5 AND 10 VOLT TRANSDUCER POWER SUPPLIES ON AND AT PROPER VOLTAGE. _____

STEPS 8 THROUGH 14 ARE TO BE COMPLETED BY THE INSTRUMENT TECHNICIAN.

8. VERIFY SCR ZEROS HAVE BEEN ADJUSTED _____
9. VERIFY ALL SCR CURRENT TRANSFORMER SHORTING PLUGS ARE INSTALLED EXCEPT FOR SCR _____.
10. VERIFY YEW POWER MEASUREMENT INSTRUMENT IS PLUGGED INTO SCR _____
11. VERIFY SECTION 10, "UHI VALVE CONTROL SYSTEMS", IS COMPLETED _____
12. SET POWER KEYSWITCH TO G-LOOP POSITION. _____
13. REMOVE BREAKER BAR AND RESET IN OFF POSITION. _____
14. ARM BREAKER USING KEYSWITCH ON TEST DIRECTOR'S CONSOLE. _____
15. VERIFY INSTRUMENT PANEL POWER ON. _____
16. VERIFY SCR KEYSWITCH OFF. _____
17. TURN POWER RECORDERS (2) TO STANDBY. _____
18. TURN CRITICAL THERMOCOUPLE RECORDER TO STANDBY. _____

19. SCR COOLANT WATER ON (i.e., SER ORANGE LIGHTS ON). _____
20. CHECK SCR KNIFE SWITCHES OPEN (i.e.SCR BREAKER ORANGE LIGHTS ON). _____
21. VERIFY ALL SCR CURRENT TRANSFORMER GREEN LIGHTS ON. _____
22. SET SCR MODE SWITCH TO POWER. _____
23. SET SCR INPUT SWITCH TO AUTO. _____
24. SCR SELECT SWITCHES SET AND VERIFIED PER "SCR SETTING TABLE" _____
25. SCR LIMIT SWITCHES SET AND VERIFIED PER "SCR SETTING TABLE". _____
26. HEATER ROD CIRCUIT BREAKERS CLOSED PER "CIRCUIT BREAKER SETTING TABLE." _____
27. VERIFY O-RING COOLING SYSTEM FUNCTIONING. _____
28. TURN RED LIGHTS TO FLASHING. _____
29. MARK MULTIPOINT RECORDER TIME LINES @ _____
(TIME) _____
30. ADJUST V-2/V-;6 TL-101 TO CLOSE V-16. _____
31. SWITCH V-2/V-16 TL-101 TO LOCAL POSITION. _____
32. ADJUST V-2/V-16 TL-101 SETPOINT TO _____ % _____
33. SWITCH V-2/V-16 TL-101 TO AUTO. _____
- COMPLETE STEPS 34 THROUGH 76 TO CONDUCT RUN _____
34. ADJUST V-1 TL-101 TO CLOSE V-1. _____
35. COMPLETE STEPS 3,7,AND 11 OF SECTION 6 "PRE-RUN PROCEDURES" TO PRESSURIZE FLASH CHAMBER WITH N₂ _____
36. FLASH CHAMBER HEATER SWITCHES OFF. _____
37. RCP-2 OFF. _____
38. OPEN V-1M. _____
39. CLOSE DV-14 TO RCP-3. _____
40. MONITOR CHANNELS _____, _____, _____, _____, _____, _____ ON COMPUTER USING TCSSS. _____
41. FILL TEST VESSEL TO _____ FEET ABOVE BOTTOM OF HEATED LENGTH (_____ % ON LT-535 A) BY OPENING V-1 SLIGHTLY. ALLOW TEST VESSEL AND BAFFLE LEVEL TO STABILIZE. _____
42. CLOSE V-1. _____
43. CLOSE V-1M. _____
44. DUMP N₂ REGULATOR DOME. _____
45. CLOSE V-18A. _____
46. CALL DACPSB INTO COMPUTER AND ENTER INFORMATION PER "DACPSB INFORMATION TABLE". _____
47. CLOSE ALL SCR KNIFE SWITCHES@ _____.
(TIME) _____

- 48. ANNOUNCE: "ATTENTION ALL HIGH BAY PERSONNEL, CLEAR THE G-LOOP ECCS TEST FACILITY. THIS IS A POWER RUN. POWER WILL BE INITIATED WHEN THE ALERT IS SOUNDED". _____
- 49. SWITCH TIMER TO AUTO. _____
- 50. SWITCH ENABLE/DISABLE SWITCH TO ENABLE. _____
- 51. SWITCH PROCEED/HOLD SWITCH TO HOLD. _____
- 52. CONFIRM INTERLOCK LIGHTS ARE OUT. _____
- 53. MARK ALL RECORDERS @ _____
(TIME) _____
- 54. ENTER "GO (CR)" INTO COMPUTER. _____
- 55. RCP-3 OFF. _____
- 56. DV-22 CLOSED. _____
- 57. START CRITICAL THERMOCOUPLE RECORDER. _____
- 58. START POWER RECORDERS (2). _____
- 59. ANNOUNCE: "THIS IS AN ECCS POWER INITIATION ALERT", AND SOUND ALERT. _____
- 60. BEGIN COUNTDOWN:
 - 5. _____
 - 4. STEAM PROBES ON _____
 - 3. _____
 - 2. _____
 - 1. KEY ON _____
 - 0. PUSH SCR START BUTTON _____ RUN _____ WILL BEGIN
- 61. VERIFY ALL SCR POWER RED LIGHTS ON. _____
FRACTIONAL POWER= _____.
- 62. AT THE FOLLOWING RUN TIMES, PERFORM THE ACTIONS INDICATED:
 - a. AT t= _____ sec, SEPARATOR #1 HEATERS OFF. _____
- 63. THE FOLLOWING ACTIONS OCCUR AT THE TIMES INDICATED:
 - t= _____ SEC, V-16 CONTROLS PRESSURE _____
 - t= _____ SEC, BUNDLE POWER ON _____
 - t= _____ SEC, BUNDLE POWER OFF _____
 - t= _____ SEC, END OF RUN _____
- 64. DO NOT PUSH STOP. _____
- 65. CHECK SCR CABINET LIGHTS OFF. _____
- 66. TYPE "Y(CR)" IN RESPONSE TO "SAVE DATA?" _____
- 67. PERFORM ROLLOUT AND RUN DRP. _____
- 68. PUSH STOP. _____
- 69. KEY OFF. _____

- 70. STEAM PROVES OFF. _____
- 71. STOP POWER RECORDERS (2) _____
- 72. STOP CRITICAL THERMOCOUPLE RECORDER. _____
- 73. ANNOUNCE: "G-LOOP FACILITY POWER IS OFF." _____
- 74. SEPARATOR #1 HEATERS ON. _____
- 75. OPEN DV-22. _____
- 76. RCP-3 ON. _____
- COMPLETE STEPS 77 THROUGH 114 TO CONDUCT RUN _____
- 77. COMPLETE STEPS 2,4,5,9, and 19 OF SECTION 6 "PRE-RUN PROCEDURES"
TO PRESSURIZE UHI ACCUMULATORS WITH N₂. _____
- 78. UHI ACCUMULATOR HEATER SWITCHES OFF. _____
- 79. RCP-1 OFF. _____
- 80. CLOSE BV-3. _____
- 81. ADJUST V-3 TL-101 TO CLOSE V-3. _____
- 82. OPEN V-5. _____
- 83. MONITOR CHANNELS _____,
ON COMPUTER USING TCSSS. _____
- 84. SUPPLY WATER TO TEST VESSEL FOR COOLING BUNDLE BY OPENING
V-1 SLIGHTLY. FILL TEST VESSEL TO _____ FT ABOVE BOTTOM
OF HEATED LENGTH(_____ % ON LT-535A). ALLOW TEST VESSEL AND
BAFFLE LEVEL TO STABILIZE. MAINTAIN LEVEL BY OPERATING DV-1. _____
- 85. ADJUST V-3 TL-101 TO CLOSE V-3. _____
- 86. CLOSE DV-1. _____
- 87. CLOSE V-5. _____
- 88. CALL DACPSB INTO COMPUTER AND ENTER INFORMATION PER "DACPSB
INFORMATION TABLE". _____
- 89. ANNOUNCE: "ATTENTION ALL HIGH BAY PERSONNEL, CLEAR THE G-LOOP
ECCS TEST FACILITY. THIS IS A POWER RUN. POWER WILL BE
INITIATED WHEN THE ALERT IS SOUNDED. _____
- 90. SWITCH TIMER TO AUTO AND RESET TO ZERO. _____
- 91. MARK ALL RECORDERS @ _____
(TIME) . _____
- 92. ENTER "GO(CR)" INTO COMPUTER. _____
- 93. RCP-3 OFF. _____
- 94. DV-22 CLOSED. _____
- 95. START CRITICAL THERMOCOUPLE RECORDER. _____
- 96. START POWER RECORDERS (2). _____
- 97. ANNOUNCE: "THIS IS AN ECCS POWER INITIATION ALERT", AND
SOUND ALERT. _____

98. BEGIN COUNTDOWN: _____
- 5. _____
 - 4. STEAM PROBES ON _____
 - 3. _____
 - 2. _____
 - 1. KEY ON _____
 - 0. PUSH SCR START BUTTON _____ RUN _____ WILL BEGIN
99. VERIFY ALL SCR POWER RED LIGHTS ON. FRACTIONAL POWER = _____
100. AT THE FOLLOWING RUN TIMES, PERFORM THE ACTIONS INDICATED:
- a. AT t= _____ SEC, SEPARATOR #1 HEATERS OFF. _____
101. THE FOLLOWING ACTIONS OCCUR AT THE TIMES INDICATED: _____
- t= _____ SEC, V-16 CONTROLS PRESSURE
 - t= _____ SEC, BUNDLE POWER ON
 - t= _____ SEC, BUNDLE POWER OFF
 - t= _____ SEC, END OF RUN _____
102. DO NOT PUSH STOP. _____
103. CHECK SCR CABINET LIGHTS OFF. _____
104. TYPE "Y (CR)" IN RESPONSE TO "SAVE DATA?" _____
105. PERFORM ROLLOUT AND RUN DRP. _____
106. PUSH STOP. _____
107. KEY OFF. _____
108. STEAM PROBES OFF. _____
109. STOP POWER RECORDERS (2). _____
110. STOP CRITICAL THERMOCOUPLE RECORDER. _____
111. ANNOUNCE: "G-LOOP FACILITY POWER IS OFF." _____
112. SEPARATOR #1 HEATERS ON. _____
113. OPEN DV-22. _____
114. RCP-3 ON. _____
- COMPLETE STEPS 115 THROUGH 147 TO CONDUCT RUN _____
115. OPEN V-5 _____
116. MONITOR CHANNELS _____, _____, _____, _____, _____, _____ ON COMPUTER USING TCSSS. _____
117. SUPPLY WATER TO TEST VESSEL FOR COOLING BUNDLE BY OPENING V-1 SLIGHTLY. FILL TEST VESSEL TO _____ FEET ABOVE BOTTOM OF HEATED LENGTH (_____ % ON LT-535A). ALLOW TEST VESSEL AND BAFFLE LEVEL TO STABILIZÉ. MAINTAIN LEVEL BY OPERATING DV-1 _____

- 118. ADJUST V-3 TL-101 TO CLOSE V-3 _____
 - 119. CLOSE DV-1 _____
 - 120. CLOSE V-5 _____
 - 121. CALL DACPSB INTO COMPUTER AND ENTER INFORMATION PER "DACPSB INFORMATION TABLE". _____
 - 122. ANNOUNCE: "ATTENTION ALL HIGH BAY PERSONNEL, CLEAR THE G-LOOP ECCS TEST FACILITY. THIS IS A POWER RUN. POWER WILL BE INITIATED WHEN THE ALERT IS SOUNDED." _____
 - 123. SWITCH TIMER TO AUTO AND RESET TO ZERO. _____
 - 124. MARK ALL RECORDERS @ _____
(TIME)
 - 125. ENTER "GO(CR)" INTO COMPUTER. _____
 - 126. RCP-3 OFF. _____
 - 127. DV-22 CLOSED. _____
 - 128. START CRITICAL THERMOCOUPLE RECORDER. _____
 - 129. START POWER RECORDERS (2). _____
 - 130. ANNOUNCE: "THIS IS AN ECCS POWER INITIATION ALERT," AND SOUND ALERT. _____
 - 131. BEGIN COUNTDOWN:
 - 5. _____
 - 4. STEAM PROBES ON _____
 - 3. _____
 - 2. _____
 - 1. KEY ON _____
 - 0. PUSH SCR START BUTTON _____
- RUN _____ WILL BEGIN
- 132. VERIFY ALL SCR POWER RED LIGHTS ON. _____
 - 133. AT THE FOLLOWING RUN TIMES, PERFORM THE ACTIONS INDICATED: _____
 - a. AT t= _____ SEC, SEPARATOR #1 HEATERS OFF.
 - 134. THE FOLLOWING ACTIONS OCCUR AT THE TIMES INDICATED: _____
 - t= _____ SEC, V-16 CONTROLS PRESSURE
 - t= _____ SEC, BUNDLE POWER ON
 - t= _____ SEC, BUNDLE POWER OFF
 - t= _____ SEC, END OF RUN _____
 - 135. DO NOT PUSH STOP. _____
 - 136. CHECK SCR CABINET LIGHTS OFF. _____
 - 137. TYPE "Y(CR)" IN RESPONSE TO "SAVE DATA?" _____
 - 138. PERFORM ROLLOUT AND RUN DRP. _____

164. BEGIN COUNTDOWN: _____
5. _____
4. _____
3. _____
2. _____
1. _____
0. _____ RUN _____ WILL BEGIN
165. VERIFY ALL SCR POWER RED LIGHTS ON. _____
FRACTIONAL POWER = _____
166. AT THE FOLLOWING RUN TIMES, PERFORM THE ACTIONS INDICATED:
a. AT t = _____ SEC, SEPARATOR #1 HEATERS OFF. _____
167. THE FOLLOWING ACTIONS OCCUR AT THE TIMES INDICATED: _____
t = _____ SEC, V-16 CONTROLS PRESSURE
t = _____ SEC, BUNDLE POWER ON
t = _____ SEC, BUNDLE POWER OFF
t = _____ SEC, END OF RUN _____
168. DO NOT PUSH STOP. _____
169. CHECK SCR CABINET LIGHTS OFF. _____
170. TYPE "Y (CR)" IN RESPONSE TO "SAVE DATA?". _____
171. PERFORM ROLLOUT AND RUN DRP. _____
172. PUSH STOP. _____
173. KEY OFF. _____
174. STEAM PROBES OFF. _____
175. STOP POWER RECORDERS (2). _____
176. STOP CRITICAL THERMOCOUPLE RECORDER. _____
177. ANNOUNCE: "G-LOOP FACILITY POWER IS OFF." _____
178. SEPARATOR #1 HEATERS ON. _____
179. OPEN DV-22. _____
180. RCP-3 ON. _____
COMPLETE STEPS 181 THROUGH 210 TO CONDUCT RUN _____
181. OPEN V-5. _____
182. MONITOR CHANNELS _____, _____, _____, _____, _____,
_____, ON COMPUTER USING TCSSS. _____
183. SUPPLY WATER TO TEST VESSEL FOR COOLING BUNDLE BY OPENING
V-1 SLIGHTLY. FILL TEST VESSEL TO _____ FEET ABOVE BOTTOM
OF HEATED LENGTH (_____ % ON LT-535A). ALLOW TEST VESSEL
AND BAFFLE LEVEL TO STABILIZE. MAINTAIN LEVEL BY OPERATING
DV-1.

- 184. ADJUST V-3 TL-101 TO CLOSE V-3. _____
- 185. CLOSE DV-1. _____
- 186. CLOSE V-5. _____
- 187. CALL DACPSB INTO COMPUTER AND ENTER INFORMATION PER "DACPSB INFORMATION TABLE". _____
- 188. ANNOUNCE: "ATTENTION ALL HIGH BAY PERSONNEL, CLEAR THE G-LOOP ECCS TEST FACILITY. THIS IS A POWER RUN. POWER WILL BE INITIATED WHEN THE ALERT IS SOUNDED." _____
- 189. SWITCH TIMER TO AUTO AND RESET TO ZERO. _____
- 190. MARK ALL RECORDERS @ _____ .
(TIME) _____
- 191. ENTER "GO (CR)" INTO COMPUTER. _____
- 192. RCP-3 OFF. _____
- 193. DV-22 CLOSED. _____
- 194. START CRITICAL THERMOCOUPLE RECORDER. _____
- 195. START POWER RECORDERS (2). _____
- 196. ANNOUNCE: "THIS IS AN ECCS POWER INITIATION ALERT", AND SOUND ALERT. _____
- 197. BEGIN COUNTDOWN:
 - 5. _____
 - 4. Steam Probes On _____
 - 3. _____
 - 2. _____
 - 1. Key On _____
 - 0. Push SCR Start Button Run _____ Will Begin
- 198. VERIFY ALL SCR POWER RED LIGHTS ON. _____
FRACTIONAL POWER = _____.
- 199. AT THE FOLLOWING RUN TIMES, PERFORM THE ACTIONS INDICATED;
 - a. AT t = _____ SEC, SEPARATOR #1 HEATERS OFF. _____
- 200. THE FOLLOWING ACTIONS OCCUR AT THE TIMES INDICATED:
 - t = _____ SEC, V-16 CONTROLS PRESSURE
 - t = _____ SEC, BUNDLE POWER ON
 - t = _____ SEC, BUNDLE POWER OFF
 - t = _____ SEC, END OF RUN _____
- 201. DO NOT PUSH STOP. _____
- 202. CHECK SCR CABINET LIGHTS OFF. _____
- 203. TYPE "Y (CR)" IN RESPONSE TO "SAVE DATA?" _____
- 204. PERFORM ROLLOUT AND RUN DRP. _____

- 205. PUSH STOP. _____
- 206. KEY OFF. _____
- 207. STEAM PROBES OFF. _____
- 208. STOP POWER RECORDERS (2). _____
- 209. STOP CRITICAL THERMOCOUPLE RECORDER. _____
- 210. ANNOUNCE: "G-LOOP FACILITY POWER IS OFF."
WHEN READY TO TERMINATE TESTING, PROCEED TO STEP 211. _____
- 211. DUMP N₂ REGULATOR DOMES. _____
- 212. SEPARATOR #1 HEATERS ON. _____
- 213. OPEN DV-22. _____
- 214. OPEN DV-14. _____
- 215. RCP-3 ON. _____
- 216. ADJUST SYSTEM PRESSURE TO _____ PSIG BY OPERATING
V-2/V-16 TL-101 SETPOINT THUMBWHEEL. _____
- 217. SWITCH V-2/V-16 TL-101 TO MANUAL AND CLOSE USING MANUAL
THUMBWHEEL. _____
- 218. TURN RED LIGHTS TO STEADY. _____
- 219. COMPLETE SECTION 7 "POST RUN PROCEDURES". _____
- 220. DISARM BREAKER USING KEYSWITCH ON TEST DIRECTORS CONSOLE. _____
- 221. CHECK BREAKER IS IN THE OFF POSITION AND INSERT LOCK BAR
AND LOCK. _____
- 222. TAPE RECORDER OFF AT TAPE METER POSITION _____.

Appendix E

BAFFLE SEAL LEAKAGE

INTRODUCTION

After initial blowdown testing in the G-2 Loop facility and prior to performing the core uncover tests, baffle seal leakage checks were made and forced flooding tests were run to check out the facility. This appendix describes the baffle leakage tests performed to determine the magnitude and the axial distribution of the leakage between the rod bundle region and the cavity behind the flow baffle. The data have shown that most of the leakage paths occurred above the baffle midplane. This observation led to the decision to run the core uncover tests with the baffle/vessel cavity prefilled to the same initial level as the bundle.

DESCRIPTION OF G-2 LOOP BAFFLE SEALS

The G-2 Loop baffle was constructed from four 304 stainless steel plates, each 177 in. (4.50 m) long by about 11 in. (0.28 m) wide, which formed a flow boundary around the rod bundle (Figure E-1). The seal along the four vertical edges of the baffle consists of 0.125 in. OD by 0.02 in. wall by 177-in. long (3.2 cm OD by 0.05 cm wall by 4.50 m long) Inconel tubing placed in 0.147 in. wide by 0.095 in. deep (0.373 cm wide by 0.24 cm wide) grooves in the baffle flanges (Figure E-2). The curved portion of the mating flange was designed to remain in contact with the Inconel tubing as the baffle is flexed under thermal stresses. The baffle plates are bolted along the axial flanges with 1/2 in. (1.3 cm) bolts placed at 2 in. (5 cm) intervals using Belleville springs under the bolt heads.

At the top (Figure E-3), each baffle plate is bolted to the upper seal ring with five 1/2 in. (1.3 cm) bolts. There is no O-ring or gasket between the baffle top flanges and the upper seal plate. (The seal gasket is between the seal ring and the seal plate.)

At the bottom (Figure E-4), each baffle plate is bolted to the lower seal ring with five 3/4 in. (1.9 cm) bolts. A metal O-ring serves as a seal between the baffle flange and the lower seal ring. A room-temperature vulcanizing material (RTV) was applied to effect a seal at the junction of this O-ring with the vertical Inconel tube seal.

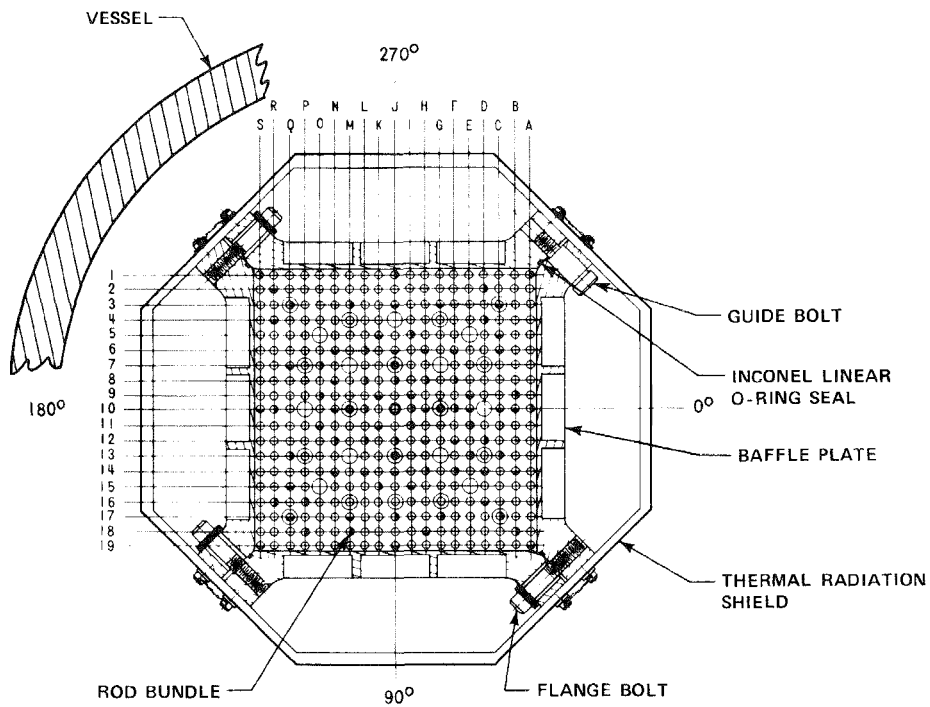


Figure E-1. G-2 Loop Bundle, Baffle, and Thermal Shield

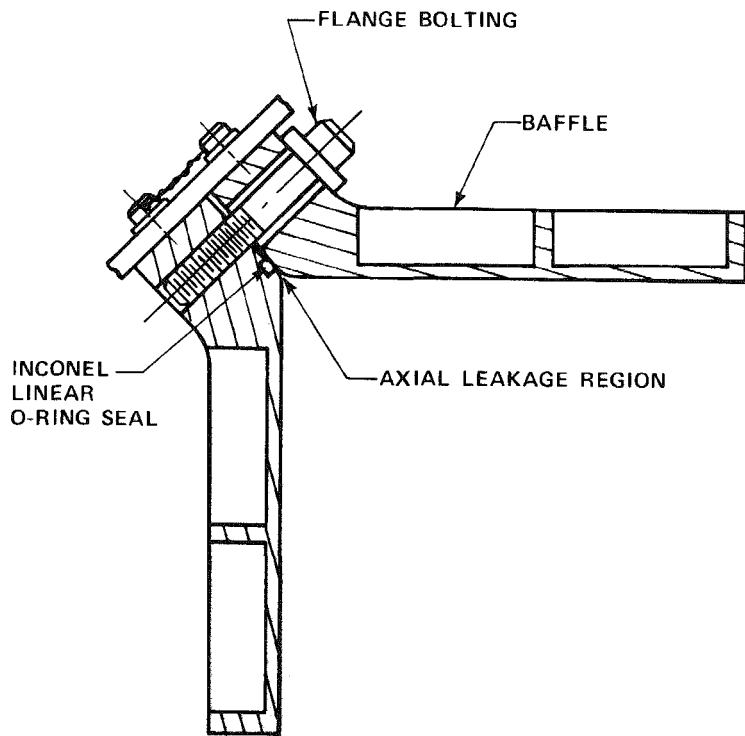


Figure E-2. G-2 Loop Axial Seal Region

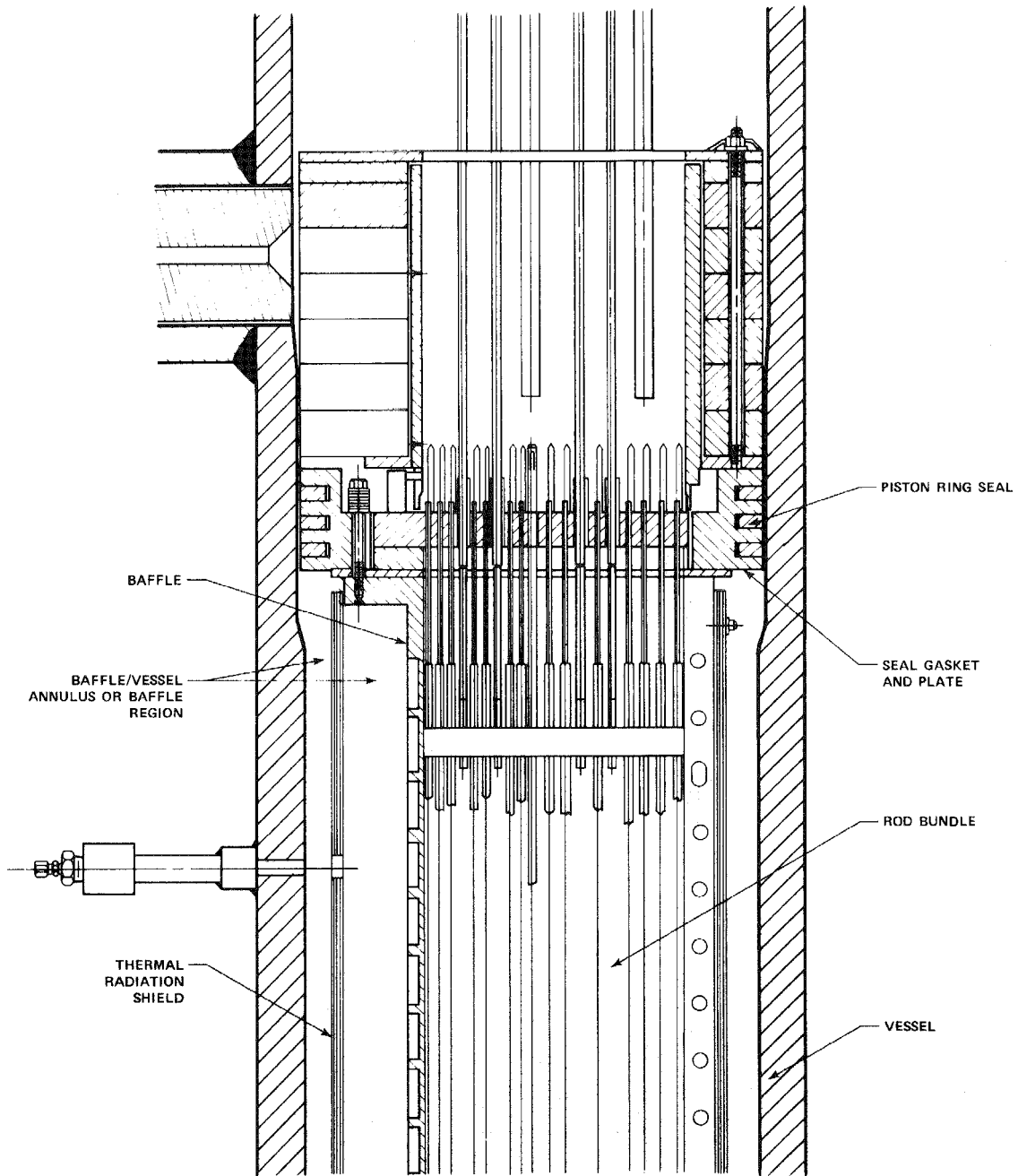


Figure E-3. G-2 Loop Upper Piston Ring Seal

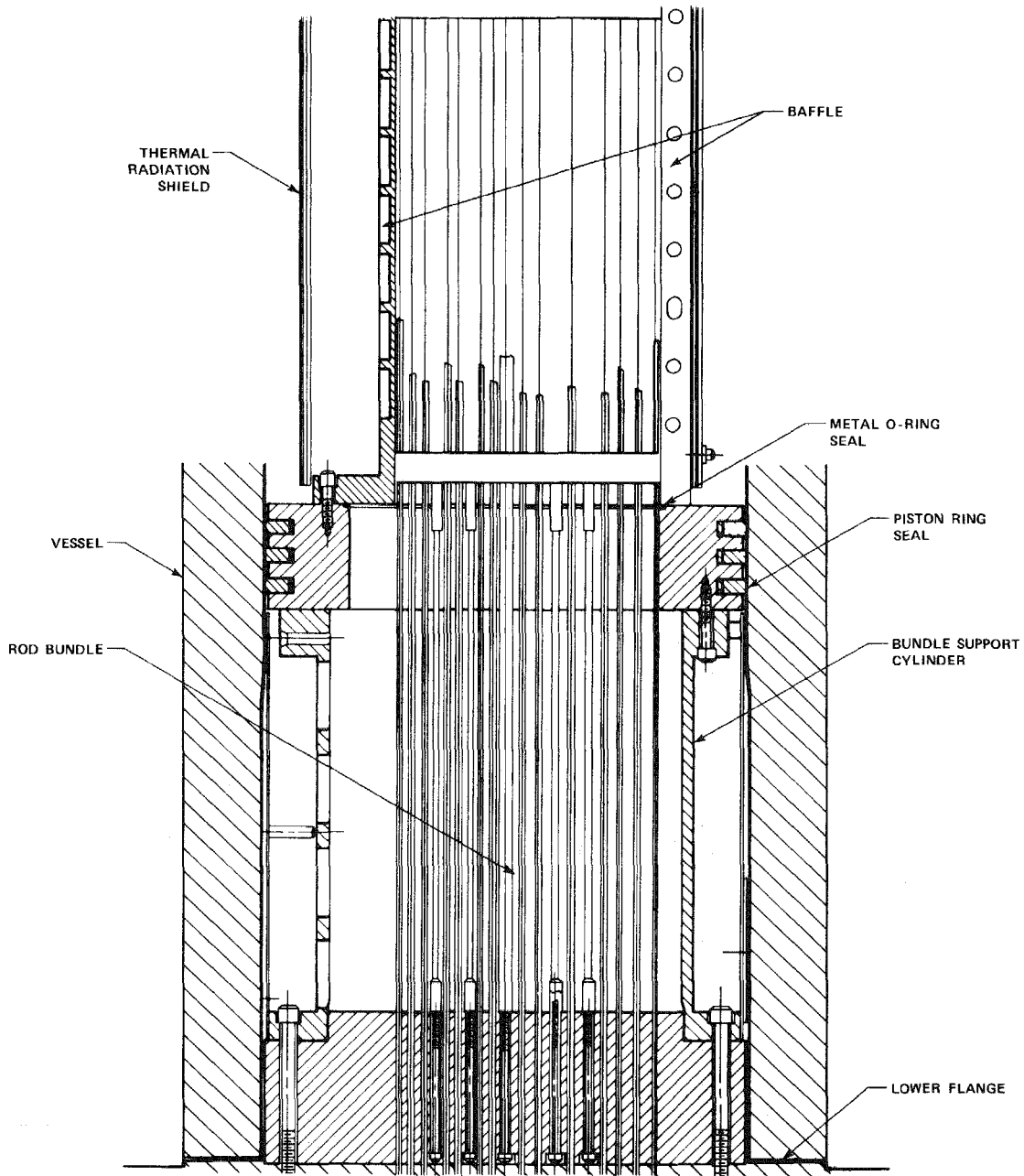


Figure E-4. G-2 Loop Lower Piston Ring Seal

BACKGROUND OF BAFFLE LEAKAGE TESTS

After the G-2 Loop bundle was installed in the test vessel, and before the bundle and baffle were ever heated up either with steam or by application of power to the heater rods, a baffle leak test was performed to check the effectiveness of the baffle seals. The test consisted of filling the baffle region (the cavity between the baffle and the vessel wall) with water at ambient conditions to a level of approximately 10 ft (3.05 m) and measuring the volume of the water that leaked from the baffle region into the bundle region and collected in the lower plenum during a 15-minute period. The water level in the baffle region during this period dropped from 121.875 in. (3.10 m) to 95.875 in. (2.44 m); that is, it was essentially constant at about 10 ft (3.05 m). The leakage rate from the baffle region into the bundle region calculated from this measurement was 0.015 lb/sec (0.0068 kg/sec). This amount of leakage, less than 1 percent of the forced flood flow rate of 1.75 lb/sec (0.79 kg/sec) [equivalent to 1 in./sec (2.5 cm/sec) flooding rate], was considered acceptable for all tests planned at that time. Under forced flooding conditions at 40 psia (0.28 MPa) [$T_{\text{sat}} = 267^{\circ}\text{F}$ (131°C)], this leakage rate extrapolates to 0.056 lb/sec (0.025 kg/sec), or 3.2 percent of the 1.75 lb/sec (0.79 kg/sec) flooding rate. The above extrapolation was based on laminar flow assumptions (that is, flow rate is directly proportional to pressure drop and inversely proportional to fluid viscosity); a lower leakage rate would result under turbulent flow conditions.

After the above leakage test, a number of forced flooding shakedown tests without baffle/vessel cavity prefill were run which (depending on run duration) indicated either negligible, or for tests which ran much beyond 100 seconds, substantial accumulation of water behind the baffle (as indicated on DP cell 635 measuring axial pressure drop).

Although the amount of accumulation behind the baffle varied from run to run, all of the G-2 Loop flooding tests performed indicated that there was little accumulation of water behind the baffle during the first 100 seconds of the run. This observation suggested that the flood water ("solid" water or low-void-fraction two-phase flow) must reach a certain height in the bundle before it finds a significant leakage area on the baffle. The leakage tests described below, identified as 9/13, 9/14, and 9/17, were performed to (1) determine the leakage rate from the bundle into the region behind the baffle (since in the original baffle seal test the flow was from the baffle into the bundle region), and (2) obtain leakage rates as a function of the height of water level maintained in the bundle.

LEAKAGE TESTS 9/13, 9/14, AND 9/17

Procedure

In the 9/13 test, the baffle was preheated with saturated steam at 60 psig (0.52 MPa) [293⁰F (145⁰C)] and the bundle region was flooded with room-temperature water at atmospheric pressure to levels of 25, 41.8, and 69 in. (0.64, 1.06, and 1.75 m) above the bottom of the baffle annulus (that is, above the beginning of the heated length of the rods). These levels were maintained constant during the measurement of leakage by manual adjustment of the deionized water supply. From one of the pressure taps at the bottom of the baffle, a tube was run to a collection tank; the other tap was connected to a sight gage to assure that no water level was building up behind the baffle. This test was limited to a maximum level of 69 in. (1.75 m) by the capacity of the deionized water supply.

The procedure in the 9/14 test was the same as in the 9/13 test except that the water levels maintained in the bundle were at 63, 88, 107, 146, 152, and 176 in. (1.60, 2.24, 2.72, 3.71, 3.86, and 4.47 m) from the bottom of the baffle. The water was supplied from the reflood tank and the deionized water supply.

The 9/17 test was like the 9/14 test but the baffle was not preheated and the water levels maintained in the bundle were at 27, 42, 68, 92, 103, 122, and 146 in. (0.69, 1.07, 1.73, 2.34, 2.62, 3.10, and 3.71 m) from the bottom of the baffle.

Results

The leakage rates calculated from the 9/13, 9/14, and 9/17 data are shown as a function of vessel water level (referenced to the bottom of the baffle region) in Tables E-1 through E-3 and in Figure E-5, and are also summarized in Table E-4. The most important information provided by these data was the fact that, at a comparable head, the leakage rates were greater than in the original test. This raised the question of whether this increase was an indication of an increase in the leakage flow area subsequent to the original test, or whether it was due to a lower hydraulic resistance associated with the direction of leakage flow from the baffle annulus into the bundle region. Another important fact is that a significant change in leakage rate occurred when the water level in the baffle annulus was raised above a certain level. [The 9/14 data show this level to be somewhere between 88.5 and 107.5 in. (2.25 and 2.73 m)].

Table E-1
9/13 TEST BAFFLE LEAKAGE RATES

Water Level in Bundle Region ^(a) [in. (m)]	Water Temperature ^(b) [°F (°C)]	Leakage Rate ^(c) [lb/sec (kg/sec)]
25 (0.64)	100 (38)	0.011 (0.0050)
25 (0.64)	100 (38)	0.011 (0.0050)
41.8 (1.06)	125 (52)	0.023 (0.010)
41.8 (1.06)	125 (52)	0.022 (0.010)
41.8 (1.06)	125 (52)	0.021 (0.0095)
69 (1.75)	200 (93)	0.103 (0.0467)
69 (1.75)	200 (93)	0.075 (0.034)
69 (1.75)	200 (93)	0.067 (0.030)
69 (1.75)	200 (93)	0.060 (0.027)

- a. Above bottom of baffle/vessel annulus
- b. From baffle temperature data
- c. From collection tank data

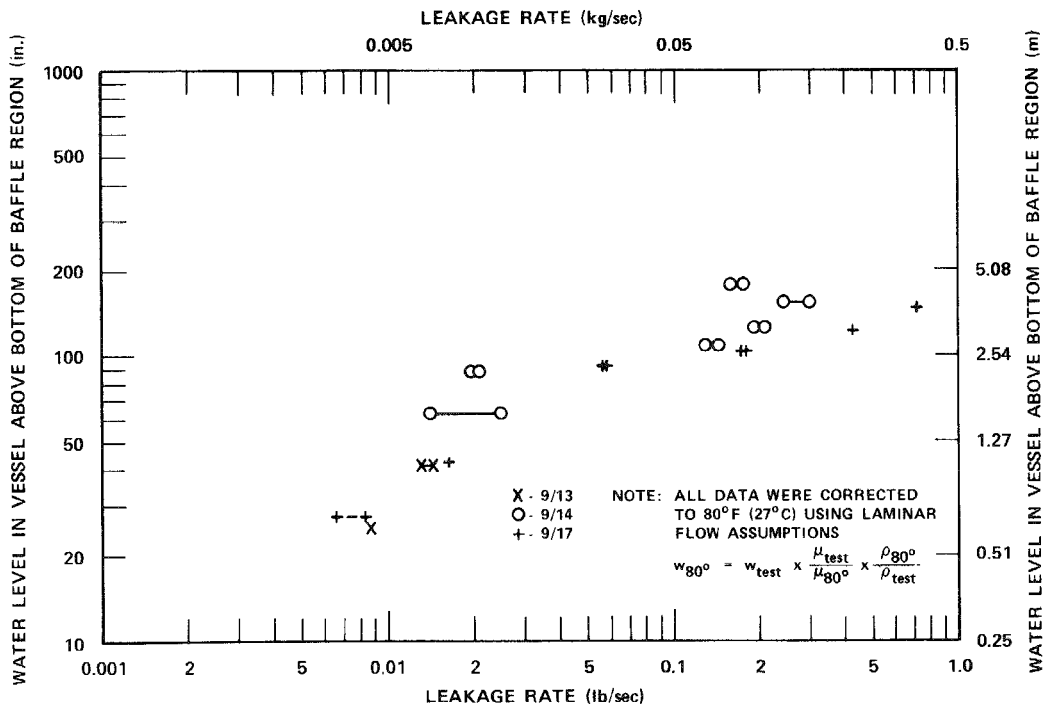


Figure E-5. G-2 Loop Baffle Leakage Data

Table E-2

9/14 TEST BAFFLE LEAKAGE RATES

Water Level in Bundle Region (a) [in. (m)]	Water Temperature(b) [°F (°C)]	Leakage Rate(c) [lb/sec (kg/sec)]
63.5 (1.61)	90 (32)	0.028 (0.013)
63.5 (1.61)	90 (32)	0.024 (0.011)
63.5 (1.61)	90 (32)	0.022 (0.010)
63.5 (1.61)	90 (32)	0.022 (0.010)
63.5 (1.61)	90 (32)	0.020 (0.0091)
63.5 (1.61)	91 (33)	0.019 (0.0086)
63.5 (1.61)	91 (33)	0.019 (0.0086)
63.5 (1.61)	92 (33)	0.018 (0.0082)
63.5 (1.61)	92 (33)	0.017 (0.0077)
63.5 (1.61)	92 (33)	0.016 (0.0073)
88.5 (2.25)	92 (33)	0.024 (0.011)
88.5 (2.25)	92 (33)	0.024 (0.011)
88.5 (2.25)	91 (33)	0.023 (0.010)
88.5 (2.25)	90 (32)	0.022 (0.010)
88.5 (2.25)	90 (32)	0.022 (0.010)
107.5 (2.73)	117 (47)	0.196 (0.0889)
107.5 (2.73)	117 (47)	0.206 (0.0934)
107.5 (2.73)	113 (45)	0.206 (0.0934)
107.5 (2.73)	110 (43)	0.200 (0.0907)
146.0 (3.71)	99 (37)	0.244 (0.111)
146.0 (3.71)	97 (36)	0.249 (0.113)
146.0 (3.71)	95 (35)	0.248 (0.112)
152.5 (3.87)	90 (32)	0.337 (0.153)
152.5 (3.87)	90 (32)	0.313 (0.142)
152.5 (3.87)	90 (32)	0.300 (0.136)
152.5 (3.87)	90 (32)	0.277 (0.126)
176.5 (4.48)	90 (32)	0.199 (0.0902)
176.5 (4.48)	91 (33)	0.183 (0.0830)

- a. Above bottom of baffle/vessel annulus
- b. In collection tank
- c. From collection tank data

Table E-3

9/17 TEST BAFFLE LEAKAGE RATES

Water Level in Bundle Region (a) [in. (m)]	Water Temperature(b) [°F (°C)]	Leakage Rate(c) [lb/sec (kg/sec)]
27.5 (0.70)	79 (26)	0.006 (0.003)
27.5 (0.70)	79 (26)	0.007 (0.003)
27.5 (0.70)	79 (26)	0.007 (0.003)
27.5 (0.70)	79 (26)	0.008 (0.004)
27.5 (0.70)	78 (26)	0.008 (0.004)
27.5 (0.70)	78 (26)	0.008 (0.004)
42.5 (1.08)	78 (26)	0.015 (0.007)
42.5 (1.08)	78 (26)	0.016 (0.007)
68.5 (1.74)	77 (25)	0.029 (0.013)
68.5 (1.74)	77 (25)	0.029 (0.013)
92.5 (2.35)	78 (26)	0.055 (0.025)
92.5 (2.35)	78 (26)	0.056 (0.025)
92.5 (2.35)	79 (26)	0.056 (0.025)
103.5 (2.63)	77 (25)	0.170 (0.0771)
103.5 (2.63)	77 (25)	0.171 (0.0775)
103.5 (2.63)	78 (26)	0.169 (0.0766)
103.5 (2.63)	80 (27)	0.174 (0.0789)
103.5 (2.63)	80 (27)	0.175 (0.794)
122.5 (3.11)	80 (27)	0.437 (0.198)
122.5 (3.11)	80 (27)	0.437 (0.198)
146.5 (3.72)	80 (27)	0.707 (0.321)

- a. Above bottom of baffle/vessel annulus
- b. From baffle temperature data
- c. From collection tank data

Table E-4

SUMMARY OF BAFFLE LEAKAGE TESTS 9/13, 9/14, AND 9/17

Test	Baffle Preheat [°F (°C)]	Leakage Direction	Water Level Maintained in Bundle Region [in. (m)]	Measured Leakage Rate ^(c) [lb/sec (kg/sec)]
9/13	293(a) (145)	Bundle to baffle/ vessel cavity	25, 42, 69 (0.64, 1.07, 1.75)	0.01, 0.02, 0.07 (0.005, 0.009, 0.03)
9/14	293(a) (145)	Bundle to baffle/ vessel cavity	63, 88, 107, 146, 152, 176 (1.60, 2.24, 2.72, 3.71, 3.86, 4.47)	0.02, 0.02, 0.20, 0.25, 0.32, 0.19 (0.009, 0.009, 0.091, 0.11, 0.15, 0.086)
9/17	None ^(b) (room temp.)	Bundle to baffle/ vessel cavity	27, 42, 68, 92, 103, 122, 146 (0.69, 1.07, 1.73, 2.34, 2.62, 3.10, 3.71)	0.007, 0.015, 0.03, 0.06, 0.17, 0.44, 0.71 (0.003, 0.0068, 0.01, 0.03, 0.077, 0.20, 0.32)

a. Saturation temperature at 60 psia (0.41 MPa)

b. Room temperature

c. Typical values (corresponding to the water levels in the adjacent columns)

Occasionally a range of leakage rates was associated with a given vessel level. For example, in the 9/13 test at the 69 in. (1.75 m) level, the leakage rate varied from 0.06 to 0.1 lb/sec (0.03 to 0.05 kg/sec) (Table E-1); in the 9/14 test at the 63 in. (1.60 m) level, the leakage rate varied from 0.016 to 0.028 lb/sec (0.0073 to 0.013 kg/sec) (Table E-2). It is important to note in this connection that the data for these water levels show a decrease in the leakage rate from measurement to measurement (see data in the tables). The explanation for this is that the temperature of the baffle was decreasing during the test, causing the temperature of the water passing through the leakage paths to decrease, hence the viscosity to increase, with time. As noted in Figure E-5, the data plotted have been temperature-corrected to 80°F (27°C), which was the typical temperature for the 9/17 data. For the 9/13 data, the baffle temperature readings obtained after the final leakage measurement were used to estimate the leakage water temperature, as no baffle temperature data were taken during the test. This, of course, did not correct for the variation of temperature with time referred to above. For the 9/14 data, no baffle temperature readings were taken; hence the temperature of the water in the drain tank was used to approximate the temperature of the leakage water. These temperatures were very likely 100°F (56°C) lower than the temperature of the water passing through the leakage paths, and thus the temperature correction of the 9/14 data is very approximate. If more accurate temperature corrections were available, the 9/14 data points shown in Figure E-3 would probably be moved farther to the left.

The 9/17 test data may be considered the best of the three tests (9/13, 9/14, and 9/17) mentioned thus far, because the 9/17 test was performed at ambient temperature (hence at a better-known temperature than the others). To extrapolate these data to the leakage temperatures occurring in forced flooding requires the knowledge of whether the leakage flow is laminar or turbulent. This, however, can only be established if the leakage flow area is known. A determination of the leakage flow area distribution along the baffle flanges could be made from a test like the 9/17 test, but with leakage rates measured for a much larger number of constant vessel levels. A more practical way, however, is to run tests in which the decrease of either the bundle or the baffle region level due to leakage (depending on whether leakage out of the bundle or into the bundle region is the item of interest) is recorded as a function of time. This latter method of testing was adopted in tests 9/25 and 10/24-25, which are discussed below.

LEAKAGE TESTS 9/25 AND 10/24-25

On September 25, 1974, a series of six tests was performed to measure the leakage rate from the baffle/vessel annulus through the baffle into the bundle under ambient

temperature and pressure conditions. For these tests the lower end of the vessel sight glass was connected to the lower tap of DP cell 635 (baffle water level transmitter), and the upper end of the sight glass was open to the atmosphere. The baffle-to-hot-leg valve V-18A and the loop exhaust valve were open, and the system was at ambient conditions. For each test the annulus was filled or partially filled, and a drain from the bottom of the test vessel was left open to drain the leakage flow. The test was started after the water supply to the annulus had been turned off. As the water level in the annulus fell, level records were taken at regular intervals either manually from the sight glass or by computer from DP cell 635. The level ranges and time durations of the test were as follows:

<u>Test No.</u>	<u>Level Range [in. (m) above bottom of heated length]</u>	<u>Time</u>	<u>Alternate Test No. (on computer record)</u>
1	177-85.25 (4.50-2.17)	1200 sec	--
2	177-85.75 (4.50-2.18)	1200 sec	--
3	177-99.5 (4.50-2.53)	600 sec	BL1
4	99.5-86 (2.53-2.18)	600 sec	BL2
5	86-80.75 (2.18-2.05)	600 sec	BL3
6	156-73.5 (3.96-1.87)	~1 hr	0

The water temperature for all tests was about 78°F (26°C).

A plot of level versus time for one of these tests is shown in Figure E-6. The irregularity in the region of the 165 in. (4.19 m) level has two causes. First, when the vessel nozzle centerline at 165 in. (4.19 m) connecting to V-18A was covered, there was no escape for the water above the nozzle in the annulus except as air leaked into the annulus to replace it. Thus, if the seal in the upper region was effective, leakage in the lower region would be mostly replaced by a measured fall in the vertical pipe to V-18A, which has a much smaller cross section than the annulus through the pipe, allowing the level to fall in the upper baffle without any change in the indicated level. Thus data with the level in the annulus above about 162 in. (4.11 m) were not used for flow rate determination.

Below the nozzle level, the leakage flow rate was determined by the rate of change of water level behind the baffle, using best estimates of the cross-sectional area

of the annulus. [The actual value of this annular area differed from the nominal 190 in² (0.12 m²) at some elevations because of the several nozzles on the vessel.] Determination of leakage rates was based on the time taken for the level to drop at least 1 to 2 in. (2.5 to 5 cm).

The results of the 9/25 tests are shown in Figure E-7. The several tests gave consistent results, with a total spread from the mean flow of about ± 10 percent at a given level from 80 to 100 in. (2.03 to 2.54 m), and about ± 15 to 20 percent from 100 to 160 in. (2.54 to 4.06 m). This consistency is taken to indicate that the water and baffle temperatures were reasonably constant, and that the baffle geometry was either constant or varied only as a repeatable function of water level, through the series of tests. There was only one flow measurement, at 75 in. (1.90 m), below the 79 in. (2.00 m) level.

The form of the curve defined by the results in Figure E-7 implies no leakage below about 68 in. (1.73 m), a fairly uniform leakage path from 68 to 75 in. (1.73 to 1.90 m) or higher, a concentrated leakage path near the 100 in. (2.54 m) level, and no leakage between 100 and 160 in. (2.54 to 4.06 m). The increase of leakage flow with water level above 100 in. (2.54 m) was apparently caused by the increase in pressure drop across the baffle.

On October 24 and 25, 1974, four tests were performed to measure baffle leakage flow rates both from the bundle outward and from the baffle/vessel annulus inward, and with both hot and cold water. The method of testing was similar to the 9/25 series. Between this series and the 9/25 tests, runs 533 through 539 were carried out, of which runs 536 through 539 had power applied to the rod bundle.

The leakage tests, the run numbers used to identify the GLOOK output, and the techniques used were as follows:⁽¹⁾

- Cold, leakage from bundle out to annulus, runs 26 to 34

With the system open and at ambient conditions, and with the baffle annulus kept empty, the bundle was filled to 199 in. (5.05 m). The water supply was turned off, and the level allowed to drop by leakage. Vessel sight glass readings were recorded manually while the Data Acquisition and Control Program (DACP) automatically recorded data. After 10 minutes, a run was automatically terminated, and

1. In all cases, V-18A was open, and in all runs but one, data were recorded by the computer (but not recorded on magnetic tape).

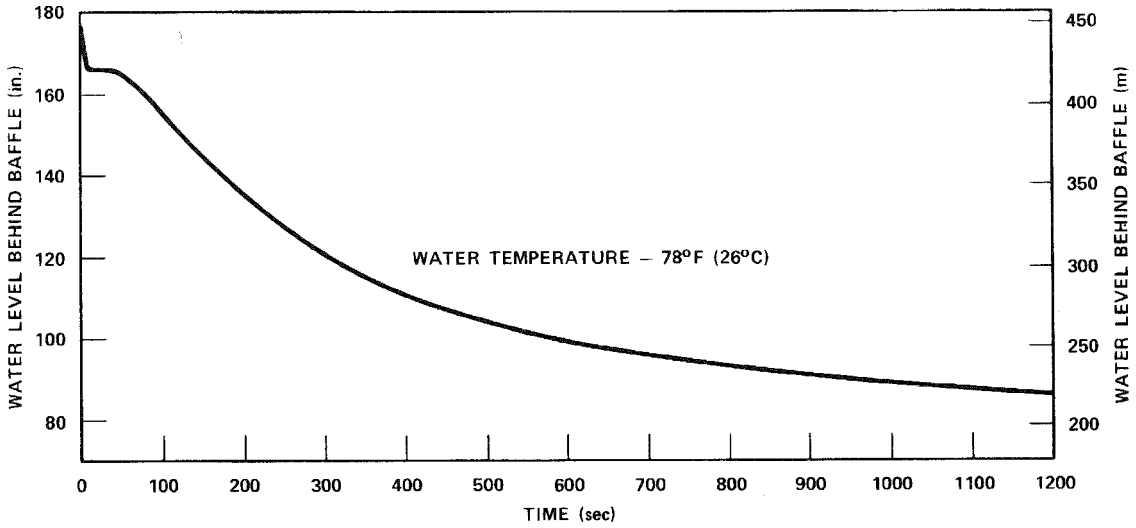


Figure E-6. Cold Baffle Leak Test Flow From Baffle to Bundle

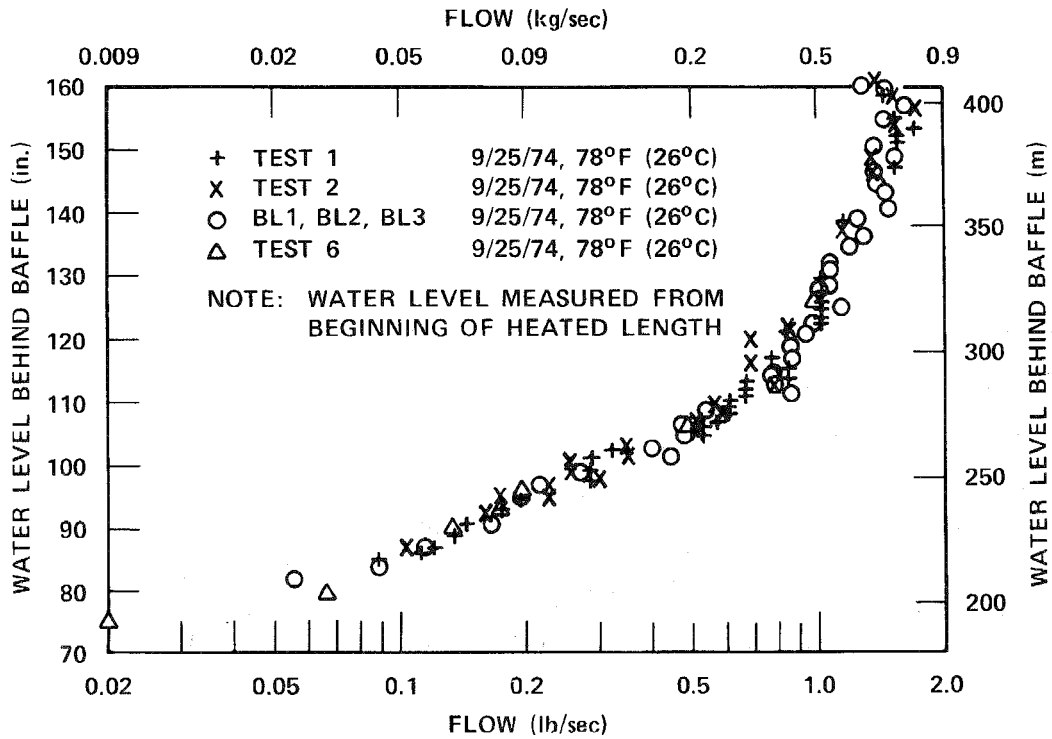


Figure E-7. Cold Baffle Leak Test Results

the recorded data were printed out. The bundle was then refilled to the level reached at the end of the run, and the next run was started. The minimum level reached was 43.5 in. (1.10 m). During the tests, measured rod thimble, steam probe, and baffle temperatures varied between 70°F and 100°F (21°C and 38°C), generally increasing with elevation and slightly with time.

- Cold, leakage from annulus into bundle, runs 35 to 39 plus one unnumbered run

The procedure of runs 26 to 34 was repeated except that the bundle was kept empty, the baffle annulus was filled to a maximum level of 108 in. (2.74 m), and the sight glass level (connected to the lower tap of DP cell 635) was recorded only at the beginning and end of each individual run. After run 39 the computer was unavailable. Therefore, a final run, 1.2 hours long, was made with sight glass readings recorded every 0.25 in. (0.64 cm). The minimum level reached was 63.75 in. (1.62 m). Baffle temperatures varied between 80°F and 90°F (27°C and 32°C).

- Hot, leakage from annulus into bundle, runs 40 to 44

Before the 10/24-25 tests, an attempt had been made to measure leakage flow with slightly subcooled water under 40 psia (0.28 MPa) steam pressure, using techniques similar to those described above. During the attempt the water level was observed first to fall, then to rise. The rise was attributed to water supplied due to condensation, and the attempt was abandoned. For runs 40 to 44, the loop was first steam heated to 267°F (131°C) [saturation at 40 psia (0.28 MPa)]. Then the steam heaters were turned off and the pressure raised to 60 psia (0.41 MPa) by introducing nitrogen from a pressure-controlled source. The pressure was so maintained for at least 1/2 hour before the tests and throughout the test series. The baffle/vessel annulus was filled with 200°F (93°C) water to 160 in. (4.06 m), then the method of runs 26 to 34 was repeated. A minimum level of 62.25 in. (1.58 m) was reached. The variation of water temperature with time and location during the series, as indicated by thermocouples in heater rod H6 and on the baffle, is shown in Figure E-8.

- Hot, leakage from bundle out to annulus, runs 19 to 25

The procedure of runs 40 to 44 was repeated except that the baffle annulus was kept empty and the bundle was first filled to a maximum level of 135 in. (3.43 m) and then drained to a minimum level of 32 in. (0.81 m). The variation of baffle temperatures with elevation and time is shown in Figure E-9.

To translate the results of the 10/24-25 tests into leakage flow rates as a function of water level, the time-sharing computer program JCLVL was written. This program accounted for variation of annulus cross-sectional area with elevation, displacement of DP cell 535 from the bottom of the heater rods, and difference between vessel and sight glass water temperature. A constant uniform vessel water

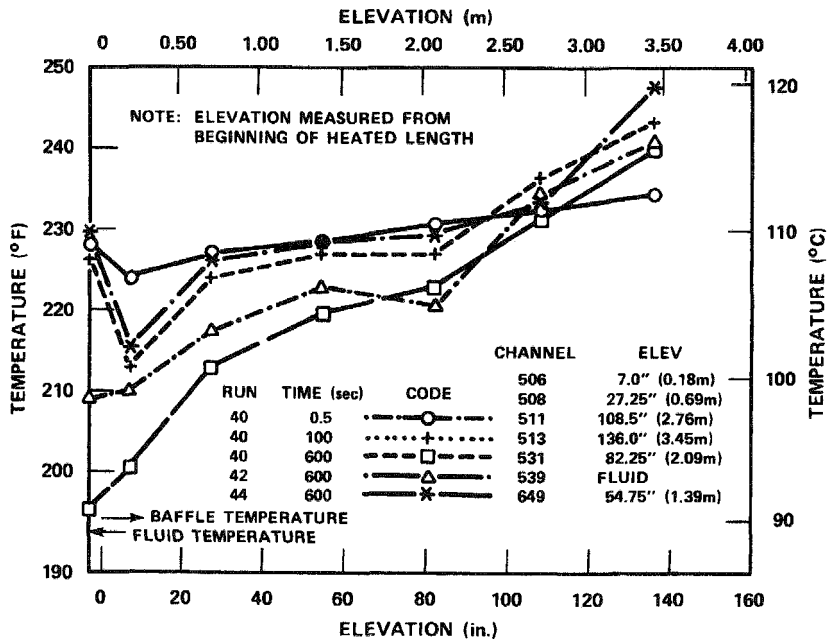


Figure E-8. Baffle Temperatures During Leak Tests, Runs 40-44

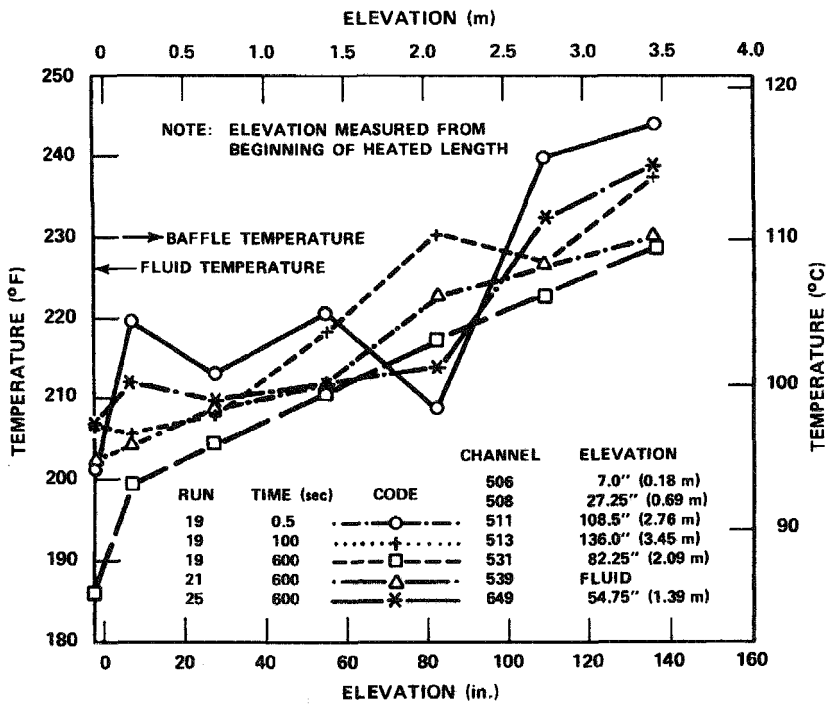


Figure E-9. Baffle Temperatures During Leak Tests, Runs 19-25

temperature was assumed for each series of tests. These data were used at increments at least as small as 1 to 2 in. (2.5 to 5 cm). After the data (time and ΔP , or sight glass level if ΔP data were missing) had been so reduced, a discrepancy between the DP cell and sight glass data was noticed. Correction to the indicated sight glass levels resulted in a shift of the results upward by 5 in. (13 cm) in water level in runs 35 to 39, and by 5 in. (13 cm) at low levels to 1 in. (2.5 cm) at high levels in runs 40 to 44.

The resulting flow versus water level plots are shown in Figures E-10 and E-11. Figure E-10 shows the flow from the annulus into the bundle, both hot and cold. Also shown for comparison is a line drawn through the cold flow data of 9/25. The newer cold flow rates were lower than those of 9/25 by a factor of 0.5 to 0.55 over the range of 80 to 150 in. (2.03 to 3.81 m). Below 80 in. (2.03 m), one flow rate point from the earlier series indicated very low flow at low levels, whereas the new data clearly indicated a smooth decrease in flow as the level decreased. Figure E-11 shows the leakage rate from the bundle outward, both hot and cold. Again the cold inward-leakage curve from 9/25 is superimposed, and indicates higher flow above 80 in. (2.03 cm) than the new cold data show. The cold bundle outflow curve seems to indicate a large leak near 160 in. (4.06 m). In addition, the difference between hot and cold flow rates is not great as in the case of leakage into the bundle, especially at low water levels.

Comparison of Figures E-10 and E-11 shows that the cold water data of 10/24-25 for inflow and for outflow were very similar, differing by only 20 percent at high and low levels and by much less in the 95 to 12 in. (2.41 to 0.30 m) region. The hot water data were similar for the two directions in the middle level, and differed by up to 20 percent at high levels. However, below 95 to 100 in. (2.41 to 2.54 m), the hot outward flow was less than the inward flow by a fraction which increased as the level decreased. This difference is close to a constant increment of 0.035 lb/sec (0.016 kg/sec) flow.

LEAKAGE TESTS 12/27 AND 1/4

At the end of the reflood test series, two more tests of leakage from the annulus to the baffle were run, using techniques identical to those of the 10/24-25 set.

Run 569, on December 27, 1974, was run with 72⁰F (22⁰C) cold water leaking from the baffle annulus into the empty bundle. The resulting leakage flow as a function of water level is compared with the 9/25 data in Figure E-12. The leakage rate was

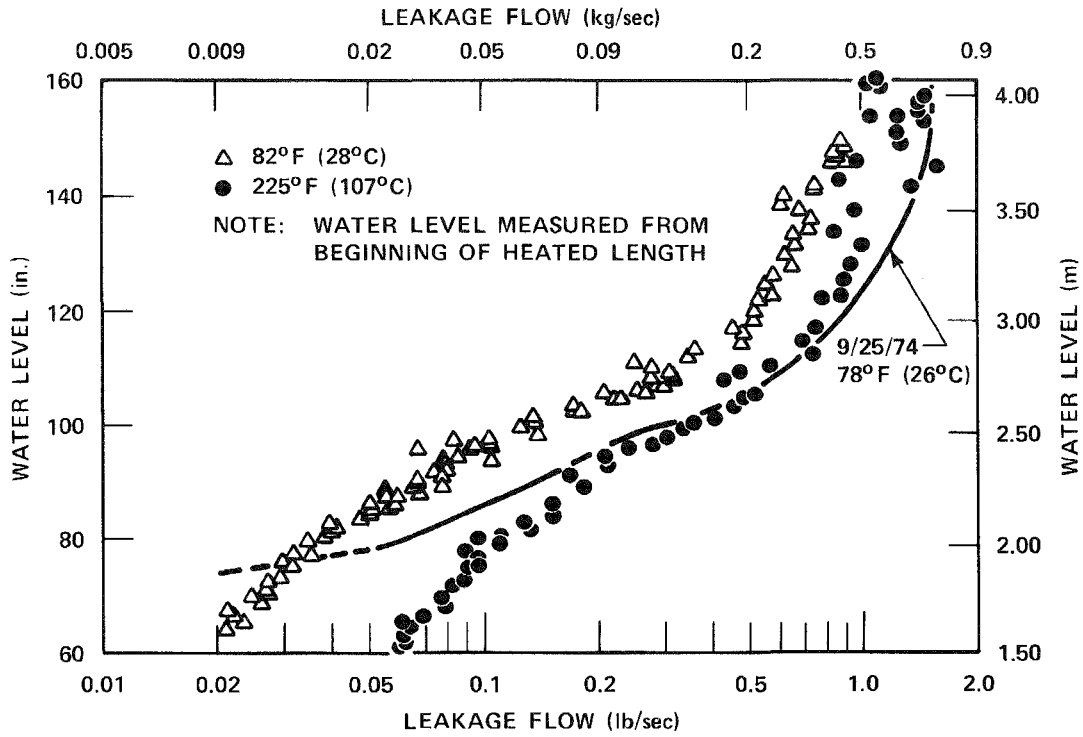


Figure E-10. Inflow Leakage for 10/24-25 Test

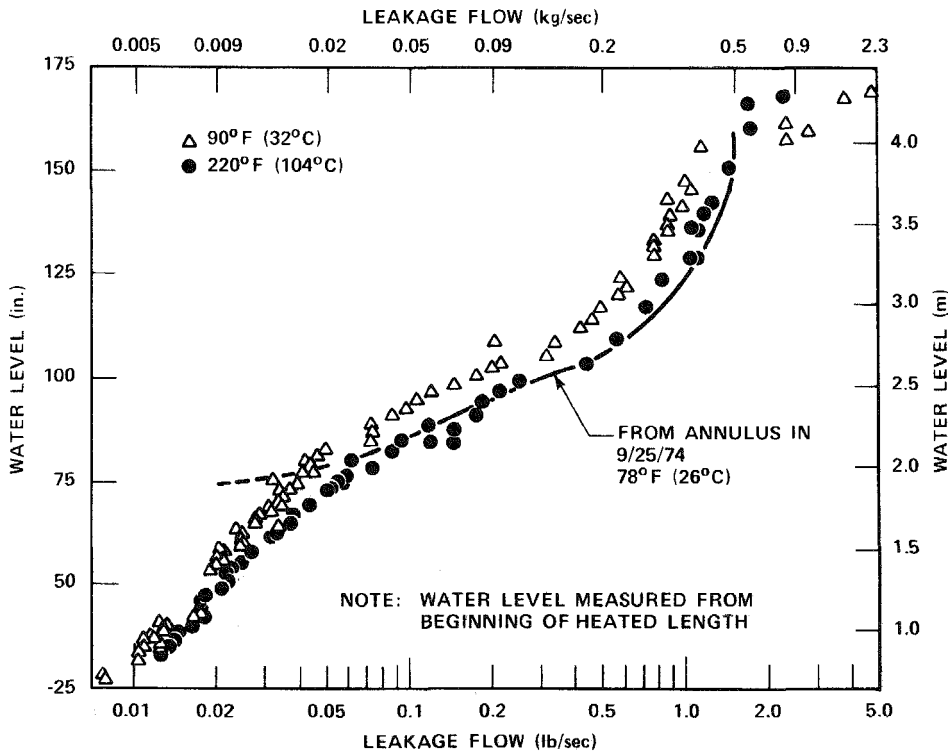


Figure E-11. Outflow Leakage for 10/24-25 Test

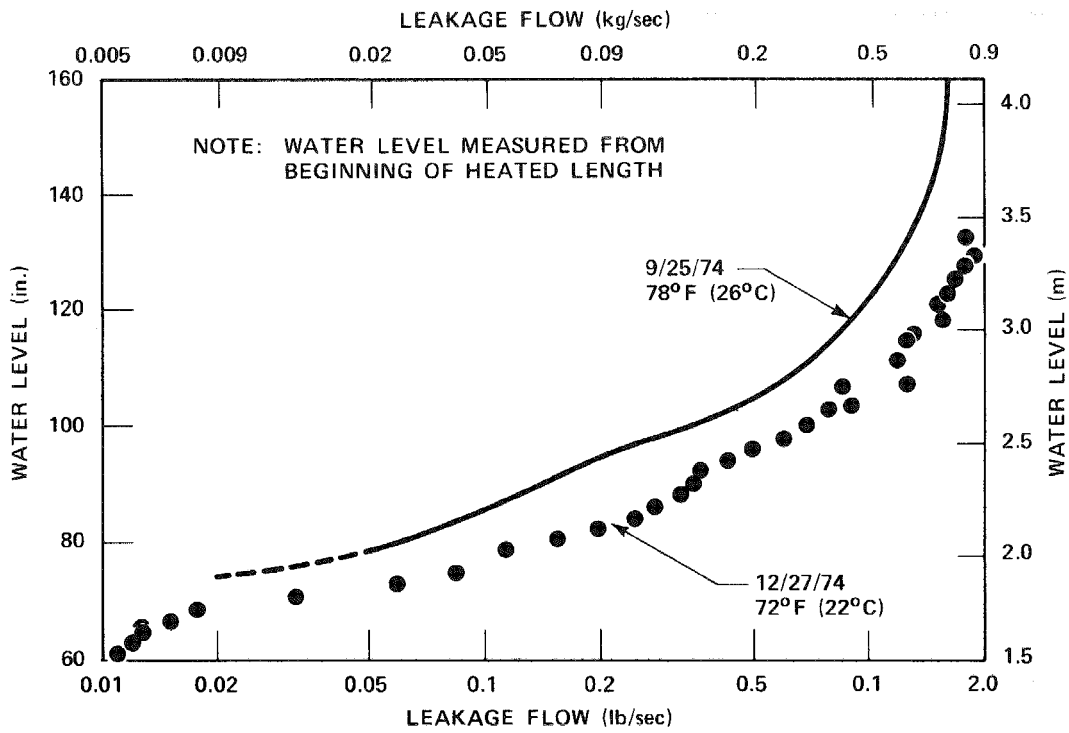


Figure E-12. Flow From Annulus for 12/27 Test

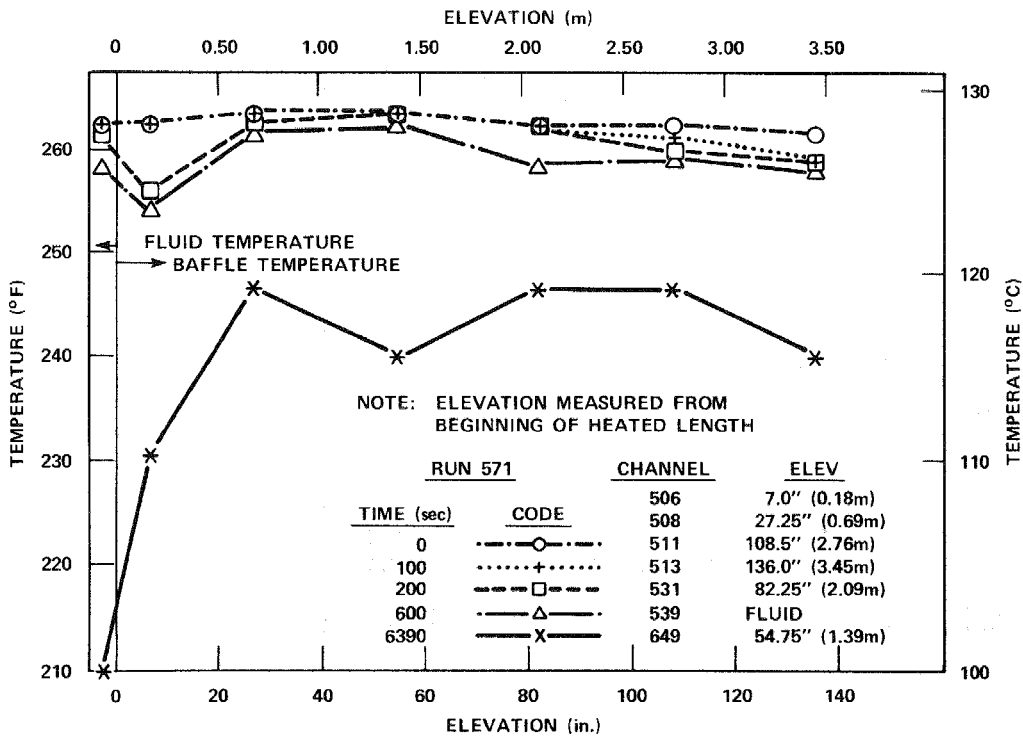


Figure E-13. Baffle Temperatures During 1/4 Test

greater than on 9/25 by 50 to 100 percent. Comparison of these results with those of the corresponding test of 10/24-25 (Figure E-10) shows that leakage in the 12/27 test was higher by a factor of 3 to 5 when the level was above 80 in. (2.03 m), but roughly the same or lower with the level at 70 in. (1.78 m) or below.

In run 571, on January 4, 1975, the baffle annulus was filled with water at approximately 260°F (127°C), with nitrogen overpressure. Measured baffle temperatures at various times are shown in Figure E-13. The leakage data were analyzed this time with the CDC-7600 program LEAK2, which is like program JCLVL except that it uses every data point, paired with another point at a level at least two inches different, rather than only using data at every 2 in. (5 cm) different, rather than only using data at every 2 in. (5 cm) in level. The resulting leakage flow versus level is compared with the cold 9/25 data in Figure E-14. Compared with the high-temperature data of 10/24-25 (Figure E-10), the leakage for the 1/4 test was greater

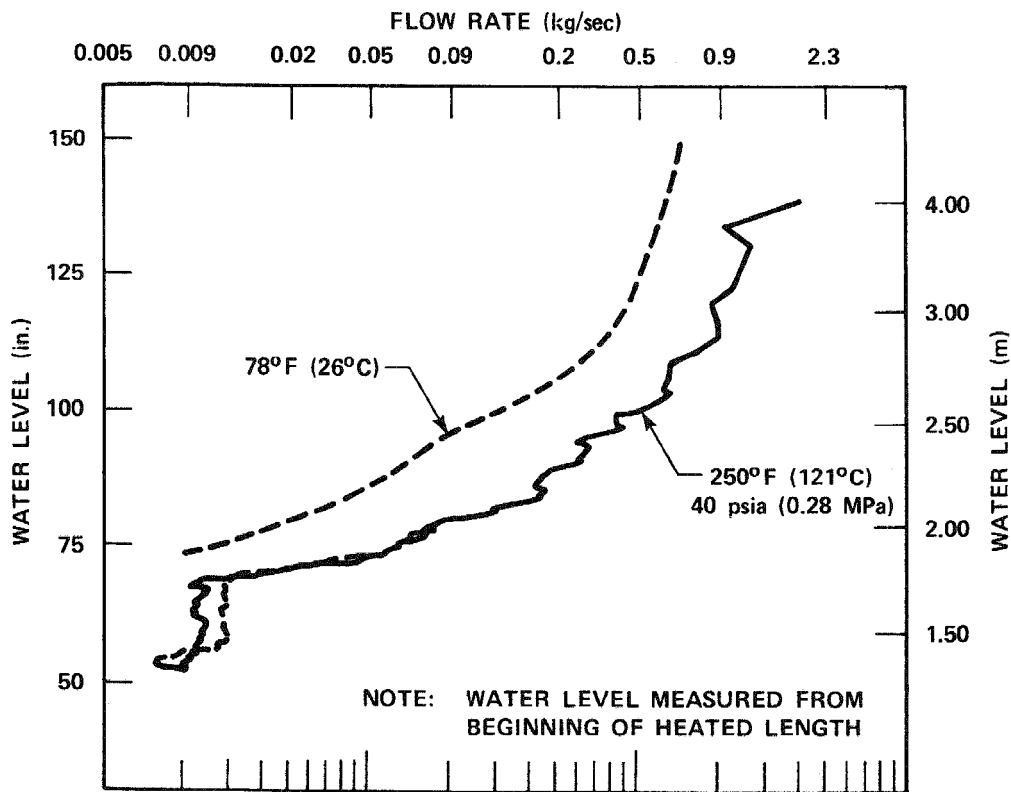


Figure E-14. Inflow Leakage for 1/4 Test

by a factor of 2 to 2.7 with the level above 80 in. (2.03 m), but was only half that in the earlier test with the level at 70 in. (1.78 m).

SUMMARY OF LEAKAGE TEST RESULTS

The general form of the curves of leakage versus level measured in several experiments before and after the reflood tests consistently indicates either no leakage or a small leakage path below the 70 in. (1.78 m) level and a somewhat larger path for leakage in the 70 to 80 in. (1.78 to 2.03 m) region. The early tests also indicate a large leakage path near the 100 in. (2.54 m) level, but in the latest tests this path seems to have opened down to about the 70 in. (1.78 m) level. There was a trend toward increasing leakage at the upper levels as the weeks passed, but with water at the 70 in. (1.78 m) level there was no clear change with time. This is indicated in Table E-5, which compares the leakage with water on one side of the baffle at various levels (and no water on the other side).

These rates may be compared with the nominal flooding rates for the reflood tests, 1.76 lb/sec (0.80 kg/sec) [1.0 in./sec (2.5 cm/sec)]. From the leakage tests run before the reflood tests, it was estimated that the leakage with the level behind the baffle at 70 or 80 in. (1.78 or 2.03 m) would be approximately 2 or 6 percent of the flooding rate, respectively. The post-reflood-test leakage data suggest no change with a 70 in. (1.78 m) level, and an increase to 11 percent of the flooding rate with an 80 in. (2.03 m) level.

LEAKAGE DURING CORE UNCOVERY TESTS

To minimize the possibility of water in the bundle leaking into the baffle/vessel cavity and causing the bundle to uncover by means other than boiloff, all core uncover tests were performed with the following conditions:

- The baffle/vessel cavity prefilled with water to the same elevation as was set in the bundle
- The flow path connecting the top of the baffle/vessel cavity to the system exhaust line valved out of the system during the execution of a test
- The flow path between the vessel lower plenum and the baffle/vessel cavity unobstructed during the execution of a test

Because of the relatively small mass flow out of the test vessel during testing, the preceding three conditions provided for about the same water level in both the bundle and the baffle/vessel cavity during a test, thereby minimizing the influence of baffle seal leakage on test performance.

Table E-5

BAFFLE LEAKAGE FLOW FROM LEAKAGE FLOW TESTS

Flow Direction	Test	Data From Figure Number	Flow at Indicated Level and Temperature [lb/sec (kg/sec)]									
			70 in. (1.78 m)		80 in. (2.03 m)		100 in. (2.54 m)		120 in. (3.05 m)		140 in. (3.56 m)	
			Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
Out	9/13, 9/14, 9/17	E-5	0.013- 0.03 (0.0059- 0.01)		0.02- 0.05 (0.009- 0.02)		0.04- 0.17 (0.02- 0.077)		0.15 0.4 (0.068- 0.2)		0.2 0.7 (0.09- 0.3)	
In	9/25	E-7			0.06 (0.03)		0.30 (0.14)		0.90 (0.41)		1.4 0.63)	
In	10/24- 25	E-10	0.03 (0.01)	0.08 (0.04)	0.04 (0.02)	0.11 (0.050)	0.13 (0.059)	0.35 (0.16)	0.51 (0.23)	0.80 (0.36)	0.80 (0.36)	1.1 (0.50)
Out	10/24- 25	E-11	0.03 (0.01)	0.04 (0.02)	0.04 (0.02)	0.07 (0.03)	0.15 (0.068)	0.30 (0.14)	0.56 (0.25)	0.80 (0.36)	0.92 (0.42)	1.2 (0.54)
In	12/27	E-12	0.02 (0.09)		0.13 (0.059)		0.63 (0.29)		1.4 (0.63)		2.0 (0.91)	
In	1/4	E-14		0.04 (0.02)		0.20 (0.091)		0.95 (0.43)		2.0 (0.91)		3.0 (1.4)

Appendix F

CORE UNCOVERY TEST DATA

(Published Under Separate Cover as
Volume 2 of This Report)

Appendix G
DATAR COMPUTER CODE

INTRODUCTION

The purpose of the DATAR model was to calculate heat fluxes and heat transfer coefficients for heater rods in the G-2 Loop test facility. It accomplishes this by using available experimental data, as read from data tapes, and as-built heater rod dimensions, coupled with a mathematical model as described below.

The DATAR code consists of two main overlays, to reduce the amount of computer memory required for code execution. These overlays consist of the following:

- The main program overlay, together with those subroutines necessary to calculate heat fluxes and subsequent heat transfer coefficients
- The overlay which reads in appropriate data and calculates quantities such as rod powers

The program provides its own automatic computer memory management, resulting in minimum expense for the execution of the code.

The main program controls the flow of all input and output data read and generated by the program. A typical computer run is conducted using the following steps:

- (1) Radial node positions are calculated based on built-in radii and interval information. It should be noted that the code performs its calculations in the radial direction only; axial conduction is ignored.
- (2) Header information is written to the DATAR output tape (run number, number of data scans, and so forth), data tapes are read and correctly positioned, and the bundle power is calculated. The sink temperature is assumed to be the saturation temperature corresponding to the specified pressure for the test.
- (3) The temperature data for a rod thermocouple are read from the main data tape, and miscellaneous information for that thermocouple, such as bundle position and axial and radial power factors, is identified in a library subroutine.
- (4) The thermocouple is considered to be good if the channel is not included in the bad channel list and the first temperature is greater than 150°F (66°C). If these two criteria are not met, a short entry is made on the output tape and data from the next channel are read.

- (5) Rod radial temperature profiles, surface heat flux, and heat transfer coefficients are calculated by successively calling subroutines containing the model described below. The number of future temperatures used is determined by the shape of the temperature versus time curve at the next time. This number is constrained to be between one and three, and may be no more than one different from the previous value.
- (6) The data and results of calculations performed in step (5) are written to output.
- (7) Steps (3) through (6) are repeated for all bundle thermocouple channels, and the run is then terminated.

DATAR uses three principal subroutines; their functions are as follows:

- To calculate the coefficient matrix, as shown below
- To calculate the temperatures and surface heat flux given the coefficient matrix
- To invert the tridiagonal coefficient matrix

Several other subroutines perform miscellaneous calculations, such as material property evaluation and data interpolation.

METHOD OF SOLUTION

A heat conduction problem is termed an inverse heat conduction problem if at least one spatial condition is specified at an interior point of a heat-conducting body. Because of this unorthodox condition, the solution to an inverse problem is vastly complicated. Even if the governing equations are linear, classical methods such as Fourier analysis and Laplace transformation would fail to yield a solution. For the Fourier method, the eigenvalues are not readily obtainable from the resulting Sturm-Liouville system of equations; hence, Fourier series representation of the solution cannot be determined. Transformation techniques lead to a solution in Laplace variable space which defies an inverse transform into the real-time space. Although the numerical method is not without difficulty, meaningful results can be obtained if due care is exercised. The basic formulation of the method of solution to the inverse heat conduction problem employed by the DATAR code is presented in the following paragraphs.

The finite difference approximation, in implicit form, of a one-dimensional heat conduction equation in cylindrical coordinates is typically

$$B(n) T(n-1) + A(n) T(n) + C(n) T(n+1) = -T'(n) - Q(n); 1 \leq n \leq N \quad (G-1)$$

where

$$B(n) = \frac{\Delta\theta}{(\Delta\theta)^2} \cdot \frac{r(n-1/2)}{r(n)} \cdot \frac{K(n-1/2)}{\rho(n)c(n)}$$

(G-2)

$$C(n) = \frac{\Delta\theta}{(\Delta\theta)^2} \cdot \frac{r(n+1/2)}{r(n)} \cdot \frac{K(n+1/2)}{\rho(n)c(n)}$$

$$A(n) = B(n) - C(n) - 1$$

$$Q(n) = \frac{q(n) \cdot \Delta\theta}{\rho(n) \cdot c(n)}$$

$T(n)$ = unknown temperature at node point n

$T'(n)$ = known temperature at node point n . This is also the initial value.

r = spatial variable

Δr = spatial increment

$\Delta\theta$ = time increment

Q = volumetric heat generation rate

N = number of intervals. Hence, there are $N + 1$ node points.

K , ρ , c are the thermal conductivity, density, and heat capacity, respectively. Their numerical values are computed at T' . If values at half intervals are required, they are evaluated at the average of two adjacent temperatures.

For $n = 1$, the node point on the centerline of the rod, $T(n - 1) = T(n + 1)$, since at this point the symmetry requires that the flux be zero. At the point $n = M$, $T(n)$ is the known measured temperature and finally, at the outer boundary point, $n = N$, $T(n + 1)$ is the desired wall temperature. If the heat-conducting body is made up of composite material, the temperature at the interface can be handled by usual means; that is, both the temperature and flux must be continuous. However, in this case, the spatial interval size, Δr , would vary from region to region such that particular node points coincide with the material interfaces and $T(M)$.

When Eq. G-1 is applied to node points $n = 1, 2, \dots, N$, and the boundary condition $T(0) = T(2)$ is combined with the finite difference equation at $n = 1$ to eliminate $T(0)$, the result is a set of N linear simultaneous equations with N unknown temperatures, $T(n)$; $n = 1, \dots, N + 1$, $n \neq M$. The solution of this set of equations

defines the temperature field at a given time step, θ . The transient solution can thus be obtained by repeating the same procedure with successive increments, $\Delta\theta$.

A linear manipulation, the method outlined above is simple in principle and straightforward in practice. Because of the implicit finite difference scheme, the stability of the computation is guaranteed. As long as reasonable increment sizes, Δr and $\Delta\theta$, are chosen, acceptable numerical accuracy can be expected.

If $M = N + 1$, the inverse heat conduction problem is reduced to a more conventional type with a flux condition specified on one boundary (centerline) and a temperature condition specified on the other (wall). In this case, the coefficient matrix for the linear equations, as defined by Eq. G-1, is tridiagonal. However, the presence of a known temperature, $T(M)$, $M \neq N + 1$, in the linear set to replace the wall temperature, $T(N + 1)$, destroys the tridiagonality and consequently complicates the solution procedure, since for linear equations with a tridiagonal coefficient matrix, the solution can be obtained by a time-saving matrix resolution technique which is not applicable to any other form of matrix.

For the time being, ignore the fact that $T(M)$ is known and assume that $T(N + 1)$ is known instead. The linear equation, written in the usual manner, is

$$[J] T = F - C(N) T(N) T(N + 1) G \quad (G-3)$$

where

$[J]$ = tridiagonal coefficient matrix defined by Eq. G-1 and G-2

\vec{T} = solution vector with N components

\vec{F} = source vector with the components defined by the quantities on the left-hand side of Eq. G-1

\vec{G} = vector with the first N-1 components equal to zero and the N-th component equal to 1; that is $q(i) = C$, $i \neq N$, $q(i) = 1$, $i = N$

If X and Y are, respectively, solutions of

$$\begin{aligned} [J] \vec{X} &= \vec{F} \\ [J] \vec{Y} &= -\vec{G} \end{aligned} \quad (G-4)$$

then the linearity of Eq. G-3 leads to

$$\vec{T} = \vec{X} + C(N) T(N + 1) \vec{Y} \quad (G-5)$$

Eq. G-5, in scalar form for $n = M$, gives

$$T(M) = X(M) + C(N) T(N + 1) Y(M)$$

or

$$T(N + 1) = \frac{T(M) - X(M)}{C(N) Y(M)} \neq 0 \quad (G-6)$$

Since all the quantities on the right-hand side of Eq. G-6 are known, the wall temperature, $T(N + 1)$, can be computed. The remaining temperature field can be obtained by repeated application of Eq. G-5.

According to Beck,⁽⁴⁾ if the temperature measurement $T(M)$ as a function of time is both accurate and frequent enough, the method outlined above would produce acceptable results. In practice, however, the accuracy and frequency demanded by the numerical method is almost impossible to achieve. Any error in $T(M)$, due to either instruments or interpretation, would be amplified in this numerical process. An error is usually propagative and oscillatory, and results from a successive over- and undercorrection of the heat balance as demanded by the governing heat conduction equation. A minute error in $T(M)$ often renders the calculations for wall temperature and wall flux useless.

Therefore, it is desirable to devise a numerical method such that the input error of $T(M)$ could be damped during the subsequent computation steps. One such method, also from Beck, is programmed in DATAR. It must be stressed that damping of input error can only improve the accuracy of the computed results by reducing the input error amplification. The inherent error due to inaccurate input data remains.

The basic principle of Beck's method is to utilize the information of $T(M)$ available over an open time span when the computation is just entering this time span. Let the parenthesized superscript denote a relative time step; then the computation of $\vec{T}^{(1)}$ would not only involve an initial value $\vec{T}^{(0)}$, but also $T^{(2)}(M)$, $T^{(3)}(M)$, This calculation is followed by an optimization process to minimize the error amplification. This optimization can be accomplished in, although it is not restricted to, a least-squared sense.

Eq. G-1 and the subscript notation defined above produces

$$B(n) T^{(1)}(n-1) + A(n) T^{(1)}(n) + C(n) T^{(1)}(n+1) = -Q(n) - T^{(0)}(n)$$

$$B(N) T^{(1)}(N-1) + A(N) T^{(1)}(N) = -Q(N) - T^{(0)}(N) - C(N) T(N+1)$$

The solution, according to Eq. G-5, is

$$\vec{T}^{(1)} = \vec{X}^{(1)} + C(N) T(N+1) \vec{Y}^{(1)} \quad (G-7)$$

In Eq. G-7, all the components in $\vec{X}^{(1)}$ and $\vec{Y}^{(1)}$ are known. $\vec{T}^{(1)}$ is, however, not known since the wall temperature $T(N+1)$ is yet to be determined.

When the computation is carried one more step into the future,

$$\begin{aligned} B(n) T^{(2)}(n-1) + A(n) T^{(2)}(n) + C(n) T^{(2)}(n+1) \\ = -Q(n) - T^{(1)}(n) \end{aligned} \quad (G-8)$$

$$= -Q(n) - X^{(1)}(n) - C(N) T(N+1) Y^{(1)}$$

$$\begin{aligned} B(N) T^{(2)}(N-1) + A(N) T^{(2)}(N) \\ = -Q(N) - T^{(1)}(N) - C(N) T(N+1) \end{aligned} \quad (G-9)$$

$$= -Q(N) - X^{(1)}(N) - C(N) T(N+1) Y^{(1)}(N) - C(N) T(N)$$

$$= -Q(N) - X^{(1)}(N) - C(N) T(N+1) [Y^{(1)}(N) + 1]$$

Eq. G-8 and G-9 form a linear system which is the same as that defined in Eq. G-3, provided that the vectors \vec{F} and \vec{G} are suitably modified. This linear set has the solution of the form of Eq. G-5, that is

$$\vec{T}^{(2)} = \vec{X}^{(2)} + C(N) T(N+1) \vec{Y}^{(2)} \quad (G-10)$$

Following the same procedure,

$$\begin{aligned} T^{(3)} &= \vec{X}^{(3)} + C(N) T(N+1) \vec{Y}^{(3)} \\ \vec{T}^{(j)} &= \vec{X}^{(j)} + C(N) T(N+1) \vec{Y}^{(j)}; \quad j = 1, 2, \dots, J \end{aligned} \quad (G-11)$$

In Eq. G-11 the vectors $\vec{X}^{(j)}$ and $\vec{Y}^{(j)}$ are known for all values of j . The computation can terminate at any value of J . This set of equations is to be optimized to obtain the value of $T(N+1)$.

At the measured point, $T^{(j)}(M)$, Eq. G-11 gives

$$T^{(j)}(M) = X^{(j)}(M) + C(N) T(N+1) Y^{(j)}(M)$$

The measured temperatures, $u^{(j)}$, are known for all values of j . The error between the computed and measured temperature is

$$\begin{aligned} \theta^{(j)} &= T^{(j)}(M) - u^{(j)} \\ &= X^{(j)}(M) + C(N) T(N+1) Y^{(j)}(M) - u^{(j)}; \quad j = 1, 2, \dots, J \end{aligned} \quad (G-12)$$

The problem is now reduced to finding a $T(N+1)$ such that θ is at a minimum. This can be accomplished by a least-squares method, that is,

$$\begin{aligned} \theta^2 &= \sum_j \{E^{(j)}\}^2 = \sum_j \{X^{(j)}(M) + C(N) T(N+1) Y^{(j)}(M) - u^{(j)}\}^2 \\ 2GdE &= 2\sum_j \{X^{(j)}(M) + C(N) T(N+1) Y^{(j)}(M) - u^{(j)}\} \{C(N) Y^{(j)}(M)\} \\ d T(N+1) &= > 0 \end{aligned}$$

or

$$\sum_j \frac{X^{(j)}(M) - u^{(j)}}{Y^{(j)}(M)} + C(N) T(N+1) = 0 \quad (G-13)$$

$$T(N+1) = -\frac{1}{C(N)} \sum_j \frac{u^{(j)} - X^{(j)}(M)}{Y^{(j)}(M)} \quad (G-14)$$

Therefore, the desired temperature field can be calculated by

$$\vec{T}(1) = \vec{X} + C(N) T(N + 1) \vec{Y}(1) \quad (G-15)$$

Obviously, Eq. G-14 defines the initial values for the computations of the subsequent time step. The computation can thus proceed repeatedly for each advance of time increment.

COMMENTS ON METHOD

Beck's method, as outlined above, has been programmed into the DATAR code. The code was subjected to a series of extensive test runs before it was released for production runs. Following is a summary of comments as a result of these runs:

- For all practical purposes, three "forward" temperatures should be sufficient, that is, $j = 3$ in Eq. G-11, to give reasonable results. Obviously, the computation time required for this choice would be increased threefold from the straightforward method.
- Increasing the value of j , generally speaking, is not desirable. Essentially Beck's method does not improve the accuracy of the numerical results with not-so-accurate input information. It merely distributes the inaccuracy to the computation of each time step, smearing the errors. Therefore, increasing the value of j decreases the resolution of the results and is hence not desirable.
- If the temperature history has a relatively sharp extreme value, Beck's method would fail because of its distributive nature cited above. One remedy for this problem is to test the input data before entering Beck's computation. If an extreme value is detected, the value of j is decreased to improve the resolution, and consequently the accuracy, of the solution.

COMMENTS ON CALCULATED DATA

As stated at the beginning of this appendix, a sink temperature, taken to be the saturation temperature at the vessel pressure, was used to calculate heat transfer coefficients. The use of saturation temperatures as sink temperatures above the two-phase froth level for a core uncover event results in the use of an excessively large heater rod surface-to-sink temperature difference to evaluate the heat transfer coefficients. The steam temperatures at the local elevations would be more appropriate for use as sink temperatures. For this reason, heat fluxes rather than heat transfer coefficients, as calculated by the DATAR code, are reported in this document.