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MASTER

AUTHOR(S): J. S. Gilbert, Q-9
M. S. Sahota, Q-9
B. E. Boyack, Q-9
C. P. Booker, Q-9
J. K. Meier, Q-9

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COMPARISONS OF TRAC-PD2 CALCULATIONS WITH SEMISCALE MOD-3 SMALL-BREAK TESTS*

by

J. S. Gilbert, M. S. Sahota, B. E. Boyack, C. P. Booker, and J. K. Meier

Safety Code Development Group
Energy Division
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545

ABSTRACT

Five experiments conducted in the Semiscale Mod-3 facility at the Idaho National Engineering Laboratory (INEL) were calculated using the latest released version of the Transient Reactor Analysis Code (TRAC-PD2). The results were used to assess TRAC-PD2 predictions of thermal-hydraulic phenomena and the effects of pump operation on system response during slow transients. Tests S-SB-P1, S-SB-P2, and S-SB-P7 simulated equivalent 2.5% communicative cold-leg breaks for early pump-trip (pumps-off), intermediate pump-trip (pumps-on), and late pump-trip (pumps-on) operation, respectively. Tests S-SB-P3 and S-SB-P4 simulated equivalent 2.5% communicative hot-leg breaks for pumps-off and pumps-on operation, respectively. Parameters examined in the study included primary system mass distribution, mass inventory, and void fraction distribution. In Tests S-SB-P3 and S-SB-P4 no core uncovery was observed nor calculated. In Test S-SB-P1 core uncovery was observed and calculated. Core uncovery was calculated but not observed in Test S-SB-P7.

*Work performed under the auspices of the US Nuclear Regulatory Commission.

I. INTRODUCTION

Five experiments have been conducted in the Semiscale Mod-3 facility at the Idaho National Engineering Laboratory (INEL) to investigate the thermal-hydraulic phenomena resulting from a 2.5% communicative small-break loss-of-coolant accident (LOCA) in a pressurized-water-reactor (PWR) system. The resulting experimental data have been used to assess the analytical capabilities of the Transient Reactor Analysis Code (TRAC). The primary objective was to assess the capability of TRAC to predict both hot- and cold-leg small-break transients. An important aspect of the current study was to determine if TRAC correctly predicts the effect of pump operation on fluid conditions near the break and the resulting influence on break flow, system depressurization, and system mass inventory.

The five experiments selected for this assessment were Tests S-SB-P1, S-SB-P2, S-SB-P3, S-SB-P4, and S-SB-P7. Tests S-SB-P1, S-SB-P2, and S-SB-P7 (Ref. 1) simulated communicative cold-leg breaks for early pump-trips (pumps-off), intermediate pump-trips (pumps-on), and late pump-trips (pumps-on) operation, respectively. Tests S-SB-P3 and S-SB-P4 (Ref. 2) simulated communicative hot-leg breaks for pumps-off and pumps-on operation, respectively. The Semiscale small-break test series was designed for compatibility with the Loss-of-Fluid Test (LOFT) facility small-break tests. The specified initial conditions closely approximate those expected in a typical full-sized commercial PWR operating at full load conditions. The break size for these tests is volume-scaled to a 2.5% (11 cm) break in the cold or hot leg of a full-sized PWR system. Only the high-pressure injection system (HPIS) supplied emergency core coolant (ECC); the accumulators were valved out.

II. TRAC DESCRIPTION

TRAC is an advanced best-estimate systems code for analyzing light-water-reactor accidents. TRAC provides this analysis capability for PWRs and for a wide variety of thermal-hydraulic experimental facilities. It features a three-dimensional calculational capability of the pressure vessel and associated internals; two-phase nonequilibrium hydrodynamics models; flow-regime-dependent constitutive equation treatment; reflood tracking capability for both bottom reflood and falling film quench fronts; and consistent treatment of entire accident sequences including the generation of consistent initial conditions.

TRAC-PD2 (Ref. 3), the most recently released detailed PWR version, contains major improvements in the areas of reflood heat transfer, solution strategy, numerics, constitutive relations, and numerical mass conservation. TRAC-PD2 was revised to correct an error in the gravity head term in the axial momentum equation for the three-dimensional VESSEL component (Ref. 4).

All the TRAC results were plotted using TRAP (TRAC Plot) [Ref. 5]. The TRAP computer program is a versatile graphics postprocessor program. To the right of each TRAP plot is a box containing the plot legend. At the top of the legend the TRAC-PD2 calculated results are indicated by a solid line and the data are identified by a symbol and instrument designation. At the bottom of the legend the test number is given, followed by the TRAC location of the calculated results. For the cladding temperature plots, the core elevation above the bottom of the heated length is specified in the last line of plot legend.

III. SEMISCALE MOD-3 SYSTEM DESCRIPTION

The Semiscale Mod-3 system consisted of an intact loop, a broken loop, an external downcomer assembly, and a pressure vessel to simulate a PWR. The intact loop included a pressurizer, steam generator, and pump. The broken loop included a steam generator, pump, and rupture valve assembly. Elevations of most system components were the same as in a full-sized PWR. The small break was simulated with a bell-mouthed orifice attached to the side of the broken-loop piping and the break orifice was volume-scaled to represent a 2.5% break in a PWR. A valve was opened to initiate blowdown. For the small-break tests, the pressure-suppression tank was disconnected from the pressure-suppression header to facilitate collecting and weighing the fluid that flows through the break.

The pressure vessel included an upper head, an upper plenum, an electrically heated core, and a lower plenum. The external downcomer assembly included an inlet annulus and downcomer pipe. In the 25-rod core, 2 rods were unpowered and another rod was replaced by a liquid-level probe. A flat radial power profile was used. The cladding thermocouples were located 0.75 mm beneath the cladding surface.

The ECC was provided by high-pressure injection pumps for each loop. Additional details about the Mod-3 system are available in the Semiscale Mod-3 system design description (Ref. 6).

IV. TEST DESCRIPTION

Initial and boundary conditions are summarized in Table I for the five Semiscale Mod-3 small-break LOCA tests considered in the assessment. The primary factors differentiating the tests were the location of the break and the operation of the primary coolant pumps. For Tests S-SB-P1, S-SB-P2, and S-SB-P7, the break simulator containing the orifice was located in the broken-loop cold leg between the pump and the external downcomer. Pump coastdown began early for Test S-SB-P1 (3.4 s after the low-pressure trip signal) and much later for Test S-SB-P7 (1099.7 s after the trip signal). The pumps remained on for the duration of Test S-SB-P2 (798.3 s after the trip signal). The break simulator for Tests S-SB-P3 and S-SB-P4 was located in the broken-loop hot leg between the vessel and the steam-generator inlet. Pump coastdown began early for Test S-SB-P3 (3.4 s after the trip signal) and at the end of Test S-SB-P4 (2135.6 s after the trip signal).

Each test was initiated from the steady-state operating conditions by opening a valve downstream of the break simulator. Core power decay, pump coastdown, and steam-generator valve actions were sequenced relative to a trip signal generated by a specified low pressure in the pressurizer. The ECC was provided by the HPIS only. The accumulators in the intact and broken loops were valved out during each test, and the tests were terminated before the system pressure fell below the normal low-pressure injection system (LPIS) set points.

TABLE I

TEST MATRIX[a]

	Test S-SB-P1	Test S-SB-P2	Test S-SB-P7	Test S-SB-P3	Test S-SB-P4
Break location	cold leg	cold leg	cold leg	hot leg	hot leg
Core power (MW)	1.96	1.97	1.97	1.965	1.968
Initial core inlet flow rate (kg/s)	12.1	12.0	11.9	10.6	10.9
Trip pressure (MPa)[b]	12.48	12.48	12.48	12.57	12.57
Time when pressurizer pressure rea[illegible] trip pressu[illegible] (s)	17.2	16.3	17.5	26.2	24.4
Sequence of ev[illegible]ts relative to the time of the pressure trip (s)					
Steam-generator steam valves closed	0.0	0.0	0.0	0.0	0.0
Core power decay started	3.4	3.4	3.4	3.4	3.4
Pump coastdowns started	3.4	798.3	1099.7	3.2	2135.6
Steam-generator feedwater valves closed	8.4	8.4	8.4	IL[c]-10.8, BL[c]-8.2	IL-12.2, BL-4.0
HPIS injection started	28.4	28.4	28.4	28.6	29.2
Auxiliary feedwater started[d]	63.4	63.4	63.4	65.0	64.5
Auxiliary feedwater shutoff[d]	553.4	798.3	2447.3	513.8	261.6
Core power terminated	1653.4	798.3	2447.3	2443.8	2135.6
Core uncovery observed	yes	no	no	no	no

[a]For all tests the system pressure is 15.6 MPa and the cold-leg temperature is 550 K.

[b]Corresponds to the pressurizer pressure. All events during the transient were relative to this trip.

[c]Intact loop (IL), broken loop (BL).

[d]As reported in Refs. 1 and 2. Actual feedwater flows were intermittent and controlled to maintain a desired steam-generator-secondary liquid level.

The pressure-suppression tank was bypassed for each test, and the break discharge was drained through a condensing system into a small catch tank. The catch-tank inventory was measured before and after the test to obtain the total integrated break flow. Each test was terminated by closing the valve downstream of the break when the system pressure dropped to a predetermined level.

V. TRAC MODEL

The TRAC input model schematic for the Semiscale Mod-3 facility configured for a cold-leg break is shown in Fig. 1. The input consisting of 35 TRAC components corresponds to the Semiscale Mod-3 hardware configuration with the following exceptions.

1. The external downcomer assembly in the test facility is modeled as an internal downcomer occupying an appropriate fraction of the outer ring of the VESSEL (component 50).

2. The pressure-suppression system is not modeled directly. A BREAK component (number 40 for the cold-leg break configuration) is introduced and the pressure at the break is specified as a boundary condition.

3. The secondary feedwater systems, both main and auxiliary, are represented by FILL components 7 and 26 for the intact and broken loops, respectively.

4. To achieve computational efficiency, the break is modeled as a TEE component with the side tube having a loss coefficient (FRIC) representing the break orifice. Two values of FRIC were selected, one for the subcooled and transition blowdowns for which the quality is less than ~2% and another for the saturated blowdown beyond this quality.

The model has 216 computational cells. The side tube of the TEE component upstream of the break (component 25 for cold-leg-break tests and component 21 for hot-leg-break tests) and the intact- and broken-loop steam-line VALVEs (components 8 and 27) were treated with fully implicit numerics. The remainder of the components were treated with semi-implicit numerics. The intact-loop PUMP uses the Semiscale pump curves.

A revised pump curve* for the broken-loop PUMP was obtained from INEL and incorporated into the input model. Because ECC for each test was provided by HPIS only, VALVE components 11 and 44 remained closed for each calculation.

The structural heat losses of the Semiscale system have been experimentally measured and shown to be a significant portion of the heat generated in the core (Ref. 7) during simulated decay heat. The heat losses were, therefore, incorporated in the TRAC model. The surrounding air temperature (variables TOUTV and TOUTL in the one-dimensional components) was

*C. B. Davis, Idaho National Engineering Laboratory personal communication (December 1980).

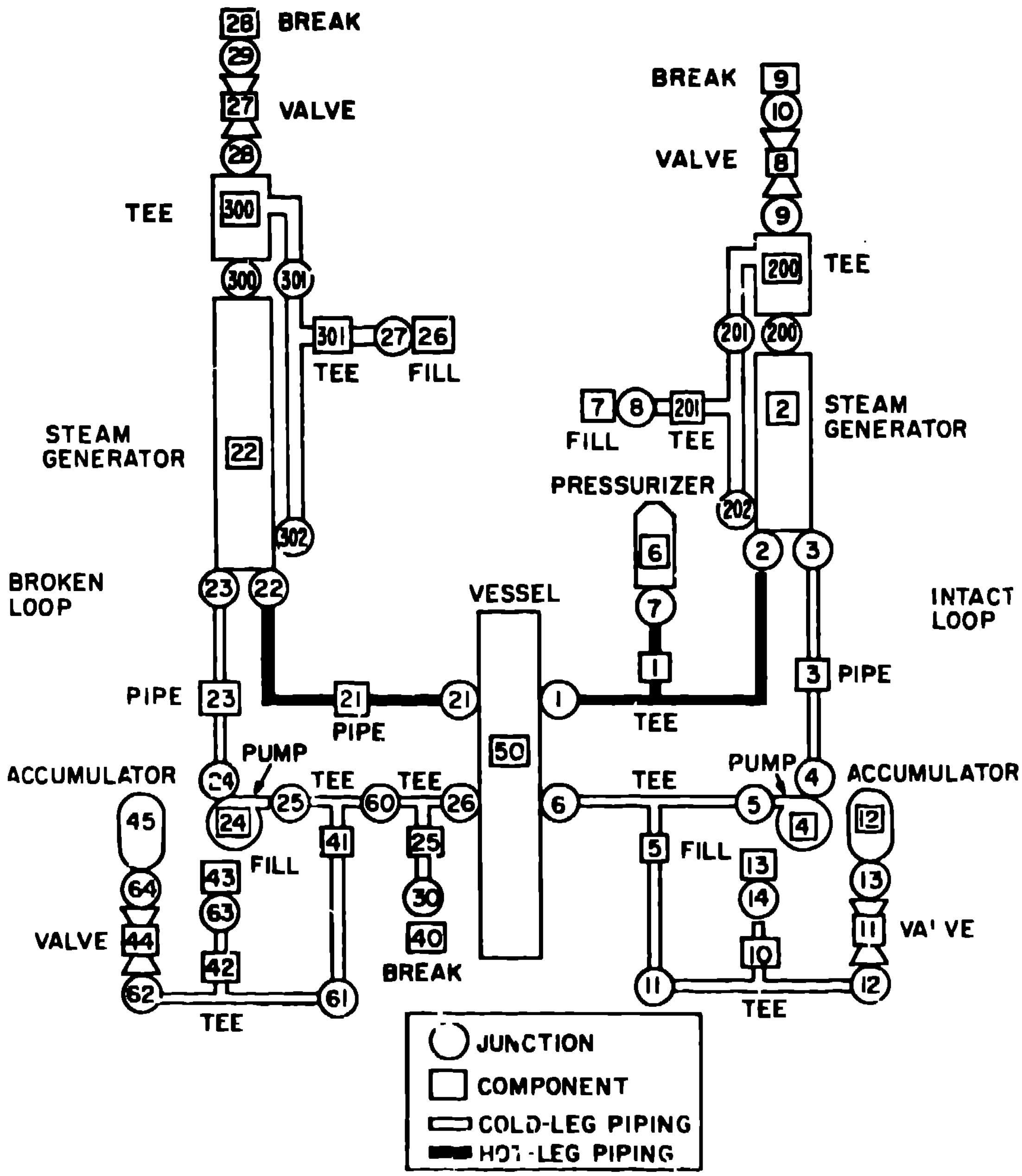

Fig. 1. TRAC model of Semiscale Mod-3 facility (cold-leg break).

assumed to be 300 K. A film coefficient was then calculated based on the outside surface area of the primary piping, primary liquid temperatures from a previous TRAC-PD2 steady state, and a heat loss of 80 kW (Ref. 7). Because TRAC-PD2 does not allow for heat loss from the VESSEL component, the entire heat loss was accounted for in the primary piping. For the present TRAC-PD2 model, the film coefficient HOUTV is 64.47 W/(m^2K) [HOUTL = 0.0].

A revised TRAC input model was prepared for the test facility configured for hot-leg-break Tests S-SB-P3 and S-SB-P4. The revisions required to represent the test facility hardware modifications are listed below (refer to Fig. 1).

1. The broken-loop hot-leg PIPE (component 21) was replaced by TEE component 21. The side tube of the TEE represents the break simulator and is connected to BREAK component 20.

2. The broken-loop cold-leg TEE (component 25) was replaced by PIPE component 25. BREAK component 40, originally connected to the side tube of TEE component 25, was eliminated.

The vessel nodalization for all tests is shown in Fig. 2. The TRAC VESSEL component represented the following Semiscale components: the inlet annulus, the pipe downcomer, the test vessel (upper and lower plenums and core), and the upper head. The vessel was divided into 2 radial rings, 2 azimuthal segments, and 19 axial levels. The core was located in ring 1, levels 4-12. Because flat radial power profiles were specified for the small-break tests under consideration, only two rods, each representative of an average rod in the given segment, were modeled. There were three re-entrant PIPE components (51, 52, and 53) to represent the upper-head bypass, the core support tube simulators, and the guide tube simulator.

VI. RESULTS

In this section, significant TRAC results are reviewed and compared to the experimental data. The cold-leg-break results are presented first. A discussion of the hot-leg-break results follows later in this section.

A. Cold-Leg-Break Tests (Tests S-SB-P1, S-SB-P2, and S-SB-P7)

1. Test S-SB-P1 (Early Pump Trip)

Experimental and calculated system pressure histories are shown in Fig. 3. During the first 50 s of the transient, when the liquid upstream of the break was subcooled, the pressure prediction lay within the data uncertainty. From 50 to 200 s, when break flow went through transition (quality ≤2%), the pressure is overpredicted by ~7%. TRAC deviates from the expected trend by either overpredicting or underpredicting both pressure and break flow during subcooled and transition blowdowns. Also, the initial liquid inventories used in the TRAC input for the steam generator secondaries were lower than in the data. This was primarily the result of an error in the experimental data reports (Refs. 1 and 2). Therefore, the heat-transfer rate from the primary to the secondary was impaired and contributed to the higher system pressure prediction. Beyond ~200 s, when the second value of FRIC at the break was used, a perturbation in

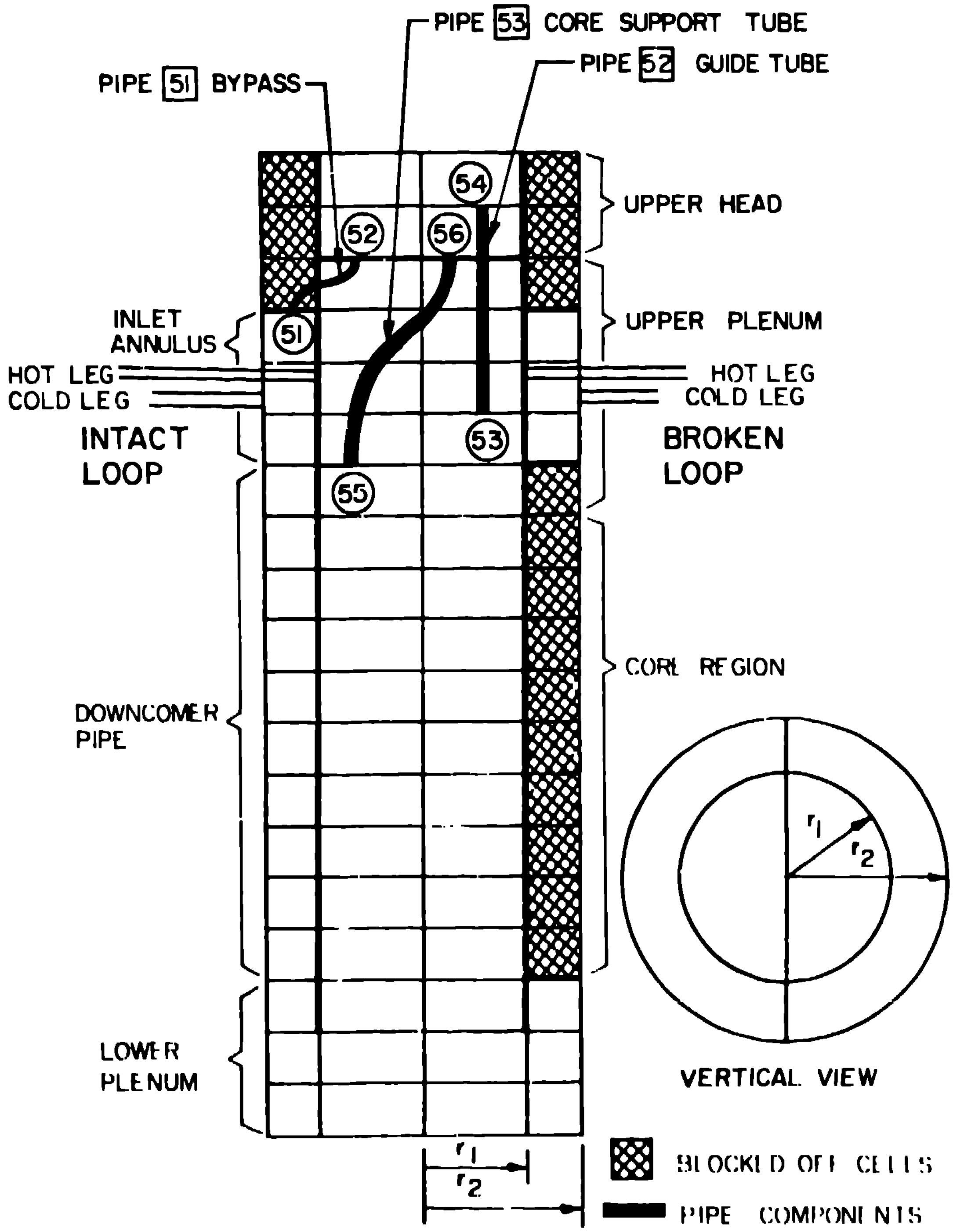

Fig. 2. Vessel nodalization.

the calculated system pressure response was observed. The rapid depressurization rate between 200 and 400 s was caused by core uncovery calculated during this time period, which reduced the vapor generation rate. A sharp rise in the calculated pressure at 600 s corresponded to core quench, which suddenly increased the vapor generation rate. The experimental and calculated trends were similar beyond 600 s.

The calculated mass distribution in the primary system is useful in understanding the core thermal response. At the end of the transient, the mass inventories retained on the primary side relative to their initial values were: intact loop = 17%, broken loop = 60%, vessel (including downcomer) = 68%, and total primary system = 43%. The broken-loop pump suction leg remained full of liquid throughout the transient, whereas the loop seal on the intact-loop pump suction was blown out around 600 s. The liquid from the intact-loop pump suction was forced into the vessel.

Experimental and predicted vessel liquid masses, including the downcomer, are shown in Fig. 4. The curve labeled "Test Data" was calculated from test data and was not measured directly. The initial underprediction of ~3 kg in the vessel liquid mass is the result of not including the liquid in the guide tube and core support tube in the calculation, whereas the data do include these masses. The total vessel volume below the top of the core, including the downcomer, was calculated as 0.0393 m^3. Using an average liquid density of

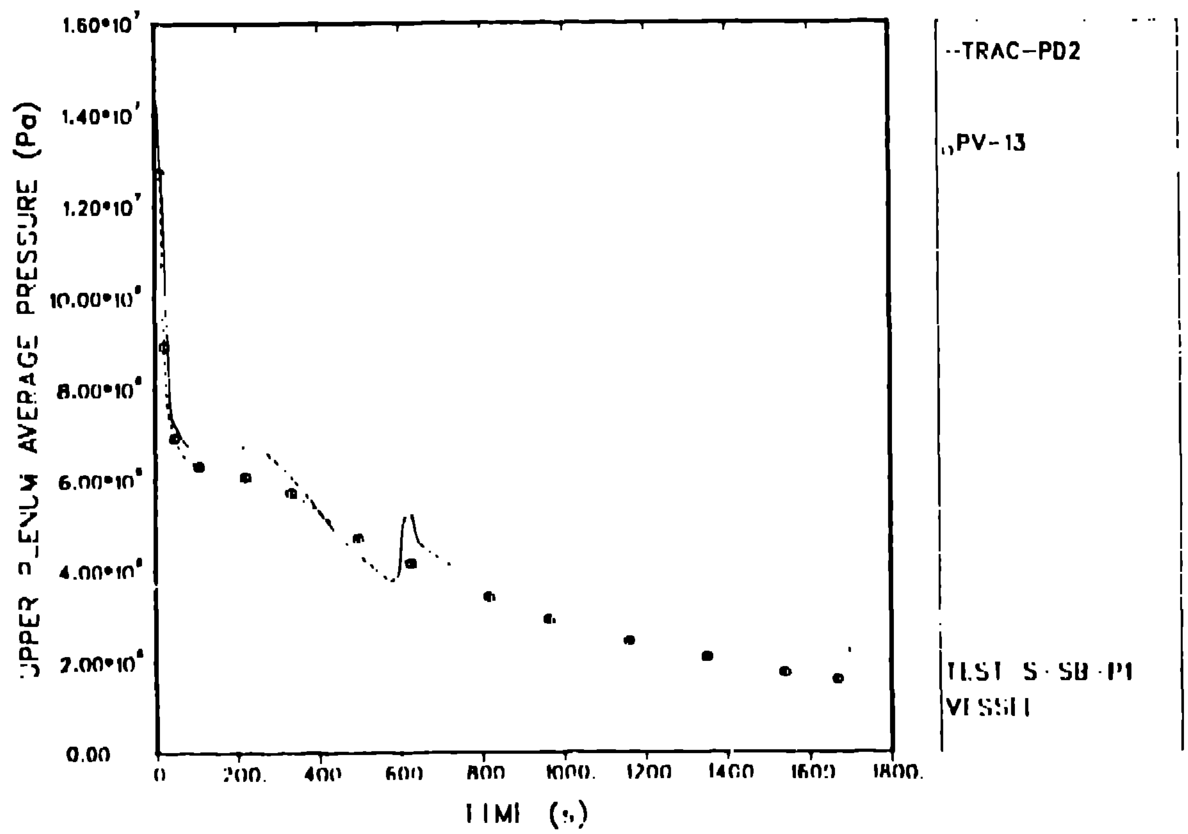

Fig. 3. Upper-plenum pressures for Test S-SB-P1.

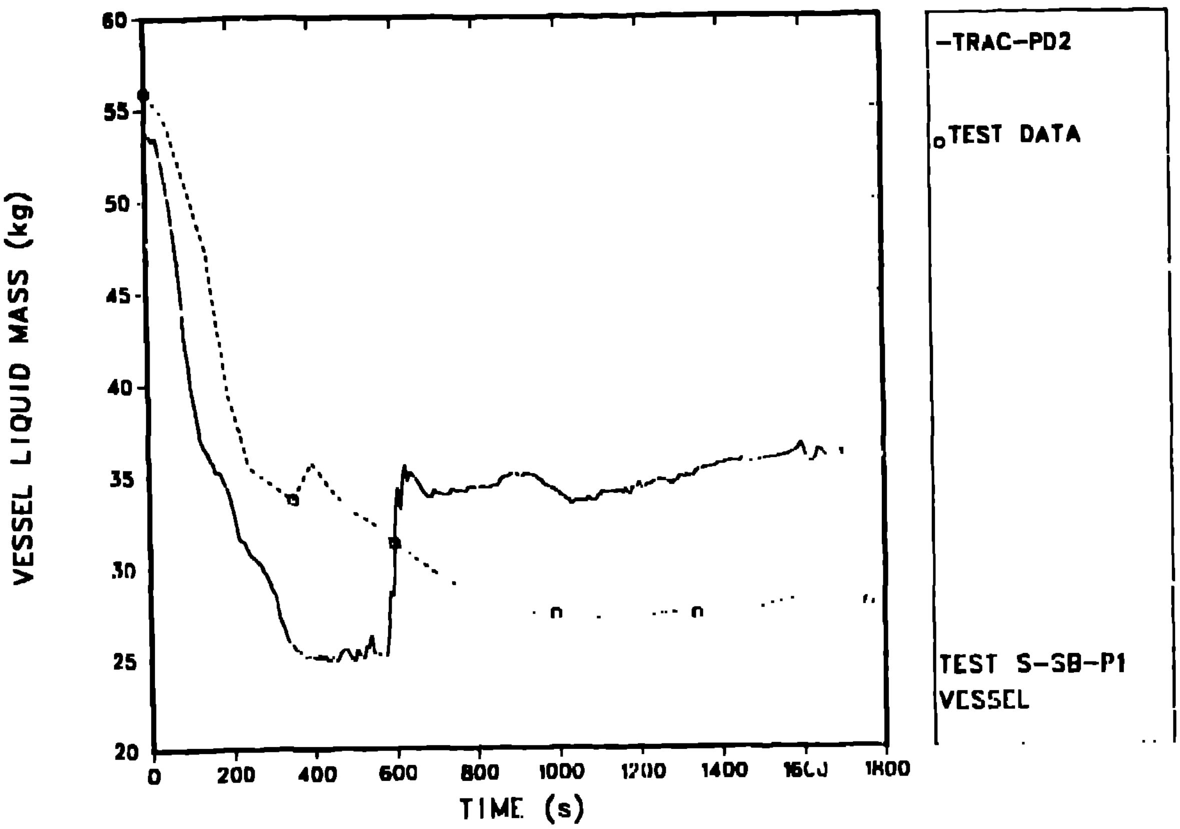

Fig. 4. Vessel liquid masses for Test S-SB-P1.

740 kg/m^3 (corresponding to the mean temperature in the core at initial conditions), 29 kg of liquid should just cover the core when the liquid level is collapsed. Thus, there was little chance of core uncovery when the liquid mass in the vessel exceeded 29 kg. The vessel mass was underpredicted by as much as 10 kg during the first 600 s of the transient, primarily because of incorrect mass distribution in the system. At 300 s into the transient, the calculated vessel liquid mass fell below 29 kg and core uncovery began. At about 600 s, the core was quenched by water entering the vessel because of intact-loop pump suction seal blowout. In the experiment, this loop seal blowout occurred at ~360 s. However, the experimental increase in vessel mass was not as dramatic as in the calculation because there was less liquid in the loops. Experimental core uncovery began after 700 s. The quenching, however, was extremely slow and was not completed during the transient. The calculated vessel liquid mass was overpredicted by ~5 kg beyond 600 s. This overprediction was caused by lower total break flow compared to the data. This lower break flow resulted in higher liquid mass in the system. Although the transient break flow data were not available, the total mass discharged through the break was measured at the end of the test. The experimental integrated break flow for this test was 168 kg as compared to a calculated mass of 148 kg. This resulted in ~20 kg greater calculated system mass because the ECC injection rates in the calculation and in the experiment were about the same.

In Fig. 5, a cladding temperature comparison of calculation and test data is given near the top of the core. Because of the underprediction of vessel liquid mass compared to the data between 300 and 600 s, core dryout was calculated near the core center during this time. Near the top of the core, the predicted dryout started around 300 s when the core began uncovering. However, the core was fully quenched at 600 s because of the intact-loop pump seal blowout. In the experiment, however, core dryout started around 700 s and the quenching was not complete at the end of the transient. No core dryout was calculated nor observed at the bottom of the core where the experimental and calculated rod temperatures followed slightly above saturation.

2. Tests S-SB-P2 and S-SB-P7 (Delayed Pump Trip)

For both these tests the initial and boundary conditions were identical with a few minor exceptions, such as small differences in the initial steam-generator-secondary liquid levels, initial primary system flow rates, and auxiliary feedwater flows. The sequences of events for both these tests were also identical except that Test S-SB-P2 was terminated at 814.6 s and Test S-SB-P7 continued until 2464.8 s, with the pumps tripped off at 1117.2 s. Thus, Test S-SB-P7 is an extension of Test S-SB-P2 beyond 814.6 s. Therefore, only the results of Test S-SB-P7 are presented in this section with reference to Test S-SB-P2 when appropriate. At the end of the transient for Test S-SB-P7,

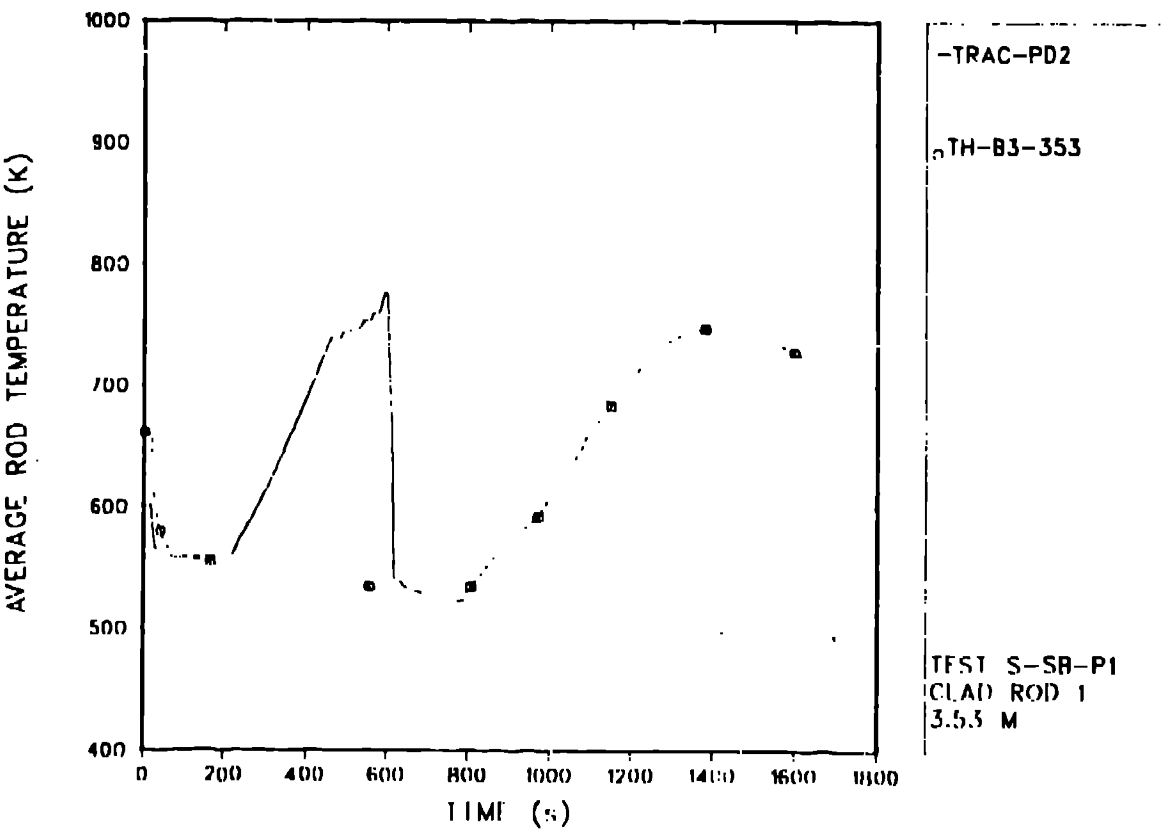

Fig. 5. Clad temperatures at 3.53-m elevation for Test S-SB-P1.

the measured and calculated integrated break flows were 174 kg and 161 kg, respectively.

Experimental and calculated system pressure histories are shown in Fig. 6. The pressure was slightly overpredicted during the first 300 s of the transient. As mentioned earlier, this overprediction represents a deviation from the expected trend when TRAC overpredicts both pressure and break flows. Low heat transfer from the intact-loop steam-generator primary to the secondary (because of lower water mass on the secondary side) was another cause for this discrepancy. Later during the transient the pressure underprediction seems to have been caused by (a) lower heat transfer from steam-generator secondaries to the primaries caused by too much cold auxiliary feedwater injected into the secondaries, (b) lower core heat transfer because of core uncovery, and (c) higher enthalpy flow out through the break (even though the calculated break flow is estimated to be ~20% too low, the total energy out is larger than in the experiment). Calculated pressure oscillations in the second half of the transient were caused by core rewets.

At the end of the transient, the calculated fraction of the initial mass inventories retained on the primary side were: intact loop = 51%, broken loop = 8%, vessel (including downcomer) = 65%, and total primary system = 49%. The intact-loop pump suction leg voided around 1000 s but, after the pump tripped at 1117 s, the liquid from HPIS injection gradually refilled the leg.

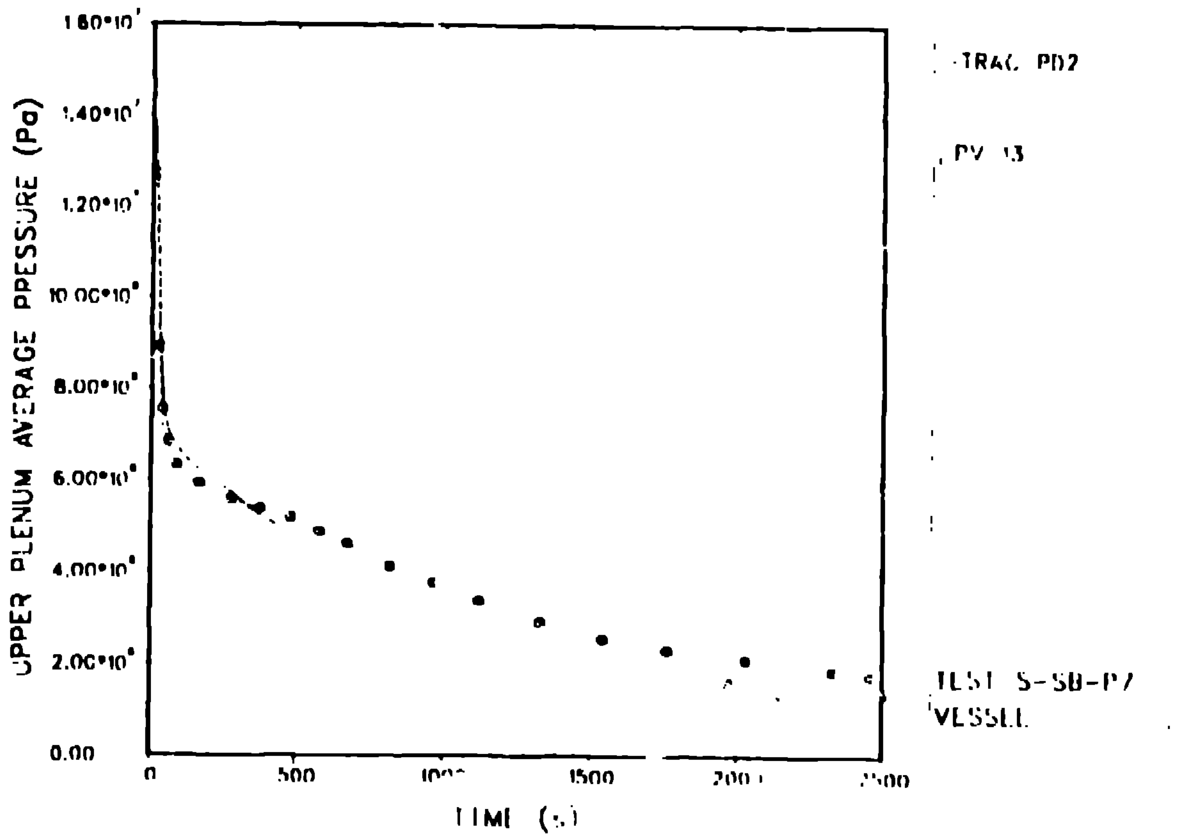

Fig. 6. Upper-plenum pressures for Test S-SB-P7.

The broken-loop pump suction continued to void throughout the transient because of the cold-leg break.

Experimental and predicted vessel liquid masses (including downcomer) are compared in Fig. 7. The mass underprediction before 1117 s (pumps-on portion) was caused by incorrect system mass distribution. Because the calculated pump performance did not degrade as much as in the test, the vessel liquid inventory was depleted through redistribution into the loops. The calculated vessel mass remained below the critical mass of 29 kg from 300 s until the pumps tripped. However, the core did not dry out because the pumps redistributed the liquid mass from the downcomer into the core. The presence of bubbles also contributed to maintaining the mixture level above the core. If the pumps had been turned off at any time after 300 s, the likelihood of a calculated core dryout would have been high. Dryout, indeed, did occur in the calculation ~200 s after the pumps were turned off at 1117 s. Oscillations in the vessel mas at 1000 s may be the result of oscillations in pump head during two-phase operation (particularly the intact-loop pump) that forced slugs of liquid into the hot legs. A sudden increase in the calculated as well as experimental core mass at 1117 s was the result of liquid draining into the vessel from the hot leg. The calculated increase, however, was much larger because of larger amounts of liquid in the loops and more complete draining. In the calculation this liquid rewet the top of core, which increased the vapor generation rate, and, in turn, pressurized the upper plenum and pushed the liquid into the cold legs through

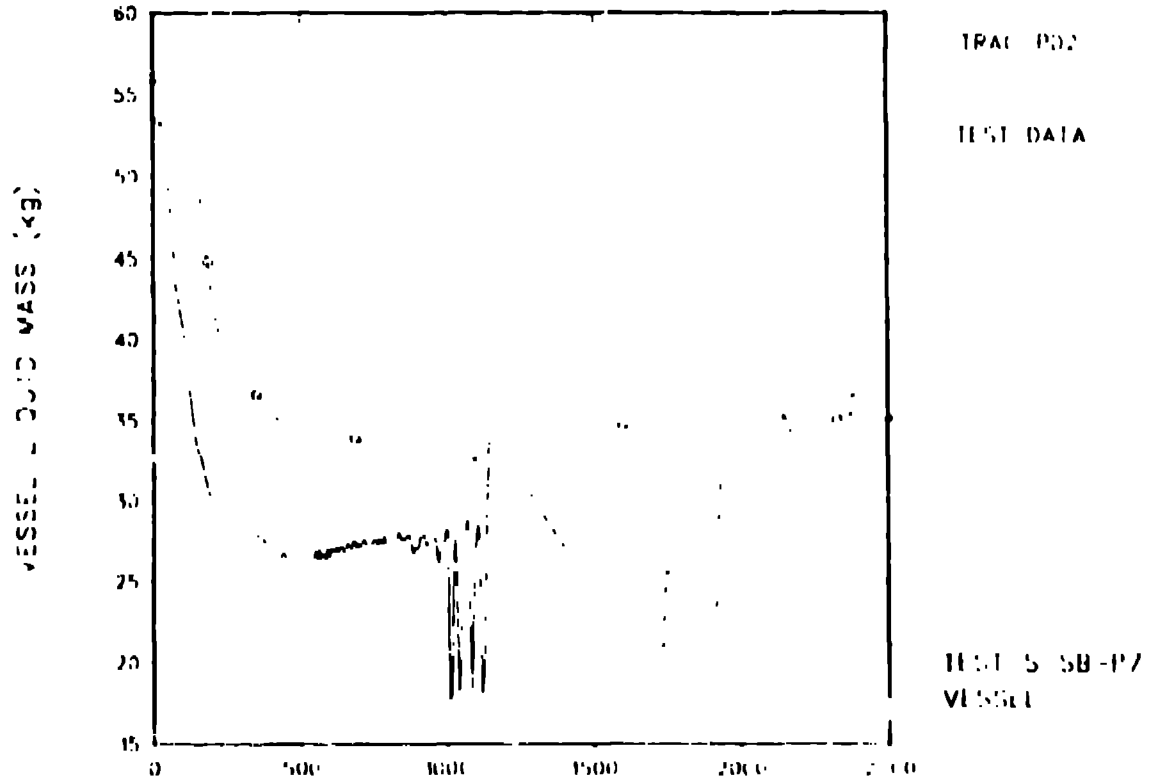

Fig. 7. Vessel liquid masses for Test S-SB-P7.

the downcomer. This depletion of vessel liquid resulted in calculated core uncovery at 1300 s with a distinct core dryout down to the center of core. The oscillations in the predicted vessel mass beyond this time were again caused by repeated core quenches. These calculated quenches were not instantaneous but rather were systematic and took place over several hundred time steps. The appearance of instantaneous increases in the vessel mass in Fig. 7 results from the compressed time scale.

Experimental and calculated cladding temperatures near the top of the core are compared in Fig. 8. At the bottom, no core dryout was observed nor calculated. The core dryout was calculated down to the center of the core, but no such observation was made in the experiment.

B. Hot-Leg-Break Tests (Tests S-SB P3 and S-SB-P4)

1. Test S-SB-P3 (Early Pump Trip)

The calculated and measured upper-plenum pressure histories are presented in Fig. 9. During the first 600 s of the transient, the calculated and measured values were close. Beyond 600 s the calculated pressure was higher than the

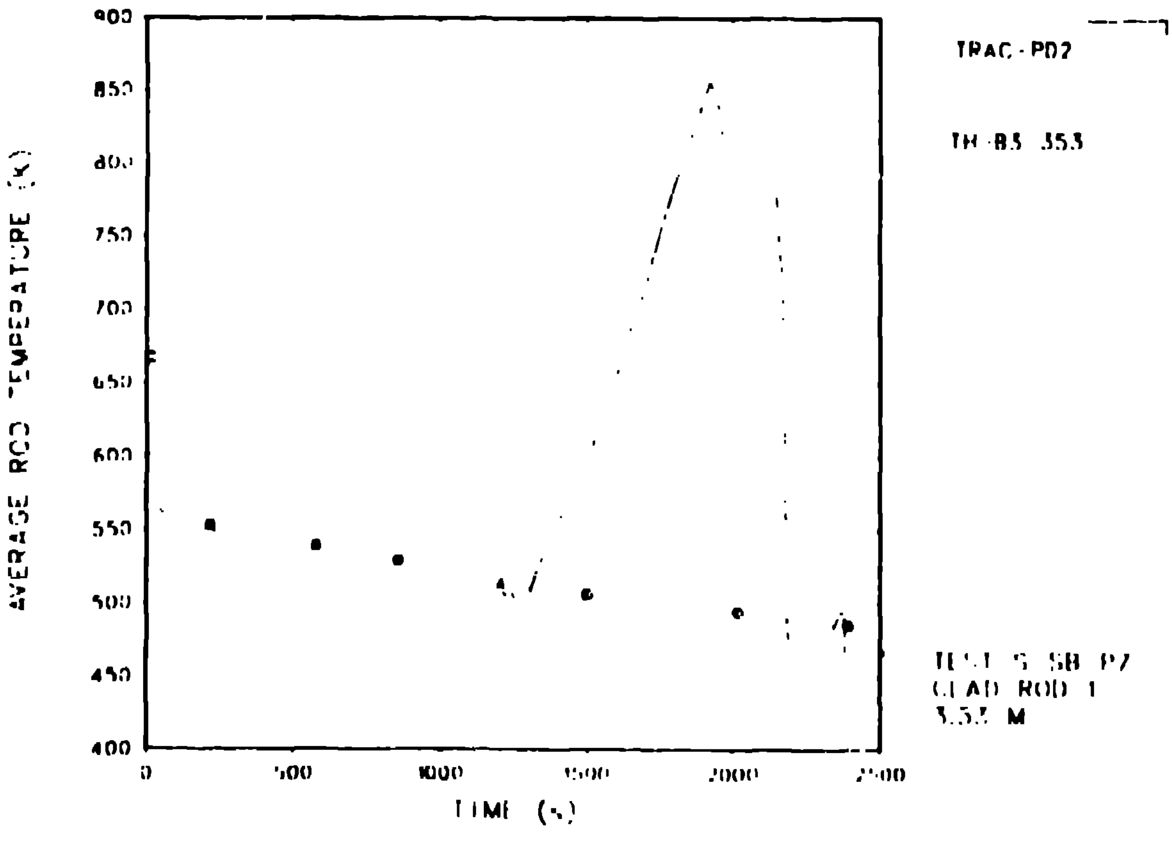

Fig. 8. Clad temperatures at 3.53-m elevation for Test S-SB-P7.

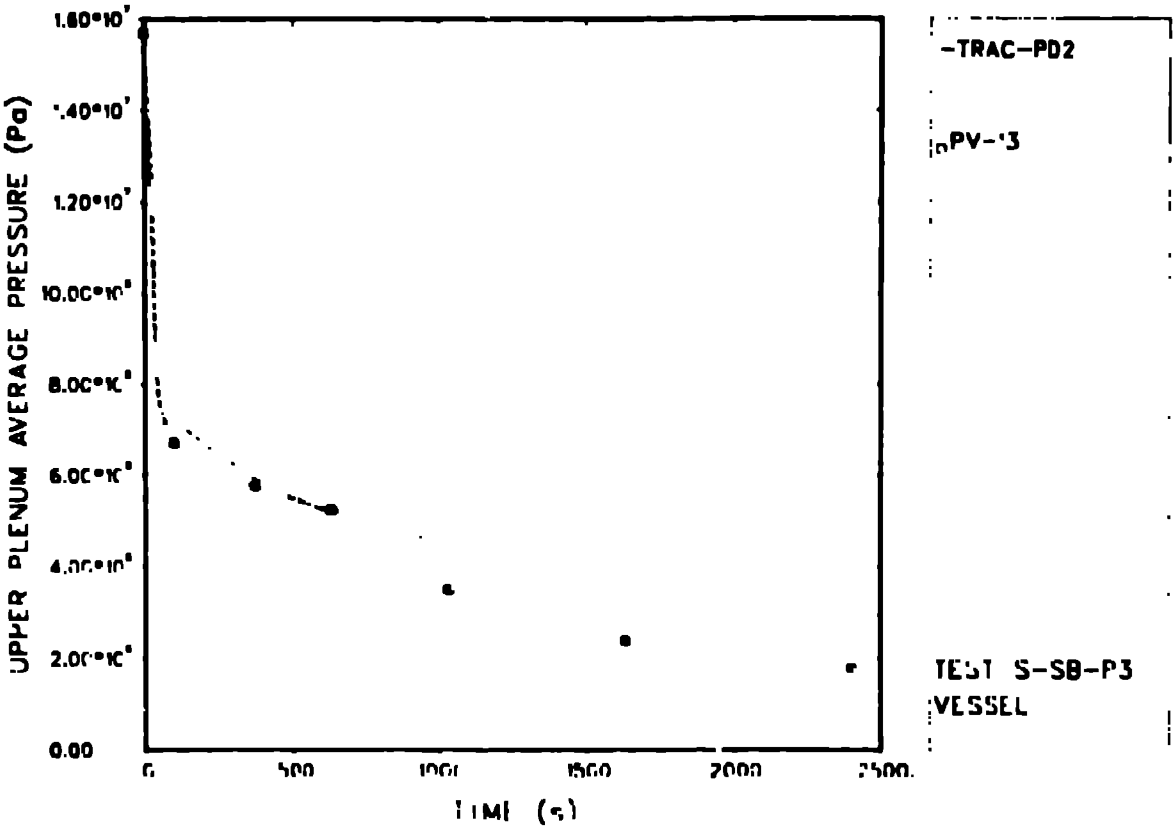

Fig. 9. Upper-plenum pressures for Test S-SB-P3.

measured pressure and the deviation between the calculated and measured pressures increased with time. Reference 7 reports that the sharp change in the measured depressurization rate near 600 s resulted from the mixture level in the broken-loop hot leg dropping below the orifice. A Storz lens recorded a well-defined liquid level and stratified flow. The FRIC value used in the TRAC model to simulate the frictional and form losses through the break orifice was not representative of the stratified flow. At test termination the measured total coolant mass lost through the break was 162 kg as compared to a calculated value of 114 kg. The measured system pressure at the end of the transient was 1.7 MPa as compared to a calculated pressure of 2.93 MPa.

At test termination the TRAC calculation indicated that 73% of the intact-loop initial mass inventory was retained as well as 56% of the broken-loop mass inventory. The upper plenum retained ~35% of its initial mass inventory throughout the test and, thus, the core did not uncover. Both the intact- and broken-loop pump suction legs (components 3 and 23) remained full of liquid throughout the test. The calculated and measured (INEL calculated from data) vessel mass inventories (including both the test vessel and external downcomer tube) are presented in Fig. 10. The final vessel inventory predicted by TRAC was 13% higher than the test value.

As previously discussed, the core did not uncover during Test S-SB-P3. The liquid-vapor mixture level in the test vessel remained above the top of the heated length of the core throughout the experiment. Adequate cooling of the

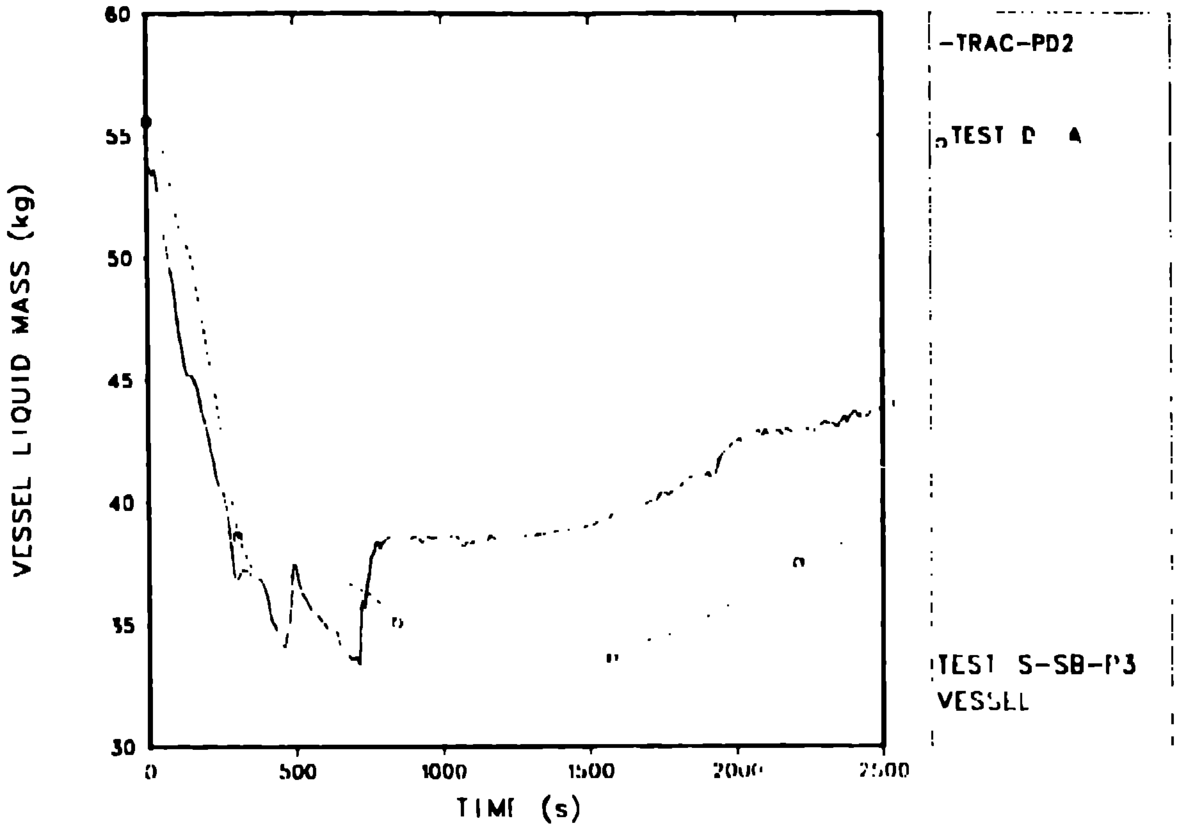

Fig. 10. Vessel liquid masses for Test S-SB-P3.

core heater rods was provided and the rod cladding temperatures followed slightly above the system saturation temperature. The comparison of calculated and measured cladding temperature was good for the first 600 s, after which the calculated system pressure (and, therefore, the saturation temperature) deviated from the test as previously discussed.

2. Test S-SB-P4 (No Pump Trip)

The calculated and measured upper-plenum pressure histories are presented in Fig. 11. During the first 550 s of the transient, the calculated and measured values are close. As in Test S-SB-P3, the measured depressurization rate increased beginning at 600 s. The change in depressurization rate again was attributed to changing from a relatively homogeneous two-phase mixture at the break to a steam environment due to stratification (Ref. 7). The TRAC calculations for Tests S-SB-P3 and S-SB-P4 did not include this phenomenon. During pumps-on Test S-SB-P4, the performance of the primary system pumps degraded because of voids at the pump inlet. In the experiment, the mass flow was negligible after 400 s in the intact loop and 900 s in the broken loop. The inadvertent trip of the intact-loop pump at 550 s in the transient, therefore, had no discernible impact on the test results. The predicted pump performance did not degrade in the same manner as in the test. For example, the effects of the inadvertent trip of the intact-loop pump beginning at 550 s are evident in the TRAC results (see Fig. 11).

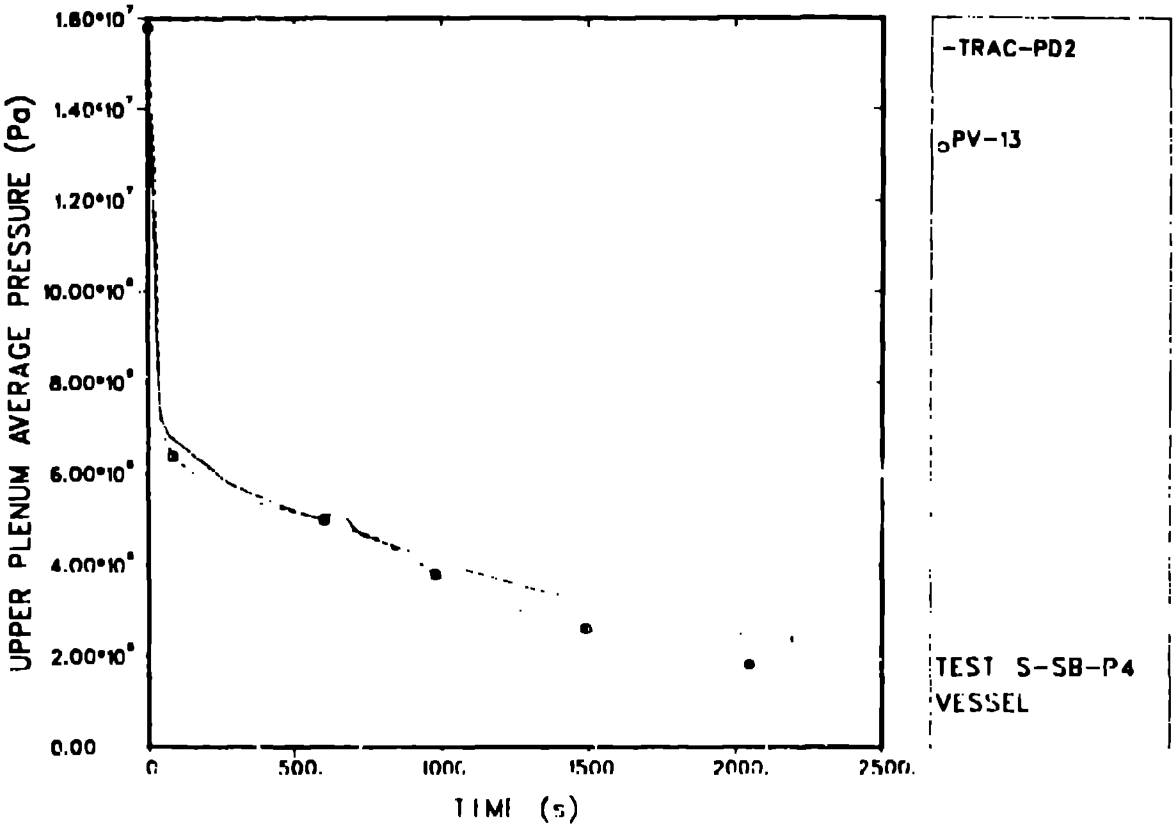

Fig. 11. Upper-plenum pressures for Test S-SB-P4.

TRAC predicts that the pumps-on operation maintains a two-phase fluid upstream of the break beginning at ~35 s after test initiation and continuing until test termination. This occurs because the predicted pump performance does not degrade to the same degree as the actual pumps. As a consequence of the higher density predicted at the break, the calculated total coolant mass lost through the break was significantly higher for Test S-SB-P4 than for Test S-SB-P3. At test termination the calculated total coolant mass lost through the break was 162 kg, whereas the measured mass for Test S-SB-P4 was 176 kg. The increase in the predicted mass flow through the break resulted in a lower system pressure for Test S-SB-P4 than for Test S-SB-P3. At test termination the calculated system pressure was 2.32 MPa as compared to the measured system pressure of 1.64 MPa.

At test termination 36% of the intact-loop initial mass inventory and 20% of the broken-loop mass inventory were retained in the TRAC calculation. The upper plenum retained ~45% of its initial mass inventory. Both the intact- and broken-loop pump suction legs (components 3 and 23) lost a large fraction of their initial liquid inventory from continued operation of the pumps. The experimental and calculated vessel mass inventories (including both the test vessel and the external downcomer tube) are presented in Fig. 12. The oscillations in the calculated vessel mass near the end of the transient were caused by oscillations in the two-phase pump heads. Consequently, slugs of liquid were intermittently forced through the hot legs. The final vessel

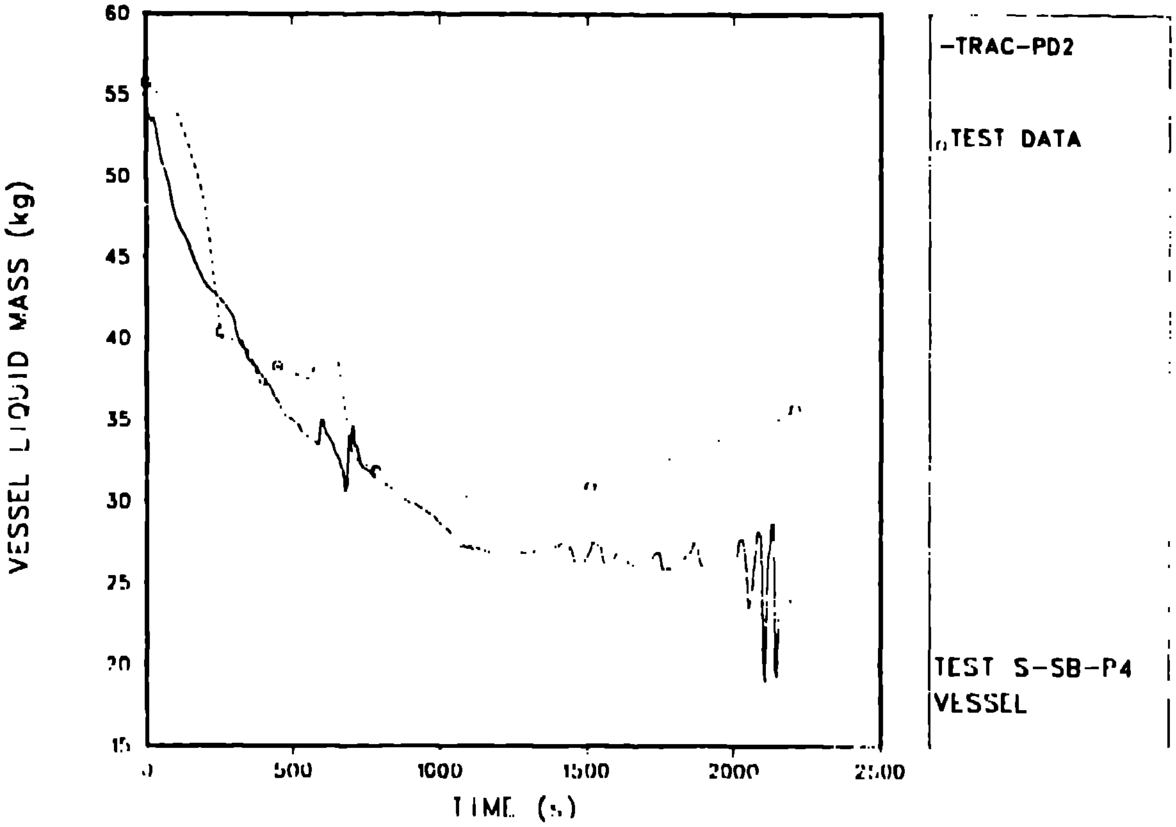

Fig. 12. Vessel liquid masses for Test S-SB-P4.

inventory predicted by TRAC was ~23% lower than the test value. The calculated vessel mass fell slightly below the critical value of 29 kg beyond 1000 s. However, no core dryout was calculated (or observed) as the mixture level remained above the top of the core because the pumps redistributed the liquid mass from the downcomer into the core and the presence of bubbles raised the mixture level. A comparison of the calculated results for Tests S-SB-P3 and S-SB-P4 indicates that a relatively greater fraction of the initial mass was lost from the broken loop and the vessel for Test S-SB-P4 because of continued pump operation.

As previously discussed, the core did not uncover during Test S-SB-P4. The mixture level in the test vessel remained above the top of the heated length of the core throughout the experiment. Adequate cooling of the core heater rods was provided and the rod cladding temperatures followed slightly above the system saturation temperature. Therefore the comparison of calculated and measured cladding temperatures is similar to that for the pressures.

Four areas where improvements and corrections may be introduced are (1) using improved pump performance curves in TRAC-PD2; (2) improving the models that characterize liquid and vapor separation in the vessel; (3) correcting errors in the steam-generator-secondary liquid level data (Refs. 1 and 2); and (4) adding a critical flow model to TRAC-PD2.

VII. CONCLUSIONS

TRAC-PD2 provides a reasonable small-break modeling capability for predicting slow-transient thermal-hydraulic phenomena and for determining the effects of pump operation on resulting system response. For the cold-leg-break and hot-leg-break tests, most comparisons between TRAC-PD2 results and experimental data generally predict correct trends. This conclusion is based on the primary system mass distribution, mass inventory, and void fraction distribution. The specific parameters compared are mass flow rate at the break, upper-plenum average pressure, vessel liquid mass, primary system mixture densities, and cladding temperatures at various elevations.

In the two hot-leg-break tests (S-SB-P3, pumps off; and S-SB-P4, pumps on), no core uncovery was observed nor calculated. For the two cold-leg-break tests (S-SB-P1, pumps off; and S-SB-P7, pumps on), core uncovery was observed for only the pumps-off test but was calculated for both pumps-off and pumps-on tests. This difference between observation and calculation for Test S-SB-P7 may occur because the available pump curves do not predict the correct two-phase behavior or because separation of the liquid and vapor phases in the upper vessel and resultant carryover of liquid into the loops is not accurately predicted. In the experiment the pump performance degraded more rapidly than in the calculation; thus, liquid remained in the vessel and prevented core uncovery rather than being distributed through the system by the pumps. A comparison of the two cold-leg-break tests (S-SB-P1 and S-SB-P7) with the two hot-leg-break tests (S-SB-P4 and S-SB-P3) determined that the cold-leg-break test with the early pump trip was most severe with respect to the vessel liquid mass inventory.

In conclusion, TRAC-PD2 can predict conservatively (in the sense of more severe consequences) the thermal-hydraulic phenomena resulting from a small-break LOCA.

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