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1-1/2-LOOP SEMISCALE ISOTHERMAL TEST PROGRAM—
PROGRAM AND SYSTEM DESCRIPTION
IN SUPPORT OF EXPERIMENT DATA REPORTS

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Light-Water Reactor Technology
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**1-1/2-LOOP SEMISCALE ISOTHERMAL TEST PROGRAM -- PROGRAM
AND SYSTEM DESCRIPTION IN SUPPORT OF
EXPERIMENT DATA REPORTS**

by

S. A. Naff
P. A. Pinson

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AEROJET NUCLEAR COMPANY

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ABSTRACT

The isothermal test series is part of the Semiscale Blowdown and Emergency Core Cooling (ECC) Project conducted by Aerojet Nuclear Company for the U. S. Atomic Energy Commission. The test series consisted of ten blowdown tests and five hot-wall tests with emphasis on emergency core coolant delivery. The blowdown tests were conducted to investigate the effects of lower plenum geometry, heat transfer configuration, ECC injection location, downcomer gap size, and break size. The hot-wall tests were conducted to investigate the effects of residual vessel wall heat on ECC delivery after blowdown was completed.

The test system included a pressure vessel with internals; an operating loop with steam generator, pump, and pressurizer; a blowdown loop with rupture assembly, simulated pump, and simulated steam generator; a pressure suppression system with suppression tank and header, and a simulated ECC system with accumulators and injection pumps.

The isothermal test program, 1-1/2-loop semiscale system, experimental instrumentation, operating procedures, and test conditions are described in this report to provide a reference document for support of the data reports specific to one or more of the isothermal tests.

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1-1/2-LOOP SEMISCALE ISOTHERMAL TEST PROGRAM -- PROGRAM

AND SYSTEM DESCRIPTION IN SUPPORT OF

EXPERIMENT DATA REPORTS

I. INTRODUCTION

The isothermal test program is part of the Semiscale Blowdown and Emergency Core Cooling (ECC) Project conducted by Aerojet Nuclear Company in the overall AEC-sponsored research and development program directed at quantifying loss-of-coolant accident (LOCA) behavior of a pressurized water reactor. The emphasis in the isothermal test program is on ECC delivery investigations.

The 1-1/2-loop semiscale system in which the isothermal test program was performed represents a new configuration for blowdown experiments in that both an intact operating loop and a broken loop are simulated. Prior to this program, the primary source of coupled-system response data was the single-loop semiscale blowdown tests^[1]. Although the single-loop tests provided valuable results for evaluating the capability of analytical models for handling the decompression in a simplified blowdown experiment, the tests were not intended to provide representative data for multiple-loop systems having strong coupling between loop hydraulic behavior, pump performance, and energy transfer processes. The 1-1/2-loop system configuration, however, was designed to provide a source of coupled-system response data from which to obtain a more comprehensive understanding of the thermal-hydraulic processes accompanying the major transient phases of an LOCA.

The operating loop in the 1-1/2-loop configuration represents three operating loops of a pressurized water reactor (PWR), and the blowdown loop with simulated pump and steam generator represents the broken loop of a PWR. A pressure suppression system including a tank and a header simulates backpressure of a containment building. The 1-1/2-loop configuration and programs, like other semiscale systems and programs, are directly related to PWR and Loss-of-Fluid Test (LOFT) safety studies. The semiscale program is closely related to the LOFT program because the semiscale and LOFT programs are the principal experimental activities that produce system coupled-response data for testing current analytical capabilities over all phases of an LOCA. However, the relationship between LOFT and semiscale extends beyond that of two programs contributing to a common data base for model assessment and verification. The scale ratio between semiscale and LOFT ($\sim 1:50$) is nearly the same as that between LOFT and a PWR; therefore, the semiscale system provides a means for assessing the scaling relationships involved in interpreting LOFT experimental results in terms of PWR response and in applying analysis techniques to the larger pressurized water reactor systems.

The results of the tests in the isothermal program are expected to provide the following: (a) a significant contribution to the existing coupled-effects data base for

development and evaluation of LOCA analytical methods, (b) a basis for determining the applicability of the steady state countercurrent flow results obtained from separate-effects tests in the semiscale program (transparent vessel tests and steady state tests) for predicting blowdown behavior, and (c) a data base, including both separate-effects and coupled-effects results for countercurrent flow, for use with data from larger scale separate effects experiments (AEC-industry cooperative programs) to establish the effect of physical scaling.

The purpose of this report is to provide a reference source of information for support of data reports relating to specific isothermal tests.

Presented are descriptions of the test program, test apparatus, instrumentation, operating procedures, and test conditions.

II. ISOTHERMAL BLOWDOWN PROGRAM DESCRIPTION

The isothermal blowdown tests investigated the response of a simulated reactor system to a sudden decompression and subsequent injection of ECC coolant. Primary emphasis was placed on determining the coupled response of the system to variations in the following:

- (1) ECC injection location
- (2) Downcomer gap size
- (3) Lower plenum geometry
- (4) Heat transfer configuration
- (5) Break nozzle configuration.

In each test, the isothermal system was heated to about 575°F, pressurized to about 2250 psig, and subjected to a controlled double-ended break in the cold leg of the blowdown loop. Test data were collected during system decompression. The differences in test hardware configurations provided the means for varying system response during the decompression. In some cases, after blowdown was completed, data were taken with ECC injection continuing until the lower plenum was filled. This postblowdown portion of testing, designated hot-wall testing, was conducted to determine the effects of stored wall heat on ECC delivery. Table I summarizes the isothermal test configurations, and the following paragraphs briefly discuss each test.

1. BLOWDOWN TESTS

(a) *Test 1001.* Test 1001 was conducted to determine the system reference hydraulic behavior during sudden decompression. The pressure vessel was equipped with the standard lower plenum (length-to-diameter ratio of 2.8:1) and the thermal liner was installed in the lower plenum. The downcomer gap size was 0.5 inch. Two 100% break area nozzles were used in the cold leg of the blowdown loop.

(b) *Test 1002.* Test 1002 was conducted to establish the effects on the water remaining in the lower plenum following blowdown due to increased heat transfer from the lower plenum walls to the fluid. Therefore, the test was conducted without the thermal liner in the lower plenum. Except for the absence of the thermal liner the system configuration was identical to that of Test 1001.

(c) *Test 1003.* Test 1003 was conducted to establish the effect on the water remaining in the lower plenum of altering the geometry of the lower plenum. For this test the length-to-diameter ratio of the lower plenum was 1.2:1 as compared to 2.8:1 for all other tests.

TABLE I
SUMMARY OF SEMISCALE ISOTHERMAL TESTS

System Configuration								
Blowdown Test	Length-to- Diameter Ratio	Downcomer Gap (in.)	Lower Plenum Thermal Shield	Break Nozzle Flow Area (%)	System Pressure at ECC Ini- tiation and Injection Location			Hot-Wall Test After Blowdown
					Blowdown Loop	Operating Loop	Lower Plenum	
1001	2.8:1	0.5	installed	100				15.1
1002	2.8:1	0.5	not installed	100				
1003	1.2:1	0.5	installed	100				
4 1004	2.8:1	0.5	installed	100	~600		~200	15.2
1006 ^[a]	2.8:1	0.5	installed	100	~600	~600		
1008	2.8:1	1.0	installed	100	~600	~600		
1009	2.8:1	1.69	installed	100	~600	~600		
1010	2.8:1	1.0	installed	100				15.3
1011 ^[b]	2.8:1	1.69	installed	80				15.4
1014 ^[c]	2.8:1	1.0	installed	100 ^[b]				15.7

[a] Tests 1005 and 1007 were canceled and their objectives met by other tests in this series.

[b] Tests 1012 and 1013 were single-ended cold leg break tests and Tests 15.5 and 15.6 were the corresponding hot-wall tests. These tests produced questionable results which do not warrant reporting.

[c] Test 1014 was a single-ended cold leg break test. Only the blowdown loop hot leg rupture assembly actuated.

(d) *Test 1004.* Test 1004 was the first isothermal test conducted with ECC injection. For this test, ECC was injected into the lower plenum to determine effects on system flow and decompression of coolant mixing in the lower plenum. ECC was also injected upstream of the double-ended cold leg break on the simulated pump side of the break to determine the effect on break flow of coolant injection.

(e) *Test 1006.* Test 1006 was conducted to determine the capability of delivering coolant through the downcomer to the lower plenum. Coolant was injected into the cold leg of the operating loop and the cold leg of the blowdown loop (upstream of the cold leg break on the simulated pump discharge side).

(f) *Test 1008.* The purpose of Test 1008 was to investigate the effects of downcomer gap size on general hydraulic system behavior with the downcomer gap in the pressure vessel enlarged to 1.0 inch. ECC was injected into the cold legs of the operating and blowdown loops.

(g) *Test 1009.* Test 1009 investigated the effects of a large downcomer gap on downcomer flow and system general hydraulic behavior with the downcomer gap in the pressure vessel enlarged to 1.69 inch. ECC was injected into the cold legs of the operating and blowdown loops.

(h) *Test 1010.* Test 1010 was conducted with a 1.0-inch downcomer gap and no ECC injection to determine the effects of a 1.0-inch downcomer gap on system general hydraulic response.

(i) *Test 1011.* Test 1011 was conducted to provide data with which to assess analytical predictions against known system response to break size variation. The downcomer gap was 1.69 inches. The break flow area used in this test was 80% of that used in other isothermal tests. ECC was not injected.

(j) *Test 1014.* Test 1014 provided information on system hydraulic response to a single-ended cold leg break; system decompression occurred through the hot leg of the blowdown loop, the simulated steam generator, simulated pump, and a portion of the cold leg. This test was conducted with a 1.0-inch downcomer gap and without ECC injection.

2. HOT-WALL TESTS

To determine effects of stored wall heat on ECC delivery, the following hot-wall tests were conducted after completion of the blowdown tests.

(a) Test 15.1 was conducted following blowdown Test 1001

(b) Test 15.2 was conducted following blowdown Test 1004

(c) Test 15.3 was conducted following blowdown Test 1010

(d) Test 15.4 was conducted following blowdown Test 1011

(e) Test 15.7 was conducted following blowdown Test 1014.

These tests were conducted with ECC injection continuing until the lower plenum was filled.

III. TEST APPARATUS

The 1-1/2-loop isothermal semiscale system shown isometrically in Figure 1 and schematically in Figure 2 consists of a pressure vessel with simulated reactor internals (electric heaters); an operating loop with a steam generator, pump, and pressurizer; a blowdown loop with rupture assemblies, a simulated steam generator, and a simulated pump; a pressure suppression system with a suppression tank and header; and a simulated ECC system with accumulators and injection pumps. The exterior of the entire system and piping is thermally insulated.

The isothermal system is designed to operate at temperature and pressure of 577°F and 2250 psig. The operating loop simulates three operating loops of a commercial PWR, and the blowdown loop simulates a single operating loop of a PWR. When test conditions are established, the system is subjected to a simulated double-ended shear cold leg break.

System liquid volumes are recorded in Table II, and experimentally determined system pressure drops and calculated hydraulic resistances are given in Table III.

1. PRESSURE VESSEL AND INTERNALS

The pressure vessel, shown in Figure 3, is constructed of 10-inch Schedule 160 carbon steel pipe conforming to ASTM A 106, Grade B. It has a length of about 12 feet, an OD of 10.75 inches, and an ID of 8.5 inches. The top and bottom heads are 10-inch Grayloc blind hubs, and the top head is fitted with a 4-inch Grayloc hub that supports an inner core barrel assembly. The vessel is designed for pressure and temperature of 2250 psig and 650°F. Six 3-inch nozzle penetrations are provided in the vessel sides, two for inlet nozzles and four for outlet nozzles. Additional penetrations are provided in the vessel for installation of instrumentation.

The length and diameter of the vessel lower plenum are varied through use of two different bottom heads and a downcomer filler extension. The standard (long) lower plenum, with the downcomer filler extension installed, is 6.5 inches in diameter and 17.6 inches in depth. The other (short) lower plenum does not utilize the downcomer filler extension and is 8.5 inches in diameter and 10.3 inches in depth. The heat transfer characteristics of the lower plenum are varied by use of a thermal shield consisting of a thermal sleeve and a bottom thermal liner plate. The thermal sleeve is a 0.010-inch-thick Type 304 stainless steel cylinder wrapped in 0.045-inch-thick Grafoil, a graphite-impregnated insulation material. The bottom thermal liner plate is a flat sheet of 0.010-inch-thick Type 304 stainless steel with a 0.060-inch layer of Grafoil underneath.

The vessel internals (Figure 3) consist of a core barrel assembly and either of two instrumented downcomer filler pieces; one filler piece provides a downcomer gap (annulus) of 0.50 inch and the other provides a downcomer gap of 1.0 inch. A 1.69-inch downcomer gap is obtained by omitting the filler pieces. The core barrel assembly has an outer core

Fig. 1 1-1/2-loop semiscale system -- isometric.

Fig. 2 1-1/2-loop semiscale system -- piping schematic.

TABLE II

LIQUID VOLUME DISTRIBUTION FOR 1-1/2-LOOP ISOTHERMAL SYSTEM

Component	Liquid Volume (ft ³)
<u>Vessel</u>	
Upper annulus	0.163
Downcomer annulus - 0.5-inch gap	0.411
- 1.0-inch gap	0.880
- 1.69-inch gap	1.618
Lower plenum	0.422
Below core turbine meter (0.334 ft ³)	
Core turbine meter (0.034 ft ³)	
Core mixer box (0.036 ft ³)	
Core inlet box (0.018 ft ³)	
Core	0.123
Core bypass	0.204
Outlet plenum	1.075
Vessel Total Liquid Volume - 0.5-inch gap	2.398
- 1.0-inch gap	2.867
- 1.69-inch gap	3.605
<u>Operating Loop</u>	
Hot leg	0.453
Pressurizer [a]	
Surge line	0.034
Steam generator	1.497
Pump suction leg	0.274
Pump	0.144
Cold leg	0.295
Operating Loop Total Liquid Volume	3.181 ^[b]
<u>Blowdown Loop</u>	
Hot leg	0.037
Steam generator simulator	0.676
Pump suction leg	0.036
Pump simulator	0.085
Pipe	0.033
Cold leg	0.024
Blowdown Loop Total Liquid Volume	0.891
System Total Liquid Volume ^[b]	
- 0.5-inch gap	6.470
- 1.0-inch gap	6.939
- 1.69-inch gap	7.677

[a] Pressurizer liquid volume is a test variable. The total volume of the pressurizer including liquid and steam volumes is 0.968 ft³.

[b] Excluding pressurizer liquid volume.

TABLE III

MEASURED SYSTEM PRESSURE DROPS AND CALCULATED FLOW RESISTANCES

Operating Loop Locations ^[a]	ΔP at 80 gpm (psid)	ΔP at 120 gpm (psid)	Maximum Error in ΔP (psid)	Average Flow Resistance ($\text{sec}^2/\text{in.}^2\text{-ft}^3$)	Maximum Error in Flow Resistance ($\text{sec}^2/\text{in.}^2\text{-ft}^3$)
Pump outlet to cold leg (DP-19-22)	0.66	1.51	± 0.02	0.33	± 0.02
Cold leg to inlet annulus (DP-22-264)	1.65	3.82	± 0.11	0.84	± 0.05
Inlet annulus to lower plenum (DP-264-228)	0.034	0.078	± 0.007	0.017	± 0.002
Lower plenum to upper plenum (DP-228-207)	3.12	7.10	± 0.11	1.58	± 0.09
Upper plenum to hot leg (DP-207-5)	1.13	2.39	± 0.04	0.55	± 0.03
Hot leg to steam generator inlet (DP-5-10)	2.73	6.37	± 0.11	1.39	± 0.08
Across steam generator (DP-10-9)	0.149	0.330	± 0.007	0.075	± 0.004
Inlet to pump (DP-9-15)	1.98	4.53	± 0.11	1.01	± 0.06
Across pump (DP-19-15)	11.3	25.8	± 0.3	5.7	± 0.3
Across orifice at steam generator exit (DP-9-13) ^[b]	1.94	4.52	± 0.11	0.99	± 0.06
Blowdown Loop Locations	ΔP at 20 gpm (psid)	ΔP at 40 gpm (psid)	Maximum Error in ΔP (psid)	Average Flow Resistance ($\text{sec}^2/\text{in.}^2\text{-ft}^3$)	Maximum Error in Flow Resistance ($\text{sec}^2/\text{in.}^2\text{-ft}^3$)
Inlet annulus to hot leg (DP-264-70)	0.53	1.57	± 0.04	3.8	± 0.2
Across simulated steam generator (DP-70-96)	3.39	11.5	± 0.2	26	± 1
Across simulated pump (DP-96-76)	5.12	17.4	± 0.8	40	± 2
Across blowdown nozzle (DP-76-61)	0.85	2.04	± 0.02	4.7	± 0.2

[a] DP-XX-XX identifies measurement device and location as defined in Section IV.

[b] Included in inlet to pump differential pressure (DP-9-15).

Item	Description
1	Vessel
2	Main Core Barrel Assembly
3	Downcomer Filler, 1/2-in. Annulus
4	Inner Core Barrel Assembly
5	Flow Mixer Box Assembly
6	Turbine Meter
7	Mixer Plate and Inlet Plate Assembly
8	Short Bottom Head
9	10-in. Head Weldment, Top
10	Heater Rod Assembly
11	Mixer Box Cover
12	Downcomer Filler Extension
13	4-in. Top Head
14	Heater Element Lock Nut
15	Turbine Meter Cover
16	Thermal Shield
17	Inner Barrel Spacer Rings (typ)
18	Standard Head
19	Set Screw (core centering pin) (typ)
20	Heater Grounding Strap
21	Downcomer Filler, 1-in. Annulus(not shown)
22	Core Inlet
23	Dowel Pin
24	Grayloc Seal Ring, 4-in.
25	Grayloc Clamp and Bolts, 4-in.
26	Grayloc Seal Ring, 10-in.
27	Grayloc Clamp and Bolts, 10-in.
28	Scintillator Shielding Cask Support-Bracket (rotated to 180°)

Fig. 3 Pressure vessel, cross-sectional view.

barrel (main core barrel assembly in Figure 3) suspended from the 10-inch top head weldment and an inner core barrel suspended from the 4-inch top head. Nine heater rods are suspended from the 4-inch top head and extend down through the inner core barrel. The inner core barrel is made from 2-3/4-inch-OD by 0.188-inch-thick stainless steel tubing. The outer core barrel is made from sections of 5- and 6-inch Schedule 80 Type carbon steel pipe conforming to ASTM A 106, Grade B (5-inch pipe in the downcomer annulus and 6-inch pipe in the upper annulus). The OD of the outer core barrel is about 5-1/4 inches.

The heater rods in the vessel heat the system water to isothermal conditions. The heaters are stainless steel-clad filament heaters about 10 feet long with a 66-inch heated section, and are arranged in a 3x3 array on approximately 0.56-inch centers. Each heater rod has a diameter of approximately 0.42 inch, and each has a power capability of 30 kW. The bottoms of the heater rods are electrically grounded to the outer core barrel. Six of the heater rods are connected to two dc sources; three rods are connected to a variable power source of 0-155 Vdc, and three rods are connected to a constant (155 Vdc) power source. The three remaining rods are not powered. For the isothermal tests, power to all heater rods is turned off before blowdown is initiated.

The coolant, chemically treated demineralized water, enters the vessel inlet annulus through the cold leg inlet nozzle and flows down to the lower plenum through the downcomer annulus formed by the inside of the downcomer filler piece and the outside of the outer core barrel. The coolant then flows up through a turbine flowmeter and then through the nine-rod heater bundle. A portion of the coolant bypasses the heater bundle by flowing between the inside of the outer core barrel and the outside of the inner core barrel. The amount of bypass flow is controlled by spacer rings which restrict the flow passage. The coolant then flows out the openings in the inner barrel and slots in the outer barrel to the vessel outlet plenum and vessel outlet nozzles. An O-ring seal is used to separate the outlet plenum from the inlet annulus.

Nozzle liners are used to reduce the 2.689-inch-ID vessel nozzles to 1.5-inch ID for the operating loop and to 1.689-inch ID for the blowdown loop. The vessel is designed for a pressure drop (nozzle-to-nozzle) of 52 psig at a vessel flow rate of 30 lb/sec.

2. OPERATING LOOP

The operating loop consists of the primary coolant piping, steam generator, pressurizer, and circulating pump. The operating loop is shown in the system schematic of Figure 2.

2.1 Operating Loop Piping

The primary coolant piping is primarily 3-inch Schedule 160, carbon steel pipe conforming to ASTM A 106, Grade B. The piping consists of replaceable spool piece

sections which are connected by 3-inch Grayloc fittings. Carbon steel is used for the Grayloc fittings and most of the piping, but Type 316 stainless steel is used for spool pieces containing turbine flowmeters. Pipe spools for instrumentation are 17-1/4 inches long and provide the capability for changing measurement locations. Pipe section lengths of the primary coolant piping in the operating loop are as follows:

Hot leg (vessel to steam generator)	167.22 in.
Pump suction (steam generator to pump)	87.81 in.
Cold leg (pump to vessel)	98.66 in.
Total operating loop piping	353.69 in.

2.2 Steam Generator

The steam generator is a tube-in-shell heat exchanger, as illustrated in Figure 4. The primary coolant flows into the inlet plenum, downward through 43 coolant tubes, into the outlet plenum, and out the exit nozzle. The tests of the isothermal series were conducted with the temperature drop around the primary loop kept to a minimum; no secondary cooling was used.

The steam generator is fabricated from carbon steel in accordance with the requirements of Section VIII of the ASME Boiler and Pressure Vessel Code; the primary coolant side has a design pressure and temperature of 2500 psig and 650°F, respectively. Distribution of volume within the steam generator is as follows:

Inlet nozzle and upper plenum	0.47 ft ³
Tube volume	0.20 ft ³
Lower plenum and outlet nozzle	0.47 ft ³
Total	1.14 ft ³

2.3 Pressurizer

The pressurizer is an electrically heated vessel connected to the primary piping between the pressure vessel and the steam generator inlet. Pressurizer operation is similar to that of its counterpart in a PWR in that the water in the partially filled pressurizer is maintained at the saturation temperature corresponding to the desired system pressure.

The pressurizer is designed for 2500 psig and 650°F and was hydro-tested to 4725 psig. It is made of 10-inch double extra strong Type 304 stainless steel pipe 45 inches long. Heat is supplied by thirty-two 0.25-kW heaters which are inserted down through the top of

Fig. 4 Steam generator, cross-sectional view.

the pressurizer into dry wells. The wells are vertically mounted 0.75-inch-OD stainless steel tubes with closed bottom ends. The wells are integral with the pressurizer top and extend downward almost to the bottom of the pressurizer. The hot leg of the primary piping is connected to the pressurizer by 3/4-inch Schedule 80 pipe. A restriction for flow resistance is used during the decompression phase of testing. The total volume of the pressurizer and surge line piping is 1.002 ft³.

2.4 Circulating Pump

The circulating pump is a volute-type, heavy-duty, horizontal centrifugal pump rated for a nominal flow of 182 gpm at a total head of 192 ft of water at 3560 rpm. The material of construction for the wetted parts (casing, impeller, shaft, ...) is Type 316 stainless steel. The remainder of the pump is of cast iron and carbon steel. The pump is designed for 2500 psig and 650°F. The specific speed of the pump is 930 rpm, the impeller diameter is 7-3/4 inches, and the total pump volume is 0.144 ft³. The pump is belt-driven through an integral torque motor by a 15 hp, variable speed, dc electric motor. Through use of the dc motor and speed controller, the pump can be set to operate at any speed between 250 and 3500 rpm. The operating conditions for the isothermal tests were attained by a pump speed of about 3000 rpm.

3. BLOWDOWN LOOP

The blowdown loop consists of a simulated pump, a simulated steam generator, two discharge nozzles, two rupture assemblies, and associated piping as illustrated in Figures 1 and 2.

3.1 Piping

The piping in the blowdown loop is 2-inch Schedule 160 carbon steel. The inside diameter of the 3-inch Schedule 160 vessel inlet and outlet nozzles is reduced from 2.626 inches to 1.689 inches by installation of a sleeve in each nozzle. With the exception of the flanges holding the rupture assemblies, all pipe flanges are 2-inch Grayloc fittings. Those holding the rupture assemblies are 2-1/2-inch 1500-lb flanges. Pipe section lengths in the blowdown loop are as follows:

Cold Leg	
Simulated pump outlet to rupture disc assembly	20.15 in.
Rupture disc assembly to vessel	22.37 in.
Simulated Steam Generator	23.69 in.
Pump Suction (simulated steam generator to simulated pump)	27.96 in.

Simulated Pump	65.42 in.
Hot Leg (vessel to simulated steam generator)	28.74 in.
Total Blowdown Loop Piping	188.33 in.

In order to establish isothermal conditions throughout the system, circulation of the fluid in the blowdown piping is maintained prior to blowdown by flowing a small amount of fluid through a 1/2-inch line from the cold leg to the hot leg. The flow rate is controlled by an air-operated modulating valve in the 1/2-inch line connecting the two legs. The 1/2-inch connecting line is closed off just prior to blowdown.

3.2 Simulated Steam Generator and Simulated Pump

The steam generator is simulated with an inlet-outlet plenum chamber of 536-in.³ volume, a 2-inch Schedule 160 U-shaped pipe of 572-in.³ volume connecting the two plenums, and a restricting orifice. The maximum height of the centerline of the U-shaped pipe line is 133 inches above the centerline of the hot leg. Four orifices (0.9942-in. diameter) are installed in the steam generator simulator to produce the desired hydraulic resistance.

The blowdown coolant pump resistance is simulated with two orifices (0.783-in. diameter). The pump suction piping is simulated with a U-trap of 2-inch Schedule 160 pipe 49.5 inches deep. It is connected to the system with Grayloc fittings.

3.3 Rupture Assemblies

Each rupture assembly consists of the blowdown nozzle, two 1450-psi banana-peel-type rupture discs, and an instrument washer bolted between two 2-1/2-inch 1500-pound slip-on flanges. Figure 5 shows the rupture assembly (without the blowdown nozzle) and Figures 6 and 7 show the different nozzle configurations used. The chamber between the rupture discs is filled with helium to about one-half the primary system pressure. When the operating pressure is reached within the primary system, the discs are ruptured by the helium being vented from the chamber to increase the differential pressure between the cavity and the primary system, causing the primary system pressure to rupture the inner (blowdown loop side) disc first and then the outer (suppression system side) disc. Also included as part of each rupture assembly is a convergent-divergent nozzle (Figures 6 and 7).

Each of the rupture nozzles is designed to simulate one-half of a double-ended shear break in a PWR primary system cold leg. The nozzles used for the 100% break area tests are sized to produce a system volume to break area ratio representative of a complete break and offset of a reactor main coolant pipe. The two 100% break area nozzles provide a system volume to total break area ratio of 1481 feet which is representative of a PWR break. The area of each of the two 80% break area nozzles is 80% of the area of the 100% nozzle. The

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①, ②, ③ and ④ Indicate Pressure
Tap HN1, HN2, HN3, and HN4, Respectively

	Dimension "A" in.
100% Break Area Nozzle	0.656 $\pm$ 0.002
80% Break Area Nozzle	0.587 $\pm$ 0.002

Fig. 6 Hot leg break nozzle assembly.

Fig. 7 Cold leg break nozzle assembly.

term cold leg nozzle refers to the nozzle on the pressure vessel side of the break, and the term hot leg nozzle refers to the nozzle on the simulated pump side of the break.

4. PRESSURE SUPPRESSION SYSTEM

The 1-1/2-loop pressure suppression system consists mainly of a pressure vessel with a downcomer and blowdown header as shown in Figure 1. Its function is to simulate the secondary containment vessel of a PWR. Blowdown effluent is discharged from the blowdown loop into a 16-inch header that simulates, in general, the drywell in a PWR pressure suppression system. The effluent flows from the header into the vessel water pool through an 8-inch downcomer. The pressure suppression vessel is oriented vertically to achieve the desired distance from the downcomer to the water surface and to the bottom of the vessel. The pressure suppression system accepts 100% of the blowdown water in the 1-1/2-loop primary system, the initial suppression vessel water, and the injected ECC water.

4.1 Pressure Suppression Tank

The total volume of the pressure suppression tank is 91.7 ft³. The tank is sized such that when it is 50% full of water, the downcomer pipe extends 2.5 feet below the water surface. Fill and drain connections are provided at the bottom of the tank and a gas pressurization nozzle is located near the top. A flanged connection is provided for the downcomer pipe. A 3-inch Schedule 40 flanged nozzle (with blind flange installed) is located in the top of the tank to provide access for spray equipment used in some isothermal tests for pressure control. Heaters are provided to maintain the desired water temperature prior to blowdown.

The downcomer pipe is 8-inch Schedule 40 carbon steel and extends downward to 3.0 feet from the bottom of the tank. Either two 1-1/2-inch vacuum breaker valves or three 1-1/2-inch check valves are provided to prevent suction of water up the downcomer after completion of the blowdown.

4.2 Pressure Suppression Header

The header is made of 16-inch Schedule 40 carbon steel pipe and has a length-to-diameter of 8.4:1. No water traps exist in the header, and the downcomer pipe connection is on the bottom of the header.

5. ECC INJECTION SYSTEM

The ECC injection system consists of two accumulator subsystems and two pump subsystems. The system can supply simulated emergency core coolant to the pressure vessel lower plenum or to the operating loop and the blowdown loop as shown in Figure 2. The ECC injection system was designed to provide simulated core cooling to the operating loop and to the blowdown loop in identical ratios of ECC flow to loop volume; that is, the operating loop ECC system (scaled to represent three injection systems of a typical PWR) provides about three times the flow of the blowdown loop ECC system (simulates the injection system of the broken loop of a typical PWR).

5.1 Accumulators

Two accumulators, which are connected to a pressure source of gaseous nitrogen, supply initial water flows to the operating loop or lower plenum and blowdown loop. The accumulator which supplies the operating loop or lower plenum has a volume of 7.7 ft³, and the accumulator which supplies the blowdown loop has a volume of 2.15 ft³.

5.2 Pumps

Two positive displacement gear-type pumps independently supplement the expended accumulator flow. These pumps provide the capability of low pressure flows which can be varied from test to test.

5.3 Isolation Valves

Six high-temperature, high-pressure, pneumatically operated and electrically controlled valves isolate the ECC injection system from the primary system. Valve operation is controlled by automatic timing devices or by remote manual control at the operations console.

5.4 Check Valves

Check valves were installed as close as practical to the primary system to minimize effects of an additional volume of fluid in the primary system.

IV. INSTRUMENTATION

The instrumentation system, shown schematically in Figure 8, provides the means for measuring test variables, recording the resultant data on magnetic tape, and producing the data in printed form.

Two hundred and twenty signal conditioning and recording channels are available of which 169 channels provide magnetic tape analog data. Digital data may be obtained from all 220 channels for warmup and backup use. The analog data are provided as X-Y plots with time referenced to test initiation as the abscissa. Time recording is provided by a timing subsystem, and time is recorded on the first channel of each magnetic tape transport.

1. INSTRUMENT SYSTEM CONFIGURATION

Measurement of test variables is accomplished by detectors located in the isothermal semiscale system. Detectors are provided for measuring fluid mass and volumetric flow rate, density, pressure, differential pressure, fluid and material temperatures, material strain, liquid level, and pump power, speed, and torque. The nomenclature used to designate specific detectors consists of (a) alphabetic symbols identifying the type of measurement (or detector type) or the location of the measurement relative to a component of the semiscale system, or both, and (b) arabic numeral suffixes to the alphabetic symbols identifying the pipe section (spool) or vessel port (station). Examples of detector designations are:

- P-1 Indicates a pressure measurement in Pipe Section 1 (the hot leg of the operating loop).
- DP-1-5 Indicates a differential pressure measurement between Pipe Sections 1 and 5.
- FD-1 Indicates a measurement of fluid momentum flux with a drag disc in Pipe Section 1.

Table IV defines the alphabetical nomenclature, and Figures 9 through 12 identify measurement stations and all instrumentation used in the isothermal blowdown tests. Figure 13 shows a typical installation for the detectors in an instrumented spool piece. Instrumented spool pieces (Spools 1, 19, 22, 41, and 70) are constructed of Type 304 stainless steel. Table V defines in greater detail the location of each measurement used in the isothermal test series. Table VI indicates the manufacturer of the detector, identifies the type of measurement device, indicates the range and response of the detector, and specifies the maximum error introduced by the measurement system.

Fig. 8 Instrumentation system schematic.

TABLE IV
DETECTOR DESIGNATIONS

<u>Measurement Designation</u>	<u>Definition of Measurement (detector type)</u>
BW	Time of break (break wire)
D	Fluid density
DP	Differential pressure
FD	Fluid momentum flux
FT	Fluid volumetric flow rate or fluid velocity
LDT	Linear displacement (linear differential transducer)
LL	Liquid level
P	Pressure
PS-RPM	Pump shaft speed
PW-PMP	Power, pump motor
RB	Fluid temperature (resistance bulb)
S	Flow direction (switch)
SGB	Strain (strain gage, bending)
SGI	Strain (strain gage rosette at the point of fluid impingement)
SGT	Strain (strain gage, tensile)
TF	Fluid temperature
TM	Material temperature
T-PMP	Pump shaft torque
TS	Fluid temperature (shielded thermocouple)
<u>Special Notation</u>	(generally used in combination with the preceding measurement designation)
B	1/8 inch from inside diameter at pipe bottom
BLA	Blowdown loop accumulator
BLP	Blowdown loop pump
C	Core
CL	Cold leg
D	Downcomer
EL	Elbow
H	1/8 inch from inside diameter at pipe middle (for metal temperature detector location)
H	Horizontal (for density measurement)
HL	Hot leg

TABLE IV (Contd.)
DETECTOR DESIGNATIONS

<u>Measurement Designation</u>	<u>Definition of Measurement (detector type)</u>
<u>Special Notation (Contd.)</u>	
HN	Rupture nozzle (HN followed by a numeral indicates nozzle instrument port)
I	1/8 inch from inside diameter at pipe top
IDL	Inside diameter, lower
IDU	Inside diameter, upper
L	Low range
LFF	LOFT free field
LFTA	LOFT analog
LFTD	LOFT digital
LH	Lower plenum head
LOFT	Loss of fluid test
LP	Lower plenum
LPA	Lower plenum accumulator
M	1/4 inch from inside diameter at pipe top
OL	Operating loop
OLA	Operating loop accumulator
OLP	Operating loop pump
PSH	Pressure suppression header
PSS	Pressure suppression system
PSV	Pressure suppression vessel
S	Surface
V	Vessel (with TM) or vertical (with D)
VOD	Vessel outside diameter

Encircled Letter Symbols Denote Measurement Types

Number Suffixes or Encircled Numbers Alone Identify System Locations (pipe spools, vessel ports, stations)

Fig. 9 1-1/2-loop semiscale system -- instrumentation isometric.

Item	Description
1	Vessel
2	Main Core Barrel Assembly
3	Downcomer Filler, U/2-in. Annulus
4	Inner Core Barrel Assembly
5	Flow Mixer Box Assembly
6	Turbine Meter (FT - C-1)
7	Mixer Plate and Inlet Plate Assembly
8	Short Bottom Head
9	10-in. Head Weldment, Top
10	Heater Rod Assembly
11	Mixer Box Cover
12	Downcomer Filler Extension
13	4-in. Top Head
14	Heater Element Lock Nut
15	Turbine Meter Cover
16	Thermal Shield
17	Inner Barrel Spacer Rings (typ)
18	Standard Head
19	Set Screw (core centering pin) (typ)
20	Heater Grounding Strap
21	Downcomer Filler, 1-in. Annulus (not shown)
22	Core Inlet
23	Dowel Pin
24	Grayloc Seal Ring, 4-in.
25	Grayloc Clamp and Bolts, 4-in.
26	Grayloc Seal Ring, 10-in.
27	Grayloc Clamp and Bolts, 10-in.
28	Scintillator Shielding Case Support Bracket (rotated to 180°) (D-275V)

All Vessel Instrumentation Rotated to 0° or 180° for Clarity

△ — Item Number

TM 45° — Type of Measurement
 45° — Rotational Location
 — Location
 — Distance from Upper Flange Face

Fig. 11 Pressure vessel with instrumentation, cross-sectional view.

Encircled Letter Symbols Denote Measurement Types

Number Suffixes or Encircled Numbers Alone Identify System Locations (vessel ports, stations)

Degrees Indicate Clockwise Orientation Around Vessel as Viewed from Vessel Top with 0° at Centerline of Operating Loop Inlet Cold Leg Nozzle

Nozzles Receding from View Plane are Omitted for Clarity

Pressure Vessel Instruments not Installed in Ports are Shown on ANC-R-2188

PENETRATION CODE	SIZE (IN.)	ANGULAR LOCATION FROM COLD LEG (CLOCKWISE)	DISTANCE FROM TOP FACE OF VESSEL (IN.)	PRIMARY USAGE	VESSEL WALL PENETRATION DIAMETER (IN.)
200	3/4 NPT	150°	7.88		.750
201	3/4 NPT	30°	7.13		.750
202	1/2 NPT	0°	5.00		.703
203			9.88	DENSITY, SOURCE	.500
204	1/2 NPT	45°	11.88		.560
205	1/4 NPT	5°	14.88		.250
206	1/2 NPT	0°	25.38		.750
207	3/4 NPT	30°	28.38		.750
208	3/4 NPT	150°	28.38		.750
209			30.38	DENSITY, SOURCE	.500
210	1/4 NPT	5°	32.88		.250
211	1/2 NPT	45°	32.38		.560
212	1 NPT	135°	49.88		1.000
213	1/4 NPT	40°	47.88		.750
214	3/4 NPT	315°	55.62	DOWNCOMER SUPPORT	
215	3/4 NPT	75°	55.62	DOWNCOMER SUPPORT	
216	3/4-16-UNF	45°	49.88		.687
217	1/4 NPT	135°	81.859		.250
218	1/4 NPT	75°	81.859		.250
219	1/4 NPT	15°	81.859		.250
220	1/4 NPT	135°	105.859		.250
221	1/4 NPT	75°	105.859		.250
222	1/4 NPT	15°	105.859		.250
223	3/4 NPT	135°	109.989		.750
224	3/4 NPT	315°	109.989		.750
225	1-1/4 NPT	0°	109.989	DENSITY	1.438
226	1 NPT	45°	116.989	TURBINE PROBE	1.000
227	1 NPT	45°	121.297	FILL LINE	1.000
228	1-1/4 NPT	0°	122.370		1.500
229	1 NPT	315°	121.297		1.000
230	3/4-16-UNF	225°	7.13		.687
231			9.88	DENSITY	.3125
232	1/4 NPT	125°	14.88		.250
233	1/4 NPT	245°	14.88		.250
234	3/4-16-UNF	225°	28.38		.687
235			30.38	DENSITY	.3125
236	1/4 NPT	125°	32.38		.250
237	1/4 NPT	230°	32.88		.250
238	1/4 NPT	330°	47.88		.250
239	1 NPT	225°	47.88	ECC	1.000
240	1/4 NPT	165°	47.88		.250
241	1/4 NPT	270°	47.88		.250
242	3/4 NPT	270°	49.88		.750
243	3/4 NPT	195°	55.62	DOWNCOMER SUPPORT	
244	1/2 NPT	225°	59.562		.500
245	1/4 NPT	315°	81.859		.250
246	1/4 NPT	255°	81.859		.250
247	1/4 NPT	195°	81.859		.250
248	1/4 NPT	315°	105.859		.250
249	1/4 NPT	255°	105.859		.250
250	1/4 NPT	195°	105.859		.250
251	1-1/4 NPT	180°	110.010	DENSITY	1.438
252	1 NPT	315°	116.989	TURBINE PROBE	1.000
253	1 NPT	225°	119.234		1.000
254	1 NPT	135°	119.234	ECC	1.000
255	3/4 NPT	240°	121.297		.750
256	3/4 NPT	120°	122.672		.750
257	1/4 NPT	80°	47.88		.250
258	3/4-16-UNF			IN LOWER HEAD	.687
259	1/2 NPT			IN LOWER HEAD	.703
260	3/4 NPT			IN LOWER HEAD	.921
261	3/4 NPT			IN LOWER HEAD	.921
262	3/4 NPT			IN LOWER HEAD	.921
263	1 NPT			IN LOWER HEAD	.921
264	1/4 NPT	45°	39.88		.840
265	1/2 NPT	45°	37.88		.540
266	1/2 NPT	299°	37.88		.840
267	1/4 NPT	299°	39.88		.540
268	1 NPT	0°	94.43		
269	1 NPT	90°	94.43		
270	1 NPT	180°	94.43		
271	1 NPT	0°	65.63		
272	1-1/4 NPT	180°	122.37		1.500
273	1-1/4 NPT	315°	7.88		1.500
274	1-1/4 NPT	315°	28.38		1.500
275			114.50		
276				IN LOWER HEAD	DENSITY

Fig. 12 Pressure vessel with instrumentation -- isometric.

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Fig. 13 Typical instrumented spool piece.

TABLE V
MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Time of Break (Break Wire)</u>	
BW-52	Blowdown loop cold leg, vessel side
BW-62	Blowdown loop cold leg, simulated pump side
<u>Density, Fluid</u>	
D-1V	Operating loop hot leg, Spool 1 (vertical)
D-5V	Operating loop hot leg, Spool 5 (vertical)
D-15V	Operating loop pump suction, Spool 15 (vertical)
D-19V	Operating loop pump discharge, Spool 19 (vertical)
D-22H	Operating loop cold leg, Spool 22 (horizontal)
D-22V	Operating loop cold leg, Spool 22 (vertical)
D-50V	Blowdown loop cold leg, Spool 50 (vertical)
D-70V	Blowdown loop hot leg, Spool 70 (vertical)
D-76V	Blowdown loop, cold leg, Spool 76 (vertical)
D-83V	Pressure suppression header near downcomer (vertical)
D-225H	Core barrel inlet, 110.0 inches and 0° (horizontal)
D-228H	Lower plenum, 122.4 inches and 0° (horizontal)
D-275V	Lower plenum (diagonal gamma beam), 114.5 inches, 315°
<u>Differential Pressure</u>	
DP-HN2-61	Blowdown loop hot leg nozzle downstream throat (Port 2) to Station 61
DP-HN4-61	Across hot leg nozzle outlet, downstream nozzle expansion section (Port 4) to Station 61
DP-LOFT	Lower plenum to upper plenum of vessel
DP-1-5	Operating loop hot leg, Spool 1 to Spool 5
DP-3-5	Operating loop hot leg, Spool 3 to Spool 5
DP-5-13	Operating loop, across steam generator, Spool 5 to Spool 13
DP-8-13	Operating loop pump suction orifice, Spool 8 to Spool 13
DP-13-15	Operating loop, Spool 13 to Spool 15
DP-19-15	Operating loop, across pump, Spool 19 to Spool 15
DP-19-15L	Operating loop, across pump, Spool 19 to Spool 15 (low range)
DP-19-22	Operating loop, Spool 19 to Spool 22
DP-22-1	Across pressure vessel, operating loop cold leg to hot leg, Spool 22 to Spool 1
DP-22-255	Operating loop cold leg to lower plenum, Spool 22 to Station 255
DP-52-62	Between rupture discs, inner disc cavities, Spool 52 to Spool 62
DP-70-96	Blowdown loop, across simulated steam generator, Spool 70 to Spool 96
DP-76-61	Across blowdown loop hot leg nozzle, Spool 76 to Station 61
DP-76-HN2	Blowdown loop, Spool 76 to hot leg nozzle downstream throat (Port 2)
DP-81-83	Pressure suppression header to downcomer entrance at header "Y"
DP-81-85	Pressure suppression header to downcomer entrance in pressure suppression tank

TABLE V (contd.)
MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Differential Pressure (Contd.)</u>	
DP-81-89	Pressure suppression header to pressure suppression tank vapor chamber
DP-83-85	Across downcomer, pressure suppression tank
DP-83-89	Pressure suppression tank downcomer entrance to pressure suppression tank vapor chamber
DP-85-89	Pressure suppression tank water to vapor chamber of pressure suppression tank
DP-96-76	Blowdown loop, across simulated pump, Spool 96 to Spool 76
DP-207-70	Vessel upper plenum to blowdown loop hot leg, Station 207 to Spool 70
DP-207-89	Vessel upper plenum to vapor chamber of pressure suppression tank
DP-213-246	Vessel downcomer, Station 213 to Station 246
DP-216-246	Vessel downcomer, Station 216 to Station 246
DP-246-249	Vessel downcomer, Station 246 to Station 249
DP-249-255	Vessel downcomer, Station 249 to Station 255
DP-255-207	Vessel lower plenum to vessel upper plenum, Station 255 to Station 207
DP-261-255	Lower plenum, Station 261 to Station 255
DP-264-50	Vessel inlet annulus to blowdown loop cold leg, Station 264 to Spool 50
DP5-HN2-HN4	Blowdown loop vessel side, downstream nozzle throat (Port 2) to downstream nozzle expansion section (Port 4)
DP6-HN2-HN4	Blowdown loop simulated pump side, downstream nozzle throat (Port 2) to downstream nozzle expansion section (Port 4)
<u>Flow (Drag Disc)</u>	
FD-1	Operating loop hot leg, Spool 1
FD-5	Operating loop hot leg, Spool 5
FD-15	Operating loop pump suction, Spool 15
FD-19	Operating loop pump discharge, Spool 19
FD-22	Operating loop cold leg, Spool 22
FD-50	Blowdown loop cold leg, Spool 50
FD-70	Blowdown loop hot leg, Spool 70
FD-76	Blowdown loop cold leg, Spool 76
FD-83	Pressure suppression header near downcomer
FD-212	In downcomer gap, 49.88 inches, 135° (target centered in gap)
FD-224	Core barrel inlet, 110 inches, 315° (target centered in gap)
FD-239	In downcomer gap, 47.88 inches, 225° (target centered in gap)
FD-253	In downcomer gap, 119.23 inches, 225° (target centered in gap)
FD-270	In downcomer gap, 94.43 inches, 180° (target centered in gap)
<u>Flow (Turbine Meter)</u>	
FT-C-1	Core barrel inlet, 110 inches
FT-ECC-BLA	In line from blowdown loop ECC injection accumulator
FT-ECC-BLP	In line from blowdown loop ECC injection pump
FT-ECC-LPA	In line from operating loop ECC injection accumulator to lower plenum

TABLE V (contd.)
MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Flow (Turbine Meter) (Contd.)</u>	
FT-ECC-OLA	In ECC line from operating loop ECC injection accumulator
FT-ECC-OLP	In ECC line from operating loop ECC injection pump
FT-PSS	Pressure suppression system spray water
FT-1	Operating loop hot leg, Spool 1
FT-19	Operating loop pump discharge, Spool 19
FT-22	Operating loop cold leg, Spool 22
FT-41	Pressurizer outlet
FT-70	Blowdown loop hot leg, Spool 70
FT-76	Blowdown loop cold leg, Spool 76
FT-212	In downcomer gap, 49.88 inches, 135°
FT-239	In downcomer gap, 47.88 inches, 225°
FT-253	In downcomer gap, 119.23 inches, 225°
FT-270	In downcomer gap, 94.43 inches, 180°
<u>Displacement (Linear Differential Transducer)</u>	
LDT-PSH	At pressure suppression header elbow (horizontal deflection)
LDT-PSV	Beneath pressure suppression vessel (vessel vertical deflection)
<u>Liquid Level</u>	
LL-LFTA-259	Lower plenum, Port 259
LL-LFTD-259	Lower plenum, Port 259
LL-PSS	Pressure suppression tank
<u>Pressure</u>	
P-ECC-BLA	Blowdown loop ECC accumulator
P-ECC-LPA	Lower plenum ECC accumulator
P-ECC-OLA	Operating loop ECC accumulator
P-LFF-HL	Hot leg stub in upper plenum
P-1	Operating loop hot leg, Spool 1
P6-HN2	Blowdown loop simulated pump side, nozzle throat, Port 2
P-10	Operating loop steam generator entrance, Spool 10
P-15	Operating loop pump suction, Spool 15
P-19	Operating loop pump discharge, Spool 19
P-22	Operating loop cold leg, Spool 22
P-40	Pressurizer outlet, Spool 40
P-50	Blowdown loop cold leg, Spool 50
P-51	Blowdown loop cold leg, downstream of vessel-side nozzle, Station 51
P-52	Blowdown loop vessel side, rupture assembly inner disc cavity, Spool 52
P-53	Blowdown loop cold leg, Spool 53
P-61	Blowdown loop downstream of hot leg nozzle, Station 61
P-62	Blowdown loop pump side, rupture assembly inner disc cavity, Spool 62
P-70	Blowdown loop hot leg, Spool 70
P-76	Blowdown loop cold leg, Spool 76

TABLE V (contd.)
MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Pressure (Contd.)</u>	
P-77	Blowdown loop cold leg, simulated pump side, inlet to pressure suppression header, Spool 77
P-80	Straight section of pressure suppression header between elbows, Spool 80
P-81	Pressure suppression header, Spool 81
P-89	Vapor chamber of pressure suppression vessel
P-207	Outlet plenum, 28.4 inches, 30°
P-255	Lower plenum, 121.3 inches, 240°
<u>Pump Speed</u>	
PS-RPM	Operating loop pump
<u>Pump Power</u>	
PW-PMP	Operating loop pump
<u>Fluid Temperature (Resistance Bulb Detector)</u>	
RB-86-6	Pressure suppression chamber water, Station 86-6
RB-211	Outlet plenum, 32.38 inches, 45°
<u>Strain, Impingement</u>	
SGI-PSH-CL-0	Pressure suppression header, outside first elbow, at impingement from cold leg, vessel side, 0°[c]
SGI-PSH-CL-60	Pressure suppression header, outside first elbow, at impingement from cold leg, vessel side, 60°[c]
SGI-PSH-CL-120	Pressure suppression header, outside first elbow, at impingement from cold leg, vessel side, 120°[c]
SGI-PSH-HL-0	Pressure suppression header, outside first elbow, at impingement from cold leg, simulated pump side, 0°[c]
SGI-PSH-HL-60	Pressure suppression header, outside first elbow, at impingement from cold leg, simulated pump side, 60°[c]
SGI-PSH-HL-120	Pressure suppression header, outside first elbow, at impingement from cold leg, simulated pump side, 120°[120]
<u>Strain, Bending</u>	
SGB-83	Strain gage, bending, gages at 90° and 270° around pipe Spool 83 (combined electrical output represents bending in horizontal plane)
<u>Strain, Tensile</u>	
SGT-PSH-HL	On top of pressure suppression header first elbow
<u>Flow Direction (Switch)</u>	
S-271	In downcomer gap, 65.6 inches, 0°, Station 271
<u>Torque</u>	
T-PMP	Operating loop pump
<u>Temperature, Fluid</u>	
TF-ECC-BLA	In line from blowdown loop ECC injection accumulator
TF-ECC-LPA	In line from operating loop ECC injection accumulator to lower plenum
TF-ECC-OLA	In line from operating loop ECC injection accumulator
TF-ECC-OLP	In line from operating loop ECC injection pump
TF-1	Operating loop hot leg, Spool 1
TF-3	Operating loop hot leg, Spool 3
TF-15	Operating loop pump suction, Spool 15
TF-19	Operating loop pump discharge, Spool 19
TF-22	Operating loop cold leg, Spool 22

TABLE V (contd.)
MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Temperature, Fluid (Contd.)</u>	
TF-40	Pressurizer outlet, Spool 40
TF-47D-180	In downcomer gap, ~48 inches, 180°, extending 1/8 inch into fluid from vessel wall side
TF-48C-0	In downcomer gap, ~48 inches, 0°, extending 1/8 inch into fluid from core barrel
TF-48C-180	In downcomer gap, ~48 inches, 180°, extending 1/8 inch into fluid from core barrel
TF-48D-0	In downcomer gap, ~48 inches, 0°, extending 1/8 inch into fluid from vessel wall side
TF-48D-180	In downcomer gap, ~48 inches, 180° extending 1/8 inch into fluid from vessel wall side
TF-50	Blowdown loop cold leg, Spool 50
TF-51	Blowdown loop cold leg downstream of vessel-side nozzle
TF-70	Blowdown loop hot leg, Spool 70
TF-76	Blowdown loop cold leg, Spool 76
TF-78D-0	In downcomer gap, ~78 inches, 0°
TF-78D-180	In downcomer gap, ~78 inches, 180°
TF-83	Pressure suppression header near downcomer entrance (1 inch from ID of header on bottom)
TF-86-1	Pressure suppression vessel, Station 86-1
TF-86-2	Pressure suppression vessel, Station 86-2
TF-86-3	Pressure suppression vessel, Station 86-3
TF-86-4	Pressure suppression vessel, Station 86-4
TF-86-6	Pressure suppression vessel, Station 86-6
TF-88	Pressure suppression vessel vapor chamber, 2 inches from tank wall
TF-95D-45	In downcomer gap, ~95 inches, 45°
TF-95D-225	In downcomer gap, ~95 inches, 225°
TF-96	Blowdown loop simulated steam generator discharge, Spool 96
TF-210	Outlet plenum, 32.88 inches, 5°
TF-211	Outlet plenum, 32.4 inches, 45°
TF-214	In downcomer gap, 55.62 inches, 315°
TF-215	In downcomer gap, 55.62 inches, 75°
TF-217	In downcomer gap, 81.86 inches, 135°
TF-219	In downcomer gap, 81.86 inches, 15°
TF-245	In downcomer gap, 81.86 inches, 315°
TF-247	In downcomer gap, 81.86 inches, 195°
TF-260-2	Lower plenum, vertical thermocouple rack, 2-inch level from inside bottom of lower head
TF-260-4	Lower plenum, vertical thermocouple rack, 4-inch level from inside bottom of lower head
TF-260-6	Lower plenum, vertical thermocouple rack, 6-inch level from inside bottom of lower head
TF-260-8	Lower plenum, vertical thermocouple rack, 8-inch level from inside bottom of lower head
TF-260-10	Lower plenum, vertical thermocouple rack, 10-inch level from inside bottom of lower head

TABLE V (contd.)

MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Temperature, Fluid (Contd.)</u>	
TF-260-12	Lower plenum, vertical thermocouple rack, 12-inch level from inside bottom of lower head
TF-260-14	Lower plenum, vertical thermocouple rack, 14-inch level from inside bottom of lower head
TF-260-16	Lower plenum, vertical thermocouple rack, 16-inch level from inside bottom of lower head
TF-260-18	Lower plenum, vertical thermocouple rack, 18-inch level from inside bottom of lower head
TF-263	In lower plenum head, Station 263
TF-268	In downcomer gap, 94.43 inches, 0°
TF-269	In downcomer gap, 94.43 inches, 90°
TF-274	Upper plenum, 28.38 inches, 315°
<u>Temperature, Metal</u>	
TM-LH-276	In lower plenum head
TM-LP-IDL	4.9 inches below lower plenum upper Grayloc flange face, 270° from cold leg centerline, 1/16 inch from ID of filler piece
TM-LP-IDU	5.0 inches above lower plenum upper Grayloc flange face, 270° from cold leg centerline, 1/16 inch from ID of filler piece
TM-LP-VOD	On vessel OD 5.0 inches above lower plenum upper Grayloc flange face, 270° from cold leg centerline
TM-PSH-EL	Pressure suppression header surface near first elbow
TM-1B	Operating loop hot leg, Spool 1, 1/8 inch from ID (bottom)
TM-1I	Operating loop hot leg, Spool 1, 1/8 inch from ID (top)
TM-19B	Operating loop cold leg, Spool 19, 1/8 inch from ID (bottom)
TM-19H	Operating loop cold leg, Spool 19, 1/8 inch from ID (middle)
TM-19I	Operating loop cold leg, Spool 19, 1/8 inch ID (top)
TM-19M	Operating loop cold leg, Spool 19, 1/4 inch from ID (top)
TM-19S	Operating loop cold leg, Spool 19, outside surface (top)
TM-22B	Operating loop cold leg, Spool 22, 1/8 inch from ID (bottom)
TM-22H	Operating loop cold leg, Spool 22, 1/8 inch from ID (middle)
TM-22I	Operating loop cold leg, Spool 22, 1/8 inch from ID (top)
TM-22M	Operating loop cold leg, Spool 22, 1/4 inch from ID (top)
TM-22S	Operating loop cold leg, Spool 22, outside surface (top)
TM-47C-0	In core barrel, ~47 inches, 0°, 1/8 inch from OD
TM-47C-180	In core barrel, ~47 inches, 180°, 1/8 inch from OD
TM-48D-0	In downcomer filler, ~48 inches, 0°, 1/16 inch from ID
TM-48D-180	In downcomer filler, ~48 inches, 180°, 1/16 inch from ID
TM-62C-45	In core barrel, ~62 inches, 45°, 1/8 inch from OD
TM-62D-45	In core barrel, ~62 inches, 45°, 1/8 inch from OD
TM-63D-45	In downcomer filler, ~63 inches, 45°, 1/16 inch from ID
TM-63D-225	In downcomer filler, ~63 inches, 225°, 1/8 inch from OD
TM-63V-45	In vessel, ~63 inches, 45°, 1/4 inch from ID
TM-63V-225	In vessel, ~63 inches, 225°, 1/4 inch from ID
TM-77C-0	In core barrel, ~77 inches, 0°, 1/8 inch from OD
TM-77C-180	In core barrel, ~77 inches, 180°, 1/8 inch from OD
TM-78D-0	In downcomer filler, ~78 inches, 0°, 1/16 inch from ID

TABLE V (contd.)
MEASUREMENT LOCATIONS

Measurement Designation ^[a]	Location Description ^[b]
<u>Temperature, Metal (Contd.)</u>	
TM-78D-180	In downcomer filler, ~78 inches, 180°, 1/16 inch from ID
TM-78V-0	In vessel, ~78 inches, 0°, 1/4 inch from ID
TM-78V-90	In vessel, ~78 inches, 90°, 1/4 inch from ID
TM 78V-180	In vessel, ~78 inches, 180°, 1/4 inch from ID
TM-83	Pressure suppression header on surface near first elbow
TM-94C-45	In core barrel, ~95 inches, 45°, 1/8 inch from OD
TM-94C-16-45	In core barrel, ~95 inches, 45°, 1/16 inch from ID
TM-94C-18-45	In core barrel, ~95 inches, 45°, 1/8 inch from ID
TM-95D-45	In downcomer filler, ~95 inches, 45°, 1/16 inch from ID
TM-95D-225	In downcomer filler, ~95 inches, 225°, 1/16 inch from ID
TM-95D-18-45	In downcomer filler, ~95 inches, 45°, 0.176 inch from OD
TM-95V-45	In vessel, ~95 inches, 45°, 1/2 inch from OD
TM-95V-225	In vessel, ~95 inches, 225°, 1/4 inch from ID
TM-95V-25-45	In vessel, ~95 inches, 45°, 1/4 inch from ID
TM-96	Blowdown loop, simulated pump suction, Spool 96, 1/16 inch from ID
TM-116D-0	In downcomer filler, ~116 inches, 0°, 1/16 inch from ID
TM-116D-45	In downcomer filler, ~116 inches, 45°, 1/16 inch from ID
TM-116D-225	In downcomer filler, ~116 inches, 225°, 1/16 inch from ID
TM-116V-0	In vessel, ~116 inches, 0°, 1/4 inch from ID
TM-116V-180	In vessel, ~116 inches, 180°, 1/4 inch from ID
TM-205-S	Vessel exterior, ~15 inches, 5°
TM-205-18	In vessel, ~15 inches, 5°, 1/8 inch from ID
TM-205-316	In vessel, ~15 inches, 5°, 3/16 inch from ID
TM-210-S	Vessel exterior, ~33 inches, 5°
TM-210-18	In vessel, ~33 inches, 5°, 1/8 inch from ID
TM-210-316	In vessel, ~33 inches, 5°, 3/16 inch from ID
TM-250-S	Vessel exterior, 106 inches, 195°
TM-250-18	Vessel wall, 106 inches, 195°, 1/8 inch from ID
TM-250-316	Vessel wall, 106 inches, 195°, 3/16 inch from ID
<u>Temperature, Fluid (Shielded Thermocouple, Steam Temperature Probe)</u>	
TS-3	Operating loop hot leg, Spool 3
TS-20	Operating loop cold leg, Spool 20

[a] Symbols for measurement designations are defined in Table IV.

[b] Vertical dimensions (in inches) are measured down from upper vessel flange face. Degrees are measured from centerline of the operating loop cold leg nozzle clockwise as viewed from vessel top.

[c] Degrees indicate counterclockwise orientation of component of rosette strain gage relative to pipe centerline.

TABLE VI

DETECTOR CHARACTERISTICS AND MEASUREMENT SYSTEM MAXIMUM ERROR

Measurement	Manufacturer	Type	Detector Range	Detector Rise-time[a]	Measurement System Maximum Error
Break time	Aerojet Nuclear Company	Break wire in a voltage drop circuit	On - off	<1 msec	
Fluid density	Technical Operations, Inc. and Aerojet Nuclear Company	Gamma attenuation	0.01 to 62.4 lb/ft ³	3.5 msec	+ 0.06 lb/ft ³
Differential pressure	BLH Electronics, Inc.	Diaphragm-bonded strain gage	+0.72 to +1500 psid	20 msec	+1.0% full scale
Momentum flux	Ramapo Instrument Company, Inc.	Strain-gaged cantilever beam with target	up to 4×10^4 lb/ft-sec ²	2 msec	+1.0% full scale
Volumetric flow	ITT Barton and Flow Technology, Inc.	Turbine	up to 200 gpm up to 800 gpm	5 msec 1 msec	+1.0% full scale +0.5% full scale
Linear displacement	Bourns, Inc.	Linear potentiometer	2 in.		
Liquid level	Aerojet Nuclear Company	Conductance	0 to 13.5 in.	1 msec	+3.5 in.
Fluid pressure	Precise Sensors, Inc.	Flush diaphragm-bonded strain gaged	0 to 3000 psig	35 μ sec	+1% full scale
Pump speed	Lebow Associates, Inc.	60-tooth gear and magnetic coil	0 to 11,000 rpm	1 msec	+10 rpm
Pump power	Ohio Semitronics, Inc. and Aerojet Nuclear Company	Hall effect multiplier	0 to 25 kW	1 msec	+0.125 kW
Material strain	Micro-Measurements Division of Vishay Intertechnology, Inc.	Strain gages			
Fluid temperature	American Standard, Inc. and Aerojet Nuclear Company	Type K thermocouple diaphragm junction	0 to 931°F	20 msec	+5°F
		Type K thermocouple exposed junction	0 to 931°F	5 msec	+5°F
	Rosemount Engineering, Inc.	Platinum resistance detector	0 to 1000°F	250 msec	+0.5°F
Material temperature	American Standard, Inc. and Aerojet Nuclear Company	Type K thermocouple grounded spaded junction	0 to 931°F	~10 msec	+5°F
Pump torque	Lebow Associates, Inc.	Strain-gaged torque cell	+500 in.-lb	1 msec	+2.5 in.-lb

[a] Risettime is the time required for the detector to go from 10 to 90% of the value of an impressed step input.

V. OPERATING PROCEDURES AND TEST CONDITIONS

For blowdown tests, the primary system is brought to operating temperature by heat additions from the core heaters and pressurizer heaters and by heat introduced into the system by operation of the primary coolant pump. The system is brought to standard operating conditions of about 2250 psig and 575°F and then subjected to a double-ended shear (simulated by the rupture disc system). The system is completely depressurized in about 30 seconds and the blowdown test is terminated. The hot-wall tests are initiated shortly after termination of the blowdown tests.

1. PRIMARY SYSTEM HEATUP AND PRESSURIZATION

The main source of heat for the primary coolant is the incore heater rods. Nine rods are mounted in a 3x3 array inside the inner core barrel at the upper end of the core. The active heater rods (30 kW each) are connected to two dc power sources to provide a variable heatup capability. Three of the rods are connected to a variable power source of 0-155 Vdc and three are connected to a constant 155-Vdc power source. The three remaining rods are not powered. Heater rod power is turned off before blowdown is initiated.

The pressurizer heaters serve to heat the water in the pressurizer to saturation temperature corresponding to the preset testing pressure. The pressurizer heatup rate is controlled manually to provide the desired pressure increase. When the normal operating system pressure is reached (2250 ± 10 psig), the heaters are placed in an automatic mode and are controlled by an on-off type pressure switch. The pressurizer liquid level is controlled automatically by a spill and makeup system to maintain a standard water level band. The automatic level control system may be overridden for plant operation when steam is not present in the pressurizer and during steam bubble formation. Pressurizer water level is recorded at blowdown initial conditions. A minimum of four hours is required to achieve blowdown conditions.

2. TESTING SEQUENCE

The following sequence of events is performed prior to each test to ensure consistent test initiation throughout the test series.

Test Initiation Sequence

- (a) Primary coolant water sample obtained for water chemistry determination
- (b) Tapes started

- (c) 120-second countdown started
- (d) T minus 60 seconds, bypass line block valve closed and verified closed
- (e) T minus 20 seconds, pump low pressure trip bypassed
- (f) T minus 10 seconds, vessel heaters turned off and system pressure recorded
- (g) T minus 5 seconds, pressure suppression tank circulating pump turned off
- (h) T minus 2 seconds, system makeup pump turned off
- (i) T minus 0 seconds, rupture discs fired, pressurizer heater off, system pressure recorded.

VI. METHODS USED TO OBTAIN TEST DATA FROM INSTRUMENT OUTPUT

The data, in many cases, are adjusted to account for instrument drift, changes in gain, detector pressure sensitivity, and detector thermal sensitivity. The following paragraphs explain the methods used to obtain and normalize the test data.

An instrumentation system calibration with a known input source is made prior to each isothermal test. Data from the calibration are reduced to obtain an average output for each channel. The average output is compared with the known calibration input such that a gain correction is obtained and applied by computer program to the test data.

1. PRESSURE

Pressure measurements are obtained by calibrated pressure transducers. With the isothermal system at steady state pretest conditions (about 2250 psig and 575°F) each pressure transducer output is normalized to agree with the pretest pressure obtained from a precision pressure gage located on the vessel head. The total change measured for each transducer as the system pressure drops from the presaturation pressure to the postsaturation pressure, as recorded from the precision pressure gage, is obtained by applying a modified calibration factor to obtain the required total pressure change.

2. DIFFERENTIAL PRESSURE

The differential pressure measurements are made with calibrated differential pressure transducers. To compensate for the pressure sensitivity of the transducer, the voltage output as a function of pressure is recorded for each detector during pretest hydrostatic operation at zero flow conditions. The resulting correction curve is applied to the recorded test data through use of a computer program.

3. TEMPERATURE

Temperature measurements are made with thermocouples and variable resistance devices. The fluid temperature data are normalized by assigning the pretest temperature to those detectors that deviate more than $\pm 3^{\circ}\text{F}$ from the pretest temperature. The pretest material temperature data are normalized by the same method only if the detector output is greater than the fluid temperature.

4. DENSITY

Fluid density data for semiscale tests are obtained by a gamma-attenuation technique that provides a measurement of the average fluid density across the section being monitored. A gamma source is placed on one side of the section and a gamma detector 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 on the calculated initial fluid density.

5. VOLUMETRIC FLOW RATE

Volumetric flow rate measurements are made with turbine flowmeters through which all fluid within a given flow channel passes. The digital signal from the flowmeter is converted directly to volumetric flow rate through use of calibration data obtained from the manufacturer and verified by Aerojet Nuclear Company.

6. VELOCITY

Velocity measurements are made with small turbine flowmeter probes inserted into the flow stream. These probes operate in a manner similar to that of conventional turbine flowmeters except that only a fraction of the fluid within a given flow passage passes through them. The digital signal from the probe is converted directly to velocity through use of calibration data obtained from the manufacturer and verified by Aerojet Nuclear Company.

7. MOMENTUM FLUX

Momentum flux measurements are made with drag disc devices. These devices are basically strain-gaged cantilever beams with an enlarged area on one end which protrudes into a flowing fluid. The analog output is proportional to fluid density times fluid velocity squared (ρv^2). On the basis of the initial fluid density and the calibration curve, 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 device, the voltage output as a function of temperature is recorded during pretest warmup at zero-flow conditions. The resulting correction curve, plus the hysteresis condition and the instrument calibration curve, is applied to the recorded test data through use of a computer data conversion program.

8. MASS FLOW RATE

Mass flow rate is not measured directly but is computed from any two of the three directly measured quantities: density, volumetric flow rate, and momentum flux. The mass flow rates within the system during the blowdown transient are calculated with a digital computer from either

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

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).

VII. REFERENCE

1. D. J. Olson, *Semiscale Blowdown and Emergency Core Cooling (ECC) Project Test Report - Tests 848, 849, and 850 (ECC Injection)*, ANCR-1036 (June 1972).