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IDAHO NATIONAL ENGINEERING LABORATORY

SEMISCALE MOD-1 PROGRAM AND SYSTEM DESCRIPTION
FOR THE REFLOOD HEAT TRANSFER TESTS
(TEST SERIES 3)

PREPARED BY AEROJET NUCLEAR COMPANY FOR
U. S. NUCLEAR REGULATORY COMMISSION
AND
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
IDAHO OPERATIONS OFFICE UNDER CONTRACT E(10-1) -1375

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**SEMISCALE MOD-1 PROGRAM AND SYSTEM DESCRIPTION
FOR THE REFLOOD HEAT TRANSFER TESTS**

(Test Series 3)

by

Edgar M. Feldman

AEROJET NUCLEAR COMPANY

DATE PUBLISHED – MAY 1976

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ABSTRACT

This document provides a reference for the experiment data reports and the topical analysis reports prepared for the Semiscale Mod-1 reflood heat transfer test series (Test Series 3) conducted in the Semiscale program.

The purpose of the reflood heat transfer test series is to investigate the reflood heat transfer characteristics of the Semiscale Mod-1 electrically heated core which contains rods with 5.5-ft heated lengths. The data provided by these tests are expected to be valuable in the calculation of core and system response during the reflood portion of integral-type tests to be performed later in the Mod-1 program.

Presented are descriptions and objectives of the overall Semiscale Mod-1 program and of the reflood heat transfer series; descriptions of the Mod-1 system configuration, test conditions, and test procedures for the reflood heat transfer test series; and descriptions of the Mod-1 data acquisition and processing system used to acquire, process, and present the data reported in the data reports for the reflood heat transfer test series.

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SEMISCALE MOD-1 PROGRAM AND SYSTEM DESCRIPTION

FOR THE REFLOOD HEAT TRANSFER TESTS

(Test Series 3)

I. INTRODUCTION

The Semiscale Mod-1 experiments represent the current phase of the Semiscale program conducted by Aerojet Nuclear Company for the United States Government. The program, which is sponsored by the Nuclear Regulatory Commission through the Energy Research and Development Administration, is part of the overall program designed to investigate the response of a water-cooled nuclear reactor system to a hypothesized loss-of-coolant accident (LOCA).

The reflood heat transfer test series (Test Series 3) consisted of 12 tests. These tests were the first tests in the Mod-1 system employing reflooding of the electrically heated core. The Semiscale Mod-1 experimental configuration for this test series utilized hardware components necessary to investigate the reflood heat transfer characteristics of the Mod-1 rod bundle.

The purpose of this report is to provide a reference source of information for support of data reports relating to the specific tests conducted in the reflood heat transfer test series. Presented are descriptions and objectives of the overall Semiscale Mod-1 program and of Test Series 3; descriptions of the Mod-1 system configuration, test conditions, and test procedures used for Test Series 3; and descriptions of the Mod-1 data acquisition and processing system used to acquire, process, and present the data reported in the data reports for Test Series 3.

II. PROGRAM DESCRIPTION

The Semiscale program consists of a continuing series of thermal-hydraulic experiments having as their primary purpose the generation of experimental data that can be applied to the development and verification of analytical models that describe loss-of-coolant accident (LOCA) phenomena in water-cooled nuclear power plants. Emphasis is placed on acquiring system effects data that characterize the most significant thermal-hydraulic phenomena likely to occur in the primary coolant system of a nuclear plant during the depressurization (blowdown) and emergency core cooling (ECC) phases of a LOCA. The experiments are performed with a test system which simulate the principal physical features of a nuclear plant but which is much smaller in volume. Nuclear heating is simulated in the experiments by a "core" composed of an array of electrically heated rods, each of which has dimensional heat flux characteristics similar to those of a nuclear fuel rod.

1. SEMISCALE MOD-1 PROGRAM

The Semiscale Mod-1 program is being conducted to investigate the thermal and hydraulic phenomena accompanying a hypothesized loss-of-coolant accident (LOCA) in a water-cooled nuclear reactor system. The Semiscale Mod-1 tests are conducted in a 1-1/2-loop system with the intact loop containing active components representative of nuclear system components and with the broken loop containing passive simulated nuclear components. Eventually the program is to employ a two-loop system, encompassing active components in both loops as well as other features of a nuclear system.

The program objectives are to:

- (1) Produce separate and integral effects, experimental, thermal-hydraulic response data to provide an experimental basis for analytical model development and assessment.
- (2) Provide data for assessing the requirements and reliability of selected loss-of-fluid test (LOFT) instrumentation.
- (3) Produce experimental data to aid other ERDA-NRC-sponsored experimental programs, such as LOFT, in optimizing test series, selecting test parameters, and evaluating test results.

Separate effects tests provide detailed information for a specific area of interest. This information is used to determine the applicability of previously developed correlations and models to the Mod-1 system and to provide an initial basis for modification of these correlations and models, if necessary. The resulting analytical description of the Mod-1 system that is supported by the separate effects test data provides insight into the interacting effects that may occur during integral-type tests.

Integral test data from the Semiscale Mod-1 test program serve two purposes in the assessment of the analytical models. The data are used to evaluate the adequacy of the analytical models that are used to predict the transient thermal-hydraulic response of a system to a LOCA. The data are also used to indicate areas of weakness in the analytical models and to suggest what changes may be necessary to improve the analytical models if a weakness is found to exist during the evaluation process.

The Semiscale Mod-1 program provides experimental data on the performance and reliability of instrumentation. Since the data requirements of Semiscale Mod-1 and LOFT are similar, much of the instrumentation used in the Semiscale Mod-1 system is of the same type as that to be used in LOFT. Some of the special instrumentation that has been designed specifically for LOFT is installed and tested in the Semiscale Mod-1 system.

2. REFLOOD HEAT TRANSFER TESTS, TEST SERIES 3

The reflood heat transfer test series was the third group of tests conducted in the Semiscale Mod-1 experimental program and was composed of 12 tests (Tests S-03-1 through S-03-8 and Tests S-03-A through S-03-D). Table I shows the dates each test of the reflood heat transfer test series was completed. These tests were the first tests conducted in the Semiscale Mod-1 system in which the electrically-heated core was subjected to the reflood process. The primary objective of these tests was to provide reflood data which can be used for calculation of core and system response during the reflood portion of integral-type tests to be performed later in the Mod-1 program. Other objectives, specific to one or several of the planned tests, were to:

- (1) Determine whether methods that have been developed for using the FLECHT^[a] reflood heat transfer coefficients to calculate heat transfer coefficients for cores with shorter than FLECHT-length rods are applicable for calculating reflood heat transfer coefficients in the Mod-1 core
- (2) Determine the effect of the Mod-1 core radial power profile on core reflood behavior
- (3) Investigate the effect of interactions between the system and the core on core reflood heat transfer

---

[a] Full length Emergency Cooling Heat Transfer test program conducted by Westinghouse Electric Corporation Nuclear Energy Systems to obtain experimental reflooding heat transfer data under simulated loss-of-coolant accident conditions for use in evaluating the heat transfer capabilities of PWR emergency core cooling systems.

- (4) Investigate the effect of intact loop flow resistance on core reflood heat transfer

- (5) Investigate the scaling parameters for reflood heat transfer and reflood system response.

2.1 Technical Approach

Twelve different reflood tests, Tests S-03-1 through S-03-8 and Tests S-03-A through S-03-D, were conducted to fulfill the test objectives outlined for the reflood heat transfer test series. These tests were designed to evaluate the reflood heat transfer characteristics of the Semsicale Mod-1 5.5-ft electrically heated core and to provide data with which to evaluate the applicability to a shorter core of various reflood heat transfer correlations developed primarily from data obtained using a 12-ft core.

The reflood heat transfer test series consisted mainly of two basic groups: constant flooding rate tests and lower plenum injection tests.

Tests S-03-1 through S-03-4 and Tests S-03-A through S-03-D were conducted using a reflood rate that did not vary appreciably during the test, while Tests S-03-5 through S-03-8 were lower plenum injection reflood tests in which the reflood rate varied depending upon the initial system conditions, the system configuration, and the transient system response. Table II summarizes the initial conditions and system configuration for the reflood heat transfer tests.

2.1.1 Constant Flooding Rate Tests. Tests S-03-1 through S-03-4 and Tests S-03-A through S-03-D were constant flooding rate tests in which the injection was made directly into the core through the core inlet manifold using the intact loop low pressure injection system. The Mod-1 system was modified for these tests and used only the cold leg of the broken loop for a blowdown path. Core exit liquid carryover was measured by use of the phase separator located in the intact loop. Each of the eight tests was performed to provide a parameter effects study. Therefore, all tests were performed with similar conditions with only certain parameters changed for each test.

Several of the initial conditions for Test S-03-4 were different from the initial conditions for the other constant flooding rate tests. The core radial power profile was

TABLE I

TEST COMPLETION DATES FOR THE
REFLOOD HEAT TRANSFER TEST SERIES

<u>Test</u>	<u>Date Completed</u>
S-03-1	1-6-76
S-03-2	1-6-76
S-03-3	1-21-76
S-03-4	1-21-76
S-03-A	2-5-76
S-03-B	1-29-76
S-03-C	1-27-76
S-03-D	1-30-76
S-03-5	2-24-76
S-03-6	3-16-76
S-03-7	3-16-76
S-03-8	2-24-76

INITIAL CONDITIONS AND CONFIGURATION FOR SEMISCALE MOD-1 REFLOOD HEAT TRANSFER TESTS

<u>Condition or Configuration</u>	<u>Test S-03-1</u>	<u>Test S-03-2</u>	<u>Test S-03-3</u>	<u>Test S-03-4</u>	<u>Test S-03-A</u>	<u>Test S-03-B</u>	<u>Test S-03-C</u>	<u>Test S-03-D</u>	<u>Test S-03-5</u>	<u>Test S-03-6</u>	<u>Test S-03-7</u>	<u>Test S-03-8</u>
Core												
Number of Active Rods	40	40	40	40	40	40	40	40	40	40	40	40
Radial Power Profile	Flat	Flat	Flat	Peaked	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Power (MW)	0.0956	0.0962	0.095	0.097	0.094	0.166	0.097	0.097	0.108	0.062	0.062	0.109
Power Decay Curve	ANS + 20%	ANS + 20%	ANS + 20%	ANS + 20%	ANS + 20%	ANS + 20%	ANS + 20%	ANS + 20%	ANS + 20%	ANS Standard	ANS Standard	ANS + 20%
Maximum Rod Power (kW/ft)												
four center rods	0.7	0.7	0.7	0.855	0.7	1.2	0.7	0.7	0.76	0.45	0.45	0.76
other rods	0.7	0.7	0.7	0.680	0.7	1.2	0.7	0.7	0.76	0.45	0.45	0.76
Rod Temperature (°F) (highest measured value)	1400	1403	1408	1401	1395	1089	1245	1400	1097	1288	1293	1088
System Pressure (psia)	60	60	60	60	20.8	62	60	60	60	35	35	20
System Configuration	[————— Cold leg break configuration with hot leg capped off at the vessel]								[————— Cold leg double ended break configuration]			
Nozzle Throat Diameter (in.)	[————— No nozzle used]								[————— 0.693]			
Phase Separator	[————— Part of system configuration]								[Not part of system configuration]			
Intact Loop Pump	---	---	---	---	---	---	---	---	Orifice at outlet	Orifice at outlet	---	Orifice at outlet
Intact Loop Steam Generator	---	---	---	---	---	---	---	---	Additional orifice at outlet	---	---	Additional orifice at outlet
Coolant Injection												
Type	forced feed	forced feed	forced feed	forced feed	forced feed	forced feed	forced feed	forced feed	gravity feed	gravity feed	gravity feed	gravity feed
Location	core inlet manifold	core inlet manifold	core inlet manifold	core inlet manifold	core inlet manifold	core inlet manifold	core inlet manifold	core inlet manifold	lower plenum	lower plenum	lower plenum	lower plenum

TABLE II (contd.)

Condition or Configuration	Test S-03-1	Test S-03-2	Test S-03-3	Test S-03-4	Test S-03-A	Test S-03-B	Test S-03-C	Test S-03-D	Test S-03-5	Test S-03-6	Test S-03-7	Test S-03-8
Coolant Injection (contd.)												
Flow Rate From Low Pressure Injection System (gpm)	3.44	1.88	1.4	1.8	1.8	1.77	1.9	1.8	4.1	4.1	4.1	4.1
Flow Rate From Accumulator Water	---	---	---	---	---	---	---	---	29	21	21	~30
ΔT Subcooled ($^{\circ}F$)	174	143	133	142	127	150	155	40	140	Varied Between 40 & 30	3	70
Initiation of Injection	[Simultaneous with the core reaching predetermined maximum temperature]											
Pressure Suppression Tank												
Water Temperature ($^{\circ}F$)	295	288	293	292	229	293	290	293	296	261	260	227
Pressure (psia)	60	60	60	60	20.8	60	60	60	60	35	35	20
Water Volume (ft ³)	30	30	30	30	30	30	30	30	30	30	30	30
Steam Generator												
Secondary Water Temperature ($^{\circ}F$)	485	515	480	486	467	462	533	501	457	447	477	474
Secondary Liquid Level (in.) [a]	125	120	115	123	96	120	123	12	Not available	110	107	Not available
Intact Loop ECC Accumulator												
Pressure (psig)	---	---	---	---	---	---	---	---	600	600	600	600
Water Volume (ft ³)	---	---	---	---	---	---	---	---	1.89	1.89	1.89	1.89
Gas Volume (ft ³)	---	---	---	---	---	---	---	---	1.11	1.11	1.11	1.11
Core Water Level (in.)	[Bottom of heated core]								[150 in. below cold leg centerline]			Bottom of heated core

[a] Above bottom of tube sheet.

peaked with the four central rods at a peak power density of 0.855 kW/ft and the remaining 36 rods at a peak power density of 0.680 kW/ft. The peak power densities for the high- and low-power rods were chosen such that the total core power was the same for the other constant flooding rate tests.

2.1.2 Lower Plenum Injection Tests. Tests S-03-5 through S-03-8 were lower plenum injection tests. During these tests water was injected into the lower plenum using an accumulator and the low pressure injection system to initiate the mutually interactive filling of the lower plenum, downcomer, and core. The objective of this test was to investigate the gravity-feed reflood behavior of the Mod-1 system in the absence of complications that can result from condensation when cold leg ECC injection is used. The test results are to be used to evaluate the capability of calculational methods to compute both reflood rates and heat transfer coefficients in the Mod-1 system.

Tests S-03-5 through S-03-8 were designed to duplicate, as closely as the Mod-1 system permits, the conditions of FLECHT-SET Test 3105B and FLECHT-SET Test 2714B^[1], respectively. The purpose was to provide coupled effects reflood tests in a facility of different scale than that of the FLECHT-SET facility so that the results can be compared with those from FLECHT-SET tests.

The intact loop flow resistance for Test S-03-6 was increased to a value larger than the intact loop resistance used for the other reflood heat transfer tests. The purpose of increasing the intact loop flow resistance for Test S-03-6 was to produce results that would be directly compared with results obtained from Test S-03-7 to evaluate the effect of intact loop flow resistance on system reflood rates and core heat transfer.

Test S-03-7 was identical to Test S-03-6 with the exception of intact loop resistance. Test S-03-7 employed normal Mod-1 intact loop resistance rather than the increased resistance used in Test S-03-6.

III. CORE OPERATION

Core power was controlled during the reflood tests to simulate the decay heating processes during the reflood portion of a LOCA. Both the ANS standard and the ANS + 20% decay curves were utilized during this test series. The normalized curves representing core power applied for each test are given in Figure 1, and the values are tabulated in Table III.

Fig. 1 Decay power after reflood initiation.

TABLE III

CORE POWER DECAY FOR SEMISCALE MOD-1 REFLOOD HEAT TRANSFER TEST CONFIGURATIONS

Time From Start of Reflood Initiation (sec)	Total Core Power ANS +20% ^[a] Tests S-02-1 - S-03-4 Tests S-03-A, S-03-C, S-03-D (MW)	Total Core Power ANS +20% Tests S-03-B (MW)	Total Core Power ANS Standard Tests S-03-6, S-03-7 (MW)	Total Core Power Tests S-20-5, S-03-8 (MW)	Power/Initial Power ANS +20%, Tests S-02-1, S-03-4, S-03-A S-03-B S-03-5, S-03-8	Power/Initial Power ANS Standard (Reflood initiation starting at 43 sec after blowdown) Tests S-03-6, S-03-7
0.0	0.097	0.172	0.062	0.105	1.0	1.0
5.0	0.094	0.167	0.061	0.101	0.970	0.975
10.0	0.091	0.162	0.059	0.098	0.940	0.95
20.0	0.085	0.151	0.058	0.092	0.880	0.92
30.0	0.081	0.143	0.056	0.087	0.830	0.90
40.0	0.077	0.136	0.0545	0.083	0.790	0.87
50.0	0.075	0.132	0.054	0.081	0.770	0.86
60.0	0.073	0.129	0.053	0.079	0.750	0.85
70.0	0.071	0.126	0.052	0.077	0.730	0.83
80.0	0.070	0.124	0.051	0.076	0.720	0.82
90.0	0.069	0.122	0.050	0.075	0.710	0.81
100.0	0.068	0.120	0.0495	0.074	0.700	0.80
120.0	0.066	0.117	0.049	0.072	0.680	0.78
140.0	0.064	0.114	0.048	0.070	0.660	0.77
200.0	0.059	0.105	0.044	0.065	0.610	0.705
300.0	0.053	0.095	0.042	0.057	0.550	0.665
400.0	0.049	0.088	0.038	0.053	0.510	0.61
500.0	0.046	0.081	0.035	0.049	0.470	0.56
600.0	0.043	0.076	0.034	0.046	0.440	0.54
700.0	0.039	0.069	0.032	0.042	0.400	0.51

[a] American Nuclear Society.

IV. TEST APPARATUS

The Semscale Mod-1 system configuration for the first eight tests (Test S-03-1 through Test S-03-4 and Test S-03-A through Test S-03-D) of the reflood heat transfer test series consisted of: a pressure vessel with simulated reactor internals; an intact loop with phase separator, steam generator, and pump; a broken loop in the cold leg break configuration with the hot leg capped off at the vessel outlet and cold leg with piping and pipe rupture assembly; a pressure suppression system with header and suppression tank; and a coolant injection system with injection pumps, accumulators, and delivery piping (see Figure 2). The system configuration to be used for Tests S-03-5 through S-03-8 was changed from the configuration of the first eight tests by the removal of the phase separator from the intact loop and by the addition of the broken loop hot leg piping with a simulated steam generator, simulated pump, and pipe rupture assembly (see Figure 3). In both system configurations the intact loop simulates three operating loops of a commercial PWR, and the broken loop simulates a broken loop of a PWR during a LOCA. The exterior of the entire system and piping is thermally insulated. The experimental system components for the two test configurations used in the reflood heat transfer test series are shown in Figures 2 through 5. System liquid volumes are recorded in Table IV and measured core, vessel, and loop hydraulic resistances are given in Tables V through VII.

Fig. 2 Semiscale Mod-1 system configuration for reflood heat transfer tests S-03-1 through S-03-4 and S-03-A through S-03-D - isometric.

ANC-A-5945

Fig. 3 Semiscale Mod-1 system configurations for reflood heat transfer tests S-03-1 through S-03-4 and S-03-A through S-03-D - schematic.

Fig. 4 Semiscale Mod-1 system configuration for reflood heat transfer tests S-03-5, S-03-6, S-03-7, and S-03-8 — isometric.

Fig. 5 Semiscale Mod-1 system configuration for reflow heat transfer tests S-03-5, S-03-6, S-03-7, and S-03-8 – schematic.

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TABLE IV

VOLUME MEASUREMENTS FOR SEMISCALE MOD-1 REFLOOD
HEAT TRANSFER TEST CONFIGURATIONS

Component	Liquid Volume (ft ³)
Vessel ^[a]	3.479
Intact Loop (without phase separator installed) ^[b]	2.238
Intact Loop (with phase separator installed) ^[b]	5.065
Broken Loop	
Cold leg break configuration (calculated)	
Hot leg side to break	0.883
Cold leg side to break	0.213
System Total Liquid Volume	
Tests S-03-1 to S-03-4 and S-03-A to S-03-D	8.757
Tests S-03-5 to S-03-8	6.813

[a] The vessel volume includes the volumes of the six vessel nozzles.

[b] Excluding pressurizer and pressurizer surge line volumes.

TABLE V

MEASURED FORWARD FLOW HYDRAULIC RESISTANCE IN THE VESSEL

Measurement	Location	$(\text{sec}^2/\text{ft}^3\text{-in.}^2)^{R'}$
DPV-9-180QQ	Inlet annulus, 9 in. below cold leg centerline (255°) to lower plenum, 180 in. below cold leg centerline (255°), elevation difference between taps is 171 in.	0.098
DPV-180-133QD	Lower plenum 180 in. below cold leg centerline (255°) to active core region 133 in. below cold leg centerline (45°)	0.388
DPV-133-117DJ	In active core region 133 in. below cold leg centerline (45°) to 117 in. below cold leg centerline (135°)	0.030
DPV-117-100JQ	In active core region, 117 in. below cold leg centerline (135°) to 100 in. below cold leg centerline (225°)	0.029
DPV-100-83QW	In active core region, 100 in. below cold leg centerline (225°) to 83 in. below cold leg centerline (315°)	0.029
DPV-83+10WC	Upper segment of active core region 83 in. below cold leg centerline (315°) to upper plenum core tube 10.5 in. above cold leg centerline (30°)	0.38
DPV-100+10QC	In active core region, 100 in. below cold leg centerline (225°) to upper plenum core tube 10.5 in. above cold leg centerline (30°)	0.41
DPV-133+10DC	In active core region, 133 in. below cold leg centerline (45°) to upper plenum core tube 10.5 in. above cold leg centerline (30°)	0.48
DPV-LP-UP	Upper plenum, 10.5 in. above cold leg centerline (30°) to lower plenum 180 in. below cold leg centerline (225°), elevation difference between taps is 191 in.	0.857
DPV-IANN-UP	Inlet annulus, 9 in. below cold leg centerline (225°) to upper plenum, 10.5 in. above cold leg centerline (30°) elevation difference between taps is 19 in.	0.889

TABLE VI

MEASURED FORWARD FLOW HYDRAULIC RESISTANCE IN THE INTACT LOOP AND VESSEL

Measurement	Location	$\frac{R'}{(\text{Sec}^2/\text{ft}^3 - \text{in.}^2)}$			
		Tests S-03-1 to S-03-4, S-03-A to S-03-D	Tests S-03-5, S-03-8	Test S-03-6	Test S-03-7
DPU-UP-1	Upper plenum 10.5 in. above cold leg centerline (30°) to hot leg, Spool 1, 31 in. from vessel center, upper plenum tap approximately 2 in. above Spool 1 tap	0.419	0.419	0.419	0.419
DPU-UP-3	Upper plenum 10.5 in. above cold leg centerline (30°) to hot leg, Spool 3, 62 in. from vessel center, upper plenum tap approximately 2 in. above Spool 3 tap	0.503 ^[a]	0.416	0.416	0.416
DPU-1-3	Hot leg Spool 1, 31 in. from vessel center to hot leg Spool 3, 62 in. from vessel center	0.11 ^[a]	0.23	0.23	0.23
DPU-3-6	Hot leg Spool 3, 62 in. from vessel center to hot leg Spool 6, 114 in. from vessel center	0.071	0.071	0.071	0.071
DPU-3-7	Hot leg Spool 3 to Cold leg Spool 7	1.431 ^[b]	4.93 ^[b,c]	1.541 ^[b]	1.541 ^[b]
DPU-SGOP-7	From steam generator outlet plenum, 269 in. from vessel center along cold leg to cold leg Spool 7 231 in. from vessel center, including orifice; Spool 7 tap is 35 in. below SGOP tap	0.894	0.894	0.894	0.894

TABLE VI (contd.)

Measurement	Location	$\frac{R^3}{\text{ft}^3 - \text{in.}^2}$ (Sec ²)			
		Tests S-03-1 to S-03-4, S-03-A to S-03-D	Tests S-03-5, S-03-8	Test S-03-6	Test S-03-7
DPU-7-10	Steam generator outlet to pump inlet, cold leg Spool 7, 231 in. from vessel center to cold leg Spool 10, 141 in. from vessel center	0.252	0.252	0.252	0.252
DPU-8C-8D	In pump trap, cold leg Spool 8, Tap 8C, 197 in. from vessel center to Tap 8D, 184 in. from vessel center; Tap 8C is 10 in. below Tap 8D	0.02	0.02	0.02	0.02
DPU-8D-8E	In pump trap, cold leg Spool 8, Tap 8D, 184 in. from vessel center to Tap 8E, 174 in. from vessel center; Tap 8D is 10 in. below Tap 8E	0.005 ^[b]	0.005 ^[b]	0.005 ^[b]	0.005 ^[b]
DUP-8E-10	From pump trap to pump inlet, pump trap Tap 8E, 174 in. from vessel center to pump inlet cold leg Spool 10, 141 in. from vessel center; Tap 8E is 12 in. below Spool 10 tap	0.245	0.245	0.245	0.245
DPU-10-12	Pump inlet to pump outlet, cold leg Spool 10, 141 in. from vessel center to cold leg Spool 12, 75 in. from vessel center; Spool 10 tap is 10 in. below Spool 12 tap	2.90 ^[b,d]	7.30 ^[b,e]	7.30 ^[b,e]	2.90 ^[b,d]
DPU-12-15	Across cold leg injection point, cold leg Spool 12, 75 in. from vessel center to cold leg Spool 15, 16 in. from vessel center	0.539	0.539	0.539	0.539

TABLE VI (contd.)

Measurement	Location	R' ($\text{Sec}^2/\text{ft}^3\text{-in.}^2$)			
		Tests S-03-1 to S-03-4, S-03-A to S-03-D	Tests S-03-5, S-03-8	Test S-03-6	Test S-03-7
DPU-15-IANN	Cold leg Spool 15, 16 in. from vessel center to inlet annulus 9 in. below cold leg center line (255°); Spool 15 tap is 9 in. above inlet annulus tap	0.319	0.319	0.319	0.319
DPU-15-1	Cold leg to hot leg, cold leg Spool 15, 16 in. from vessel center to hot leg Spool 1, 31 in. from vessel center; Spool 15 tap is 8.5 in. below Spool 1 tap	1.677	1.677	1.677	1.677

- [a] Includes calculated phase separator R' .
- [b] Calculated value.
- [c] Includes additional orifice with $R' = 3.39$.
- [d] Locked rotor forward flow pump R' .
- [e] Includes additional orifice with $R' = 4.4$.

TABLE VII

MEASURED FORWARD FLOW HYDRAULIC RESISTANCE IN THE BROKEN LOOP AND VESSEL

Measurement	Location	(Sec ² /ft ³ -in. ²)		
		Tests S-03-1 to S-03-4, S-03-A to S-03-D	Tests S-03-5, S-03-8	Tests S-03-6, S-03-7
DPB-UP-30	Vessel upper plenum, 10.5 in. above cold leg centerline at 30° to hot leg Spool 30, 18 in. from vessel center; upper plenum tap is 2 in. above Spool 30 tap	[a]	0.120 ^[b]	0.120 ^[b]
DPB-30-32U	Hot leg spool 30, 18 in. from vessel center to Spool 32 upper tap, 73 in. from vessel center; Spool 30 tap is 30 in. below Spool 32 upper tap	[a]	12.45	12.45
DPB-30-38	Across entire simulated steam generator assembly and instrument spool downstream of simulated steam generator, hot leg Spool 30, 18 in. from vessel center to cold leg Spool 38, 305 in. from vessel center along hot leg; Spool 30 is 40 in. above Spool 38	[a]	52.4	52.4
DPB-32U-36L	Across simulated steam generator orifice assembly, hot leg Spool 32 upper tap, 73 in. from vessel center to Spool 36 lower tap, 242 in. from vessel center; Spool 32 upper tap is 16 in. above Spool 36 lower tap	[a]	25.83	25.83
DPB-SGOR	Across first orifice plate of simulated steam generator, taps 87 and 95 in. from vessel center along hot leg; elevation difference between taps is 7 in.	[a]	2.09	2.09

TABLE VII (contd.)

Measurement	Location	$\frac{R^3}{\text{ft}^3 - \text{in.}^2}$ (Sec ²)		
		Tests S-03-1 to S-03-4, S-03-A to S-03-D	Tests S-03-5, S-03-8	Tests S-03-6, S-03-7
DPB-38-40	Across simulated pump, cold leg Spool 38, 305 in. from vessel center along hot leg to cold leg Spool 40, 365 in. from vessel center along hot leg	[a]	32.7	210.0
DPB-40-42	Across elbow leading to spool upstream of pump-side nozzle, cold leg Spool 40, 365 in. from vessel center along hot leg to Spool 42, 415 in. from vessel center along hot leg; Spool 40 tap is 40 in. below Spool 42 tap	[a]	1.05 ^[b]	1.05 ^[b]
DPB-42-43	Across pump-side nozzle, cold leg Spool 42, 415 in. from vessel center along hot leg to cold leg Spool 43, 427 in. from vessel center along hot leg	[a]	4.23	4.23
DPB-42-HN1	Spool 42 upstream of pump-side nozzle, 415 in. from vessel center along hot leg to nozzle throat, 419 in. from vessel center along hot leg	[a]	17.52	17.52
DPB-21-23	Cold leg Spool 21, 49 in. from vessel center to cold leg Spool 23, 92 in. from vessel center	0.487	0.487	0.487
DPB-23-CN1	Cold leg Spool 23, 92 in. from vessel center to vessel-side nozzle throat, 92 in. from vessel center	[a]	17.29	17.29

TABLE VII (contd.)

<u>Measurement</u>	<u>Location</u>	<u>(Sec² R'³/ft³-in.²)</u>		
		<u>Tests</u> <u>S-03-1 to S-C3-4,</u> <u>S-03-A to S-C3-D</u>	<u>Tests</u> <u>S-03-5, S-03-8</u>	<u>Tests</u> <u>S-03-6, S-03-7</u>
DPB-23-24	Across vessel-side nozzle, Spool 23, 92 in. from vessel center to Spool 24, 104 in. from vessel center	[a]	5.14	5.14
[a] Not applicable.				
[b] Calculated value.				
[c] Simulated pump with 9 orifice plates.				

1. VESSEL ASSEMBLY

The Semsicale Mod-1 vessel assembly consists of: pressure vessel, vessel filler, vessel filler insulator, core barrel, core barrel insulator, and 40-electrical-heater-rod core. The Semsicale Mod-1 vessel assembly forms the following internal regions: inlet annulus, downcomer annulus or gap, lower plenum, core, and upper plenum. A cross-sectional view of the vessel with core is shown in Figure 6.

1.1 Pressure Vessel

The pressure vessel consists of an upper section, midsection, lower section, upper head, lower head, and nozzles. The upper section is constructed of 10-inch Schedule 160 ASTM A-106 Grade B carbon steel pipe. The lower section and midsection are constructed of 10-inch Schedule 160, 316 ASME SA-376 stainless steel pipe. The upper and lower heads are Grayloc blind hubs constructed of 316 ASME SA-182 stainless steel. The lower head has a thermal liner plate fitted flat against the bottom inside surface. The liner plate is Grafoil 0.015 inch thick. The nozzles are constructed of ASME SA-182 Grade F 316 stainless steel and are welded in place. The separate pressure vessel segments are connected by Grayloc connectors.

The assembled pressure vessel is about 21 feet long. It has an OD of 10.75 inches and an ID of 8.585 inches. The vessel is designed for pressure of 2,500 psig and temperature of 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.

1.2 Vessel Filler

The vessel filler is constructed of 8-inch Schedule 160 pipe (316 stainless steel ASTM A-312) which slip fits inside the vessel. It has an OD of 8.545 inches and an ID of 7.100 inches. The filler ID is increased to 8.190 inches from about 3 inches above to about 10.5 inches below the cold leg centerline to form the inlet annulus region.

1.3 Vessel Filler Insulator

The inside of the vessel filler is lined with a 1/8-inch-thick 304 stainless steel ASTM A-269 insulator. There is a gap of 0.050-inch between the vessel filler and the stainless steel insulator.

1.4 Core Barrel

The core barrel is constructed of copper alloy No. 175 (Cu-Be). It has an OD of 5.490 inches and an ID of 4.875 inches. The core barrel entrance is about 163 inches below the cold leg centerline.

Fig. 6 Cross section of vessel with core.

1.5 Core Barrel Insulator

The outside of the core barrel is clad with a 1/8-inch-thick 304 stainless steel ASTM A-269 insulator. There is a gap of 0.050-inch between the core barrel and the stainless steel insulator.

1.6 Electrically Heated Core

The electrically heated core consists of two subassemblies identified as the core simulator and the core barrel assembly. A cross-sectional view of the vessel with core is shown in Figure 6.

The core simulator consists of the pressure vessel upper head, V-seals, seal spacer plate, electric heater retainers, cap screws, 40 electric heater rods, grid spacers, core heat shield, core insulators, core side plates, and side plate flange. The core simulator is installed as a unit inside the core barrel assembly located in the pressure vessel. The pressure vessel upper head, which is a part of the primary coolant system pressure boundary, serves as a mounting structure for the core simulator. The 40 electric heater rods pass through the upper head and are effectively clamped to it. A collar welded on each heater rod seats on a V-type pressure seal and on the seal spacer plate as shown in Figure 7. Above the heater rod collars are 37 cruciform-shaped heater rod retainers. Each retainer shares four rod collars and has a socket-head cap screw through its center which serves to clamp the rods to the vessel upper head.

The electric heater rods, illustrated in Figure 8, have a dual stainless steel (Type 316L) composite sheath. The heated length (66 inches) and the outside diameter (0.422 inch) of each rod are identical to the corresponding dimensions of the LOFT nuclear fuel rods. The inner sheath wall thickness is 0.010 inch and is creased concavely, relative to the outside diameter, at four equal circumferential spaces along the total length so as to accept four stainless steel-sheathed thermocouple assemblies of 0.025-inch diameter. The outer sheath wall thickness is 0.025 inch. The outer sheath is assembled over the creased tube after installation of the thermocouples, and the composite assembly is redrawn. The heating element is 55% copper, 45% nickel alloy wire, coiled with a varying pitch, and sized to develop the required power. Compacted boron nitride insulates the heater element assembly from the composite sheath.

The 40 electrical heater rods are assembled in a matrix as shown in Figure 9. The rods are located and held in radial position by grid spacers as shown in Figure 10. Ten grid spacers are located at elevations along the length of the core simulator. The grid spacers position the heater rods so that they are located on a typical PWR fuel rod pitch (0.563 inch). Axial locations of the grid spacers along the heated length of the core are identical with those in the LOFT core. Filler pieces are inserted in the triangle-shaped channels around the outside of the grid spacer. The filler pieces block coolant flow through these channels.

Fig. 7 Heater rod mounting and pressure seal in vessel upper head.

Fig. 8 Semiscale Mod-1 electric heater rod.

Fig. 9 Vessel cross section and core layout.

Between adjacent grid spacers and around the periphery of the active core (the 40 heater rods) are four heat shield assemblies (Figure 9), which serve as a radiant heat shield. These assemblies comprise a heat shield (0.018-inch-thick stainless steel) and heat shield retainer. Outside the grid spacers and core heat shields are four core assembly side plates which extend the full length of the core simulator.

The principal components of the core barrel assembly are: the core barrel, pressure vessel upper spool piece, core barrel insulator, upper plenum filler, inlet plate, and turbine flowmeter housing. This assembly provides the housing for the core assembly, separates the downcomer annulus from the upper plenum, and provides lateral support and positioning of the core assembly while allowing separate removal and installation of that assembly.

The core barrel is a 0.615-inch-thick beryllium copper cylinder (copper alloy No. 175) that serves as the core simulator housing and also the electrical ground path for the heater rods. The barrel entrance is about 163 inches below the cold leg centerline. The core barrel insulator (1/8-inch-thick stainless steel) acts as a thermal shield during ECC injection when steam is trapped in a gap of 0.050-inch between the barrel and barrel insulator. The

Fig. 10 Grid spacer.

insulator serves to minimize the generation of steam in the downcomer annulus, thus lessening the flow resistance for ECC water as it traverses the downcomer.

For Tests S-03-1 through S-03-4 and Tests S-03-A through S-03-D, an inlet plate and injection manifold were attached to the bottom of the core barrel. The inlet plate is designed to provide scaled hydraulic resistance at the entrance to the core. The injection manifold provides for ECC injection directly into the core at the core inlet. The core injection manifold consists of a series of two sections of tubing. The larger section attaches to the core barrel inlet plate while the smaller section exits the vessel through the lower plenum head. Seals are used at the core barrel attachment point and the lower head penetration to maintain the pressure integrity of the vessel. A cross section of the lower portion of the vessel showing the core injection manifold is shown in Figure 11.

Tests S-03-5 through S-03-8 of the reflood heat transfer test series were conducted with the configuration as shown in Figure 6. An inlet plate and turbine flowmeter housing are attached to the bottom of the core barrel. The inlet plate is located between the core barrel and the flowmeter housing and is designed to provide scaled hydraulic resistance at the entrance to the core. The flowmeter housing contains the mixture plate and a turbine flowmeter and is an extension of the core barrel. The mixture plate is positioned above the flowmeter and is used to obtain a scaled resistance between the flowmeter and the bottom of the inlet plate.

The elevation of the heated length of the Semiscale Mod-1 core with respect to the cold leg centerline is similar to that in LOFT; that is, the top of the heated length is 77 inches below the cold leg centerline. Of the 40 active rods in the core, the central four rods have a maximum power capability of 19 kW/ft, and the remaining 36 rods have a maximum power capability of 10.66 kW/ft. Each high-power heater is designed to produce a total power of 66.2 kW at 173 V dc, and each low-power heater is designed to produce a total power of 36.9 kW at 173 V dc. When assembled as the simulated core, the heaters provide a total power capability of 1.6 MW.

1.7 Vessel Internal Regions

The vessel internal regions can be located by following the coolant path through the vessel. The coolant enters the vessel inlet annulus region through the cold leg inlet nozzles. The inlet annulus region extends about 10.5 inches below the cold leg centerline. The coolant then flows down to the lower plenum region through the downcomer annulus formed between the inside of the vessel filler insulator and the outside of the core barrel insulator. The downcomer gap size is 0.42 inch, resulting in a cross-sectional area of the downcomer annulus of 0.0575 ft^2 . The length of the region is about 152 inches. The coolant then flows up into the core region. (During the reflood heat transfer tests using the core injection manifold this part of the normal coolant path is blocked.) The flow passes through the 40-rod electrical core until it reaches the upper plenum region leaving the core. The flow passes out the openings in the core barrel into the upper plenum and then out the outlet nozzles. A seal separates the inlet annulus from the upper plenum region.

Fig. 11 Cross section of vessel with core and injection manifold.

2. INTACT LOOP

The intact loop consists of the primary coolant piping, phase separator, steam generator, and pump. The basic intact loop configuration remained the same for all Test Series 3 tests. However, the phase separator was removed for Tests S-03-5 through S-03-8, and loop resistances were modified using orifice plates as required (see Table II and Figures 3 and 5).

2.1 Intact Loop Piping

Piping Spools 6, 7, 8, 9, 10, 11, and 15 are made of 3-inch Schedule 160 Grade 316 stainless steel conforming to ASME SA-376. All other piping spools are made of 3-inch Schedule 160 carbon steel conforming to Grade B ASTM A-106. The piping spool sections are joined by 3-inch Grayloc connectors.

2.2 Phase Separator

A phase separator was installed in the intact loop (see Figure 2) to measure the vessel outlet fluid quality during the forced reflood rate tests (Tests S-03-1 through S-03-4 and Tests S-03-A through S-03-B). This device consists of a large upper tank, where phase separation occurs, with a smaller water collection well attached to the bottom. The tank portion of the separator has an inside diameter of 16.1 in. and is 30 in. long. The inlet pipe to the tank is curved in such a way that the incoming two-phase mixture is forced to have a circular or vortex type of motion around the tank's axis. Phase separation is accomplished by centrifugal forces on the phases combined with the effects of liquid attachment to the tank wall and reduced entrainment due to low fluid velocities throughout the tank. The water collection well installed on the bottom of the tank has an inside diameter of 6.1 in. and a length of 90.5 in. (see Figure 12). The depth of the water collected in the well is measured by differential pressure transducers attached from the bottom to the top of the well.

2.3 Steam Generator

The intact loop steam generator is of the tube-and-shell design having a double-pass tube side of the "U" bend configuration and a single-pass shell side. The primary coolant passes through the tube side; and the secondary coolant, with resultant steam generation, passes through the shell side. The steam generator is situated in the vertical position with primary inlet-outlet ports located in the head of the primary side inlet-outlet plenum. A cutaway view is given in Figure 13.

Major subassemblies of the unit are: the primary side inlet-outlet plenum, the tube sheet and tube bundle, and the secondary containment shell and internals.

Fig. 12 Phase separator.

Fig. 13 Intact loop steam generator.

The primary side inlet-outlet plenum consists of a hemispherical head welded to a 12-inch, 1500-lb weld neck flange which mates with the lower surface of the tube sheet. The plenum has external inlet and outlet nozzles for the primary system connections and an internal divider plate which divides flow between the tube inlets and outlets on the lower surface of the tube sheet. The inlet-outlet plenum assembly is constructed of Type 316 stainless steel.

The tube bundle assembly consists of an Inconel tube sheet, which is 3-5/8 inches thick across the diameter of the mating lower plenum flange, and 54 U-bend tubes. The tubes are constructed of Inconel 600 and have an inner diameter of 0.402 inch and a wall thickness of 0.049 inch. They are arranged on a 0.75-inch triangular pitch and have an average length of 16.85 feet. Six baffle plates extending about one-half of the way across the bundle are spaced at equal intervals along the tube length.

Major components of the secondary shell and internals, as shown in Figure 13, are: the shell, the inlet nozzle spray ring, the flow separator assembly, and the secondary flow restrictor.

The secondary shell is a section of 12-inch Schedule 80 pipe, 172 inches in length. The upper end is enclosed with a pipe cap, and a 12-inch weld neck flange is welded to the lower end. Nozzles and fittings are provided for the feedwater supply line, the steam exhaust line, secondary system drains, and instrumentation.

The inlet nozzle spray ring of carbon steel pipe is situated between the downcomer sleeve and the outer shell. This ring is connected to the feedwater supply system by a 1-1/2-inch nozzle through the vessel wall. The circumference of the spray ring has 24 openings (0.187-inch diameter), which permit feedwater to be injected downward into the downcomer annulus.

The flow separator assembly is constructed from 10-inch-OD 304 stainless steel tubing with 0.125-inch-thick walls.

The secondary flow restrictor is constructed from 10.07-inch-ID 304 stainless steel tubing with 0.1046-inch-thick walls.

2.4 Primary Coolant Pump

The intact loop pump is a volute-type, heavy duty, horizontal, centrifugal pump. The pump is rated for a nominal flow of 180 gpm at a total head of 192 feet of water when operated at rated speed of 3,560 rpm. The material of construction for the wetted parts – that is, the casing, impeller, hub disc, and shaft – is Type 316 stainless steel. The remainder of the pump is of case iron and steel. The pump is designed for 2,500 psig and 650°F. The specific speed of the pump is 930, and the impeller diameter is 7-3/4 inches. The performance curve for pump operation at rated speed is given in Figure 14.

Fig. 14 Intact loop primary coolant pump performance curves.

The pump is coupled to a 25-hp, 2,500-rpm, dc motor through a speed variation system which allows pump speed reduction to any desired operating point. For Series 3 testing the pump was not operated.

3. BROKEN LOOP

The broken loop consists of the primary coolant piping, simulated steam generator, simulated pump, and two rupture assemblies. The broken loop configurations for Test Series 3 are shown in Figures 3 and 5.

3.1 Broken Loop Piping

Piping sizes used in the blowdown loop are 3-inch Schedule 160, 2-inch Schedule 160, 1-1/2-inch Schedule 80, and 1-inch Schedule 80. Piping Spools 20, 21A, 30, 31, 32, and 36 are 3-inch pipe. Piping Spools 22, 23, 31A, 37, 38, and 42 are 2-inch pipe. Piping Spools 40 and 41 are 1-1/2-inch pipe. Spool 31AA reduces gradually from 3 inches to 2 inches. All piping material is seamless austenitic steel pipe conforming to ASME SA-376, Grade 136. With the exception of the flanges holding the rupture assemblies, all pipe spool piece connections are made with Grayloc connectors.

3.2 Simulated Steam Generator

The steam generator simulator models the LOFT steam generator simulator and is shown in Figure 15. It consists of a housing in the form of an inverted "U" in which are installed 14 orifice plates, seven in each U-leg. Each orifice plate has three holes whose diameter closely approximates the orifice hole diameter in the LOFT simulator. Orifice plate thickness also approximates that of LOFT. The orifice plate spacing is adjustable, and the plates are removable. Spacing of the orifice plates initially is identical to that of the LOFT simulator plates.

The steam generator simulator housing is designed for a pressure of 2,500 psig at 650°F. Housing material is Grade 316 stainless steel pipe (conforming to ASME AS-376) and Grayloc connectors (conforming to ASME SA-182). Internal parts (orifice plates, spacers, sleeves, etc.) are also of stainless steel. Pipe joints utilize Grayloc hubs and are located to provide ease of installation and system versatility.

3.3 Simulated Pump

The broken loop simulated pump is modeled after the LOFT pump simulator and is shown in Figure 16. It consists of a housing made of 3-inch Schedule 160 stainless steel pipe, in which a maximum of 14 orifice plates can be installed. Each orifice plate has three holes located on a triangular pitch; hole diameter is approximately equal to that of the holes in the orifice plates in the LOFT simulator. Orifice plate thickness also approximates LOFT orifice plate thickness. Spacing of the orifice plates can be adjusted, and the plates are

NOTE
All Dimensions
Shown are in Inches
Unless Otherwise
Specified.

Fig. 15 Broken loop steam generator simulator.

NOTE

All Dimensions Shown are in
Inches Unless Otherwise Specified

Fig. 16 Broken loop pump simulator.

removable. For Tests S-03-6 and S-03-7 nine orifice plates with the hole pattern staggered between plates were used. Four orifice plates with the hole pattern staggered between only the first and second plate were used for Tests S-03-5 and S-03-8.

The simulated pump housing is designed for a pressure of 2,500 psig at 650°F. Housing material is Grade 316 stainless steel pipe (conforming to ASME SA-182). Internal parts (orifice plates, spacers, sleeves, etc.) are also made of Grade 316 stainless steel. The simulated pump is connected to the blowdown loop piping by Grayloc connectors.

3.4 Rupture Assemblies

Rupture assemblies, each consisting of a rupture disc subassembly and a blowdown nozzle subassembly, as shown in Figure 17, are used in the broken loop, except that rupture discs have not been installed.

Figure 18 shows a blowdown nozzle subassembly. Each blowdown nozzle simulates one-half of a double-ended offset shear. The broken loop cold leg nozzle was removed for Tests S-02-1 through S-03-4 and Tests S-03-A through A-03-D. Nozzles with different throat sizes are used to provide different break areas. The ratio of liquid volume to break area for Semiscale is based on the ratio of system liquid volume to loop pipe area for a typical PWR system. For simulated cold leg breaks this ratio is about 2,970 ft, and for simulated hot leg breaks this ratio is about 1,670 ft. Maintaining these ratios for an average Semiscale system liquid volume of about 7.78 ft³ results in a maximum scaled cold leg break area of 0.00262 ft². The specified break area percentage for a given test is expressed in terms of the maximum scaled area for the appropriate break location (hot or cold leg). Therefore, double-ended offset shear break simulations are specified at 200% hot or cold leg breaks.

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Fig. 17 Rupture assembly.

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4. PRESSURE SUPPRESSION SYSTEM

The pressure suppression system consists mainly of a pressure vessel with a downcomer and header. The configuration is depicted in Figures 19 and 20. The effluent is discharged from the broken loop (through two 3-inch Schedule 160 pipes) into a 16-inch header that simulates, in general, the drywell in a PWR pressure suppression system and, specifically, the LOFT 42-inch header. 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 distances from the downcomer to the water surface and to the bottom of the vessel.

4.1 Vessel

The total vessel volume is 90 ft³. The vessel is so sized that, when the vessel is 50% full of water, the downcomer pipe extends 2.5 feet below the water surface. 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 vessel.

4.2 Downcomer

The 8.625-inch-OD downcomer pipe penetrates through the side of the pressure suppression vessel near the top and extends horizontally to the axial center of the vessel and then downward to a point three feet from the bottom.

Inside the pressure suppression vessel, the downcomer pipe has a bolted connection which allows replacement of the vertical portion of the downcomer.

4.3 Header

The 16-inch header is designed so that no water traps exist. Accordingly, the downcomer pipe connection is on the bottom of the header. A pressure relief device, designed for a minimum capacity of 6.5 lb/sec of saturated steam at a pressure of 250 psia, is mounted on the header.

Fig. 19 Pressure suppression system – plan view.

Fig. 20 Pressure suppression vessel.

5. PRESSURE SUPPRESSION STEAM SUPPLY SYSTEM

The pressure suppression steam supply system is designed as an auxiliary system to the pressure suppression system. The steam supply system is designed to inject steam into the pressure suppression system for the purpose of maintaining the header pressure within ± 2 psi of a specified constant value between 20 and 80 psia. During the reflood heat transfer tests the steam was injected into the pressure suppression vessel through the port previously used for the relief valve. The system is capable of supplying up to 0.5 lb/sec of steam at 60 psia and 0.3 lb/sec at 20 psia.

For the reflood heat transfer tests the pressure suppression steam supply was used prior to the tests for heating the primary system and containment system to saturation temperature at test operating pressures by flowing steam through the system and out drains in the vessel and intact loop piping. During the tests the steam supply system was used to maintain header pressure at the test operating value.

6. COOLANT INJECTION SYSTEM

The coolant injection systems for the intact loop and the broken loop are each composed of three systems: the high pressure injection system (HPIS), the low pressure injection system (LPIS), and the accumulator injection system (AIS). Systems injecting coolant into the broken loop function independently of those injecting into the intact loop. The coolant injection systems are shown in Figures 3 and 5. The broken loop injection system was not used during the reflood heat transfer tests.

6.1 Intact Loop Injection System

The intact loop injection system consists of an HPIS, an LPIS, an AIS, and piping and valving.

The intact loop HPIS is piped to its respective loop injection points separate of the AIS and LPIS injection lines and injects into the loop through an injection point common with the AIS and LPIS lines. The HPIS water supply comes from a makeup system storage tank and is available at temperatures of 50 to 180°F. Activation of the HPIS is based on primary coolant pump outlet pressure; actuation setpoint may be set in the range of 1,500 to 1,800 psig. An alternate mode of injection actuation is based on actuating the pump discharge valve at a predetermined time after rupture. Two positive displacement Sprague Engineering pumps, Model S-440-100 SS, each having a capacity of 0.418 gpm (97.0 in.³ minimum at 2,000 psi), are used to provide 0.81 gpm at 1,500 to 1,800 psig for the intact loop. The pumps are air driven.

The HPIS pumps function as the makeup system charging pumps during normal operation and, when an experiment is about to be performed, are switched to function as HPIS pumps by pump discharge line valves. The HPIS was not used during the reflood heat transfer tests.

The intact loop LPIS injects into either the cold leg of the intact loop, lower plenum, upper plenum, core inlet, or inlet annulus or any combination of these. Activation of the LPIS injection occurs at an intact loop pump discharge pressure of 100 psig or at a predetermined time during a test. The temperature of the water supplied to the LPIS from the makeup system is adjustable within the range of 50 to 180°F. An Oberdorfer Model 300 gear pump serves as the intact loop LPIS pump, which at 1,400 rpm has the capacity of 5.4 gpm at injection pressure of 0 psig and 4.5 gpm at injection pressure of 100 psig.

The intact loop AIS is composed of an accumulator tank, a remotely operated block valve at the accumulator, an isolation valve near the injection point, check valves, a gate valve for throttling flow, and piping for coolant injection. Injection locations are the same as for the intact loop LPIS.

The accumulator is isolated from its respective injection points by a remotely operated isolation valve and a manual shutoff valve. Check valves are located in the line to prevent reverse flow. Nitrogen gas overpressure in the accumulator provides the driving force for injecting the stored coolant at flood rates similar to those of LOFT.

The effective liquid volume capable of discharge and the gas-to-liquid volume ratios are controlled by various combinations of liquid level and changeable lengths of discharge pipe extending from the top of the tank down through the nitrogen gas and into the liquid. The effective liquid volume is determined by the depth the pipe extends into liquid. Heaters are provided in the accumulators for water temperature control over the range of 50 to 180°F.

The accumulator tank for the intact loop is designed and fabricated of Type 316 stainless steel and has a volume of 6.95 ft³. It is a vertical vessel consisting of 12-inch Schedule 80 pipe with a 900-lb weld neck and modified 900-lb blind flange at the top and a 12-inch butt-welded cap on the bottom. The tank is somewhat greater than 10 feet in length.

Fittings are provided on the accumulator tank for filling, draining, and sampling. Gas overpressure is supplied by the nitrogen system through a pressure regulator and shutoff valve. The tank is provided with a pressure relief valve set to open at 770 psig.

Each injection point has a check valve and manual gate valve located as close to the injection point as physically possible. Each of the injection systems (HPIS, AIS, and LPIS) has a check valve and remotely operated shutoff valve near the pump or accumulator discharge point.

V. INSTRUMENTATION SYSTEM

The Semiscale Mod-1 instrumentation system provides for the acquisition, processing, and presentation of test data. The instrumentation system is composed primarily of individual detectors, signal conditioning equipment, signal processing equipment, recording equipment, and display equipment. Figure 21 schematically displays the instrumentation, data acquisition, and processing system. Individual detectors at selected locations in the test system provide data in the form of electrical signals. The data signals are then subjected to a signal conditioning process in which they are processed through low voltage level amplifiers and, when necessary, through additional signal conditioning electronics.

After the signal conditioning process is performed, the data are recorded on tape in analog form or digitized and recorded on tape in digital form. The digital data thus obtained are then presented in tabular or graphic form.

Fig. 21 Instrumentation, data acquisition, and processing system.

1. DATA ACQUISITION AND PROCESSING SYSTEM

The data acquisition and processing system interfaces with the detectors and processes the data for warmup, monitoring, and presentation in engineering units.

The Semiscale Mod-1 data acquisition system consists of two hardware subsystems, an analog data acquisition system (ADAS), and a digital data acquisition and processing system (DDAPS).

The ADAS, which is primarily used as a redundant system in case of major DDAPS failure, consists of seven analog magnetic tape units which can be operated in either the record or playback mode. Up to 80 channels are recorded on one of the tape transports in an FM multiplex mode at bandwidths of 250 Hz and 1 kHz. An additional 78 data channels can be recorded at bandwidths to 10 kHz on the other six FM tape units on a one-channel-per-tape-track basis.

The DDAPS is an online system capable of recording up to 256 channels of data at frequencies of less than 50 Hz on disc type memory devices. This system is capable of producing data plots of all DDAPS channels and can also be used to digitize and plot the data recorded on the ADAS.

The DDAPS plots created have a resolution on the vertical axis of system full scale divided by 1,000. The horizontal axis, used to indicate time, represents 920 equally spaced data samples. The data curves are produced by connecting the sample points with straight lines.

During Semiscale Mod-1 system testing, the DDAPS is used to record about 200 measurements. The ADAS is used to record up to 158 measurements, most of which are a duplicate recording of the measurements recorded on the DDAPS. The data presented in the experiment data reports are obtained from the DDAPS system. The DDAPS system is used for convenience because this system provides digital data directly. The analog data could be digitized using the IBM 360/75 computer to obtain improved frequency response. However, for graphs for the time duration presented in data reports, no improvement in data resolution is recognized.

The DDAPS and ADAS have a time correlation of $\pm 50 \mu\text{sec}$ between any data taped. The ADAS has calibration signals recorded with the data to allow gain and off-set corrections to the data during processing of the detector signals. The DDAPS has an internal self-check and calibration system which, during the acquisition and processing of the detector signals, automatically corrects for gain and off-set variations in the data. The total uncertainty induced by the DDAPS is $\pm 0.1\%$ of full scale^[a].

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[a] Full scale refers to the data acquisition and processing system electrical data signal range and represents the actual monitored full range in engineering units for individual detectors.

Estimated electrical pickup noise in transmission lines is $\pm 0.1\%$ of full scale. The root-sum-square summation technique applied to the individual acquisition and processing uncertainty estimates yields a probable uncertainty of $\pm 0.52\%$ of full scale.

2. INSTRUMENTATION USED TO OBTAIN TEST DATA

Measurement of test variables is accomplished by detectors located in the Semiscale Mod-1 system. Detectors are provided for measuring: fluid and material temperatures and pressure; volumetric flow rate; velocity; momentum flux; density; liquid level; pump torque, power, and speed; core current, voltage, and power. 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 in the Semiscale Mod-1 system, or both, and (b) arabic numerals identifying the pipe section (spool), detector location, or core grid spacer. In the case of the differential pressure measurements, each detector has low pressure tap locations associated with it. The two locations are designated similarly to other instrument locations. However, the order in which the locations are given designates the polarity of the data; the first location indicated is the positive reference. System reference locations are:

Steam generators	Divide hot and cold legs.
Vessel cold leg centerline	References vertical vessel locations. Arabic numerals indicate distances from the cold leg centerline. Angular vessel locations are in degrees clockwise from the intact loop cold leg centerline as viewed from the top of the vessel.
Vessel centerline	References detector locations in the intact and broken loops. Arabic numerals indicate distances from the vessel centerline along the centerline of the appropriate hot or cold leg, with the exception that locations in the broken loop cold leg (hot leg) piping between the rupture assemblies and the steam generator in the cold leg (hot leg) configuration are specified along the centerline of the broken loop hot (cold) leg.
Core heater rods	Reference core fluid and material thermocouple locations. As indicated on Figure 22, any rod in the core can be described by two coordinates in terms of the columns (alphabetic symbols) and rows (arabic numerals) of Figure 22. Core fluid

Fig. 22 Semiscale Mod-1 core heater rod configuration nomenclature — top view.

	thermocouple nomenclature identifies the four adjacent rod positions by using alphabetic symbols and arabic numerals to define coordinates of the heater rod.
Bottom of the heated length of the core heater rods	References material thermocouple locations. Arabic numerals represent distances above the bottom of the heated length of the core heater rods.
Core grid spacers	Reference fluid thermocouple locations. Arabic numerals identify the grid spacers on which the thermocouples are located. The grid spacers are numbered consecutively from 6 through 10, with 6 at the top.
Piping Spool ID	References material thermocouple locations. Arabic numerals represent distances from the piping spool ID. For example, 16 = 1/16 in., 4 = 1/4 in.
Bottom of steam generator tube sheet	References locations in the steam generator. Arabic numerals represent distances from the bottom of the tube sheet.

Figure 23 shows a typical installation for detectors in an instrumented spool piece. Table VIII indicates types of measurement capability, the manufacturer of the detector, the type of measurement device, the general range and response of the detector, and the total expected error in the reported data assuming transducer output signals result from homogeneous flow conditions.

The total expected error is obtained by applying the root-sum-square summation technique to all the individual errors occurring in the instrument, acquisition, and processing systems. All individual errors are considered to be independent, to be normally distributed, and to represent 2σ confidence limits.

Physical conditions which occur during pretest warmup and during the blowdown tests overrange some detectors in the system. Detectors in the system are capable of withstanding the overrange conditions without any change in operation or measuring characteristics when the physical conditions are again within the detector range.

2.1 Fluid Temperature

Fluid temperature measurements are made using thermocouples and variable resistance devices. Zero off-sets and nonlinearities occurring during acquisition are corrected

Fig. 23 Typical instrumented spool piece.

TABLE VIII

DETECTOR CHARACTERISTICS AND MEASUREMENT SYSTEM TOTAL EXPECTED ERROR^[a]

Measurement	Manufacturer	Type	Detector Range	Detector Rise-time ^[b]	Measurement System Total Expected Error
Fluid temperature	ARI Industries and Aerojet Nuclear Company	Type J thermocouple, welded junction	0 to 1,400°F	20 msec	+5°F
		Type K thermocouple, exposed junction	0 to 2,300°F	5 msec	+5°F
		Platinum resistance detector	0 to 1,000°F	250 msec	+0.5°F
Material temperature	Aerojet Nuclear Company	Type K thermocouple grounded, spaded junction	0 to 2,300°F	~10 msec	+7°F
		Type J thermocouple grounded, spaded junction	0 to 1,400°F	~10 msec	+7°F
Fluid pressure	Precise Sensors, Inc.	Flush diaphragm-bonded strain gage	0 to 3,000 psig	35 μ sec	+1% full scale ^[c]
			0 to 750 psig	35 μ sec	+1% full scale ^[c]
			0 to 100 psig	35 μ sec	+1% full scale
Differential pressure	SLM Electronics, Inc.	Diaphragm-bonded strain gage	+0.72 to +1,500 psid	20 msec	+1.1 to +20% full scale ^[c]
Volumetric flow rate	ITT Barton, Flow Technology, Inc. and Potter Instrument Company	Turbine	up to 100 gpm	3 msec	+1.5 gpm
			200 gpm	3 msec	+6.5 gpm
			400 gpm	5 msec	+10.0 gpm
Fluid velocity	Flow Technology, Inc.	Turbine	0 to 18 ft/sec	3 msec	+5% full scale ^[c]
			0 to 36 ft/sec	3 msec	+5% full scale ^[c]
			0 to 50 ft/sec	3 msec	+5% full scale ^[c]
Momentum flux	Ramapo Instrument Company, Inc. and Aerojet Nuclear Company	Strain-gaged cantilever beam with target	up to 13.1×10^4 lb/ft-sec ²	2 msec	+200 to +1,000 lb/ft-sec ²
Fluid density	Technical Operations, Inc. and Aerojet Nuclear Company	Gamma attenuation	0.01 to 100 lb/ft ³	3.5 msec	+200 to +1,000 lb/ft-sec ²
Pump torque	Lebow Associates, Inc.	Strain-gaged torque cell	+500 in.-lb	1 msec	+4.5 in.-lb
Pump speed	Lebow Associates, Inc.	60-tooth gear and magnetic coil	0 to 3,600 rpm	1 msec	+36 rpm
Pump power	Ohio Semitronics, Inc. and Aerojet Nuclear Company	Hall-effect multiplier	0 to 24.2 kW	1 msec	+0.34 kW
Core current	Aerojet Nuclear Company	Shunt circuit	0 to 10k amps		+100 amps
Core voltage		Digital voltmeter	0 to 200 volts		+2 volts
Core power	Ohio Semitronics, Inc. and Aerojet Nuclear Company	Hall-effect multiplier	0 to 16 MW		+32 kW

[a] The total expected error is obtained by using the root-sum-square summation technique applied to all the individual errors occurring in the instrument, acquisition, and processing systems. All error components were considered to be independent, normally distributed, and to represent 2 σ confidence limits.

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

[c] Full scale refers to detector full scale range.

during data processing. The total expected error for thermocouples is $\pm 5^{\circ}\text{F}$ and for variable resistance devices $\pm 0.5^{\circ}\text{F}$.

2.2 Material Temperature

Material temperature measurements are made using thermocouples. Zero off-sets and nonlinearities occurring during data acquisition are corrected during data processing. The total expected error is $\pm 7^{\circ}\text{F}$ for both Type J and Type K thermocouples.

2.3 Pressure

Pressure measurements are obtained with calibrated pressure transducers. Some of the transducers are flush mounted and some are mounted in standoffs. Pressure data corrections are made for discrepancies noted between pressure measurements made with the Norwood transducers and pressure measurements made with a precision pressure gauge at steady state system conditions. The total expected error is $\pm 1\%$ of transducer full scale.

2.4 Differential Pressure

The differential pressure measurements are made with calibrated differential pressure transducers. Transducer pressure sensitivity is corrected for by recording transducer voltage output as a function of pressure during pretest hydrostatic operation and then applying the resulting correction curve to the recorded test data through use of a computer program. Total expected errors vary from approximately $\pm 1.1\%$ to $\pm 20.0\%$ of transducer full scale. The average total expected error used for all differential pressure transducers used in the system is about $\pm 3.0\%$ of transducer full scale.

2.5 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. The total expected errors, which vary with transducer range, are given in Table VIII.

2.6 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. The total expected error is $\pm 5\%$ of transducer full scale.

2.7 Momentum Flux

Momentum flux measurements are made with drag disc devices. These devices are basically strain-gauged 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 conditions and the instrument calibration curve, is applied to the recorded test data through use of a computer data conversion program. The total expected error varies from about ± 200 to $\pm 1,000$ lb/ft-sec², depending on the transducer range.

2.8 Density

Fluid density data 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 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. The total expected error is approximately ± 1.0 lb/ft³.

2.9 Liquid Level

Differential pressure cells are used to measure liquid level at various system locations. The total expected error associated with the differential pressure measurements is ± 1.0 inch.

2.10 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 with the system during the blowdown transient are calculated with a digital computer from either

for density and momentum flux measurements, or

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

for density and volumetric flow rate measurements

$$m = \rho v A .$$

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).

2.11 Pump Characteristics

The torque transmission to the impeller of the circulating pump is measured by use of a torque cell attached directly to the pump shaft. The total expected error is ± 4.5 in.-lb_f.

Pump speed data are obtained by the use of a gear and sensor pickup coupled with electrical frequency processing. The sensor produces a voltage signal as each gear tooth passes by the sensor. The total expected error for data above 100 rpm is ± 36 rpm; the measuring system is not capable of providing meaningful data below 100 rpm.

Pump power is measured using a halltron. This device measures the current and voltage applied to the pump motor and effectively multiplies them together to produce a voltage output proportional to the power. The total expected error is ± 0.34 kW.

2.12 Core Characteristics

A shunt circuit is used to measure the total core current. The shunt circuit technique uses a voltage measurement across a known precision resistor in the shunt circuit to provide current data. The total expected error is $\pm 1\%$ full scale.

Core voltage data are obtained by using a digital voltmeter. The total expected error is $\pm 1\%$ full scale.

The measured core current and core voltage are processed through a Hall-effect multiplier to obtain the total core power. The measurement is considered to have a total expected error of 2% full scale.

VI. REFERENCE

1. J. P. Waring, E. R. Rosal, L. E. Hochreiter, *PWR-FLECHT-SET Phase B₁ Data Report*, WCAP-8431 (December 1974).

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