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SEMISCALE PROJECT TEST DATA REPORT -- TEST 851

T. E. Curry

Aerojet Nuclear Company

NATIONAL REACTOR TESTING STATION

Idaho Falls, Idaho — 83401

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Reactor Technology
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SEMISCALE PROJECT TEST DATA REPORT -- TEST 851

BY

T. E. Curry

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ABSTRACT

This document presents the test data from a decompression experiment (Test 851) performed in the Semiscale Project as part of the Water Reactor Safety Program of the U.S. Atomic Energy Commission. The data are intended to provide a basis for assessing analytical codes used to predict the response of pressurized water reactors to decompression and ECC injection during a hypothetical major loss-of-coolant accident (LOCA).

Semiscale Test 851 was initiated by a hot leg (outlet piping) break of a system that included both a single operating loop and a vessel with an electrically heated rod bundle. The objective of this test was to obtain experimental information relative to the effects of coolant injection on the availability of cooling fluid to a heater rod bundle and on primary system decompression phenomena.

The substantial differences between the semiscale test system and a large nuclear reactor, and the differences in the related phenomenologies during a postulated LOCA, make invalid extrapolation of the results of this test to a reactor. The test data are intended only for purposes of development and evaluation of analysis methods. This document describes the system hardware and test conditions, discusses the data acquisition, processing, and normalization methods, and presents data plots for pressures, temperatures, densities, flow rates, and power for Test 851.

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SEMISCALE PROJECT TEST DATA REPORT -- TEST 851

I. INTRODUCTION

The Semiscale Project^[1] is part of the Water Reactor Safety Program^[2] of the U.S. Atomic Energy Commission. The experiments in this project are conducted by establishing, in small systems, operating conditions similar to those expected in a power reactor and then initiating a simulated primary piping break of controlled size and location. The phenomena occurring in the system after the break are observed and recorded for subsequent analysis. The data from these experiments are intended to provide a basis for assessing analytical models used to predict the response of pressurized water reactors to decompression and ECC injection during a hypothetical major loss-of-coolant accident (LOCA). The substantial differences between the semiscale test system and a large nuclear reactor, and the differences in the related phenomenologies during a postulated LOCA, make extrapolation of the results of this test to a reactor invalid.

Semiscale Test 851, reported in this document, was conducted to obtain experimental data for an outlet piping break relative to the effect of coolant injection on the availability of cooling fluid to a heater rod bundle and on primary system decompression. Test results from the Semiscale Project have been reported previously for decompression tests involving vessels with and without unheated internals^[3], tests with the single-loop system configuration with and without unheated vessel internals^[4-6], single-loop tests with electrical heat^[7], and a single loop test involving coolant injection for inlet piping breaks^[8,9].

The purpose of this report is to present the data from Test 851 for the benefit of those engaged in model development and evaluation. Included in this report are a description of the hardware configuration and test conditions, an account of procedures and the sequence of events, and a presentation of test data. The methods used to normalize the test data are also briefly described.

II. HARDWARE DESCRIPTION

This section describes the equipment used in single-loop semiscale Test 851 with an electrically heated rod bundle and with coolant injection. The purpose of this section is to present information on the semiscale test system and hardware and on the system hydraulic parameters to aid in understanding the test data.

1. COMPONENTS

The general layout of the major components and interconnecting piping is shown in Figure 1. The piping in the primary coolant loop is five-inch, double-extra strong, Type A-106 carbon steel, except for the transition pieces at the coolant circulation pump. These transition pieces are carbon steel, and are four-inch, Schedule-160 pipe at the pump inlet and three-inch, Schedule-160 pipe at the pump outlet. A recirculating loop, which includes the pressurizer, two auxiliary heaters, and a block valve, has been included to provide for system heatup. The recirculating loop piping is constructed of 30 feet of one-inch, Schedule-80 pipe.

Figure 1 also shows the location of detector instrumentation for the primary loop. The instrument locations are designated by station numbers; the additional numbers further identify the stations as to distance (in feet) downstream from Station 1 and the elevation (in feet, shown in parenthesis) from the floor of the test cell.

1.1 Suspension System

The pressure vessel is mounted in a framework including six load cells in trunnion supports for measurement of vertical and horizontal thrust forces during blowdown.

The primary coolant piping is supported by flexible pipe hangers, and the steam generator is supported by a flexible pedestal to allow for thermal expansion. Additional support for the piping is provided by a restraining trolley near the blowdown nozzle and by the pipe attachment to the pressure vessel and primary coolant pump.

The primary pump is mounted on a steel platform and is free to slide as necessary to prevent stress loads that might be caused by pipe expansion during heatup of the system.

1.2 Pressure Vessel and Internals

The pressure vessel is fabricated of Type 316 stainless steel and is shown in cutaway in Figure 2. Figure 3 shows the vessel with internals and identifies the various components. Instrumentation locations on and in the pressure vessel are identified in Figure 4. The nomenclature for identifying detectors is given in Section IV.

Fig. 1 Single-loop semiscale system -- outlet break configuration.

Fig. 2 Single-loop semiscale -- vessel cutaway.

Fig. 3 Single-loop semiscale vessel with internals.

Fig. 4 In-vessel instrumentation.

INC-C-15894

The volume of liquid in the pressure vessel with internals is 5 ft³, distributed as follows:

Component	Volume (ft ³)
Inlet Nozzle	0.135
Inlet Plenum	1.62
Heater Rod Region	0.54
Inactive Region Around Rod Bundle	0.17
Outlet Plenum	2.40
Outlet Nozzle	0.135
TOTAL	5.00

The vessel has an overall length of 77-3/4 inches, an inside diameter of 14-1/2 inches, and a wall thickness of 3-7/10 inches. The rod bundle support barrel has an inside diameter of 11.93 inches and an outside diameter of 12.75 inches.

Two five-inch flanges are located on one side of the vessel 10-3/4 inches from each end for connection of the primary loop. The inside diameter of the flanges is 4-1/16 inches. Six instrumentation access nozzles are located on the vessel. Two 5-inch and two 7-inch trunnions provide for attachment of the vessel to the support frame. The coolant injection nozzle is made from 2-1/2-inch, Schedule-160 pipe and is installed in the vessel at the inlet nozzle elevation, and displaced 37 degrees from the center line of the inlet nozzle (Figure 1).

The electrically heated rod bundle contains 120 heater pins located in the vessel on a triangular pitch of 31/32 inch, as shown in Figure 5. The cartridge-type heaters consist of a nine-inch Nichrome heating element within a 65-mil, 0.44 inch-OD, Nickel-200 sheath. The heating element is insulated with boron nitride and the remainder of the cartridge is insulated with magnesium oxide. The heaters are capable of operating at a heat flux of 1000 W/in.², providing a total heating capability of about 1.5 MW. The heaters have a parallel resistance of 16 mΩ and at full power require about 9700 A. Individual heater pin locations and the locations of thermocouples on the instrumented heaters pins are identified in Figure 5.

1.3 Steam Generator

A cutaway isometric of the steam generator (primary coolant heat exchanger) is shown in Figure 6. Primary coolant flows into the lower plenum, up through the 43 coolant tubes, into the upper plenum, and out the exit nozzle. Heat is removed from the primary coolant by spraying secondary coolant water at atmospheric pressure through three rings of spray nozzles located around the tube bundle. The amount of heat removed from the primary coolant in the steam generator is controlled by regulating the quantity of secondary system water sprayed onto the tubes. The steam generator was fabricated from carbon steel in accordance with the requirements of Section VIII of the ASME Boiler and Pressure Vessel Code, and the primary side has a design pressure and temperature of 2500 psig and 650°F. The distribution of the volume within the steam generator is as follows:

Pin 71 Removed for Installation of
Differential Pressure Pickup (DP-C-I)
and Pressure Pickups P-O-ID and P-I-ID

Line of Sight for
Gamma Attenuation
Density System
(designated D-O-I;
D-C-I)

180° Ref

Line of Sight for
Gamma Attenuation
Density System
(designated D-T-I)

Vessel Wall

Flow Skirt

270° Ref

90° Ref

Cladding Thickness 0.065"
Diameter 0.440"

Top Vessel
Nozzle
0° Ref

Angular Location of
Mounting Rack for Fluid
Thermocouples Designated
TF-O-#, TF-C-#, TF-I-#

TM-#-T; TM-#-M; TM-#-B
Thermocouple Junction ~ 0.015
Inch Beneath Cladding OD

TM-#-O; Thermocouple
Junction ~ 0.015 Inch
Beneath Cladding OD

TM-#-I; Thermocouple
Junction in Insulation

TM-#-T
9.0" (heated length)
TM-#-O
7.0"
TM-#-I
4.5"
TM-#-M
2.0"
TM-#-B

Typical Instrumented
Heater Pin

5 Thermocouples Each on
19 Instrumented Pins: Pins 12,13,16,29,30,37,
50,61,62,63,65,66,
85,89,92,93,106,
110 and 116

INC-C-15888

Instrument Legend

Typical Designation	Meaning
TM-61-I	Temperature Metal - Pin 61 - in Insulation
TM-38-B	Temperature Metal - Pin 38 - Bottom of Heated Length, Imbedded in Cladding
TM-40-T	Temperature Metal - Pin 40 - Top of Heated Length, Imbedded in Cladding
TM-61-O	Temperature Metal - Pin 61 - Center of Heated Length, Imbedded in Cladding
TM-61-M	Temperature Metal - Pin 61 - Center of Heated Length, Imbedded in Cladding (Rotated 90° from TM-61-O)

Fig. 5 Vessel internals -- heater pin and thermocouple locations.

INC-B-15880

Fig. 6 Steam generator -- cutaway.

Component	Volume (ft ³)
Inlet Nozzle and Lower Plenum	0.47
Tubes	0.20
Upper Plenum and Outlet Nozzle	0.47
TOTAL	1.14

1.4 Pressurizer

The pressurizer is connected to the piping between the pressure vessel and the steam generator inlet. The semiscale pressurizer operates similarly to its counterpart in a large pressurized water reactor in that it is partially filled with water maintained at the saturation temperature corresponding to the desired system pressure.

The pressurizer was designed according to the requirements of Section VIII of the ASME Boiler and Pressure Vessel Code, with a rating of 2500 psig and 668°F, and was hydrostatically tested at 4725 psig. The volume of the pressurizer (including an extension vessel) is 1.61 ft³. The pressurizer is made of 10-inch extra-strong, Type 304 stainless steel pipe, and is 45 inches long. Heat is supplied by thirty-two 0.25-kW heaters, which are inserted in 0.5-inch stainless steel tubes sealed at the bottom. Piping from the pressurizer to the primary system includes two auxiliary heaters as shown in Figure 1.

1.5 Primary Coolant Pump

The primary coolant pump is a canned-rotor pump with a horizontal outlet and a bottom vertical inlet. A simplified cross section of the pump and motor is shown in Figure 7. The pump is rated for a nominal flow of 350 gpm at a total head of 125 feet of water when operated at 3550 rpm, 2340 psig, and 540°F. The pump has a design pressure of 2500 psig and design temperature of 600°F. Pump performance curves for 3550 rpm operation are shown in Figure 8. The specific speed of the pump is about 1800, and the outside diameter of the impeller is seven inches. The inertia of the moving parts is 3.5 lb-ft². The internal volume of the pump, including inlet and outlet nozzles, is 0.25 ft³.

The pump is driven by a 75 hp, 440-V ac motor, which operates at about 40% of its full-load capacity at rated speed. The pump motor is driven by a gasoline-engine-driven ac generator. Pump motor speed can be reduced by reducing the frequency (and voltage) out of the generator.

1.6 Blowdown Nozzle

The configuration and dimensions of the blowdown nozzle and rupture discs are shown in Figure 9. In some tests, extra instrument washers (Component 2) for housing detectors may be installed between the tee (Component 3) and the extension spool (Component 4). Instrument washers can also be installed between the extension spool and the orifice plate (Component 5). The orifice plate is changed as necessary to provide the desired break area for each test.

Initiation of rupture during a test is accomplished by use of the two rupture discs shown in the rupture disc assembly of Figure 9. The space between these discs is filled with pressurized nitrogen gas: the discs are designed to rupture at less than the primary coolant

Fig. 7 Primary coolant pump -- cross section

Fig. 8 Pump performance curves.

Number	Component	Length (inches)
1	Vessel Flange	17
2	Instrument Washer	1 15/16
3	Blowdown Tee	22 1/2
4	Extension Spool	22 3/4
5 A	Orifice Plate 60	1/2
5 B	Orifice Plate 50	1/2
5 C	Orifice Plate 30	1/2
5 D	Orifice Plate 10	7/8
5 E	Orifice Plate 6	7/8
5 F	Orifice Plate 2	1
6	Rupture Disc Assembly	8 1/2
7	Nozzle Spindle	14 5/8

Fig. 9 Rupture disc assembly.

system pressure. For Test 851, when the primary system had reached operating conditions, rupture was initiated by overpressurizing the space between the discs, causing the downstream disc to break, and allowing the primary system pressure to rupture the upstream disc.

1.7 Coolant Injection System

The coolant injection system is shown in Figure 10. The system consists of the accumulator tank and 29 feet of 2-1/2-inch, Schedule-160 pipe. A block valve, throttle

Fig. 10 Single-loop semiscale -- accumulator coolant injection system.

INC-8-17655

valve, swing check valve, and turbine flowmeter were installed in the pipe. For Test 851, the accumulator was filled with 2.6 ft³ of water, which is enough to cover the bundle of heater

rods. The accumulator was pressurized to 600 psig with 1.4 ft³ of nitrogen gas and the water in the tank was heated to 147°F prior to the test. Also, for Test 851, a 3/8-inch orifice was installed at the accumulator flange to provide a cold flooding rate of 1.25 in./sec (30 gpm) with 150-psi pressure difference. The liquid was injected directly into the inlet plenum of the pressure vessel.

1.8 Power Supply

Power is provided to the in-vessel electrical heater pins from a bank of 170 submarine storage cells. Each of the cells provides 2.07 V, open circuit, and has an internal resistance of 65 $\mu\Omega$ when fully charged. The theoretical maximum power output from each cell is about 16.5 kW at 16,000 A, and the short circuit current is about 32,000 A. Heat to the heater rod bundle is provided by 136 cells. Control power at 28 V is obtained from an additional 14 cells. The remaining 20 cells are spares. For versatility, busing for the batteries has been arranged to provide several different heater voltages.

The power to the heater pins is controlled by a 20,000 A, motor-driven, water-cooled, carbon-pipe rheostat which has the capability of varying the total load resistance from 20 to 29 m Ω . With the rheostat, a rod bundle power of 1.2 MW can be maintained for about 15 minutes.

2. SYSTEM HYDRAULIC PARAMETERS

For convenience in performing analyses involving the single-loop semiscale test system, the system pressure drop and volume distribution are given in the following paragraphs.

2.1 Pressure Drop

The system pressure drops are given in Table I for normal system operation at 2300 psig, 585°F, and a flow rate of 330 gpm. The pressure drop across the heater rod bundle at the given system conditions is about 3.5 psi. The approximate pressure drops at a reduced flow rate can be obtained from the equation

$$\frac{Q_1^2}{\Delta P_1} = \frac{Q_2^2}{\Delta P_2}$$

where

Q = the flow rate (gpm)

ΔP = the pressure drop (psi).

2.2 System Volume Distribution

The distribution of system volumes is given in Table II.

TABLE I
PRESSURE DROPS ACROSS SEMISCALE COMPONENTS

<u>Instrument Station^[a]</u>	<u>Component</u>	<u>ΔP (psi)</u>
9 to 14	Cold leg (pump to vessel)	1.0 ^[b]
14 to 1	Pressure vessel	4.7
1 to 5	Hot leg (vessel to steam generator)	1.0
5 to 6	Steam generator	2.5
6 to 31	Pipe (steam generator to pump)	0.4

[a] Instrument stations are identified in Figure 1.

[b] A butterfly valve is positioned as necessary to increase this pressure drop to obtain the desired system total pressure drop.

TABLE II
SEMISCALE SYSTEM VOLUME DISTRIBUTION

<u>Instrument Station^[a]</u>	<u>Component</u>	<u>Volume (ft³)</u>
8 to 14	Cold leg pipe	1.42
14 to 1	Pressure vessel	5.00
1 to 5	Hot leg pipe	2.22
5 to 27	Steam generator	1.14
27 to 31	Pipe (steam generator to pump)	1.21
31 to 8	Primary pump	0.25
	Pressurizer	1.61
	Pressurizer piping	<u>0.15</u>
TOTAL		13.00

[a] Instrument stations are identified in Figure 1.

III. SEQUENCE OF EVENTS AND TEST CONDITIONS FOR TEST 851

The same general sequence of events was followed for system warmup and test initiation for nearly all single-loop semiscale tests. Warmup to the desired system pressure and isothermal temperature was achieved by operation of the two auxiliary heaters (Figure 1) in the auxiliary circulation loop. This process required about eight hours. During warmup, the excess fluid due to thermal expansion was drained from the system through a throttle valve near the pump inlet.

About 20 minutes prior to test initiation the auxiliary heaters were turned off and the block valve in the auxiliary loop was closed. Steam generator cooling was initiated and about 0.8 MW power was applied to the heater rods to continue heatup. The power was gradually increased to the pretest level. The initial temperature difference across the bundle was established by controlling the primary system fluid flow rate with the variable-speed pump and concurrently controlling the cooling water flow to the secondary side of the steam generator. Just prior to system rupture, the pressurizer makeup pump and pressurizer heaters were turned off.

System rupture was initiated by overpressurizing the outer rupture disc of the rupture assembly in the blowdown nozzle (system pressure ruptures the inner disc within 1 to 2 msec after the outer disc ruptures). The blowdown nozzle was attached to a tee at the vessel outlet nozzle (Figure-1) and was orificed to a flow area of 0.009 ft^2 , or 10% of the system pipe cross-sectional area.

Injection of coolant into the inlet plenum was initiated by operation of a swing check valve when the vessel inlet plenum dropped below 600 psig. Test conditions and significant test events for Test 851 are summarized in Tables III and IV.

TABLE III
CONDITIONS FOR TEST 851

Break Size Control Device	Orifice
Break Size	10% (0.009 ft ²)
Break Location	Top Outlet (Station 1)
Pressure (psig)	2255
System Flow Rate (gpm)	229
Flow Control ^[a]	Butterfly Valve
Pump Speed (rpm)	3550
Pump Head (ft of water)	175
Initial Pressure Differences ^[a,b,c]	
Stations 14 to 1	2.30
Stations 1 to 5	0.50
Stations 5 to 6	1.20
Station 6 to Pump	0.20
Pump to Station 14	52.3
Total Initial System Pressure Drop	56.5
Core Power (MW)	1.13
Temperature Difference Across Core (°F)	36
Initial Temperatures (°F) ^[b]	
Station 1	602
Station 5	598
Station 6	566
Station 10	566
Station 14	566
Station 15	585
Coolant Injected (Directly Into Inlet Plenum) ^[a]	
Initial Accumulator Pressure (psig)	600
Fluid Temperature (°F)	147
Water Volume (ft ³)	2.6
Gas Volume (ft ³)	1.4
Flooding Rate (gpm average)	35

[a] System modifications for this test:

1. Butterfly valve throttled as necessary for flow control.
2. Coolant injection directly into inlet plenum.
3. Loop orifices removed.
4. Pressurizer steam volume 422 in.³.

[b] Station locations are shown on Figure 1.

[c] The initial pressure difference from the vessel inlet to the outlet plenum was 1.65 psi.

TABLE IV

SEQUENCE OF EVENTS AND WATER REMAINING

Rupture (Steam Generator Off)	0 sec
Coolant Injection	11.5 sec
Bundle Power Off ^[a]	16.5 sec
Pump Off	17.0 sec
Coolant Injection Complete (Valve Closed)	39 sec
Decompression Complete	60 sec
Water Remaining After Test	
Loop Low Point	0 at 7 min
Pump Inlet	0 at 7 min
Steam Generator Inlet	0 at 7 min
Vessel	59 lb at 10 min
Coolant Injection System	57 lb at 25 min

[a] To assure heater-rod cladding integrity, power was shut off when the cladding temperature of a monitored rod increased to about 900°F.

IV. DATA FROM SINGLE-LOOP

This section presents a description of the detector and data normalization techniques, and the methods of data acquisition and processing that were used for the single-loop semiscale test series of which Test 851 was the final experiment. In many cases, the recorded data were corrected to account for instrument drift, detector temperature sensitivity, or both. A brief discussion of these data normalization procedures and a brief description of the detector and measurement capabilities are included in the first part of this section. The second part briefly describes the data acquisition system.

1. DETECTOR AND DATA NORMALIZATION

The measurements taken during semiscale Test 851 include fluid pressure, fluid differential pressure, fluid temperature (and temperature difference), heater rod cladding temperature, piping and component wall temperature, fluid density, rod bundle and pin power, pump coastdown speed, and valve positions. Selections from the data obtained for these measurements are presented. Data obtained for momentum flux and volumetric flow were used to calculate flow rates which are also presented. Information to permit the reader to interpret the data plots is contained in the following brief discussions.

1.1 Fluid Pressure (P)

The initial semiscale system pressure (pressure in vessel outlet plenum) was measured with a precision pressure gage that has a specified accuracy of within $\pm 0.25\%$ (± 14.5 psi of full scale). During the blowdown transient, the pressures were measured with pressure transducers, the majority of which are of the strain-gage type with a 3000-psi range. On the basis of the manufacturer's specifications, at constant temperature the absolute value of the pressure measurements is within $\pm 5\%$ of full scale, and for the approximately 400°F temperature change that occurs during the blowdown transient, the error for a full scale reading is less than ± 480 psig and for a zero pressure reading the error is less than 60 psig. In general, the test data indicates the pressure measurement error to be less than ± 90 psi when compared with the saturation pressure determined from the measured temperature.

In a typical semiscale decompression experiment, starting at 2250 psig, the pressure drops about 1000 psi during subcooled blowdown in less than 100 msec and is accompanied by a fluid temperature change of about 5 to 6°F. For the remainder of the decompression (saturated blowdown), the pressure decreases relatively slowly to atmospheric pressure and fluid temperatures decrease about 400°F to atmospheric conditions. To improve the accuracy of the information obtained from the pressure transducers, the pressure traces are modified in the following manner:

- (1) The system pressure in the vessel outlet plenum as indicated by the precision pressure gage is recorded with the semiscale system at steady state pretest conditions (approximately 2255 psig). During subsequent data processing the pressure for each pressure transducer output is normalized to agree with pretest pressures obtained from the precision pressure gage, with appropriate corrections made for the fluid pressure drop around the loop.

- (2) The total change measured for each transducer as the system pressure drops from the saturation pressure to atmospheric pressure is obtained by applying a modified calibration factor to obtain the required total pressure change.

1.2 Differential Pressure (DP)

Several different types of differential pressure transducers are used in the semiscale blowdown experiments. These devices have ranges of ± 100 inches of water (based on a water density of 62.4 lb/ft^3) and ± 400 psi. The transducers are recalibrated following a test to determine the zero shift of the transducer due to pressure and temperature changes. The differential pressure traces are then modified in the following manner:

- (1) The zero shift determined from the calibration of the transducer is applied to the data.
- (2) The initial prerupture measured differential pressure is normalized to the initial known differential pressure calculated from system flow rates and pump characteristic curves.
- (3) If the zero shift correction does not result in a zero differential pressure at the end of the transient, a linear (with time) correction is applied for thermal drift.

1.3 Fluid Temperature (TF) and Temperature Difference (DT)

All fluid temperature measurements were made with Chromel-Alumel thermocouples. Those in the loop piping and in system components are spaded-junction thermocouples having a 0.065-inch sheath diameter. The thermocouples in the loop are inserted into the approximate center of the flow stream through tapped holes in the instrument washer.

The thermocouples used for fluid temperature measurements within the vessel are of the grounded-junction type and have a 0.025-inch sheath diameter. The vessel thermocouple leads are attached to support racks and penetrate the vessel at the top head.

For selected semiscale system components, such as the rod bundle and the steam generator, the fluid temperature difference was measured by directly comparing the output of thermocouples on either side of the component. For example, the temperature difference across the steam generator (DT-SG-1) was measured by comparing the output of thermocouples on the inlet and outlet sides.

The only modification of the fluid temperature data for semiscale tests consists of assigning the initial condition temperatures to all temperature data at the time of rupture. The initial condition temperatures are all determined at various system locations with resistance temperature bulbs that have an accuracy of within $\pm 2^\circ\text{F}$.

1.4 Materials Temperatures (TM)

The temperatures of heater rod cladding, piping and component walls, and vessel internals (bundle support structure) were measured with Chromel-Alumel thermocouples. The rod cladding temperature thermocouples had a 0.025-inch sheath diameter and were

located as shown in Figure 5. Each of the 19 instrumented rods was equipped with four spaded-junction thermocouples imbedded within the cladding (about 0.015 inch beneath the outside surface of the cladding) and with one thermocouple in the boron nitride insulation between the cladding and the heater element.

The temperatures of the system components, the piping walls, and the bundle support structure were measured with grounded-spaded-junction thermocouples imbedded at various depths within the material. The locations of the thermocouples on the bundle support structure were shown in Figure 4.

No corrections or modifications were applied to the materials temperature data.

1.5 Density (D)

Fluid density data for semiscale tests are obtained by a gamma-attenuation technique that provides a measurement of the average fluid density across the flow section being monitored. A gamma source is placed on one side of the section and a photo-multiplier tube is placed on the opposite side. The gamma beam is collimated and passed through reliefs in the pressure boundary and through the fluid to the photoscintillation detector. The output from the scintillation detector is amplified and recorded in volts, and is processed using a computer data conversion program based on a derived calibration factor and the calculated initial fluid density. The estimated accuracy of the density measurements is within $\pm 5\%$ of the detector full scale reading.

1.6 Fluid Flow Rates (ST or V)

The fluid flow rates within the system during the blowdown transient are calculated with a digital computer from the equation:

$$m = [\rho(\rho v^2) A^2]^{1/2}, \text{ or } m = \rho v A$$

where:

- m = fluid flow rate (lb/sec)
- ρ = measured density (lb/ft³)
- ρv^2 = measured momentum flux (lb/sec²-ft)
- v = velocity (ft/sec)
- A = cross-sectional flow area (ft²)

The cross-sectional flow area and density and the momentum flux as functions of time are input to the digital computer for the flow rate calculations. The momentum flux measurements are made with calibrated drag disc devices which give an output in volts. On the basis of the initial density and the calibration curve for a particular detector, the initial voltage from the instrument is assigned a value commensurate with initial pretest steady state flow conditions. To compensate for the thermal sensitivity of the momentum flux detectors, the voltage output as a function of temperature is recorded for each detector during pretest warmup at zero-flow conditions. The resulting correction curve and the instrument calibration curve are applied to the recorded test data through a computer data conversion program.

Because the injected fluid remains a subcooled liquid throughout decompression, the mass flow rate is determined from

$$m = \rho Q$$

where Q = volumetric flow rate. The density of the injected liquid is determined from fluid pressure and temperature measurements. The volumetric flow rate is measured with a turbine meter. The signal from the meter is converted directly to the volumetric flow rate based on the manufacturer's calibration data, which have also been verified by Aerojet Nuclear Company. The measurement error is less than $\pm 2\%$ of the measurement range.

1.7 Bundle and Rod Power (PWR)

The power applied to all heater rods and to individual heater rods is measured directly. The measurement instruments have a measurement error of less than 0.025 MW and 0.2 kW for total bundle power and individual rod power, respectively. The total bundle power and, in some cases, the individual rod power can also be determined from voltage and current measurements.

1.8 Valve Positions (PO)

The positions of various valves in the semiscale system during the blowdown transient were determined through the use of linear potentiometers attached to the valve stems.

1.9 Break Initiation Time (R)

Recording of the various semiscale test measurements begins well before the time of rupture. In order to establish the initiation of the blowdown transient for application to the test data, the time of rupture is determined from a resistance break wire immediately downstream from the inner rupture disc (Station 18 as shown in Figure 1). A low voltage is applied across the break wire. Upon system rupture, the wire is broken and the recorded voltage in the break wire circuit provides a record of break initiation.

2. DATA ACQUISITION SYSTEM

The test equipment and instrumentation system was assembled to acquire transient and steady state information regarding hydrodynamic, mechanical, and thermal phenomena occurring during blowdown. The data acquisition and processing system was designed to accommodate changes in measurement requirements for the various tests.

2.1 Detector Patch Facilities

A termination point for signal cabling, referred to as the detector patch panel, serves as an interface between the detector wiring from the test cell and the signal cabling from the signal conditioning equipment. All instrumentation cabling, with the exception of the thermocouple cabling, terminates at the detector patch panel. The detector patch panel is designed to facilitate continuity of cable shields through the patch. Thermocouple patch panels are installed at various locations on the test equipment to reduce the length of thermocouple cabling.

2.2 Signal Conditioning

The signal conditioning equipment consists of low-level amplifiers, strain gage completion networks and power supplies, attenuation networks, thermocouple reference junctions, and the equipment necessary to record, monitor, and calibrate data channels. Signal cables from the detector patch panel are terminated at appropriate conditioning equipment.

Cabling from the signal conditioning equipment (with the exception of that from the charge amplifiers and attenuator networks) and all remaining signal cabling from the detector patch panel are terminated at the low-level input patch panel. The low-level input patch panel allows channel changes and provides system versatility by providing convenient detector-amplifier pairing to form the various data acquisition channels.

2.3 Data Recording

The recording equipment used in the blowdown tests consists of nine 14-channel, high-performance, magnetic tape recorders and one 18-channel oscillographic recorder. Two of the tape recorders are part of FM multiplex systems. For data recording, the magnetic tape recorders are operated in the frequency modulation mode at 30 in./sec, producing a dc to 10 kHz frequency response with an overall record, store, and reproduce accuracy within $\pm 1\%$ of full scale. The tape recorders can also be operated in the direct mode to reproduce a 0.3 to 250 kHz frequency with reduced amplitude accuracy to within about $\pm 15\%$ of full scale. In semiscale, this capability is used to record the timing data. Two recorders of the data systems are operated in direct mode to fulfill the requirements of the FM multiplex systems. The accuracy of the FM multiplex systems has been found to be within $\pm 1\%$ of full scale.

The oscillographic recorder is used as a diagnostic tool during system assembly, and to provide a readily available record of pertinent data immediately after a test. The bandwidth of the oscillograph-driver-amplifier combination with the fluid-damped galvanometers and current drive is dc to 3 kHz with nonlinearity and readability within $\pm 5\%$ of full scale.

Timing information for data correlation and event correlation is provided by simultaneously directly recording an IRIG "A" modulated 10 kHz carrier signal on one track of each of the tape recorders. Timing for the oscillograph is provided by an internal generator.

2.4 Data Processing

The semiscale analog data recorded on magnetic tapes are converted to digital data through use of a data processing computer that serves as an interface between the analog acquisition systems and a digital computer. This interface is designed to:

- (1) Input, convert, and format data acquired on analog magnetic tape for further processing by the digital computer
- (2) Establish a time reference for data required from any single test or experiment
- (3) Display the reduced data values in the form of listings or plots as functions of an independent variable, usually time.

The data processing computer (DDP-124), through use of an X-Y plotter, is capable of producing data plots for test variables that are measured directly, such as pressure and temperature. With the data processing computer, the data can be edited, linearized, smoothed, filtered, sorted, averaged, or differenced. Test parameters, which require the mathematical combination of two or more variables (such as the combination of density and momentum flux to obtain flow rate), or other types of mathematical processing, are processed with a digital computer through the use of several simple mathematical processing codes.

V. DATA PLOTS -- TEST 851

Previous sections of this report have summarized the data acquisition, processing, and normalization techniques used in the semiscale tests. The data package included here represents selected data from Semiscale Test 851 in the form of computer-generated data plots. Table V presents a summary of the selected data; the accompanying data plots are presented in the order listed in the table. The data plots generally are for 90 sec duration following time of rupture; time of rupture is 10 sec on the data plots. Short-term (90-msec) data plots have been added from two vessel pressure detectors (P-0-1SA and P-0-1SA) and for the rupture initiation time detector (R-18). Time of rupture for the short term plots is 10 msec.

TABLE V

SUMMARY OF DATA PLOTS FOR SEMISCALE TEST 851

Type of Measurement	Detector Designation	Detector Identification and Location
Fluid Pressure	P-1 (Figure 11) P-3A (Figure 12) P-4A (Figure 13) P-5 (Figure 14) P-6 (Figure 15) P-7A (Figure 16) P-9 (Figure 17) P-10A (Figure 18) P-13A (Figure 19) P-14 (Figure 20) P-15 (Figure 21) P-17 (Figure 22) P-I-1SA (Figure 23) P-O-1SA (Figure 24) P-ECC (Figure 25)	Numbers refer to station locations as shown in Figure 1. <u>Primary Loop Locations</u> -- The letter A indicates the detector was located in a water-cooled standoff pipe rather than mounted flush with the inside surface of the pipe. The standoff pipes are 12 inches long and have an inside diameter of 0.300 inch. <u>Vessel Locations</u> -- The data presented for inlet (I) and outlet (O) plenum pressures were recorded with a strain-gaged pressure transducer. Representative locations are shown in Figure 4. Accumulator pressure.
Differential Pressure	DP-5-7 (Figure 26) DP-10-7 (Figure 27) DP-11-12 (Figure 28) DP-ECC (Figure 29)	Across steam generator. Across pump. Across butterfly valve. Between vessel inlet plenum and accumulator.
Fluid Temperature	TF-1 (Figure 30) TF-3 (Figure 31) TF-5 (Figure 32) TF-6 (Figure 33) TF-10 (Figure 34) TF-13 (Figure 35) TF-14 (Figure 36) TF-15 (Figure 37) TF-17 (Figure 38) TF-RL-2 (Figure 39) TF-ECC-1 (Figure 40) TF-ECC-2 (Figure 41) TG-ECC-1 (Figure 42) TF-C-1 (Figure 43) TF-C-3 (Figure 44) TF-C-4 (Figure 45) TF-I-1 (Figure 46) TF-I-2 (Figure 47) TF-I-3 (Figure 48) TF-I-4 (Figure 49) TF-I-5 (Figure 50) TF-I-8 (Figure 51) TF-I-9 (Figure 52) TF-I-10 (Figure 53) TF-O-1 (Figure 54) TF-O-2 (Figure 55) TF-O-3 (Figure 56) TF-O-4 (Figure 57) TF-O-6 (Figure 58) TF-O-7 (Figure 59)	<u>Primary Loop Locations</u> -- Numbers refer to stations as shown in Figure 1. Located in the recirculation loop auxiliary heater nearest the steam generator (Figure 1). Located in the accumulator at the elevation of fluid outlet nozzle. Located in the coolant injection line 15 feet from the accumulator vessel. Located in the gas volume (top) of the accumulator. <u>Vessel Locations</u> -- Fluid thermocouples located in the heater rod region (C), the vessel inlet plenum (I), and the vessel outlet plenum (O) are shown in Figure 4. Thermocouples TF-I-8 through TF-I-10 are installed on a vertical rack located on the axial center line of the vessel inlet plenum at the following distances above the inside surface of the bottom head: TF-I-8 - 5.0 inch. TF-I-9 - 2.5 inch. TF-I-10 - 0.5 inch.
Fluid Temperature Difference	DT-SG-1 (Figure 60)	Difference across steam generator (Stations 5 and 6).
Heater Rod Cladding Temperature	TM-13-B (Figure 61) TM-13-O (Figure 62) TM-13-T (Figure 63) TM-30-B (Figure 64) TM-30-M (Figure 65) TM-30-O (Figure 66) TM-30-T (Figure 67)	

TABLE V (Contd.)

SUMMARY OF DATA PLOTS FOR SEMISCALE TEST 851

Type of Measurement	Detector Designation	Detector Identification and Location
	TM-50-B (Figure 68) TM-50-O (Figure 69) TM-61-B (Figure 70) TM-61-M (Figure 71) TM-61-O (Figure 72) TM-61-T (Figure 73) TM-67-B (Figure 74) TM-67-O (Figure 75) TM-65-M (Figure 76) TM-65-O (Figure 77) TM-89-B (Figure 78) TM-89-O (Figure 79) TM-89-T (Figure 80) TM-92-B (Figure 81) TM-110-B (Figure 82) TM-110-O (Figure 83) TM-110-T (Figure 84) TM-116-B (Figure 85) TM-116-M (Figure 86) TM-116-T (Figure 87)	The location of the heater rods within the vessel and the elevations of the thermocouples in the cladding are shown in Figures 4 and 5.
Support Structure Temperature	TM-CS-1-210 (Figure 88) TM-CS-3-210 (Figure 89) TM-CS-2-290 (Figure 90) TM-CS-1-330 (Figure 91) TM-CS-3-330 (Figure 92)	The elevations and angular displacements of thermocouples in the rod bundle support structure are shown in Figure 4.
Steam Generator Tube Wall Temperature	TM-SG-1S (Figure 93)	Located on the outside of a center bundle tube at the axial midplane of the steam generator.
Piping Wall Temperature	TM-14 (Figure 94) TM-14A (Figure 95) TM-24 (Figure 96) TM-24A (Figure 97) TM-24B (Figure 98) TM-32 (Figure 99) TM-32A (Figure 100) TM-32B (Figure 101)	Numbers refer to station locations shown in Figure 1. Those thermocouples without an added letter designation are attached to the outside surface of the pipe wall. The letters A and B designate thermocouples imbedded 1/16 and 3/16 inch, respectively, from the inside surface of the pipe wall.
Density	D-1 (Figure 102) D-3 (Figure 103) D-5 (Figure 104) D-6 (Figure 105) D-14 (Figure 106) D-15 (Figure 107) D-I-1 (Figure 108) D-O-1 (Figure 109) D-C-1 (Figure 110)	<u>Loop Locations</u> --- Numbers refer to station locations shown in Figure 1. The location of density detectors in the vessel inlet (I) and outlet (O) plenums, and in the heater rod (C) region are shown in Figure 4.
Fluid Flow Rates	ST-1 ^[a] (Figure 111) ST-21 (Figure 112) ST-28-7 (Figure 113) ST-14 (Figure 114) ST-15 (Figure 115) V-ECC-T (Figure 116)	The numbers refer to the station locations shown in Figure 1 at which both momentum flux and density were measured. For the flow rate ST-28-7, the momentum flux was measured at a point between the two stations, and the density from nearby Station 6 was used to calculate the flow rate. Flow rate in coolant injection line calculated from pressure temperature and volumetric flow rate; the volumetric flow rate was measured with a turbine meter.
Bundle and Rod Power	PWR-30 (Figure 117) PWR-61 (Figure 118) PWR-62 (Figure 119) PWR-TOT (Figure 120)	Power to individual heater rods, shown in Figure 5. Total power to semiscale rod bundle.
Valve Position	PO-ECC-1 (Figure 121)	ECC shutoff valve.
Break Initiation Time	R-18 (Figure 122)	Resistance break wire located at Station 18 (Figure 1).

[a] Figures are labeled "flow rate" in upper right corner.

1

Fig. 11 P-1.

10

Fig. 12 P-3A

1

2

3

Fig. 15 P-6

11

Fig. 16 P-7A

Fig. 17 P-9

Fig. 18 P-10A

Fig. 21 P-15

Fig. 22 P-17

41

7

Fig. 23 P-I-ISA

(A) P-O-1SA (SHORT TERM)

(B) P-O-1SA (LONG TERM)

Fig. 24 P-O-1SA

23

Fig. 25 P-ECC

13

Fig. 26 DP-5-7

15

Fig. 27 DP-10-7

1

Fig. 28 DP-11-12

59

Fig. 29 DP-ECC

62

Fig. 30 TF-1

35

Fig. 33 TF-6

36

Fig. 34 TF-10

39

Fig. 35 TF-13

21

Fig. 36 TF-14

63

Fig. 37 TF-15

66

Fig. 38 TF-17

51

Fig. 39 TF-RL-2

21

Fig. 40 TF-ECC-1

60

61

38

Fig. 43 TF-C-1

26

Fig. 44 TF-C-3

12

Fig. 45 TF-C-4

40

Fig. 46 TF-I-1

25

Fig. 47 TF-I-2

27

Fig. 48 TF-I-3

2

13

Fig. 49 TF-I-4

42

Fig. 50 TF-I-5

11

Fig. 51 TF-I-8

17

Fig. 52 TF-I-9

16

Fig. 53. TF-I-10

14

Fig. 54 TF-0-1

64

28

65

Fig. 57 TF-0-4

23

Fig. 58 TF-0-6

37

Fig. 59 TF-0-7

25

Fig. 60 DT-SG-1

24

50

54

Fig. 63 TM-13-T

19

Fig. 64 TM-30-B

47

Fig. 65 TM-30-M

43

Fig. 66 TM-30-O

53

Fig. 67 TM-30-T

55

Fig. 68 TM-50-B

56

Fig. 69 TM-50-0

15

Fig. 70 TM-61-B

18

Fig. 71 TM-61-M

29

Fig. 72 TM-61-O

28

Fig. 73 TM-61-T

30

Fig. 74 TM-62-T

19

Fig. 75 TM-65-B

41

Fig. 76 TM-65-M

24

49

48

Fig. 79 TM-89-O

7

Fig. 80 TM-89-T

57

Fig. 81 TM-92-B

5

Fig. 82 TM-110-B

8

Fig. 83 TM-110-0

52

Fig. 84 TM-110-T

22

Fig. 85 TM-116-B

20

Fig. 86 TM-116-M

18

Fig. 87 TM-116-T

45

Fig. 88 TM-CS-1210

46

Fig. 89 TM-CS-3-210

44

Fig. 90 TM-CS-2-290.

Fig. 91 TM-CS-1-330.

Fig. 92 TM-CS-3-330.

16

32

33

Fig. 95 TM-14A

29

Fig. 96 TM-24

30

Fig. 97 TM-24A

31

Fig. 98 TM-24B

37

Fig. 99 TM-32

38

Fig. 100 TM-32A

39

26

Fig. 102 D-1

33

Fig. 103 D-3

34

Fig. 104 D-5

36

17

20

Fig. 107 D-15

32

Fig. 108 D-I-1

35

31

Fig. 111 ST-1

Fig. 112 ST-21

Fig. 113 ST-28-7

Fig. 114 ST-14.

Fig. 115 ST-15..

Fig. 116 V-ECC-T

22

Fig. 117 PWR-30

27

Fig. 118 PWR-61

58

Fig. 119 PWR-62

Fig. 120 PWR-TOT

1

Fig. 121 PO-ECC-1

Fig. 122 R-18

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