Multiloop Integral System Test (MIST): Final Report

Inter-Group Comparisons

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ABSTRACT

The multiloop integral system test (MIST) was part of a multiphase program started in 1983 to address small-break loss-of-coolant accidents (SBLOCAs) specific to Babcock & Wilcox-designed plants. MIST was sponsored by the U.S. Nuclear Regulatory Commission, the Babcock & Wilcox Owners Group, the Electric Power Research Institute, and Babcock & Wilcox. The unique features of the Babcock & Wilcox design, specifically the hot leg U-bends and steam generators, prevented the use of existing integral system data or existing integral system facilities to address the thermal-hydraulic SBLOCA questions. MIST and two other supporting facilities were specifically designed and constructed for this program, and an existing facility -- the once-through integral system (OTIS) -- was also used. Data from MIST and the other facilities will be used to benchmark the adequacy of system codes, such as RELAP5 and TRAC, for predicting abnormal plant transients.

The individual tests are described in detail in Volumes 2 through 8 and Volume 11, and are summarized in Volume 1. Inter-group comparisons are addressed herein. These comparisons are grouped as follows: mapping versus SBLOCA transients, SBLOCA, pump effects, and the effects of noncondensable gases. Appendix A provides an index and description of the microfiched plots for each test, which are enclosed with the corresponding Volumes 2 through 8. The discharge orifice characteristics are tabulated in Appendix B.

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EXECUTIVE SUMMARY

Introduction

The multiloop integral system test (MIST) was a scaled 2-by-4 (2 hot legs and 4 cold legs) physical model of a Babcock & Wilcox (B&W), lowered-loop, nuclear steam supply system (NSSS). MIST was designed to operate at typical plant pressures and temperatures. Experimental data obtained from this facility during post-small-break loss-of-coolant accident (SBLOCA) testing are used for computer code benchmarking. The MIST interactions are of intrinsic interest because they may provide insight into expected plant behavior. MIST was necessarily atypical of a plant in certain important respects, however. The MIST interactions therefore are not to be applied directly to a plant.

MIST consisted of two 19-tube, once-through steam generators, a reactor, a pressurizer, 2 hot legs, and 4 cold legs with scaled reactor coolant pumps. Other loop components included a closed secondary system, 4 simulated reactor vessel vent valves (RVVVs), a pressurizer power-operated relief valve (PORV), hot leg and reactor vessel upper head vents, high-pressure injection (HPI), core flood system, and critical flow orifices for scaled leak simulation. Guard heaters, used in conjunction with passive insulation to reduce model heat loss, were used on all primary system components as well as the steam generator secondaries. MIST is illustrated in Figure 1.

Boundary Systems

The MIST boundary systems were sized to power-scale the plant boundary conditions. HPI and auxiliary feedwater (AFW) characteristics were based on composite plant characteristics. Scaled model vents were included in both hot legs and in the reactor vessel upper head. Leaks were located in the cold leg suction and discharge piping, and the upper and lower elevations of steam generator B (for tube rupture simulation). The desired vent and leak flows were obtained using power-scaled restrictors.

Heat Losses and Guard Heaters

MIST was designed to minimize heat losses from the reactor coolant system. Fin effects (instrument penetrations through the insulation) were minimized by using 1/4-inch penetrations for most of the instrumentation. Heat losses due to conduction through component supports were minimized by designing the supports to reduce the cross-sectional area and placing insulating blocks between load-bearing surfaces. The reactor coolant system piping and vessels were covered with passive insulation, active insulation (or guard heaters), and an outer-sealed jacket (to prevent chimney effects). The guard heaters were divided into 42 zones, each controlled by a zonal temperature difference and pipe metal temperature.

Instrumentation

MIST had approximately 850 instruments. These instruments were interfaced to a computer-controlled, high-speed data acquisition system. MIST instrumentation consisted of measurements of temperature, pressure, and differential pressure. Fluid level and phase indications were provided by optical viewports, conductivity probes, differential pressures, and gamma densitometers. Mass flow rates at the system boundaries were measured using Coriolis flowmeters and weigh scales. Loop mass flow rates were measured using venturis or turbines.

Transient Test Program

The MIST transient tests were defined to generate integral system data for code benchmarking. The transient test series was divided into the following seven groups:

- Mapping
- Boundary systems
- Leak and HPI configurations
- HPI-PORV cooling (feed and bleed)
- Steam generator tube rupture
- Noncondensable gas (NCG) and venting
- Reactor coolant pump (RCP) operation

The mapping tests were intended to examine the initial post-SBLOCA transient interactions. In these tests, the primary system inventory was carefully controlled and slowly varied to allow the examination of the normally rapid and overlapping post-SBLOCA events. The mapping tests are described in Volume 2 of the MIST Final Report, and the six groups of transient tests are described in Volumes 3 through 8. These tests are summarized in Volume 1. The boundary system controls, such as guard heating and steam generator secondary level controls, were varied in Test Group 31. The leak size, location, and isolation status, as well as HPI capacity, were varied singly in Test Group 32. Test Group 33 addressed HPI-PORV cooling. Tube rupture transients were tested in Group 34. Test Group 35 involved venting and noncondensable gases. The Group 36 tests and Core Uncovery Test 3801AA involved pump operation. Inter-test comparisons are presented herein.

Inter-group comparisons have been made using the following four groupings:

- Mapping Versus SBLOCA
- SBLOCA
- Pump Effects
- Effects of Noncondensibles

1. Mapping Versus SBLOCA

The mapping test transients and interactions are compared to those of the SBLOCA tests. The mapping and SBLOCA tests are first separately reviewed. Their key events are identified, with special emphasis on the conditions surrounding interruption. Specific inter-test comparisons completed section 2. These discussions of mapping test interactions versus those of SBLOCA transients include the following conditions:

- Reduced-capacity HPI
- RVVVs closed
- Mapping without HPI

Traces of primary system pressure versus primary system total fluid mass are used extensively for these comparisons and throughout this volume. These

traces, labelled to describe key events and timing, provide a comprehensive summary of major test trends on a single plot.

Flow Interruption

The flow interruption mechanisms differed between the SBLOCA and mapping tests. HPI was throttled in the mapping tests, to gradually reduce the primary system total fluid inventory, while holding core power constant. In the SBLOCA transients, on the other hand, core power was reduced to simulate post-trip decay and scaled plant HPI head-flow characteristics were used, obtaining increased HPI flow rates as the primary system was depressurized. As a result of these basic differences between the two types of tests, HPI was generally sufficient to condense all of the core-generated steam in the SBLOCA transients, but insufficient in the mapping tests. Loop flow persisted in the mapping tests until all the core-region fluid saturated and the subsequent increased core void production uncovered the hot leg nozzles. The primary system then repressurized quite rapidly until boiler-condenser mode (BCM) depressurizations or, in several mapping tests, until the PORV lifted. In the SBLOCA transients, on the other hand, the primary system depressurized upon the interruption of loop flow. Interruption occurred when the downcomer level first descended to the elevation of the cold leg nozzles, permitting the condensation of core-generated vapor by HPI.

2. SBLOCA Reproducibility

The reproducibility of several near-nominal SBLOCA tests conducted before the enlargement of the leak flow area, and also conducted after this enlargement, was examined. The pressure-versus-mass trends of these tests were remarkably similar. In all of these tests, the steam generator primary level of the interrupted loop descended toward the elevation of the steam generator upper tubesheets as the initial refill of the steam generator secondaries was being completed. In a few of these tests having sufficient inter-loop asymmetries to support such a level imbalance, notably Nominal SBLOCA Test 3109, a steam generator primary level entered the steam generator while feed was still active, causing an early AFW-BCM depressurization. The pressure-versus-mass traces of these tests thus differed from those of the tests without the early BCM, but these inter-test differences gradually diminished as the test progressed.

The remainder of the SBLOCA discussion pertained to the following inter-test comparisons:

- Abnormal transient operating guidelines (ATOG)
- Venting
- PORV
- Pump operation

ATOG

Of two tests controlled by operators versed in plant procedures, the PORV was opened in Test 3106 whereas the pumps were bumped in Test 3601. The resulting trends of the two tests were surprisingly similar, considering their dissimilar control methods. Refill and post-refill cooldown were achieved relatively early in both of these operator-controlled tests. Venting also promoted refill and suppressed the multiple pre-refill hot leg U-bend spillovers in a comparison of venting Test 3501 with SBLOCA Nominal Repeat Test 3110.

PORV

The PORV comparison of section 3 involved the Nominal Feed-and-Bleed Test 3301 and SBLOCA Test 3204 simulating a PORV break. The major inter-test difference of boundary conditions involved the availability of steam generators in SBLOCA Test 3204. Also, the PORV was opened to initiate Test 3204 whereas the PORV first actuated on overpressure, due to the interruption of feed, in HPI-PORV Cooling Test 3301. Whereas the primary system generally depressurized and refilled in SBLOCA Test 3204, the primary voided extensively in Test 3301, reflecting the aforementioned inter-test differences in boundary conditions.

Pump Operation

Operation of the model reactor coolant pumps had a profound effect on the SBLOCA transient interactions. With the pumps operating throughout a SBLOCA transient, the primary system quickly depressurized and refilled. The key interactions were twofold: (1) the forced convection of saturated liquid to the break site, thereby minimizing the break mass flow rate while sustaining

the break volumetric flow rate as well as the rate of energy removal by the break discharge, and (2) the continued primary-to-secondary heat transfer sustained by forced flow. In SBLOCA Test 3602 with the pumps kept in operation, the loop refilled in just more than 1 hour, whereas in the comparison Nominal Repeat SBLOCA Test 3110, even single-loop refill was delayed until 500 minutes and then was preceded by multiple, intermittent hot leg U-bend spillovers.

3. Pump Effects

Pump Performance in Two-Phase Flow

The performance of the model reactor coolant pumps in two-phase flow was compared among three dissimilar tests, namely Mapping Test 3008, SBLOCA Test 3602, and Core Uncovery Test 3801. The test spans for comparison were chosen to cover periods of increasing void fraction with the pumps not yet degraded. The pumps generally performed similarly in two-phase flow, their performance becoming more variable as pump suction void fraction exceeded approximately 12%. Similar responses of normalized head, homologous flow, and homologous head were observed. However, pump input electrical power decreased somewhat with increasing void fraction in Mapping Test 3008 and Core Uncovery Test 3801, but remained approximately constant up to 12% void fraction in SBLOCA Test 3602.

HPI-PORV Cooling

The model reactor coolant pumps were operated initially, and tripped on the loss of subcooling margin (SCM), in HPI-PORV Cooling Test 3604 and in Tube Rupture Test 3605. These two tests otherwise repeated their nominal counterparts, Nominal HPI-PORV Cooling Test 3301 and Nominal Tube Rupture Test 3401. Initial pump operation had a pronounced impact on the HPI-PORV cooling transient. The primary loop fluid remained subcooled in Test 3604 with pumps, whereas the loop fluid saturated and voiding during the initial depressurization in Test 3301 without forced flow. The additional loop fluid subcooling obtained initially with forced flow allowed the primary system pressure to stabilize as liquid reached the PORV site. The primary system voided extensively only as HPI was throttled to control the SCM.

Tube Rupture

Pump operation had only a transitory effect on the tube rupture transient. The pressure-versus-time trace of Test 3605 with pumps diverged from that of Nominal Tube Rupture Test 3401 as the primary system initially depressurized further and more rapidly in Test 3605, but these inter-test differences were depleted within 10 minutes. The trends of Tests 3605 and 3401 then became virtually identical.

4. Noncondensibles

SBLOCA tests with and without NCG were compared for a cold leg discharge break location and for a cold leg suction break. The boundary conditions of the discharge break tests (3505 and 3110) were otherwise similar, but the suction break tests with NCG (Tests 3507 and 3508) both used continuous hot leg high-point venting, unlike the counterpart test without NCG (Test 3203). Noncondensibles diminished the BCM depressurizations and, by fostering cold leg voiding, generally diminished the primary system fluid inventories.

Figure 1. Reactor Coolant System -- Multiloop Integral System Test (MIST)

1. INTRODUCTION

The multi-loop integral system test (MIST) was a scaled 2-by-4 (2 hot legs and 4 cold legs) physical model of a Babcock & Wilcox (B&W), lowered-loop, nuclear steam supply system (NSSS). MIST was sponsored by the U.S. Nuclear Regulatory Commission, the B&W Owners Group, the Electric Power Research Institute, and B&W. The MIST results are presented in the following eleven volumes:

1. Summary
2. Mapping Tests, Group 30
3. SBLOCA Tests With Varied Boundary Conditions, Group 31
4. SBLOCA Tests With Altered Leak and HPI Configurations, Group 32
5. HPI-PORV Cooling Tests, Group 33
6. Steam Generator Tube Rupture Tests, Group 34
7. Noncondensable Gas and Venting Tests, Group 35
8. Pump Operation Tests, Group 36, and Core Uncovery Test 3801
9. Inter-Group Comparisons
10. RELAP5/MOD2 Calculations Versus MIST Observations
11. Phase 4 Tests

A set of microfiched plots accompanies each of Volumes 2 through 8, and provides a comprehensive description of their respective tests. These plots are indexed and described in Appendix A herein. The discharge orifice sizes are provided in Appendix B.

Inter-group comparisons are provided herein. These comparisons are arranged, in sections 2 through 5, using the following four groupings:

- Mapping Versus SBLOCA Interactions

- SBLOCA
- Pump Effects
- Effects of Noncondensibles

Detailed discussions of the comparison tests have been provided in the preceding volumes, therefore the tests are summarized herein only to the extent necessary to explain the comparisons.

The mapping tests and nominal SBLOCA tests are reviewed in section 2. Their major interactions are identified and compared using annotated traces of primary system pressure versus primary system total fluid mass. The inter-group differences of interruption interactions are addressed at length.

The SBLOCA comparisons of section 3 include the following:

Reproducibility

ATOG

Venting

PORV

Pump Operation

The general effects of pump operation are discussed in section 4. Pump performance in two-phase flow is compared among three dissimilar tests. Also, feed-and-bleed tests and tube rupture tests with and without pumps are compared. The effects of noncondensibles are explored in section 5, and these inter-group comparisons are summarized in the final section.

An index of comparison types and tests compared is provided in Table 1.1. Of the 49 tests available for comparison, 33 are compared.

Table 1.1. Inter-Group Comparisons

Entries indicate the section wherein the corresponding tests are compared. Section titles are listed at the end of the table.

Test	Section:	2.1	2.2	2.3	2.4.1	2.4.2	2.4.3	3.1.1	3.1.2	3.2	3.3	3.4	3.5	4.1	4.2	4.3	5.1	5.2
<u>Group 30 - Mapping</u>																		
T300001: Test 0, Increased Leak Size - 10-cm ²		X		X	X													
T3001BB: Test 1, Pressurizer Isolated		X																
T3003AA: Test 3, Nominal - 5-cm ²		X																
T3004CC: Test 4, HPI Inactive		X					X											
T300504: Test 5, RVVVs Closed		X				X												
T300605: Test 6, Unequal Steam Generator Levels		X																
T3007CC: Test 7, Lowered Steam Generator Levels		X																
T300806: Test 8, Pumps Operating		X													X			
T3009AA: Test 9, Cold Leg Discharge Leak		X																
<u>Group 31 - SBLOCA: Varied Boundary Conditions</u>																		
T310101: Test 1, RVVVs Closed						X												
T310201: Test 2, RVVVs Open								X										
T310302: Test 3, Guard Heaters Deenergized								X										
T310403: Test 4, Band Steam Generator Level Control																		
T3105AA: Test 5, Throttled AFW and Asymmetric Cooldown																		
T310699: Test 6, ATOG										X								
T310702: Test 7, No Augmentation of Core Power								X										
T3109AA: Test 9, Nominal								X										
T311000: Test 10, Nominal Repeat			X	X					X		X		X				X	
T3111AA: Test 11, Maximum Feed Wetting																		
<u>Group 32 - SBLOCA: Altered Leak and HPI Configurations</u>																		
T320101: Test 1, Reduced Leak Size - 5-cm ²																		
T320201: Test 2, Increased Leak Size - 50-cm ²																		
T320302: Test 3, Cold Leg Suction Leak									X									X
T3204AA: Test 4, PORV Break												X						
T320503: Test 5, Leak Isolated									X									
T320604: Test 6, Reduced-Capacity HPI					X													

Table 1.1. Inter-Group Comparisons (Cont'd)

Test	Section:	2.1	2.2	2.3	2.4.1	2.4.2	2.4.3	3.1.1	3.1.2	3.2	3.3	3.4	3.5	4.1	4.2	4.3	5.1	5.2
<u>Group 33 - HPI-PORV Cooling</u>																		
T33018B: Test 1, Nominal												X				X		
T330201: Test 2, Reduced-Capacity HPI																		
T330302: Test 3, Delayed HPI																		
T330499: Test 4, Surge Line Uncovery																		
<u>Group 34 - Steam Generator Tube Rupture</u>																		
T340100: Tube Rupture Test 1, Nominal																	X	
T340213: Test 2, One-Tube Rupture and PORV Depressurization																		
T340302: Test 3, Low-Elevation Tube Rupture																		
T3404AA: Tube Rupture Test 4, Steam Generator Isolated																		
T340504: Tube Rupture Test 5, Steam Line Break																		
T3406AA: Test 6, Repeat Low-Elevation Tube Rupture																		
T340799: Test 7, One-Tube Rupture and Pres- surizer Venting																		
<u>Group 35 - Noncondensibles and Venting</u>																		
T350101: Test 1, Venting Without Noncondensibles												X						
T3502CC: Test 2, Noncondensable Gas Threshold							X											
T350312: Test 3, Hot Leg Venting With Nonconden- sibles																		
T350502: Test 5, Noncondensibles Without Venting																	X	
T350700: Test 7, Helium and Suction Leak																		X
T350800: Test 8, Nitrogen and Suction Leak																		X
<u>Group 36 - Pump Operation and Core Uncovery</u>																		
T3600AA: Test 0, Nominal SBLOCA With Pumps Configuration						X				X								
T3601AA: Test 1, ATOG SBLOCA With Pumps Available										X								
T3602DD: Test 2, SBLOCA With Pumps Operating													X		X			

Table 1.1. Inter-Group Comparisons (Cont'd)

Test	Section:	2.1	2.2	2.3	2.4.1	2.4.2	2.4.3	3.1.1	3.1.2	3.2	3.3	3.4	3.5	4.1	4.2	4.3	5.1	5.2
T360301: Test 3, Worst Stop SBLOCA																		
T360499: Test 4, Feed and Bleed - Pumps Stopped on Loss of SCM															X			
T360514: Test 5, Tube Rupture - Pumps Stopped on Loss of SCM																X		
T3801AA: Core Uncovery														X				

Report Sections

2. Mapping Vs SBLOCA	3.2. ATOG
2.1. Review of Mapping	3.3. Venting
2.2. SBLOCA Transients	3.4. PORV
2.3. Key Events	3.5. Pump Operation
2.4. Specific Comparisons	4. Pump Effects
2.4.1. Reduced HPI	4.1. Performance
2.4.2. RVVVs Closed	4.2. Feed and Bleed
2.4.3. Without HPI	4.3. Tube Rupture
3. SBLOCA	5. Effects of ncg
3.1. Reproducibility	5.1. Discharge Break
3.1.1. Before Area Change	5.2. Suction Break
3.1.2. After Area Change	

2. MAPPING TEST VERSUS SBLOCA TRANSIENTS

Mapping tests were performed to provide insight into the SBLOCA interactions. Whereas the initial transient events occurred rapidly and sometimes simultaneously, the mapping tests were performed to obtain deliberate transitions among interactions. The primary system inventory was reduced gradually by throttling the HPI flow rate to be just less than the leak mass flow rate.

The mapping test key events are indicated on traces of primary system pressure versus primary system total fluid mass. Three key events are identified as follows:

- HPI condensation of core-generated steam
- Interruption of loop flow
- AFW-BCM

The mass deficits at which these events occurred were similar among the applicable mapping tests. HPI condensation was insufficient to handle all of the core steam generation; thus, the core-region fluid gradually heated, culminating in saturation throughout the core. As saturation occurred, loop flow interrupted and the primary system repressurized. This repressurization was halted by the AFW-BCM, but intermittent repressurizations sometimes lifted the PORV.

The SBLOCA transients are also conveniently displayed using traces of primary system pressure versus mass. The nominal SBLOCA transients were similar, but quite unlike those of the mapping tests. HPI condensation was generally more than sufficient to offset the core steam generation in the SBLOCA transients. As HPI condensation began, the hot leg riser fluid phases separated, the U-bends voided, and loop flow interrupted, but the primary system gradually depressurized through HPI-leak cooling and HPI condensation of core-generated steam.

The mapping tests and nominal SBLOCA tests are addressed herein for inter-type comparisons. The details of the mapping tests are given in Volume 2, those of the nominal SBLOCA tests are given in Volumes 3 (for Test 3109AA), 4 (Test 311000), and 8 (Test 3600AA). The mapping tests are reviewed in section 2.1, the nominal SBLOCA transients are briefly addressed in section 2.2. Key interactions and events, particularly interruption, are discussed in section 2.3. Section 2.4 provides comparisons of specific, somewhat similar SBLOCA and mapping test transients. These observations are summarized in the final section.

2.1. Review of the Mapping Tests

The mapping tests, Group 30, have been described in detail in Volume 2, and are briefly discussed herein for inter-group comparison. The major interactions of each mapping test are indicated on axes of primary system pressure versus primary system total fluid mass (Figures 2.1.1 through 2.1.9).

Primary system total fluid mass is readily converted to mass deficit using the initial total fluid mass. The mapping tests are listed in Table 2.1, and the mass deficits of their major interactions are tabulated in Table 2.2. The plots are each made using calculated mass with the discharge mass flow rates obtained from weigh tank measurements. (This source of total fluid mass, rather than the indicated value, was selected because it was generally quite stable and because it was available for each test, whereas the indicated mass was unavailable for Test 8 in which the model coolant pumps were kept in operation.) The Table 2.1 entries were obtained by visual inspection of the three traces of total fluid mass -- indicated, calculated using measured flow rates, and calculated using weigh tank measurements.

The interactions of the nominal mapping test are discussed below, those of the off-nominal mapping tests are discussed briefly in subsequent paragraphs. Volume 2 provides the details of these mapping tests, including test specifications, conduct, and observations.

2.1.1. Nominal Mapping Test 3

Draining from the lower reactor vessel piping was initiated at 12 minutes with a primary system total fluid mass of approximately 965 lbm (Figure 2.1.3). The pressurizer drained shortly after the initiation of the mass

reduction, at approximately 950 lbm, and the primary system saturated (Figure 2.1.10) after the removal of another 15 lbm of primary system fluid (Figure 2.1.11). During this initial draining phase, the loop flow rates remained stable (Figure 2.1.12), the hot leg and core region levels remained full (Figures 2.1.13 and 2.1.14), and the primary system gradually depressurized toward 1300 psia (Figure 2.1.15).

The temperature of the fluid in the reactor vessel upper head determined the primary system pressure at which this fluid would saturate and begin to flash. The test had begun with the reactor vessel upper-head fluid temperatures approximately 6 degrees warmer than the core exit and hot leg fluid temperatures. These warmer upper head fluid temperatures lingered from the test that preceded Test 3. The temperature excess had largely dissipated by the time the loop fluid saturated, therefore it had little net impact on Test 3. The primary system fluid temperatures approached saturation with a primary system total fluid mass of 940 lbm, 2.6% less than the initial fluid mass. The reactor vessel level began to decline (Figure 2.1.14) but the hot legs remained full (Figure 2.1.13).

The primary system total fluid mass was gradually reduced from 940 to 910 lbm between 50 and 80 minutes (Figure 2.1.11). The HPI mass flow rate was reduced slightly, to 280 lbm/h (Figure 2.1.16), to effect this mass reduction. The primary system gradually repressurized during this period (Figure 2.1.15), apparently due to core void production and the slightly reduced heat removal capacity of the HPI and leak flow streams. The RVVVs remained open (Figure 2.1.17) and the downcomer remained liquid full as the reactor vessel level declined toward the elevation of the RVVVs (Figure 2.1.14).

The reactor vessel level descended to the elevation of the RVVVs at 80 minutes (Figure 2.1.14) and a primary system total fluid mass of 910 lbm (Figure 2.1.11), approximately 5.7% less than the initial total fluid mass. The RVVVs began to discharge vapor to the downcomer, and thus the downcomer level began to descend (Figure 2.1.14). The resulting reactor vessel-to-downcomer level imbalance counteracted the usual natural circulation driving head caused by the core fluid density reduction. Thus, both the loop flow rates (Figure 2.1.12) and the differential pressures across the RVVVs (Figure 2.1.18) began to decrease. The hot leg riser levels remained full but the

levels beyond the U-bends declined a few feet (Figure 2.1.13), offsetting the reduced flow losses in the outer portions of the loops (hot leg nozzle to cold leg nozzle).

The RVVVs had remained open throughout the gradual reduction of primary system total fluid mass. As the downcomer level decreased below that of the reactor vessel sufficiently to deplete the RVVV differential pressures, the RVVVs closed (Figure 2.1.17), and generally remained closed as the downcomer and reactor vessel levels continued to decline. The interruption of the RVVV discharge caused the downcomer fluid to cool (Figure 2.1.19). The (lower reactor vessel-downcomer) leak flow rate increased (Figure 2.1.16) due to both the gradual primary system pressurization and the cooling of the leak site fluid. The HPI flow rate was periodically increased to moderate the rate of primary system mass loss.

The downcomer level reached the elevation of the cold leg nozzles at 115 minutes (Figure 2.1.14) and a primary fluid mass of 870 lbm (Figure 2.1.11), approximately 10% less than the initial mass. The RVVVs opened (Figure 2.1.17), the primary system pressure stabilized (Figure 2.1.15), and the downcomer fluid began to warm (Figure 2.1.19). The hot leg riser levels briefly receded from the U-bend spillover elevations (Figure 2.1.13), causing a momentary reduction of the loop and downcomer flow rates (Figures 2.1.12 and 2.1.20). After the hot leg risers had refilled, the downcomer flow rate stabilized near 3% of scaled full flow. The average cold leg flow rate was 2% of scaled full flow, but cold leg B1 remained stagnated. These conditions persisted through 177 minutes and 830 lbm.

The downcomer fluid continued to warm following RVVV actuation (Figure 2.1.19), attesting to the excess energy of core vapor generation over the HPI condensing capacity. As the primary system total fluid mass approached 830 lbm (Figure 2.1.11), 14% less than initially, the lower downcomer fluid saturated. The accompanying increased core voiding affected system conditions generally. The hot leg riser and stub levels began to fluctuate and to recede from the U-bend spillover elevation (Figure 2.1.13). The hot leg U-bends voided (Figure 2.1.21). The loop and downcomer flow rates virtually stagnated (Figures 2.1.12 and 2.1.20). The primary system pressurized quite

rapidly (Figure 2.1.15) due to the interruption of primary-to-secondary heat transfer. The RVVVs remained open (Figure 2.1.17).

The repressurization greatly amplified the rate of reduction of primary system fluid mass (Figure 2.1.11). Notwithstanding this enhanced rate of mass loss, the repressurization was arrested after the removal of an additional 1% of the initial fluid mass. The steam generator primary levels descended into the steam generators (Figure 2.1.13), causing the secondary systems to reactivate and obtaining AFW-BCM -- the condensation of primary vapor near the point of introduction of AFW.

Beyond 183 minutes and a primary system total fluid mass less than 820 lbm, the primary system pressure fluctuated (Figure 2.1.15) due to intermittent AFW-BCMs. The primary system pressure variations became of increasing frequency and decreasing magnitude as the primary system total fluid mass was further reduced, culminating in a pool BCM depressurization at 243 minutes and 700 lbm, nearly 28% less than the initial total fluid mass.

2.1.2. Off-Nominal Mapping Tests

Increased Leak Size, Test 0

An increased leak size, 10 versus 5-cm² (scaled) was used in Test 0 (300001). Core power was maintained at the nominal setting, 3.9% of scaled full power. HPI-leak cooling was thus enhanced in Test 0 (Figure 2.1.1). The major interactions of Test 0 resembled those of Nominal Test 3, but the primary system pressure was generally suppressed (Figure 2.1.22).

Pressurizer Isolated, Test 1

The pressurizer was isolated in Mapping Test 1 (Test 3001BB, Figure 2.1.2). The earlier interactions of Test 1 were similar to those of the Nominal Mapping Test through flow interruption and the first BCM depressurization (Figure 2.1.23). However, the leak partially plugged in Test 3 at 200 minutes and 735 lbm primary system inventory (Figure 2.1.2). The primary system inventory then began to increase due to the continuing HPI flow. The primary system repressurization at 210 minutes and 755 lbm was halted by spillover flow in loop B. Shortly thereafter the leak path was reopened. The system conditions quickly realigned towards those of the earlier mass-reduction phase. For example, flow interrupted and the primary system

U

pressurized at 260 minutes and 755 lbm system inventory, much as it had earlier at 186 minutes and 770 lbm inventory. Test 1 thus provided insight regarding the reachievement of conditions and interactions.

No HPI-Leak Cooling, Test 4

HPI was not used in Mapping Test 4 (Test 3004CC, Figure 2.1.4). Also, core power was reduced from the nominal 3.9% of scaled full power to 1.4%, and a smaller-than-nominal leak size was used in Mapping Test 4. The early global interactions of Test 4 were like those of Nominal Test 3 (Figure 2.1.24), indicating that the reduced core power of Test 4 approximately balanced the power not offset through HPI-leak cooling as in the Nominal Test. Upon interruption of loop flow, the rate of primary system repressurization of Test 4 was less than that of Test 3, reflecting the core power reduction of Test 4.

RVVVs Closed, Test 5

The RVVVs were kept closed in Mapping Test 5 (Test 300504, Figure 2.1.5). Although the interactions of Test 5 were somewhat similar to those of Nominal Test 3 (Figure 2.1.25), the events of Test 5 occurred at a higher primary system total fluid inventory than in the Nominal Test, and the repressurizations were suppressed. Almost continuous AFW-BCM occurred in Test 5, whereas in Nominal Test 3, the intermittent BCM depressurizations were followed by periods of significant primary system repressurization. Primary system pressure was thus limited to approximately 1750 psia in Test 5 versus pressure peaks as high as 2200 psia in the Nominal Mapping Test. Mapping Test 5 is discussed in more detail in section 2.4.2.

Unequal Steam Generator Levels, Test 6

Unequal steam generator secondary levels, 10 ft in steam generator A and the nominal 31.6 ft in B, were employed in Mapping Test 6 (Test 300605, Figure 2.1.6). The major system interactions were similar to those usually encountered until the interruption of loop flow at 130 minutes and a mass deficit of approximately 16% (Figure 2.1.26). Steam generator A having the lowered secondary level remained quite inactive following flow interruption. Although the primary system repressurization was intermittently halted by steam generator B AFW-BCMs, the general repressurization continued to the

PORV actuation pressure. Then, the enhanced rate of reduction of primary system fluid mass quickly depleted the hot leg A inventory and lowered the hot leg B levels sufficiently to enhance the BCM depressurization. Also, as a result of the inactivity of steam generator A with a lowered secondary level, pool BCM (in steam generator B) was not obtained until the total primary system fluid inventory had been lowered more than usual. Pool BCM occurred at 230 minutes and the primary system total fluid inventory was 39% less than the initial inventory.

Lowered Steam Generator Levels, Test 7

Both steam generator secondary levels were lowered to 10 ft from the usual 31.6 ft in Mapping Test 7 (Test 3007CC, Figure 2.1.7). This change in boundary system settings amplified the trends of Test 6, which had one lowered secondary level. As had occurred in Test 6, the primary system quickly repressurized to the PORV actuation setpoint when primary-to-secondary heat transfer was impeded by the interruption of loop flow. Approximately 50 lbm of primary system inventory were removed during the PORV actuations between 77 and 84 minutes. Then, the steam generators reactivated, dropping the primary system pressure to 1500 psia through AFW-BCMs. The secondary control levels were well below the elevation of the cold leg spillovers. The cold leg spillover, at the pump discharge, is the highest elevation of the cold leg piping. The cold leg suction piping and steam generator primaries could be drained below this elevation, 25.8 feet, only by discharging from that region of the loop. The steam generator secondary levels were being maintained at 10 feet, therefore pool BCM was precluded. After the steam generator secondary feed control systems had returned the secondary levels to their control values, feed deactivated and the primary system again repressurized to the PORV lift pressure. The primary system inventory was about 30% below its initial value when the PORV again actuated. The impact of the lowered steam generator control levels thus became increasingly evident as the test progressed and as the primary system inventory was further reduced (Figure 2.1.27).

Pumps Operating, Test 8

The model reactor coolant pumps were kept in operation throughout Mapping Test 8 (Test 300806, Figure 2.1.8). The events of Test 8 were totally unlike

those of the other mapping tests (Figure 2.1.28). With a primary system total fluid inventory approaching 50% of its initial value, the pumps continued to generate sufficient flow to maintain primary-to-secondary heat transfer. The primary system depressurized to just above the steam generator secondary pressures during the initial mass-reduction phase. Even with all pumps intermittently degrading, the primary system repressurized only slightly throughout the test.

Cold Leg Discharge Leak, Test 9

A cold leg B1 discharge leak was used in Test 9 (Test 3009AA) versus the nominal lower-reactor vessel leak site. The leak site fluid saturated at 172 minutes and 880 lbm inventory, attesting to the inability of HPI-leak cooling to offset core power (Figure 2.1.9) with HPI throttled and power maintained at 3.9% of scaled full power. The leak mass flow rate reduction upon saturation of the leak site fluid promoted a further reduction of HPI flow, thus virtually nullifying HPI condensation of core-generated steam. Loop flow interrupted and the primary system repressurized at a relatively high primary system total fluid inventory (Figure 2.1.29). PORV actuation was obtained at an inventory of 830 lbm, approximately less than 15% of the initial fluid inventory.

FINAL DATA

T300001: Group 30 Mapping Test 0, Increased Leak Size - 10 cm².

Figure 2.1.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3001BB: Group 30 (Mapping) Test 1, Pressurizer Isolated.

Figure 2.1.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3003AA: Group 30 (Mapping) Test 3, Nominal.

Figure 2.1.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

Figure 2.1.4 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3003AA: Group 30 (Mapping) Test 3, Nominal.

Figure 2.1.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

Figure 2.1.4 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.1.5 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T300605: Group 30 (Mapping) Test 6, Unequal SG Levels.

Figure 2.1.6 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3007CC: Group 30 (Mapping) Test 7, Lowered SG Levels.

Figure 2.1.7 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T300806: Group 30 Mapping Test 8, Pumps Operating.

Figure 2.1.8 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3009AA: Group 30 (Mapping) Test 9, Cold Leg Discharge Leak.

Figure 2.1.9 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm2.

Figure 2.1.10 Selected Reactor Vessel and Hot Leg Fluid Temperatures

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm2.

Figure 2.1.11 Primary System Total Fluid Mass (PLMLs)

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm².

Figure 2.1.12 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm².

Figure 2.1.13 Hot Leg Riser and Stub Collapsed Liquid Levels

FINAL DATA
T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm².

Figure 2.1.14 Core Region Collapsed Liquid Levels

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm2.

Figure 2.1.15 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm².

Figure 2.1.16 Primary System Boundary Flow Rates

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm2.

2-25

Figure 2.1.17 Reactor Vessel Vent Valve Positions

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm2.

2-26

Figure 2.1.18 Reactor Vessel Vent Valve Differential Pressures (RVDPs)

FINAL DATA
T3003AA: Group 30 (Mapping) Test 3, Nominal.

Figure 2.1.19 Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs)

FINAL DATA

T3003FA: Group 30 (Mapping) Test 3, Nominal.

2-28

Figure 2.1.20 Downcomer (Venturi) Flow Rate

FINAL DATA

T3003AA: Group 30 Mapping Test 3, Nominal - 5 cm2.

Figure 2.1.21 Hot Leg U-Bend Void Fractions from Differential Pressures (64.8 to 66.6 ft, HnVFs

FINAL DATA

Mapping Test 0 (10 cm2 Leak) Vs 3 (Nominal, 5 cm2).

Figure 2.1.22 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Mapping Test 1 (Pressurizer Isolated) Vs 3 (Nominal).

Figure 2.1.23 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Mapping Test 4 (No HPI-Leak Cooling) Vs 3 (Nominal).

Figure 2.1.24 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Mapping Test 5 (RVVVs Closed) Vs 3 (Nominal, Auto RVVVs).

Figure 2.1.25 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Mapping Test 6 (Unequal SG Levels) Vs 3 (Nominal).

Figure 2.1.26 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Group 30 Mapping Test 7 (10-ft SG Levels) Vs 3 (Nominal, 31.6 ft).

Figure 2.1.27 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Mapping Test 8 (Pumps Running) Vs 3 (Nominal, Natural Circ.)

Figure 2.1.28 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

Mapping Test 9 (Leak @ CL B1 Discharge) Vs 3 (Nominal, Lower RV-DC).

Figure 2.1.29 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

2.2. SBLOCA Transients

The SBLOCA test transients have been described in detail in Volumes 3 and 4. The nominal SBLOCA test, 3109AA, used a scaled 10-cm² cold leg B1 discharge leak, full HPI, and a simulation of post-trip power decay. The major interactions of the nominal SBLOCA are shown on axes of primary system pressure versus primary system total fluid mass (Figure 2.2.1) to facilitate inter-group comparisons. Although the earlier interactions of Test 9 paralleled those of the mapping tests, two basic differences are apparent. Whereas the primary system generally repressurized in the mapping tests, little repressurization occurred in the SBLOCA transient. Secondly, the mapping tests were conducted so as to gradually lower the total primary system fluid inventory, but in the SBLOCA transient the fluid inventory was allowed to respond to the event-generated variations of the primary system boundary flow rates. Specifically, the HPI flow rate increased and, in general, the leak mass flow rate decreased as the primary system pressure was reduced, such as by BCM.

The three nominal SBLOCA transients (Nominal Test 3109, Repeat Nominal Test 3110, and Nominal With Pumps Configuration Test 3600) are over-plotted in Figure 2.2.2. Although the three tests evidenced some differences, their similarities are noteworthy. Contrast their behavior with that of Mapping Test 0, which also used a 10-cm² leak size (Figure 2.2.3). Inter-test differences were apparent virtually from the start of the tests.

FINAL DATA

T3109AA: Group 31 Test 9, Nominal SBLOCA.

Figure 2.2.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA
SBLOCA Nominal Tests 3109, 3110, and 3600.

Figure 2.2.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

SBLOCA Nominal Tests 3109, 3110, and 3600 Vs Mapping Test 0.

Figure 2.2.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

2.3. Key Events Governing the Interruption of Loop Flow

The interactions of the mapping tests have been shown to be superficially quite unlike those of the SBLOCA transients, apparently due to the differences in magnitude of the relative proportions of core power and the power offset by HPI-leak cooling. The earliest interactions surrounding interruption are of particular interest and are discussed below. Because the nominal SBLOCA leak size was 10 cm² and HPI-leak cooling was related directly to leak size, Mapping Test 0 having a 10-cm² leak, rather than the Nominal Mapping Test with a 5-cm² leak, is selected for discussion.

2.3.1. Mapping Test 0, 10-cm² Leak

Mapping Test 0 (300001) was begun with HPI and leak mass flow rates of approximately 900 lbm/h (Figure 2.3.1). The HPI flow rate was gradually reduced to create a primary system mass deficit. The leak mass flow rate also decreased in response to the depressurization of the primary system.

The reactor vessel upper-head began to void at 82 minutes (Figure 2.3.2). At 124 minutes, the reactor vessel collapsed liquid level reached the elevation of the RVVVs. The differential pressure across the vent valves had been sustained by the fluid density reduction through the core. This differential pressure was now offset by selective voiding of the downcomer -- the reactor level stabilized near the elevation of the RVVVs as the downcomer level descended approximately 1 ft, then both levels declined while maintaining the offset. The downcomer flow rate, which had exceeded the loop flow rate, thus declined toward the sum of the four cold leg flow rates plus the leak (and HPI) flow rate (Figures 2.3.3 and 2.3.4). The RVVVs closed between 128 and 130 minutes in response to the decreasing differential pressure and remained closed except for sporadic actuations (Figure 2.3.5).

The downcomer level approached the elevation of the cold leg nozzles at 156 minutes, triggering the condensation of core-generated steam by interaction with HPI-cooled fluid. The condensation depressurization (Figure 2.3.6) caused the RVVVs to open between 158 and 160 minutes. The current HPI flow rate of approximately 700 lbm/h (Figure 2.3.1) was sufficient to condense the steam generated at 3% of scaled full power; HPI plus the subcooled fluid

residing in the cold legs and downcomer were more than sufficient to offset core power, which was held constant at 3.9% of scaled full power.

As HPI condensation began, the reactor vessel level dropped toward the elevation of the hot leg nozzles (Figure 2.3.2), the hot leg riser levels briefly evidenced voiding (Figure 2.3.7), and the loop flow rates virtually stagnated (Figure 2.3.4). The downcomer flow rate indications became variable with an average value that was small compared to that preceding the condensation event. The loop A cold leg flow rates subsequently reactivated, but loop B evidenced inter-cold leg flow.

The primary system depressurized beyond 160 minutes through HPI condensation (Figure 2.3.6). The core region fluid saturated to progressively lower elevations (Figure 2.3.8), reflecting a small excess of core power over HPI condensing capacity and HPI-leak heat removal capacity. The hot leg risers generally indicated full beyond 160 minutes and the loop A flow rates gradually increased. The downcomer and core inlet fluid attained saturation at 219 minutes. The leak mass flow rate remained near 700 lbm/h (Figure 2.3.1), indicating that the leak-site fluid remained subcooled. Loop flow had been limited to cold leg A1. As all of the core-region fluid saturated at 219 minutes, the loop A riser level briefly receded from the U-bend (Figure 2.3.7), the U-bends evidenced voiding (Figure 2.3.9), cold leg A1 stagnated (Figure 2.3.4), and the primary system began to pressurize at a rate of approximately 26 psi/min (Figure 2.3.6). This repressurization was halted within 10 minutes when the steam generator primary levels descended into the steam generators, triggering condensation of primary system vapor and, hence, depressurization of the primary through the boiler-condenser mode.

In summary, certain key events triggered transitions among the types of interactions. The descent of the downcomer level to the cold leg nozzle elevation triggered HPI condensation and the transition from strongly to weakly coupled primary-to-secondary heat transfer. This transition occurred at 157 minutes and a primary system total fluid inventory of 895 lbm (Figure 2.3.10), 11.6% less than the initial total inventory. The second major event occurred at 218 minutes and 830 lbm, 18.0% less than the initial total primary mass. This event was the saturation of all of the core region fluid.

The hot leg A riser level receded from the U-bend spillover elevation, loop flow interrupted, and the primary system began to repressurize quite rapidly. The final key event occurred at 227 minutes and 815 lbm, 19.5% less than the initial mass. Both steam generator primary levels descended below the elevation of the upper tubesheet and the BCM began.

2.3.2. Other Mapping Tests

The key events of Mapping Test 0 occurred generally in each of the mapping tests. The exceptions were those two mapping tests in which direct HPI condensation was precluded (Test 4 without HPI and Test 5 with the RVVVs closed), and the pumps-operating Mapping Test 8 in which steam generator heat transfer was maintained. The occurrences of the key events are summarized in Table 2.3.

The mass deficit of the key events was quite consistent among the six mapping tests of interest. HPI condensation began at primary system fluid mass deficits ranging from 8.5 to 11.1%. Saturation throughout the core region occurred between 12.7 and 18%, followed by BCM condensation within an additional 2% mass deficit. The RVVVs generally remained open throughout each of these mapping tests, except as the downcomer level descended from full to the elevation of the cold leg nozzles. Loop flow, albeit less than initially, and primary-to-secondary heat continued as the vent valves reopened. In each of these six tests, voiding at the hot leg U-bends, interruption of loop flow, and repressurization of the primary system occurred only as the core region fluid saturated throughout its length. The progression of saturation to successively lower core elevations was caused by the excess of core power, which was held constant in the mapping tests, over the heat removal capacity of HPI-leak cooling. This heat removal capacity, in turn, was restricted by the method of controlling inventory in the mapping tests -- the leak was kept active, but HPI was throttled to gradually reduce the primary system total fluid inventory. In the SBLOCA transients, however, core power was reduced to simulate post-trip decay, and the HPI flow rate was responsive to scaled head-flow characteristics. In the SBLOCA transients, HPI-leak cooling thus offset more of the current core power as the transients progressed.

2.3.3. Interruption in an SBLOCA Transient

Nominal Repeat Test 311000 was sufficiently symmetric that the loop A BCM during steam generator refill, which had occurred in Nominal Test 3109AA, was precluded. The Test 10 transient thus involved a period of intermittent loop B flow from 2.5 to approximately 15 minutes. The RVVVs remained open throughout this period, thus demonstrating that RVVV activity was not a prerequisite to intermittent flow interruptions. Each interruption involved an ordered sequence of flow rate and fluid enthalpy changes. The several-minute interval required to transport core fluid temperature changes up the hot leg riser and to the U-bend elevation was central to the cyclic interactions. The final flow interruption was triggered by the onset of HPI condensation, when the downcomer level descended to the elevation of the cold leg nozzles.

Description of Flow-Heating Interactions

A decrease of loop flow rate caused the core exit and, later, the hot leg fluid temperatures to increase. The expansion of the lower-elevation fluid both refilled the hot leg riser and enhanced the loop natural circulation driving head, causing the loop flow rate to increase. The warmer hot leg fluid that initiated the flow rate increases was transported up the hot leg riser over a several-minute period. As this warmer fluid continued to rise, it reduced the loop natural circulation driving force. This effect may be visualized as raising the elevation of the thermal center of the heat-addition side of the loop flow circuit. Moreover, the hot leg fluid heating culminated at saturation. As the saturated fluid reached the highest hot leg elevations, the U-bend began to void and the hot leg riser liquid level receded from the U-bend spillover elevation, causing an abrupt reduction of loop flow. This flow reduction again caused core fluid heating, thus regenerating the cycle. Each cycle involved fluid cooling as well as heating. The periodic flow increases drew subcooled fluid into the core, ultimately subcooling the core exit. This cooling of the core-region fluid detracted from the natural circulation driving force, but the delay between subcooling and flow reduction suggested that saturation and voiding near the U-bend were the predominant mechanisms of flow reduction. The flow-heating events of Nominal Repeat Test 311000 are summarized in Table 2.4.

First Cycle, 2.5 to 5 Minutes

The first cycle of flow-heating interactions in Test 311000 began at 2.5 minutes. The test initiating actions had just been completed, the RVVVs had opened at 2 minutes (Figure 2.3.11), and the hot leg B U-bend fluid had saturated (Figure 2.3.12) and receded from the U-bend (Figure 2.3.13) due to the initial primary system depressurization to saturation. Loop A had saturated and interrupted due to the initial discharge of the pressurizer inventory; it remained interrupted and largely inactive. Hence, the loop B interactions alone governed loop flow (Figure 2.3.14).

The loop and downcomer flow decrease at 2.5 minutes (Figure 2.3.15) caused fluid heating. The core exit fluid began to heat at 2.8 minutes, saturating at 3.6 minutes (Figure 2.3.16). The fluid heatup progressed to the reactor vessel nozzle elevation at 2.9 minutes and traversed the hot leg B upturn region at 3.4 minutes (Figure 2.3.12). The hot leg B riser refilled (Figure 2.3.13), and the loop and downcomer flow rates began to increase at 4.0 minutes (Figures 2.3.14 and 2.3.15). However, the warmer fluid continued to pass up the hot leg B riser, reaching the hot leg B U-bend spillover at 5.1 minutes (Figure 2.3.12). The hot leg B riser level declined as the upper elevation fluid saturated (Figure 2.3.13) and the loop B U-bend voiding increased (Figure 2.3.17); thus, the loop and downcomer flow rates began to decrease at 5.4 minutes (Figures 2.3.14 and 2.3.15).

Second Cycle, 5.4 to 9 Minutes

The flow rate decrease near 5.4 minutes triggered a second cycle of flow-heating interactions. The fluid temperature increase was evidenced at the core exit at 5.8 minutes (Figure 2.3.16) but did not reach the U-bend region until some 3 minutes later (Figure 2.3.12). The fluid at the core outlet nozzles and hot leg B inlet began to heat beyond 6 minutes, the riser refilled (Figure 2.3.13), and the loop B flow rate began to increase at 7.3 minutes (Figure 2.3.14). The core exit fluid saturated at 6.7 minutes and the hot leg B riser fluid saturated sequentially with elevation (Figures 2.3.16 and 2.3.12), culminating in saturation at the B U-bend spillover at 9.2 minutes. The loop B U-bend upstream fluid began to evidence voiding (Figure 2.3.17), the upstream spillover void fraction approached 100% and, at

9.2 minutes, the loop and downcomer flow rates began to decrease (Figures 2.3.14 and 2.3.15), thus finishing the second complete cycle of flow-heating interactions.

Third Cycle Terminating in RVV Closures

The third cycle of interactions, which began with the flow reduction at 9.2 minutes, was modified somewhat by the completion of the refill of the steam generator secondaries at approximately 9.6 minutes. Whereas the hot leg B riser refilled near 10 minutes (Figure 2.3.13) as the fluid heatup progressed, the much-diminished steam generator activity prevented the resurgence of loop flow, thus slowing the transport of fluid through hot leg B. The cold leg B flow rate did ultimately increase near 13 minutes (Figure 2.3.14), by which time the saturated fluid had progressed up the hot leg B riser to the 30-ft elevation (Figure 2.3.12). The steam generator B secondary resurged at 13.2 minutes (Figure 2.3.18). The RVVs had remained open since 2 minutes, and the reactor vessel upper-head void had expanded somewhat sporadically since 3.5 minutes (Figure 2.3.19). As loop flow reactivated, the RVVs closed near 14 minutes (Figure 2.3.11). The downcomer level stabilized about 1 ft above the elevation of the cold leg nozzles.

Final Interruption as the RVVs Reopened

The loop B cold leg flow rate abruptly declined at 14.5 minutes (Figure 2.3.14) as the B U-bend saturated and voided (Figure 2.3.17). The differential pressures across the RVVs increased sporadically from 0.05 psi (Figure 2.3.20) as the loop flow rate stagnated, causing the individual vent valves to re-open between 14.9 and 15.5 minutes (Figure 2.3.11). The downcomer collapsed liquid level then resumed its descent, reaching the elevation of the cold leg nozzles at 15.5 minutes (Figure 2.3.19). This level change precipitated HPI condensation of core-generated steam, and hence, a marked change in system interactions. Rather than hovering near the elevation of the spillover, the hot leg B riser levels began a prolonged and continuous descent (Figure 2.3.13). Whereas the local loop B U-bend upstream void fractions had varied similarly between 0 and approximately 100%, first the void fraction measured just upstream of the spillover increased toward 100%, then 2 minutes later the void fraction measured over the lower upstream portion of the U-bend began a similar increase (Figure 2.3.17). These void

fraction variations were indicative of the gradual descent of a virtually stagnant interphase interface versus the relatively dynamic U-bend interactions evidenced during the earlier voiding events. Loop flow was thus precluded after RVVV actuation. The RVVVs remained open (Figure 2.3.11), the downcomer level remained near the cold leg nozzles (Figure 2.3.19), and loop flow remained stagnant, although inter-cold leg flow began in loop B (Figure 2.3.14). The primary system gradually depressurized (Figure 2.3.18) through the net fluid volume reduction obtained by HPI condensation.

FINAL DATA

T300001: Group 30 Mapping Test 0, Increased Leak Size - 10 cm2.

Figure 2.3.1 Primary System Boundary Flow Rates

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

Figure 2.3.2 Core Region Collapsed Liquid Levels

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

2-51

Figure 2.3.3 Downcomer (Venturi) Flow Rate

FINAL DATA

T300001: Group 30 (Mappng) Test 2, Increased Leak Size.

Figure 2.3.4 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

2-51

Figure 2.3.3 Downcomer (Venturi) Flow Rate

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

Figure 2.3.4 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

Figure 2.3.5 Reactor Vessel Vent Valve Positions

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

Figure 2.3.6 Primary and Secondary System Pressures (GPO1s)

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

Figure 2.3.7 Hot Leg Riser and Stub Collapsed Liquid Levels

FINAL DATA

T300001: Group 30 (Mapping) Test 0, Increased Leak Size.

Figure 2.3.8 Core Unit Cell Fluid Temperatures (RVTCs)

FINAL DATA

T300001: Group 30 (Mappng) Test 0, Increased Leak Size.

Figure 2.3.9 Hot Leg U-Bend Void Fractions from Differential Pressures (64.8 to 66.6 ft, HnVFs)

FINAL DATA

T300001: Group 30 Mapping Test 0, Increased Leak Size - 10 cm2.

Figure 2.3.10 Primary System Total Fluid Mass (PLMLs)

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.11 Reactor Vessel Vent Valve Positions

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.12 Selected Hot Leg B Riser Fluid Temperatures (HITCs)

FINAL DATA

T311020: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.13 Hot Leg Riser and Stub Collapsed Liquid Levels

FINAL DATA

T311000: Group 31 SBLOCA Test 10, Nominal Repeat.

Figure 2.3.14 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.15 Downcomer (Venturi) Flow Rate

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.16 Core Unit Cell Fluid Temperatures (RVTCs)

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.17 Hot Leg B U-Bend Void Fractions from Differential Pressures (H2VFs)

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.18 Primary and Secondary System Pressures (GPO1s)

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.19 Core Region Collapsed Liquid Levels

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 2.3.20 Reactor Vessel Vent Valve Differential Pressure (RVDPs)

2.4. Specific Comparisons

Similar mapping and SBLOCA tests are compared below. These comparisons are as follows:

- SBLOCA Test 3206 with Reduced-Capacity HPI Versus Mapping Test 0
- RVVVs Closed: SBLOCA Test 3101 Versus Mapping Test 5
- Mapping Without HPI: Draining Phase of NCG Threshold Test 3502 Versus Mapping Test 4

2.4.1. SBLOCA With Reduced-Capacity HPI Versus Mapping Test 0

Reduced-capacity HPI was used in SBLOCA Test 320604, thus moving its boundary conditions towards those of the mapping tests, in which HPI was throttled to reduce the primary system total fluid mass. Indeed, the HPI flow rates in SBLOCA Test 6 remained much lower than those of Mapping Test 0, which used a 10-cm² leak (Figure 2.4.1).

SBLOCA Test 6 was characterized by a rapid reduction of total mass and early saturation of the leak-site fluid, followed by a gradual depressurization at almost constant mass (Figure 2.4.2). This behavior was quite unlike that of Mapping Test 0 (Figures 2.1.1 and 2.4.3). The difference in behavior was caused by the inter-test difference of core power versus HPI capacity.

The initial leak mass flow rate of SBLOCA Test 6 greatly exceeded the reduced-capacity HPI flow rate (Figure 2.4.4), although this excess diminished somewhat with the primary system depressurization (Figure 2.4.5). The initial effluent energy transfer in Test 6 thus approximately equalled core power (Figure 2.4.6) such that the sum of effluent energy transfer plus steam generator heat transfer far exceeded core power. Primary-to-secondary heat transfer was virtually eliminated by 10 minutes in Test 6, but the post-trip decay simulation had already reduced core power (including augmentation) to 2.5% of scaled full power, just more than one-half of its initial value.

As the downcomer level reached the elevation of the cold legs and HPI condensation began, the leak-site fluid saturated (Figure 2.4.7), drastically reducing the leak mass flow rate (Figure 2.4.4). However, the effluent energy transfer rate dropped to a lesser degree (Figure 2.4.6) because the increased leak fluid enthalpy somewhat offset the decreased leak mass flow

rate. The primary system pressure remained almost constant (Figure 2.4.5), reflecting an almost exact balance between core void production and the sum of HPI condensation and the volumetric break flow rate.

In the usual mapping tests, the core region fluid completely saturated, triggering interruption of loop flow and a relatively rapid repressurization of the primary system. In SBLOCA Test 6, loop flow interrupted as HPI condensation began, but primary system pressure remained constant as previously mentioned. However, the core region fluid did heat toward saturation in SBLOCA Test 6 (Figure 2.4.8). The upper 4 feet had saturated by 9 minutes, as HPI condensation began. The lower-elevation core and downcomer fluid temperatures gradually rose. The core fluid down to 7.2 ft, 3 ft above the bottom of the core, had saturated by 20.5 minutes. Just before the core inlet fluid reached saturation, the system interactions changed markedly. The leak site was uncovered, the leak fluid enthalpy increased to that of a two-phase mixture (Figure 2.4.7), and the primary system depressurized beyond 30 minutes (Figure 2.4.5) due to the enhanced break volumetric flow rate. The primary system mass balance was also perturbed (Figure 2.4.4): The diminished break mass flow rate started primary system refill, even with reduced-capacity HPI, at a primary system pressure of more than 1300 psia.

The core region fluid did eventually saturate in SBLOCA Test 6, but without primary system repressurization. Whereas core power greatly exceeded the effluent energy transfer in Mapping Test 0, in SBLOCA Test 6 they were approximately balanced by the time of the complete saturation of the core fluid.

2.4.2. RVVVs Closed: SBLOCA Test 3101 Versus Mapping Test 5

The RVVVs were kept closed in both SBLOCA Test 3101 and Mapping Test 5. The SBLOCA test otherwise used the nominal SBLOCA conditions: 10-cm² cold leg B1 discharge leak, full HPI capacity, steam generator refill to 31.6 ft, and a post-trip power reduction simulating decay. Mapping Test 5 employed a constant 31.6-ft steam generator secondary level. Also, a 5-cm² lower reactor vessel leak was used in Test 5, HPI was throttled to less than the leak mass flow rate to obtain a controlled reduction of primary fluid mass, and core power was held constant at 3.9% of scaled full power. The flow

interruption sequences of both tests were unlike those commonly encountered with the RVVVs operational.

The primary system saturated at 40 minutes (Figure 2.4.9) and a total primary system fluid mass of 906 lbm (Figure 2.4.10), 3% less than the initial total mass, in Mapping Test 5. The primary system then slowly repressurized as the primary system mass was further reduced, and as the reactor vessel voiding increased (Figure 2.4.11). The reactor vessel level reached the elevation of the RVVVs at 74 minutes, but the closed RVVVs prevented steam venting to the downcomer and precluded HPI condensation of core-generated steam. The reactor vessel level descended to the nozzle elevation at 83 minutes (Figure 2.4.11) and a primary fluid mass of 870 lbm (Figure 2.4.10), 7% less than initially. Immediately, the piping upstream of the hot leg U-bends began to void intermittently (Figure 2.4.12). The downcomer flow rate became variable (Figure 2.4.13) and the primary system pressure began to rise (Figure 2.4.14). The hot leg riser levels remained below the U-bend spillover elevation beyond approximately 100 minutes (Figure 2.4.15) and a primary system total fluid mass of 855 lbm, 9% less than initially. The primary system began to repressurize more rapidly than before, but the varying steam generator primary levels soon began to descend into the steam generators, permitting BCM heat transfer. The pressure rise was thus arrested at approximately 1700 psia (Figure 2.4.14); this occurred at 110 minutes and a primary system total fluid mass of 835 lbm, 11% less than the initial mass. The primary system thus progressed from single-phase circulation and heat transfer to BCM quickly and with relatively little repressurization. Instrumental to this rapid transfer were the more than 10-ft oscillations of the hot leg riser and steam generator primary levels (Figure 2.4.15). The oscillations were accompanied by similar variations of the core level (Figure 2.4.11), which obtained alternating periods of steam venting and nozzle recovery. The interruption occurred with the lower-elevation core fluid subcooled (Figure 2.4.16), unlike the interruptions of most of the mapping tests.

Prolonged loop circulation also occurred in SBLOCA Test 3101, but with loop A interrupted due to the initial pressurizer outsurge and only loop B active (Figure 2.4.17). Unlike Mapping Test 5, the hot leg levels evidenced little

oscillation during interruption (Figure 2.4.18). Interruption of loop flow was triggered by BCM heat transfer in steam generator A. As steam generator A reactivated at 42 minutes and 850 lbm (Figure 2.4.19), approximately 10% of the initial total fluid mass, the loop A levels rose at the expense of the reactor vessel and loop B levels (Figures 2.4.18 and 2.4.20). The reactor vessel level dropped below the elevation of the hot leg nozzles, precluding the intermittent steam venting that had occurred in Mapping Test 5. The average cold leg and downcomer flow rates dropped toward zero (Figures 2.4.17 and 2.4.21), the primary system first depressurized through BCM heat transfer to steam generator A, then repressurized (Figure 2.4.22) due to the interruption of both loop flow and BCM. The steam generator primary levels in both loops soon became aligned for BCM (Figure 2.4.18). Subsequent heat transfer depressurized the primary, initiating refill. However, steam generator heat transfer was subsequently interrupted when the steam generator primary levels were raised above the upper tubesheet elevation, obtaining primary system repressurization and another period of primary system mass loss. In this fashion, primary system pressure and mass continued to cycle for the duration of SBLOCA Test 3101 (Figures 2.4.19 and 2.4.23). The pressure-versus-mass trace of Test 3101 was thus quite curious (Figure 2.4.24). Apparently, although the condition cycles were not repetitive with time, they traversed similar ranges of pressure versus mass. Primary system pressure generally remained higher in Mapping Test 5 than in SBLOCA Test 3101 (Figures 2.1.5 and 2.4.23). This pressure difference was due to the smaller leak size and reduced HPI flow rates of Test 5 compared to those of SBLOCA Test 3101, and to the reduction of core power in Test 3101 but not in Mapping Test 5.

2.4.3. Mapping Without HPI: Draining Phase of NCG Threshold Test 3502 Versus Mapping Test 4

Test 3502CC, the noncondensable gas threshold test, was conducted in the following three distinct phases: (1) primary system mass reduction to establish stable BCM, (2) gas addition without HPI or primary system discharges, and (3) primary system venting and sampling to establish the apparent loop gas burden. Test 3502CC, particularly the second, gas-addition phase, has been described in detail in Volume 7. The first phase of Test 3502CC, the draining phase, somewhat resembled a mapping test. A scaled 5-cm² lower-reactor vessel leak was opened to effect the drain. Core power was

held constant at a relatively low value of 1.4% of scaled full power. HPI was not used throughout Test 3502CC. The steam generator secondary levels were held constant at a nominal 31.6 ft, steam generator secondary pressure was limited to a maximum of 1010 psia.

The primary system inventory was depleted much more rapidly than in a mapping test (Figure 2.4.25) because of the combined effects of a 5-cm² leak and no HPI. The primary system first saturated at 4 minutes (Figure 2.4.26), and loop A interrupted shortly thereafter. The reactor vessel voided volume expanded continually beyond 8 minutes (Figure 2.4.27), the reactor vessel level achieved the elevation of the RVVVs, and the downcomer began to void beyond 8 minutes. The downcomer level reached the elevation of the cold leg nozzles at 20 minutes. The primary system depressurized slightly, apparently due to condensation of core-generated steam by the subcooled cold leg fluid, and loop flow became intermittent (Figure 2.4.28). The lower-elevation core fluid remained subcooled as flow interrupted (Figure 2.4.29). Beyond 30 minutes, the primary system gradually repressurized with primary-to-secondary heat transfer interrupted, then abruptly depressurized through AFW-BCM heat transfer. However, the reduction of primary system fluid mass was virtually stopped at 37 minutes (Figure 2.4.25) when the leak became plugged. Thereafter, the primary fluid mass was reduced in a series of step functions (Figure 2.4.30) as the leak was intermittently opened and closed, first to clear the leak and later to obtain stable pool BCM. These draining evolutions have been described in Volume 7.

As the primary system mass was intermittently reduced in Test 3502CC, the primary system sporadically depressurized (Figure 2.4.31), initially through AFW-BCMs. The combination of step function changes of both primary system mass and pressure obtained a somewhat curious trace using these two variables (Figure 2.4.32). Finally, with a primary system mass approximately 40% less than the initial total fluid mass, quite stable pool BCM was achieved. The draining phase of Test 3502CC was thus terminated at 270 minutes after maintaining pool BCM for 30 minutes.

HPI was not used in Mapping Test 4 (3004CC). The primary system inventory depletion was accomplished by opening a scaled 1-cm² lower-reactor vessel leak for the first 3.5 hours of testing, then a scaled 2-cm² lower-reactor

vessel leak for the duration of the test. The mass depletion rate of Mapping Test 4 was thus quite unlike that of the first phase of NCG Threshold Test 3502CC -- it was continuous and gradual (Figure 2.4.33), rather than rapid and intermittent as in the draining phase of the NCG threshold test. However, there were several key inter-test similarities. Their steam generator secondary controls were similar, namely constant level in both steam generators at 31.6 ft, and pressure was controlled to 1010 psia. Core power was maintained at 1.4% of scaled full power in both tests. Also, in both tests, HPI was kept inactive.

Interruption in Mapping Test 4, like that of the NCG test, occurred with the lower-elevation core fluid subcooled (Figure 2.4.34), rather than being saturated as in the mapping tests with active HPI condensation. In both Mapping Test 4 and the NCG threshold test, loop flow became intermittent (Figure 2.4.35) as the downcomer level descended to the elevation of the cold leg nozzles (Figure 2.4.36). Longer-duration flow interruptions and periods of primary system repressurization (Figure 2.4.37) occurred as the core-region level receded from the elevation of the hot leg nozzles. Intermittent AFW-BCMs obtained abrupt depressurizations of the primary system. As the primary system mass deficit approached 30% of the initial mass, pool BCMs obtained more-pronounced depressurizations of the primary system. The major interactions of Mapping Test 3004 have been keyed to primary system pressure versus mass in Figure 2.1.4.

The pressure-versus-mass trends of NCG Threshold Test 3502 are compared to those of Mapping Test 4 in Figure 2.4.38. Although the intermittent and rapid drains of Test 3502 affected its trends during the AFW and pool BCM phases, the two tests exhibited similar characteristics. Intermittent repressurizations interspersed with AFW-BCMs began at 800 lbm, about 15% less than the initial mass. The primary system pressure peaked near 1900 psia in both tests. Also, in both tests, the primary system depressurized toward the steam generator secondary pressure through pool BCM at a primary system mass below 600 lbm, almost 40% less than the initial total fluid mass.

FINAL DATA

SBLOCA Test 3206 (Reduced HPI) Vs Mapping Test 0 (10 cm²).

Figure 2.4.1 HPI Flow Rates

FINAL DATA

T320604: Group 32 Test 6, SBLOCA With Reduced HPI.

Figure 2.4.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

SBLOCA Test 320604 (Reduced HPI) Vs Mapping Test 300001 (10 cm²).

Figure 2.4.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T320604: Group 32 Test 6, SBLOCA With Reduced HPI.

Figure 2.4.4 Primary System Boundary Flow Rates

FINAL DATA

T320604: Group 32 Test 6, SBLOCA With Reduced HPI.

Figure 2.4.5 Primary and Secondary System Pressures (GPO1s)

FINAL DATA

T320604: Group 32 Test 6, SRLOCA With Reduced HPI.

Figure 2.4.6 Primary System Energy Transfer

FINAL DATA

T320604: Group 32 Test 6. SRLOCA With Reduced HPI.

Figure 2.4.6 Primary System Energy Transfer

FINAL DATA

T320604: Group 32 Test 6, SBLOCA With Reduced HPI.

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Figure 2.4.5 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T320604: Group 32 Test 6, SBLOCA With Reduced HPI.

Figure 2.4.7 Leak Fluid Enthalpy

FINAL DATA

T320604: Group 32 Test 6, SBLOCA With Reduced HPI.

Figure 2.4.8 Core Unit Cell Fluid Temperatures (RVTCs)

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.9 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.10 Primary System Total Fluid Mass (PLMLs)

FINAL DATA
T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.11 Core Region Collapsed Liquid Levels

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.12 Hot Leg U-Bend Void Fractions from Differential Pressures (64.8 to 66.6 ft, HnVFs)

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.13 Downcomer (Venturi) Flow Rate

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.14 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.15 Hot Leg Riser and Stub Collapsed Liquid Levels

FINAL DATA

T300504: Group 30 (Mapping) Test 5, RVVVs Closed.

Figure 2.4.16 Core Unit Cell Fluid Temperatures (RVTCs)

FINAL DATA
T310101: Group 31 SBLOCA Test 1, RVVVs Closed.

Figure 2.4.17 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA
T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.18 Hot Leg Riser and Stub Collapsed Liquid Levels

FINAL DATA
T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.18 Hot Leg Riser and Stub Collapsed Liquid Levels

FINAL DATA

T310101: Group 31 SBLOCA Test 1, RVVVs Closed.

Figure 2.4.17 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA
T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.19 Primary System Total Fluid Mass (PLMLs)

FINAL DATA
T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.20 Core Region Collapsed Liquid Levels

FINAL DATA

T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.21 Downcomer (Venturi) Flow Rate

FINAL DATA

T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.22 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T310101: Group 31 Test 1, RVVVs Closed.

Figure 2.4.23 Primary and Secondary System Pressures (GP01s)

FIANL DATA

RVVVs Closes: SBLOCA Test 3101 Vs Mapping Test 3005.

Figure 2.4.24 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.25 Primary System Total Fluid Mass (PLMLs)

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.26 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.27 Core Region Collapsed Liquid Levels

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.28 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.29 Core Unit Cell Fluid Temperatures (RVTCs)

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.30 Primary System Total Fluid Mass (PLMLs)

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.31 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T3502CC: Group 35 Test 2, Noncondensable Gas Threshold.

Figure 2.4.32 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

Figure 2.4.33 Primary System Total Fluid Mass (PLMLs)

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

Figure 2.4.34 Core Unit Cell Fluid Temperatures (RVTCs)

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

Figure 2.4.35 Cold Leg (Venturi) Flow Rates (CnVN20s)

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

Figure 2.4.36 Core Region Collapsed Liquid Levels

FINAL DATA

T3004CC: Group 30 (Mapping) Test 4, No HPI-Leak Cooling.

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Figure 2.4.37 Primary and Secondary System Pressures (GPOIs)

FINAL DATA

NCG Test 3502 (Draining Phase) Vs Mapping Test 3004 (Without HPI).

Figure 2.4.38 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

2.5. Summary

The interactions of the mapping tests and of the SBLOCA transients are conveniently identified on traces of primary system pressure versus primary system total fluid mass. The event occurrences are then readily restated in terms of mass deficit, the difference between the initial and current total fluid mass normalized to the initial mass. The mapping tests generally underwent the same interactions. These interactions included

- Pressurizer drained
- Saturation of the loop fluid
- HPI condensation
- Saturation of all the core fluid and interruption of loop flow
- AFW-BCM
- Pool BCM

Compared to Nominal Mapping Test 3, the larger leak size of Mapping Test 0 obtained increased leak and HPI flow rates, enhanced HPI condensation, and thereby lower primary system pressures. The pressurizer isolation of Mapping Test 1 had little effect on the transient, but an inadvertent leak blockage during Test 1 demonstrated the retraceability of the interactions as a function of total fluid mass.

In Mapping Test 4, which had no HPI and reduced core power, the primary system repressurized gradually after the saturation of loop fluid, then rapidly upon the interruption of loop flow. The mass deficits at which these interactions began were similar to those in the other tests. The RVVVs were closed in Mapping Test 5, thus precluding direct HPI condensation. The other interactions occurred at lower mass deficits than had been observed in the Nominal Mapping Test, and primary system pressure remained lower with the RVVVs closed.

Unequal steam generator secondary levels were used in Mapping Test 6, and lower levels in Mapping Test 7. The initial behavior of pressure versus mass was similar to that of the Nominal Mapping Test, but in both Tests 6 and 7, higher primary system pressures and PORV actuations were encountered after AFW-BCMs.

The pumps were kept operating in Mapping Test 8. Through a mass deficit approaching 50%, primary-to-secondary heat transfer remained active and primary system pressure remained just above the steam generator secondary pressures. A cold leg discharge leak was used in Mapping Test 9. As the leak-site fluid saturated early in the mass-reduction sequence, HPI was throttled extensively to accommodate the reduction of the leak flow rate. Test 9 thus had little or no HPI below a mass deficit of 8%, but retained nominal core power, 3.9% of scaled full power. The primary system repressurized directly, lifting the PORV at a mass deficit of 15.2%.

The interactions of the SBLOCA transients paralleled those of the mapping tests, but the pressure-versus-mass traces were quite dissimilar. In the SBLOCA transients, the HPI flow rate varied inversely with primary system pressure, using scaled plant head-flow characteristics. However, in the mapping tests, HPI was reduced with primary system pressure to maintain the mass reduction schedule while the leak flow rate decreased with pressure. As primary system pressure decreased, such as during the initial depressurization to saturation, HPI-leak cooling offset less power and HPI could condense less core-generated steam in the mapping tests, whereas the reverse trends applied in the SBLOCA transients. Also, core power was held constant in the mapping tests, nominally at 3.9% of scaled full power, but reduced to simulate post-trip decay in the SBLOCA transients.

The three nominal SBLOCA transients generated remarkably similar traces of primary pressure versus mass. These three tests are Nominal Test 3109AA, Nominal Repeat Test 311000, and Nominal With Pumps Configuration Test 3600AA. Certain inter-test similarities prevailed as is evident in their pressure-versus-mass traces. These traces bear little similarity to those of the mapping tests.

The vent valves generally remained open throughout each of the mapping tests, closing only as the downcomer level descended toward the elevation of the cold leg nozzles. The downcomer and core levels aligned to deplete the differential pressure across the vent valves, causing them to close during this reduction of level.

Core-generated steam, discharged through the RVVVs, began to condense on the HPI-cooled fluid as the downcomer level descended to the cold leg nozzles. The HPI condensation capacity was insufficient to offset all of the core power in the mapping tests, as previously noted. Therefore, the core region fluid gradually heated, saturating to progressively lower elevations in the core. When the entire core fluid inventory had saturated, the interactions were abruptly altered. Prior to the change, the excess of core power over HPI-leak cooling had been offset by lingering primary-to-secondary heat transfer. As the core fluid completely saturated, the U-bend regions voided, ostensibly due to the increased core void production with no subcooling. Loop flow interrupted and the primary system repressurized relatively rapidly. This repressurization continued until the lowered hot leg and steam generator primary levels permitted (AFW) BCM.

Interruption in the mapping tests thus occurred with the RVVVs open, and was keyed to the complete saturation of the core region fluid. In the SBLOCA transients, however, the core inlet fluid generally remained subcooled. Intermittent loop flow reductions and interruptions often occurred early in the transients (in the first 15 minutes) due to the coupling of core flow and core fluid temperature rise versus the several-minute transport time between the core exit and the hot leg U-bends. Because the HPI condensing capacity was generally more than sufficient to handle all of the core steam production in the SBLOCA transients, the onset of HPI condensation generally interrupted loop flow. As the downcomer level reached the cold leg nozzle elevation and condensation began, the RVVVs opened, core-generated steam was vented to the downcomer, the hot leg fluid stratified by phase, the U-bends voided, the now-quiescent hot leg riser levels gradually and continually declined, and loop flow stagnated.

The root difference between the mapping and SBLOCA tests regarding interruption was HPI condensing capacity versus core steam production. With the HPI capacity smaller as in the mapping tests, loop flow and primary-to-secondary heat transfer were sustained until the core inlet fluid saturated, then the primary system repressurized due to the excess core power and core steam production. In the general SBLOCA transients, however, primary-to-secondary heat transfer were not needed to offset core power. The HPI condensing

capacity was generally more than sufficient to handle core steam production. As HPI condensation began, the RVVVs opened and loop flow interrupted but the primary system gradually depressurized.

Table 2.1. Mapping Tests, Group 30

Test	Variable:	Leak Size, cm ²	Leak Location	Core Power, %	Steam Generator A/B Secondary Levels, ft	Pressurizer Status	RVVV Status	Pump Status	Duration, Minutes
	Setting								
	1	5	RV-DC	3.9	31.6/31.6	Unisolated	Operational	Off	
	2	10	BI CLD	1.4	10/31.6	Isolated	Closed	Operating	
	3	1.2	--	---	10/10	--	--	--	
0 Larger Leak		2							317
1 Isolated Pressurizer						2			319
3 Nominal		1	1	1	1	1	1		281
4 No HPI		3		2					230
5 RVVVs Closed							2		259
6 Unequal Steam Generator Levels					2				256
7 Lower Steam Generator Levels					3				130
8 Pumps Operating								2	268
9 CLD Leak			2						239

Table 2.2. Major Interactions Versus Mass Deficit, Mapping Tests

- Mass deficit entries reflect the approximate deficit at the beginning of the interaction.
- Mass deficit is the difference between the initial primary system total fluid mass and the approximate current mass, divided by the initial mass, expressed as a percentage.
- Events are discussed in the accompanying text.

<u>Test:</u>	0 Increased Leak Size	1 Pressurizer Isolated	3 Nominal	4 Without HPI	5 RVVVs Closed	6 Unequal Steam Generator Levels	7 Lowered Steam Generator Levels	8 Pumps Operating	9 Cold Leg Discharge Leak
<u>Interaction</u>									
Pressurizer drained	3.2	na	1.6	2.1	2.1	1.6	2.1	1.9	1.0
Saturation	5.6	0.5	2.6	3.2	3.2	2.7	3.2	2.4	2.1
HPI condensation	11.6	9.8	9.6	na	na	10.3	11.3	na	8.5
Interruption of loop flow	18.0	15.8	14.0	15.1	9.1	15.8	16.7	na	12.7
AFW-BCM	19.5	17.4	15.0	16.9	11.2	16.8	19.1	na	14.3
Pool BCM	29.8	20.7	27.5	28.0	15.0	39.1	na	na	na
PORV actuation	na	na	na	na	na	17.4	23.7	na	15.2

Table 2.3. Key Events Versus Mass Deficit, Selected Mapping Tests

- Event 1: Downcomer level descended to cold leg nozzles;
HPI condensation of core-generator vapor began.
- Event 2: All core fluid saturated;
Hot leg U-bend voided;
Loop flow interrupted;
Primary system repressurizing.
- Event 3: Steam generator primary levels descended below upper tubesheet;
BCM began;
Primary system depressurizing.

Test	Mass Deficit, % of Initial Mass		
	Event 1	Event 2	Event 3
0 Increased Leak Size	11.6	18.0	19.5
1 Pressurizer Isolated	9.8	15.8	17.4
3 Nominal	9.6	14.0	15.0
6 Unequal Steam Generator Levels	10.3	15.8	16.8
7 Reduced Steam Generator Levels	11.3	16.7	19.1
9 Cold Leg Discharge Leak	8.5	12.7	14.3

Table 2.4. Flow-Heating Events, Nominal Repeat Test 311000

Entries indicate the time in minutes of the corresponding event or condition. The table is arranged to clarify the interactions of repetitive flow-heating events early in an SBLOCA.

	Time, Minutes:	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
RVVs: Open		2.0													15.5	
Close													13.6			
Collapsed Liquid Levels																
Hot leg B riser: Declines		2.5			5			8.5						14.2	15.5	
Refills			3			6				10					15.5	
Core: Declines more rapidly			3.5				7			10					15	
Flow Rates																
Cold leg: Decreases		2.5			5.4				9.2					14.4		-16
Increases				4.0			7.3						~13		15.3	
Downcomer: Decreases		2.5			5.3				9.2					~14.7		
Increases				~4			7.5							~14		
Fluid Temperatures																
Core Exit																
Increases		2.8			5.8				9.4					14.8		
Saturates			3.6			6.7			9.9						15.1	
Subcools		(2.1)		4.4				8.2						~14		
Nozzles																
Increases		2.9				6.0			9.7							
Saturates				~4			7.2			10.5						
Subcools		(2.26)		4.8				8.7						~14.8		

Table 2.4. Flow-Heating Events, Nominal Repeat Test 311000 (Cont'd)

Time, Minutes:		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
<u>Fluid Temperatures (Cont'd)</u>																
Hot leg B upturn @ 22.4 ft																
Increases			3.4			6.2				10.8						
Saturates		-2.3		4.3			7.5					12.4				
Subcools		2.4		4.8				8.8								
Hot leg B above viewport, 29.6 ft																
Increases			3.8			6.5						12.1				
Saturates		-2.3		4.6				8.1					13.1			
Subcools		2.4		4.9						10.2						
Hot leg B @ 40 ft																
Increases				4.1			7.8					12.8				
Saturates		-2.4			5.0			8.7						14.1		
Subcools		2.6			5.4					10.2						
Hot leg B @ 50.8 ft																
Increases				4.7				8.4					13.3			
Saturates		2.4			5.2				9.0					14.3		
Subcools			3.0		5.9					10.2						
Hot leg B spillover, 66.4 ft																
Increases					5.1			8.9					13.9			
Saturates		2.4			5.3				9.2					14.4		
Subcools				4.1			-7.5			10.2						

3. SBLOCA

Individual SBLOCA tests or test types are compared to tests of other groups having similar features. Reproducibility of the SBLOCA tests is addressed in section 3.1. Two groups are formed for comparison -- those tests conducted before the leak flow area enlargement, and those conducted after. These tests are found to be remarkably similar; inter-test differences of primary system pressure versus mass clearly reflect the imposed inter-test differences. Subsequent sections address more specific inter-group comparisons. These comparisons include

- ATOG
- Venting
- PORV
- Pump operation

The two tests controlled by operators versed in plant procedures were surprisingly similar, considering that the earlier test was conducted without forced flow and involved PORV actuation, whereas the later test involved pump bumps. The venting comparison, Test 3501 versus (SBLOCA) Nominal Repeat Test 3110, clearly indicated venting effects -- for example, refill was achieved earlier with venting, and occurred without repetitive hot leg U-bend spillovers.

The PORV comparison uses the PORV Break Test 3204 and the Nominal HPI-PORV Cooling Test 3301. The major differences between these two tests were the higher primary system pressure early in Test 3301, and the continuing availability of the steam generators in SBLOCA Test 3204. These differences combined to obtain quite different test transients. The primary system generally depressurized and refilled in SBLOCA Test 3204, but Test 3301 experienced extensive and long-duration voiding.

the following inter-group comparison involved pump operation: SBLOCA Test 3002 with the model reactor coolant pumps kept operating versus Nominal Repeat SBLOCA Test 3110. The pump-operation effects predominated the comparison. Pump operation both maximized the leak fluid enthalpy and sustained primary-to-secondary heat transfer. The loop was refilled in just more than 1 hour whereas, without forced flow, even single-loop refill was delayed until 500 minutes and was preceded by several brief periods of rapid change of loop conditions due to spillovers.

3.1. Reproducibility

Inter-test comparisons among the SBLOCA tests of Group 31 have indicated that the leak flow area effectively enlarged between the tests conducted on or before 12 July 1986 and those conducted later, as has been discussed in Volume 3. These two groups of SBLOCA tests, those conducted before and those conducted after the leak flow area change, are candidates for inter-group comparisons.

3.1.1. Tests Conducted Before the Leak Area Enlargement

The SBLOCA tests conducted before the leak flow area change were entirely from Group 31. These tests have each been described at length in Volume 3, and certain inter-test comparisons have been drawn. The inter-test comparisons herein are thus general and brief.

The following five SBLOCA tests were conducted on or before 12 July 1986:

- 1: 3101, RVVVs Closed
- 2: 3102, RVVVs Open
- 3: 3103, Guard Heaters Deenergized
- 7: 3107, No Augmentation of Core Power
- 9: 3109, Nominal

Test 1 was excluded from this comparison because its interactions, due to the deletion of RVVV effects, were vastly different from those of the other tests, as discussed in Volume 3 and in section 2 herein.

The four tests remaining for comparison followed very similar trends of primary system pressure versus mass (Figure 3.1.1), except Nominal Test 9.

In Test 9, the primary system depressurized at a relatively high primary system total fluid mass, and remained at a lower pressure and higher mass until well into the refill period.

The early depressurization of Test 9 was caused by an AFW-BCM in interrupted loop A at 8 minutes (Figure 3.1.2), while AFW was still active for the initial refill of the steam generator secondaries. As has been discussed in Volume 3, the conditions for this early BCM in the interrupted loop were approached in all of the SBLOCA tests with near-nominal boundary conditions, but were achieved only in selected tests. These tests were characterized by sufficient inter-loop asymmetry to prolong the loop B flow and heat transfer activity while allowing the interrupted-loop level to enter the steam generator during steam generator refill, within the first 9 to 10 minutes of the transient. Such conditions were not obtained in the other three tests of this comparison (Figures 3.1.3 through 3.1.5). The boundary condition change separately imposed in these three tests -- open RVVVs, guard heaters deenergized, and no augmentation of core power -- apparently was each less conducive to initial inter-loop asymmetries than were the nominal settings of these boundary conditions.

The primary system pressures of the four tests approximately merged during the refill period (Figure 3.1.1), attesting to the reattainment of like global system conditions after traversing dissimilar earlier interactions and conditions. The refill repressurization of Test 2 with the RVVVs open was virtually coincident with that of Nominal Test 9. Little refill repressurization occurred with the guard heaters deenergized in Test 3.

The four test transients encountered similar events and event timings through the start of refill (Figures 3.1.2 through 3.1.5), with the exception of the early AFW-BCM in Test 9. Even with the boundary condition variations among the tests, intermediate hot leg levels occurred between approximately 90 and 95 minutes in each of the four tests.

Alternating AFW-BCMs occurred in Test 7, beginning at 61 minutes. However, the robust primary system depressurization was maintained, and the pressure-versus-mass trace of Test 7 continued to parallel those of the other tests.

The imposed boundary condition differences apparently had heightened impact later in the transients. For example, repressurization was suppressed with the guard heaters deenergized in Test 3, as has already been noted. Also in Test 3, spillover was achieved much earlier than usual and refill occurred at 165 minutes, after only 1 spillover. The timing and pressure-versus-mass trends of the other three tests were not markedly dissimilar. The first spillovers occurred between 270 and 330 minutes among the remaining three tests, and the refill of one loop occurred between 390 and 450 minutes. The events following spillover were highly dependent on the details of HPI throttling and steam generator secondary control; thus, inter-test comparisons later in the transients were not as direct as during the depressurization and early refill phases. In view of these limitations, upon spillover the primary system depressurized more in Test 7 without core power augmentation than in either Nominal Test 9 or Test 2 with the RVVVs open. The RVVVs ostensibly affected the reestablishment of natural circulation upon loop refill. However, the pressure-versus-mass trends of Test 2 with the RVVVs open were not unlike those of Nominal Test 9 with the RVVVs actuating automatically on differential pressure.

3.1.2. Tests Conducted After Enlargement of the Leak Flow Area

The following near-nominal tests used the enlarged (scaled) 10-cm² cold leg B1 discharge leak:

- 3104 Band Steam Generator Level Control
- 3105 Throttled AFW and Asymmetric Cooldown
- 3106 ATOG
- 3110 Repeat of Nominal
- 3111 Maximum Feed Wetting
- 3205 Leak Isolated

This list of tests was reduced to make room for other tests of interest. Tests 3104, 3105, 3106, and 3111 have been separately compared to the Nominal SBLOCA Test, in Volume 3, and were excluded from this comparison. Tests 3203 and 3600 were added to the comparison. Test 3203 used a cold leg suction rather than discharge leak, but otherwise used the nominal boundary system

controls for much of the test. Test 3600 was a repeat of the nominal SBLOCA but with MIST configured for operation of the model pumps. Volume 8 demonstrated that the leak flow area of Test 3600 more nearly corresponded to the area after enlargement rather than before. The four tests to be compared are then

- 10: 3110, Repeat of Nominal SBLOCA
- 3: 3203, Cold Leg Suction Leak
- 5: 3205, Leak Isolated
- 0: 3600, Nominal Repeat with Pumps Configuration

Nominal Repeat Test 10, unlike Test 3109 of the preceding comparison, did not depressurize through an early, interrupted-loop BCM. Thus, a lower minimum total primary fluid mass occurred in Test 10 than in Test 9 (Figure 3.1.6). The Test 10 depressurization mechanism leading to refill was prolonged HPI condensation of core-generated steam followed by BCMs (Figure 3.1.7). As the primary system repressurized with intermediate hot leg and steam generator primary levels, the pressure-versus-mass variations of Test 10 became almost identical to those of Nominal Test 3109 (Figure 3.1.6).

The Test 3 transient using a cold leg suction break (Figure 3.1.8) was quite similar to the Test 10 transient. However, at 195 minutes in Test 3, the primary system was depressurized by opening the PORV and by the resulting BCMs.

The leak was isolated at 30 minutes in Test 5. Following leak isolation, the primary system repressurized and gained fluid mass in a fashion that was almost a mirror image of the trends before leak isolation (Figure 3.1.9). The primary system refilled, recoupled, and depressurized beginning at 50 minutes, leading to subsequent interruptions of HPI to control the SCM.

Test 0 was a repeat of the nominal SBLOCA but with MIST configured for pump operation. As explained in Volume 8, the reduced system hydraulic resistance due to the replacement of the cold leg venturis with turbine meters obtained a somewhat higher initial natural circulation flow rate, a lower core fluid temperature rise, and therefore, a lower initial primary system pressure to obtain the specified initial SCM. The B1 cold leg discharge scaled 10-cm^2

leak orifice had been replaced after the other tests of this comparison and before Test 0, but the flow area of this orifice more nearly corresponded to the enlarged flow area common to this comparison. Flow area notwithstanding, the reduced initial primary system pressure of Test 0 obtained a correspondingly reduced leak flow rate, sustained circulation in loop B, and hence, sufficient inter-loop asymmetries to cause an early, interrupted-loop BCM as had occurred in Nominal Test 3109. The early interactions of Test 0 (Figure 3.1.10) thus more nearly resembled those of Nominal Test 3109, which was conducted with the smaller leak flow area than those of Nominal Repeat Test 10. The PORV was opened during the later stages of Test 0 (Figure 3.1.10) as it had been in Test 3 (Figure 3.1.8). As had occurred in Test 3, the PORV actuation obtained an immediate depressurization followed by subsequent BCM depressurizations, as the PORV discharge lowered the steam generator primary levels sufficiently to allow condensation of primary system vapor.

The four subject tests are compared through 30 minutes, the time of leak closure in Test 3, in Figure 3.1.11. The primary system pressure-versus-mass trends of Tests 10, 3, and 5 are identical; Isolated Leak Test 5 overlays Nominal Repeat Test 10 during the depressurization through HPI condensation. The trends of Test 0, Repeat Nominal With Pumps Configuration, are unlike those of the other three tests. Its lower initial pressure is apparent. At approximately 900 lbm total primary system fluid mass, the primary system depressurized only in Test 0 through an interrupted-loop BCM while feed remained active to complete the initial refill of the steam generator secondaries. This depressurization reduced the Test 0 pressure some 200 psi below those of the other tests.

This inter-test difference persisted through the start of primary system refill, but gradually diminished during the subsequent repressurization with intermediate hot leg steam generator primary levels (Figure 3.1.12). The pressure-versus-mass traces virtually merged as the repressurizations approached their maxima. The event timing as well as conditions were comparable among Tests 10, 3, and 0 (Figures 3.1.7, 3.1.8, and 3.1.10). The PORV was opened at 195 minutes in Test 3 and at 210 minutes in Test 0. These two tests then experienced almost identical depressurizations and variations of primary system total fluid mass (Figure 3.1.12).

FINAL DATA SBLOCA Tests Before Leak Area Enlargement

Figure 3.1.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA
Repeat-Nominal Vs Nominal SBLOCA Tests

Figure 3.1.6 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

Tue May 3 14:08:40 1988

910ppVpm

Tue May 3 11:58:12 1988

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 3.1.7 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T320302: Group 32 SBLOCA Test 3, Cold Leg Suction Leak.

Figure 3.1.8 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T320503: Group 32 SBLOCA Test 5, Leak Isolated.

Figure 3.1.9 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3600AA: Group 36 Test 0, Nominal SBLOCA With Pumps Configuration.

Figure 3.1.10 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA SBLOCA Tests After Leak Area Enlargement

Figure 3.1.11 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA
SBLOCA Tests After Leak Area Enlargement

Figure 3.1.12 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

3.2. ATOG

SBLOCA Tests 310699 and 3601AA were both conducted by operators versed in plant operations. The model reactor coolant pumps were not available in Test 3106, but were available in Test 3601; the tests otherwise had identical boundary system controls. A scaled 10-cm² cold leg B1 discharge leak was opened at test initiation. Both tests were begun in subcooled natural circulation. As saturation was approached, the core power reduction simulating decay was instituted, the reactor vessel vent valve controls were transferred to automatic, and both steam generator secondaries were refilled to 20.7 ft, which was equivalent to the natural circulation setpoint of 50% in the operating range using full-capacity AFW. Control of the test loop was then transferred to the operator versed in plant procedures. This operator then had control of the MIST boundary systems -- HPI; steam generator secondary pressure, level, and steam flow rate; and the PORV and hot leg high-point vents. Additionally, the operator could bump the model pumps in Test 3601 (and was encouraged to do so to enhance the MIST data base).

Early primary-to-secondary heat transfer was prolonged and enhanced in both ATOG tests by operator-instigated AFW throttling and alterations of steam generator secondary control pressure. When the primary system pressure stabilized in Test 3106 due to intermediate hot leg levels, the operator induced BCMs by actuating the PORV (3.1.1). The consequent primary system depressurization augmented the HPI flow rate while suppressing the leak mass flow rate. The operator then closed the PORV and obtained a spillover followed by loop refill.

PORV actuations were not used in Test 3601, ATOG With Pumps Available. Abrupt primary system depressurizations were obtained through two pump bumps (Figure 3.2.2). Thus, as in Test 3106, loop refill and depressurization were obtained relatively early in the Test 3601 transient.

Tests 3106 and 3601 were conducted five months apart. MIST was configured for natural circulation in Test 3106, but for forced circulation in Test 3601. Different operators versed in plant procedures controlled the two tests. The operator actuated the PORV in Test 3106 but not in Test 3601. Pump bumps were used in Test 3601 but not in Test 3106. Notwithstanding these many differences between tests, they traversed quite similar primary

system pressures versus time (Figure 3.2.3). This inter-test similarity is even more striking in a comparison of primary system pressure versus primary system total fluid mass (Figure 3.2.4). The primary system pressures in both tests were reduced to approximately 600 psia through HPI condensation and BCMs. These depressurizations obtained refill from a minimum primary system total fluid mass of approximately 790 lbm, about 16% less than the initial total mass, in both tests. In Test 3601, the depressurization obtaining the start of refill was augmented by a pump bump. As the primary system refilled, in both tests the primary system pressure stabilized. A second pump bump in Test 3601 obtained another abrupt primary system depressurization at a total fluid mass of 840 lbm. In Test 3106, however, a more gradual depressurization was instigated near 880 lbm by PORV actuations and consequent BCMs. The post-refill conditions of the two tests were virtually identical: primary system pressure less than 300 psia and primary system total fluid mass of approximately 1000 lbm (Figure 3.2.4).

FINAL DATA
T310699: Group 31 SBLOCA Test 6, ATOG.

Figure 3.2.1 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T3601AA: Group 36 Test 1, ATOG With Pumps Available.

Figure 3.2.2 Primary and Secondary System Pressures (GPO1s)

FINAL DATA

ATOOG SBLOCA Test 3601 (Pumps Available) Vs 3106 (Pumps Unavailable).

Figure 3.2.3 Reactor Vessel Pressure

FINAL DATA

ATOG SBLOCA Test 3601 (Pumps Available) Vs Test 3106 (Pumps Unavailable).

Figure 3.2.4 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

3.3. Venting

Test 3501 of the noncondensibles and venting group was conducted with continuous hot leg venting but without noncondensibles. Both hot leg high-point vents and the nominal scaled 10-cm² cold leg B1 discharge leak were opened at test initiation. Test 3501 was thus comparable to the nominal SBLOCA test except for the introduction of continuous hot leg venting.

Tests 3501 and 3110 (Repeat of Nominal SBLOCA) are compared in Figure 3.3.1. The general trends of these two tests were quite similar, and were almost coincident during the initial phases of depressurization and primary system mass reduction. However, during the primary system refill phase, the primary system gradually repressurized without venting (Test 3110), whereas the primary system pressure remained almost constant during refill in Test 3501.

The annotated traces of primary system pressure versus primary system total fluid mass reveal additional inter-test differences (Figures 3.3.2 and 3.3.3). Refill spillovers were observed without venting (Figure 3.3.2), delaying the loop A refill until 500 minutes. With venting (Figure 3.3.3), loop A spillover and refill occurred sequentially and in less than one-third of the time required for refill without venting. The earlier refill with venting is also illustrated in Figure 3.3.4. The suppression of the primary system repressurization during refill with venting was apparently due primarily to the primary fluid volume discharged by the vents. The venting activity in Test 3501 obtained slightly cooler hot leg riser metal temperatures than those of Test 3110 (Figure 3.3.5), but the hot leg stub metal temperatures exhibited the opposite trend (Figure 3.3.6). (The abrupt drop of the Test 3105 metal temperatures, just before 2 hours, reflected the desuperheating of this metal due to the rising riser and stub liquid levels.)

FINAL DATA

SBLOCA Test 3501 (Venting) Vs Test 3110 (Nominal Repeat).

Figure 3.3.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T311000: Group 31 Test 10, Repeat of Nominal SBLOCA.

Figure 3.3.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T350101: Group 35 Test 1, Venting Without Noncondensibles.

Figure 3.3.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA
SBLOCA Test 3501 (Venting) Vs 3110 (Nominal Repeat)

Figure 3.3.4 Hot Leg Riser Collapsed Liquid Levels

FINAL DATA
SBLOCA Test 3501 (Venting) Vs 3110 (Nominal Repeat)

Figure 3.3.5 Hot Leg Riser Metal Temperatures at 59.8 ft

FINAL DATA
SBLOCA Test 3501 (Venting) Vs 3110 (Nominal Repeat)

Figure 3.3.6 Hot Leg Stub Metal Temperatures at 59.8 ft

3.4. PORV

SBLOCA Test 3204 simulated a stuck-open PORV. With the PORV continually open and using full-capacity HPI, some of the boundary conditions of Test 3204 were like those of the Nominal HPI-PORV Cooling Test, Test 3301.

Test 3301BB was the Nominal HPI-PORV Cooling (Feed-and-Bleed) Test. Steam generator feed was interrupted to initiate the test. The primary system pressurized to the PORV actuation point at 16 minutes. The PORV was then held open manually, and full-capacity HPI was activated. The primary system quickly depressurized until the loop fluid saturated. The ensuing variations of primary system pressure and total fluid mass were largely governed by the conditions of the PORV-site fluid and adjustments of the HPI flow rate (Figure 3.4.1). The primary system generally depressurized through both HPI condensation of the core-generated vapor and the primary fluid volume reduction due mainly to the PORV discharge. The primary system total fluid mass decreased until the PORV-site fluid saturated at 18 minutes, then increased until HPI was interrupted with an SCM of 100F at 135 minutes. The primary system mass then declined rapidly, from approximately 980 to 825 lbm, until the pressurizer surge line was uncovered and HPI was reactivated and its flow rate adjusted. The primary system total fluid mass increased gradually beyond 3 hours, still with a slowly decreasing primary system pressure.

Test 3204 of the SBLOCA series employed a PORV break. The test was initiated by opening the PORV; full-capacity HPI was activated as the loop fluid saturated near 2 minutes. The boundary conditions of Test 3204 then resembled those of Nominal Feed-and-Bleed Test 3301 beyond 16 minutes, except that the steam generators remained active in Test 3204. This steam generator activity significantly influenced the progress of Test 3204 (Figure 3.4.2). Until the PORV-site fluid subcooled at 30 minutes, the HPI flow rate was sufficient to increase the primary system total fluid mass and thus to refill loop A at 19 minutes. The primary system then generally cooled through single-loop natural circulation heat transfer, and depressurized through fluid contraction and, later, HPI throttling. The primary system fluid mass gradually decreased beyond 30 minutes when the PORV-site fluid subcooled. Whereas loop A remained full and circulating, the loop B hot leg and steam

generator primary levels descended sufficiently to trigger AFW-BCM between 63 and 70 minutes, obtaining a 150-psi reduction of primary system pressure and a corresponding increase in the rate of gain of primary system total fluid mass.

Tests 3204 and 3301 exhibited dissimilar pressure-versus-mass characteristics (Figure 3.4.3). Upon HPI activation in SBLOCA Test 3204, the primary system pressure was sufficiently low to obtain an excess of HPI over PORV mass flow rate. Augmented by primary-to-secondary heat transfer, both subcooled and through vapor condensation, the primary system pressure was generally reduced and the primary system total fluid mass generally increased. The PORV actuation pressure was achieved in Feed-and-Bleed Test 3301, rather than opening the PORV manually. The PORV flow rate thus exceeded the HPI flow rate and the primary system initially lost mass. The pressure-versus-mass traces of the two tests converged briefly, near 30 minutes, with the PORV-site fluid approximately saturated. This brief period of inter-test similarity was disrupted when the PORV-site fluid subcooled in Test 3204 and, in Test 3301 at 135 minutes, HPI was interrupted with an SCM approaching 100F.

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.

Figure 3.4.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3204AA: Group 32 SBLOCA Test 4, PORV Break.

Figure 3.4.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA
Nominal Feed & Bleed T3301 Vs PORV-Break SBLOCA T3204.

Figure 3.4.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

3.5. Pump Operation

The model reactor coolant pumps were operated throughout SBLOCA Test 3602. Controlled conditions were otherwise those of Nominal Repeat SBLOCA Test 3110, which was conducted entirely without forced flow. The interactions of the two tests were dissimilar (Figure 3.5.1). The primary system remained coupled to the steam generator secondaries throughout Pumps-Operating Test 3602. The primary system depressurization was interrupted only briefly as its mechanism transferred from leak discharge to the depressurization of the steam generator secondaries (Figure 3.5.2). Depressurization as well as primary system refill were augmented by the forced convection of saturated fluid to the leak site, thereby accentuating the HPI-leak mass flow rate excess. The primary system refilled in just more than 1 hour, with the pump operating. Thereafter, its pressure-versus-mass trends were governed by pressurizer spray and by HPI throttling to control both the SCM and pressurizer level. Pumps-Operating Test 3602 was completed within 6 hours at less than 300 psia and 1160 lbm total primary fluid.

Repeat Nominal Test 3110 has been the subject of several inter-test comparisons herein, notably the reproducibility discussion of section 3.1. Test 3110 was conducted entirely without forced flow. Its initial depressurization, ending at loop saturation, was followed by gradual depressurizations through HPI condensation of core-generated steam as well as BCMs (Figure 3.1.7). The leak-site fluid remained subcooled, in contrast to the saturated conditions that were obtained with the pumps operating. The leak discharge mass flow rate remained elevated in Test 3110, therefore the primary system continued to lose inventory during approximately the first hour of the gradual depressurization. The loops had been refilled by this time, with the pumps running. The start of primary system refill in Repeat Nominal Test 3110 obtained intermediate hot leg and steam generator primary levels, interrupted primary-to-secondary heat transfer, and a gradual primary system repressurization. The repressurization of a similar magnitude with the pumps running occurred as HPI pressurized the already refilled loop, subsequently obtaining a sufficient SCM and pressurizer level to invoke pressurizer spraying and HPI throttling. These conditions of Pumps-Running Test 3602 occurred at approximately 1-1/2 hours, while the primary system conditions in

Repeat Nominal Test 3110 were approaching a long-duration equilibrium. Primary-to-secondary heat transfer remained largely dominant until 4-1/2 hours, and then was reactivated abruptly and intermittently through periods of hot leg U-bend spillover flow. Without forced flow, loop A was finally refilled beyond 8 hours, and single-loop natural circulation cooling ensued. At test completion near 11 hours, the primary system fluid inventory was approximately 1000 lbm versus 1160 lbm obtained in Test 3602 within 4 hours.

FINAL DATA

SBLOCA: Pumps Operating T3602 Vs Nominal Repeat T3110.

Figure 3.5.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 3.5.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

4. PUMP EFFECTS

The impact of pump operation on an SBLOCA transient has been addressed in section 3.5. The assessment of the effects of pump operation is extended herein, and includes

- Pump operation in two-phase flow
- Feed and bleed
- Tube rupture

The comparison of pump operation in two-phase flow employs three dissimilar tests: namely, Mapping Test 3008, SBLOCA Test 3602, and Core Uncovery Test 3801. Because the three test transients were dissimilar, different time spans were selected from each test for inter-test comparison. Each of these spans covered periods of increasing void fraction with the pumps not yet degraded. The pumps generally performed similarly for void fractions up to 12%, judging from their indications of normalized head, homologous head, and homologous flow. However, the pump input electrical power decreased with increasing void fraction in Mapping Test 3008 and Core Uncovery Test 3801, but not in SBLOCA Test 3602.

The feed-and-bleed comparison involves the Nominal HPI-PORV Cooling Test 3301 and Test 3604, HPI-PORV Cooling With Pumps Stopped on Loss of SCM. Whereas the primary system voided early in the transient and extensively as the transient progressed without forced flow, in Test 3604 the primary system pressure initially stabilized when the PORV-site fluid subcooled, delaying loop saturation for more than 1 hour. In Test 3604, significant reductions of the primary system total fluid mass occurred only as HPI was throttled to control the SCM. The final status of the two tests was similar.

Pump operation had only a temporary effect on the tube-rupture transient, and that inter-test difference occurred early in the transient. In Test 3605

with the pumps operating initially, the primary system depressurized more rapidly and to a lower value than in Nominal Tube Rupture Test 3401 without forced flow. The primary system pressure stabilized in Test 3605 while it decreased through early AFW-BCMs and HPI condensation in Test 3401, causing their traces of pressure versus mass to become almost coincident.

4.1. Pump Performance in Two-Phase Flow

The model reactor coolant pumps were operated in two-phase flow in the following four tests:

- 8: 3008, Mapping With Pumps Operating
- 2: 3602, SBLOCA With Pumps Operating
- 3: 3603, Worst Stop SBLOCA
- 1: 3801, Core Uncovery

Tests 2 and 3 have been compared in Volume 8, therefore only Tests 8, 2, and 1 are compared herein. Other than for pump operation, these three tests were quite dissimilar.

In Mapping Test 8, the primary system mass was gradually reduced by throttling HPI to control the leak-HPI flow rate imbalance. The primary system remained coupled to the steam generator secondaries, even with intermittent forced liquid flow and a primary system void fraction exceeding 40%. The steam generator secondary pressures were held constant, therefore most of the transient consisted of a gradual reduction of primary system mass at a constant primary system pressure. The pressure-versus-mass trace of Mapping Test 3008 is thus basically a horizontal line (Figure 4.1.1).

SBLOCA Test 3602, like Mapping Test 3008, involved continuous pump operation and a small break -- a scaled 10-cm² break in Test 2 versus a 5-cm² break in Test 8. However, HPI head-flow characteristics were used in Test 2, rather than throttling HPI for mass reduction as in the Mapping Tests. Also, the steam generator secondaries were depressurized to obtain a cooldown rate of 100F/h, when the primary-to-secondary temperature difference becomes less than 50F, rather than maintaining a constant secondary pressure as in the mapping tests. Thus, although primary-to-secondary heat transfer was maintained in both Tests 2 and 8, their transient interactions were dissimilar.

In SBLOCA Test 2, the primary system depressurized through both HPI cooling and primary-to-secondary heat transfer to the depressurizing steam generators, obtaining a diminished leak flow rate and an enhanced HPI flow rate. The primary system depressurization rate was enhanced by the forced-convection transport of saturated fluid to the cold leg discharge leak site. In SBLOCA Test 2, the loop was refilled in just more than 1 hour; pressurizer spraying and HPI throttling governed the subsequent pressure-versus-mass transient (Figure 4.1.2).

Core Uncovery Test 3801, the third test compared with the pumps running in two-phase flow, was also quite unlike the other two tests. The test was initiated by interrupting feed and opening both the PORV and a letdown simulation. The performance of pump A2 degraded upon the restoration of feed near 8 minutes, although the primary system total fluid mass had barely been perturbed from its initial value (Figure 4.1.3). HPI was virtually interrupted at 10 minutes, causing a prolonged reduction of primary fluid mass. Intermittent steam generator feed activity affected the primary system pressure, degraded the performance of the pumps in concert with the progressively increased system voiding, and finally triggered core heatups. System recovery steps were instituted at 101 minutes following the third core superheating event.

The pump performance of the three tests is compared during the periods of undegraded pump performance with increasing void fraction (Figures 4.1.4 through 4.1.6). These comparison periods vary greatly among the three tests, due to their dissimilar transients, and are as follows:

Mapping Test 8, 55 to 110 minutes

SBLOCA Test 2, 6 to 35 minutes

Core Uncovery Test 1, 5.4 to 8.1 minutes

Because of their unequal time spans, each of the data records over the brief comparison period of Test 1 was used, but approximately every tenth scan of Tests 8 and 2 was used.

The pump input electrical power of Mapping Test 8 gradually decreased with void fraction and became increasingly scattered among the pumps at higher void fractions (Figure 4.1.7). The power decrease became more pronounced at

the higher void fractions, especially above 12%, but the decrease up to 12% void fraction was only approximately 1% of the input power at zero voids, which was approximately 28 kW. Pump power versus void fraction for SBLOCA Test 2 also became more scattered with increasing void fraction, but evidenced no general reduction (Figure 4.1.8). The power to pumps 3 and 4 (A2 and B2) decreased slightly with void fraction, the power to pump 2 (B1) increased approximately 3% as void fraction reached 15%, and the power to pump 1 (A1) decreased sharply.

The anomalous behavior of pump A1 in SBLOCA Test 2 has been discussed at some length in Volume 8. Although pump A1 performed somewhat uncharacteristically throughout the test, its disparate behavior was particularly noticeable beyond 38 minutes -- in particular, it developed less head and mass flow rate as its inlet void fraction abruptly decreased. As has been discussed in Volume 8, these pump A1 trends were apparently real rather than being attributable to measurement discrepancies, but the cause of these trends has not been determined. The pump power versus void fraction for Test 2 over this period highlights the pump A1 idiosyncracies -- its input electrical power decreased approximately 15% as its pump-inlet void fraction declined to 10% (Figure 4.1.9).

Pump power varied inversely with void fraction in Core Uncovery Test 3801, as it had in Mapping Test 8. However, the power to the individual pumps was more scattered at lower void fractions than it had been in the Mapping Test. Power declined by about 3% as the pump inlet void fraction increased from 0 to 12% (Figure 4.1.10).

Pump normalized head was the two-phase head divided by rated head, both expressed as liquid heights, where the two-phase head was the measured head converted to an equivalent liquid height using the pump suction fluid density. Unlike pump power versus void fraction, the normalized-head trends were quite consistent among the three tests (Figures 4.1.11 through 4.1.13). In each case, the normalized head increased almost linearly with void fraction, then abruptly decreased above 12 to 14% void fraction. The pumps began to lose head at slightly unequal void fractions. The uncharacteristic behavior of pump A1 in SBLOCA Test 2 is apparent (Figure 4.1.12) but only at the highest void fractions. In Core Uncovery Test 1, the sampled void

fractions did not extend to the head-degradation range (Figure 4.1.13) (because of the early degradation of the performance of a pump).

Homologous flow was defined as the normalized flow divided by the square of the normalized pump speed (which was near unity in the test periods being compared), where normalized flow was the ratio of observed to rated volumetric flow rates. The trends of homologous flow were similar among the three tests, at least for void fractions up to 12% (Figures 4.1.14 through 4.1.16); homologous flow increased by 4% approximately linearly as the pump inlet void fractions increased to 12%. The performances of the individual pumps diverged at higher void fractions. Above approximately 12% void fraction, two pumps began to lose homologous flow with increasing void fraction in SBLOCA Test 2, but all pumps except pump 2 (B1) lost flow in Mapping Test 8. The sustenance of pump 3 (A2) in SBLOCA Test 2 may have been due to the uncharacteristic performance of adjacent pump 1 (A1) in that test.

The final comparison involves homologous head, which was the ratio of the normalized head to the square of the homologous flow. The pumps have been observed to perform quite consistently (for void fractions up to 12%) for both of these ingredient variables. Whereas the change of normalized head with void fraction was approximately direct, the change of homologous flow was approximately the square root of the change of void fraction. Homologous head, involving the square of flow in the denominator, should thus remain constant over the lower void fractions. This statement is approximately true (Figures 4.1.17 through 4.1.19). However, pump 2 (B1) began to lose homologous head in SBLOCA Test 2 above 8% void fraction (Figure 4.1.18) due to its increasing homologous flow (Figure 4.1.15). Homologous flow became increasingly disparate among the pumps at the higher void fractions. The outlying performance of pump A1 in SBLOCA Test 2 then became particularly noticeable (Figure 4.1.18).

FINAL DATA

Pump Tests: Mapping T3008, SBLOCA T3602, & Core Uncovery T3801

Figure 4.1.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 4.1.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA
T3801AA: Core Uncovery

Figure 4.1.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T300806: Group 30 Mapping Test 8, Pumps Operating.

6-7

Figure 4.1.4 Pump Suction Void Fraction From Gamma Densitometers (puNfv)

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 4.1.5 Pump Suction Void Fraction From Gamma Densitometers (puNfv)

FINAL DATA
T3801AA: Core Uncovery

4-11

Figure 4.1.6 Pump Suction Void Fraction From Gamma Densitometers (puNfv)

FINAL DATA

T300806: Group 30 Mapping Test 8, Pumps Operating.

Figure 4.1.7 Pump Electrical Power Vs Void Fraction, 55 to 110 Minutes

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 4.1.8 Pump Electrical Power Vs void Fraction, 6 to 35 Minutes

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 4.1.9 Pump Electrical Power Vs Void Fraction, 6 to 62 Minutes

FINAL DATA
T3801AA: Core Uncovery.

Figure 4.1.10 Pump Electrical Power Vs Void Fraction, 5.4 to 8.1 Minutes

FINAL DATA

T300806: Group 30 Mapping Test 8, Pumps Operating.

Figure 4.1.11 Observed Normalized Pump Head Vs Void Fraction, 55 to 110 Minutes

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 4.1.12 Observed Normalized Pump Head Vs Void Fraction, 6 to 35 Minutes

FINAL DATA
T3801AA: Core Uncovery.

Figure 4.1.13 Observed Normalized Pump Head Vs Void Fraction, 5.4 to 8.1 Minutes

FINAL DATA

T300806: Group 30 Mapping Test 8, Pumps Operating.

Figure 4.1.14 Pump Homologous Flow Vs Void Fraction, 55 to 110 Minutes

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

Figure 4.1.15 Pump Homologous Flow Vs Void Fraction, 6 to 35 Minutes

FINAL DATA
T3801AA: Core Uncovery.

Figure 4.1.16 Pump Homologous Flow Vs Void Fraction, 5.4 to 8.1 Minutes

FINAL DATA

T300806: Group 30 Mapping Test 8, Pumps Operating.

Figure 4.1.17 Observed Pump Homologous Head Vs Void Fraction, 55 to 110 Minutes

FINAL DATA

T3602DD: Group 36 Test 2, SBLOCA With Pumps Operating.

4-23

Figure 4.1.18 Observed Pump Homologous Head Vs Void Fraction, 6 to 35 Minutes

FINAL DATA
T3801AA: Core Uncovery.

Figure 4.1.19 Observed Pump Homologous Head Vs Void Fraction, 5.4 to 8.1 Minutes

4.2. Feed and Bleed

The model reactor coolant pumps were operated initially in HPI-PORV Cooling Test 3604, and the boundary system controls were otherwise those of the Nominal HPI-PORV Cooling Test 3301. However, the test transients were quite dissimilar (Figure 4.2.1). Nominal HPI-PORV Cooling Test 3301 was compared to the SBLOCA Test with a simulated stuck-open PORV, Test 3204, in section 3.4 (and has been described in detail in Volume 5). The pressure-versus-mass behavior of Test 3301 was governed largely by the state of the fluid at the PORV site (Figure 3.4.1) and, later in the transient, by adjustments of the HPI flow rate based on SCM. Test 3604 with pumps operating initially was similar in that regard (Figure 4.2.2), but there were significant differences between the two tests. With MIST initialized in natural circulation, the depressurization following PORV actuation was first arrested when the loop fluid saturated (Figure 3.4.1); this occurred within 2 minutes of PORV actuation. Within 10 additional minutes, primary system voiding had progressed sufficiently to trigger primary system depressurization through the condensation of core-generated vapor by HPI.

In Test 4 with the pumps operating initially, the initial depressurization was first arrested as liquid reached the PORV site, and again when the upper reactor vessel fluid saturated and then voided. The loop fluid remained subcooled until 70 minutes, more than 1 hour after PORV actuation, and HPI condensation was not encountered.

In both Tests 3604 using pumps and Nominal Feed-and-Bleed Test 3301 initialized in natural circulation, HPI was throttled based on the SCM, the pressurizer surge line was uncovered, and both hot leg vents were opened, all during the latter stages of the two transients. The timing of these later events was similar between the two tests (Figures 3.4.1 and 4.2.2), and their pressure-versus-mass responses were also similar (Figure 4.2.1).

FINAL DATA
Feed & Bleed With Pumps T3604 Vs Nominal T3301.

Figure 4.2.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T360499: Group 36 Test 4, Feed & Bleed - Pumps Stopped On Loss Of SCM.

Figure 4.2.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

4.3. Tube Rupture

The model reactor coolant pumps were operated initially in Test 3605 and were stopped on the loss of SCM. Test 3605 otherwise replicated the conditions of Test 3401, Nominal Tube Rupture. Due to the lower primary fluid saturation temperature with pumps running, the primary system initially depressurized to a lower value, and at a somewhat faster rate, in Test 3605 than in Test 3401 (Figure 4.3.1). However, the primary system pressures of the two tests reconverged at approximately 10 minutes, and their pressure-versus-time traces remained almost identical.

Without forced flow, the primary system fluid saturated and began to void at approximately 1-1/2 minutes and 1500 psia (Figure 4.3.2). However, the primary system subsequently resumed its depressurization through BCMs in steam generator A while its initial refill remained in progress. The relatively early occurrence of these BCMs, at approximately 3 minutes and again at 7 minutes, attests to the relatively high rate of inventory depletion caused by the high-elevation rupture of 10 tubes. In Test 3605 with pumps running initially, the initial primary system depressurization to saturation depleted the primary-to-secondary temperature difference sufficiently to stabilize the primary system pressure (Figure 4.3.3), thereby merging with the pressure-versus-time trace of Test 3401.

Beyond 10 minutes, both test transients encountered the HPI condensation of core-generated vapor, prolonged reverse heat transfer from intact steam generator A, and intermittent and robust heat transfer to ruptured steam generator B. Through these mechanisms, the primary system depressurized quite rapidly in both tests and the inter-loop conditions became highly asymmetric. Both test transients subsided shortly after 100 minutes. The intact steam generator A secondary had been reactivated, primary loop A had begun to be refilled, and both steam generator secondaries had been depressurized to nearly the facility low-pressure limit.

FINAL DATA

Tube Rupture: With Pumps T3605 Vs Nominal T3401.

Figure 4.3.1 Reactor Vessel Pressure (RVGP01)

FINAL DATA

T340100: Group 34 Test 1, Nominal Tube Rupture.

Figure 4.3.2 Primary and Secondary System Pressures (GP01s)

FINAL DATA

T360514: Group 36 Test 5, Tube Rupture - Pumps Stopped On Loss Of SCM.

Figure 4.3.3 Primary and Secondary System Pressures (GP01s)

5. EFFECTS OF NONCONDENSIBLES

The NCG tests of Group 35 employed both cold leg suction and discharge, scaled 10-cm² leaks, thus suggesting comparisons to the SBLOCA tests (without NCG) of Groups 31 and 32. SBLOCA tests with and without NCG having cold leg discharge leaks are compared in section 5.1, and those having cold leg suction leaks are compared in section 5.2.

Of the NCG tests having a cold leg discharge break, Test 3505 was selected for comparison (with Repeat Nominal SBLOCA Test 3110) because of its absence of hot leg venting. The BCM depressurizations were generally lessened in Test 3505 with NCGs. The NCG test also attained lower primary system fluid inventories than Test 3110, reflecting cold leg voiding.

NCG Tests 3507 and 3508 having cold leg suction breaks are compared to SBLOCA Test 3203, also having a suction break. However, continuous hot leg high-point venting was employed in both NCG tests, but not in Test 3203. The three tests were similar through the initial depressurization, HPI condensation, and BCM phases to the start of refill. Then, the PORV was opened in Test 3203, whereas the leak was closed in the NCG tests.

5.1. Cold Leg Discharge Break

Noncondensable Gas Test 3505 used a scaled 10-cm² cold leg B1 discharge break, as had been used in Nominal Repeat Test 3110. In Test 3505, helium was injected continuously into the lower-reactor vessel piping from leak initiation at time 0 until 108 minutes. Neither hot leg venting nor leak isolation were employed in NCG Test 3505, both of which conditions were comparable to those of Test 3110. The pressure-versus-mass traces of two tests highlight several inter-test differences (Figure 5.1.1). Whereas the primary system gradually depressurized following saturation in the Repeat Nominal Test (Figure 3.1.7), the pressure remained near saturation in Test

3505 (Figure 5.1.2), so that the depressurization through HPI condensation began from a higher pressure than in Test 3110.

The inter-test differences grew as HPI condensation and depressurization continued. The cold legs began to void in the NCG test, obtaining a lower primary system mass at pressure than in Test 3110. Whereas BCM depressurization began at 36 minutes in Test 3110, at 38 minutes in Test 3505 the cold leg voiding had progressed sufficiently to uncover the leak site. The rate of inventory loss declined but the break site fluid temperature continued to indicate subcooling due to the effects of the noncondensibles. The primary system began to be depressurized through BCMs in gas Test 3505 at 57 minutes. This depressurization obtained a positive HPI-leak mass balance. As refill began and the steam generator primary levels were raised in the NCG test, the BCM depressurization was diminished and then halted at a primary system pressure of approximately 700 psia. The BCM depressurization of Test 3110 was halted at 85 minutes and 450 psia as system refill obtained intermediate levels. The primary system then gradually repressurized to 650 psia, i.e. about the post-BCM pressure of the NCG test, but at a significantly higher primary system total fluid mass that was reflected by the extensive cold leg voiding in Test 3505.

The inter-test differences continued through the completion of the tests. Repeat Nominal Test 3110 abruptly depressurized through spillovers (accompanied by HPI throttling) at 270 and 315 minutes, and through single-loop natural circulation with continued HPI throttling after 500 minutes. In Test 3505, however, the primary system very slowly depressurized after the helium injection had been completed at 108 minutes. The hot leg A riser was refilled at approximately 320 minutes, but with little impact on primary system pressure. Upon test completion at 7 hours, the pressure remained above 500 psia, and the primary fluid mass was some 100 lbm less than it had been in the repeat nominal test.

FINAL DATA

SBLOCA: CLD Break With NCG Test 3505 Vs Repeat Nominal Test 3110.

Figure 5.1.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T350502: Group 35 Test 5, Noncondensibles Without Venting.

Figure 5.1.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

5.2. Cold Leg Suction Leak

NCG and Venting Tests 3507 and 3508 used cold leg suction leaks, as had been used in SBLOCA Test 3203. Helium was injected into the lower reactor vessel piping in Test 3507, and nitrogen in Test 3508. Also, in the two Group 35 tests, both hot leg high-point vents were kept open throughout the transients. The PORV was opened in all three tests being compared, but under differing circumstances.

The SBLOCA Test 3203 transient (Figure 5.2.1) was similar to that experienced in the several SBLOCA tests having discharge rather than suction leaks. The transient events included

- Rapid depressurization to saturation
- Brief AFW-BCM involving the steam generator of the interrupted loop (A) during secondary refill
- Mass reduction at constant pressure during intermittent loop flow
- Gradual depressurization through the condensation of core-generated steam by HPI
- Abrupt primary system depressurization, leading to the start of refill, via AFW-BCMs
- Interruption of primary-to-secondary heat transfer due to intermediate levels, gradual primary system repressurization toward equilibrium

Unlike most other SBLOCA tests, in Test 3203 the PORV was opened at 195 minutes to ascertain its impact on equilibrium. The primary system depressurized relatively rapidly, first due to the PORV discharge itself and then due to BCMs triggered by the decreasing steam generator primary levels. The test was completed at 422 minutes, with a primary system pressure approaching 200 psia.

NCG Tests 3507 and 3508 were initiated by opening both hot leg high-point vents and initiating the noncondensable injection, as well as by opening the scaled 10-cm² cold leg B1 suction leak. The subsequent events were similar to those which had occurred without noncondensibles. However, in both NCG tests, the BCM depressurizations were not as distinct as they had been without NCG, and the primary system depressurized slightly as the gas injections were completed at 109 minutes (Figures 5.2.2 and 5.2.3). The cold

leg suction leak was closed at 124 minutes in Test 3507 and at 146 minutes in Test 3508. In both NCG tests, the hot legs refilled within a few minutes of leak closure, but the primary system repressurization continued unabated. A spillover had occurred before leak closure in Test 3508, but also without a pronounced depressurization. The primary system continued to repressurize in both NCG tests, increasing the SCM and thereby prompting PORV actuation and HPI throttling to control the SCM. These events occurred at 139 minutes in Test 3507, and at 158 minutes in Test 3508. The remainder of both tests continued with the PORV held open and HPI throttled.

The pressure-versus-mass trends of the three tests were similar through the primary repressurization phase (Figure 5.2.4). NCG Tests 3507 and 3508 depressurized through the start of refill at slightly higher primary system inventories than did SBLOCA Test 3203, apparently due to the continuous hot leg venting of the NCG tests. The transients diverged upon PORV actuation in Test 3203 versus leak closure in the NCG tests. Upon the PORV actuations to control SCM in the NCG tests, the primary system depressurized at a higher primary system fluid inventory than in the SBLOCA test, due to the absence of the leak discharge.

T320302: Group 32 SBLOCA Test 3, Cold Leg Suction Leak.

Figure 5.2.1 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T350700: Group 35 Test 7, Helium and Suction Leak.

Figure 5.2.2 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

T350800: Group 35 Test 8, Nitrogen and Suction Leak.

Figure 5.2.3 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

FINAL DATA

SBLOCA CLS: Helium Test 3507 and Nitrogen Test 3508 Vs Test 3203.

Figure 5.2.4 Reactor Vessel Pressure Vs Primary System Total Fluid Mass

6. SUMMARY

The MIST interactions are of intrinsic interest because they may provide insight into expected plant behavior. MIST was necessarily atypical of a plant in certain important respects, however. The MIST interactions therefore are not to be applied directly to a plant. Inter-group comparisons have been made using the following four groupings:

- Mapping Versus SBLOCA
- SBLOCA
- Pump Effects
- Effects of Noncondensibles

6.1. Mapping Versus SBLOCA

The mapping test transients were compared to those of the SBLOCA tests. The mapping and SBLOCA tests were first separately reviewed. Their key events were identified, with special emphasis on the conditions surrounding the interruption of loop flow. Specific inter-test comparisons of mapping test interactions with those of SBLOCA transients included the following conditions:

- Reduced-capacity HPI
- RVVVs closed
- Mapping without HPI

Traces of primary system pressure versus primary system total fluid mass were used extensively for these comparisons and throughout this volume. These traces, labelled to describe key events and timing, provided a comprehensive summary of major test trends on a single plot.

Flow Interruption

The flow interruption mechanisms differed between the SBLOCA and mapping tests. HPI was throttled in the mapping tests, to gradually reduce the primary system total fluid inventory, while holding core power constant. In the SBLOCA transients, however, core power was reduced to simulate post-trip decay and scaled plant HPI head-flow characteristics were used, obtaining increased HPI flow rates as the primary system was depressurized. As a result of these basic differences between the two types of tests, HPI was generally sufficient to condense all of the core-generated steam in the SBLOCA transients, but insufficient in the mapping tests. Loop flow persisted in the mapping tests until all the core region fluid saturated and the subsequent increased core void production uncovered the hot leg nozzles. The primary system then repressurized quite rapidly until BCM depressurizations or, in several mapping tests, until the PORV lifted. In the SBLOCA transients, however, the primary system depressurized upon the interruption of loop flow. Interruption occurred when the downcomer level first descended to the elevation of the cold leg nozzles, permitting the condensation of core-generated vapor by HPI.

6.2. SBLOCA

Reproducibility

The reproducibility of several near-nominal SBLOCA tests conducted before the enlargement of the leak flow area, and also conducted after this enlargement, was examined. The pressure-versus-mass trends of these tests were remarkably similar. In all of these tests, the steam generator primary level of the interrupted loop descended toward the elevation of the steam generator upper tubesheets as the initial refill of the steam generator secondaries was being completed. In a few of these tests having sufficient inter-loop asymmetries to support such a level imbalance, notably Nominal SBLOCA Test 3109, a steam generator primary level fell into the steam generator while feed was still active, causing an early AFW-BCM depressurization. The pressure-versus-mass traces of these tests thus differed from those of the tests without the early BCM, but these inter-test differences gradually diminished as the test progressed.

The remainder of the SBLOCA discussions pertained to the following inter-test comparisons:

- ATOG
- Venting
- PORV
- Pump operation

ATOG

Of two tests controlled by operators versed in plant procedures, the PORV was opened in Test 3106 whereas the pumps were bumped in Test 3601. The resulting trends of the two tests were surprisingly similar, considering their dissimilar control methods. Refill and post-refill cooldown were achieved relatively early in both of these operator-controlled tests. Venting also promoted refill and suppressed the multiple pre-refill hot leg U-bend spillovers in a comparison of venting Tests 3501 with SBLOCA Nominal Repeat Test 3110.

PORV

The PORV comparison of section 3 involved the Nominal Feed-and-Bleed Test 3301 and SBLOCA Test 3204 simulating a PORV break. The major inter-test difference of boundary conditions involved the availability of steam generators in SBLOCA Test 3204. Also, the PORV was opened to initiate Test 3204 whereas the PORV first actuated on overpressure, due to the interruption of feed, in HPI-PORV Cooling Test 3301. Whereas the primary system generally depressurized and refilled in SBLOCA Test 3204, the primary voided extensively in Test 3301, reflecting the aforementioned inter-test differences in boundary conditions.

Pump Operation

Operation of the model reactor coolant pumps had a profound effect on the SBLOCA transient interactions. With the pumps operating throughout an SBLOCA transient, the primary system quickly depressurized and refilled. The key interactions were twofold: (1) the forced convection of saturated liquid to the break site, thereby minimizing the break mass flow rate while sustaining the break volumetric flow rate as well as the rate of energy removal by the

break discharge, and (2) the continued primary-to-secondary heat transfer sustained by forced flow. In SBLOCA Test 3602 with the pumps kept in operation, the loop refilled in just more than 1 hour whereas, in the comparison Nominal Repeat SBLOCA Test 3110, even single-loop refill was delayed until 500 minutes and then was preceded by multiple, intermittent hot leg U-bend spillovers.

6.3. Pump Effects

Pump Performance in Two-Phase Flow

The performance of the model reactor coolant pumps in two-phase flow was compared among three dissimilar tests: namely, Mapping Test 3008, SBLOCA Test 3602, and Core Uncovery Test 3801. The test spans for comparison were chosen to cover periods of increasing void fraction with the pumps not yet degraded. The pumps generally performed similarly in two-phase flow, their performance becoming more variable as pump suction void fraction exceeded approximately 12%. Similar responses of normalized head, homologous flow, and homologous head were observed. However, pump input electrical power decreased somewhat with increasing void fraction in Mapping Test 3008 and Core Uncovery Test 3801, but remained approximately constant up to 12% void fraction in SBLOCA Test 3602.

HPI-PORV Cooling

The model reactor coolant pumps were operated initially and tripped on the loss of SCM in HPI-PORV Cooling Test 3604 and in Tube Rupture Test 3605. These two tests otherwise repeated their nominal counterparts, Nominal HPI-PORV Cooling Test 3301 and Nominal Tube Rupture Test 3401. Initial pump operation had a pronounced impact on the HPI-PORV cooling transient. The primary loop fluid remained subcooled in Test 3604 with pumps, whereas the loop fluid saturated and voided during the initial depressurization in Test 3301 without forced flow. The additional loop fluid subcooling obtained initially with forced flow allowed the primary system pressure to stabilize as liquid reached the PORV site. The primary system voided extensively only as HPI was throttled to control the SCM.

Tube Rupture

Pump operation had only a transitory effect on the tube rupture transient. The pressure-versus-time trace of Test 3605 with pumps diverged from that of Nominal Tube Rupture Test 3401 as the primary system initially depressurized further and more rapidly in Test 3605, but these inter-test differences were depleted within 10 minutes. The trends of Tests 3605 and 3401 then became virtually identical.

6.4. Noncondensibles

SBLOCA tests with and without NCG were compared for a cold leg discharge break location and for a cold leg suction break. The boundary conditions of the discharge break tests (3505 and 3110) were otherwise similar, but the suction break tests with NCG (Tests 3507 and 3508) both used continuous hot leg high-point venting, unlike the counterpart test without NCG (Test 3203). Noncondensibles diminished the BCM depressurizations and, by fostering cold leg voiding, generally diminished the primary system fluid inventories.

APPENDIX A
Description and Index of Microfiched Plots

Microfiched plots are enclosed with each of Volumes 2 through 8. These plots cover exhaustively each individual test. They are of sufficient scope to describe most major test interactions. The standard plot set applies to each test of the group but, infrequently, plots were substituted or deleted due to instrument availability. This appendix provides supporting information and the cross-indexes necessary to easily access and understand the plots. Because the microfiched plots span an entire test, the plots included with the text should be consulted for subtle interactions, particularly for those events that are of short duration. The sections below address the following topics:

- Plot indexes
- Inaccuracies
- Plotting interval and frequency
- Conversion factors
- Calculated variables

1. Plot Indexes

Tables A.1 through A.4 and Figures A.1 through A.4 compose a complete index of the enclosed microfiched plots. Table A.1 is indexed by system and by type of measurement, and lists the plot that contains that data. Table A.2 gives the description, plotted instruments, and conversion factors for each enclosed plot. Table A.3 is the reverse of Table A.2 -- Table A.3 is indexed by instrument and lists the enclosed plot(s) that pertain to each instrument. Table A.4 is a complete listing of all of the MIST instruments; the description and elevation of each instrument are provided. Finally, Figures A.1 through A.4 are schematics of MIST showing the instrument locations.

To investigate a particular plot, enter Table A.2 with the plot identifier printed on the lower right-hand corner of each plot. Table A.2 provides a description of the plot as well as a listing of the instrument readings being plotted. These are the six-character alpha-numeric instrument identifiers called "VTABs." Upper-case VTABs represent measurements or direct syntheses of measurements, and lower-case VTABs represent calculated values. To obtain

additional information regarding the plotted measurements, refer to Table A.4.

To obtain information concerning a local phenomena, refer to Figures A.1 through A.4 to locate the instruments that may provide data of interest. Refer to Table A.4, if necessary, to refine the selection of instruments of interest. Finally, enter Table A.3 to determine the plots that contain the readings of interest. Alternatively, enter Table A.1 with the measurements of interest and read the corresponding plots directly.

2. Inaccuracies

The enclosed plots as well as the text plots use revised final data, rather than the preliminary data contained in the Immediate Reports. The final data have been reprocessed at least once, both to delete erroneous data and to incorporate revised conversion algorithms. The revised final data include the error correction addressed in PMG Correspondence Number 699 dated 15 July 1987. That is, in each data set included herein, the conversions of pressure transducer output to engineering data have correctly applied the adjustments for the transducer sensitivity to absolute pressure.

The calculated variables, denoted by lower-case descriptors and described briefly in section 5 of this appendix, are subject to inaccuracies of assumptions and measurement syntheses.

3. Plotting Intervals and Data Frequency

Each test consisted of three periods of data taking, namely pre-test steady-state, the test transient, and post-test refill, venting, and gas collection. The pre-test portion was recorded at negative times referenced to the zero-time datum at test initiation, which was leak opening in Group 35. The post-test portion occurred after the test loop operator recorded test termination, and was generally characterized by abrupt changes in system conditions, such as those caused by HPI increase and alteration of core power. These post-test manipulations were continued, with the data acquisition system active, until loop refill was achieved and gas venting and sampling were completed, primarily to obtain gas closure. The microfiched plots exclude the pre-test and post-test data; they extend from time 0 until test termination.

The plots are constructed to clearly indicate the frequency of the plotted data. The first curve (first in the plot legend and using the "+" symbol) has its symbol plotted at every tenth plotted point. The subsequent curves are plotted at the same data frequency as the first curve, but have their symbols positioned for clarity rather than as an indication of data frequency. To illustrate the interpretation of the density of the "+" symbols, consider a plot spanning 0 to 80 minutes having five "+" symbols per inch of plotted abscissa. Each inch of plotted abscissa spans 10 minutes. The "+" symbols thus appear at 2.5-minute intervals. There are 10 plotted points per plotted "+" symbol, thus the points are plotted every 0.25 minutes or 15 seconds. Data were generally acquired at 5-second intervals. Thus, every third acquired point has been plotted in this example.

4. Conversion Factors

The key MIST conversion factors are listed below.

Power: 1% of scaled full power

$$= 33 \text{ kW} = 31.3 \text{ Btu/s}$$

Primary Flow Rate (Total Primary System):

1% of scaled full flow

$$= 0.46 \text{ lbm/s} = 1660 \text{ lbm/h} = 0.21 \text{ kg/s}$$

Secondary Flow Rate (Total Secondary System):

1% of scaled full flow

$$= 0.0384 \text{ lbm/s} = 138. \text{ lbm/h} = 0.0174 \text{ kg/s}$$

MIST piping was larger than power-to-volume scaled in consideration of two-phase phenomena and hydraulic losses. Whereas the plant-to-MIST power scaling factor was 817, the corresponding volume scaling factor was 620 for the total primary system volume (CFT excluded), and 600 for the primary system excluding the CFT and the pressurizer.

5. Calculated Variables

Calculated variables, denoted by lower-case descriptors, involve extensive assumptions, calculations, and measurement syntheses, and are thus subject to inaccuracies. The bases of the energy calculations and volume balances are

described in the following subsections. These discussions are preceded by a description of the smoothing technique that has been employed extensively in the calculations described herein.

5.1. Smoothing

Smoothing was used to obtain the PORV, CFT discharge, steam generator B steaming, and tube rupture mass flow rates, the primary and secondary system heat transfer due to changes in metal stored energy, the heat transfer due to changes in fluid stored energy of the steam generator secondaries, and the trended, indicated total primary fluid mass used to calculate the tube rupture flow rate. Smoothing was required to avoid the high-frequency noise introduced by differencing over relatively short time increments. It was also required to compensate for spurious individual signals sometimes encountered in the data base. For example, the CFT differential pressure and, hence, level and mass indications sometimes included a single aphysical point when the CFT reactivated and when it deactivated, apparently due to the abrupt changes of CFT conditions. Smoothing was then required to prevent these relatively large and instantaneous tank fluid mass changes from being erroneously interpreted as large positive and negative tank discharge mass flow rates.

The smoothing technique was designed to preserve trends while ignoring noise. The technique was sufficiently responsive to accurately reflect rapid changes in conditions such as the sudden and continuing change in steam generator fluid stored energy obtained when full-capacity feed flow was introduced to refill the steam generator secondaries. The smoothing technique involved comparisons of current and future trends. To illustrate the technique, assume that the available variable is core flood tank fluid mass versus time, and the desired output is core flood tank discharge mass flow rate. The current flow rate was obtained by differencing the mass entries over the next time increment; the flow rate trend was obtained by differencing the current mass and the mass averaged over several time increments beyond the next time increment. If the sign of the current and trended flow rates disagreed, then the change in flow rate over the previous increment was extended to the current increment. If the signs of the current and trended flow rates agreed, then the lesser flow rate change was used. Whichever flow rate was

used, the mass at the next time increment was obtained from the current mass by applying the flow rate used. This technique ignored noise, followed trends, was responsive to rapid changes in slope (flow rate, in the example), and, through the mass-update step applying the flow rate used, conserved the supplied variable.

5.2. Steam Generator Secondary Energy Balance

Steam generator secondary energy balances were performed to obtain the primary-to-secondary heat transfer. This may be compared directly to the steam generator primary-side heat transfer during periods of relatively high primary flow rate, such as during pre-test steady state. However, during most of the test transients, the primary flow rate was of insufficient magnitude to admit to the direct, primary-side determination of steam generator heat transfer. Thus, the secondary side energy balances were important not only intrinsically but also to provide primary-to-secondary heat removal for the primary system energy balance. The overall balance is first addressed, then the calculations of the individual secondary side heat transfer components are described.

5.2.1. Steam Generator Heat Transfer

Primary-to-secondary heat transfer for steam generators A (qs1pts) and B (qs2pts) were obtained by adding the following heat transfer rates:

- The rate of change of steam generator secondary fluid stored energy (qs1fl and qs2fl).
- The rate of change of steam generator secondary metal stored energy (qs1met and qs2met).
- The uncompensated steam generator secondary losses to ambient (qs1lta and qs2lta).
- The steam flow minus feed flow energy transfer (qs1smf and qs2mf).

The primary-to-secondary heat transfer was set to zero in the HPI-PORV cooling tests in which feed was interrupted and the steam generator secondaries were pressurized with nitrogen as they dried out (to maintain the primary-to-secondary pressure difference within the facility limits while minimizing primary-to-secondary heat transfer). The nitrogen in the secondaries gradually affected the secondary pressure transducer readings, thus

affecting the steam generator level, mass, and fluid stored energy indications. To avoid these erroneous indications, the total primary-to-secondary heat transfer was set to zero in the HPI-PORV cooling tests when the steam-minus-feed heat transfer decreased below 0.1% of scaled full power, but not later than 25 minutes after feed interruption.

Neither the primary system energy balance nor the steam generator B secondary energy balance explicitly considered the tube rupture effects (in Test Group 34). The steam generator B primary-to-secondary heat transfer was calculated from the secondary system energy balance, however. Thus, this primary-to-secondary heat transfer as well as the primary system energy balance included the rupture contribution.

5.2.2. Steam Generator Secondary Fluid Stored Energy and Rate of Change

The rates of change of fluid stored energy in steam generators A (qs1fl) and B (qs2fl) were obtained by applying the smoothing technique, described separately herein, to the steam generator A and B total fluid energies (es1fl and es2fl). The total fluid stored energy in each generator was obtained by summing the liquid energy contribution and the vapor contribution. The liquid was assumed to be saturated, the vapor was assumed to trend toward the steam outlet temperature but to respond to changes in saturation temperature, and to be no less than saturation. This dual assignment of the vapor temperature was necessitated by the gradual cooling of the steam outlet temperature when steam flow was interrupted followed by rapid reheating when steam flow was reactivated, with neither trend reflecting actual changes of the vapor stored energy.

Similar to the vapor temperature assignment, the liquid mass was trended toward the indicated fluid mass but made to respond to changes in steam and feed flow rates. This logic was applied to avoid the indicated fluid mass changes obtained by momentary interactions between feed flow and level indications, while retaining responsiveness to actual flow rate changes. The vapor mass was obtained by combining the steam generator elevation not occupied by liquid and the vapor density.

5.2.3. Steam Generator Secondary Metal Stored Energy and Rate of Change

The rates of change of secondary metal stored energy for steam generators A ($qs1met$) and B ($qs2met$) were obtained by applying the smoothing technique, described separately herein, to the total secondary metal stored energies of steam generators A ($es1met$) and B ($es2met$). The metal masses of each steam generator were subdivided into that portion adjacent to liquid and that portion adjacent to vapor, according to the current collapsed liquid level (obtained as described for the secondary fluid stored energy calculations).

Both metal subdivisions were assigned base temperatures. The base temperature of the metal adjacent to liquid was assigned saturation temperature, the metal adjacent to vapor was assigned a base temperature equal to the trended vapor temperature (also described for the total secondary fluid energy calculations). The metal temperatures were assumed to change toward their current base temperatures using exponential decay of the temperature difference. The associated time constants were 1 minute for metal adjacent to liquid and 2 minutes for metal adjacent to vapor. These time constants were based on metal dimensions and characteristics, but were adjusted based on comparisons of calculated metal stored energy changes versus those inferred from other steam generator secondary measurements. The liquid and metal exponential decay were also applied to govern the transfer of metal mass between liquid-adjacent and vapor-adjacent regions, based upon steam generator level change.

5.2.4. Steam Generator Secondary Uncompensated Heat Losses

The uncompensated losses to ambient from the secondaries of steam generators A ($qs1lta$) and B ($qs2lta$) were set to 0.06% of scaled full power each at 550F, and to zero at and below 180F, with linear variation with secondary saturation temperature. The value at 550F was obtained by the examination of steady-state pre-test data. The 180F lower value and the linear variation were taken from whole-loop heat loss data.

5.2.5. Steam and Feed Energy Transfer

The combined steam and feed generators A ($qs1smf$) and B ($qs2smf$) were obtained by differencing the appropriate flow rate-enthalpy products. For

those tube rupture (Group 34) tests in which the steam generator B steam flow rates were unavailable, the steam flow rate was calculated from the indicated versus calculated steam generator B mass balance. The calculated mass balance involved the calculated tube rupture mass flow rate, therefore the calculated steam generator B steaming rate was of limited accuracy. Smoothing was applied to the calculated steaming rate.

The quality of the steam generator B secondary exit steam was calculated from the steam flow meter differential pressures (DPs) when they were available. If they were unavailable, the steam enthalpy was calculated at secondary pressure and the steam exit temperature, defaulting to that of saturated steam if the steam exit temperature was within 1F of saturation. When the DPs were available, the measured DP was compared to those with liquid only (DPL) and with vapor only (DPV). The DP-difference was $DPLV = DPV - DPL$. If the measured DP was less than $DPL + 0.1 DPLV$, then the steam enthalpy was limited to the saturated liquid enthalpy or less. If the measured DP was greater than $DPV - 0.1 DPLV$, then the steam exit enthalpy was limited to the saturated vapor enthalpy or greater. And if the measured DP (DPM) was intermediate, then the steam exit quality was obtained using the approximation

$$x = (DPM - DPL) / (DPV - DPL)$$

and the steam exit enthalpy was determined from this quality. This x-approximation was based on that of Murdock as reported by Tong (Boiling Heat Transfer and Two-Phase Flow, page 102). Although this determination of steam enthalpy as well as the calculation of tube rupture flow rate and steam generator B steaming rate involved numerous approximations, the resulting primary fluid total energy was generally similar to the indicated primary fluid total energy.

5.3. Primary System Energy Balance

The primary system energy balance provided a calculated total fluid energy based on the integral of the net heat transfer summed over each of the boundary streams. This calculated value was completely independent of the indicated total fluid energy, which was obtained from measured levels and fluid conditions within the primary system. The calculated and indicated

total primary system fluid energies thus provided a basic consistency check, reflecting at least the qualitative consistency of the myriad measurements embodied in the two energy balances. The total fluid energy calculation is described in section 5.3.1, and the calculations of the contributions are addressed in the later subsections. Section 5.3.4 deals with the PORV total mass flow rate and discharge fluid enthalpy calculations. Because of the absence of a measurement of PORV effluent enthalpy, enthalpy was calculated by comparing the observed mass flow rate to the predicted critical mass flow rate.

5.3.1. Calculated Primary System Total Fluid Energy and Normalization

The calculated primary system total fluid energy (e_{prflc}) was obtained by adding the current energy change to the total at the previous time increment. The calculated value at the start of the test, time zero, was set equal to the indicated total primary system fluid energy at time zero. The current energy change was obtained by multiplying the net primary system heat transfer by the current time increment. The net primary system heat transfer was the core input power (q_{corein}) less the sum of the following contributions:

- The steam generator A primary-to-secondary heat transfer (q_{slpts}).
- The steam generator B primary-to-secondary heat transfer (q_{s2pts}).
- The net effluent (discharges minus HPI) heat transfer (q_{lkhpi}).
- The change in primary metal stored energy (q_{prmet}).
- The uncompensated primary system heat losses to ambient (q_{prlta}).

Normalization of Total Primary Fluid Energy

The normalized calculated primary fluid energy (e_{prflnc}) was obtained by dividing the calculated primary total fluid energy by the indicated primary total fluid energy at time zero. If the reactor coolant pumps were operating, however, several liquid level measurements were unavailable and the indicated total fluid energy was not meaningful. In this instance, the total fluid energy at time zero was assumed to be 450,000 Btu (based on customary initial conditions). Also in this instance of pumps operating, the indicated

total fluid energy (eprfli) was set to negative infinity (forcing plot interruption) until the pumps were stopped. The pump stop was assumed to occur when the pump A1 speed (using variable C1TA20) decreased below 500 rpm.

5.3.2. Core Input Power

Core power corrected for electrical resistive losses (qcorein) was obtained by subtracting the estimated electrical loss from the measured core electrical power (supplied in variable RVWM20). The estimated loss (kW) was $4.01 \times 10^{-7} i^2$ where "i" was the core electrical current (amps) supplied in variable RVAM01.

5.3.3. Primary Metal Stored Energy and Heat Transfer

Primary metal stored energy (eprmet) calculations used component metal masses, local fluid temperatures, and time constants. Three fluid temperature indications were supplied for each of the 21 metal components. If the first identified temperature measurement contained any error indications then the second was used, and similarly if the second contained error indications. If all three indications had error indications, then the corresponding fluid temperature was set to the average of the fluid temperatures associated with the other components.

Each metal component was assumed to transfer heat from or to its base temperature. The base temperature was taken to be the local fluid temperature for components that were guard heated. For components that were not guard heated, the base temperature was taken to be midway between the local fluid temperature and the temperature of the metal face that was only passively insulated. Based on observations of loop heat loss, the uncompensated heat losses were negligible near 180F. Therefore, the passively insulated metal face temperature was taken to be 180F when the local fluid temperature was that value, 280F when the fluid temperature was 550F, and varying linearly with local fluid temperature; the 100F insulation temperature drop at 550F fluid temperature was chosen quite arbitrarily.

The component metal temperatures were advanced toward their current base temperatures using the exponential decay of the temperature difference, $(1 - \exp(-t/\tau))$, to account for the time delay associated primarily with metal energy conduction. Time constants (τ) of 2 and 15 minutes were applied to the general primary metal and to the flanges, respectively. These time

constants were based on the metal configuration but were modified by comparing calculated heat release rates to those inferred from total primary fluid energy trends; based on flange metal temperature trends, the time constants of the pump and lower reactor vessel flanges may have been much larger than those used. Smoothing (described elsewhere herein) was applied to obtain the heat transfer rate (q_{prmet}) due to changes in primary metal stored energy.

5.3.4. PORV Mass Flow Rate, Enthalpy, and Heat Transfer

The total PORV mass flow rate (f_{porv}) was obtained by combining the PORV flow meter reading with the separator differential pressure change. The flow meter readings were multiplied by the appropriate time increments to obtain discharged mass. The separator differential pressure was converted to fluid mass using separator area and fluid density. The two indications of discharged mass versus time were combined and differenced, using the smoothing technique described elsewhere herein, to obtain PORV mass flow rate.

The PORV discharge fluid enthalpy (h_{porv}) was obtained from the total PORV mass flow rate and the uppermost pressurizer fluid temperature. The PORV total mass flow rate was first checked against the mass flow rate predicted using the Homogeneous Equilibrium Model (HEM) critical flow prediction and system pressure at 5% quality and at 95% quality. If the observed flow rate was intermediate to the values predicted at the two extreme qualities, then the two-phase enthalpy of the PORV discharge was obtained iteratively by varying the estimated quality until the predicted flow rate matched the observed flow rate. Convergence was aided by forming the linear expression for predicted flow rate versus quality at the current bracketing conditions, and entering this expression with observed flow rate to assign the estimated quality for the next iteration. If the observed flow rate was greater than that predicted at 5% quality, then the PORV enthalpy was set to the lesser of the saturated liquid enthalpy and the enthalpy corresponding to system pressure and the uppermost pressurizer fluid temperature. Similarly at high qualities, if the observed mass flow rate was less than that predicted at system pressure and 95% quality, then the PORV discharge fluid enthalpy was set to the greater of saturated vapor enthalpy, and the enthalpy at system pressure and the uppermost pressurizer fluid temperature. (This algorithm frequently obtained subcooled PORV discharge fluid enthalpy, and did so in a

suitably smooth fashion, but rarely obtained a superheated PORV fluid enthalpy.) The PORV effluent energy transfer (q_{porvf}) was the product of the PORV total mass flow rate and the PORV discharge fluid enthalpy.

5.3.5. Uncompensated Primary System Heat Losses

The primary system uncompensated heat losses to ambient (q_{prlta}) were based on the pump region fluid temperatures. These temperatures were chosen because the largest losses occurred in this region. The eight RTDs bracketing the four pumps were used to establish the pump region fluid temperatures. Only RTD signals without error indications were used.

The total primary system uncompensated loss was taken to be 0 at and below 180F, and 0.545% of scaled full power at the 550F pump region temperature, and to vary linearly with temperature. The loss at 550F was extracted from steady-state pre-test data. The bounding temperature of 180F and the linear slope were estimated from the heat loss data transmitted in PMG Communication Number 12 dated 12 January 1987.

5.3.6. Tube Rupture Mass Flow Rate

The tube rupture mass flow rate (f_{tr}) was obtained from the differential pressure-based flow rate when it was available. Otherwise, the rupture mass flow rate was calculated to fulfill the primary mass balance, that is, to equate the indicated mass balance with that obtained by integrating the primary boundary mass flow rates. Smoothing was applied to the indicated primary mass as well as to the calculated tube rupture mass flow rate. Also, the components of the total indicated fluid mass, as well as the sum of the components, were updated only when the incremental fluid mass change reflected a physically realizable flow rate. These change limits were 6,000 lbm/h applied to the fluid mass of each primary system component and 12,000 lbm/h applied to the primary system total fluid mass.

5.4. Primary System Volume Balance

The primary system volume balance provided insight into the mechanisms for primary system pressure changes. The volume balance was the imposed volume balance -- the contributions of each of the boundary systems were estimated and considered, but the internal primary system fluid volume changes in response to changes in primary system conditions were ignored. For example,

core void production and condensation due to steam generator heat removal and HPI subcooling were included, but flashing due to depressurization and due to a liquid level increase covering hot metal were omitted. The resulting imposed rather than total volume balance was generally sufficient to confirm pressure changes. The extension of the imposed volume balance to include internal fluid volume changes would have required unwarranted assumptions, such as the amount and energy content of slightly subcooled liquid reacting to a particular depressurization. The net volume balance is described first, then the components are addressed.

Each of the volume balance terms is designated using a leading lower-case "a," for example "anet" and "acore." Each of these terms is expressed in units of percentage of scaled full power. This set of units is directly applicable to core void production and to the condensation contributions of HPI, the CFT, and uncompensated losses to ambient. For the volume balance contributions of injection and discharge streams, however, the mass flow rate must first be recast as volumetric flow rate by dividing by the fluid density of the discharge stream. Then, the volumetric flow rate is converted to the equivalent core void production by multiplying by the ratio of vaporization enthalpy to vaporization specific volume. As a result of these conversions, each of the volume balance terms is expressed in a consistent set of units; also, the volume balance expressed in units of fractional power is more readily compared among systems of differing scale than is a volume balance expressed in absolute units, such as volume per unit time.

5.4.1. Net Rate of Change of Primary Fluid Volume

The net rate of change of primary fluid volume (anet) was the core volume generation rate (acore) less the sum of the contributions to the fluid volume rate of change.

The net primary fluid volume rate of change was multiplied by the time increments to obtain volume versus time, then differenced using the smoothing technique (described separately herein) to obtain the smoothed net rate of change of primary fluid volume (anetw). The smoothed rate of change of primary system pressure (pdotw) was similarly obtained by applying the smoothing technique to primary system pressure versus time. The ratio of pressure change to volume change used the smoothed values (anetw and pdotw).

Logarithm-based values were formed for plotting. These were the base-10 logarithms of the absolute values of the variable multiplied by the sign of the variable. To avoid misleading signs, these plotting variables were set to negative infinity, interrupting the plots, when the absolute value of the variable was less than unity. The log-based plotting variables so formed included "pdotwl" from the smoothed pressure change rate (pdotw), and "poal" from the ratio of pressure change (pdotw) to volume change (anetw). The log-based ratio (poal) was also set to negative infinity when the denominator, the smoothed rate of change of primary system volume, dropped below the equivalent of 0.1% of scaled full power. Each of the volume rates of change was expressed as the equivalent void production rate, percentage of scaled full power, which was offset by that rate of change.

5.4.2. Core

The core volume production rate (acore) was the core void production rate less the sum of inlet subcooling and condensation due to RVVV region uncompensated heat losses to ambient. The core void production rate was set to zero if the core region collapsed liquid level was greater than 25 ft or if the measured core exit fluid temperature was more than 1F subcooled. The entire core power input was assigned to core void production if the core region liquid level was less than 23 ft, the downcomer mass flow rate was less than 1% of scaled full flow, and the measured core outlet fluid temperature was less than 1F subcooled. If neither the condition for zero or full void generation rate was met, then the core void generation rate was set to the core power input less the inlet subcooling, the product of the measured downcomer flow rate and the core inlet fluid subcooling. If the core region liquid level was less than 25 ft, then the core volume production rate was reduced by the RVVV region losses to ambient, which were taken to be 11% of the primary system total uncompensated losses (qprlta), described separately herein.

5.4.3. HPI

The HPI fluid volume removal rate (ahpi) was HPI condensation plus condensation due to pump region uncompensated losses to ambient, less the HPI injection flow rate. The maximum HPI condensation rate was the product of the HPI mass flow rate and the injection subcooling, the difference between

the enthalpy of saturated liquid and the HPI fluid enthalpy. If the downcomer liquid level was below 20 ft, the HPI condensation was set to its maximum value. If the downcomer level was greater than 22.5 ft, HPI condensation was set to zero. If the downcomer level was near the nozzles (20 to 22.5 ft), then the HPI condensation term was set to the minimum of the core volume production rate, and the product of the HPI flow rate and the apparent HPI fluid heating. The HPI fluid heating was taken from the injection fluid enthalpy to the minimum of saturated liquid enthalpy and, if a leak was active, the leak fluid enthalpy. If individual cold leg discharge levels were below 23.1 ft, then the intermediate-level HPI condensation term was advanced toward the maximum HPI condensation in proportion to the number of high-pressure injection points uncovered. Note that there was no allowance (correction) for the effects of NCG on condensation.

The HPI volume source (negative condensation), due to the injection itself, was the injection mass flow rate divided by injected fluid density. This was converted to the equivalent core void generation rate by multiplying the HPI volumetric flow rate by the ratio of the vaporization enthalpy to the vaporization specific volume. The (HPI) maximum condensation due to uncompensated losses to ambient was the pump region loss, 61% of the total primary system uncompensated loss (q_{prlta}), described elsewhere herein. The HPI condensation contribution due to pump region losses was advanced from zero toward maximum in proportion to the number of individual cold legs with discharge levels below 25 ft (the cold leg spillover elevation was 25.8 ft).

5.4.4. CFT

The CFT volume reduction contribution ($acft$) was CFT condensation less the injection effect. The CFT condensation term was zero if the downcomer liquid level was greater than 24 ft (the CFT connection was at 23.2 ft). If the downcomer level was below 24 ft, the CFT condensation was the product of the CFT discharge mass flow rate and the CFT injection fluid subcooling. The injection volume-addition term was the CFT injection volumetric flow rate, mass flow rate divided by injection fluid density, and converted to the equivalent core void production rate by multiplying by the ratio of the vaporization enthalpy to the vaporization specific volume.

5.4.5. Steam Generators

The steam generator volume reduction rate (asgs) was the sum over both steam generators of steam generator condensation of primary vapor plus condensation due to uncompensated losses to ambient (in the hot leg region, primarily). If a steam generator primary liquid level was below 52.1 ft, the elevation of the upper tubesheet, then its condensation was the primary-to-secondary heat transfer (qslpts or q2spts). For reverse heat transfer, if the associated primary liquid level was above the lower tubesheet, then volume production was taken as the (negative) primary-to-secondary heat transfer rate. The maximum condensation due to uncompensated losses to ambient was 28% of the total primary system uncompensated heat loss (qprlta), which has been described elsewhere herein. This steam generator condensation contribution due to losses was activated as the associated steam generator primary level decreased below 52.1 ft.

5.4.6. Leak, PORV, Vents, and Tube Rupture

The volume reduction contributions due to the leak (aleak), PORV (aporv), vents (ahpv), and tube rupture (asgtr) were analogous, and were each equal to the corresponding volumetric flow rate converted to equivalent core void production by multiplying by the ratio of the vaporization enthalpy to the vaporization specific volume. The discharge volumetric flow rates were obtained by dividing the discharge mass flow rates by the discharge fluid densities. These densities were obtained at system pressure and the appropriate discharge fluid enthalpy. The leak fluid enthalpy (hclk) was obtained from measurement, and the PORV enthalpy (hporvf) was calculated from the PORV flow rate as described elsewhere herein. If the supplied enthalpy was in the two-phase region, then the discharge fluid density (RHO) was calculated assuming equilibrium, i.e.

$$RHO = \frac{(1 - x)}{RHO_f} + \frac{x}{RHO_g}$$

where x, RHO_f, and RHO_g were the equilibrium quality and the saturated liquid and vapor densities.

Table A.1. Base Plots Indexed by Systems and Types of Measurements

Certain plot types are provided only for selected tests, as indicated in the notes below. Plots are also substituted or omitted according to data availability.

- Notes:**
1. Conductivity probe information is supplied for tests 3008, 3304, 3407, Group 36, and 3801.
 2. Pump characteristics are supplied only for pumps-operating tests: 3008, 3602, 3603, 3604, 3605, and 3801.
 3. Viewport interpretations are supplied for tests 3109, 3206, 3303, 3401, 3507, and 3801.
 4. PORV fluid enthalpy is provided for those tests in which the PORV was active.
 5. Noncondensable gas volumes are plotted only for noncondensable gas tests: 3502, 3503, 3505, 3507, and 3508.
 6. Steam generator B steam enthalpy is supplied for the tube rupture tests, Group 34.

Measurement	Plot
PRIMARY SYSTEM	
FLUID TEMPERATURE	
Loop A Cold Legs	C1RT0
Loop B Cold Legs	C2RT0
Cold Leg Nozzles, Top of Rake	CLTC1
Cold Leg Nozzles, Bottom of Rake	CLTC2
Downcomer (Quadrant A1)	DCTC6
Core Exit and Hot Leg	PRKT1
Composite	PRRT0
Reactor Vessel	RVTC0
METAL TEMPERATURE	
Loop A Cold Legs	C1MT1
Loop B Cold Legs	C2MT1
PRESSURE	
Reactor Vessel	PSGP1

Table A.1. Base Plots Indexed by Systems and Types of Measurements (Cont'd)

Measurement	Plot
LEVEL	
Cold Leg Suction	CLLV4
Cold Leg Discharge	CLLV5
Core Region (RV and DC)	COLV1
Hot Leg Riser and Stub	HLLV1
Pressurizer	PZLV1
Steam Generators	SCLV2
FLOW RATE	
Cold Legs	CLFL1 or 3
Cold Leg Total and Downcomer	PRFL7 or DCFL1
RVVVs	VVFL1
POWER	RVKW1
REACTOR VESSEL VENT VALVES	
Differential Pressures	VVDP1
Temperature Differences	VVTD1
Limit Switches	VVLS1
FLUID TEMPERATURE DIFFERENCES	
Maximum Among RCP Rake Temperatures	CLTD1
Maximum Among Cold Leg Nozzle Rake Temperatures	CLTD2
Core, Steam Generators	COTD0 or 1
Key	PRTD2
SCM and Control	PSTD1
VOID FRACTIONS (From Differential Pressures)	
Hot Leg A Riser	H1VF1
Hot Leg B Riser	H2VF1
Hot Leg U-Bend	HLVF1
Reactor Vessel	RVVF1
MASS BALANCE	PRML2
ENERGY BALANCE	PRQE2, PRTE2
VOLUME BALANCE	PRPA0, 2, 3

Table A.1. Base Plots Indexed by Systems and Types of Measurements (Cont'd)

Measurement	Plot
CONDUCTIVITY PROBE INFORMATION (Note 1)	
Hot Leg A Lower Elevation	H1CP1
Hot Leg A Upper Elevation	H1CP2
Hot Leg B Lower Elevation	H2CP1
Hot Leg B Upper Elevation	H2CP2
Reactor Vessel	RVCP1
Steam Generator B Secondary	S2CP1, 2
REACTOR COOLANT PUMP CHARACTERISTICS (Note 2)	
Current	PUAM1
Pressure Drop	PUDP1
Observed Homologous Flow	PUHF1
Observed Homologous Head	PUHH1
Normalized Head	PUHN1
Normalized Volumetric Flow Rate	PUQN1
Suction Fluid Temperature	PURT1
Normalized Speed	PUSN1
Void Fraction from gamma densitometers)	PUQN1
Electrical Power	PUWM1
VIEWPORT INTERPRETATIONS (Note 3)	
Hot Leg Horizontals	HLVP2
Hot Leg Risers	HLVP3
Hot Leg U-Bends	HLVP4
PRIMARY BOUNDARY SYSTEMS	
TEMPERATURES	PBTC1
PRESSURE	
Core Flood Tank	CFGP1
FLOW RATES (HPI, PORV,)	PBFL3
FLUID MASS	
Core Flood Tank	CFML1
GUARD HEATER POWER	
Primary Components	PRG01
Pressurizer and Steam Generators	PZGQ1

Table A.1. Base Plots Indexed by Systems and Types of Measurements (Cont'd)

Measurement	Plot
LIMIT SWITCHES	
Discharge Streams	PBLS1
Injection Streams	PBLS2
PORV ENTHALPY (Note 4)	PZEN1
NONCONDENSIBLE GAS VOLUMES (Note 5)	NCMS1, 2
SECONDARY SYSTEMS	
TEMPERATURES	
Saturation and Control	PSTC3
Feedwater	SGRT1
Steam	SGRT2
PRESSURE	PSGP1
LEVEL	
Steam Generator	SCLV2
FLOW RATE	
Steam and Feed	SCFL3
MASS BALANCE	SCML2
ENTHALPY	
Steam Generator B Steam (Note 6)	S2EN1
ENERGY TRANSFER	SGQE3, 6

Table A.2. Basic MIST Plots

M I S T P L O T S

PLOT	TITLE	ORDINATE(S) Y-VARIABLES & DESCRIPTIONS ABSCISSA	OFFSETS (if any)	ORDINATE CONVERSION FACTORS (A and B where $y_2 = A*y_1 + B$)	
1 C1MT1 c1mt1	Loop A Cold Leg Metal Temperatures (C1,3MTs)	Temperature, F C1MT01 A1 Riser, 2 6ft(11) C1MT02 " 17 3 (2) C1MT03 " Disch,23 5 (3) C1MT04 " Pump (4) C3MT01 A2 Riser, 2 6 (31) C3MT02 " 17 3 (2) C3MT03 " Disch,23 5 (3) C3MT04 " Pump (4) time	Temperature, K	5556E+00	2554E+03
2 C1RT0 c1rt0	Loop A Cold Leg Fluid Temperatures (RTDs)	Temperature, F P1RT02 SG A Outlet @ -3 2ft C1RT01 Pump A1 Inlet, 23 5 C3RT01 A2 " C1RT02 Pump A1 Disch, 25 8 C3RT02 A2 " DCTC09 DC Above Noz,A1@21 9 DCTC15 Below Noz,A1@20 9 RVRF20 RV Saturation time	Temperature, K	5556E+00	2554E+03
3 C2MT1 c2mt1	Loop B Cold Leg Metal Temperatures (C2,4MTs)	Temperature, F C2MT01 B1 Riser, 2 6ft(21) C2MT02 " 17 3 (2) C2MT03 " Disch, 23 5 (3) C2MT04 " Pump (4) C4MT01 B2 Riser, 2 6 (41) C4MT02 " 17 3 (2) C4MT03 " Disch, 23 5 (3) C4MT04 " Pump (4) time	Temperature, K	5556E+00	2554E+03

Table A.2. Basic MIST Plots (Cont'd)

4	C2PT0 c2rt0	Loop B Cold Leg Fluid Temperatures (RTDs)					
		Temperature, F		Temperature, K		5556E+00	2554E+03
		P2RT02	SG B Outlet @ -3 2ft				
		C2RT01	Pump B1 Inlet, 23 5				
		C4RT01	B2 "				
		C2RT02	Pump B1 Disch , 25.8				
		C4RT02	B2 "				
		DCTC10	DC Above Noz,B1@21 9				
		DCTC17	Below Noz,B1@20 9				
		RVRF20	RV Saturation time				
5	CFGP1 cfgp1	Primary System and Core Flood Tank Pressures (GP01s)					
		Pressure, psia		Pressure, MPa ✓		6895E-02	.0000E+00
		RVGP01	RV @ 29.0ft (RV)				
		CFGP01	CFT 49.3 (CF)				
			time				
6	CFML1 cfml1	Core Flood Tank Liquid and Fluid Mass (CFMa20s)					
		Mass, lbm		Mass, kg		.4536E+00	.0000E+00
		CFML20	Liquid (L)				
		CFMS20	Fluid (S)				
			time				
7	CLFL1 clfl1	Cold Leg (Venturi) Flow Rates					
		Flow Rate, % (of full CL flow rate)		Flow Rate, lbm/h		.4140E+03	.0000E+00
		avgfpc1	CL Average				
		fpc1a1	Cold Leg A1				
		fpc1b1	" B1				
		fpc1a2	" A2				
		fpc1b2	" B2				
			time				
8	CLFL3 clfl3	Cold Leg (Turbine Meter) Mass Flow Rates (CnTM01s)					
		Flow Rate, lbm/h		Flow Rate, % (of full CL flow)		.2415E-02	.0000E+00
		C1TM01	A1 (1)				
		C2TM01	B1 (2)				
		C3TM01	A2 (3)				
		C4TM01	B2 (4)				
			time				

Table A.2. Basic MIST Plots (Cont'd)

9 CLLV4 cllv4	Cold Leg Suction Collapsed Liquid Levels (CnLV22s).			
	Level, ft		Level, m	.3048E+00 .0000E+00
	C1LV22	Cold Leg A1 (1)		
	C2LV22	" B1 (2)		
	C3LV22	" A2 (3)		
	C4LV22	" B2 (4)		
	zIts	CL Spillover time	25.800	

10 CLLV5 cllv5	Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)			
	Level, ft		Level, m	.3048E+00 .0000E+00
	C1LV23	Cold Leg A1 (1)		
	C2LV23	" B1 (2)		
	C3LV23	" A2 (3)		
	C4LV23	" B2 (4)		
	zIts	CL Spillover time	25.800	

11 CLLV6 cllv6	Cold Leg Suction Collapsed Liquid Levels (CnLV32s).			
	Level, ft		Level, m	.3048E+00 .0000E+00
	C1LV32	Cold Leg A1 (1)		
	C2LV32	" B1 (2)		
	C3LV32	" A2 (3)		
	C4LV32	" B2 (4)		
	zIts	CL Spillover time	25.800	

12 CLTC1 cltc1	Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3ft, CnTC11s).			
	Temperature, F		Temperature, K	.5556E+00 .2554E+03
	C1TC11	Cold Leg A1 (1)		
	C2TC12	" B1 (2,12)		
	C3TC11	" A2 (3)		
	C4TC11	" B2 (4)		
		time		

13 CLTC2 cltc2	Cold Leg Nozzle Fluid Temperatures, Bottom of Rake (21.2ft, CnTC14s)			
	Temperature, F		Temperature, K	.5556E+00 .2554E+03
	C1TC14	Cold Leg A1 (1)		
	C2TC14	" B1 (2)		
	C3TC14	" A2 (3)		
	C4TC14	" B2 (4)		
		time		

Table A.2. Basic MIST Plots (Cont'd)

14 CLTD1 cltd1	Maximum Differences Among RCP Rake Fluid Temperatures.			
	Temperature Difference, F		Temperature Difference, K	.5556E+00 .0000E+00
	dtrake1	Pump A1		
	dtrake2	" B1		
	dtrake3	" A2		
	dtrake4	" B2		
		time		
15 CLTD2 cltd2	Maximum Differences Among CL Nozzle Rake Fluid Temperatures			
	Temperature Difference, F		Temperature Difference, K	.5556E+00 .0000E+00
	dtrake5	Cold Leg A1		
	dtrake6	" B1		
	dtrake7	" A2		
	dtrake8	" B2		
		time		
16 COLV1 colv1	Core Region Collapsed Liquid Levels.			
	Level, ft		Level, m	.3048E+00 .0000E+00
	RVLV20	Core		
	DCLV20	Downcomer		
	zlts	El. of RVVVs, 24.2ft	24.200	
	zlts	" nozzles, 21.25	21.250	
	zlts	"top of core, 16.7	16.700	
	zlts	"top of RVUH, 29.4	29.400	
		time		
17 COTD1 cotd0	Core Fluid Temperature Rise.			
	Temperature Difference, F		Temperature Difference, K	.5556E+00 .0000E+00
	dtcore	Across Core		
		time		
18 DCFL1 dcfl1	Downcomer (Venturi) Flow Rate.			
	Flow Rate, lbm/h		Flow Rate, % (of full flow)	6040E-03 .0000E+00
	DCVN20	DCVN20		
		time		

Table A.2. Basic MIST Plots (Cont'd)

19	DCTC6 dctc6	Downcomer Quadrant A1 Fluid Temperatures (DCTCs).					
		Temperature, F		Temperature, K		.5556E+00	.2554E+03
		DCTC01	RVVVs, 24.2ft (01)				
		DCTC05	Below ", 23.8 (05)				
		DCTC09	Above Noz, 21.9 (09)				
		DCTC15	Below " , 20.9 (15)				
		DCTC30	Above Trans, 17.5 (30)				
		DCTC41	Below " , 15.3 (41)				
		DCTC42	@ 11.5 (42)				
		DCTC46	@ 7.6 (46)				
		DCRT01	DC Bottom, 1.4 (RT01)				
		RVRF20	RV Saturation time				
20	HICP1 hicp1	Hot Leg A Lower-Elevation Conductivity Probe Signals (HICPs).					
		Signal, V					
		HICP01	@ 23.2ft (01)				
		HICP02	28.5 (02)				
		HICP03	36.2 (03)				
		HICP04	43.4 (04)				
		HICP05	50.7 (05)				
			time				
21	HICP2 hicp2	Hot Leg A Upper-Elevation Conductivity Probe Signals (HICPs).					
		Signal, V					
		HICP06	@ 59.7ft (06)				
		HICP07	63.6 (07)				
		HICP08	65.7 (08)				
		HICP09	66.6 (09)				
		HICP10	65.6 (10)				
			time				
22	HIVF1 hivf1	Hot Leg A Riser Void Fractions From Differential Pressures (HIVFs).					
		Void Fraction		Void Fraction, %		.1000E+03	.0000E+00
		HIVF02	21 to 23ft (02)				
		HIVF03	23 27 (03)				
		HIVF04	27 30 (04)				
		HIVF05	35 37 (05)				
		HIVF06	42 44 (06)				
		HIVF07	49 52 (07)				
		HIVF08	57 62 (08)				
		HIVF09	62 65 (09)				
		HIVF10	65 67 (10)				
			time				

Table A.2. Basic MIST Plots (Cont'd)

23	H2CP1 h2cp1	Hot Leg B Lower-Elevation Conductivity Probe Signals (H2CPs).					
		Signal, V					
		H2CP01	@ 23	1ft	(01)		
		H2CP02	28	5	(02)		
		H2CP03	36.1		(03)		
		H2CP04	43.4		(04)		
		H2CP05	50.7		(05)		
			time				
24	H2CP2 h2cp2	Hot Leg B Upper-Elevation Conductivity Probe Signals (H2CPs)					
		Signal, V					
		H2CP06	@ 59	7ft	(06)		
		H2CP07	63	6	(07)		
		H2CP08	65.6		(08)		
		H2CP09	66.8		(09)		
		H2CP10	65	6	(10)		
			time				
25	H2VF1 h2vf1	Hot Leg B Riser Void Fraction From Differential Pressures (H2VFs)					
		Void Fraction		Void Fraction, %		.1000E+03	0000E+00
		H2VF02	21 to 24ft	(02)			
		H2VF03	24	28	(03)		
		H2VF04	28	30	(04)		
		H2VF05	35	37	(05)		
		H2VF06	42	45	(06)		
		H2VF07	50	52	(07)		
		H2VF08	58	63	(08)		
		H2VF09	63	65	(09)		
		H2VF10	65	66	6 (10)		
			time				
26	HLLV1 hllv1	Hot Leg Riser and Stub Collapsed Liquid Levels.					
		Level, ft		Level, m		.3048E+00	.0000E+00
		H1LV21	HL A	Riser			
		zsgp1	"	SG + Stub			
		H2LV21	HL B	Riser			
		zsgp2	"	SG + Stub			
		z1ts	Elev	of HLUB, 66 Sft	66.500		
		z1ts	"	Upper Tubesheet	52.100		
			time				

Table A.2. Basic MIST Plots (Cont'd)

27	HLVF1 hlvf1	Hot Leg U-Bend Void Fractions From Diff1. Pressures (64.8 to 66.6 ft, HnVFs).			
		Void Fraction		Void Fraction, %	
		H1VF10	A, Upstream (110)		.1000E+03 .0000E+00
		H1VF11	" Downstream(11)		
		H2VF10	B, Upstream (210)		
		H2VF11	" Downstream(11)		
		time			
28	HLVP2 hlvp2	Hot Leg Horizontal Viewport Indications (HnMS01s).			
		Interpretation Code			
		H1MS01	Hot Leg A (1)		-.100
		H2MS01	B (2)		
		time			
29	HLVP3 hlvp3	Hot Leg Riser Viewport Indications (HnMS02s).			
		Interpretation Code			
		H1MS02	Hot Leg A (1)		-.100
		H2MS02	B (2)		
		time			
30	HLVP4 hlvp4	Hot Leg U-Bend Viewport Indications (HnMS03s).			
		Interpretation Code			
		H1MS03	Hot Leg A (1)		-.100
		H2MS03	B (2)		
		time			
31	NCMS1 ncms1	Noncondensibles Collected and Discharge Valve Status.			
		Volume (scf) & Status ("odd"=open)			
		V2RF20	NCG Volume (V2RF20)		
		PZLS02	PORV Status (PZLS02)		
		H1LS01	HL A Vent " (H1LS01)	2.000	
		H2LS01	HL B " (H2LS01)	4.000	
		time			
32	NCMS2 ncms2	Noncondensibles Gas Volumes			
		Volume, scf			
		GARF21	Volume Added (GA)		
		V2RF20	" Collected (V2)		
		time			

Table A.2. Basic MIST Plots (Cont'd)

<hr/>					
33	PBFL3	Primary System Boundary Flow Rates.			
	pbfl3				
		Flow Rate, lbm/h		Flow Rate, kg/h	
		HPMM05	HPI (HPMM05)		.4536E+00 .0000E+00
		fleak	Leak (fleak)		
		fcft	CFT (fcft)		
		fporv	PORV (Total fporv)		
		V2MM03	HL Vents (V2MM03)		
		V2MM02	RV Vent (V2MM02)		
		ftr	SGTR (Calcd ftr)		
			time		
<hr/>					
34	PBLS1	Primary System Discharge Limit Switch Indications (LSs).			
	pbls1				
		Valve Position ("even" = valve closed)			
		V1LS03	CLS Leak (V103)		
		V1LS04	CLD Leak #1 (04)	2 000	
		V1LS05	" #2 (05)	4.000	
		V1LS06	" #3 (06)	6.000	
		V1LS07	" #4 (07)	8.000	
		PZLS02	PORV (PZ02)	10 000	
		H1LS01	HLHPV-A (H101)	12.000	
		H2LS01	" -B (H201)	14.000	
		RVLS09	RVUHV (RV09)	16.000	
		S2LS03	SGTR-Upper (S203)	18.000	
		S2LS04	" -Lower (04)	20.000	
			time		
<hr/>					
35	PBLS2	Primary System Injection Limit Switch Indications (LSs).			
	pbls2				
		Valve Position ("even" = valve closed)			
		CFLS01	CFT To DC(A) (CF01)		
		CFLS02	" (B) (02)		
		HPLS01	HPI To CL A1 (HP01)	2 000	
		HPLS02	" B1 (02)	2 000	
		HPLS03	" A2 (03)	2.000	
		HPLS04	" B2 (04)	2.000	
			time		
<hr/>					

Table A.2. Basic MIST Plots (Cont'd)

36	PBTC1p pbtc1p	Single-Phase Discharge and HPI Fluid Temperatures (TC01s)					
		Temperature, F		Temperature, K		.5556E+00	.2554E+03
		HPTC01	HPI (HP)				
		V1TC01	CLS Leak (V1)				
		V1TC02	CLD Leak (V102)				
		DCRT01	Lower DC (DCRT)				
		RVRF20	RV Saturation time				
<hr/>							
37	PRFL7 prfl7	Primary System Venturi Flow Rates.					
		Flow Rate, % (of full primary flow rate)		Flow Rate, lbm/h		.1656E+04	.0000E+00
		avgfpc1	Cold Leg Total				
		fpdcven	Downcomer time				
<hr/>							
38	PRGQ1 prgq1	Guard Heater Specified Power Per Primary Component.					
		Power, kW		Power, Btu/h		.3412E+04	.0000E+00
		ghqrv	Reactor Vessel				
		ghqh1	Hot Leg A				
		ghqh2	Hot Leg B				
		ghqc1	Cold Legs				
		ghqdc	Downcomer time				
<hr/>							
39	PRKT1 prkt1	Composite Core Exit and Hot Leg Fluid Temperatures.					
		Temperature, F		Temperature, K		.5556E+00	.2554E+03
		RVTC15	Core Exit (RVTC15)				
		RVTC16	RV at Nozzle ("16)				
		H1TC01	A-HL Inlet(H1TC01)				
		H1TC03	" Beyond Surge (3)				
		H1TC08	" Midway(47ft,"08)				
		H1TC16	" HLUB (H1TC16)				
		H2TC01	B-HL Inlet(H2TC01)				
		H2TC08	" Midway(47ft,"08)				
		H2TC16	" HLUB (H2TC16)				
		RVRF20	RV Saturation time				

Table A.2. Basic MIST Plots (Cont'd)

40	PRML2 prml2	Primary System Total Fluid Mass (PLMLs)					
		Mass, lbm		Mass, kg	4536E+00	0000E+00	
		PLML20	Indicated	(20)			
		PLML21	Calcd Fm Flows	(21)			
		PLML22	"	Scales (22)			
			time				
<hr/>							
41	PRPA0 prpa0	Primary Fluid Volume Changes By Components					
		Equivalent Power, % of scaled full power					
		acore	Core Voiding				
		asgs	SG Condensation				
		ahpi	HPI Cond - Input				
		acft	CFT	"			
		aleak	Leak Discharge				
		aporv	PORV	"			
		ahpvs	HPVs	"			
		asgtr	SGTR	"			
		anet	Net	Core-Sinks			
			time				
<hr/>							
42	PRPA2 prpa2	Primary Fluid Volume and Pressure Changes, dV/dt and dp/dt					
		dV/dt, Equivalent Power (% of scaled full pow+/-log10 (dp/dt , psi/min)			1000E+01	0000E+00	
		anet	Volume Change, dV/dt				
		anetw	Smoothed dV/dt				
		pdotw1	Smoothed dp/dt				
			time				
<hr/>							
43	PRPA3 prpa3	Primary System Response dp/dt divided by dV/dt					
		+/-log10 (dp/dV , (psi/min) / % full power)					
		poal	(dp/dt)/(dV/dt)				
			time				
<hr/>							
44	PRQE2 prqe2	Primary System Energy Transfer					
		Energy Transfer, % of scaled full power			Energy Transfer, Btu/h	1126E+06	0000E+00
		qcorein	Core				
		qs1pts	Steam Generator A				
		qs2pts	"	" B			
		qlkhp1	Effluent - (HPI+CFT)				
		qprmet	Metal dE/dt				
		qprlta	Losses To Ambient				
			time				

Table A.2. Basic MIST Plots (Cont'd)

45	PRRT0 prrt0	Primary System Fluid Temperatures (RTDs).					
		Temperature, F		Temperature, K		.5556E+00	.2554E+03
		H1RT01	HL A Inlet, 23.3ft				
		H2RT01	B "				
		P1RT01	SG A Inlet, 53.1				
		P2RT01	B "				
		P1RT02	A Outlet, -3.1				
		P2RT02	B "				
		DCRT01	Downcomer, 1.4				
		RVRF20	RV Saturation time				
<hr/>							
46	PRTD2 prtd2	Key Temperature Differences					
		Temperature Difference, F		Temperature Difference, K		.5556E+00	.0000E+00
		dtcore	Across Core				
		dtasgp	" A-SG				
		dtbsgp	" B-SG				
			time				
<hr/>							
47	PRTE2 prte2	Primary System Total Fluid Energy.					
		Energy, BTU					
		eprfl1	Indicated				
		eprflc	Calculated				
			time				
<hr/>							
48	PSGP1 psgp1	Primary and Secondary System Pressures (GP01s)					
		Pressure, psia		Pressure, MPa		.6895E-02	.0000E+00
		RVGP01	Primary (RV)				
		S1GP01	Steam Gen. A (S1)				
		S2GP01	" B (S2)				
			time				
<hr/>							
49	PSTC3p pstc3p	Core Exit and Steam Generator Secondary Saturation Temperatures.					
		Temperature, F		Temperature, K		.5556E+00	.2554E+03
		RVTC11	Core exit (RVTC11)				
		RVTC15	" (15)				
		S1RF20	SG A Satn. (S1RF20)				
		S2RF20	SG B " (S2)				
			time				

Table A.2. Basic MIST Plots (Cont'd)

50	PSTD1 pstd1	Control Temperature Differences.			
		Temperature Difference, F		Temperature Difference, K	5556E+00 .0000E+00
		dtscm	Subcooling Margin		
		dtcmag	(Core - A-SG Satn.)		
		dtcmbsg	(Core - B-SG Satn.)		
		zlts	DT = 50F		50.000
		zlts	DT = 75F		75.000
			time		

51	PUAM1 puam1	Pump Current (CnAM01s)			
		Current, A			
		C1AM01	A1 (1)		
		C2AM01	B1 (2)		
		C3AM01	A2 (3)		
		C4AM01	B2 (4)		
			time		

52	PUDP1 pudp1	Pump Pressure Drop (CnDP07s)			
		Differential Pressure, psi			
		C1DP07	RCP A1 (1)		
		C2DP07	B1 (2)		
		C3DP07	A2 (3)		
		C4DP07	B2 (4)		
			time		

53	PUHF1 puhf1	Observed Pump Homologous Flow (puNhf).			
		Homologous Flow, hf=q _n /s _n			
		pu1hf	RCP A1 (1)		
		pu2hf	B1 (2)		
		pu3hf	A2 (3)		
		pu4hf	B2 (4)		
			time		

54	PUHH1 puhh1	Observed Pump Homologous Head (puNhh).			
		Homologous Head, hh=h _n /h _{f2}			
		pu1hh	RCP A1 (1)		
		pu2hh	B1 (2)		
		pu3hh	A2 (3)		
		pu4hh	B2 (4)		
			time		

Table A.2. Basic MIST Plots (Cont'd)

55	PUHN1 puhn1	Pump Normalized Head			
		Normalized Head, $hn=h2ph/hr$			
		pu1hn	RCP A1 (1)	Observed	
		pu2hn	B1 (2)		
		pu3hn	A2 (3)		
		pu4hn	B2 (4)		
		pu1dh	RCP A1 - SS/RELAP		
		pu2dh	B1		
		pu3dh	A2		
		pu4dh	B2		
		time			
56	PUQN1 puqn1	Normalized Cold Leg Volumetric Flow Rate (Time-Shifted & Trended)			
		Normalized Q, $qn=q/qr$			
		pu1qn	Cold Leg A1 (1)		
		pu2qn	B1 (2)		
		pu3qn	A2 (3)		
		pu4qn	B2 (4)		
		time			
57	PURT0 purt0	Pump Suction Fluid Temperature (CnRT01s)			
		Temperature, F		Temperature, K	
		C1RT01	RCP A1 (1)		5556E+00
		C2RT01	B1 (2)		2554E+03
		C3RT01	A2 (3)		
		C4RT01	B2 (4)		
		RVRF20	RV Saturation		
		time			
58	PUSN1 pusn1	Pump Normalized Speed			
		Normalized Speed, $sn=s/sr$			
		pu1sn	RCP A1 (1)		
		pu2sn	B1 (2)		
		pu3sn	A2 (3)		
		pu4sn	B2 (4)		
		time			
59	PUVF2 puvf2	Pump Suction Void Fraction From Gamma Densitometers (CnGD21)			
		Void Fraction (Limited 0 to 1)		Void Fraction, %	
		C1GD21	RCP A1 (1)		1000E+03
		C2GD21	B1 (2)		0000E+00
		C3GD21	A2 (3)		
		C4GD21	B2 (4)		
		time			

Table A.2. Basic MIST Plots (Cont'd)

60 PUWM1 puwm1	Pump Electrical Power (CnWM04s).			
	Power, kW			
	C1WM04	RCP A1 (1)		
	C2WM04	B1 (2)		
	C3WM04	A2 (3)		
61 PZEN1 pzni1	Power-Operated Relief Valve Enthalpy (Based On Flow Rate)			
	Enthalpy, Btu/lbm		Enthalpy, J/kg	
	hporvf	PORV (hporvf)		.2326E+04 .0000E+00
	hf	Satd. Liquid (hf)		
	hg	Satd. Vapor (hg)		
62 PZGQ1 pzgq1	Guard Heater Specified Power, Pressurizer and Steam Generators			
	Power, kW		Power, Btu/h	
	ghqpz	Pressurizer		.3412E+04 .0000E+00
	ghqs1	Steam Generator A		
	ghqs2	Steam Generator B		
63 PZLV1 pzlv1	Pressurizer Collapsed Liquid Level (PZLV20)			
	Level, ft		Level, m	
	PZLV20	Level		.3048E+00 .0000E+00
	zlts	Surgeline Low Point	15.400	
	zlts	Bottom Of Pzr	18.000	
64 RVCP1 rvcp1	Reactor Vessel Conductivity Probe Signals (RVCPs)			
	Signal, V			
	RVCP01	Below Noz, 21.1ft(01)		
	RVCP02	Above ", 21.3 (02)		
	RVCP03	Below RVVVs, 24.1(03)		
	RVCP04	Above " 24 2(04)		
	time			

Table A.2. Basic MIST Plots (Cont'd)

65	RVKW0 rvkw0	Core Power					
		Power, kW		Power, % of scaled full power	.3026E-01	.0000E+00	
		RVWM20	Measured (RVWM20)				
		qdecay	Decay				
		qdecay	Decay + 0.40%	13.200			
		qdecay	" 0.57%	18.800			
			time				
66	RVTC0 rvtc0	Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs).					
		Temperature, F		Temperature, K	.5556E+00	2554E+03	
		DCRT01	Lower DC, 1.4ft (RT)				
		RVTC01	Lower RV, 2.0 (1)				
		RVTC02	Core In, 4.5 (2)				
		RVTC06	12.2 (6)				
		RVTC08	14.2 (8)				
		RVTC11	Core Out, 16.6 (11)				
		RVTC16	Nozzles, 21.2 (16)				
		RVTC21	RVVVs, 24.2 (21)				
		RVTC23	RV Top, 29.6 (23)				
		RVER20	RV Saturation				
			time				
67	RVVF1 rvvf1	Reactor Vessel Void Fractions From Differential Pressures (RVVFs).					
		Void Fraction		Void Fraction, %	.1000E+03	.0000E+00	
		RVVF02	14-17ft, Core Ex(2)				
		RVVF03	17-21, To Nozzle(3)				
		RVVF04	21-24, To RVVVs (4)				
		RVVF05	24-29, Above " (5)				
			time				

Table A.2. Basic MIST Plots (Cont'd)

68 S2CP1 s2cp1	Steam Generator B Secondary Conductivity Probe Signals (S2CPs)				
	Signal, V				
	S2CP01	@ 28 0ft	(01)		
	S2CP02	29 0	(02)		
	S2CP03	29 5	(03)		
	S2CP04	30 0	(04)		
	S2CP05	30 5	(05)		
	S2CP06	31 0	(06)		
	time				
69 S2CP2 s2cp2	Steam Generator B Secondary Conductivity Probe Signals (S2CPs)				
	Signal, V				
	S2CP07	@ 31 5ft	(07)		
	S2CP08	32 0	(08)		
	S2CP09	32 5	(09)		
	S2CP10	33 0	(10)		
	S2CP11	33 5	(11)		
	S2CP12	34 0	(12)		
	time				
70 S2EN1 s2en1	Steam Generator B Steam Exit Enthalpy				
	Enthalpy, Btu/lbm		Enthalpy, J/kg		
	hs2stem	hs2stem			2326E+04 0000E+00
	time				
71 SGFL2 sgfl2	Steam Generator Secondary System Flow Rates				
	Flow Rate, % (of full SG secy flow rate)		Flow Rate, lbm/h		
	fpfeeda	SG A Feed			6912E+02 0000E+00
	fpstema	" Steam			
	fpfeedb	SG B Feed			
	fpstemb	" Steam			
	time				
72 SGLV2 sglv2	Steam Generator Collapsed Liquid Levels				
	Level, ft		Level, m		
	P1LV20	SG A Primary			3048E+00 0000E+00
	S1LV20	" Secondary			
	P2LV20	SG B Primary			
	S2LV20	" Secondary			
	zlts	Elev of UTSheet	52 100		
	zlts	" 30 6 ft	30 600		
	zlts	" 32 6 ft	32 600		
	time				

Table A.2. Basic MIST Plots (Cont'd)

73	SCML2 sgml1	Steam Generator Secondary Fluid Mass Balances			
		Mass, lbm		Mass, kg	.4536E+00 .0000E+00
		calmssa	SG A Calculated		
		tinmssa	" Indicated		
		calmssb	SG B Calculated		
		tinmssb	" Indicated		
			time		
74	SGQE3 sgqe3	Steam Generator A Energy Transfer.			
		Energy Transfer, BTU/h		Energy Transfer, kW	.2931E-03 .0000E+00
		qs1smf	Steam - Feed		
		qs1fl	Fluid dE/dt		
		qs1met	Metal "		
		qs1lta	Loss		
			time		
75	SGQE6 sgqe6	Steam Generator B Energy Transfer.			
		Energy Transfer, BTU/h		Energy Transfer, kW	.2931E-03 .0000E+00
		qs2smf	Steam - Feed		
		qs2fl	Fluid dE/dt		
		qs2met	Metal "		
		qs2lta	Loss		
			time		
76	SGRT1 sgrt1	Feedwater Temperatures (SFs).			
		Temperature, F		Temperature, K	.5556E+00 .2554E+03
		SFRT01	SG A (RT01)		
		SFTC01	" (TC01)		
		SFRT02	SG B (RT02)		
		SFTC02	" (TC02)		
			time		
77	SGRT2 sgrt2	Steam Generator Steam Outlet Temperatures (SSTCs).			
		Temperature, F		Temperature, K	.5556E+00 .2554E+03
		SSTC01	SG A exit (01)		
		SSTC03	" " (03)		
		SSRT01	" at orifice (RT01)		
		S1RF20	" saturation(1RF20)		
		SSTC02	SG B exit (02)		
		SSTC04	" " (04)		
		SSRT02	" at orifice (RT02)		
		S2RF20	" saturation(2RF20)		
			time		

Table A.2. Basic MIST Plots (Cont'd)

78	VVDP1 vvdpl	Reactor Vessel Vent Valve Differential Pressures (RVDPs)					
		Differential Pressure, psi		Differential Pressure, Pa		.6895E+04	.0000E+00
		RVDP06	A1 (06)				
		RVDP07	B1 (07)				
		RVDP08	A2 (08)				
		RVDP09	B2 (09)				
			time				
79	VVFL1 vvfl1	Reactor Vessel Vent Valve Flow Rates (RVORs)					
		Flow Rate, lbm/h		Flow Rate, kg/h		4536E+00	.0000E+00
		RVOR01	A1 (01)				
		RVOR02	B1 (02)				
		RVOR03	A2 (03)				
		RVOR04	B2 (04)				
			time				
80	VVL51 vvls1	Reactor Vessel Vent Valve Positions.					
		Valve Position ("even" = closed)					
		posvv1	A1		2.000		
		posvv2	B1		4.000		
		posvv3	A2		6.000		
		posvv4	B2		8.000		
			time				
81	VVTD1 vvtd1	Temperature Differences Across Vent Valves					
		Temperature Difference, F		Temperature Difference, K		5556E+00	.0000E+00
		dtvva1	RVVV A1				
		dtvvb1	" B1				
		dtvva2	" A2				
		dtvvb2	" B2				
			time				

Table A.3. Cross-Index of Plots to Variables

<u>VARIABLE</u>	<u>Plot(s) Containing Variable</u>	
<hr/>		
1 C1AM01	puam1	
2 C1DP07	pudp1	
3 C1GD21	puvf2	
4 C1LV22	c1lv4	
5 C1LV23	c1lv5	
6 C1LV32	c1lv6	
7 C1MT01	c1mt1	
8 C1MT02	c1mt1	
9 C1MT03	c1mt1	
10 C1MT04	c1mt1	
11 C1RT01	c1rt0	purt0
12 C1RT02	c1rt0	
13 C1TC11	c1tc1	
14 C1TC14	c1tc2	
15 C1TM01	c1f13	
16 C1WM04	puwm1	
<hr/>		
17 C2AM01	puam1	
18 C2DP07	pudp1	
19 C2GD21	puvf2	
20 C2LV22	c1lv4	
21 C2LV23	c1lv5	
22 C2LV32	c1lv6	
23 C2MT01	c2mt1	
24 C2MT02	c2mt1	
25 C2MT03	c2mt1	
26 C2MT04	c2mt1	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

27	C2RT01	c2rt0	put0
28	C2RT02	c2rt0	
29	C2TC12	cltc1	
30	C2TC14	cltc2	
31	C2TM01	clf13	
32	C2WM04	puwm1	
<hr/>			
33	C3AM01	puam1	
34	C3DP07	pudp1	
35	C3GD21	puvf2	
36	C3LV22	cllv4	
37	C3LV23	cllv5	
38	C3LV32	cllv6	
39	C3MT01	clmt1	
40	C3MT02	clmt1	
41	C3MT03	clmt1	
42	C3MT04	clmt1	
43	C3RT01	clrt0	put0
44	C3RT02	clrt0	
45	C3TC11	cltc1	
46	C3TC14	cltc2	
47	C3TM01	clf13	
48	C3WM04	puwm1	
<hr/>			
49	C4AM01	puam1	
50	C4DP07	pudp1	
51	C4GD21	puvf2	
52	C4LV22	cllv4	
53	C4LV23	cllv5	
54	C4LV32	cllv6	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

83 GARF21	ncms2				
82 DCVN20	dctf11				
81 DCTC46	dctc6				
80 DCTC42	dctc6				
79 DCTC41	dctc6				
78 DCTC30	dctc6				
77 DCTC17	c2r10				
76 DCTC15	c1r10	dctc6			
75 DCTC10	c2r10				
74 DCTC09	c1r10	dctc6			
73 DCTC05	dctc6				
72 DCTC01	dctc6				
71 DCRT01	dctc6	pbic1p	prt0	rvtc0	
70 DCLV20	colv1				
69 CFMS20	cfm11				
68 CFML20	cfm11				
67 CFLS02	pb1s2				
66 CFLS01	pb1s2				
65 CFGP01	cfgp1				
64 CAWM04	puwm1				
63 CATM01	c1f13				
62 CATC14	c1tc2				
61 CATC11	c1tc1				
60 CART02	c2r10		prt0		
59 CART01	c2r10				
58 CAMT04	c2mt1				
57 CAMT03	c2mt1				
56 CAMT02	c2mt1				
55 CAMT01	c2mt1				

Table A.3. Cross-Index of Plots to Variables (Cont'd)

84	H1CP01	h1cp1	
85	H1CP02	h1cp1	
86	H1CP03	h1cp1	
87	H1CP04	h1cp1	
88	H1CP05	h1cp1	
89	H1CP06	h1cp2	
90	H1CP07	h1cp2	
91	H1CP08	h1cp2	
92	H1CP09	h1cp2	
93	H1CP10	h1cp2	
94	H1LS01	ncms1	pb1s1
95	H1LV21	h1lv1	
96	H1MS01	h1vp2	
97	H1MS02	h1vp3	
98	H1MS03	h1vp4	
99	H1RT01	prrt0	
100	H1TC01	prkt1	
101	H1TC03	prkt1	
102	H1TC08	prkt1	
103	H1TC16	prkt1	
104	H1VF02	h1vf1	
105	H1VF03	h1vf1	
106	H1VF04	h1vf1	
107	H1VF05	h1vf1	
108	H1VF06	h1vf1	
109	H1VF07	h1vf1	
110	H1VF08	h1vf1	
111	H1VF09	h1vf1	
112	H1VF10	h1vf1	h1vf1
113	H1VF11	h1vf1	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

114	H2CP01	h2cp1	
115	H2CP02	h2cp1	
116	H2CP03	h2cp1	
117	H2CP04	h2cp1	
118	H2CP05	h2cp1	
119	H2CP06	h2cp2	
120	H2CP07	h2cp2	
121	H2CP08	h2cp2	
122	H2CP09	h2cp2	
123	H2CP10	h2cp2	
124	H2LS01	ncms1	pblc1
125	H2LV21	h1lv1	
126	H2MS01	h1vp2	
127	H2MS02	h1vp3	
128	H2MS03	h1vp4	
129	H2RT01	prrt0	
130	H2TC01	prkt1	
131	H2TC08	prkt1	
132	H2TC16	prkt1	
133	H2VF02	h2vf1	
134	H2VF03	h2vf1	
135	H2VF04	h2vf1	
136	H2VF05	h2vf1	
137	H2VF06	h2vf1	
138	H2VF07	h2vf1	
139	H2VF08	h2vf1	
140	H2VF09	h2vf1	
141	H2VF10	h2vf1	h1vf1
142	H2VF11	h1vf1	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

143	HPLS01	pb1s2	
144	HPLS02	pb1s2	
145	HPLS03	pb1s2	
146	HPLS04	pb1s2	
147	HPMM05	pbfl3	
148	HPTC01	pbtc1p	
149	PILV20	sglv2	
150	P1RT01	prrt0	
151	P1RT02	c1rt0	prrt0
152	P2LV20	sglv2	
153	P2RT01	prrt0	
154	P2RT02	c2rt0	prrt0
155	PLML20	prml2	
156	PLML21	prml2	
157	PLML22	prml2	
158	PZLS02	ncms1	pb1s1
159	PZLV20	pzlv1	
160	RVCP01	rvcp1	
161	RVCP02	rvcp1	
162	RVCP03	rvcp1	
163	RVCP04	rvcp1	
164	RVDP06	vvdp1	
165	RVDP07	vvdp1	
166	RVDP08	vvdp1	
167	RVDP09	vvdp1	
168	RVGP01	cfqp1	psqp1

Table A.3. Cross-Index of Plots to Variables (Cont'd)

169	RVLS09	pbis1							
170	RVLV20	colv1							
171	RVOR01	vvf11							
172	RVOR02	vvf11							
173	RVOR03	vvf11							
174	RVOR04	vvf11							
175	RVRF20	c1rt0	c2rt0	dctc6	pbtc1p	prkt1	prn+0	pur+0	rvtc0
176	RVFC01	rvtc0							
177	RVTC02	rvtc0							
178	RVTC06	rvtc0							
179	RVIC08	rvtc0							
180	RVTC11	pstc3p	rvtc0						
181	RVTC15	prkt1	pstc3p						
182	RVTC16	prkt1	rvtc0						
183	RVTC21	rvtc0							
184	RVTC23	rvtc0							
185	RVVF02	rvvf1							
186	RVVF03	rvvf1							
187	RVVF04	rvvf1							
188	RVVF05	rvvf1							
189	RVWM20	rvkw0							
<hr/>									
190	SIGP01	psgp1							
191	SILV20	sglv2							
192	SIRF20	pstc3p	sgrt2						

Table A.3. Cross-Index of Plots to Variables (Cont'd)

193	S2CP01	s2cp1	
194	S2CP02	s2cp1	
195	S2CP03	s2cp1	
196	S2CP04	s2cp1	
197	S2CP05	s2cp1	
198	S2CP06	s2cp1	
199	S2CP07	s2cp2	
200	S2CP08	s2cp2	
201	S2CP09	s2cp2	
202	S2CP10	s2cp2	
203	S2CP11	s2cp2	
204	S2CP12	s2cp2	
205	S2GP01	psgp1	
206	S2LS03	pbls1	
207	S2LS04	pbls1	
208	S2LV20	sglv2	
209	S2RF20	pstc3p	sgrt2
<hr/>			
210	SFRT01	sgrt1	
211	SFRT02	sgrt1	
212	SFTC01	sgrt1	
213	SFTC02	sgrt1	
<hr/>			
214	SSRT01	sgrt2	
215	SSRT02	sgrt2	
216	SSTC01	sgrt2	
217	SSTC02	sgrt2	
218	SSTC03	sgrt2	
219	SSTC04	sgrt2	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

220	VILS03	pb1s1	
221	VILS04	pb1s1	
222	VILS05	pb1s1	
223	VILS06	pb1s1	
224	VILS07	pb1s1	
225	VITC01	pbtc1p	
226	VITC02	pbtc1p	
227	V2MM02	pbfl3	
228	V2MM03	obfl3	
229	V2RF20	ncme1	ncme2
230	acft	prpa0	
231	acore	prpa0	
232	ahp1	prpa0	
233	ahpvs	prpa0	
234	aleak	prpa0	
235	anet	prpa0	prpa2
236	anetw	prpa2	
237	aporv	prpa0	
238	asgs	prpa0	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

239	asytr	prpa0	
240	avgfpcl	clfl1	prfl7
241	calmssa	sgml1	
242	calmssb	sgml1	
243	dtasgp	prtd2	
244	dtbsgp	prtd2	
245	dtcmaag	pstd1	
246	dtcmbeg	pstd1	
247	dtcore	cotd0	prtd2
248	dtrake1	cltd1	
249	dtrake2	cltd1	
250	dtrake3	cltd1	
251	dtrake4	cltd1	
252	dtrake5	cltd2	
253	dtrake6	cltd2	
254	dtrake7	cltd2	
255	dtrake8	cltd2	
256	dtscm	pstd1	
257	dtvva1	vvtd1	
258	dtvva2	vvtd1	
259	dtvvb1	vvtd1	
260	dtvvb2	vvtd1	
261	eprflc	prte2	
262	eprfli	prte2	
263	fcf1	pbfl3	
264	fleak	pbfl3	

Table A.3. Cross-Index of Plots to Variables (Cont'd)

265 fpc1a1	c1f11	266 fpc1a2	c1f11	267 fpc1b1	c1f11	268 fpc1b2	c1f11	269 fpcdrven	prt17	270 fpcfeeda	sgf12	271 fpcfeeda	sgf12	272 fpcdrv	fbf13	273 fpcstema	sgf12	274 fpcstemb	sgf12	275 fts	fbf13	276 ghhqcl	prt9q1	277 ghhqdc	prt9q1	278 ghhqhl	prt9q1	279 ghhqhs	prt9q1	280 ghhqpz	prt9q1	281 ghhqrv	prt9q1	282 ghhqsl	prt9q1	283 ghhqse	prt9q1	284 hf	pzen1	285 hg	pzen1	286 hporvf	pzen1	287 hszstem	szent1
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Table A.3. Cross-Index of Plots to Variables (Cont'd)

288	pdotw1	prpa2
289	poa1	prpa3
290	posvv1	vv1s1
291	posvv2	vv1s1
292	posvv3	vv1s1
293	posvv4	vv1s1
294	pu1dh	puhn1
295	pu1hf	puhf1
296	pu1hh	puhh1
297	pu1hn	puhn1
298	pu1qn	puqn1
299	pu1sn	pusn1
300	pu2dh	puhn1
301	pu2hf	puhf1
302	pu2hh	puhh1
303	pu2hn	puhn1
304	pu2qn	puqn1
305	pu2sn	pusn1
306	pu3dh	puhn1
307	pu3hf	puhf1
308	pu3hh	puhh1
309	pu3hn	puhn1
310	pu3qn	puqn1
311	pu3sn	pusn1
312	pu4dh	puhn1

Table A.3. Cross-Index of Plots to Variables (Cont'd)

313	pu4hf	puhf1		
314	pu4hh	puhh1		
315	pu4hn	puhn1		
316	pu4qn	puqn1		
317	pu4sn	pusn1		
<hr/>				
318	qcorein	prqe2		
<hr/>				
319	qdecay	rvkw0	rvkw0	rvkw0
<hr/>				
320	q1khpi	prqe2		
<hr/>				
321	qpr1ta	prqe2		
322	qprmet	prqe2		
<hr/>				
323	qs1f1	sgqe3		
324	qs11ta	sgqe3		
325	qs1met	sgqe3		
326	qs1pts	prqe2		
327	qs1smf	sgqe3		
328	qs2f1	sgqe6		
329	qs21ta	sgqe6		
330	qs2met	sgqe6		
331	qs2pts	prqe2		
332	qs2smf	sgqe6		

Table A.3. Cross-Index of Plots to Variables (Cont'd)

333	tinmssa	sgml1									
334	tinmssb	sgml1									
335	zlts	c1lv4	c1lv5	c1lv6	colv1	colv1	colv1	colv1	h1lv1	h1lv1	pstd1
335	zlts	pstd1	pzlv1	pzlv1	sglv2	sglv2	sglv2				
336	zsgp1	h1lv1									
337	zsgp2	h1lv1									

APPENDIX B
Discharge Orifice Sizes

Table B.1 provides the discharge orifice sizes for each MIST test, listed in chronological order. The locations and throat diameters (in inches) are listed. Each orifice is installed in 3/8" O.D. x 0.065" wall stainless steel tubing, except for the reactor coolant pump seal (RCPS) and cold leg discharge #3 (CLD3) leak sites. The RCPS orifices are installed in 1/2" O.D. x 0.065" wall stainless steel tubing and the CLD3 orifice is installed 1" x schedule 80 stainless steel pipe. The key orifices used to initiate each test are noted with an arrow or underline.

Table B.1. Discharge Orifices

Orifice sizes are indicated as THROAT DIAMETER IN INCHES.

TESTID	DATE	CLD1	2	3	4	CLS	PORV	RVUHV	HPV-A	HPV-B	RV/DC1	RV/DC2
000513	05/07/86	0.0325	▶0.0465	0.1095	0.0475	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
000514	05/08/86	0.0325	▶0.0465	0.1095	0.0475	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
000531	05/20/86	0.0325	▶0.0465	0.1095	0.0475	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
000532	05/20/86	0.0325	▶0.0475	0.1095	0.0475	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
000533	05/23/86	0.0325	▶0.0475	0.1095	0.0475	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
000534	05/23/86	0.0325	▶0.0475	0.1095	0.0475	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
310000	06/14/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0491	0.0348
300001	06/17/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0491	0.0348
300304	06/17/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348
300305	06/18/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348
3004CC	06/23/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0226	▶0.0156
3001BB	06/24/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348
300504	06/24/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348
300605	06/25/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348
310899	06/26/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
3109AA	07/01/86	CAPPED	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
3009AA	07/08/86	▶0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
310702	07/09/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
310302	07/10/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
310101	07/11/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
310201	07/12/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
310403	07/13/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
320604	07/14/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
320302	07/15/86	0.0325	0.0475	0.1095	0.0498	▶0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
310699	07/16/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
3105AA	07/18/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
320402	07/19/86	0.0325	0.0475	0.1095	0.0498	0.0491	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
320503	07/19/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
320101	07/20/86	▶0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
320201	07/21/86	0.0325	0.0475	▶0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
3003AA	07/22/86	0.0325	0.0475	0.1095	0.0498	▶0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
3109BB	07/23/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348
3106AA	07/24/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348

Table B.1. Discharge Orifices (Cont'd)

Orifice sizes are indicated as THROAT DIAMETER IN INCHES.

TESTID	DATE	CLD1	2	3	4	CLS	PORV	RVUHV	HPV-A	HPV-B	RV/DC1	RV/DC2		
3301AA	07/31/86	0.0325	0.0475	0.1095	0.0498	0.0491	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
330201	08/01/86	0.0325	0.0475	0.1095	0.0498	0.0491	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	UP-LO	
330302	08/02/86	0.0325	0.0475	0.1095	0.0498	0.0491	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	TB RUP	
3301BB	08/03/86	0.0325	0.0475	0.1095	0.0498	0.0491	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
340213	08/04/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0190	UPPER
3404AA	08/20/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863	UPPER
340100	08/21/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863	UPPER
340302	08/21/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863	LOWER
340504	08/22/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863	UPPER
3007CC	08/27/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348		
3204AA	08/26/86	0.0325	0.0475	0.1095	0.0498	0.0491	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
311000	09/03/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
3111AA	09/16/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0226	0.0226		
350101	09/18/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	▶0.0155	▶0.0155	0.0226	0.0226		
350202	09/25/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0226	▶0.0348		
3502AA	09/26/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	▶0.0226	0.0348		
3502CC	10/09/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	▶0.0348		
350502	10/14/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
350312	10/16/86	0.0325	▶0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	▶0.0155	▶0.0155	0.0348	0.0348		
3406AA	10/21/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863	LOWER
350700	10/22/86	0.0325	0.0475	0.1095	0.0498	▶0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
350800	10/24/86	0.0325	0.0475	0.1095	0.0498	▶0.0491	0.0491	0.0155	▶0.0155	▶0.0155	0.0348	0.0348		
370199	11/21/86	0.0325	0.0475	0.1095	0.0498	0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		PRSZR
370299	11/25/86	0.0325	0.0475	0.1095	0.0498	▶0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		UP-VNT
3702AA	11/25/86	0.0325	0.0475	0.1095	0.0498	▶0.0491	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
360000	03/02/87	0.0325	▶0.0475	0.1095	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		0.0155
340799	03/03/87	0.0325	0.0475	0.1095	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863U	0.0155
360514	03/13/87	0.0325	0.0475	0.1095	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	▶0.0863U	
360499	03/14/87	0.0325	0.0475	0.1095	0.0475	0.0270	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
330499	03/16/87	0.0325	0.0475	0.1095	0.0475	0.0270	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
3600AA	03/17/87	0.0325	▶0.0475	0.1095	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348		
300806	08/14/87	0.0325	CAPPED	0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	▶0.0348	0.0348		

Table B.1. Discharge Orifices (Cont'd)

Orifice sizes are indicated as THROAT DIAMETER IN INCHES.

TESTID	DATE	CLD1	2	3	4	CLS	PORV	RVUHV	HPV-A	HPV-B	RV/DC1	RV/DC2	
3601AA	08/20/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
360201	08/25/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
3801AA	08/28/87	0.0325	0.02586	0.1558	0.0475	0.0270	▶0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
360301	09/01/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
3602DD	09/02/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
4SECOA	09/17/87	0.0325	0.02586	0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
4SECO C	09/21/87	0.0325	0.02586	0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	RCP SEAL LEAK
4SECO2	09/25/87	0.0325	0.02586	0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	
													C1=.0093 C2=.0080
													C3=.00803 C4=.0097
410AT3	11/12/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
4NOML3	11/17/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
4SGPF2	11/19/87	0.0325	0.02586	0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
4SBO11	11/24/87	0.0325	0.02586	0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
410BD1	12/01/87	0.0325	0.02586	0.1558	▶0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
4100B1	12/08/87	0.0325	0.02586	▶0.1558	0.0475	0.0270	0.0491	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
4100B2	12/11/87	0.0325	0.02586	▶0.1558	0.0475	0.0270	0.0400	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4
4CR3T2	12/14/87	0.0325	0.02586	0.1558	0.0475	0.0270	0.0400	0.0155	0.0155	0.0155	0.0348	0.0348	C1,C2,C3,C4