BWR Refill-Reflood Program—Core Spray Distribution Experimental Task Plan

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BWR Refill-Reflood Program—Core Spray Distribution Experimental Task Plan

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Research Project 1377-1
NUREG/CR-1558
GEAP-25272**

Interim Report, February 1981

Prepared by

**GENERAL ELECTRIC COMPANY
175 Curtner Avenue
San Jose, California 95125**

**Principal Investigator
T. Eckert**

Prepared for

**United States Nuclear Regulatory Commission
Washington, D.C. 20555**

**Program Management Representative
W. D. Beckner**

**General Electric Company
San Jose, California 95125**

**Program Management Representative
G. W. Burnette**

**Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304**

**EPRI Project Manager
M. Merilo**

**Water Reactor System Technology Program
Nuclear Power Division**

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Prepared by
General Electric Company
San Jose, California

EPRI PERSPECTIVE

PROJECT DESCRIPTION

A major consideration in the design of engineered safety systems and licensing of boiling water reactors (BWRs) is that sufficient emergency core coolant (ECC) be provided to cool the reactor core in the event of a loss-of-coolant accident (LOCA). There are at present two major research programs addressing the entire LOCA transient which are jointly managed and funded by the U.S. Nuclear Regulatory Commission, Electric Power Research Institute, and General Electric. These are the Blowdown-Emergency Core Cooling Program (RP495) and the Refill-Reflood Program (RP1377-1). Though these programs are closely related, they are being performed under separate contracts. The present project is a part of the Refill-Reflood Program, which addresses the thermal-hydraulic behavior of most BWR plants during the refill and reflood phases of LOCAs on a generic basis.

PROJECT OBJECTIVE

In a BWR one of the emergency core cooling systems for protection against a LOCA is the core spray system. This generally consists of a set of nozzles, designed to distribute ECC water in the form of a spray, over the top of the core so that each fuel bundle receives at least a specified minimum amount of coolant. Present calculation methods cannot account for the spray distribution in the presence of condensation; therefore, full-scale testing of spray systems is an important part of their design and evaluation.

The specific objective of this task is to provide core spray distribution data in a steam environment, applicable to BWR-4,-5 geometry. These data will be useful for best-estimate model qualification, as a check on an existing prediction methodology, and for the identification of further model requirements.

PROJECT RESULTS

This report describes the experimental test plan which has been designed to meet the required objectives. It includes a description of the experimental facilities and a specification of the test matrix. Test results obtained for the BWR-6 (218)

geometry, which were not funded as a part of the present program, are also presented.

This report should be useful to those interested in model development and computer code assessment for BWR core spray systems. Related work on a single nozzle spray distribution has been presented in EPRI Key Phase Report NP-1344.

Mati Merilo, Project Manager
Nuclear Power Division

ABSTRACT

An experimental task plan for the BWR/4 core spray task of the Refill-Reflood Test Program is presented. The test program will provide core spray distribution data for a 30 degree sector of the BWR/4&5-218 design. This design uses different nozzle types and different sparger elevations than the BWR/6-218 design which was tested previously. Test parameter ranges are specified; individual tests are defined; and measurement and data utilization plans are defined.

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SUMMARY

One of the tasks in the EPRI, NRC and G.E. sponsored boiling water reactor (BWR) Refill-Reflood program is to provide emergency core cooling system core spray distribution data, from tests performed in a steam environment typical of those expected in a BWR upper plenum during the later stages of a loss-of-coolant accident. These data will be useful for best estimate model qualification, as a check on an existing core spray calculation methodology and for the identification of any further modeling requirements.

This document describes the test facilities, the planned test matrix and the measurement and data utilization plans.

Three facilities will be used; a full scale air-water facility, a single nozzle steam water facility, and a full radius 30 degree sector steam-water facility. The independent parameters which will be varied are the spray and steam flow rates, whereas the system pressure and spray temperatures will be maintained constant.

A schedule for the performance of the tests is also presented.

Section 1

INTRODUCTION

1.1 BACKGROUND

Single nozzle tests performed in steam and air have shown different spray distributions between the two environments.¹ A methodology incorporating air and steam testing was developed for predicting full core spray distributions in a steam environment. The methodology was confirmed with the BWR/6 design as described in NEDO-24712.² BWR/6 data are supplied in Appendix A.

The current test program will demonstrate the application of the methodology to the BWR/4&5 designs. These designs have different core spray sparger locations and different nozzle types than the BWR/6 design.

1.2 OBJECTIVES

The objectives of this program are to (a) provide core spray distribution data from steam environment tests for best estimate model qualification; (b) provide additional confirmation of the existing methodology; and (c) identify any further model requirements. The specific program objectives are presented in an excerpt from the Contract Project Agreement in Appendix B.³

The effects of sparger flow rate and sparger-to-sparger interaction on core spray distribution will be studied with this test program.

This document presents the BWR/4&5-218 30-deg sector core spray test plan and provides information on parameter and range selection, test matrix, hardware, and test scheduling.

1.3 TEST PLAN APPROACH

The hardware design basis for the BWR/4&5 core spray program is the BWR/4-218 core spray system (BWR/5-218 is identical). The lower sparger will be tested in a 30-deg sector. Sparger-to-sparger interaction effects will be investigated using a double sparger arrangement with one nozzle on each sparger. The upper

sparger will not be tested in a 30-deg sector due to hardware limitations, according to the Contract Project Agreement³ scope [it would mechanically interfere with the BWR/6-218 spargers at the 30-deg Sector Steam Test Facility (SSTF)].

The selection of independent parameters is presented in Section 3. The criteria used for selection of these parameters is based on both previous experience and current evaluation of the loss-of-coolant accident (LOCA) transient. Areas of interest considered in choosing the parameters include: (a) separability of thermal and hydraulic effects on the spray, (b) representative reactor conditions, and (c) steam flow to the core spray during operation.

1.4 CORE SPRAY METHODOLOGY (APPLICATION OF TEST RESULTS)

The BWR/4&5 core spray program tests will be compared with the distribution calculated with the core spray methodology. A flow chart and explanation of the confirmation of the core spray methodology is provided in Figure 1-1.

Figure 1-1. Core Spray Methodology

Section 2

BWR/4&5-218 CORE SPRAY HARDWARE DESCRIPTION

2.1 GENERAL DESCRIPTION OF THE TEST FACILITIES

The steam tests will be performed in the Horizontal Spray Facility (HSF) at San Jose and in the 30-deg SSTF at Lynn, Massachusetts. The simulator tests will be performed in both the Vallecitos Spray Facility (VSF) at the Vallecitos Nuclear Center (VNC) and in the HSF. A description of these test facilities is given below.

2.1.1 Horizontal Spray Facility

The HSF facility was designed to mock up a portion of the top of the reactor core for testing a single nozzle in a pressurized steam environment. The facility is used to determine the spray characteristics of the core spray nozzles (see Figure 2-1).

The mock-up consists of several mechanisms and structures. One mechanism (header mechanism) positions and holds a short section of the sparger containing one nozzle. Another mechanism (movable grid) holds and positions the collection tanks which are used in place of the fuel bundles. The grid mover mechanism can linearly position the grid over a 30-in. span. Thus, the system can sample the spray with a relatively small number of collection tanks and produce a large number of collection points. A baffle behind the header mechanism simulates the shroud wall. The core mock-up does not include the fuel bundle handles or shroud head.

The mock-up is contained in an unfired pressure vessel measuring 6-ft i.d. x 21 ft long. The supporting systems consist of a water recirculation loop for the spray, three heat exchangers to subcool the spray and a 7000 lbm/hr boiler to produce the steam.

Figure 2-1. Horizontal Spray Facility

2.1.2 30-deg Sector Steam Test Facility

The 30-deg sector internals provide accurate representation of the reference BWR/6-218 (624 bundle) reactor through the use of prototypical hardware and geometry. A schematic representation of the test section components is given in Figure 2-2. The upper plenum is a full-scale mock-up of a 30-deg sector of the reference upper plenum with accurate simulation of geometric shape, and shroud head curvature and height. Standpipes simulating the steam separators extend up from the shroud head. The upper and lower core spray spargers are full-scale mock-ups of 30-deg sectors of the reference high pressure core spray (HPCS) and low pressure core spray (LPCS) spargers with regard to size, curvature, location and nozzles. The core region simulation includes both mock fuel bundles and bypass region. The core region is full-scale in cross section, but is approximately 5 ft shorter than the BWR reference due to overall facility height limitations. Fifty-eight mock fuel bundles are included in the 30-deg sector (42 complete bundles and 16 partial bundles having removable cover plates and baffles to simulate the 30-deg boundary within the partial bundle). The bundles utilize production version hardware for channel, channel fasteners and spacer, upper tie plate, lower tie plate, and finger springs. Simulated fuel rods are included in both the upper and lower tie plate regions. Upper fuel rod simulation includes production version expansion springs, end pins, locking tab washers, hexagon nuts, and one fuel rod spacer. A steam injector tube is provided in each bundle below the upper rods to deliver the channel steam from the steam distribution manifold located outside the 30-deg shroud wall. A weir-tube measuring device⁴ is provided in each bundle above the lower rods to measure the liquid flow. The bypass region flow area is simulated and includes dummy control rods mounted on production version fuel support castings. Leakage and flow path simulation between bundle, bypass, upper plenum, lower plenum, and guide tube is assured by using production version hardware in conjunction with accurate representations of the top fuel guide and core plate. Twelve volume-scaled guide tube regions are provided (one for each of the twelve centrally located side-entry fuel supports). The lower plenum volume represents the scaled volume of the reference lower plenum region outside the guide tubes.

The SSTF pressure vessel (14 ft i.d. and 27 ft inside height) serves as a pressure envelope for the 30-deg sector internals. The vessel is designed with numerous nozzles and penetrations to permit attaching the various process lines which service the internals and to provide routing for the various instrumentation lines and cables.

Figure 2-2. 30-Deg Steam Sector Test Section

An air-conditioned control room houses the process control equipment and data acquisition system (DAS). Process instrumentation and valves are provided to monitor and control temperature, pressure and flow in the steam supply headers, water recirculation lines, emergency core cooling system (ECCS) lines, and vent system (as indicated on Figure 2-3).

Test instrumentation and signal conditioning include pressure and differential pressure transducers, and thermocouples as shown on Figures 2-2 and 2-3. The ECCS spray distribution is determined from individual bundle flow measurements provided by weir flow elements internal to each mock fuel bundle.

A schematic of facility and external loop hardware is shown in Figure 2-3. A steam supply of 110,000 lbm/hr at 150 psia and 388°F is available. Steam is routed to the pressure vessel through a 10-in. header to an upper plenum supply nozzle and to a mock fuel bundle supply nozzle. Water is supplied to the facility from a condensate tank and retained in a supply tank which is part of the ECCS water supply and recirculation loop. The temperature of the water in the tank can be controlled by recirculation through a heat exchanger loop. The ECCS supply system provides flows representative of the reference BWR/6-218 reactor. The system consists of three pumps connected in parallel to provide up to 1800 gpm at 130 psi to the main ECCS header. This main header in turn supplies the three individual ECCS lines which are routed to separate nozzles on the pressure vessel.

2.1.3 Vallecitos Spray Facility

The VSF facility was designed to mock up the top of the reactor core for testing a 360-deg spray sparger and nozzles in an air atmosphere. A full complement of mock fuel bundles makes up the core, each bundle having a weir type flow measuring device attached to the bottom. Different pumps in the water recirculation loop provide the spray water for any desired flow from a single nozzle test to a 360-deg full sparger test. Used primarily for full sparger testing in air, the facility can also be used to perform single nozzle spray distribution tests by using a single nozzle sparger pipe mounted in front of a portion of the core mock-up. In this configuration, simulator nozzle development testing can be performed at this facility.

Figure 2-3. 30-Deg SSTF - Loop Control

2.2 SPARGER AND NOZZLE DESIGN

As mentioned previously, the SSTF accurately mocks up a 30-deg sector of a BWR/6-218 upper plenum and core. For BWR/4&5-218 testing, the facility will be modified by the addition of a BWR/4&5-218 sparger (lower only) and by the removal of the fuel bundle handles from the edge row of bundles (which are not present in BWR/4-218 reactors). With these modifications the facility mocks up a BWR/4-218 reasonably well.

The 30-deg lower sparger with seven* nozzle assemblies will be added to the 30-deg sector internals as shown in Figure 2-4. The sparger and nozzle assemblies will be based on the design of a typical BWR/4-218 plant. The nozzle positions relative to the core mock-up are shown in Figure 2-5. The nozzle assembly details and configurations are shown in Figure 2-6.

The double sparger test assembly can be installed into the core mock-up when the upper plenum and the 30-deg spargers attached to it are removed. The installation is shown in Figure 2-7. Each sparger of the double sparger test rig can accommodate a maximum of three nozzle assemblies with the nozzle centerline of the middle assembly corresponding to the collection grid centerline. Single nozzle and two nozzle tests described in the Phase 3 test matrix will use only the middle nozzle position of each sparger. The test rig has a backing plate which simulates the shroud wall and encourages typical reactor steam currents to the spray nozzle.

*A BWR/4&5-218 360-deg sparger has 104 spray nozzles. Therefore a 30-deg sector should have $8\frac{2}{3}$ nozzles. A sector with seven nozzles will produce spray distributions similar to, but not completely representative of, actual reactor performance (somewhat less flow density).

Figure 2-4. Placement of BWR/4&5 Lower Sparger Into 30-Deg SSTF

Figure 2-5. 30-Deg Lower Sparger Nozzle Positions (BWR/4-218 at 30-Deg SSTF)

FIGURE NUMBER	ORIFICE A (BORE SIZE)	ORIFICE B (BORE SIZE)
3	158B7896P2 (0.620)	158B7896P6 (0.560)
5	158B7896P3 (0.750)	158B7896P6 (0.560)

FIGURE NUMBER	ORIFICE A (BORE SIZE)	ORIFICE B (BORE SIZE)	NOZZLE (NAME)
8	158B7896P3 (0.750)	158B7896P4 (0.880)	158B7896G1 (1-in. VNC 9/16)
11	158B7896P3 (0.750)	158B7896P3 (0.750)	158B7896G2 (1-in. VNC 14/16)

Figure 2-6. Nozzle Assemblies for BWR/4&5-218 Core Spray

Figure 2-7. Test Rig Installation

Section 3

INDEPENDENT PARAMETERS AND TEST MATRIX

3.1 PARAMETERS AND RANGES

The hardware design basis for the BWR/4&5 core spray program is the BWR/4-218 core spray system (BWR/5-218 is identical). The operating parameters specified for the tests are representative of the system at pump runout flow conditions. The environmental parameters chosen for the tests are the same as used in confirming the methodology in the BWR/6 program.²

3.1.1 System Pressure

The reactor vessel pressure decreases with time during a LOCA and core spray operation. The test series presented herein is run at 29.5 psia for comparison with core spray methodology predictions. This matches the reference condition used previously for the BWR/6 methodology program², and also provides for an approximate match in the densities of the steam and air environments used for the methodology prediction tests.

3.1.2 Spray Temperature

The source of water for the BWR core spray system is the suppression pool with a supply temperature variation from 40 to 160°F (bulk pool temperature could approach 180°F to 190°F for some plants). The test series presented herein is to be run at 145°F.

3.1.3 Spray Flow Rate

Most of the testing will be performed using a flow equivalent to 5900 gpm per 360-deg sparger, which is typical of BWR/4 designs. This results in single nozzle flow rates of 73 gpm for the 1-in. VNC type nozzles and 39 gpm for the S3101 nozzles.* Additional tests will be performed at lower and higher flows to identify parameter effects.

3.1.4 Steam Flow

The reference tests will be performed with 50% of the condensing steam supplied from the core channels, to simulate updraft, and 50% from the steam separator pipes. All steam tests will be performed with at least 110% of condensing steam being supplied to the vessel. The 10% excess steam will be vented from the system to facilitate pressure control and to avoid the buildup of non-condensable gases.

*On a 360-deg sparger there are

50 Spraco 3101 nozzles at 39 gpm	=	1950 gpm
54 1-in. VNC nozzles at 73 gpm	=	<u>3942 gpm</u>
		5892 gpm total

On the seven-nozzle SSTF sparger there are

4 Spraco 3101's at 39 gpm	=	156
3 1-in. VNC's at 73 gpm	=	<u>219</u>
		375 gpm

For the reactor nozzles in air tests (Phase 4) the SSTF sparger uses eight nozzles.

4 Spraco 3101's at 39 gpm	=	156
4 1-in. VNC's at 73 gpm	=	<u>292</u>
		448 gpm

3.2 SHAKEDOWN TESTING

As the equipment of the test facilities has already been checked out and found to be in good order, shakedown testing will be kept to a minimum. For the 30-deg lower sparger, however, a shakedown test has been identified to measure and balance the nozzle flow rates by orificing so that each nozzle of each type has the same flow (+5%). This is a standard procedure for each BWR sparger design.

3.3 TEST MATRIX

The test matrix for the BWR/4&5-218 core spray distribution testing is shown in Table 3-1. The matrix includes a total of 28 tests, broken into 5 test phases.

The first test phase consists of single nozzle spray distribution tests performed in steam at the HSF. The second phase of testing is simulator nozzle development to be performed at the VSF. The simulator nozzles will be developed based on the test results of Phase 1. Phase 3 of the test matrix has been designed to provide double sparger interaction effects in a steam environment. The single nozzle test results of Phase 3 (performed at the 30-deg SSTF) will be compared to the results from Phase 1 (performed at the HSF) to provide tieback between the two facilities. Phase 4 will be 30-deg sparger tests with reactor nozzles in air at the SSTF. Shakedown testing will ensure equal spray flow rates from each nozzle type and spray distribution testing will measure the distribution at 448 gpm and 351 gpm. Phase 5 will test the 30-deg sparger with simulator nozzles in air. Shakedown testing will ensure equal spray flow rates from each nozzle type and spray distribution testing will measure the distribution at 376 and 295 gpm (the simulator at position L1 is deleted due to its interference with a sector wall)*. This data will provide the 30-deg MIE when compared to the GENUS superposition of single nozzle simulator data (obtained in Phase 2). Phase 6 is 30-deg lower sparger reactor nozzle spray distribution testing in steam. Spray flow rate is changed to quantify its effects on the spray distribution.

A detailed plan of data evaluation, comparison, and utilization is presented in Section 5.

* This was judged to be acceptable because the spray from this nozzle is directed downward at the wall and has a minimal effect on the sector centerline spray distribution.

Table 3-1

TEST MATRIX

Phase 1. Single Nozzle Spray Distribution In Steam - (HSF)

<u>Parameter</u>	<u>Test No.</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
Nozzle Type	1 in. VNC 14/16		S3101		1 in. VNC 9/16		S3101	
Nozzle Assy Figure No.	11	12	3	5	8	7	5	3
Sparger	Upper	Upper	Upper	Upper	Lower	Lower	Lower	Lower
Spray Flow (gpm)	73	73	39	39	73	73	39	39
Spray Temperature (°F)	145	145	145	145	145	145	145	145
System Pressure (psia)	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5

Phase 2. Simulator Nozzle Development - (VSF)

<u>Parameter</u>	<u>Test No.</u>	
	<u>11*</u>	<u>12*</u>
Nozzle Type Being Simulated	1 in. VNC 9/16	S3101
Sparger	Lower	Lower
Spray Flow (gpm)	73	39
Spray Temperature (°F)	80	80
System Pressure (psia)	Air	Air

*Tests 11 and 12 may consist of multiple runs as necessary.

Table 3-1

TEST MATRIX (Continued)

Phase 3. Double Sparger Tests (SSTF)

Parameter	<u>Test No.</u>					
	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>
Nozzle Type	1 in. VNC Type Nozzles			S3101 Type Nozzles		
Upper Nozzle Assembly Figure No.	11	-	11	3	-	3
Lower Nozzle Assembly Figure No.	-	8	8	-	5	5
Spray Flow (gpm)	73	73	73	39	39	39
Spray Temperature (°F)	145	145	145	145	145	145
System Pressure (psia)	29.5	29.5	29.5	29.5	29.5	29.5

Phase 4. 30-Deg Reactor Nozzles - Air Tests

	<u>Test No.</u>		
	<u>19RN</u>	<u>22</u>	<u>31</u>
Spray Flow (gpm)	448 ± 10	448 ± 10	351 ± 7
Spray Temperature (°F)	80° ± 5	80° ± 5	80° ± 5
Test Description	Measure single nozzle flows and adjust sparger orifices as necessary to make flows agree ±5%.	Spray Dist. Data	Spray Dist. Data

Phase 5. 30-Deg Simulator Nozzles - Air Tests

	<u>Test No.</u>		
	<u>19SN</u>	<u>20</u>	<u>21</u>
Spray Flow (gpm)	375 ± 7	375 ± 7	295 ± 5
Spray Temperature (°F)	80° ± 5°	80° ± 5°	80° ± 5°
Test Description	Measure single nozzle flows and adjust orificing as necessary to make flows agree ±5%.	Spray Dist. Data	Spray Dist. Data

Table 3-1

TEST MATRIX (Continued)

Phase 6.^a 30-Deg Reactor Nozzles - Steam Tests

	<u>Test No.</u>					
	<u>23</u>	<u>24</u>	<u>25</u>	<u>26</u>	<u>27</u>	<u>28</u>
Spray Flow (gpm)	375 ±10	412 ±10	450 ±10	488 ±10	124 ±10	251 ±10
Spray Temperature (°F)	145 ±3	145 ±3	145 ±3	145 ±3	145 ±3	145 ±3
System Pressure (psia)	29.5 ±0.5	29.5 ±0.5	29.5 ±0.5	29.5 ±0.5	29.5 ±0.5	29.5 ±0.5
Core Steam (lb/hr)	10,200	11,200	12,200	13,200	9,000 ^b	9,000 ^b
Upper Plenum Steam (lb/hr)	17,200	18,200	19,200	20,200	10,000	11,500
Vent Steam EST (lb/hr)	7,000	7,000	7,000	7,000	12,300	7,000
Condensing Steam Required (lb/hr)	20,400	22,400	24,500	26,500	6,700	13,500

^aUse the sparger orifice adjustments made during test 19RN. Use only seven nozzles.

^b9000 lbs is the minimum controllable core steam flow rate.

Section 4

MEASUREMENT PLAN

This section outlines the measurement objectives and then presents a measurement plan for the testing to be performed at the 30-deg SSTF.

4.1 MEASUREMENT OBJECTIVES

To accomplish the program objectives, a measurement system is provided to:

1. Assure that the specified steady-state conditions for the test have been established. The steady-state conditions of interest are spray flow, spray temperature, system pressure, nozzle ΔP , and steam flows (30-deg SSTF and HSF only).
2. Measure the spray distribution along a horizontal plane.
3. Determine the water mass balance of the test section.

4.2 TEST APPARATUS INSTRUMENTATION

The measurement requirements for the 30-deg SSTF testing are summarized in Table 4-1. This table shows the parameters to be measured in the various regions of the test apparatus. These parameters are the same as those measured in the BWR/6 program.²

The ECC systems are instrumented to provide the basic measurements of flow-rate, injection fluid temperature, and injection fluid pressure. The loop control instruments for the 30-deg SSTF are shown in Figure 2-3. The test section instruments are shown in Figure 2-2.

Table 4-1

MEASUREMENT REQUIREMENTS FOR 30-DEG SSTF TESTING

<u>Mock Fuel Bundles</u>	<u>Upper Plenum</u>	<u>Lower Plenum</u>
Liquid Down Flow (58 ea)	Pressure	Pressure
Steam Injection Rate	Temperature	Water Drain Temperature
Upper Tie Plate Temperature (16 ea)	Water Level	Water Level
Steam Injection Temperature (4 ea)	Steam Temperature in Standpipes	
	Steam Temperature Close to Nozzles	
<u>System Flow Rates</u>	<u>ECC Systems</u>	<u>Bypass</u>
Upper Plenum Steam	<u>Lower Sparger</u>	Temperature in Upper Region
Core Steam	Flow	Temperature in Lower Region
Drain Flow	Temperature	Water Level
	ΔP to Upper Plenum	
	<u>Upper Sparger</u>	
	Flow	
	Temperature	
	ΔP to Upper Plenum	

Section 5

DATA UTILIZATION

5.1 COMPARISON WITH PRETEST PREDICTION

The main objective of this test series is to demonstrate the applicability of the core spray methodology to the BWR/4&5-218 geometry. Test Phases 1, 2 and 5 are used to develop the pretest prediction for Test 24 in Phase 6 (145°F, 29.5 psia).

5.2 DOUBLE SPARGER INTERACTION

A second objective of this test series is to provide double nozzle interaction effects by performing single nozzle tests and dual nozzle (adjacent nozzles from the upper and lower spargers) tests in a steam environment. The data from Phase 3 covers this objective. For the 1-in. VNC type nozzles, Test 15 will be compared to the superposition of Tests 13 and 14. For the SPRACO 3101 type nozzles Test 18 will be compared to the superposition of Tests 16 and 17. These comparisons will be used to evaluate the amount of interaction between nozzles.

The single nozzle tests of Phase 3, (Tests 13, 14, 16 and 17) will be compared to their counterpart tests at HSF to check for tieback between the two facilities.

5.3 EMPIRICAL COMPARISONS

The test data and comparisons of Phase 6 will provide an experimental basis for evaluating the system sensitivity to variations in the spray flow rate. These comparisons are identified below in Table 5-1.

Table 5-1
VARIATION IN SPRAY FLOW

<u>Test No.</u>	<u>Spray Flow (gpm)</u>	<u>System Pressure (psia)</u>
23	375	29.5
24	412	29.5
25	450	29.5
26	488	29.5
27	124	29.5
28	251	29.5

Section 6

SCHEDULE

A bar chart of the BWR/4&5-218 core spray distribution testing schedule is shown in Figure 6-1. The final test report will be issued during the second quarter of calendar year 1980.

REVISION A
1-24-80

Figure 6-1. Testing Schedule

Section 7

REFERENCES

1. "General Electric Company Analytical Model for Loss-of-Coolant Analysis in Accordance with 10CFR50 Appendix K Amendment No. 3 -- Effect of Steam Environment on BWR Core Spray Distribution," General Electric Company, April 1977 (NEDO-20566-3).
2. S. A. Sandoz, L. L. Myers, D. G. Schumacher, W. A. Sutherland, G. E. Dix, "Core Spray Design Methodology Confirmation Tests," General Electric Company, August 1979 (NEDO-24712).
3. Contract NRC-04-79-184, BWR Refill-Reflood Program, NRC, EPRI, GE-NED.
4. D. W. Danielson, "Lynn SSTF Bundle Flow Measurement System Description and Calibration," General Electric Company, August 1979 (NEDO-24706).

APPENDIX A

BACKGROUND DATA BWR/6-218 METHODOLOGY CONFIRMATION DESIGN

The following core spray distribution data are of the BWR/6-218 Methodology Confirmation Design. These data were used to support the General Electric Document NED0-24712, Core Spray Design Methodology Confirmation Tests. Test facility and test hardware descriptions are presented in NED0-24712.

CORE SPRAY DISTRIBUTION DATA
BWR/6-218 IN. METHODOLOGY CONFIRMATION DESIGN

A. SINGLE NOZZLE TESTS – HORIZONTAL SPRAY FACILITY

SPARGER	NOZZLE	FIGURE NUMBER OF DATA	TEST NUMBER OF REACTOR NOZZLE IN STEAM	TEST NUMBER OF SIMULATOR NOZZLE IN AIR
UPPER	S2935M	A-1	7901-4	7901-20
	1-in. OE STREET	A-2	N/A	7901-21
	1-in. OE STREET WITH NIPPLE	A-3	7901-13	7901-12
LOWER	S2935M	A-4	7901-8	7901-19
	1-in. OE STREET	A-5	7901-6	7901-22
	0.75-in. OE	A-6	7901-2	7901-1

B. 30-deg REACTOR NOZZLES IN AIR

SPARGER	FIGURE NUMBER OF DATA	VALLECITOS SPRAY FACILITY TEST NUMBER	30-deg SECTOR STEAM TEST FACILITY TEST NUMBER
UPPER	A-7	2-007C	T7X
LOWER	A-8	2-008C	T8X
DOUBLE	N/A	N/A	N/A

C. 30-deg SIMULATOR NOZZLES IN AIR (VALLECITOS SPRAY FACILITY –
30-deg SECTOR STEAM TEST FACILITY TIEBACK)

SPARGER	FIGURE NUMBER OF DATA	VALLECITOS SPRAY FACILITY TEST NUMBER	30-deg SECTOR STEAM TEST FACILITY TEST NUMBER
UPPER	A-9	3-001B	SS-1
LOWER	A-10	3-008A	SS-2
DOUBLE	A-11	3-005A	SS-3

D. 30-deg REACTOR NOZZLES IN STEAM

SPARGER	FIGURE NUMBER OF DATA	VALLECITOS SPRAY FACILITY TEST NUMBER	30-deg SECTOR STEAM TEST FACILITY TEST NUMBER
UPPER	A-12	N/A	CS-3.2
LOWER	A-12	N/A	CS-3.1
DOUBLE	A-13	N/A	1-3A

BWR/6 – 218 CORE SPRAY DATA

TEST 7901-4
NOZZLE TYPE S2935M
SPARGER UPPER
ATMOSPHERE 29.5 psia STEAM
SPRAY FLOW (gpm) 61.8
SPRAY TEMPERATURE (°F) 145.8

TEST 7901-20
NOZZLE TYPE S2935 SIMULATOR
SPARGER UPPER
ATMOSPHERE AIR
SPRAY FLOW (gpm) 61.5
SPRAY TEMPERATURE (°F) 74.0

COLLECTOR FLOWS
ARE gpm/ft²

Figure A-1. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

Figure A-2. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 7901-13
NOZZLE TYPE 1-in. OE W/NIPPLE
SPARGER UPPER
ATMOSPHERE 29.5 psia STEAM
SPRAY FLOW (gpm) 51.4
SPRAY TEMPERATURE (°F) 145.7

TEST 7901-12
NOZZLE TYPE 1-in. OE W/NIPPLE
SPARGER UPPER SIMULATOR
ATMOSPHERE AIR
SPRAY FLOW (gpm) 51.0
SPRAY TEMPERATURE (°F) 71.6

COLLECTOR FLOWS
ARE gpm/ft²

Figure A-3. BWR/6-218 Core Spray Data

BWR/6 - 218 CORE SPRAY DATA

TEST 7901-8
 NOZZLE TYPE S2935M
 SPARGER LOWER
 ATMOSPHERE 29.5 psia STEAM
 SPRAY FLOW (gpm) 64.0
 SPRAY TEMPERATURE (°F) 145.9

TEST 7901-19
 NOZZLE TYPE S2935M SIMULATOR
 SPARGER LOWER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) 57.4
 SPRAY TEMPERATURE (°F) 73.5

COLLECTOR FLOWS
 ARE gpm/ft²

Figure A-4. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 7901-6
 NOZZLE TYPE 1-in. OE STREET
 SPARGER LOWER
 ATMOSPHERE 44.2 psia STEAM
 SPRAY FLOW (gpm) 72.9
 SPRAY TEMPERATURE (°F) 145.9

TEST 7901-22
 NOZZLE TYPE 1-in. OE STREET SIMULATOR
 SPARGER LOWER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) 70.6
 SPRAY TEMPERATURE (°F) 73.7

COLLECTOR FLOWS
 ARE gpm/ft²

Figure A-5. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 7901-2
NOZZLE TYPE 0.75-in. OE
SPARGER LOWER
ATMOSPHERE 29.5 psia STEAM
SPRAY FLOW (gpm) 50.5
SPRAY TEMPERATURE (°F) 145.8

TEST 7901-1
NOZZLE TYPE 0.75-in. OE SIMULATOR
SPARGER LOWER
ATMOSPHERE AIR
SPRAY FLOW (gpm) 49.7
SPRAY TEMPERATURE (°F) 62.2

COLLECTOR FLOWS
ARE gpm/ft²

Figure A-6. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 2-007C
 NOZZLE TYPE 30-deg REACTOR
 SPARGER UPPER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) ≈ 520
 SPRAY TEMPERATURE (°F) ≈ 80

TEST T7X
 NOZZLE TYPE 30-deg REACTOR
 SPARGER UPPER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) 520.4
 SPRAY TEMPERATURE (°F) 95.5

COLLECTOR FLOWS
 ARE gpm/BUNDLE

Figure A-7. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 2-008C
 NOZZLE TYPE 30-deg REACTOR
 SPARGER LOWER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) ≈ 520
 SPRAY TEMPERATURE (°F) ≈ 80

TEST T8X
 NOZZLE TYPE 30-deg REACTOR
 SPARGER LOWER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) 520.2
 SPRAY TEMPERATURE (°F) 80.2

COLLECTOR FLOWS
 ARE gpm/BUNDLE

1.28	11.5	12.3	16.1	18.3	15.0	11.5	0.31
4.49	15.4	11.8	9.68	13.2	10.7	6.54	0.81
2.65	3.82	5.81	3.17	4.58	5.23	2.8	1.28
	6.63	5.1	2.68	3.61	5.05	6.73	
	4.64	2.71	2.63	2.89	3.66	3.69	
	3.76	2.19	2.73	2.51	2.87	1.65	
	0.46	2.51	3.2	2.37	2.24	0.72	
		6.44	3.57	2.95	4.55		
		2.63	3.61	2.54	3.09		
		4.45	3.53	2.03	2.21		
			6.7	2.92			
			9.77	4.02			
			10.1	3.27			
			13.0	14.4			
			*

5.10	12.0	16.2	12.4	16.8	15.1	10.1	0.85
5.73	12.5	15.8	7.61	7.14	11.9	7.83	2.43
	3.75	6.39	2.89	3.91	6.27	3.17	
	4.65	4.97	2.91	3.54	5.15	5.06	
	4.47	3.58	2.78	3.09	4.43	5.38	
		2.80	2.92	2.01	3.18		
		1.96	3.00	2.81	2.87		
		2.99	2.86	3.47	4.82		
		1.97	3.18	2.82	2.69		
			3.05	3.79			
			3.40	3.78			
			4.24	5.43			
			6.41	5.55			
			*				

Figure A-8. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 3-001B
NOZZLE TYPE 30-deg SIMULATOR
SPARGER UPPER
ATMOSPHERE AIR
SPRAY FLOW (gpm) ≈ 528
SPRAY TEMPERATURE (°F) ≈ 80

TEST SS-1
NOZZLE TYPE 30-deg SIMULATOR
SPARGER UPPER
ATMOSPHERE AIR
SPRAY FLOW (gpm) 528.4
SPRAY TEMPERATURE ($^{\circ}\text{F}$) ≈ 80

COLLECTOR FLOWS
ARE gpm/BUNDLE

1.78	8.48	7.86	10.6	15.6	6.39	4.57	2.06
2.58	13.4	10.9	15.5	14.1	9.95	8.09	1.95
1.26	4.61	6.55	7.41	6.35	6.59	6.31	0.85
	6.95	7.11	3.86	7.30	6.36	7.48	
	5.65	6.87	4.06	4.74	5.12	4.91	
	5.00	7.02	6.40	6.18	5.21	4.46	
	0.77	7.9	8.04	8.03	5.00	1.52	
		7.64	7.44	8.73	9.38		
		2.56	4.80	6.97	7.00		
		1.76	4.11	5.43	6.72		
		0.13	3.12	5.93	0.32		
			2.8	5.28			
			1.67	2.93			
			1.18	1.83			
			*	℄

3.78	6.56	10.2	11.7 13.0	6.23	4.24	2.78
2.87	7.86	10.6	14.3 12.6	9.23	8.93	2.68
	5.41	5.69	7.39 6.30	6.98	6.56	
	6.88	6.75	4.57 6.03	5.12	6.44	
	4.88	6.62	3.64 5.12	4.20	5.20	
		6.12	5.12 3.71	3.70		
		7.68	6.19 5.02	4.19		
		7.54	7.82 7.84	5.85		
		3.01	5.66 7.96	4.78		
			5.64 8.65			
			3.82 8.17			
			2.36 6.12			
			1.07 2.80			
			✱			

Figure A-9. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 3-008A
 NOZZLE TYPE 30-deg SIMULATOR
 SPARGER LOWER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) ~ 510
 SPRAY TEMPERATURE (°F) ~ 80

TEST SS-2
 NOZZLE TYPE 30-deg SIMULATOR
 SPARGER LOWER
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) 510.2
 SPRAY TEMPERATURE (°F) ~ 80

COLLECTOR FLOWS
 ARE gpm/BUNDLE

0.91	10.6	11.4	11.6	15.5	13.0	11.4	0.46
3.61	14.85	10.7	10.7	15.2	10.8	7.50	0.96
3.09	5.97	3.92	4.03	5.17	5.11	1.94	0.91
	8.52	5.84	3.33	4.67	5.9	6.93	
	5.23	3.91	2.30	3.58	3.57	5.68	
	5.68	4.11	2.24	3.28	3.10	2.53	
	0.39	3.59	2.68	3.15	2.43	1.29	
		4.53	3.17	3.65	4.53		
		2.12	3.61	4.04	3.12		
		2.47	5.01	4.90	2.96		
		0.20	8.31	6.4	0.13		
		0.46	8.15	9.79	0.33		
			6.77	9.00			
			5.83	7.85			
			*	⊕

5.22	11.6	13.9	12.8	16.7	15.8	8.67	0.50
5.70	8.74	10.3	12.0	5.67	10.4	6.78	0.95
	4.82	3.92	4.73	5.21	5.04	4.53	
	6.24	5.82	3.81	5.05	5.11	5.82	
	5.16	5.37	3.02	5.31	3.82	5.25	
		4.76	3.17	3.12	3.99		
		3.61	2.91	4.48	3.39		
		4.53	4.89	4.81	6.19		
		2.74	4.42	4.62	2.83		
			4.77	6.51			
			4.35	6.99			
			4.73	8.87			
			4.27	7.39			
			*	⊕			

Figure A-10. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 3-005A
 NOZZLE TYPE 30-deg SIMULATOR
 SPARGER DOUBLE
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) ≈ 520/≈ 510
 SPRAY TEMPERATURE (°F) ≈ 80/≈ 80

TEST SS-3
 NOZZLE TYPE 30-deg SIMULATOR
 SPARGER DOUBLE
 ATMOSPHERE AIR
 SPRAY FLOW (gpm) 522.2/508.6
 SPRAY TEMPERATURE (°F) ≈ 80/≈ 80

COLLECTOR FLOWS
 ARE gpm/BUNDLE

1.88	16.4	17.8	18.9	19.9	22.0	16.91	1.81
4.39	19.0	18.7	17.9	18.7	18.1	14.8	1.27
3.28	14.0	14.8	12.3	19.7	14.5	8.08	1.49
0.35	18.0	13.4	12.1	14.6	17.1	17.0	0.31
	15.4	10.6	9.49	10.8	9.30	12.1	
	7.04	11.6	9.12	9.76	7.57	7.57	
	0.08	10.3	11.9	11.1	6.16	2.16	
		9.31	12.4	13.0	10.3		
		3.68	13.7	13.6	7.13		
		3.09	13.7	12.4	8.18		
		0.31	12.8	16.8	0.29		
			10.7	12.6			
			6.6	8.91			
			4.18	5.39			
			*	⊕

7.61	16.4	20.0	20.0	20.0	20.0	12.4	1.16
6.50	17.6	20.0	20.0	17.6	19.2	11.7	1.20
	10.2	9.68	10.8	13.4	14.0	8.45	
	14.9	12.3	11.4	12.0	13.4	16.7	
	17.4	11.8	8.96	9.25	10.1	14.9	
		13.1	7.65	6.23	6.57		
		9.10	9.32	10.8	7.51		
		10.2	12.8	12.3	8.16		
		5.10	14.2	14.8	5.93		
			11.6	16.1			
			9.82	14.0			
			6.19	10.8			
			3.68	5.43			
			*	⊕			

Figure A-11. BWR/6-218 Core Spray Data

BWR/6 - 218 CORE SPRAY DATA

TEST CS-3.2
 NOZZLE TYPE 30-deg REACTOR
 SPARGER UPPER
 ATMOSPHERE 29.5 psia STEAM
 SPRAY FLOW (gpm) 525
 SPRAY TEMPERATURE (°F) 145

TEST CS-3.1
 NOZZLE TYPE 30-deg REACTOR
 SPARGER LOWER
 ATMOSPHERE 29.5 psia STEAM
 SPRAY FLOW (gpm) 525
 SPRAY TEMPERATURE (°F) 145

COLLECTOR FLOWS
 ARE gpm/BUNDLE

5.96	11.8	15.2	19.1	20.0	10.7	7.81	2.58
4.31	15.5	14.6	15.9	17.2	12.8	13.5	1.95
	6.95	5.15	2.85	5.34	6.41	4.87	
	10.3	6.50	2.26	6.00	5.90	7.24	
	9.59	8.43	2.54	5.59	4.88	7.86	
		4.91	3.32	4.51	3.89		
		2.88	2.76	4.04	4.35		
		3.47	2.92	3.20	4.28		
		2.93	2.87	2.66	2.35		
			4.82	4.05			
			7.80	4.65			
			10.9	6.21			
			9.56	4.11			
			*C

8.64	20.0	20.0	18.0	20.0	20.0	16.5	0.35
3.25	9.05	10.3	9.00	6.89	6.87	7.45	1.18
	7.70	6.38	2.74	4.99	6.26	3.96	
	7.21	8.67	2.65	4.65	49.1	5.71	
	7.66	9.22	3.60	5.63	4.12	6.58	
		7.85	5.77	4.72	5.18		
		6.31	6.71	5.34	4.56		
		7.71	7.47	5.83	5.14		
		5.16	7.22	4.06	2.45		
			6.16	3.65			
			4.42	2.21			
			3.54	1.58			
			2.05	0.81			
			*C				

Figure A-12. BWR/6-218 Core Spray Data

BWR/6 – 218 CORE SPRAY DATA

TEST 1-3A
NOZZLE TYPE 30-deg REACTOR
SPARGER DOUBLE
ATMOSPHERE 29.5 psia STEAM
SPRAY FLOW (gpm) 524.4/525.8
SPRAY TEMPERATURE (°F) 142.7/144.5

TEST N/A
NOZZLE TYPE _____
SPARGER _____
ATMOSPHERE _____
SPRAY FLOW (gpm) _____
SPRAY TEMPERATURE (°F) _____

COLLECTOR FLOWS
ARE gpm/BUNDLE

16.5	20.0	20.0	20.0	20.0	20.0	20.0	1.06
5.31	20.0	13.5	15.4	14.2	13.2	18.4	1.40
	9.58	18.6	8.56	16.8	17.3	5.14	
	20.0	20.0	13.7	17.2	16.4	20.0	
	15.7	14.6	10.0	8.57	12.3	20.0	
		6.65	9.87	3.93	6.36		
		8.85	13.0	6.38	5.57		
		15.6	19.2	10.4	5.75		
		8.21	13.1	9.35	3.36		
			8.60	7.10			
			3.44	2.84			
			1.06	0.98			
			0.42	0.47			
			*	℄			

A 10x10 grid with a vertical dashed line in the center. An 'x' is marked at the intersection of the dashed line and the 5th horizontal line from the bottom, with a 'c' next to it.

Figure A-13. BWR/6-218 Core Spray Data

APPENDIX B

TASK WORKSCOPE FOR BWR/4 CORE SPRAY PROGRAM (An excerpt from the BWR Refill-Reflood Program Workscope) Contract NRC-04-79-184

4.2 CORE SPRAY DISTRIBUTION

Objectives: To provide core spray distribution data from steam environment tests (including long term cooling conditions) for best estimate model qualification. Provide additional confirmation of the existing methodology (see Section 3.3.1) and identify any further model requirements.

Scope:

- 4.2.1 Prepare an Experimental Task Plan according to Section 5.0 that describes the planned experiments, core spray distribution analysis method, and model qualification acceptance criteria. The experiments will include the following:
 - a. Facility and instrumentation checkout
 - b. BWR/4 lower header 30° sector spray distribution tests in air
 - c. BWR/4 single nozzle spray distribution tests in steam
 - d. Development of air simulators for BWR/4 nozzles
 - e. Dual nozzle (adjacent nozzles from BWR/4 upper and lower headers) test in steam environment
 - f. Spray distribution tests in air using the BWR/4 lower header with simulator nozzles in the 30° Sector Facility
 - g. Spray distribution tests in a steam environment using the BWR/4 nozzles and lower header in the 30° Sector Facility
- 4.2.2 Complete the design, fabrication and installation of BWR/4 type lower header and nozzles into the 30° Sector Facility (Section 3.1.1). The

- 4.2.2 Complete the design, fabrication and installation of BWR/4 type lower header and nozzles into the 30° Sector Facility (Section 3.1.1). The facility will also include capability to test a dual nozzle combination (adjacent nozzles from upper and lower headers) typical of BWR/4 nozzle configurations. Document the facility design for these tests per Section 5.0.
- 4.2.3 Perform pretest predictions of the spray distribution using the Core Spray Distribution Methodology (Section 3.3).
- 4.2.4 Perform the test system calibration, instrumentation calibration, facility checkout and shakedown tests.
- 4.2.5 Perform the tests per the approved Experimental Task Plan or as modified by the PMG.
- 4.2.6 Reduce the data to obtain spray flows, header system pressure, upper plenum pressure, and distribution of flow to individual bundles; for steam environment tests additionally obtain steam flow rates and temperatures.
- 4.2.7 Verify the test data as specified in the Experimental Task Plan.
- 4.2.8 Process and store measured and derived data on computer tape.
- 4.2.9 Analyze and evaluate the experimental data to assess spray distribution in steam and air environments.
- 4.2.10 Provide post-test comparisons of predictions with data, evaluate the adequacy of the core spray distribution prediction methodology, and determine any prediction deficiencies requiring further model development. (This modification is not included in current scope.)
- 4.2.11 Prepare a task topical report per Section 5.0.

Below are five index cards that allow for filing according to the four cross-references in addition to the title of the report. A brief abstract describing the major subject area covered in the report is included on each card. For information regarding index card subscriptions to past and future EPRI publications contact the Research Reports Center, P.O. Box 50490, Palo Alto, California 94303. Telephone (415) 965-4081.

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Distribution Experimental Task Plan**

Contractor: General Electric Company

The core spray distribution experimental task plan of the BWR Refill-Reflood Program is summarized. A description of the experimental facilities, a specification of the test matrix, test results obtained for the BWR-6 (218) geometry, and a test schedule are presented.

EPRI Project Manager: M. Merilo

Cross-References:

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