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This document was prepared primarily for preliminary or internal use. It has not received full review and approval. Since there may be substantive changes, this document should not be considered final.

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September 1979

TEST PREDICTION FOR SEMISCALE MOD-3 TEST S-SB-2 - SMALL BREAK TEST SERIES

B. W. Murri
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U.S. Department of Energy
Idaho Operations Office • Idaho National Engineering Laboratory

This is an informal report intended for use as a preliminary or working document

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U. S. Nuclear Regulatory Commission

EG&G Idaho

EG&G Idaho, Inc.

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INTERIM REPORT

TEST PREDICTION FOR
SEMISCALE MOD-3 TEST S-SB-2
SMALL BREAK TEST SERIES

by

B. W. Murri
D. M. Snider
S. E. Dingman
C. P. Fineman

SEMISCALE PROGRAM

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Semiscale Experiment Specification
and Analysis Branch

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This RELAP4 model of the Semiscale Mod-3 system for small breaks analysis has been reviewed by the Pretest Prediction Consistency Review Committee.

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SUMMARY

This document contains a pretest analysis of the Semiscale Mod-3 system thermal-hydraulic response for the first test in the small break test series (Test S-SB-2). This test series was designed to be compatible with small break loss-of-coolant experiments defined for the Loss-of-Fluid Test (LOFT) Program and computer code calculations performed by the Code Assessment and Applications Program to predict pressurized water reactor (PWR) system behavior during a small break loss-of-coolant accident (LOCA). Results of the Semiscale small break tests will be used to investigate scaling effects pertinent to LOFT and Semiscale and to assess analytical models used in the computer codes.

Test S-SB-2 is an integral small break loss-of-coolant test associated with the Semiscale small break test series. The primary objective of Test S-SB-2 is to provide information on the natural circulation phenomena and the potential for core uncovery which may result from the slow depressurization during a small break in the primary cold leg pipe near the vessel for the case where high pressure injection flow is not sufficient to makeup system mass discharged through the break.

The break configuration for Test S-SB-2 will represent a 2.5% communicative cold leg break with a total break area of 0.0613 cm^2. The test will be initiated at a core power of 2.1 MW and will utilize a 25-rod electrically heated core consisting of 23 powered rods and 1 unpowered rod (one of the rod locations has been utilized for a liquid level probe). The radial power profile will be flat with a peak axial power density of 38.69 kW/m. The steam generator secondaries and the primary coolant pumps for both the intact and broken loops will be operated in a manner which simulates the expected performance in a PWR system. Emergency core coolant will be injected into both the intact and broken loop cold legs. Upper head injection will not be used in this experiment. Test S-SB-2 will be conducted from an initial pressure of 15.5 MPa with a cold leg fluid temperature of 550 K and a core differential temperature of 33 K.

The pretest analysis for Test S-SB-2 was performed using the RELAP4/MOD7 computer code to provide a prediction of the system thermal-hydraulic response during the test.

The pretest calculation was made from initiation of rupture to 856 s. The pump seals were calculated to blowout at 278 s, which resulted in a decrease in mass in the pump seals and cold leg. The reduction in mass in the cold leg led to a decrease in break flow (change from subcooled to two phase) and a reduction in core inlet flow. The core total liquid mass was calculated to decrease throughout the transient. However, the mixture level (which represents gas and liquid), remained high until 400 s, and then decreased rapidly. Core temperatures followed the saturation temperature until 605 s when there was a minor temperature excursion (780 K peak). With the start of accumulator injection at 838 s, the temperatures decreased to near saturation temperatures and remained cool. The results of the pretest calculation were compared to results of the audit calculation for a Westinghouse PWR cold-leg 2.1% break.

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I. INTRODUCTION

This report contains the pretest analysis for the Semiscale Mod-3 system thermal-hydraulic response for Test S-SB-2 which will be the first test in the Semiscale Mod-3 small break test series (Reference 1). Semiscale performs pretest analysis for the purpose of (1) obtaining insight into the expected behavior of the system during the test, (2) ensuring that initial conditions, operating procedures and instrumentation ranges are adequate to meet the test objectives, and (3) providing an indication of unexpected adverse conditions which could arise during the experiment. In making the analysis, engineering judgement was used in modeling the system while still adhering to the Pretest Prediction Consistency Committee guidelines. This report identifies the prerupture system conditions, presents the expected behavior of key variables, and provides a comparison of the Test S-SB-2 calculated results with results from the Code Assessment and Applications Program calculation for a Westinghouse pressurized water reactor (PWR) with a 2.1% cold-leg break (Reference 2). The PWR calculations was performed as a licensing audit calculation for the Nuclear Regulatory Commission (NRC) and as such, the modeling options chosen were standard for licensing calculations. On the other hand, the Semiscale calculation was run as a best-estimate calculation and the modeling options chosen were believed to give a best estimate of the system behavior. The RELAP4/MOD7 (Reference 3) model used to predict the system small break response for Test S-SB-2 is described briefly in Section II.1 with a more thorough description given in Appendix A. The RELAP4/MOD7 model used for the PWR calculation is described in Appendix B. Scaling considerations for comparing the two calculations are discussed in Section III.

The operating conditions for Test S-SB-2 are listed in Table I. The break configuration will represent a 2.5% communicative cold leg break with a total break area of 0.0613 cm^2. The test will be conducted at an initial core power of 2.1 MW and an initial core mass flow rate of 11.7 kg/s. The heated core for this test will have

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TABLE I

INITIAL CONDITIONS AND OPERATIONAL REQUIREMENTS FOR TEST S-SB-2

Initial Conditions	
Pressurizer Pressure	15.51 MPa
Hot Leg Fluid Temperature	583.3 K
Cold Leg Fluid Temperature	550.0 K
Core Inlet Flow Rate	11.7 kg/s
Total Core Power	2.1 MW
Radial Power Profile	F[illegible]
Pressurizer Liquid	13.1 kg
Steam Generator Secondary Pressure	5.86 MPa
Steam Generator Feedwater Temperature	495 K
Steam Generator Secondary Water Level	
Intact Loop	2.95 m
Broken Loop	9.98 m
Configuration	
Break Size	2.5%
Break Type	Communicative
Break Location	Cold Leg
Pressurizer Location	Intact Loop
Pressurizer Line Resistance (m^{-4})	5.9×10^{8}
Intact Loop ECC Injection Location (all systems)	Cold Leg
Broken Loop ECC Injection Location (all systems)	Cold Leg
Intact Loop Accumulator Line Resistance (m^{-4})	8.59×10^{8}
Broken Loop Accumulator Line Resistance (m^{-4})	7.73×10^{9}
ECC Injection	
Intact Loop Accumulator	
Actuation Pressure	4.24 MPa
Liquid Volume	0.04480 m^3
Nitrogen Volume	0.02635 m^3
Temperature	300 K
Intact Loop HPIS	
Actuation Pressure	12.41 MPa
Delay	25 s
Injection Rate	see Fig. 2
Temperature	300
Intact Loop LPIS	
Actuation Pressure	0.883 MPa
Injection Rate	see Fig. 3
Temperature	300 K

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TABLE I (contd)

Broken Loop Accumulator	
Actuation Pressure	4.24 MPa
Liquid Volume	0.01493 m^3
Nitrogen Volume	0.00878 m^3
Temperature	300 K
Broken Loop HPIS	
Actuation Pressure	12.41 MPa
Delay	25 s
Injection Rate	see Fig. 2
Temperature	300 K
Broken Loop LPIS	
Actuation Pressure	0.883 MPa
Injection Rate	see Fig. 3
Temperature	300 K
Transient Conditions	
SCRAM (power decay)	See Table II
Pressure Setpoint	12.58 MPa
Time Delay	3.4 s
Steam Generator Secondaries	
Steam Valve Relief Pressure	7.7 MPa
Steam Valve Isolation	12 s after scram
Main Feedwater Isolation	5 s after scram
Auxiliary Feedwater Initiation	60 s after scram
Auxiliary Feedwater Flow Rate	
Intact Loop	0.0296 kg/s
Broken Loop	0.0099 kg/s
Auxiliary Feedwater Temperature	300 K

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23 powered rods and 1 unpowered rod (one of the rod locations has been used for a liquid level probe). The radial power profile will be flat with a peak axial power density of 38.69 kW/m. All rods will have a chopped cosine axial power profile as shown in Figure 1. The core inlet fluid temperature will be 550 K and the core fluid temperature differential will be 33 K. The electrical power decay will follow the decay curve shown in Table II. The normalized pump speed for intact and broken loop pumps is given in Table III. Emergency core coolant (ECC) injection is to be made into both the intact loop and broken loop cold legs using accumulators and high pressure injection system (HPIS) and low pressure injection system (LPIS) pumps. The HPIS and LPIS flow rates as a function of pressure are shown in Figures 2 and 3, respectively. ECC water is to be ambient for this test. The pressure suppression system will be controlled to maintain a containment pressure of 241 kPa throughout the test.

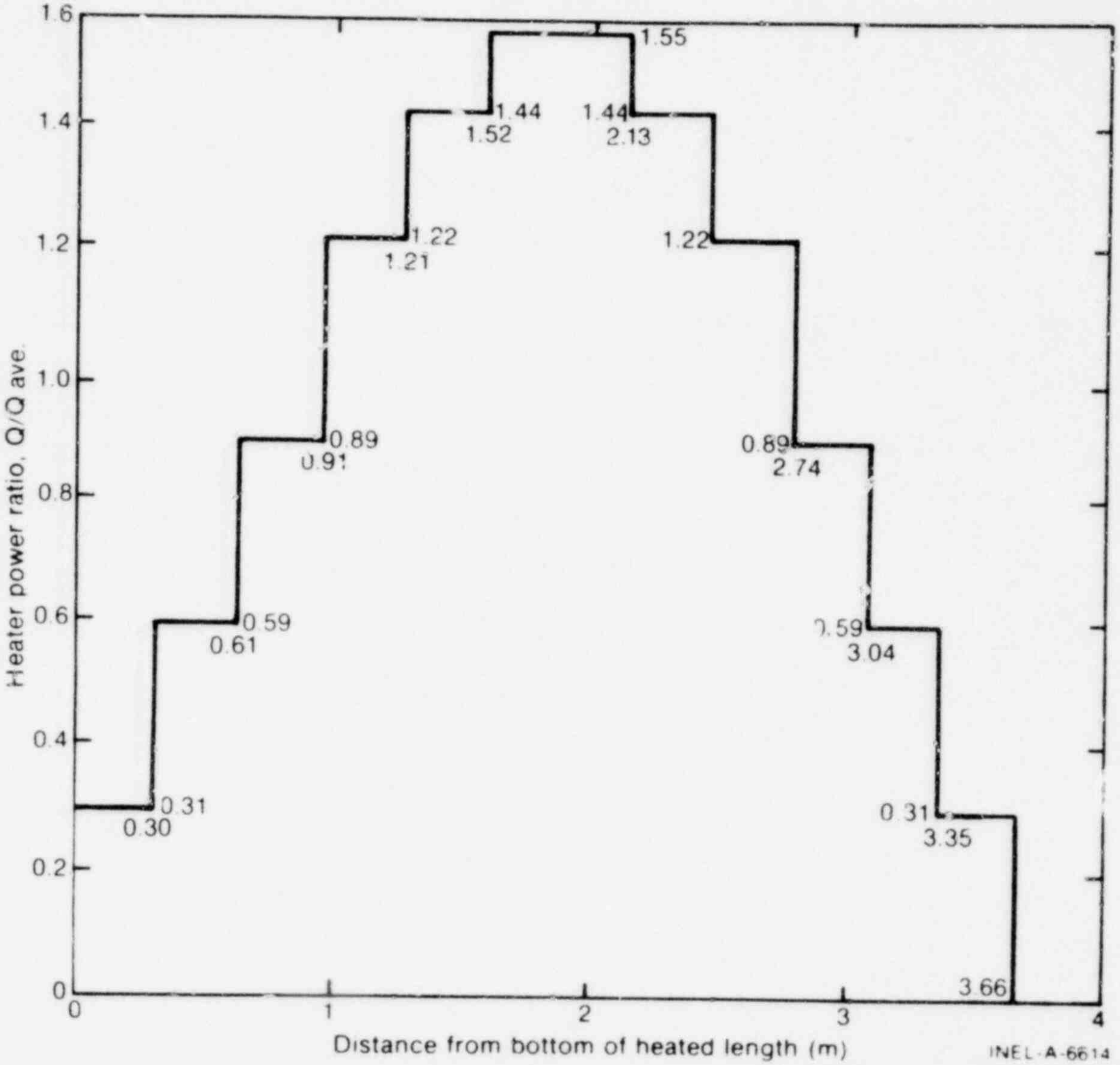

Fig. 1 Axial power profile.

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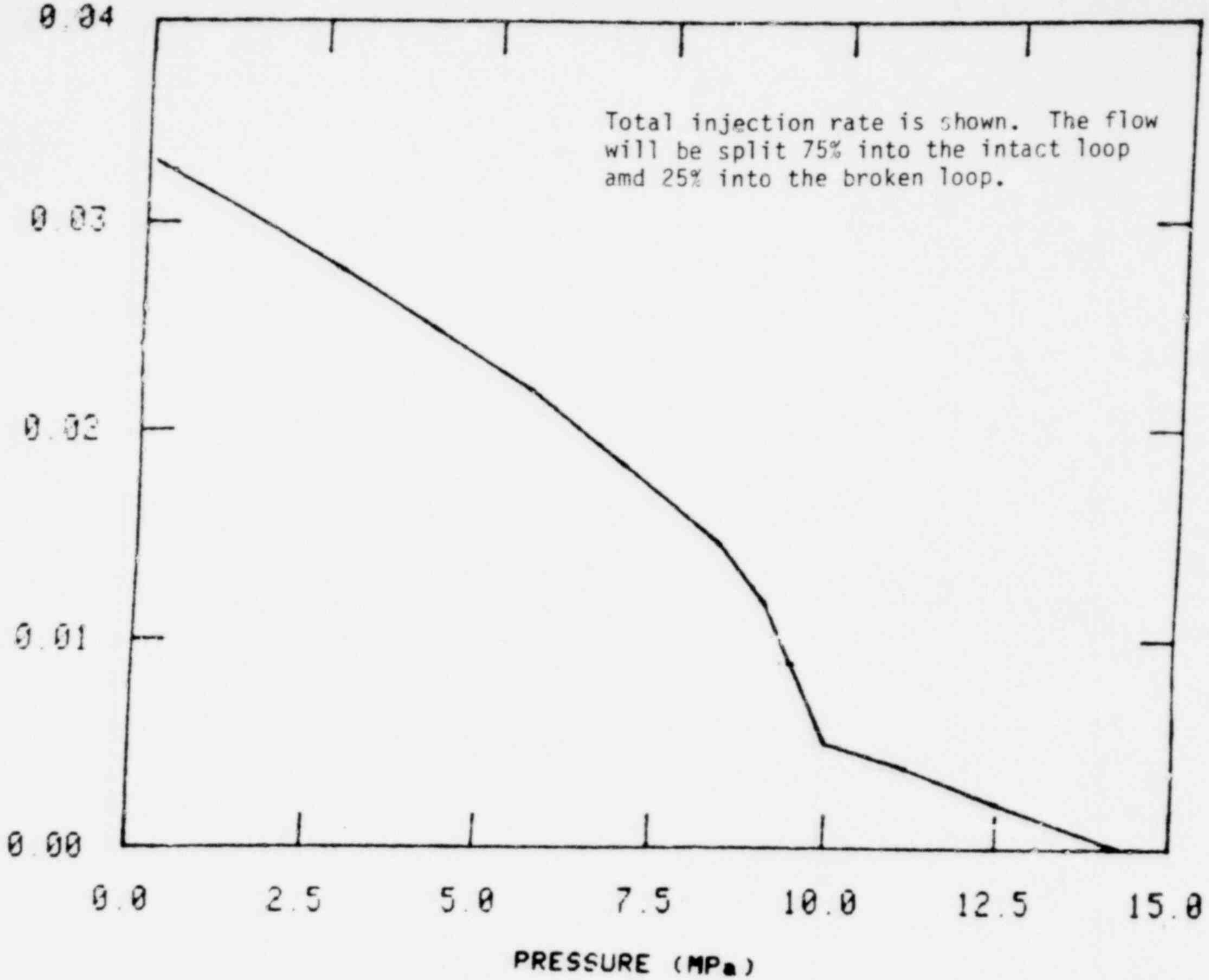

Fig. 2 HPIS flow rate.

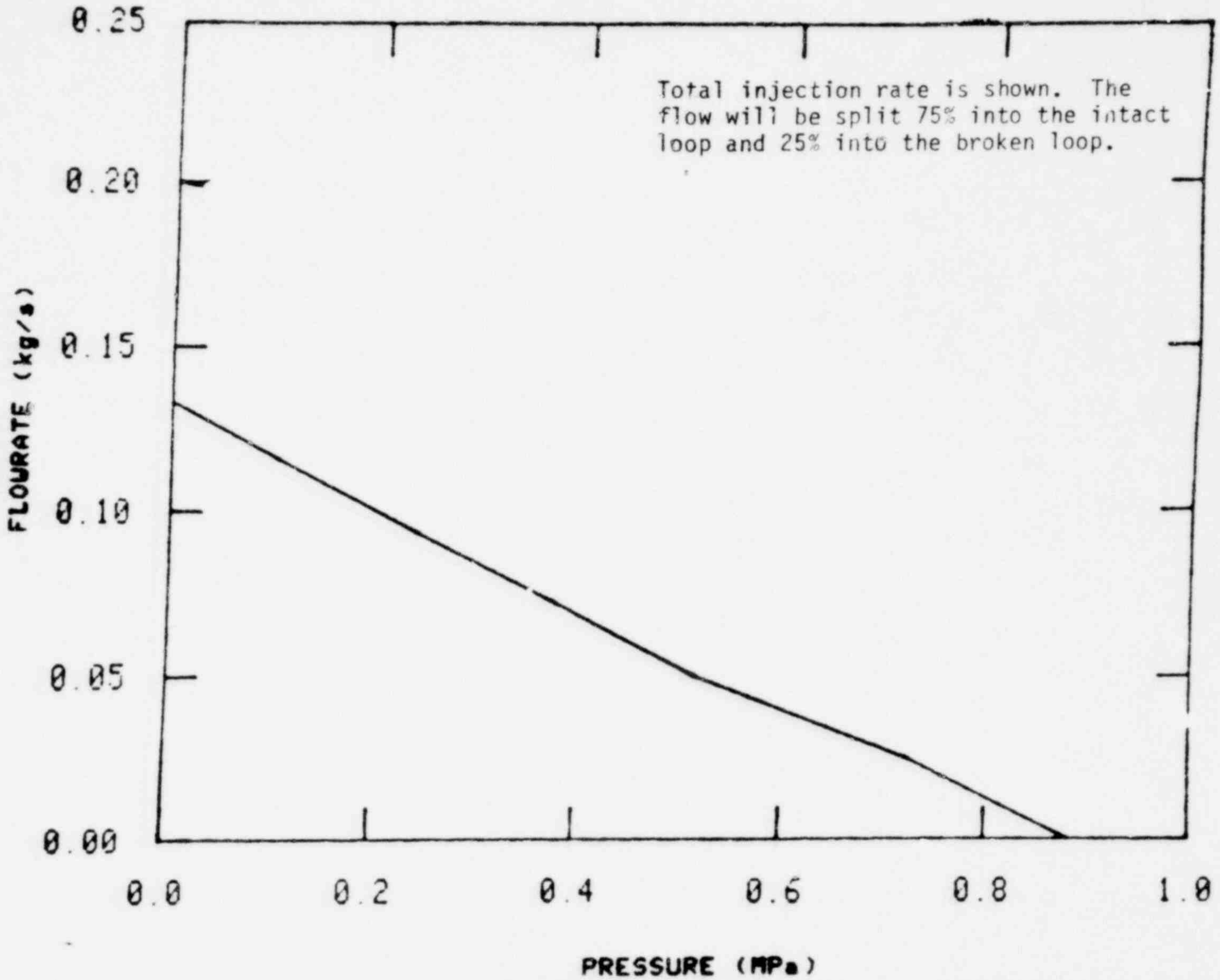

Fig. 3 LPIS flow rate.

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TABLE II

POWER DECAY FOR TEST S-SB-2

Time after trip (s)	Normalized Power	Normalized Voltage
0*	1.0	1.000
3	0.4	0.632
6	0.123	0.351
20	0.06	0.245
30	0.052	0.228
60	0.044	0.210
100	0.04	0.200
200	0.035	0.187
1000	0.023	0.152

* Time = 0 s is defined as 3.4 s after the pressurizer pressure reaches 12.58 MPa.

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TABLE III

PUMP SPEED FOR TEST S-SB-2

Time after trip (s)	Normalized Value
0*	1.00
10	0.550
20	0.375
30	0.280
40	0.235
50	0.215
60	0.200
120	0.100
130	0.000

* Time = 0 s is defined as 3.4 s after the pressurizer pressure reaches 12.58 MPa.

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II. RELAP4 MODEL DESCRIPTION

The RELAP4/MOD7 (Update 92*) computer code was used to predict the system response during the blowdown, vessel refill, and core reflood of Test S-SB-2. The model nodalization representing the Semiscale system is shown in Figure 4. A more detailed description of the model and a listing** of the input for Test S-SB-2 is contained in Appendix A. The Henry-Fauske and homogeneous equilibrium (HEM) critical flow models were used for the subcooled and two phase break flow regimes, respectively. A break flow multiplier of 1.0 was used during both the subcooled regime and the saturated regime. Vertical slip was used in the model at all downcomer, core, and support and guide tube junctions. To be consistent with the use of slip in the core, the bubble rise model was not used in either the upper or lower plenums. The standard bubble rise model was used in the downcomer, core, upper head, pressurizer, pump suctions, and steam generator secondaries. Heat conductors were included in the upper plenum to model the energy stored in the upper plenum and upper head structures, and heat conductors were used to model heat transfer from piping, downcomer wall and core barrel. Conductors were also used in the lower plenum to model energy stored in the unpowered rod sections. The upper plenum was nodalized into three control volumes in an attempt to simulate the mixing between the upper plenum fluid and fluid draining from the upper head through the guide and support tubes. All heat conductors which would be exposed to the environment were insulated on the outer surfaces and thus did not account for energy transfer from the system to the environment. The pressure suppression tank (Volume 6 in Figure 4) was represented as a time-dependent volume filled with saturated vapor at a constant pressure of 241 kPa. The pump power was tripped off at scram, and the intact and broken loop pumps followed the coastdown curve shown in Table III.

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* RELAP/MOD7 historical code configuration control number is H007184B.

** Input to RELAP4/MOD7 historical code configuration control number is H00994IB.

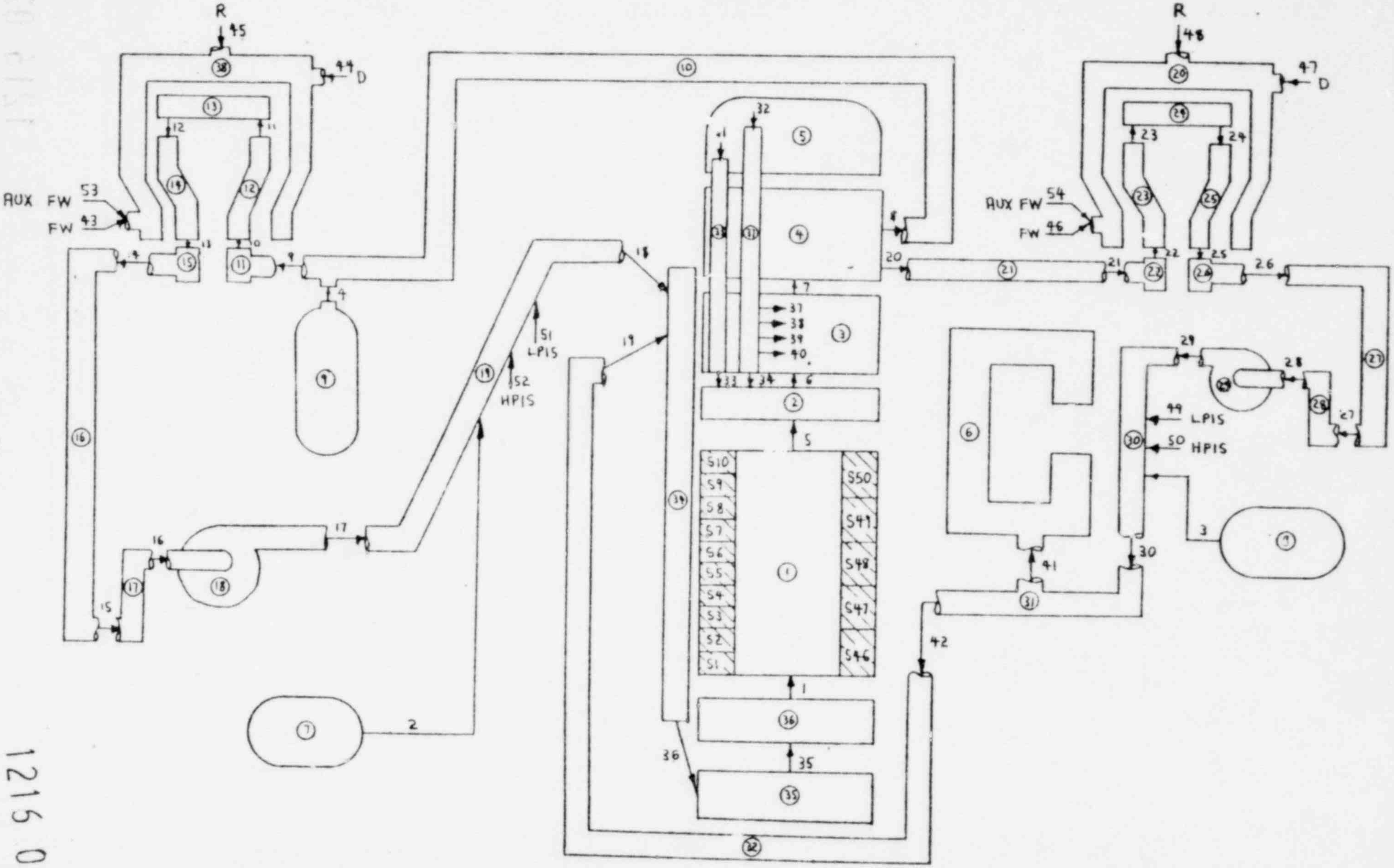

Fig. 4 RELAP4/MOD7 model for Test S-SB-2.

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III. SCALING CONSIDERATIONS

Due to inherent scaling compromises, the results obtained from tests in the Semiscale small break test series are not to be considered entirely representative of those expected in a PWR under similar conditions. Data from these tests will be used primarily to benchmark small break code capability and to evaluate scale effects by comparison to LOFT system results. Nevertheless, the value of Semiscale data is increased through an understanding of scaling limitations and their potential effect on results.

Several specific scaling concerns have been identified and categorized as either manageable or accountable. Those distortions considered manageable will require physical modification to the system to be effectively mitigated. Included in this category are excessive external heat loss and atypical steam generator configuration. Scaling distortions that are defined as accountable cannot be physically eliminated but may be assessed analytically. Scaling influences on flow regimes and critical flow are included in this category.

In the subsections that follow each of the identified scaling distortions is discussed and evaluated as to potential effect. It is important to recognize that an extensive technical evaluation of the impact of scaling on small break behavior in Semiscale has not yet been completed. Indeed, the data forthcoming from the small break tests series will be utilized as an integral part of that evaluation.

1. HEAT LOSSES

The heat losses from the piping, vessel and downcomer to the environment and heat loss to cooled instruments in the Semiscale Mod-3 system represent approximately 6% of initial core power. The heat loss should be on the order of 0.07% to be representative of that in a PWR. To compensate for the excess heat losses in Semiscale, the core power in Test S-SB-2 will be increased. Additionally, recent installation of a honeycomb downcomer insulator and improved insulation of the loop piping should reduce the heat loss.

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A long-term solution to the heat loss problem includes the installation of strip heaters and high quality external insulation. In the pretest calculation heat structures were modeled with an insulated outer surface, and thus heat loss between the system and environment was not accounted for. An analysis is currently underway to quantify the effect on system response caused by piping heat loss and increased core power to offset it. It is recognized that the increase in core power has the potential to distort core coolant void distribution and uncovered core temperature response.

2. FLOW REGIMES

Scaling influences can induce flow regime differences between Semiscale and a PWR during a small break LOCA. The flow regime differences can in turn affect the wetted surface areas, pressure drops, and critical break flow characteristics. Since the RELAP4 calculations for both Semiscale and a PWR assume homogeneous flow, the effects of scale on flow regime characteristics cannot be evaluated with the code. The potential difference in flow regime behavior between Semiscale and a PWR during a small break LOCA has been investigated analytically using the Dukler-Taitel method (Reference 4) in conjunction with the results of the PWR audit calculation. A sample result is shown in Figure 5 which compares the predicted flow regime in the broken loop cold leg pipe (between the break and the pump) in Semiscale and the PWR. Good agreement is obtained when mass flow rates in Semiscale are assumed to scale properly.*

3. LOOP PUMPS

The head performance of the small-scale Semiscale pumps is expected to degrade more rapidly than in PWR pumps as coolant void fraction increases. However, for Test S-SB-2, the Semiscale primary

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* Comparison of LOFT and Semiscale mass flow rates indicate this to be a valid premise.

PREDICTED FLOW REGIMES IN SEMISCALE AND PWR COLD
LEG PIPING DUKLER-TAITEL METHOD - PWR 4 IN. BREAK
AUDIT CALCULATION MASS FLUXES USED

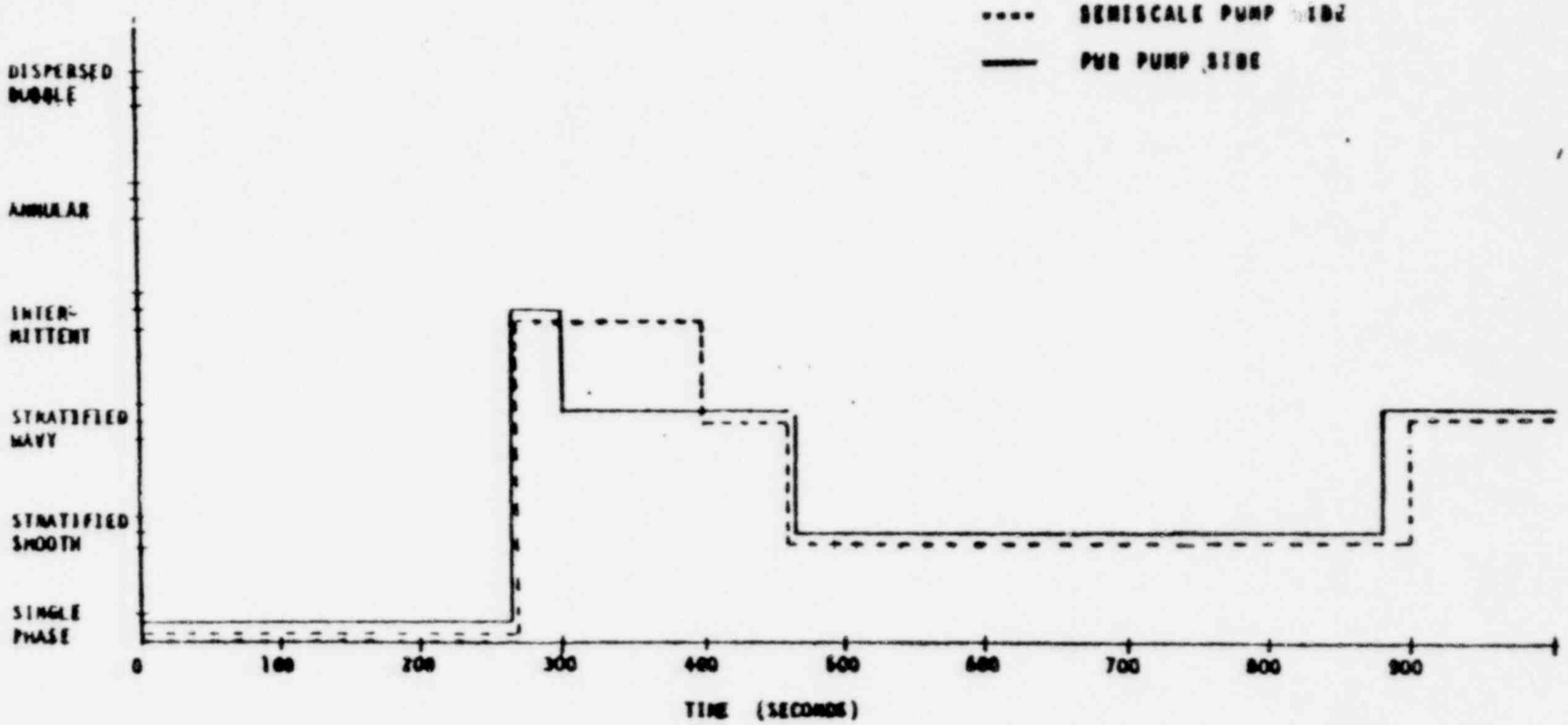

Fig. 5 Predicted flow regimes in Semiscale and PWR cold leg piping.

coolant pumps are tripped at scram and will coastdown before significant voiding occurs. Consequently, pump performance is not considered a scaling distortion for this test.

4. CRITICAL FLOW

The critical flow characteristics of the Mod-3 system can be affected by piping flow regimes, system coolant distribution, and the small size of the break orifice. The piping flow regimes and the relative coolant distribution can affect the timing and duration of the transition from single-phase to two-phase flow at the break, and as a result, the system depressurization. The small break size may be influenced by boundary layer effects (vena contracta) and by bubble sizes which could be comparable to the orifice diameter.

Flow regime agreement between Semiscale and a PWR in the vicinity of the break may potentially be quite good, as evidenced by the comparison shown in Figure 5. Break uncovery time occurs as the pump seals blow out, and in either system, the breaking of the water seals is influenced by the mass discharge rate from the system and the relative amount of coolant in the upper parts of the system which can drain into the pump suction pipes. Figure 6 compares coolant volume inventory (as a percent of total volume) as a function of elevation in Semiscale and a PWR. Because the Semiscale system is, relatively speaking, shorter than a PWR, distortions in coolant inventory to elevation relationship exist in the upper and lower portions of the system. However, in the vicinity of the cold leg centerline the coolant inventory agreement is quite good, with the Semiscale system containing approximately 10% more coolant than the PWR at this location. Thus Semiscale and PWR have close to the same potential for draining water into the pump suction pipes, and both maintain the pump seals for about the same duration. It can be concluded that if the break discharge is scaled properly, then, seal blowout and break uncovery time in Semiscale should be comparable to that in a PWR. This conclusion is born out by the RELAP4 analysis as discussed later in this text.

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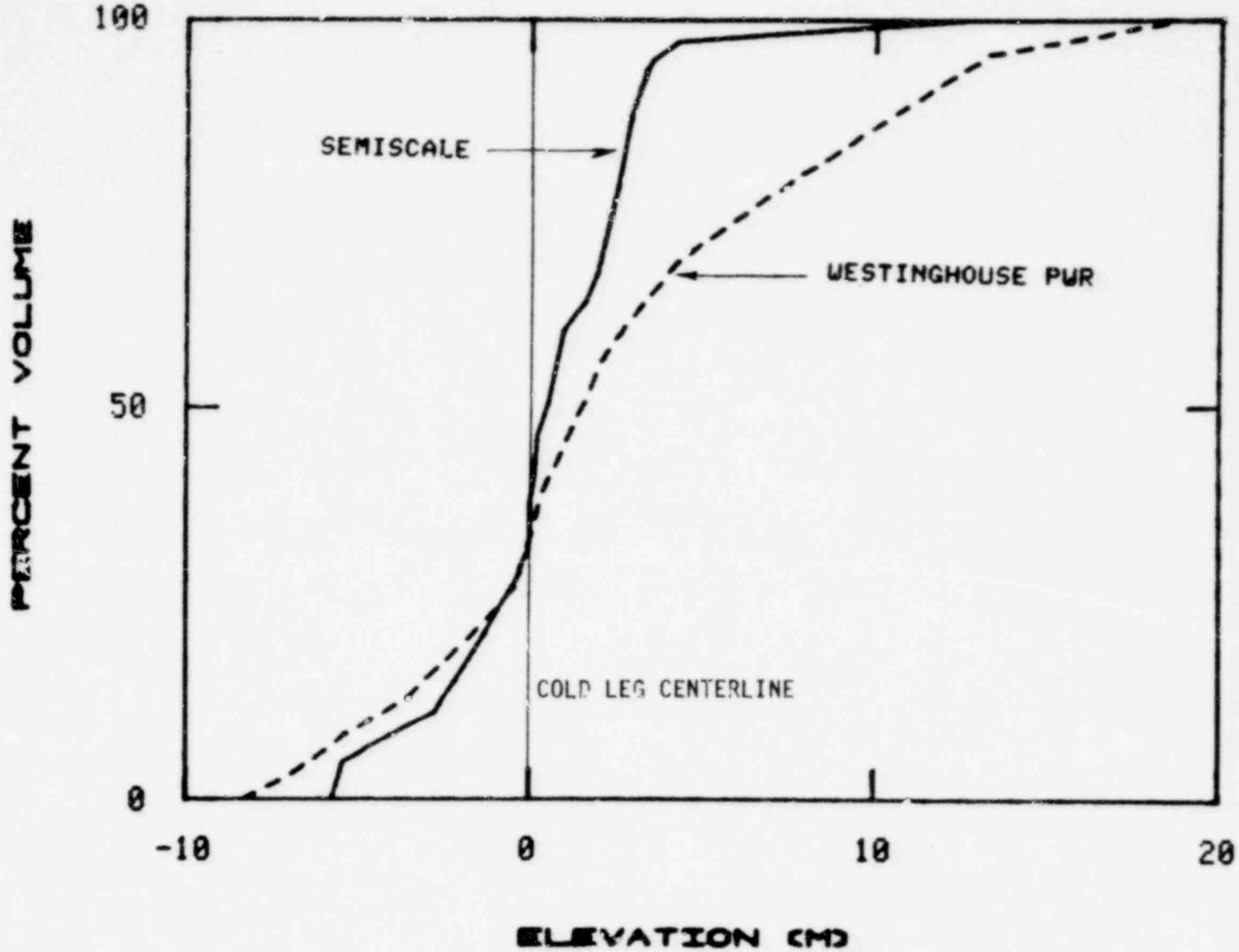

Fig. 6 Coolant volume inventory in Semiscale and PWR.

With regard to break orifice size, results from the Three Mile Island accident simuations in Semiscale (Reference 5) indicate that critical flow atypicality is not evidenced in orifices as small as 0.091 cm in diameter. Moreover, an independent calibration of the break orifice utilized for Test S-SB-2 is to be conducted to better characterize its critical flow behavior.

5. STEAM GENERATOR

The Semiscale steam generators may produce atypical system response because of disproportionately large secondary side volumes and an elevation mismatch between the intact and broken loop steam generators. The broken loop steam generator secondary is approximately five times larger than if it were properly scaled to a PWR and the intact loop steam generator is 30% larger. These distortions may result in atypical heat transfer from primary to secondary which is an important means of heat rejection during a small break. Current plans call for the replacement of the intact loop steam generator (Type I, scaled to LOFT) with a Type II steam generator (similar to what is now in the broken loop). This will eliminate the elevation mismatch problem. Furthermore, design modifications are currently being explored to minimize the secondary volume distortions. However, neither the replacement of the intact loop steam generator nor volume modifications will occur prior to completion of the current small break test series.

Elevation differences between the intact and broken loop steam generators may affect fallback and flow separation in Semiscale relative to a PWR. During natural circulation the differences in elevation may also affect the magnitudes and relative flow distributions between the intact and broken loops. The differences in elevation, however, can be partially compensated for by adjusting loop resistance. The broken loop resistance in Semiscale is to be adjusted to account for the differences in steam generator elevations. A posttest calculation may be required if the differences in loop resistances between the pretest calculation and the actual test are found to influence results significantly.

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A qualitative indication of steam generator design effects is afforded by a comparison of the pretest prediction and PWR audit calculation results. This comparison (discussed in Section IV.4) indicates that the scaling distortions did not result in appreciable differences in primary-to-secondary heat transfer, on a scaled basis.

6. DIMENSIONALITY

Since Semiscale is essentially a one-dimensional facility, multi-dimensional coolant behavior that may occur in a PWR during a small break LOCA may not be well represented. In general, it is felt that multi-dimensional fluid behavior in a PWR would be restricted primarily to the core region, in terms of radial flow components induced by radial power variations. The quantitative affect on PWR core thermal-hydraulic behavior caused by potential multi-dimensional flow patterns is unknown. Moreover, one-dimensional codes such as RELAP4 are unable to address the question of multi-dimensionality in Semiscale versus a PWR.

7. GENERAL SCALING COMMENTS

The Semiscale core geometry, core elevation, and pump loop seal elevations are matched directly with those from a Westinghouse PWR. Therefore, the timing and magnitude of important phenomena relating to pump seal blowout and core uncovery should be similar to the expected behavior in a PWR (assuming system depressurization and primary side heat transfer are matched correctly).

In-core heat transfer and cladding temperature response above the core liquid level will be affected by electric rod thermal properties and fixed axial power profile representation in Semiscale, as opposed to a PWR core utilizing fuel rods arranged to produce a peaked axial profile.

IV. PREDICTED SYSTEM BEHAVIOR

Presented in this section is a discussion of the system behavior from the pretest calculations for Test S-SB-2. The results of the pretest calculation are demonstrated through the use of several calculated system variables, including system depressurization, flow rates, mixture levels, densities, heat transfer rates, and temperatures. To provide additional system analysis, a few key parameters describing system behavior are compared to those obtained from the PWR audit calculation.

A sequence of events in their order of occurrence in the pretest calculation is listed in Table IV.

1. DEPRESSURIZATION RATE

Directly following initiation of the simulated pipe rupture, the system pressure was calculated to decrease from 15.5 to 7.4 MPa during the first 30 s of the transient, as shown in Figure 7. This depressurization period corresponded to the time required for the system to depressurize to the saturation pressure associated with the core fluid temperature. Stabilization of the system pressure occurred at about 7.4 MPa when the system pressure and steam generator secondary pressure (Figure 8) equalized. At 340 s the fluid exiting the break changed from subcooled to two-phase, resulting in a decrease in mass flow but an increased enthalpy discharge at the break location and thus, increased system depressurization rate. At 838 s, the accumulators began emptying into the system which led to an increased depressurization rate. The increased depressurization rate resulted from complete mixing of subcooled and saturated water at the accumulator injection points. This complete mixing is an inherent limitation in the code and is not expected to occur in the actual test.

The Semiscale system depressurization behavior was very similar to that which occurred in the PWR calculation (Figure 7); however, the pressure for Test S-SB-2 was consistently lower than that for the

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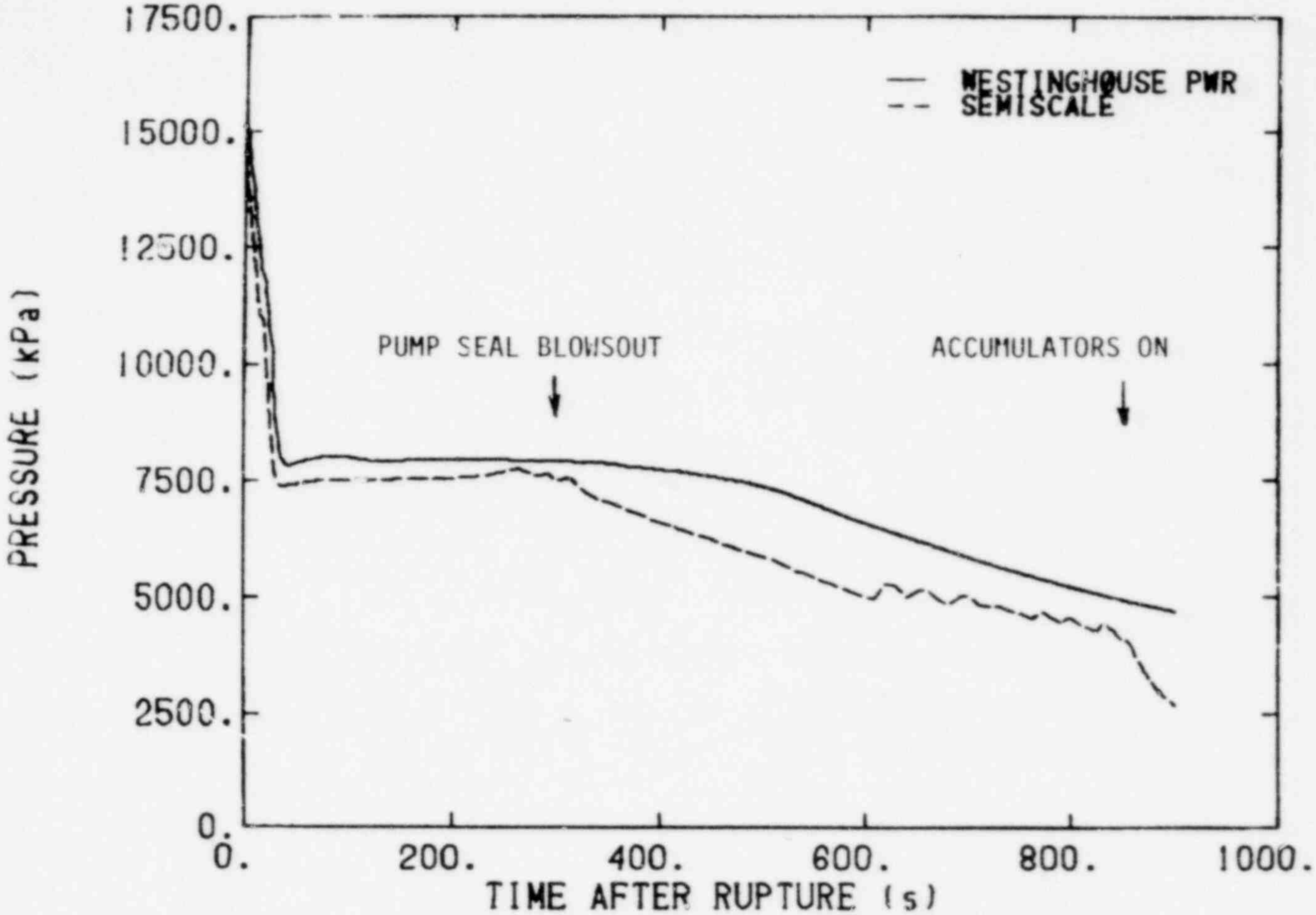
TABLE IV

CALCULATED SEQUENCE OF EVENTS FOR TEST S-SB-2

Time (s)	Event
0.0	Break nozzle opens, subcooled blowdown commences.
12.9	Scram signal received, steam generator discharge valves begin to close (pressurizer pressure falls to 12.58 MPa).
16.3	Reactor scram, pump power tripped off.
17.4	Steam generator discharge valves fully closed.
21.3	Main feedwater starts to ramp off.
25.8	Main feedwater completely off.
31.6	Pressurizer valve closes (pressurizer mixture level falls to 3.05 cm).
41.3	HPIS initiated.
62.0	Intact loop steam generator relief valve opens.
76.3	Steam generator auxiliary feedwater comes on.
838.0	Intact loop and broken loop accumualtor flow initiated.



PRETEST CALCULATIØN FØR TEST S-SB-2

Fig. 7 Calculated pressure response in Test S-SB-2 and PWR.

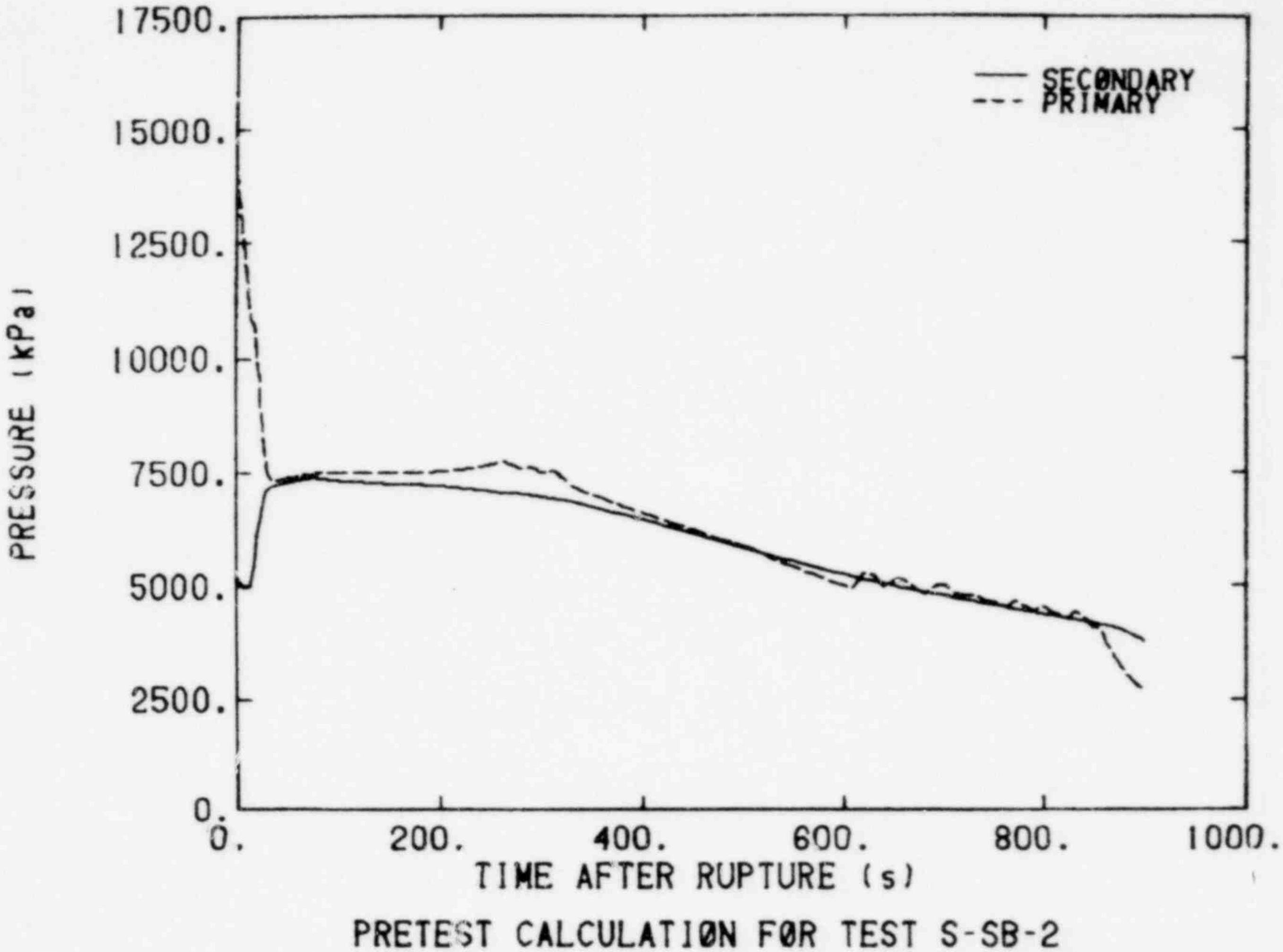


Fig. 8 Calculated intact loop steam generator primary and secondary pressures.

PWR. This led to earlier occurrence of events (trips based on pressure) in the S-SB-2 calculation than were calculated to happen in the PWR. The lower pressure attained in the pretest calculation can be attributed to a great extent on a larger subcooled break flow rate allowed by a larger break size (2.5% for Semiscale compared to 2.1% for the PWR).

2. BREAK FLOW

The calculated break flow for Test S-SB-2 is shown in Figure 9 as compared with the volume-scaled PWR calculated break flow. Subcooled flow at the break was calculated to last until about 340 s after rupture in both calculations, at which time the pump seals were blown out (as seen by the drop in mixture level at the broken loop pump suction in Figure 10). Loss of water in the pump seals brought about a rapid decrease in mass upstream from the break, which in turn lead to a transition from subcooled to two phase break flow. Throughout the transient, the calculated break flow was higher than the HPIS (Figure 11), allowing the system to depressurize.

The Semiscale calculated break flow rate was higher than the volume-scaled PWR flow rate during the subcooled period and lower than the PWR flow rate during the two phase period. The higher flow rate in the subcooled period was a result of a larger break area (scaled) in Semiscale than in the PWR (2.5% for Semiscale compared to 2.1% for the PWR). In the experiment, the small size of the break orifice (relative to the boundary layer) may lead to a flow rate less than that calculated in the prediction. In the two phase break period, two different break flow models were employed for the Semiscale and PWR calculations. In the Semiscale calculation, the HEM flow table was used while in the PWR calculation, the Moody flow table was used. The Moody critical flow table generally gives break flow rates larger than HEM and thus the larger PWR (scaled) flow rate would be expected.

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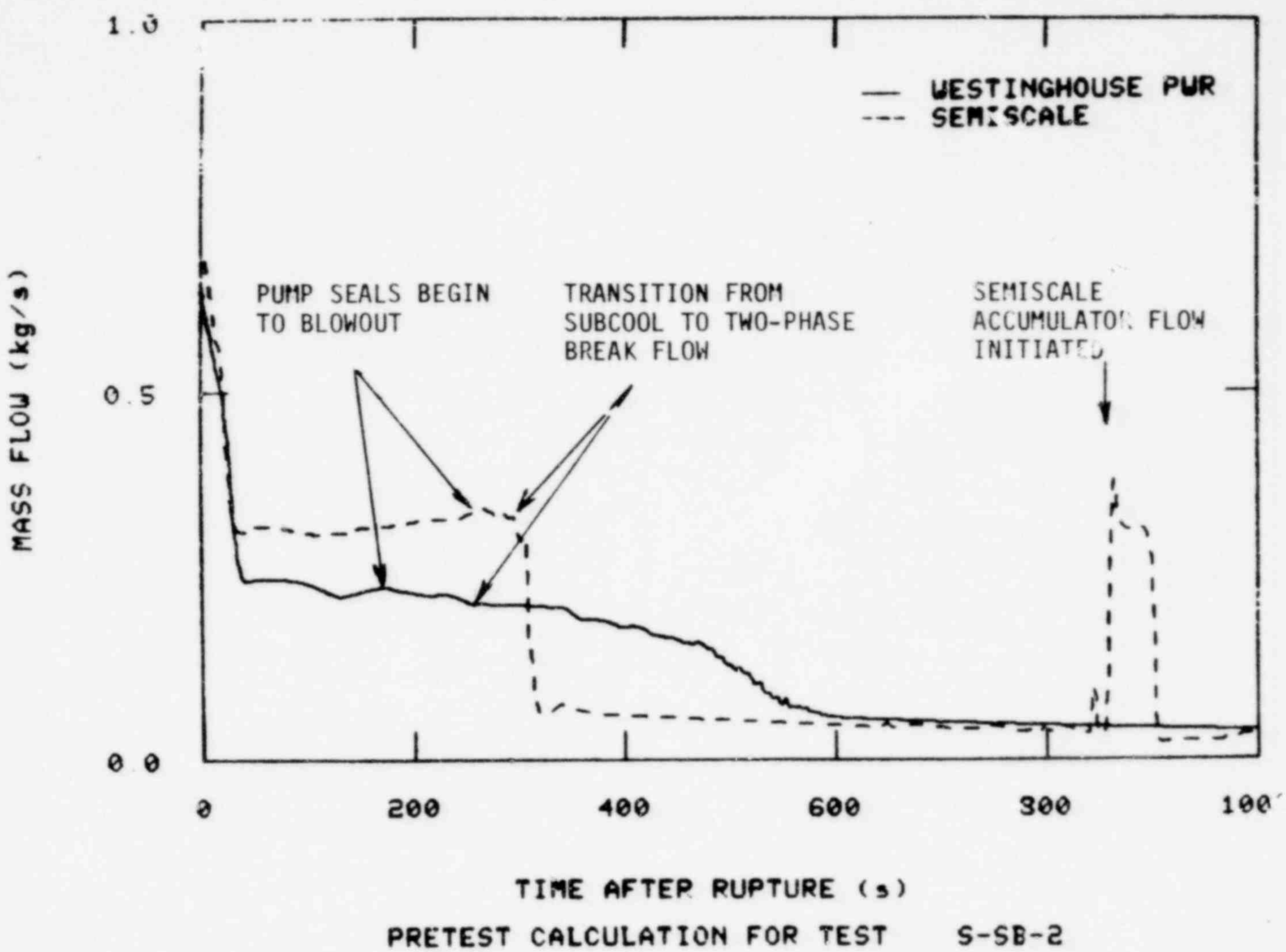

Fig. 9 Calculated break flow for Test S-SB-2 and PWR.

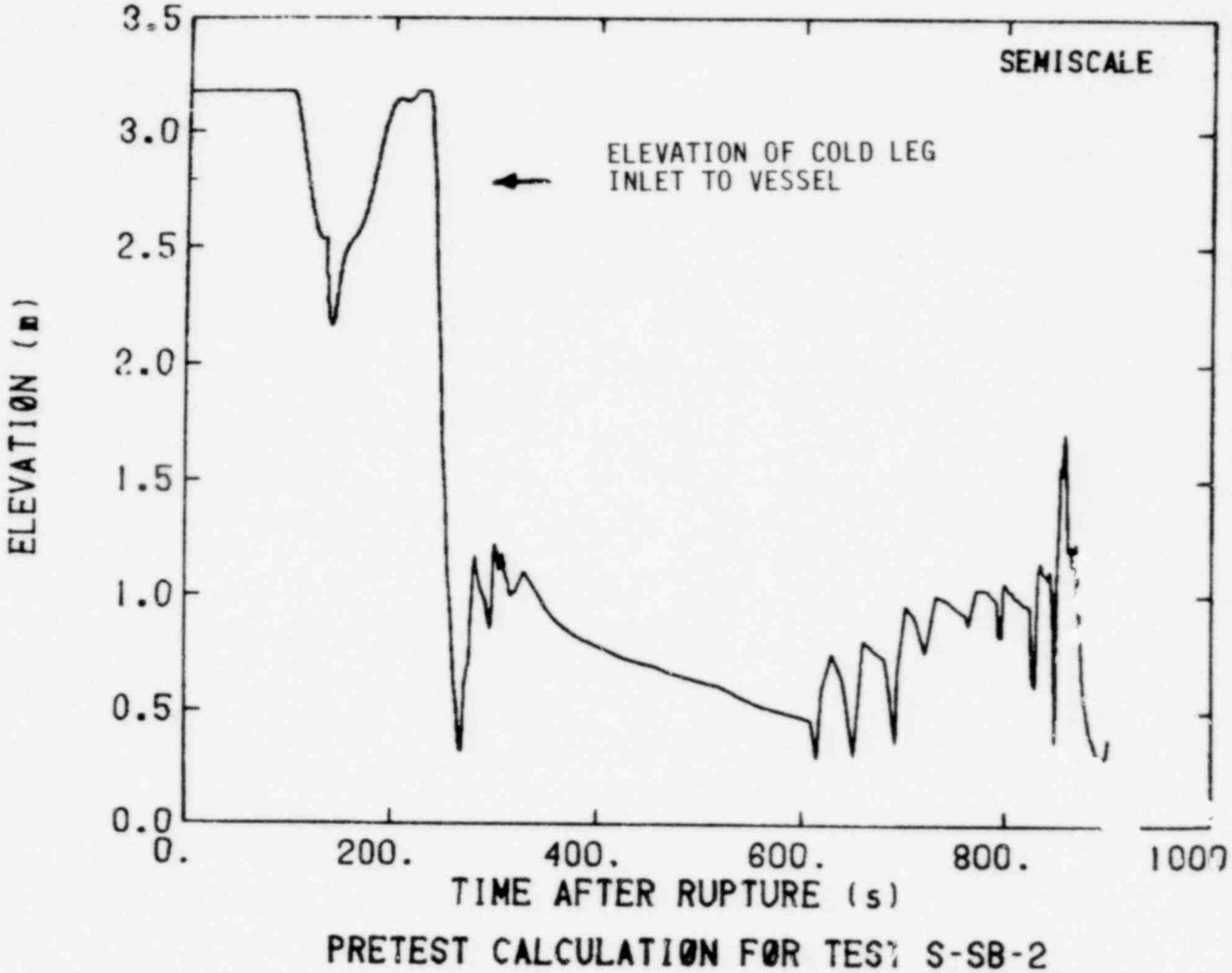

Fig. 10 Calculated mixture level in the broken loop pump suction seal for Test S0SB-2 and PWR.

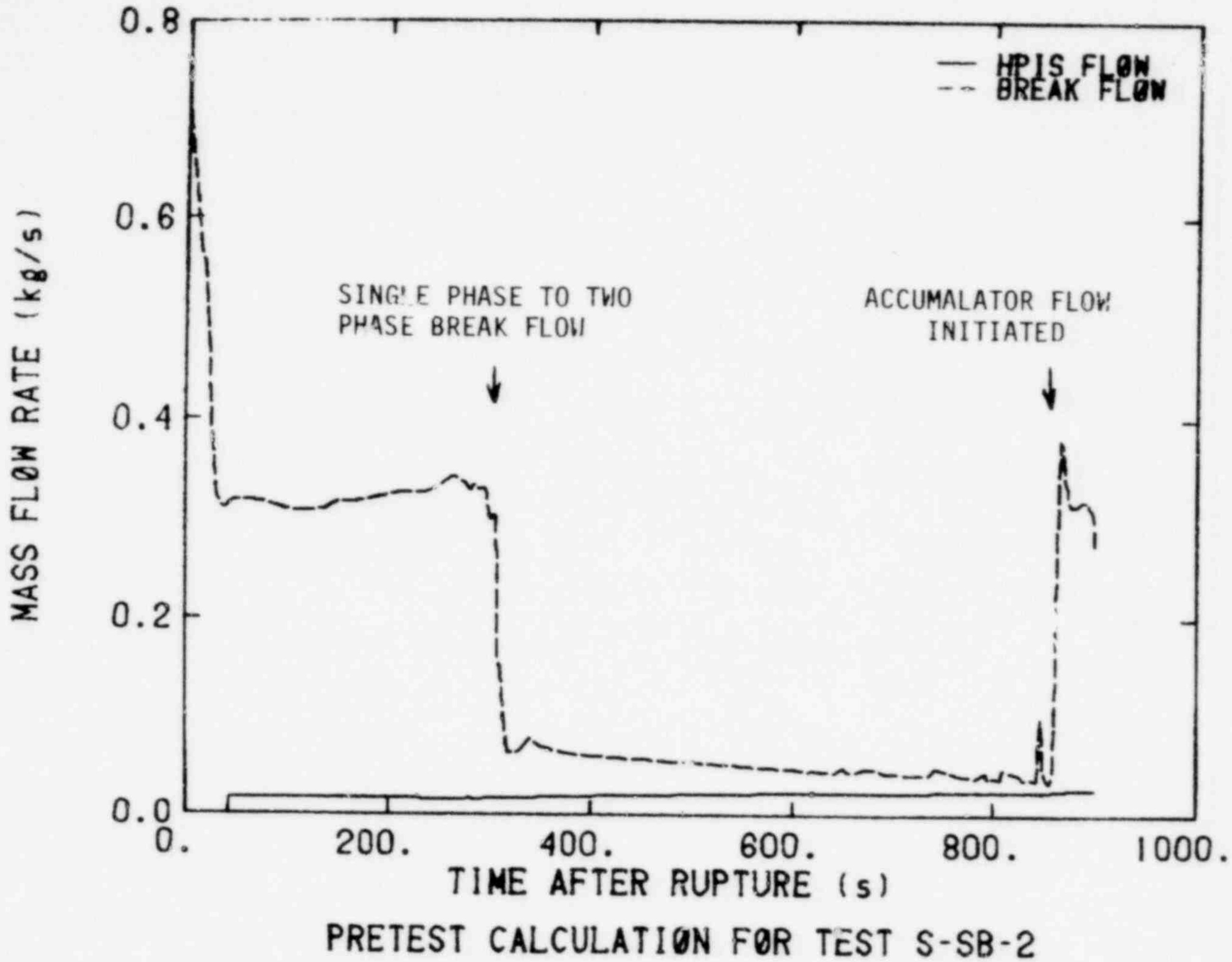

Fig. 11 Calculated break flow and total HPIS flow for Test S-SB-2.

3. CORE MIXTURE LEVEL

The calculated mixture level for the Semiscale core is shown in Figure 12. This level represents a combined gas and liquid mixture, and although at times the mixture level was near the top of the core, the total liquid mass decreased until initiation of accumulator injection (Figure 13).

The mixture level is one of the more important parameters and its behavior addresses directly one purpose of the experiment, which is to determine if core uncovery will occur. From examining Figure 12, it is observed that the calculated mixture level decreased (for an extended time) at about 400 s after rupture (core uncovery) and then began oscillating until the accumulators came on. The drop in core mixture level from 400 s to 600 s led to a mild core temperature excursion which lasted until accumulator injection began. The oscillations beginning at 600 s are of a manometer type as suggested by the level in the core being 180^{0} out of phase with the downcomer level as shown in Figure 12. However, as seen from the core inlet flow (Figure 14) there was no net mass transfer between downcomer and core. The driving force for the oscillations was partially due to core heat transfer. As the core mixture level dropped, core heat transfer decreased and reduced steam generation. The reduction in steam generation reduced the pressure above the core, and the downcomer head of water forced a greater amount of water into the core. This influx of coolant in turn increased the core heat transfer rate and steam generation which in turn increased the pressure and reduced the core inlet flow. The oscillations were terminated when accumulator ECC water was injected into the system.

The calculated mixture level in the Semiscale core was much different than that calculated for the PWR (Figure 15) even though the behavior of other parameters around the system was quite similar. In the PWR calculation, the core remained full until about 810 s after rupture. The PWR core remained partially uncovered until initiation of accumulator injection at 1007 s. The two calculations used

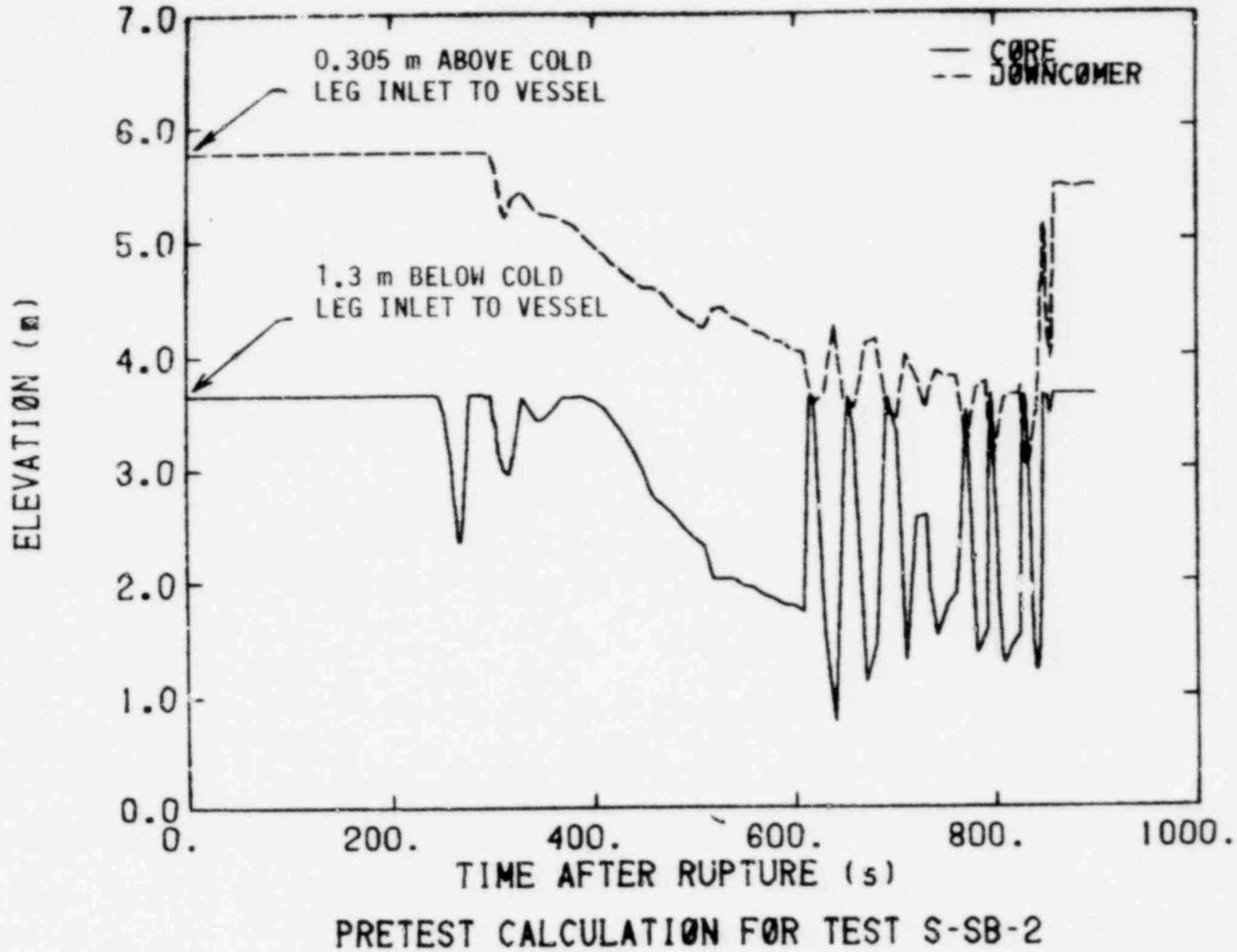

Fig. 12 Calculated core and downcomer mixture levels in Test S-SB-2.

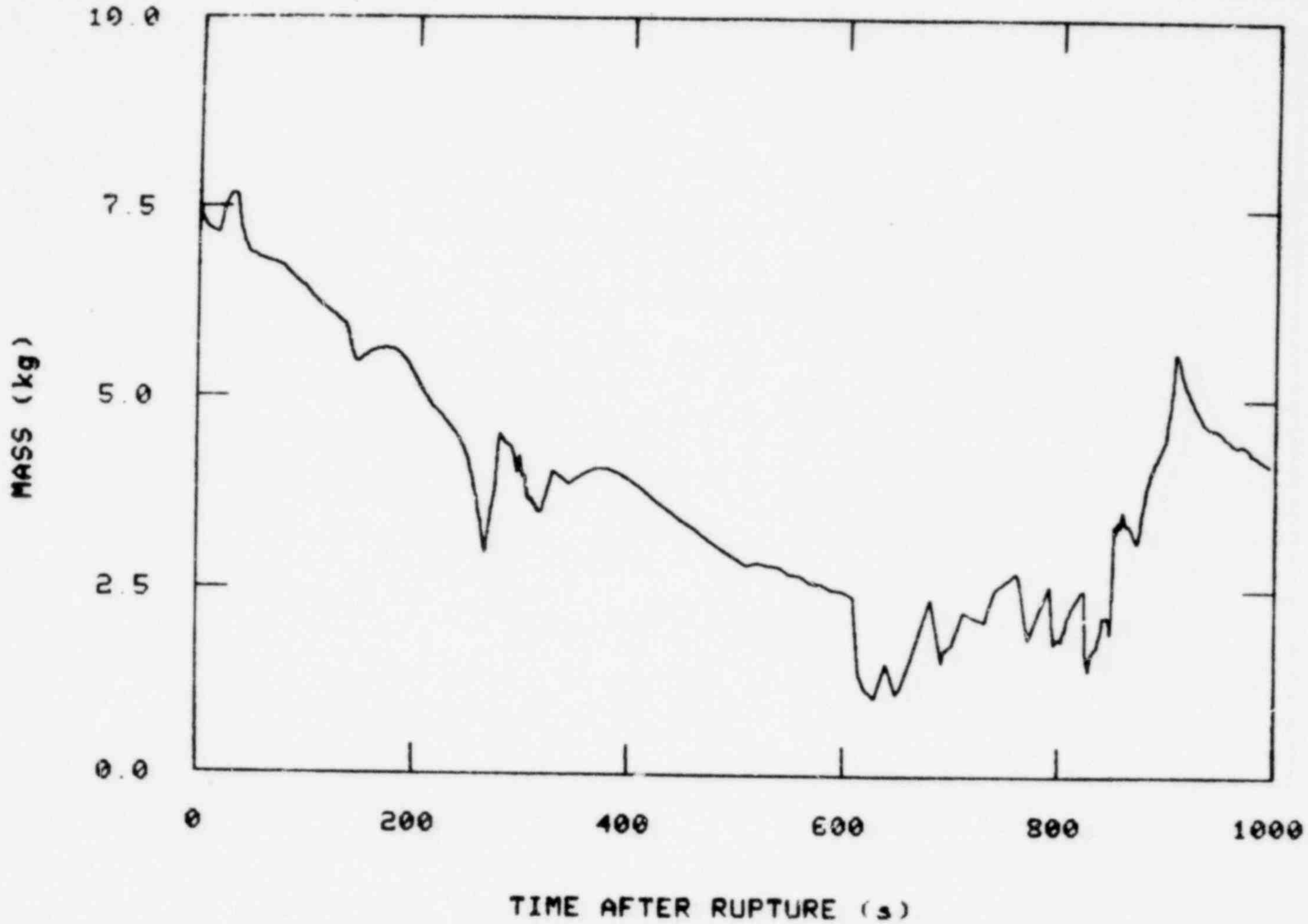

Fig. 13 Calculated core total mass for Test S-SB-2.

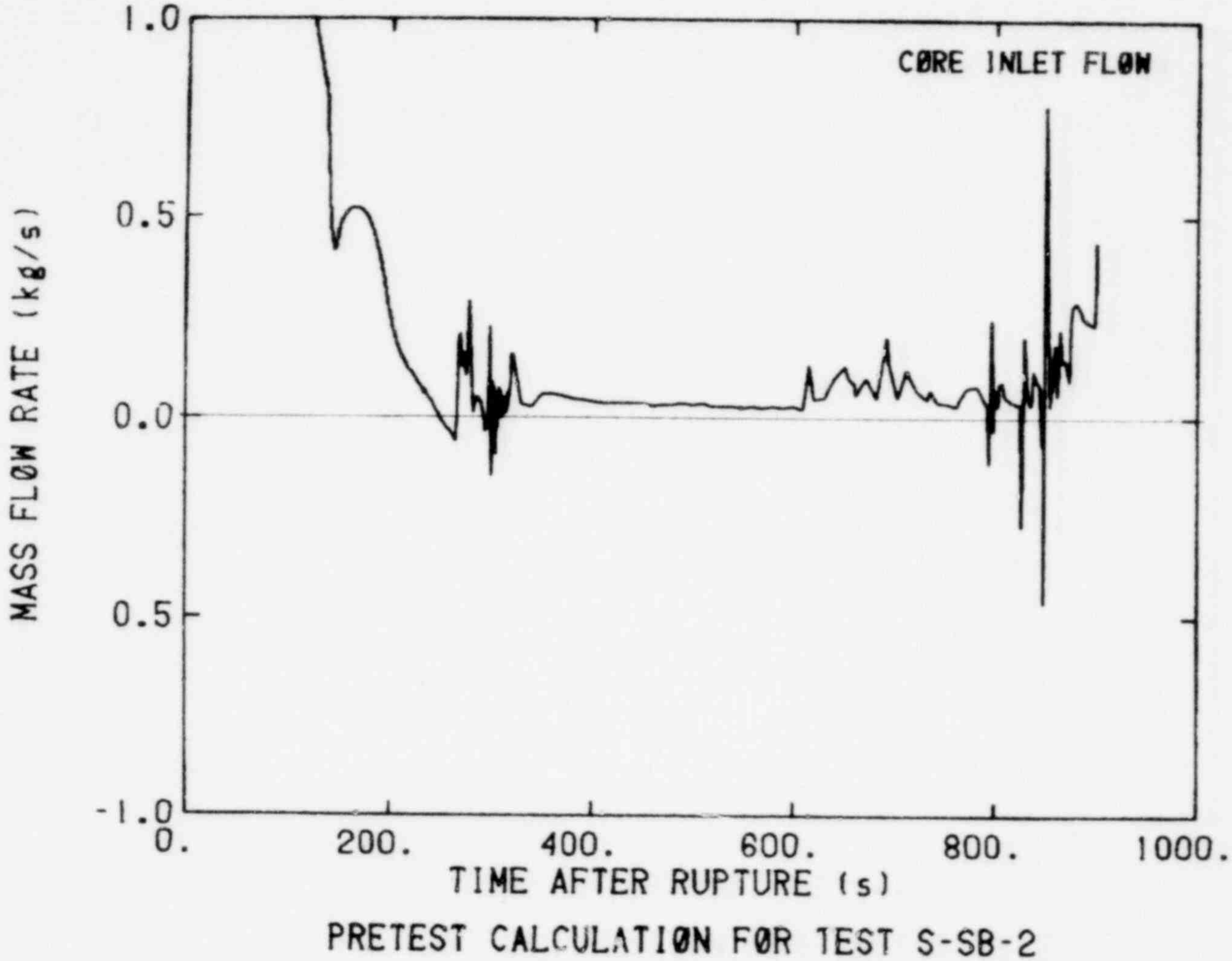

Fig. 14 Calculated core inlet flow rate for Test S-SB-2.

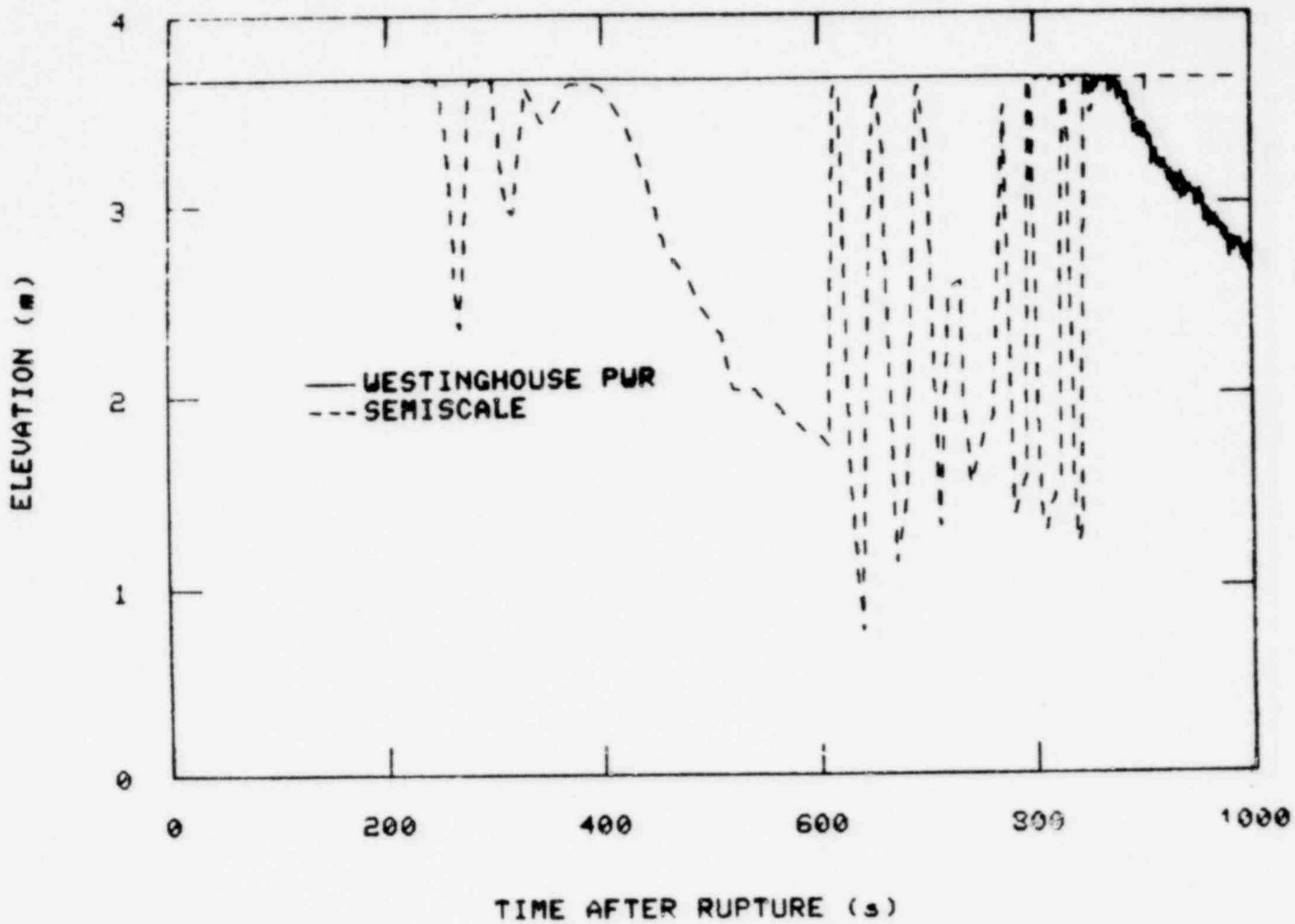

Fig. 15 Calculated core mixture level for Test S-SB-2 and PWR.

1216 044

different modeling in the core region (See Appendix A and Appendix B), and this modeling difference may be the source of differences between the two calculations. Posttest examination of calculated versus measured mixture level will provide a judgement of the merit of the modeling used in Semiscale. The effect of differences in RELAP4 modeling between Semiscale and a Westinghouse PWR will be addressed once experimental data has been obtained.

4. STEAM GENERATOR HEAT TRANSFER

The steam generator total heat transfer rates for the pretest calculation are compared to the volume-scaled steam generator total heat transfer rates calculated for the PWR in Figure 16. One scaling concern for steam generators is that the excessive size of the Semiscale secondary volumes could result in atypical heat transfer to the secondaries. In this calculation, scaling of the secondary volumes did not represent a major problem, as the total heat transfer rates for the Semiscale steam generators compared quite well to the PWR steam generator total heat transfer rates. A second scaling concern is that the use of two different size steam generators may lead to abnormal behavior between the intact and broken loop. The second concern does not appear to pose a major problem since not only does the total steam generator energy compare well but so does the energy transfer from the individual steam generators.

5. CORE CLAD TEMPERATURES

The peak cladding temperatures calculated for the Semiscale core (Figure 17) followed the saturation temperature until about 500 s, when core uncovery reached the top of heat conductor 49 (refer to Figure 4). The cladding temperature peaked at 780 K before the core began refilling at about 605 s. The peak cladding temperature for the Semiscale core compares well with the PWR core peak cladding temperature up to 500 s. This would be expected since the system depressurization rates compare well and the core cladding temperatures follow the saturation temperatures, as long as the mixture level is

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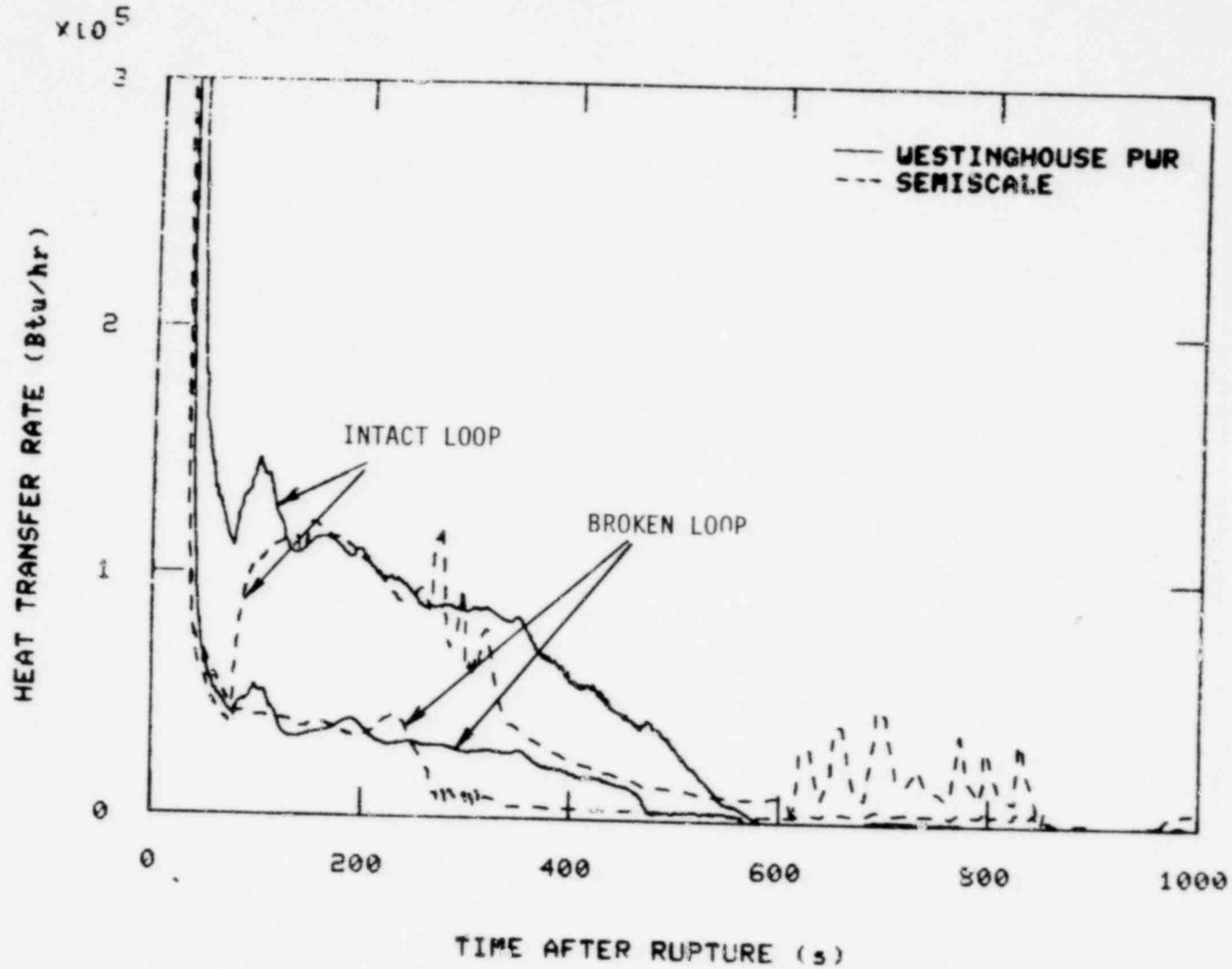

Fig. 16 Calculated steam generator total energy transfer for Test S-SB-2 and PWR.

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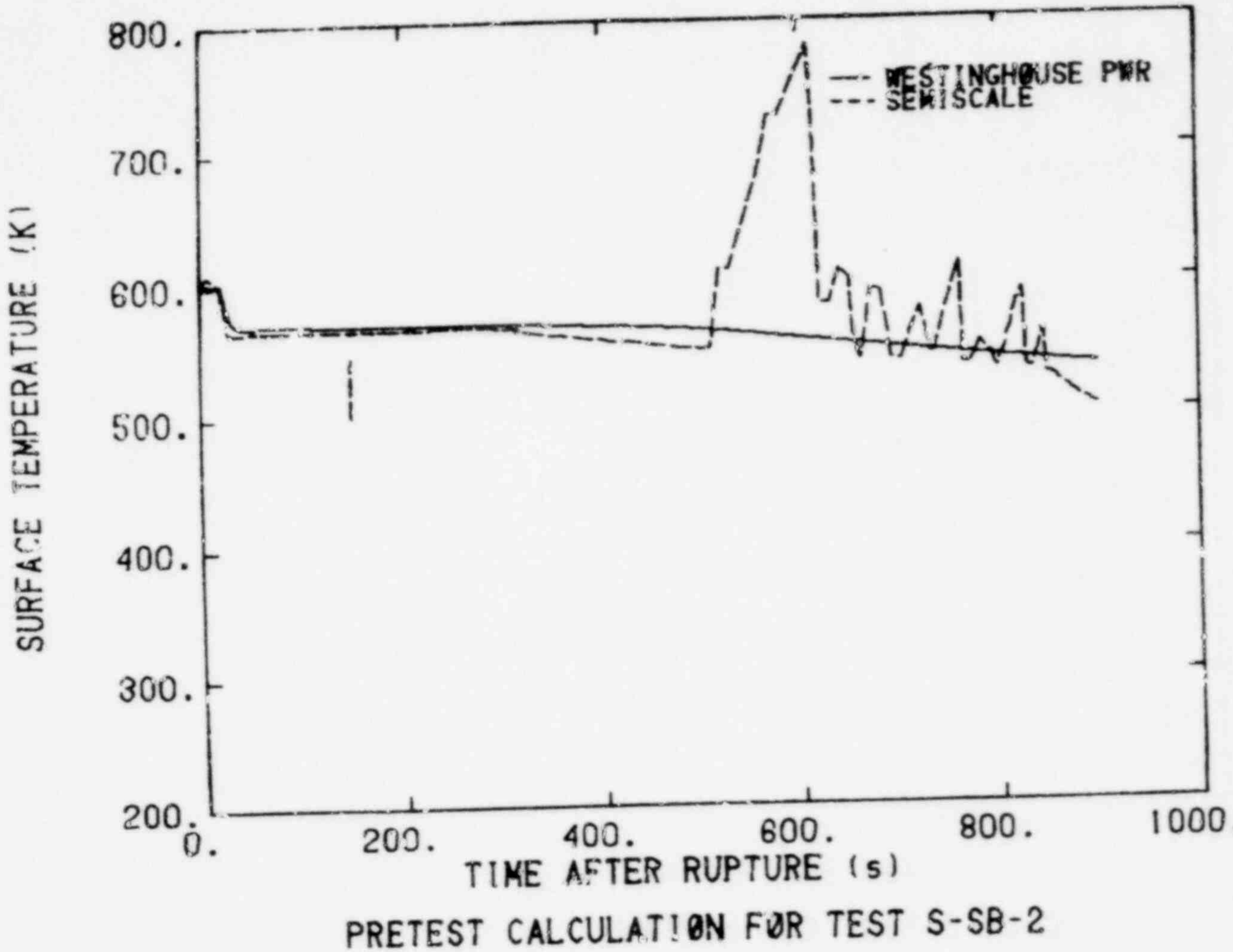

Fig. 17 Calculated core temperatures response for Test S-SB-2.

above the heated core. The peak cladding temperature for the PWR core rose to a maximum of 670 K after the core had partially uncovered at about 1000 s. Accumulator flow was initiated at 1007 s in the PWR calculation, and the surface temperatures decreased to near the saturation temperature.

6. CONCLUSION

Substantial core uncovery is calculated to occur in Test S-SB-2, as shown in Figure 12. As a result of core uncovery, the peak cladding temperature reached a maximum of 780 K before the core was quenched by accumulator flow at 838 s.

Two significant factors bear on the degree of confidence placed on the validity of this pretest prediction. First, it is recognized that the calculation does not embody all of the features that are potentially necessary to describe the thermal-hydraulic phenomena expected. For example, the RELAP4 code is unable to predict flow regime definition beyond homogeneous or separated condition (and even this is restricted to selected model nodes). Also, the RELAP4 model used did not account for the external system heat loss expected in the test, nor the increased core power to be employed to offset this heat loss.

Secondly, experience with the RELAP4 code has shown that results can be very sensitive to model input (i.e., nodalization, code options). This is particulary true of the prediction of core uncovery, which ultimately determines the severity of the transient. In addition to the importance of correctly predicting mass and energy inventory in the system, reliance must be placed upon a model for level swell behavior. An insufficient basis presently exists for evaluating the various bubble rise options available in the RELAP4 1216 048
code and selecting the optimum approach.

In conclusion, it must be stressed that the expectation of good agreement between the pretest prediction and test data for Test S-SB-2 is significantly lower than has been the case for large break experiments of the past. The refinement of models and identification of deficiencies can only be made possible by the experience gained through posttest analysis as the small break test series proceeds.

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V. REFERENCES

1. Semiscale Program, Appendix SB to the Semiscale Experimental Operating Specification - Mod-3 Small Break Test Series, SEMI-TR-011, EG&G Idaho, Inc. (August 1979).

2. C. A. Dobbe, C. D. Fletcher, and E. E. Ross, Audit Calculations for Westinghouse PWR Small Cold-Leg Breaks, CAAP-TR-054, EG&G Idaho, Inc. (August 1979).

3. RELAP4/MOD7 User's Manual, CDAP-TR-78-036 (August 1978).

4. Y. Taitel and A. E. Dukler, "A Model for Predicting Flow Regime Transitions in Horizontal and Near Horizontal Gas-Liquid Flow," AIChE Journal (Vol. 22, No. 1), (January 1976).

5. T. K. Larson, G. G. Loomis, and R. W. Shumway, Semiscale Simulations of the Three Mile Island Transient - A Summary Report, SEMI-TR-010, EG&G Idaho, Inc. (July 1979).

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APPENDIX A

RELAP4 MODEL FOR TEST S-SB-2

APPENDIX A

RELAP4 MODEL FO' TEST S-SB-2

The nodalization diagram for the RELAP4 model used for the Test S-SB-2 prediction is shown in Figure A-1. The model includes 38 control volumes and 54 junctions. Twc control volumes are used to represent the lower plenum, one volume to represent the core mixer box, one volume to represent the core, and three volumes to represent the upper plenum. The inlet annulus, downcomer, guide tube, support tubes and the upper head are each represented by one control volume. Table A-I provides physical descriptions of the control volumes used in the model. Table A-II describes the junctions used in the model which connect the control volumes, as well as those which join fill volumes to control volumes. Fill junctions are used to represent the high pressure injection sytem (HPIS), the low pressure injection system (LPIS), and the intact and broken loop steam generator secondary water supply.

A total of 50 heat slabs are used to represent heat conducting solids in contact with the coolant in the core, downcomer, steam generators, vessel, and piping. Heat conductors in the core are capable of modeling both high and low power rods although for Test S-SB-2 all rods had equal power. The high power rods are represented by 10 axial heat slabs, and the low power rods are represented by 5 axial heat slabs. The core heat conductor and fluid volume nodalization are shown in Figure A-2.

The more significant code analytical options used in this calculation, including heat transfer correlations, vertical slip, and bubble rise model, are listed in Table A-III. The RELAP4 input listing for Test S-SB-2 is given in Table A-IV.

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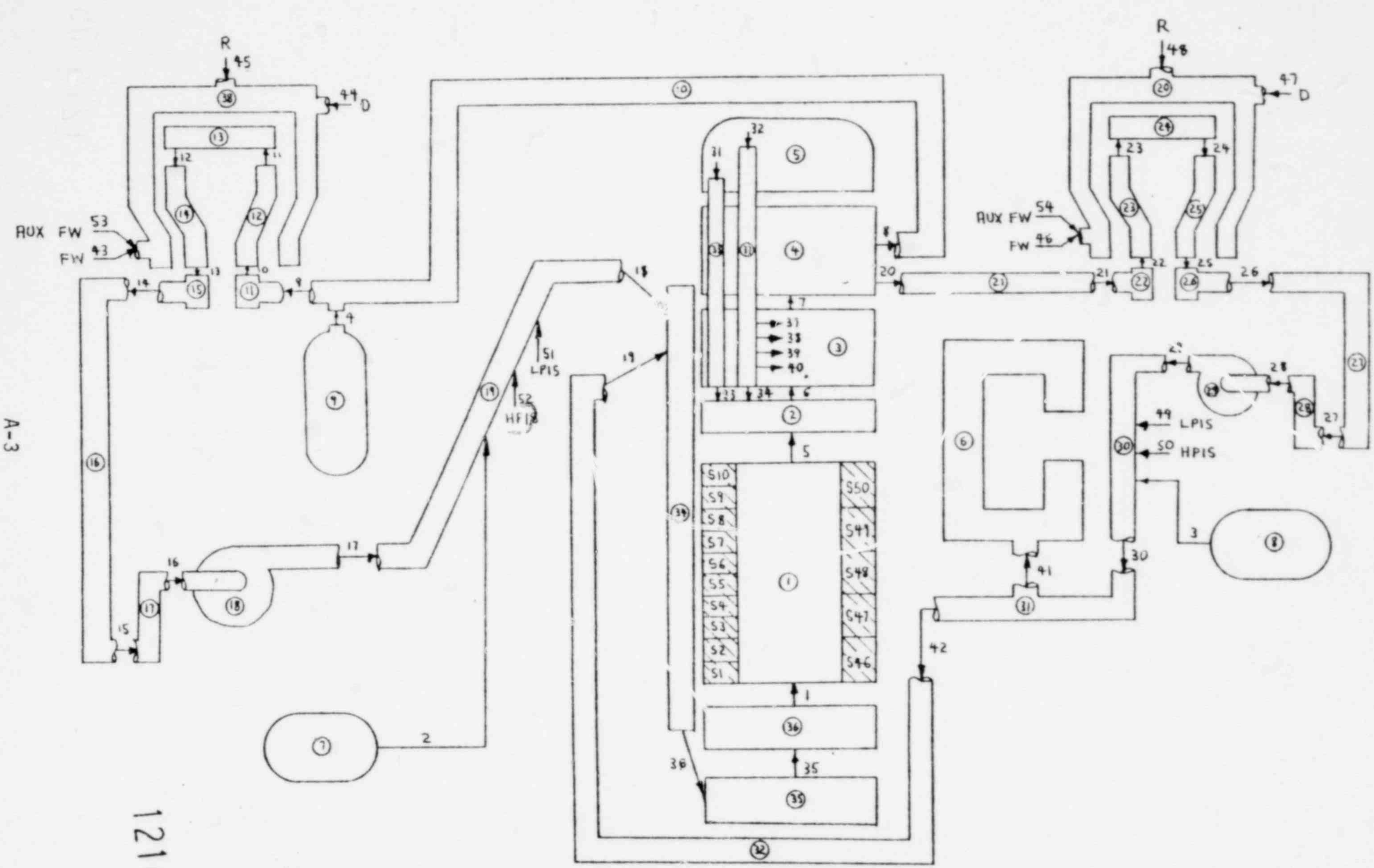

Fig. A-1. RELAP4/MOD7 model for Test S-SB-2.

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TABLE A-I

RELAP4/MOD7 MODEL CONTROL VOLUME DESCRIPTION FOR TEST S-SB-2

Control Volume	Description
1	Core
2	Bottom of the upper plenum
3	Mid-volume of the upper plenum
4	Top volume of the upper plenum
5	Upper head
6	Pressure suppression vessel
7	Accumulator - intact loop
8	Accumulator - broken loop
9	Pressurizer
10	Intact loop hot leg
11	Intact loop steam generator inlet plenum
12, 13, 14	Intact loop steam generator tube bundle
15	Intact loop steam generator outlet plenum
16	Intact loop pump suction - downflow
17	Intact loop pump suction - upflow
18	Intact loop pump
19	Intact loop cold leg
20	Broken loop steam generator secondary
21	Broken loop hot leg
22	Broken loop steam generator inlet plenum
23, 24, 25	Broken loop steam generator tube bundle
26	Broken loop steam generator outlet plenum
27	Broken loop pump suction - downflow
28	Broken loop pump suction - upflow
29	Broken loop pump
30	Broken loop pump discharge
31	Break assembly
32	Broken loop cold leg
33	Support tubes
34	Inlet annulus and downcomer
35	Lower plenum

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TABLE A-I (contd)

Control Volume	Description
36	Core mixer box
37	Guide tube
38	Intact loop steam generator secondary

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TABLE A-II

RELAP4/MOD7 MODEL JUNCTION DESCRIPTION FOR TEST S-SB-2

Junction	Description
1	Core mixer box, core
2	Intact loop accumulator, intact loop cold leg
3	Broken loop accumulator, broken loop cold leg
4	Pressurizer, intact loop hot leg
5	Core, bottom of upper plenum
6	Bottom of upper plenum, mid-volume of upper plenum
7	Mid-volume of upper plenum, top volume of upper plenum
8	Top volume of upper plenum, intact loop hot leg
9	Intact loop hot leg, intact loop steam generator inlet plenum
10	Intact loop steam generator inlet plenum, intact loop steam generator tube bundle
11, 12	Intact loop steam generator tube bundle juctions
13	Intact loop steam generator tube bundle, intact loop steam generator outlet plenum
14	Intact loop steam generator outlet plenum, intact loop pump suction - downflow
15	Intact loop pump suction - downflow, intact loop pump suction - upflow
16	Intact loop pump suction - upflow, intact loop pump
17	Intact loop pump, intact loop cold leg
18	Intact loop cold leg, inlet annulus and downcomer
19	Broken loop cold leg, inlet annulus and downcomer
20	Top volume of upper plenum, broken loop hot leg
21	Broken loop hot leg, broken loop steam generator inlet plenum
22	Broken loop steam generator inlet plenum, broken loop steam generator tube bundle
23, 24	Broken loop steam generator tube bundle junctions
25	Broken loop steam generator tube bundle, broken loop steam generator outlet plenum

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TABLE A-II(contd)

Junction	Description
26	Broken loop steam generator outlet plenum, broken loop pump suction - downflow
27	Broken loop pump suction - downflow, broken loop pump suction - upflow
28	Broken loop pump suction-upflow, broken loop pump
29	Broken loop pump, broken loop pump discharge
30	Broken loop discharge, break assembly
31	Upper head, support tubes
32	Upper head, guide tubes
33	Support tubes, bottom of upper plenum
34	Guide tube, bottom of upper plenum
35	Lower plenum, core mixer box
36	Inlet annulus and downcomer, lower plenum
37, 38	Guide tube, mid-volume of upper plenum
39, 40	" " " " " " "
41	Pressure suppression vessel, break assembly
42	Break assembly, broken loop cold leg
43	Intact loop steam generator feedwater
44	Intact loop steam generator discharge
45	Intact loop steam generator relief valve
46	Broken loop steam generator feedwater
47	Broken loop steam generator discharge
48	Broken loop steam generator relief valve
49	Broken loop LPIS
50	Broken loop HPIS
51	Intact loop LPIS
52	Intact loop HPIS
53	Intact loop steam generator auxiliary feedwater
54	Intact loop steam generator auxiliary feedwater

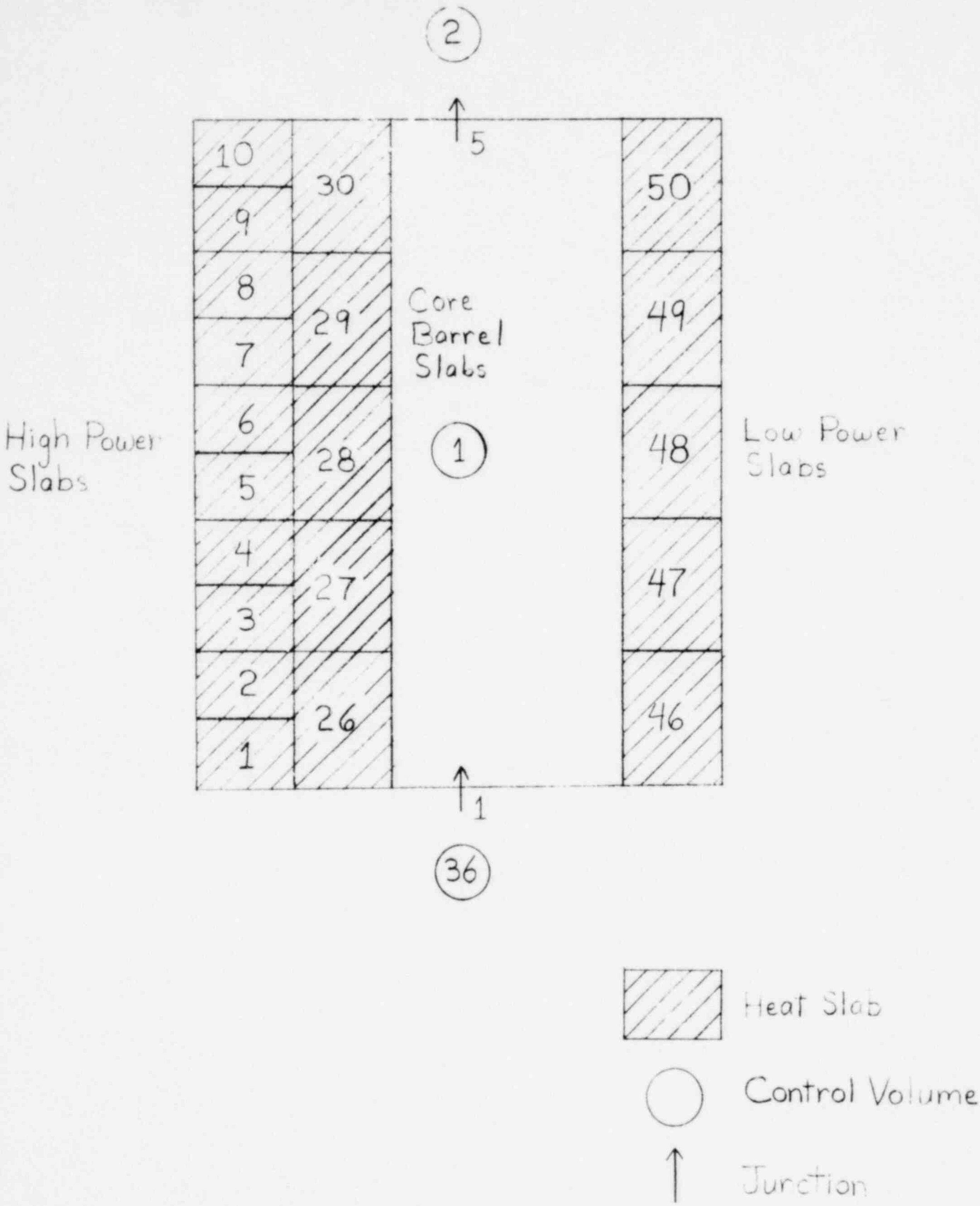

Fig. A-2. RELAP4/MOD7 core model for Test S-SB-2.

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TABLE A-III

RELAP4/MOD7 INPUT OPTIONS FOR TEST S-SB-2

1. MVMIX=0 (compressible flow with momentum flux) is used at all junctions except the following: MVMIX=-2 for junctions associated with the steam generator secondary relief and discharge valves, and MVMIX=3 for junctions associated with the accumulators, pressurizer, guide and support tubes, main and auxiliary feedwater, and high and low pressure injection systems.

2. Vertical slip is used at all vertical juctions in the reactor vessel, except between the core mixer box and core, and at all vertical junctions between the steam generator tube bundles and the downflow pump suctions.

3. The standard bubble rise model (velocity 0.91 m/s and gradient of 0.8) is used in the pump suctions, steam generator secondaries, pressurizer, downcomer, core, and upper head. A bubble rise model allowing complete separation of phases within a control volume is used in the accumulators.

4. Critical flow is modeled using the Henry-Fauske/HEM option. A flow rate multiplier of 1.0 is applied to HEM, as well as to subcooled Henry Fauske.

5. Core heat transfer is calculated by using (1) HTS2 heat transfer surface, (2) implicit wall temperature solution on the right side of all conductors, (3) modified Tong-Young transition boiling correlation, and (4) Condie-Bengston III (HTS2) and Condie-Bengston IV (HTS3) film boiling correlation.

6. The enthalpy transport model is used to initialize the calculation, but is not used during the transient.

7. The new slip velocity model developed for RELAP4/MOD7 is used to provide a flow regime dependent correlation, which results in a more accurate value for interphase slip velocities.

8. The RELAP4/MOD7 self-initialization routine is used to effect an initial system pressure balance and energy balance.

9. Steam generator secondaries utilize the natural convection option for heat transfer.

TABLE IV

RELAP4/MOD7 LISTING FOR TEST S-SB-2

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

*RUN S-SB-2
*
*
*     1) RELAP4/MOD7 MODEL
*     2) ONE VOLUME CORE
*     3) 2.5 PERCENT BREAK (AREA=6.175E-5 FT2)
*
*
*
*
*
*
*
*
*
** PROBLEM DIMENSION DATA **
010001 -2 0 5 18 38 5 1 54 2 6 2 12 50 14 7 15 0 0
** PROBLEM CONSTANT DATA **
010002 2.1 1.
** WATER PACKING AND MIXTURE LEVEL SMOOTHING DATA **
030003 50 0 0 .0001
030004 50 0.
** UNCOUPLE H.T. TIME STEPS **
030006     0. -.1  0
** TIME STEP DATA **
030010   2  10  1  0  .01   .00001      2.     3900.
030020   2  10  1  0  .09   .0001      10.
030030  20   6  1  0  .09   .0001      35.
030040  34   5  1  0  .06   .00005     50.
030050 200  17  1  0  .01   .00001   9000.
** TRIP CONTROL DATA **
040010 1   1  0  0 5000.    0.           *END OF PROBLEM
040020 2   1  0  0    0.    0.           *OPEN BREAK NOZZLE
040030 3  -4  9  0 1825.    3.4          *SCRAM & PUMP COASTDOWN
040040 4  +4 38  0 1065.    0.           *INTACT LOOP SG RELIEF VALVE
040050 5  +4 20  0 1065.    0.           *BROKEN LOOP SG RELIEF VALVE
040060 6  -5  9  0    .1    0.           *CLOSE PRESSURIZER VALVE
040070 7  -5  7  0  0.01    1.           *INTACT LOOP ACCUMULATOR
040080 8  -5  8  0  0.01    0.           *BROKEN LOOP ACCUMULATOR
040090 9  -4  9  0 1825.   28.4          *INTACT LOOP HPIS
040100 10 -4  9  0 1825.   28.4          *BROKEN LOOP HPIS
040110 11  1  0  0 5000.    0.           *INTACT LOOP LPIS
040120 12  1  0  0 5000.    0.           *BROKEN LOOP LPIS
040130 13 -4  9  0 1825.    0.           *S.G. DISCHARGE
040140 14 -4  9  0 1825.   63.4          *I.L. S.G. AUX. F.W.
040150 15 -4  9  0 1825.   63.4          *B.L. S.G. AUX. F.W.
040160 16 -4 30  0   15.    1.           *TURN ON NONEQUILIB. MODEL IN BL
040170 17 -4 30  0   15.    1.           *TURN ON NONEQUILIB. MODEL IN IL & VESSEL
040180 18 -4  9  0 1825.    8.4          *S.G. FEEDWATER
** CONTROL VOLUME DATA **

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```


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```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

050011 5 0 2265.0046 578.5 -1. .368328 12. 12. 0 .030694 .0332 -16.26166 0 17
050021 0 0 2255.9356 610. -1. .05175 1.0009 1.0009 0 .05171 .05544 -4.2617 0 17
050031 0 0 2252.064  610. -1. .090244 2.17744 2.17744 0 .041445 .09894 -3.2608 0
050032 17
050041 0 0 2250. 610. -1. .276993 5.5417 5.5417 0 .049983 .153691 -1.08336 0 17
050051 5 0 2250.     544. -1. .4716 8.7235 8.7235 0 .05406 .176869 5.1615 0
050061 5 1 94.3 -1. 0. 11007.936 50. 5.45 0 7.79 3.4 -8.4 0
050071 1 0 615. 80. 0. 2.506 2.506 1.575 0 1. 1.12838 0. 0
050081 1 0 615. 80. 0. .837 .837 .527 0 1. 1.12838 0. 0
050091 5 0 2247.655 -1. 0. .978 4.53 3.042 0 .2553 .5701 .6 0
050101 0 0 2249.0169 610. -1. .3555 .21867 .21867 0 .03755 .21867 .599 0
050111 0 0 2232.5242 610. -1. .366 2.38567 2.38567 0 .15342 .44197 .81767 0
050121 0 0 2230.561  593.47 -1. .26833 5.6162 5.6162 0 .0476 .0335 3.20334 0
050131 0 0 2227.7369 565.61 -1. .26834 2.86422 2.86422 0 .0476 .0335 8.81956 0
050141 0 0 2227.6365 549.62 -1. .26833 5.6162 5.6162 0 .0476 .0335 3.20334 0
050151 0 0 2226.1486 544. -1. .34 1.995 1.995 0 .17043 .46583 1.20833 0
050161 2 0 2214.1667 544. -1. .407241 10.30833 10.30833 0 .03755 .21867 -9.1 0
050171 2 0 2213.7505 544. -1. .430467 8.35508 8.35508 0 .03755 .21867 -9.1 0 17
050181 0 0 2246.7864 544. -1. .144 1.03117 1.03117 0 .03491 .21083 -.92183 0 17
050191 0 0 2281.2049 544. -1. .304918 .21867 .21867 0 .03755 .21867 -.10933 0 17
050201 4 0 0. 525.26  .072 3.46 41. 32.743 0 .0855 .25  8.40883 0
050211 0 0 2247.6025 610. -1. .079153 .1115 .1115 0 .009764 .1115 .65258 0
050221 0 0 2244.7785 610. -1. .101793 5.89475 5.89475 0 .017266 .1483 .764083 0
050231 0 0 2233.7763 589.48 -1. .164643 25. 25. 0 .0065857 .06475 6.658833 0
050241 0 0 2219.7806 566.14 -1. .09491 8.75 8.75 0 .005423 .06475 31.65883 0
050251 0 0 2216.6247 551.79 -1. .164643 25. 25. 0 .0065857 .06475 6.658833 0
050261 0 0 2215.3569 544. -1. .096644 5.588 5.588 0 .017295 .14839 1.323333 0
050271 2 0 2216.0668 544. -1. .106591 10.42333 10.42333 0 .009764 .1115 -9.1 0
050281 2 0 2215.0709 544. -1. .084115 8.24583 8.24583 0 .009764 .1115 -9.1 0 17
050291 0 0 2300.988  544. -1. .02934 .8963 .8963 0 .032735 .204156 -.85417 0 17
050301 0 0 2281.6807 544. -1. .019236 .1115 .1115 0 .009764 .1115 -.05575 0 17
050311 0 0 2261.2619 544. -1. .019086 .1115 .1115 0 .009764 .1115 -.05575 0 17
050321 0 0 2280.605  544. -1. .036843 .1115 .1115 0 .009764 .1115 -.05575 0 17
050331 0 0 2251.0243 610. -1. .13591 8.8598 8.8598 0 .001534 1.892 -3.2608 0
050341 5 0 2280.4049 544. -1.  722327 18.9075 18.9075 0 .0342 .1388 -17.9075 0
050342     17
050351 0 0 2278.4465 544. -1. .3853 .9896 .9896 0 .3893 .293 -18.8971 0 17
050361 0 0 2276.4035 530. -1. .080457 1.64584 1.64584 0 .049209 .0859 -17.9075 0
050362     17
050371 0 0 2250.1776 610. -1. .05296 14.3028 14.3028 0 .003703 .27452 -3.2608 0
050381 3 0 0. 525.26 .0176 7. 15.52 9.678 0 .04 .042 2.495 0
** BUBBLE-RISE MODEL DATA **
060011 0. -2.                    *ACCUMULATORS
060021 .8 3.                     *PUMP SUCTION-IL AND BL
060031 0.2747 24.34              *INTACT LOOP SG SECONDARY
060041 0.2766 3.79               *BROKEN LOOP SG SECONDARY
060051  .8  -1.                  *DOWNCOMER, CORE, UPPER HEAD AND PRESSURIZER
** TIME-DEPENDENT VOLUME DATA FOR PSS TANK **
070100   4
070101   330.   43.5   0.   0.   5.45

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
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POOR ORIGINAL

TABLE A-IV (contd)

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
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070102  1130.    14.5   0.  0.  5.45
070103  2000.    14.5   0.  0.  5.45
** JUNCTION DATA **
080011 36 1 0 0    25.79
080021 7 19 0 2      0.
080031 8 30 0 4      0.
080041 9 10 0 1      0.
080051 1 2 0 0     25.79
080061 2 3 0 0     25.79
080071 3 4 0 0     25.79
080081 4 10 0 0    19.35
080091 10 11 0 0   19.35
080101 11 12 0 0   19.35
080111 12 13 0 0   19.35
080121 13 14 0 0   19.35
080131 14 15 0 0   19.35
080141 15 16 0 0   19.35
080151 16 17 0 0   19.35
080161 17 18 -1 0  19.35
080171 18 19 1 0   19.35
080181 19 34 0 0   19.35
080191 32 34 0 0    6.45
080201 4 21 0 0     6.45
080211 21 22 0 0    6.45
080221 22 23 0 0    6.45
080231 23 24 0 0    6.45
080241 24 25 0 0    6.45
080251 25 26 0 0    6.45
080261 26 27 0 0    6.45
080271 27 28 0 0    6.45
080281 28 29 -2 0   6.45
080291 29 30 2 0    6.45
080301 30 31 0 0    6.45
080311 5 33 0 0     0.
080321 5 37 0 0     0.
080331 33 2 0 0     0.
080341 37 2 0 0     0.
080351 35 36 0 0   25.79
080361 34 35 0 0   25.79
080371 37 3 0 0     0.
080381 37 3 0 0     0.
080391 37 3 0 0     0.
080401 37 3 0 0     0.
080411 31 6 0 3     0.
080421 31 32 0 0    6.45
080431 0 38 5 5     1.894
080441 0 38 7 6    -1.894
080451 0 38 9 0     0.
080461 0 20 6 5      .631
080471 0 20 8 6     -.631

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1216 062

POOR ORIGINAL

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080481 0 20 10 0    0.
080491 0 30 4 0     0.
080501 0 30 2 0     0.
080511 0 19 3 0     0.
080521 0 19 1 0     0.
080531 0 38 11 0    0.
080541 0 20 12 0    0.
080012 .030694 -16.26166 0. 4.7061 4.7061 0 5 2 0 0. 0. 0  2 0. 0
080022 .00499 0. 0. 369.2 369.2 1 -1 2 3 .07971 0. 0 0 0. 0
080032 .00499 0. 0. 3322.3 3322.3 1 -1 2 3 .07971 0. 0 0 0. 0
080042 .003 .6 0. 490.8 490.8 1 5 2 3 .0618 0. 0 0 0. 0
080052 .030694 -4.2617  0. 3.9018 3.9018 0 5 2 0 0. 0. 0 1 0. 0
080062 .017208 -3.2608 0. .7546 .7546 0 5 2 0 .14802 0. 0 0 -1. 0
080072 .041445 -1.08336 0. 1.39324 1.39324 0 5 2 0 0. 0. 0 0 -1. 0
080082 .03755 .70833 0. 2.7227 2.7227 1 5 2 0 .21867 0. 0 0 0. 0
080092 .03755 .61767 0. 35.038 35.038 0 5 2 0 .21867 0. 0 0 0. 0
080102 .0476 3.20334 0. .51139 .51139 0 5 2 0 .0335 0. 0 2 0. 0
080112 .0476 8.81954 0. 2.9302 2.9302 0 5 2 0 .0335 0. 0 3 0. 0
080122 .0476 8.81954 0. 2.9334 2.9334 0 5 2 0 .0335 0. 0 3 1. 0
080132 .0476 3.20334 0. 2.3928 2.3928 0 5 2 0 .0335 0. 0 1 1. 0
080142 .03755 1.20833 0. 36.833 36.833 0 5 2 0 0. 0. 0 0 1. 0
080152 .03755 -8.94891 0. 1.209 1.209 1 5 2 0 0. 0. 0 0 0. 0
080162 .03755 -.854255 0. .0146 .0146 1 5 2 0 0. 0. 0 0 0. 0
080172 .03755 0. 0. .01474 .01474 1 5 2 0 .21867 0. 0 0 0. 0
080182 .03755 0. 0. 4.4449 4.4449 1 5 2 0 .21867 0. 0 0 1. 0
080192 .009764 0. 0. 1.4901 1.4901 1 5 2 0 .1115 0. 0 0 0. 0
080202 .009764 .70833 0. 3.0329 3.0329 1 5 2 0 .1115 0. 0 0 0. 0
080212 .009764 .764083 0. 2.652 2.652 0 5 2 0 .1115 0. 0 0 0. 0
080222 .0065857 6.658833 0. .6574 .657 0 5 2 0 .0648 0. 0 2 0. 0
080232 .0065857 31.65883 0. .48 .48 0 5 2 0 .0648 0. 0 3 0. 0
080242 .0065857 31.65863 0. 1.417 1.417 0 5 2 0 .0648 0. 0  3 1. 0
080252 .0065857 6.658833 0. 2.485 2.485 0 5 2 0 .0648 0. 0 1 1. 0
080262 .009764 1.32333 0. 1.3724 1.3724 0 5 2 0 .1115 0. 0 0 1. 0
080272 .009764 -9.04425 0. .945 .945 1 5 2 0 .1115 0. 0 0 0. 0
080282 .009764 -.85417 0. .0149 .0149 1 5 2 0 .1115 0. 0 0 0. 0
080292 .0010347 0. 0. 0.0 0.0 1 5 2 0 .03625 0. 0 0 0. 0
080302 .009764 0. 0. .392 .6384 1 5 2 0 .1115 0. 0 0 0. 0
080312 .001534 5.599 0. 12.28 12.28 0 5 2 3 .044194 0. 0 0 1. 0
080322 .003703 11.042 2902. 75.8 75.8 0 5 0 3 .044194 0. 0 0 1. 0
080332 .001534 -3.2608 0. 1. 1. 0 5 2 3 .044194 0. 0 0 1. 0
080342 .01227 -3.2608 0. 66.62 66.62 0 5 2 3 .125 0. 0 0 1. 0
080352 .046266 -17.9075 0. 1.7626 1.7626 0 5 2 0 0. 0. 0 0 -1. 0
080362 .026039 -17.9075 0. 3.446 3.446 0 5 2 0 0. 0. 0 0 1. 0
080372 .01912 -1.4463 0. 1.22 1.22 1 5 2 3 .03902 0. 0 0 0. 0
080382 .01912 -1.9254 0. 1.22 1.22 1 5 2 3 .03902 0. 0 0 0. 0
080392 .01912 -2.4046 0. 1.22 1.22 1 5 2 3 .03902 0. 0 0 0. 0
080402 .01912 -2.8838 0. 1.22 1.22 1 5 2 3 .03902 0. 0 0 0. 0
080412 6.598E-5 0. 0. 0. 0. 1 5 2 0 0. 0. 0 0 0. 0
080422 .009764 0. 0. .6384 .392 1 5 2 0 0. 0. 0 0 0. 0
080432 .012 2.5 0. .752 .39 1 5 2 3 .155 0. 0 0 0. 0

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1216 063

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080442 .007 15.4 1. 3350. 3350. 1 5 0 -2 .0472 0. 0 0 0. 0
080452 .021 15.4 0. .752 .39 0 5 2 -2 .0472 0. 0 0 0. 0
080462 .004 10. 0. .752 .39 1 5 2 3 .0797 0. 0 0 0. 0
080472 .007 48. 1. 3350. 3350. 1 5 0 -2 .0472 0. 0 0 0. 0
080482 .007 48. 0. .752 .39 0 5 2 -2 .0472 0. 0 0 0. 0
080492 .00499 0. 0. .752 .39 1 5 2 3 .0797 0. 0 0 0. 0
080502 .00499 0. 0. .752 .39 1 5 2 3 .0797 0. 0 0 0. 0
080512 .00499 0. 0. .752 .39 1 5 2 3 .0797 0. 0 0 0. 0
080522 .00499 0. 0. .752 .39 1 5 2 3 .0797 0. 0 0 0. 0
080532 .012 2.5 0. .752 .39 1 5 2 3 .155 0. 0 0 0. 0
080542 .004 10. 0. .752 .39 1 5 2 3 .0797 0. 0 0 0. 0
** STAGNATION OPTION **
082000 0
** HENRY-FALSKE-HEM CRITICAL FLOW MODEL **
082003 1. 1. 1. .02
** INTACT LOOP PUMP DATA **
090011   11  2     1    1    0    3500.      0.8022     267.2  440.
090012   101.      38.3      62.3       0.   0.         8.72
** BROKEN LOOP PUMP DATA **
090021   22  2     1    1    0   15250.0     1.1022     51.3    261.
090022   2.20    .22    62.3   0.     0.    0.
** PUMP HEAD MULTIPLIER CURVE **
091001   -11          0.0 0.0        0.1  0.0        0.15 0.05       0.24 0.8
091002                0.3 0.96       0.4  0.98       0.6  0.97       0.8  0.9
091003                0.9 0.8        0.96 0.5        1.0  0.0
** PUMP TORQUE MULTIPLIER CURVE **
092001   -9           0.0 -.17       0.0001 -.17     0.006 0.0       0.1  0.0
092002                0.15 .15       0.24  0.56      0.8  0.56       0.96 0.45
092003                1.0 0.0
**  PUMP SPEED VS TIME DATA (INTACT LOOP PUMP)  **
098011 3 10 0. 2807.70 10. 1544.24 20. 1052.89
098012 30. 786.16 40. 659.81 50. 603.66 60. 561.54
098013 120. 280.77 130. 0.0 9000. 0.0
** PUMP SPEED VS TIME DATA (BROKEN LOOP PUMP)  **
098021 3 10 0. 16808.55 10. 9244.70 20. 6303.21
098022 30. 4706.39 40. 3950.01 50. 3613.84 60. 3361.71
098023 120. 1680.86 130. 0.0 9000. 0.0
** PUMP CURVE INPUT INDICATOR **
100000    16  16     0      16
** SINGLE-PHASE PUMP HEAD HOMOLOGOUS CURVE (INTACT LOOP) **
101011    1    1     -2      0.0   1.2          1.0   1.0
101021    1    2     -5      0.0  -0.35         0.3  -0.2          0.5   0.0
101022                       0.8   0.545        1.0   1.0
101031    1    3     -5     -1.0   1.5         -0.8   1.275       -0.6   1.375
101032                      -0.4   1.375        0.0   1.2
101041    1    4     -6     -1.0   1.5         -0.8   1.15        -0.6   0.95
101042                      -0.4   0.83        -0.2   0.775        0.0   0.725
101051    1    5     -3      0.0   0.975        0.5   1.35         1.0   1.95
101061    1    6     -5      0.0   0.725        0.2   0.725        0.4   0.8
101062                       0.0   1.025        1.0   1.95

00000000011111111112222222222333333333344444444445555555555666666666677777777778
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TABLE A-IV (contd)

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00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

101071   1    7    -3    -1.0   0.175      -0.50 0.65        0.0  0.975
101081   1    8    -5    -1.0   0.175      -0.75 -.15        -0.55 -.3
101082                   -0.275 -.4         0.0 -0.35
** SINGLE-PHASE PUMP TORQUE HOMOLOGOUS CURVE (INTACT LOOP) **
101091   2    1    -6     0.0   0.54        0.2   0.59        0.4   0.65
101092                    0.6   0.77        0.8   0.95        0.9   0.98
101093                    0.95  0.96        1.0   0.87
101101   2    2    -8     0.0  -0.15        0.2   0.02        0.4   0.22
101102                    0.6   0.46        0.8   0.71        0.9   0.81
101103                    0.95  0.65        1.0   0.67
101111   2    3    -6    -1.0   0.62       -0.8   0.63       -0.6   0.53
101112                   -0.4   0.46       -0.2   0.49       -0.0   0.54
101121   2    4    -6    -1.0   0.62       -0.8   0.53       -0.6   0.46
101122                   -0.4   0.42       -0.2   0.39       -0.0   0.36
101131   2    5    -7     0.0  -0.63        0.2  -0.51        0.4  -0.16
101132                    0.6  -0.29        0.8  -0.20        0.9  -0.16
101133                    1.0  -0.13
101141   2    6    -6     0.0   0.36       0.2   0.32        0.4   0.27
101142                    0.6   0.18        0.8   0.05        1.0  -0.13
101151   2    7    -6    -1.0  -1.44       -0.8  -1.25       -0.6  -1.08
101152                   -0.4  -0.92       -0.2  -0.77        0.0  -0.63
101161   2    8    -6    -1.0  -1.44       -0.8  -1.12       -0.6  -0.79
101162                   -0.4  -0.52       -0.2  -0.31        0.0  -0.15
** SINGLE-PHASE PUMP HEAD HOMOLOGOUS CURVE (BROKEN LOOP) **
102011   1    1    -5     0.0    1.782      0.297  1.906     0.595 1.625
102012                    0.892 1.187       1.0    1.0
102021   1    2    -4     0.0  -1.636       0.682  0.0       0.79  0.296
102022                    1.0   1.0
102031   1    3    -5    -1.0   1.5        -0.8   1.275     -0.6   1.375
102032                   -0.4   1.375       0.0   1.2
102041   1    4    -6    -1.0   1.5        -0.8   1.15      -0.6   0.95
102042                   -0.4   0.83       -0.2   0.775      0.0   0.725
102051   1    5    -3     0.0   0.975       0.5   1.35       1.0   1.95
102061   1    6    -5     0.0   0.725       0.2   0.725      0.4   0.8
102062                    0.6   1.025       1.0   1.95
102071   1    7    -3    -1.0   0.175      -0.50  0.65       0.0   0.975
102081   1    8    -5    -1.0   0.175      -0.75 -.15       -0.55 -.3
102082                   -0.275 -.4         0.0 -0.35
** SINGLE-PHASE PUMP TORQUE HOMOLOGOUS CURVE (BROKEN LOOP) **
102091   2    1    -6     0.0   0.54        0.2   0.59       0.4   0.65
102092                    0.6   0.77        0.8   0.95       0.9   0.98
102093                    0.95  0.96        1.0   0.87
102101   2    2    -8     0.0  -0.15        0.2   0.02       0.4   0.22
102102                    0.6   0.46        0.8   0.71       0.9   0.81
102103                    0.95  0.65        1.0   0.87
102111   2    3    -6    -1.0   0.62       -0.8   0.66      -0.6   0.53
102112                   -0.4   0.46       -0.2   0.49      -0.0   0.54
102121   2    4    -6    -1.0   0.62       -0.8   0.53      -0.6   0.46
102122                   -0.4   0.42       -0.2   0.39      -0.0   0.36
102131   2    5    -7     0.0  -0.63        0.2  -0.51       0.4  -0.16

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
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1216 065

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12345678901234567890123456789012345678901234567890123456789012345678901234567890

102132                   0.6 -C.29      0.8 -C.2C      0.9 -0.16
1C2133                   1.0 -C.13
1C2141   2   6   -6      C.0  C.36     0.2  0.32      C.4  C.27
1C2142                   0.6  C.18      0.8  0.C5      1.0 -0.13
1C2151   2   7   -6     -1.0 -1.44     -0.8 -1.25     -0.6 -1.08
1C2152                  -C.4 -C.92     -0.2 -0.77      0.0 -0.63
1C2161   2   8   -6     -1.0 -1.44     -C.8 -1.12     -0.6 -0.79
102162                  -0.4 -C.52     -C.2 -C.31      0.0 -0.15
** 2-PHASE PUMP HEAD HOMOLOGOUS CURVE (BOTH LOOPS) **
1C4C11   1   1    7      0.0  C.C       C.1  0.83      0.2  1.09
1C4C12                   0.5  1.02      C.7  1.C1      0.9  0.94
1C4C13                   1.0  1.0
1C4C21   1   2    8      0.0  0.0       0.1 -0.C4      0.2  0.C
1C4C22                   0.3  C.1       C.4  0.21      0.8  0.67
1C4C23                   C.9  C.8       1.0  1.0
1C4C31   1   3   1C     -1.0 -1.16     -C.9 -1.24     -0.8 -1.77
1C4C32                  -0.7 -2.36     -C.6 -2.79     -0.5 -2.91
1C4033                  -0.4 -2.67     -.25 -1.69     -0.1 -0.C5
1C4C34                   0.0  C.0
1C4041   1   4   10     -1.0 -1.16     -C.9 -0.78     -0.8 -0.5
1C4042                  -0.7 -0.31     -C.6 -C.17     -0.5 -0.08
1C4C43                  -C.35 0.C      -C.2  0.C5     -0.1  0.08
1C4044                   0.0  C.11
1C4C51   1   5    6      C.0  C.0       C.2 -C.C34     0.4 -0.65
1C4C52                   C.6 -C.93      C.8 -1.19      1.0 -1.47
1C4C61   1   6   1C      0.0  C.11      C.1  C.13      0.25 0.15
1C4C62                   C.4  C.13      C.5  0.C7      0.6 -0.04
1C4C63                   0.7 -0.23      0.8 -0.51      0.9 -0.91
1C4C64                   1.0 -1.47
1C4C71   1   7    2     -1.0  C.0       C.0  0.C
1C4C81   1   8    2     -1.0  C.C       C.C  C.0
** 2-PHASE PUMP TORQUE HOMOLOGOUS CURVE (BOTH LOOPS) **
1C4C91   2   1   -8      0.0  0.54      C.2  0.59      0.4  0.65
1C4C92                   0.6  C.77      C.8  C.95      0.9  0.98
104093                   0.95 0.96      1.0  C.87
1C41C1   2   2   -8      C.0 -C.15      C.2  C.02      C.4  0.22
1C4102                   0.6  0.46      C.8  0.71      0.9  0.81
1C41C3                   0.95 0.85      1.C  C.87
1C4111   2   3   -6     -1.0  C.62     -C.8  C.66     -0.6  0.53
1C4112                  -0.4  C.46     -C.2  0.49      0.0  0.54
1C4121   2   4   -6     -1.0   0.62     -0.8  C.53     -0.6  C.46
1C4122                  -0.4  0.42     -C.2  0.39      0.0  0.36
1C4131   2   5   -7      C.0 -0.63      C.2 -0.51      C.4 -0.39
1C4132                   0.6 -C.29      C.8 -C.2C      0.9 -0.16
1C4133                   1.0 -0.13
1C4141   2   6   -6      0.0  0.36      C.2  C.32      0.4  0.27
1C4142                   0.6  0.18      C.8  0.C5      1.0 -0.13
1C4151   2   7   -6     -1.0 -1.44     -C.8 -1.25     -0.6 -1.C8
1C4152                  -0.4 -C.92     -C.2 -0.77      0.0 -0.63
1C4161   2   8   -6     -1.0 -1.44     -0.8 -1.12     -0.6 -0.79

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POOR ORIGINAL

1216 066

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1234567890123456789012345678901234567890123456789012345678901234567890123 567890

104162                       -0.4 -0.52      -0.2 -0.31       0.0 -0.15
** VALVE DATA **
110010   6 0 0 0. 0. 0. 0.          *PRESSURIZER SURGE LINE (JCT. 4)
110020  27 0 0 0. 0. 0. 0.          *INTACT LOOP ACCUMULATOR (JCT. 2)
110030  -2 0 0 0. 0. 0. 0.          *COMMUNICATIVE BREAK NOZZLE (JCT. 41)
110040  28 0 0 0. 0. 0. 0.          *BROKEN LOOP ACCUMULATOR (JCT. 3)
110050  18 1 0 0. 0. 0. 0.          *S.G. FEEDWATER
110060  13 2 0 0. 0. 0. 0.          *S.G. DISCHARGE
**   LEAK DATA   **
120100   -3  18   15.               *S.G. FEEDWATER
120101       0.    1.
120102      10.0    0.
120103   9000.     0.
120200   -3 13  15.                 *S.G. DISCHARGE
120201       0.    1.
120202      10.    0.
120203   9000.     0.
** FILL TABLES **
130100 9 2 17 3 0 LBS/SEC 80. 0. 0.          *I.L. HPIS (J52)
130101   15. 10.908   35. 10.824  55. 10.740  75. 10.657  105. 10.532
130102   128. 10.427  215. 10.051  415. 9.152  615. 8.191  815. 7.23
130103   1015. 6.039  1215. 4.785  1315. 3.845  1445. 1.651  1615. 1.275
130104   1815. .69   2075. 0.
130200 10 2 17 3 0 LBS/SEC 80. 0. 0.        *B.L. HPIS (J50)
130201   15. 3.636   35. 3.608  55. 3.58  75. 3.552  105. 3.511
130202   128. 3.476  215. 3.35  415. 3.051  615. 2.73  815. 2.41
130203   1015. 2.013  1215. 1.595  1315. 1.282  1445. .55  1615. .425
130204   1815. .23   2075. 0.
130300 11 2 7 3 0 LBS/SEC 80. 0. 0.         *I.L. LPIS (J51)
130301   15. 38.448   35. 30.926  55. 23.821  75. 16.361  105. 6.296
130302   128. 0.  1815. 0.
130400 12 2 7 3 0 LBS/SEC 80. 0. 0.         *B.L. LPIS (J49)
130401   15. 12.816   35. 10.309   55. 7.940  75. 5.454  105. 2.765
130402   128. 0.  1815. 0.
130500 2 1 2 4 0 LBS/SEC 900. 434.90      *I.L. SG FEEDWATER (J43)
130501       0. 157.633
130502   9000. 157.633
130600 2 1 2 4 0 LBS/SEC 900. 434.90      *B.L. SG FEEDWATER (J46)
130601       0. 157.633
130602   9000. 157.633
130700 2 1 2 3  0  LBS/SEC 529. 1. 0.      *I.L. SG STEAM DISCHARGE (J44)
130701       0. -258.
130702   9000. -258.
130800 2 1 2 3  0  LBS/SEC 527.2 1. 0.     *B.L. SG STEAM DISCHARGE (J47)
130801       0.   -86.
130802   9000.   -86.
130900   4  2 4 4 0 LBS/SEC  1100. 560. 0. *I.L. SG RELIEF VALVE (J45)
130901       0.      0.
130902   1099.      0.
130903   1100. -102.86

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000000000111111111122222222223333333333444444444455555555556666666666777777777788
12345678901234567890123456789012345678901234567890123456789012345678901234567890

130904  2000. -102.66
131000   5  2 4 4 0 LBS/SEC  1100. 560. 0. *B.L.SG RELIEF VALVE (J48)
131001      0.      0.
131002  1099.       0.
131003  1100. -102.86
131004  2000. -102.86
131100 14   1 2 4 0 LBS/SEC   900. 80. 0. *I.L. S.G. AUX. F.W. (J53)
131101      0.      6.465
131102  9000.       6.465
131200 15   1 2 4 0 LBS/SEC   900. 80. 0. *B.L. S.G. AUX. F.W. (J54)
131201      0.      6.465
131202  9000.       6.465
** KINETICS CONSTANT DATA **
140000 0 0. 0. 0. 0.
** SCRAM TABLE DATA **
141000   -9   3
141001      0.  1.000
141002      3.   .400
141003      8.   .123
141004     10.   .060
141005     30.   .052
141006     60.   .044
141007    100.   .040
141008    200.   .035
141009   1000.   .023
**  HEAT TRANSFER SURFACE CARD   **
150000   2  0   0  2
** HEAT SLAB DATA **
** CORE HEAT SLABS (HIGH POWER RODS) **
150011 0 1 1 0 2 0 0 0. 1.9886 .01748 0. .0111 0. .0111 0. 12. 0. 2.
150021 0 1 1 1 2 0 0 0. 0.9943 .00874 0. .0111 0. .0111 0. 12. 2. 3.
150031 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 3. 4.
150041 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 4. 5.
150051 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 5. 6.
150061 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 6. 7.
150071 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 7. 8.
150081 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 8. 9.
150091 0 1 1 1 2 0 0 0. .9943 .00874 0. .0111 0. .0111 0. 12. 9. 10.
150101 0 1 1 1 2 0 0 0. 1.9886 .01748 0. .0111 0. .0111 0. 12. 10. 12.
** CORE HEAT SLABS (LOW POWER RODS) **
150461 0 1 1 0 2 0 0 0. 4.6401 .04079 0. .02903 0. .0508 0. 12. 0. 3.
150471 0 1 1 1 2 0 0 0. 3.0934 .02719 0. .02903 0. .0508 0. 12. 3. 5.
150481 0 1 1 1 2 0 0 0. 3.0934 .02719 0. .02903 0. .0508 0. 12. 5. 7.
150491 0 1 1 1 2 0 0 0. 3.0934 .02719 0. .02903 0. .0508 0. 12. 7. 9.
150501 0 1 1 1 2 0 0 0. 4.6401 .04079 0. .02903 0. .0508 0. 12. 9. 12.
** INTACT LOOP SG HEAT SLABS **
150131 12 38 2 0 3 0 0 31.9177 39.6986 .146216 .0335 .04167 .0335 .04167
150132 8.4804 8.4804 .70835 6.32453
150141 13 38 2 1 3 0 0 16.2777 20.2460 .074569 .0335 .04167 .0335 .04167
150142 8.4804 8.4804 6.32455 9.18675

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150151 14 38 2 0 3 0 0 31.9177 39.6986 .146216 .0335 .04167 .0335 .04167
150152 8.4604 8.4604 .70835 6.32453
150161 13 38 2 1 3 0 0 16.2777 20.2460 .074569 .0335 .04167 .0335 .04167
150162 8.4804 8.4804 6.32455 9.18875
** BROKEN LOOP SG HEAT SLABS **
150171 23 20 3 0 3 0 0 9.4589 10.652 .04106 .06475 .072917 .06475 .072917
150172 25. 30. 0. 23.25
150181 24 20 3 1 3 0 0 2.93125 3.30096 .012724 .06475 .072917 .06475 .072917
150182 8.75 30. 23.25 32.
150191 25 20 3 0 3 0 0 9.4589 10.652 .04106 .06475 .072917 .06475 .072917
150192 30. 30. 0. 23.25
150201 24 20 3 1 3 0 0 2.93125 3.30096 .012724 .06475 .072917 .06475 .072917
150202 8.75 30. 23.25 32.
150211 23 0 4 0 1 0 0 .71196 0. .424093 .06475 0. .06475 0. 1.75 0. 0. 1.75
150221 25 0 4 0 1 0 0 .71196 0. .424093 .06475 0. .06475 0. 1.75 0. 0. 1.75
** LOWER PLENUM HEAT SLABS **
150231 35 0 5 0 1 0 0 2.2466 0. .5655 .293 0. .293 0. .9896 0. 0. .9896
150241 0 35 6 0 2 0 0 0. 2.73326 .02403 0. .0478 0. .0476 0. .9896 0. .9896
** MIXER BOX HEAT SLABS **
150251 0 36 6 1 2 0 0 0. 4.54576 .039965 0. .0478 0. .0478 0. 1.64584 0. 1.64584
** CORE BARREL HEAT SLABS **
150261 1 0 11 1 1 0 0 2.81 0. .553657 .029056 0. .029056 0. 12. 0. 0. 3.
150271 1 0 11 1 1 0 0 1.87333 0. .369104 .029056 0. .029056 0. 12. 0. 3. 5.
150281 1 0 11 1 1 0 0 1.87333 0. .369104 .029056 0. .029056 0. 12. 0. 5. 7.
150291 1 0 11 1 1 0 0 1.87333 0. .369104 .029056 0. .029056 0. 12. 0. 7. 9.
150301 1 0 11 1 1 0 0 2.81 0. .553657 .029056 0. .029056 0. 12. 0. 9. 12.
** UPPER PLENUM HEAT SLABS **
150311 2 0 11 1 1 0 0 .570967 0. .18407 .05544 0. .05544 0. 1.0008 0. 0. 1.0008
150321 3 0 12 0 1 0 0 1.64699 0. .35857 .099 0. .099 0. 2.1775 0. .21916 2.17744
150331 4 0 12 1 1 0 0 4.66073 0. 1.01466 .154 0. .154 0. 5.5417 0. 0. 5.5417
** UPPER HEAD HEAT SLAB **
150341 5 0 12 0 1 0 0 7.33672 0. 1.5919 .17687 0. .17687 0. 8.7235 0. 0. 8.7235
** DOWNCOMER HEAT SLABS **
150351 36 34 7 0 1 0 0 1.64811 1.488984 .082018 .077828 .08542
150352 .077828 .08542 1.64584 1.45 0. 1.64584
150371 34 0 8 0 1 0 0 8.22961 0. .586568 .182083 0. .182083 0. 15. 0. 2.1667
150372 16.55333
150381 34 0 9 1 1 0 0 3.8627 0. .39097 .14275 0. .14275 0. 2.35419 0.
150382 16.55333 16.9075
150391 0 34 10 0 2 0 0 0. 2.7502 .13636 0. .14275 0. .14275 0. 2. 16.63666
150392 16.71999
** INTACT LOOP PIPING HEAT SLABS **
150111 10 0 13 0 1 0 0 6.4106 0. .273029 .21867 0. .21867 0. 9.3317 0. 0. .21867
150121 16 0 13 0 1 0 0 7.0855 0. .300994 .21867 0. .21867 0. 10.308 0. 0. 0.
150361 17 0 13 0 1 0 0 5.7431 0. .243967 .21867 0. .21867 0. 8.3551 0. 0. 0.
150401 19 0 13 0 1 0 0 5.4959 0. .234076 .21867 0. .21867 0. 8.0003 0. 0. .21867
** BROKEN LOOP PIPING HEAT SLABS **
150411 21 0 14 0 1 0 0 2.46384 0. .069812 .1115 0. .1115 0. 7.03375 0. 0. .1115
150421 27 0 14 0 1 0 0 3.61634 0. .108176 .1115 0. .1115 0. 10.9008 0. 0. 0.
150431 28 0 14 0 1 0 0 3.01737 0. .085482 .1115 0. .1115 0. 8.614 0. 0. 0.

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150441 30 0 14 0 1 0 0 .650067 0. .019536 .1115 0. .1115 0. 1.97 0. 0. .1115
150451 32 0 14 0 1 0 0 1.321752 0. .03742 .1115 0. .1115 0. 3.77333 0. 0. .1115
**  S.G. SECONDARY NATURAL CONVECTION CARDS  **
150134  2
150144  2
150154  2
150164  2
150174  2
150184  2
150194  2
150204  2
** CORE HEAT SLAB DATA CARD **
160010     2 6 10 0. .02935  0. 0.
160020     2 6 10 0. .02902  0. 0.
160030     2 6 10 0. .03978  0. 0.
160040     2 6 10 0. .04696  0. 0.
160050     2 6 10 0. .05054  0. 0.
160060     2 6 10 0. .05054  0. 0.
160070     2 6 10 0. .04696  0. 0.
160080     2 6 10 0. .03978  0. 0.
160090     2 6 10 0. .02902  0. 0.
160100     2 6 10 0. .02935  0. 0.
160460     2 6 10 0. .09080  0. 0.
160470     2 6 10 0. .13493  0. 0.
160480     2 6 10 0. .15724  0. 0.
160490     2 6 10 0. .13493  0. 0.
160500     2 6 10 0. .09060  0. 0.
** HEAT SLAB GEOMETRY CARD **
** CORE REGION, GEOM=1, MTRL=3,4,3,1,1 **
170101 2 5 3 1 0. .002917 0.                         *BORON NITRIDE
170102 0   4 4    .006458 1.                         *CONSTANTAN
170103 0   3 4    .005125 0.                         *BORON NITRIDE
170104 0   1 4    .001    0.                         *316 STAINLESS STEEL
170105 0   1 4    .002083 0.                         *316 STAINLESS STEEL
** INTACT LOOP SG TUBES, GEOM=2, MTRL=5 **
170201 2 1 5 4 .01675 .004083 0.                     *INCONEL 600
** BROKEN LOOP SG TUBES, GEOM=3, MTRL=5 **
170301 2 1 5 4 .032375 .004083 0.                    *INCONEL 600
** BROKEN LOOP SG, GEOM=4, MTRL=1 **
170401 2 1 1 5 .032375 .1667 0.                      *316 STAINLESS STEEL
** LOWER PLENUM WALLS, GEOM=5, MTRL=1,2,1 **
170501 2 3 1 2 .406254 .00833 0.                     *316 STAINLESS STEEL
170502 0   2 1         .00417 0.                     *AVERAGE 2-PHASE
170503 0   1 3         .16667 0.                     *316 STAINLESS STEEL
** CORE ROD EXTENSIONS, GEOM=6, MTRL=7,3,1,1 **
170601 2 4 7 1 0. .0104167 0.                        *COPPER (CA 102)
170602 0   3 1    .004083  0.                        *BORON NITRIDE
170603 0   1 1    .001     0.                        *316 STAINLESS STEEL
170604 0   1 1    .002083  0.                        *316 STAINLESS STEEL
** MIXER BOX, GEOM=7, MTRL=1,2,1 **

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170701 2 3 1 4 .159375 .03125 0.                       *316 STAINLESS STEEL
170702 0   2 1         .00417 0.                       *AVERAGE 2-PHASE
170703 0   1 2         .00833 0.                       *316 STAINLESS STEEL
** DOWNCOMER, GEOM=8, MTRL=1,6,2,1 **
170801 2 4 1 2 .09104 .007913 0.                       *316 STAINLESS STEEL
170802 0   6 2         .009542 0.                      *GRAFOIL
170803 0   2 1         .00083  0.                      *AVERAGE 2-PHASE
170804 0   1 2         .0365   0.                      *316 STAINLESS STEEL
** INLET ANNULUS, GEOM=9, MTRL=1,2,1 **
170901 2 3 1 2 .271375 .00833 0.                       *316 STAINLESS STEEL
170902 0   2 1         .00417 0.                       *AVERAGE 2-PHASE
170903 0   1 2         .0755  0.                       *316 STAINLESS STEEL
** INLET ANNULUS, GEOM=10, MTRL=1,2,1 **
171001 2 3 1 2 .14325 .04425 0.                        *316 STAINLESS STEEL
171002 0   2 1        .00417 0.                        *AVERAGE 2-PHASE
171003 0   1 2        .00833 0.                        *316 STAINLESS STEEL
** CORE BARREL WALL, GEOM=11, MTRL=1,2,1,1,1 **
171101 2 5 1 2 .132114 .00175 0.                       *316 STAINLESS STEEL
171102 0   2 1         .001667 0.                      *AVERAGE 2-PHASE
171103 0   1 2         .008333 0.                      *316 STAINLESS STEEL
171104 0   1 3         .056392 0.                      *316 STAINLESS STEEL
171105 0   1 2         .072    0.                      *316 STAINLESS STEEL
** UPPER PLENUM, GEOM=12, MTRL=1,2,1,1 **
171201 2 4 1 2 .133854 .008333 0.                      *316 STAINLESS STEEL
171202 0   2 1         .004167  0.                     *AVERAGE 2-PHASE
171203 0   1 3         .054167  0.                     *316 STAINLESS STEEL
171204 0   1 4         .073956  0.                     *316 STAINLESS STEEL
** INTACT LOOP PIPING, GEOM=13, MTRL=1 **
171301 2 1 1 4 .109333 .0365 0.                        *316 STAINLESS STEEL
** BROKEN LOOP PIPING, GEOM=14, MTRL=1 **
171401 2 1 1 4 .05575 .023417 0.                       *316 STAINLESS STEEL
** THERMAL CONDUCTIVITY DATA **
180101    -3          100.          7.75            $   316L  STAINLESS  STEEL
180102                800.         11.00            $   316L  STAINLESS  STEEL
180103               1600.         14.30            $   316L  STAINLESS  STEEL
180201    -2          212.          0.02            $   AVERAGE   TWO-PHASE  DATA
180202                572.          0.03            $   AVERAGE   TWO-PHASE  DATA
180301    -6          400.          8.1             $   BORON NITRIDE
180302                900.          6.6             $   BORON NITRIDE
180303               1200.          5.8             $   BORON NITRIDE
180304               1500.          4.9             $   BORON NITRIDE
180305               1800.          3.7             $   BORON NITRIDE
180306               1900.          3.5             $   BORON NITRIDE
180401    -2            0.         14.00            $   CONSTANTAN
180402               3000.         14.00            $   CONSTANTAN
180501    -6          100.          8.5             $   INCONEL 600
180502                300.          9.6             $   INCONEL 600
180503                500.         10.6             $   INCONEL 600
180504                700.         11.6             $   INCONEL 600
180505                900.         12.6             $   INCONEL 600

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180506               1100.          13.6                $     INCONEL 600
180601    -8          250.          2.875               $     GRAFOIL
180602                500.          2.458               $     GRAFOIL
180603                750.          2.083               $     GRAFOIL
180604               1000.          1.833               $     GRAFOIL
180605               1250.          1.742               $     GRAFOIL
180606               1500.          1.683               $     GRAFOIL
180607               2000.          1.667               $     GRAFOIL
180608               3000.          1.750               $     GRAFOIL
180701    -4           32.        224.0                 $     COPPER   CA 102
180702                212.        218.0                 $     COPPER   CA 102
180703                572.        212.0                 $     COPPER   CA 102
180704                932.        207.0                 $     COPPER   CA 102
** VOLUMETRIC HEAT CAPACITY DATA **
190101    -4          400.          61.3                $     316L  STAINLESS  STEEL
190102                600.          64.6                $     316L  STAINLESS  STEEL
190103                800.          67.1                $     316L  STAINLESS  STEEL
190104               1000.          69.35               $     316L  STAINLESS  STEEL
190201    -2          212.           1.0                $     AVERAGE  TWO-PHASE  DATA
190202                572.          64.0                $     AVERAGE  TWO-PHASE  DATA
190301    -7          400.          37.5                $     BORON NITRIDE
190302                800.          46.3                $     BORON NITRIDE
190303               1200.          54.6                $     BORON NITRIDE
190304               1600.          58.3                $     BORON NITRIDE
190305               2000.          60.5                $     BORON NITRIDE
190306               2400.          61.4                $     BORON NITRIDE
190307               3400.          62.5                $     BORON NITRIDE
190401    -7          212.          56.                 $     CONSTANTAN
190402                572.          61.                 $     CONSTANTAN
190403                932.          67.                 $     CONSTANTAN
190404               1472.          73.                 $     CONSTANTAN
190405               2192.          78.                 $     CONSTANTAN
190406               2552.          84.                 $     CONSTANTAN
190407               3000.          90.                 $     CONSTANTAN
190501    -2          100.          57.225              $     INCONEL  600
190502               1000.          57.225              $     INCONEL  600
190601    -9           80.4         11.900              $     GRAFOIL
190602                170.4         14.700              $     GRAFOIL
190603                260.4         17.150              $     GRAFOIL
190604                350.4         19.600              $     GRAFOIL
190605                440.4         21.350              $     GRAFOIL
190606                530.4         22.400              $     GRAFOIL
190607                620.4         23.800              $     GRAFOIL
190608                710.4         25.200              $     GRAFOIL
190609                800.4         26.320              $     GRAFOIL
190701    -2          100.          51.336              $     COPPER   CA 102
190702                600.          51.336              $     COPPER   CA 102
*
* CHANGES FOR MOD-1 I.L. PUMP SUCTION PIPE
*

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*50161 2 0 2213.2370 544. -1. .1915 4.8678 4.8678 0 .03755 .21867 -3.457 0
*50171 2 0 2212.8198 544. -1. .2140 5.6990 5.6990 0 .03755 .21867 -3.457 0
*80151 16 17 0 0 16.11 .03755 -3.348 0. 1.209 1.209 1 5 2 0 0. 0. 0 0 0. 0
*
* TEMPERATURE BALANCE
* CORE BOUNDARY VOLUMES
220200  36  2
*
* I.L. S.G.
220100  11  12  13  14  38  15  43  44
*
* B.L. S.G.
220110  22  23  24  25  20  26  46  47
*
* CORE FLOW PATH
220210  1
*
* S.G. - CORE
220261 15 16 17 18 19 34 35 36 32 31 30 29 28 27 26
*
* CORE - S.G.
220281 2  3  4  10  11  21  22
*
* I.L. PUMP - S.G.
220300  18  17  16  15
*
* B.L. PUMP - S.G.
220301  29  28  27  26
* PRESSURE BALANCE
* PARALLEL FLOW PATHS
* 22031X NONE
*
* DEAD END FLOW PATHS
220320  4
220321  33
220322  34
220323  32
*
* MAIN FLOW LOOP
220400  4  10  11  12  13  14  15  16  17  18
220401  4  3  2  1  36  35  34  19  18
*
* NON MAIN FLOW LOOP
220402  4  21  22  23  24  25  26  27  28  29
220403  34  32  31  30  29
*
* NEGATIVE RESIDUAL TURNOFF
220408  1
*

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APPENDIX B

RELAP4 MODEL FOR AUDIT CALCULATION

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APPENDIX B

RELAP4 MODEL FOR AUDIT CALCULATION

The nodalization diagram for the RELAP4/MOD7 model used for the Westinghouse PWR 2.1% cold-leg break calculation is shown in Figure B-1. The model includes 40 control volumes and 47 junctions. One control volume is used to represent the lower plenum, one volume to represent the core mixer box, three volumes to represent the core, and one volume to represent the upper plenum. Table B-I provides physical descriptions of the control volumes used in the model. Table B-II describes the junctions used in the model which connect the control volumes. Fill junctions are used to represent the intact and broken loop injection systems and steam generator secondary water supplies.

A total of 21 heat slabs are used to represent heat conducting solids in contact with the coolant in the core, steam generators, and reactor vessel. The fuel rods are represented by 6 axial heat slabs of equal length.

Table B-III lists the more significant code analytical options used in this calculation, such as heat transfer correlations, vertical slip, and bubble rise model.

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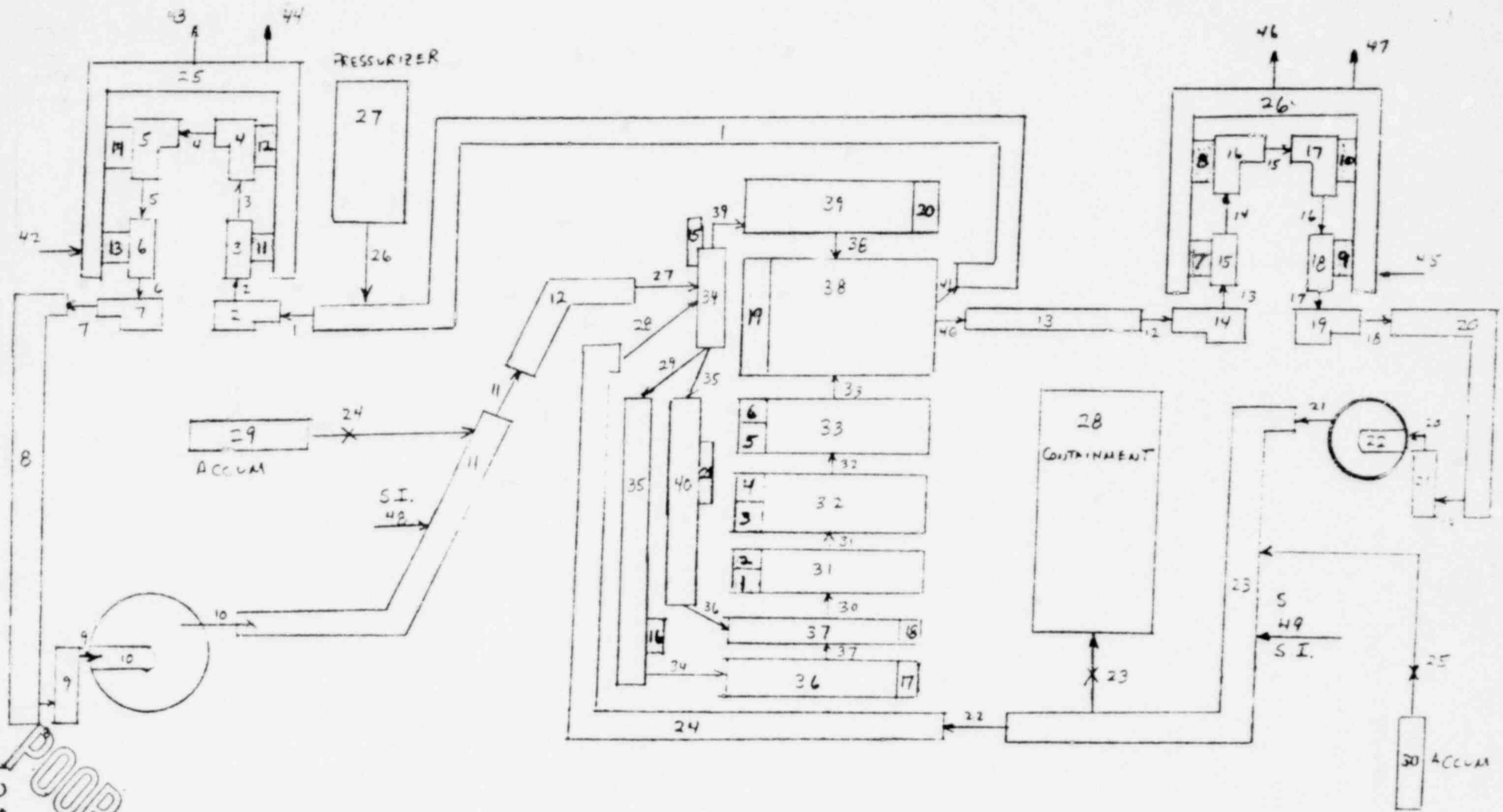

Fig. B-1. RELAP4/MOD7 mode: for Westinghouse PWR.

TABLE B-I

RELAP4/MOD7 MODEL CONTROL VOLUME DESCRIPTION FOR PWR

Control Volume	Description
1	Intact loop hot leg
2	Intact loop steam generator inlet plenum
3, 4, 5, 6	Intact loop steam generator tube bundle
7	Intact loop steam generator outlet plenum
8	Intact loop pump suction - downflow
9	Intact loop pump suction - upflow
10	Intact loop pump
11, 12	Intact loop cold leg
13	Broken loop hot leg
14	Broken loop steam generator inlet plenum
15, 16, 17, 18	Broken loop steam generator tube bundle
19	Broken loop steam generator outlet plenum
20	Broken loop pump suction - downflow
21	Broken loop pump suction - upflow
22	Broken loop pump
23	Broken loop pump discharge and break assembly
24	Broken loop cold leg
25	Intact loop steam generator secondary
26	Broken loop steam generator secondary
27	Pressurizer
28	Pressure suppression vessel
29	Intact loop accumulator
30	Broken loop accumulator
31, 32, 33	Core
34	Inlet annulus
35	Downcomer
36	Lower plenum
37	Core mixer box
38	Upper plenum
39	Upper head
40	Core baffle region

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TABLE B-II

RELAP4/MOD7 MODEL JUNCTION DESCRIPTION FOR PWR

Junction	Description
1	Intact loop hot leg, intact loop steam generator inlet plenum
2	Intact loop steam generator inlet plenum, intact loop steam generator tube bundle
3, 4, 5	Intact loop steam generator tube bundle juctions
6	Intact loop steam generator tube bundle, intact loop steam generator outlet plenum
7	Intact loop steam generator outlet plenum, intact loop pump suction - downflow
8	Intact loop pump suction - downflow, intact loop pump suction - upflow
9	Intact loop pump suction - upflow, intact loop pump
10	Intact loop pump, intact loop cold leg
11	Intact loop cold leg junction
12	Broken loop hot leg, broken loop steam generator inlet plenum
13	Broken loop steam generator inlet plenum, broken loop steam generator tube bundle
14, 15, 16	Broken loop steam generator tube bundle junctions
17	Broken loop steam generator tube bundle, broken loop steam generator outlet plenum
18	Broken loop steam generator outlet plenum, broken loop pump suction - downflow
19	Broken loop pump suction - downflow, broken loop pump suction - upflow
20	Broken loop pump suction-upflow, broken loop pump
21	Broken loop pump, broken loop pump discharge and break assembly
22	Broken loop discharge and break assembly, broken loop cold leg

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TABLE B-II (contd)

Junction	Description
23	Broken loop pump discharge and break assembly, presure suppression vessel
24	Intact loop accumulator, intact loop cold leg
25	Broken loop accumulator, broken loop pump discharge and break assembly
26	Pressurizer, intact loop hot leg
27	Intact loop cold leg, inlet annulus
28	Broken loop cold leg, inlet annulus
29	Inlet annulus, downcomer
30	Core mixer box, core
31, 32	Core junctions
33	Core, upper plenum
34	Downcomer, lower plenum
35	Inlet annulus, core baffle region
36	Core baffle region, core mixer box
37	Lower plenum, core mixer box
38	Upper head, upper plenum
39	Inlet annulus, upper head
40	Upper plenum, broken loop hot leg
41	Upper plenum, intact loop hot leg
42	Intact loop steam generator main and auxiliary feedwater
43	Intact loop steam generator discharge
44	Intact loop steam generator relief valve
45	Broken loop steam generator main and auxiliary feedwater
46	Broken loop steam generator discharge
47	Broken loop steam generator relief valve

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TABLE B-III

MODELING OPTIONS FOR PWR CALCULATIONS

1. MVMIX = 0 (compressible flow with momentum flux) is used at all junctions, except that MVMIX = 3 (incompressible flow with no momentum flux) is used at junctions between the vessel and hot or cold legs, pressurizer and accumulator junctions, core bypass paths and all fill junctions.

2. Vertical slip is used at all vertical junctions in the model except in the steam generator tubes.

3. Wilson bubble rise is used in all vessel volumes (except bypass volume), pressurizer, and pump suction volumes. (Bubble gradient = 0.8). Complete phase separation is modeled in the accumulator. A constant bubble rise velocity and bubble gradient are used in the steam generator secondaries. The values are code calculated to achieve an initial energy balance.

4. Critical flow is modeled using the Henry-Fauske/Moody option. A multiplier of 1.0 is applied to both Henry-Fauske (subcooled) and Moody (saturated).

5. Core heat transfer is calculated with the default and/or recommended options for the RELAP4/MOD6 Update 4 code. These are (1) use of HTS2 heat transfer surface, (2) CHF calculated with recommended CHF correlations, (3) Transition boiling calculated with modified Tong-Young correlation, and (4) film boiling calculated with the Condie-Bengston III film boiling correlation. The recommended CHF correlations are the W-3 correlation for the subcooled regime, Hsu and Beckner's modified W-3 correlation for saturated high flow and Smith and Griffith's modified Zuber for saturated low flow regime.

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TABLE B-III (contd)

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6. The enthalpy transport model is used to initialize the calculation but is not used during the transient.

7. The new slip velocity model developed for RELAP4/MOD7 is utilized. The new model employs a flow regime dependent correlation which results in a more accurate calculation, of interphase slip velocities.

8. The RELAP4/MOD7 self-initialization routine is used to effect initial system pressure and energy balances.

9. Steam generator secondaries utilize the natural convection option for heat transfer.

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