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SIMULATION OF LOFT ANTICIPATED-TRANSIENT EXPERIMENTS L6-1, L6-2, AND L6-3 USING TRAC-PF1/MOD1*

by

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ABSTRACT

Anticipated-transient experiments L6-1, L6-2, and L6-3, performed at the Loss-of-Fluid Test (LOFT) facility, are analyzed using the latest released version of the Transient Reactor Analysis Code (TRAC-PF1/MOD1). The results are used to assess TRAC-PF1/MOD1 trip and control capabilities, and predictions of thermal-hydraulic phenomena during slow transients. Test L6-1 simulated a loss-of-steam load in a large pressurized-water reactor (PWR), and was initiated by closing the main steam-flow control valve (MSFCV) at its maximum rate, which reduced the heat removal from the secondary-coolant system and increased the primary-coolant system pressure that initiated a reactor scram. Test L6-2 simulated a loss-of-primary coolant flow in a large PWR, and was initiated by tripping the power to the primary-coolant pumps (PCPs) allowing the pumps to coast down. The reduced primary-coolant flow caused a reactor scram. Test L6-3 simulated an excessive-load increase incident in a large PWR, and was initiated by opening the MSFCV at its maximum rate, which increased the heat removal from the secondary-coolant system and decreased the primary-coolant system pressure that initiated a reactor scram. The TRAC calculations accurately predict most test events. The test data and the calculated results for most parameters of interest also agree well.

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I. INTRODUCTION

The latest released version of the Transient Reactor Analysis Code, TRAC-PF1/MOD1 (Ref. 1), is an advanced best-estimate systems code for analyzing postulated accidents, anticipated and operational transients, and balance-of-plant calculations in pressurized-water reactors (PWRs) and in a wide variety of thermal-hydraulic test facilities.

Several experiments have been conducted in the Loss-of-Fluid Test (LOFT) facility to investigate the thermal-hydraulic phenomena resulting from anticipated transients in non-loss-of-coolant accidents (non-LOCAs) in which a reactor scram may or may not occur. The LOFT initial conditions closely approximated those in a typical full-sized commercial PWR. The data from Tests L6-1, L6-2, and L6-3 (Ref. 2) are used to assess TRAC-PF1/MOD1 analytical capabilities.

Tests L6-1, L6-2, and L6-3 simulated loss-of-steam load, loss-of-forced coolant flow, and excessive-load increase, respectively, in a large PWR. Our assessment modeled a complicated system using at least one of every type of TRAC-PF1/MOD1 component modules except for a turbine, an accumulator, and a three-dimensional vessel. Many components were interconnected in series and/or parallel branches. Thus, the ability of TRAC-PF1/MOD1 to handle synergistic and systems effects in a complicated system during a slow anticipated transient was assessed. The ability to predict control actions for these transients was of specific interest.

II. LOFT SYSTEM DESCRIPTION

The LOFT facility is a 50-MW (thermal) PWR with instrumentation to measure and to provide data on the system thermal-hydraulic conditions. Its operation is typical of a large [~1000-MW (electric)] commercial PWR operation. The facility consists of a reactor vessel with a nuclear core; an intact loop with an active steam generator, pressurizer, and two primary-coolant pumps (PCPs) connected in parallel; a broken loop with simulated pump, simulated steam generator, and two quick-opening blowdown valve assemblies; a blowdown suppression system; and an emergency core-coolant (ECC) injection system that includes two low-pressure injection-system (LPIS) pumps, two high-pressure injection-system (HPIS) pumps, and two accumulators. Reference 3 contains additional details on the LOFT system.

III. TEST DESCRIPTION

Experiment L6-1 simulated a loss-of-steam load in a large PWR, and was initiated by closing the main steam-flow control valve (MSFCV) at its maximum rate (5% stem movement per second) from its initial steady-state open position. The pressurizer cycling heaters were turned on when the experiment began, but were turned off at 6.1 s because the primary pressure increased. The system pressure continued to increase because the secondary-side heat removal capability was impaired. The pressurizer spray was initiated at 9.1 s to reduce the primary-coolant system (PCS) pressure, and continued until 30.4 s. The PCS pressure continued to rise, initiating a reactor scram at 21.8 s. Immediately after the reactor scram, the primary system started to depressurize. The MSFCV automatically began to open at 22.2 s to reduce the steam-generator secondary-side pressure, and closed at 40.6 s. Low system pressure turned on the pressurizer backup heaters at 32.5 s. The MSFCV again opened and closed automatically at 91.2 s and 104.4 s, respectively, and manually was opened and closed starting at 312.6 s. The pressurizer backup heaters turned off at 415.4 s. The experiment was terminated at 700 s.

Experiment L6-2 simulated a loss-of-forced coolant flow in a large PWR. The experiment was initiated by tripping power to the PCPs, allowing the pumps to coast down. At 2.0 s after test initiation, low primary-coolant flow caused the plant protection system to initiate a reactor scram. The MSFCV started to close at 1.8 s, and was closed completely at 13.4 s. The pressurizer backup heaters turned on at 6.0 s to moderate the primary-side pressure decrease, and remained on until 97.2 s. Natural circulation was established at ~23 s, and, ~6 s later, the combined heat from the core and the pressurizer heaters exceeded the heat loss to the steam generator and to the environment. Therefore, the primary-system pressure began to recover. The system pressure and the pressurizer liquid level returned to their operating ranges before 200 s. The operators manually restarted the PCPs at 204.2 s to initiate plant recovery.

Experiment L6-3 simulated an excessive-load increase in a large PWR, and was initiated by opening the MSFCV at its maximum rate from its initial steady-state open position. The system pressure started to drop as the valve opened and the pressurizer backup heaters turned on at 10.2 s. The core power increased initially because of increased secondary-side heat removal, and reached a maximum 42.2 MW at 15.6 s when a low system-pressure signal caused a reactor scram. Immediately after the reactor scram, the MSFCV started to close because increased steam-generator secondary-side pressure was required. The primary-system pressure continued to decrease, and at 26.4 s the HPIS began to inject ECC into the cold leg, which helped to recover the system pressure. The core and pressurizer-heater energy exceeded the steam-generator heat transfer and ambient losses at ~33 s. The HPIS injection, the pressurizer backup heaters, and the pressurizer cycling heaters shut off at ~50 s, 105.4 s, and 154.9 s, respectively. The system pressure returned to its normal operating value before 200 s.

The blowdown suppression system was not used in these experiments. The broken loop was connected to the intact loop through 1-in. warmup lines to prevent broken-loop stagnation.

IV. TRAC MODEL

Figures 1, 2, and 3 show the TRAC model of the LOFT facility, the steam-generator secondary-side noding, and the one-dimensional vessel noding, respectively. Although TRAC-PF1/MOD1 can model a three-dimensional vessel, all vessel elements are modeled with one-dimensional components to assess their utility and to save computation time in a slow transient when the three-dimensional effects are insignificant. The input model consists of 39 components containing 144 cells and 48 junctions, and corresponds to the LOFT hardware configuration with the following exceptions.

1. The pressure-suppression system is not modeled because it was not used in the experiment.
2. The HPIS is represented by a FILL (component 17). The remaining ECC system is omitted from the TRAC model because the LOFT L-6 experiments had no accumulator or LPIS injection.

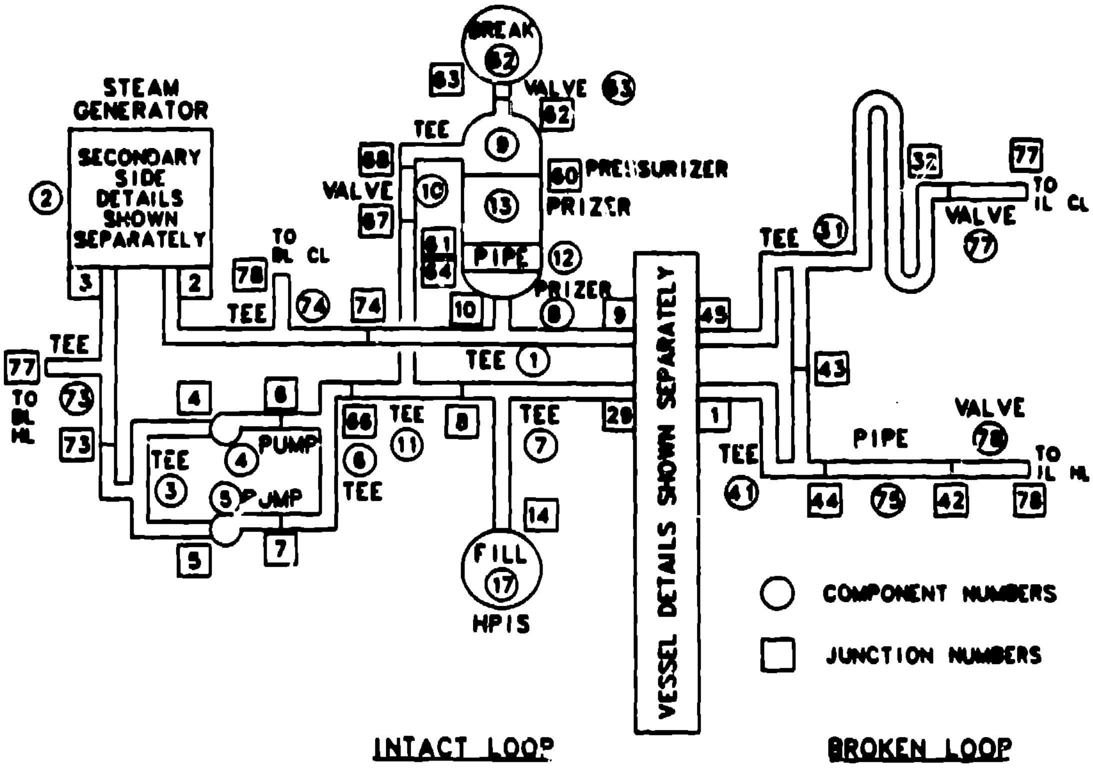

Fig. 1.
TRAC model of the LOFT facility.

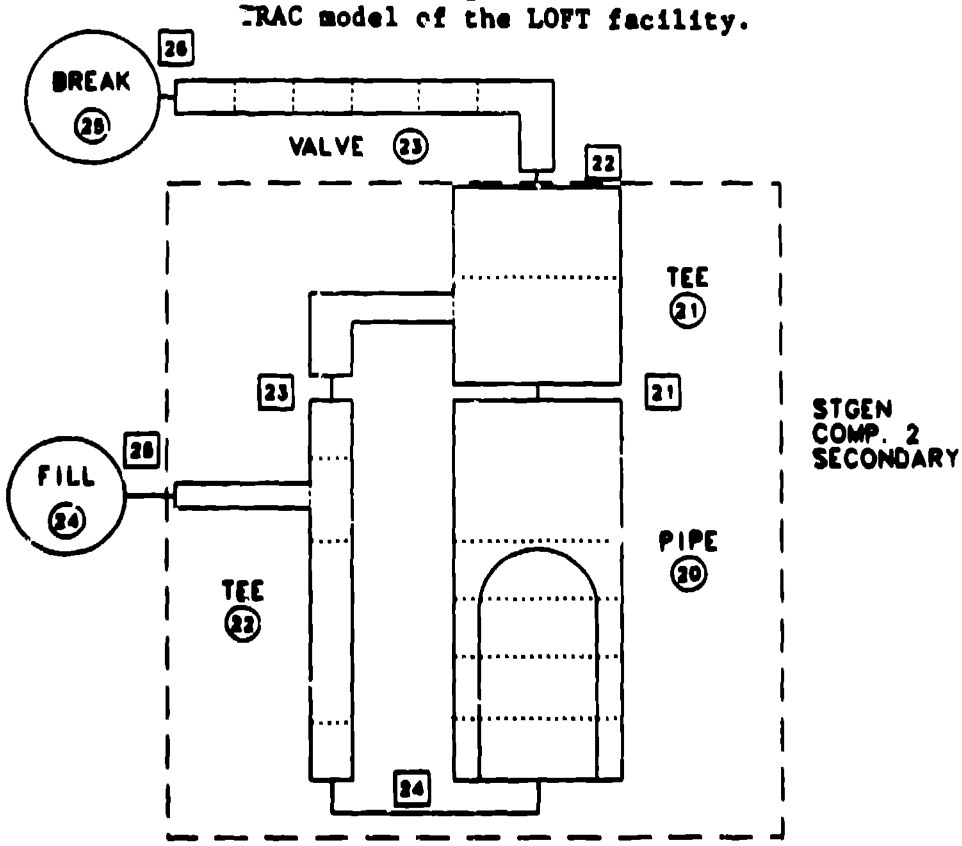

Fig. 2.
Steam-generator secondary-side noding for the LOFT facility.

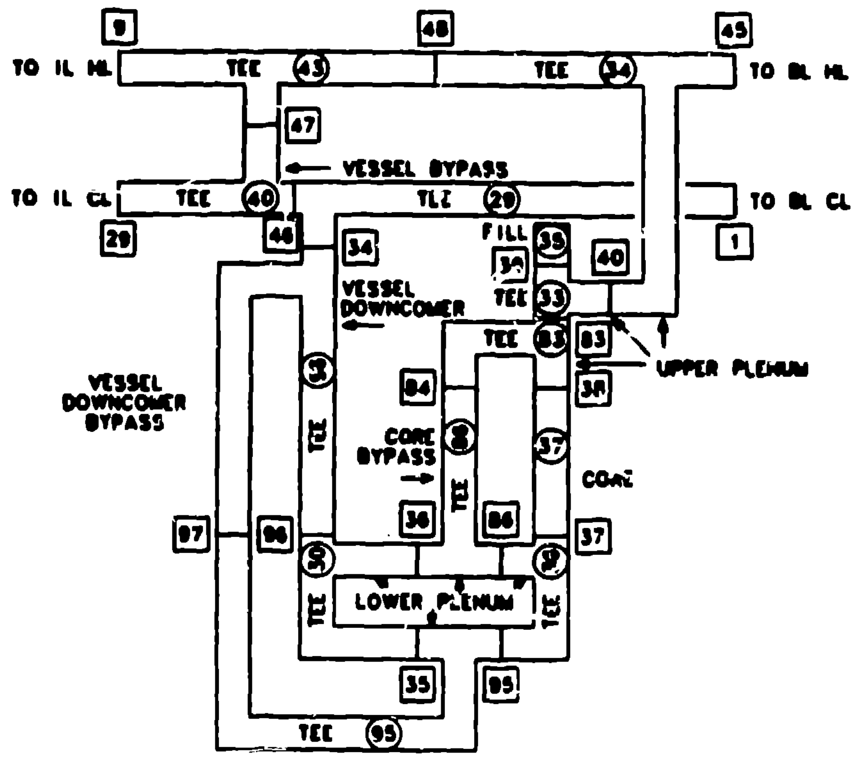

Fig. 3.
One-dimensional vessel noding for the LOFT facility.

Ollikkala[4] reported the following LOFT structural heat losses: a 6-kW heat loss from the pressurizer, a 10-kW heat loss from the steam-generator secondary side, and a 174-kW heat loss from the primary system (excluding the pressurizer). These heat losses are incorporated in the TRAC model. Based on our assumption that the surrounding air temperature was 305 K, we calculated average film coefficients based on outside surface areas of the pressurizer, the steam-generator secondary side, and the primary system.

The reactor power is modeled using point kinetics with reactivity feedback. The delayed-neutron and decay-heat concentrations were determined from the steady-state core-power histories for the three experiments. All automatic-control components, such as the feedwater-valve and MSFCV controllers, pressurizer heaters, and spray controllers, are modeled using the extensive TRAC-PF1/MOD1 trip and control logic. Twenty-four signal variables, 21 trips, and 29 control blocks are required to model the entire LOFT control system. Table I lists the trip set points needed to model the controls. These

TABLE I

MAJOR TRIP SET POINTS

Parameter	Set Point
System low-pressure scram (MPa)	14.36
System high-pressure scram (MPa)	15.77
Intact-loop hot-leg high-temperature scram (K)	583.3
Low primary-coolant mass-flow scram (kg/s)	433.5
High core-averaged power scram (MW)	51.5
Steam-generator secondary-side low liquid-level scram (m)	2.0
Power-operated relief-valve opening (MPa)	16.70
Power-operated relief-valve closing (MPa)	16.56
Pressurizer spray turned on (MPa)	15.24
Pressurizer spray turned off (MPa)	14.90
Pressurizer cycling heaters turned on (MPa)	14.75
Pressurizer cycling heaters off (MPa)	14.93, 14.90, 14.94[a]
Pressurizer backup heaters turned on (MPa)	14.62, 14.61, 14.55[a]
Pressurizer backup heaters turned off (MPa)	14.80, 14.75, 14.77[a]
HPIS turned on (MPa)	13.297
HPIS turned off (MPa)	15.500
MSFCV opening before reactor scram (MPa)	5.425, 5.495, 5.395[a]
MSFCV closing before reactor scram (MPa)	5.315, 5.385, 5.285[a]
MSFCV opening after reactor scram	
between 0 and 75 s (MPa)	6.9900
between 75 and 200 s (MPa)	6.9764
between 200 s and end of transient (MPa)	6.9464
MSFCV closing after reactor scram	
between 0 and 75 s (MPa)	6.7500
between 75 and 200 s (MPa)	6.6500
between 200 s and end of transient (MPa)	6.6000

[a] These values are for Tests L6-1, L6-2, L6-3, respectively. Different set-point values based on the test data were required.

set points were obtained from the best-estimate prediction,[5] the quick-look report,[6] the test data report,[2] and the posttest analysis report.[7] Some discrepancies in the set points listed in these sources were resolved by determining the actual test conditions when the events occurred from the test data report.[2]

V. RESULTS

A. Test L6-1 (Loss-of-Steam Load)

Table II lists the initial conditions and specified test parameters for the three tests. The TRAC steady-state calculation closely approximates the actual test conditions. Table III lists the main events during the transient for the test and the calculation. The measured and calculated times agree well except for the pressurizer-heater operation because there are minor differences between the measured and the calculated system pressures.

The TRAC calculation was terminated at 700 s. Because most events of interest occurred during the early part of the transient, most of the comparisons cover the first 250 s of the transient to maintain clarity in the figures. All the calculated parameters compared with the test data remained consistently within the measurement uncertainty in the 250-700-s time span.

Figure 4 compares the calculated and the measured core powers. Because the calculated reactor scram occurred 2.7 s before that observed in the experiment (Table III), the calculated power decay occurs earlier than the measured decay. The power, though considerably within the data uncertainty, is slightly overpredicted after the reactor scram because the test curve lies within the dead-band range of the detector. Therefore, the actual discrepancy, if any, may be much smaller than that shown in Fig. 4.

Figure 5 compares the TRAC-calculated and the measured pressurizer pressures. The calculation is consistently within the measurement uncertainty. At ~10 s, the pressurizer spray temporarily reduces the primary-side pressure. This reduction is predicted by the calculation. The reactor scram also is calculated at approximately the correct time (~20 s). Both the calculation and the experiment show that the reduced pressure turns off the pressurizer spray at ~30 s and that ~3 s later the pressurizer heaters turn on. The pressure drop near 100 s corresponds to the MSFCV opening, which was caused by the high

TABLE II

INITIAL CONDITIONS

Parameter	Test L6-1 Actual	Test L6-1 Calculated	Test L6-2 Actual	Test L6-2 Calculated	Test L6-3 Actual	Test L6-3 Calculated
Core power (MW)	36.9	36.9[a]	37.2	37.2[a]	36.9	36.9[a]
Pressurizer pressure (MPa)	14.78	14.78[a]	14.78	14.78[a]	14.87	14.87[a]
Pressurizer liquid volume (m^3)	0.63	0.63[a]	0.65	0.65[a]	0.64	0.64[a]
Primary-coolant mass flow (kg/s)	478.5	478.5	465.9	465.7	479.3	479.0
Intact-loop cold-leg temperature (K)	552.8	552.8	553.5	553.3	552.6	552.2
Intact-loop hot-leg temperature (K)	567.5	567.6	568.5	568.3	567.3	566.8
Pump speed (rad/s)	334	344[b]	325	335[b]	334	344[b]
Steam-generator secondary-side pressure (MPa)	5.37	5.39[c]	5.44	5.45[c]	5.34	5.39[c]
Steam-generator secondary-side liquid level (m)	3.183	3.135[d]	3.139	3.136[d]	3.120	3.134[d]
Steam-generator secondary-side mass flow (kg/s)	20.1	19.2	20.1	17.8	20.7	17.7

[a] Specified as input parameter.

[b] Controlled to maintain the desired primary-coolant mass flow during the steady-state calculation.

[c] Controlled within maximum and minimum values of 5.425 MPa and 5.315 MPa for Test L6-1, 5.495 MPa and 5.385 MPa for Test L6-2, and 5.395 MPa and 5.285 MPa for Test L6-3. (See Table I.)

[d] Controlled as specified according to the expression, liquid level = 2.9464 + 0.00508 times the core power in MW, which gives desired liquid levels of 3.134 m for Test L6-1, 3.135 m for Test L6-2, and 3.134 m for Test L6-3, respectively. However, the actual liquid level for Test L6-1 did not meet specifications.

TABLE III

TEST L6-1 SEQUENCE OF EVENTS

Event	Test Time (s)	Calculated Time (s)
MSFCV started to close	2.0[a]	2.0
Pressurizer cycling heaters turned off	6.1	8.1
Pressurizer spray turned on	9.1	10.7
Reactor scrammed	21.8	19.1
MSFCV started to open	22.2	22.1
Pressurizer spray turned off	30.4	32.7
Pressurizer cycling heaters turned on	31.4	34.4
Pressurizer backup heaters turned on	32.5	36.1
MSFCV started to close	33.2[b]	33.5
MSFCV started to open	91.2	94.0
MSFCV started to close	99.2[b]	100.7
Pressurizer backup heaters turned off	--[c]	288.4
MSFCV started to open	312.6	314.4
MSFCV started to close	333.2[b,d]	321.6
Pressurizer backup heaters turned on	--[c]	328.0
Pressurizer backup heaters turned off	415.4	399.8
Pressurizer cycling heaters turned off	--[c]	475.8
Transient terminated	700.0	700.8

[a]Reference 2 reports that the valve closing was initiated at 0.0 s. However, the data show an ~2-s time delay before any movement in the valve position was observed.

[b]Reference 2 reports only the times when the valve was fully closed. The times when the valve started to close were estimated from the times when the valve was fully closed, the valve-stem position when the valve was open, and the valve-stem movement rate.

[c]Not observed in the experiment.

[d]Questionable because the valve would discharge several times the mass of steam actually observed in the experiment and would reduce the secondary-side pressure drastically if it had been open for such a long time span.

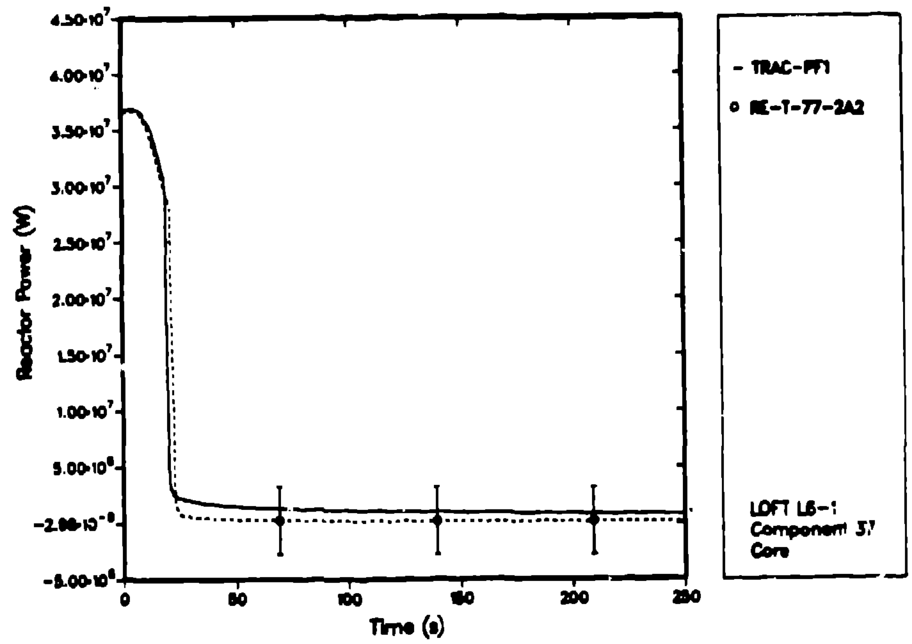

Fig. 4.
Comparison of the TRAC-calculated and the measured core powers for Test L6-1.

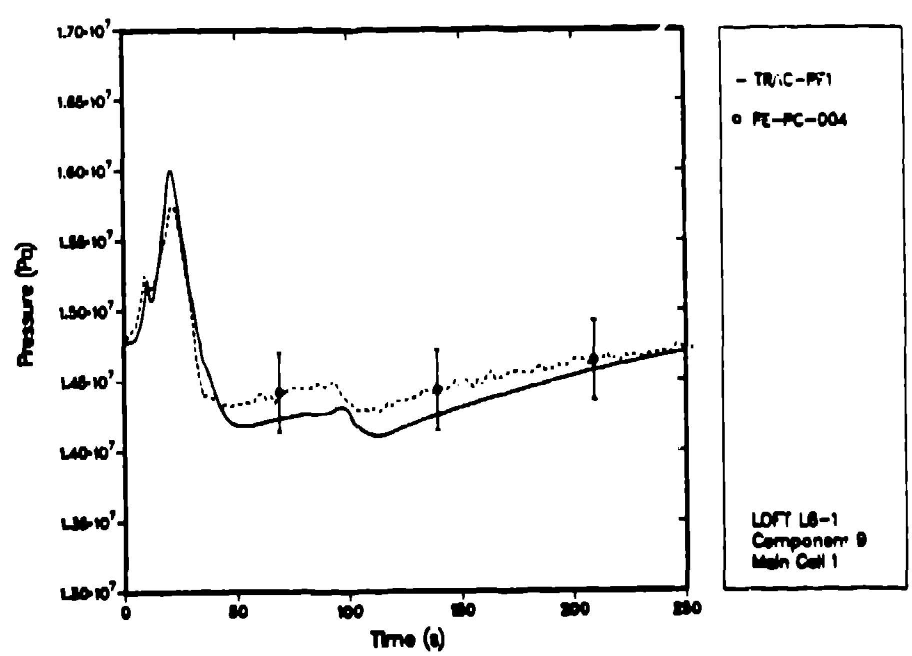

Fig. 5.
Comparison of the TRAC-calculated and the measured pressurizer pressures for Test L6-1.

secondary-side pressure. TRAC correctly and accurately predicts all events. A slightly higher rate of repressurization in the calculation between 100 and 250 s probably was caused by a slightly smaller pressurizer-vapor volume in the calculation. This discrepancy was resolved entirely in a sensitivity run in which we reduced the initial pressurizer liquid level (and, hence, increased the steam volume) significantly within the measurement uncertainty. Figure 6 shows a long-term comparison of the calculated and the measured system pressures that highlights the excellent system-pressure calculation for the entire transient. The pressure drop near 300 s corresponds to the third MSFCV opening, and a small blip in the calculated pressure near 500 s occurred because the pressurizer cycling heaters turned off.

Figure 7 compares the TRAC-calculated and the measured secondary-side pressures. Figures 8 and 9 compare the MSFCV mass flows and the pressurizer liquid-level histories, respectively. The calculations are consistently and significantly within the measurement uncertainty. The small discrepancy

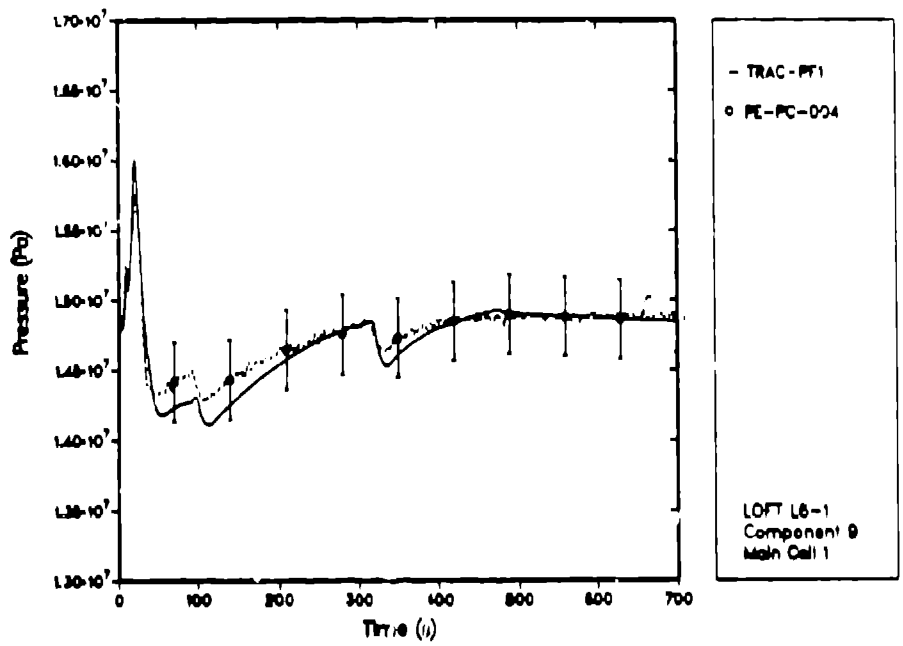

Fig. 6.
Long-term comparison of the TRAC-calculated and the measured pressurizer pressures for Test L6-1.

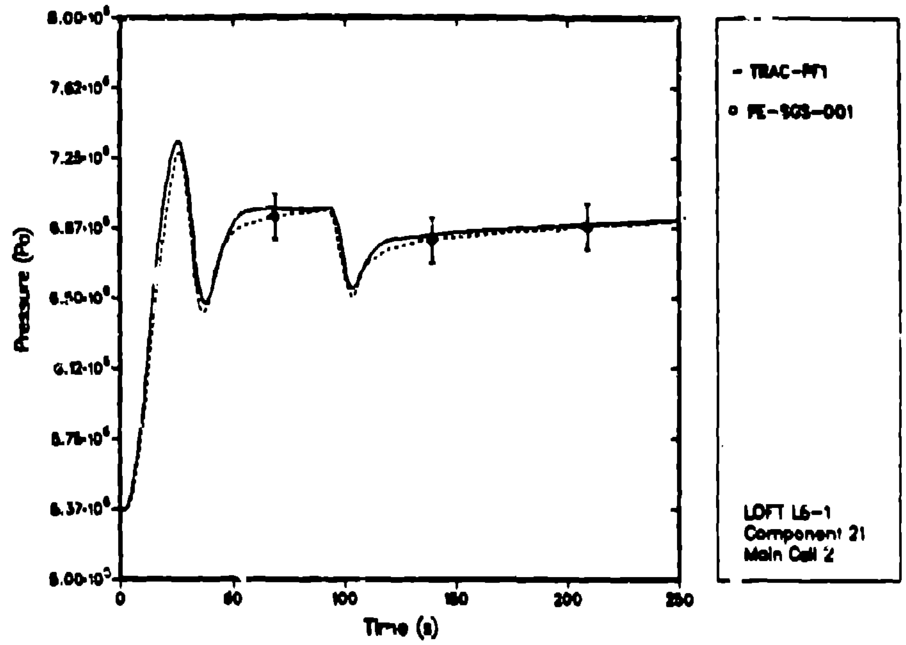

Fig. 7.
Comparison of the TRAC-calculated and the measured secondary-side pressures for Test L6-1.

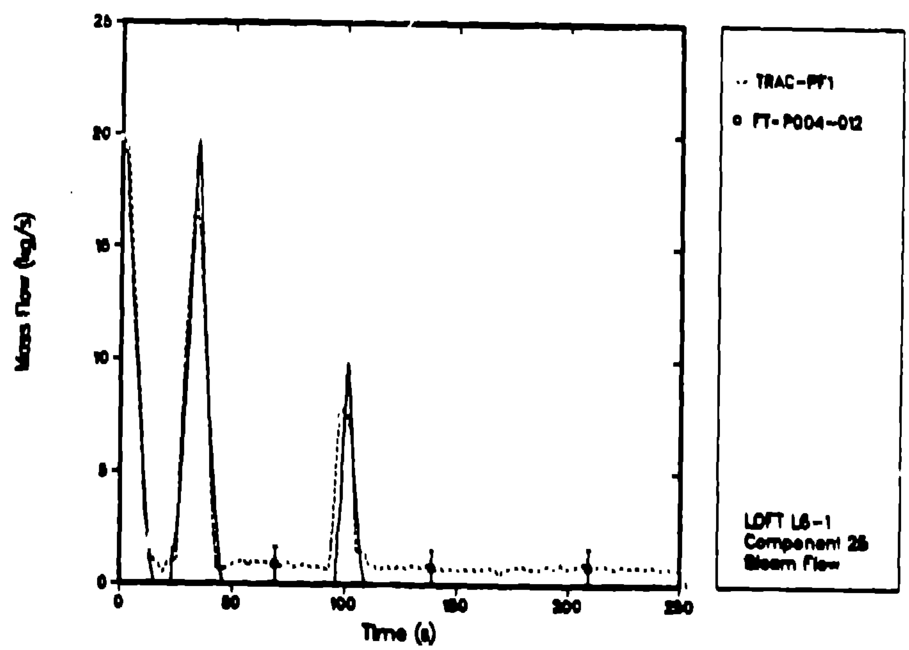

Fig. 8.
Comparison of the TRAC-calculated and the measured steam-generator secondary-side steam mass flows for Test L6-1.

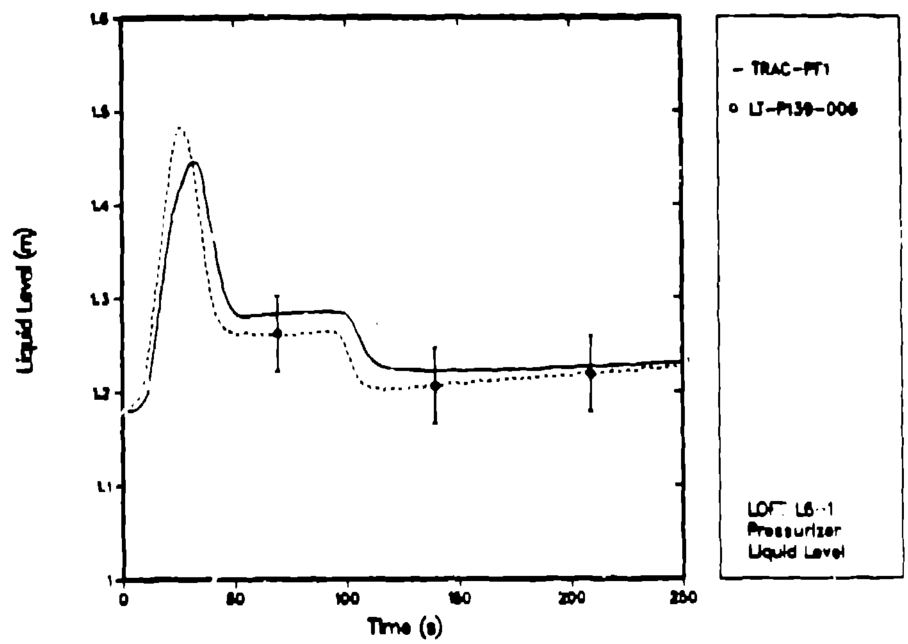

Fig. 9.
Comparison of the TRAC-calculated and the measured pressurizer liquid-level histories for Test L6-1.

between the measured and the calculated steam mass flows when the MSFCV is fully closed is caused by an unknown amount of leakage through the MSFCV. However, because the measured flow is within the dead-band range of the instrument, the actual discrepancy may be insignificant. We did not model any leakage through the MSFCV for Test L6-1.

The Cray-1 central-processor-unit (CPU) time required to simulate a 700-s system transient was 228 s at an average 0.78-s time step. Therefore, the TRAC Test L6-1 calculation ran over three times faster than real time.

B. Test L6-2 (Loss-of-Forced Coolant Flow)

The comparison of the TRAC-calculated and the actual initial conditions for Test L6-2 (Table II) shows good agreement. Table IV lists the main events during the transient for the test and the calculation. The code approximates the test conditions except for the pressurizer-heater operation because the system pressure is overpredicted; however, the calculation is within the data uncertainty. Because the initiation time for the MSFCV closing may be

TABLE IV

TEST L6-2 SEQUENCE OF EVENTS

Event	Test Time (s)	Calculated Time (s)
Pumps tripped	0.0	0.0
Reactor scrammed	2.0	3.2
MSFCV closing initiated	1.8[a]	4.5
Pressurizer cycling heaters turned on	--[b]	6.5
Pressurizer backup heaters turned on	6.0	10.2
Pressurizer backup heaters turned off	97.2	61.2
Pressurizer cycling heaters turned off	--[c]	92.3
Code calculation terminated	--	200.3[d]

[a]Questionable because the trip that initiates the MSFCV closing becomes active only after a reactor scram.

[b]Not reported in Ref. 2. However, the trip set points are such that the cyling heaters must turn on before the backup heaters and must turn off after the backup heaters.

[c]Observed much later in the experiment (414.9 s).

[d]The experiment ended at 700 s. However, because the PCPs were turned on and off manually between 200 and 700 s and because the primary events of interest occurred before 200 s, the TRAC calculation was terminated at 200 s.

incorrect (footnote a in Table IV), in the calculation we forced the MSFCV to start closing at 4.5 s to get the correct steam-generator secondary-side steam mass flow.

Figure 10 compares the measured and the calculated core powers. The agreement is good. Again, because the measurement is within the dead-band range of the detector, a discrepancy between the calculated and the measured core powers after the reactor scram may be much smaller than that shown in Fig. 10.

Figures 11 and 12, respectively, show the pressurizer and steam-generator secondary-side pressures. Although within the measurement uncertainty, the pressures are slightly overpredicted.

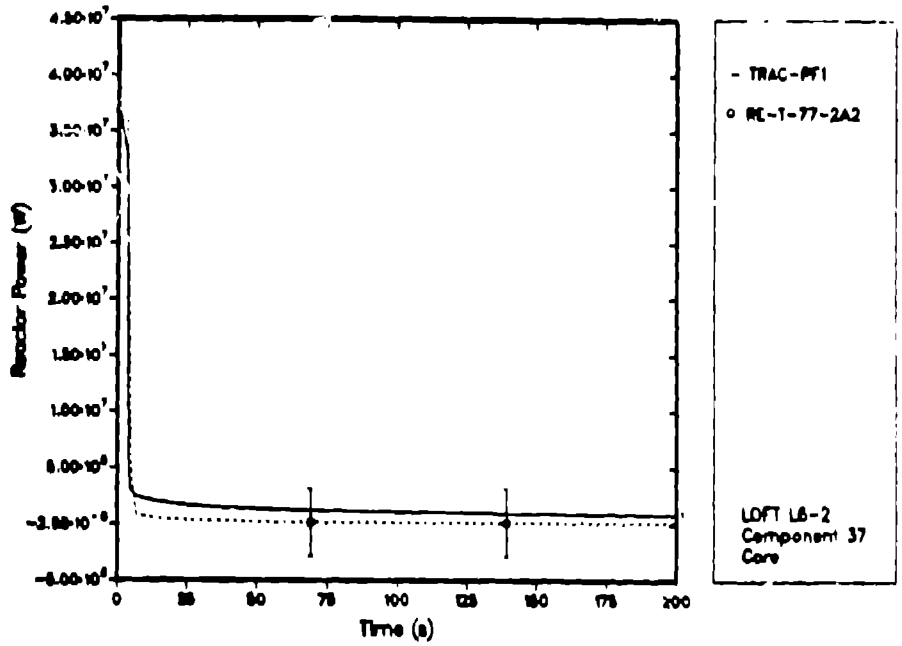

Fig. 10.
Comparison of the TRAC-calculated and the measured core powers for Test L6-2.

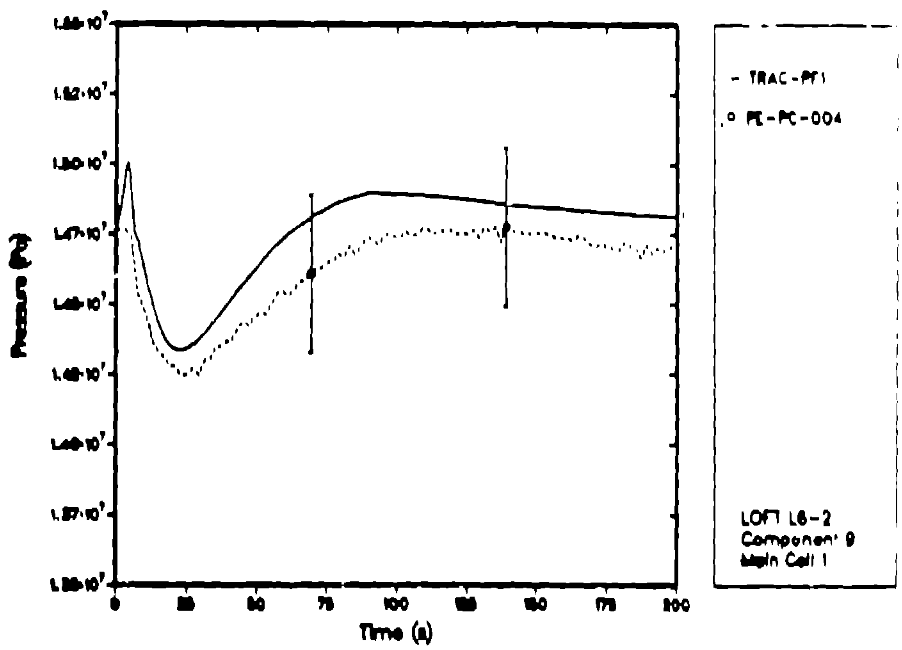

Fig. 11.
Comparison of the TRAC-calculated and the measured pressurizer pressures for Test L6-2.

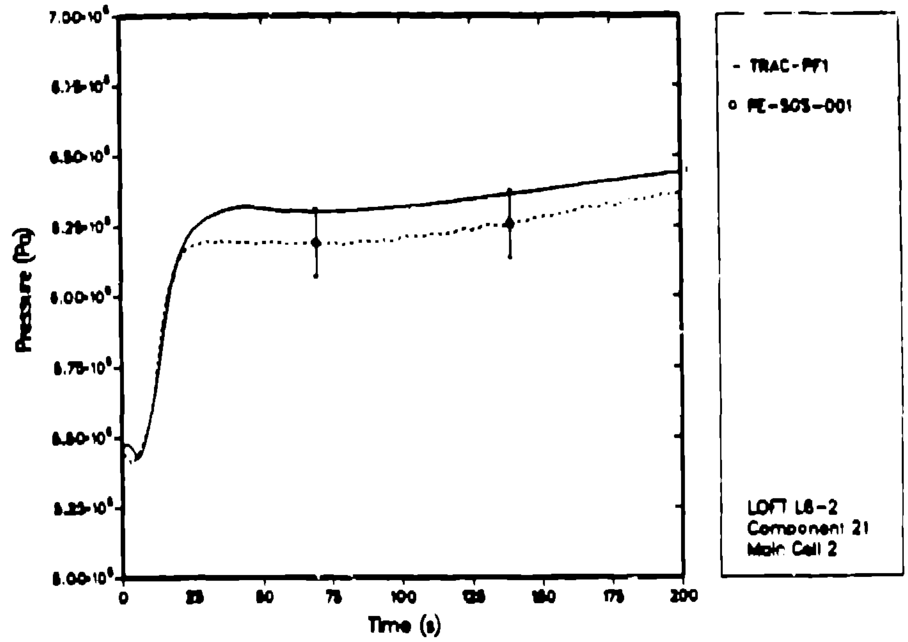

Fig. 12.
Comparison of the TRAC-calculated and the measured secondary-side pressures for Test L6-2.

Figure 13 compares the calculated and the measured intact-loop mass flows. The agreement is excellent. Figure 14 compares the test and the calculated steam-generator secondary-side steam mass flows. The underpredicted mass-flow at the start of the transient is coincidental because the MSFCV was closing at the end of the steady state. (The controller that operates the MSFCV maintains the secondary-side pressure within the specified limits. When the pressure falls below the lower limit, the valve starts to close and does not start to open until the upper set-point pressure limit is exceeded.) As mentioned in Sec. V.A, the discrepancy between the measured and the calculated mass flows after the valve is fully closed is caused by an unknown amount of leakage through the MSFCV.

Figure 15 shows the excellent agreement between the calculated and the measured pressuriser liquid levels.

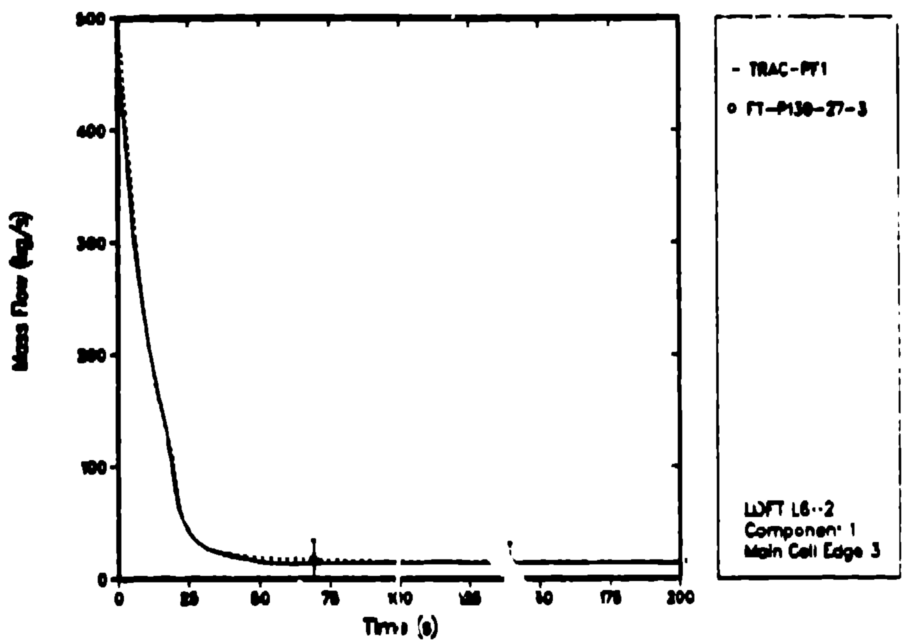

Fig. 13.
Comparison of the TRAC-calculated and the measured intact-loop mass flows for Test L6-2.

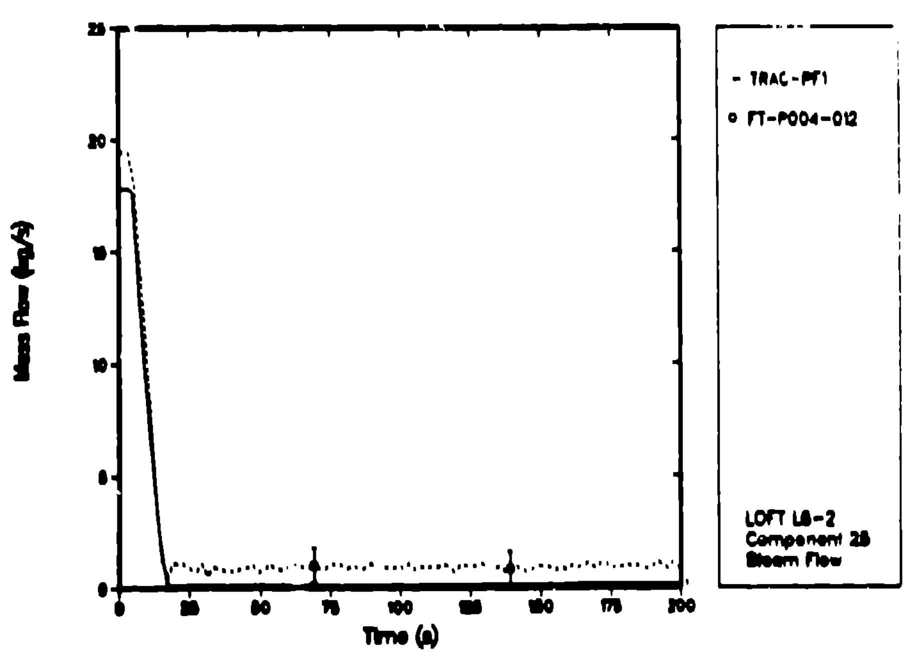

Fig. 14.
Comparison of the TRAC-calculated and the measured steam generator secondary steam mass flows for Test L6-2.

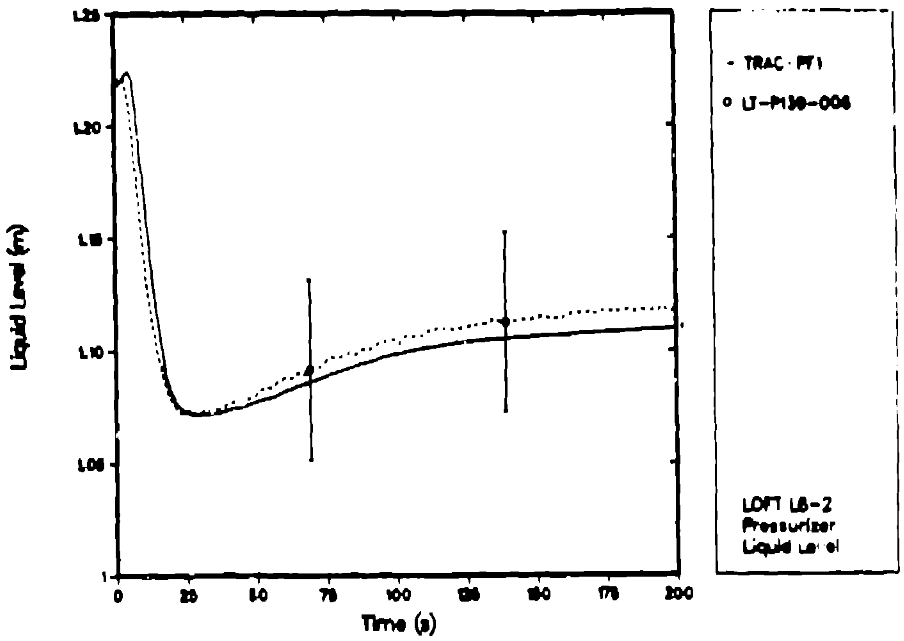

Fig. 15.
Comparison of the TRAC-calculated and the measured pressurizer liquid-level histories for Test L6-2.

The calculation took 110 s of CPU time on a Cray-1 computer to simulate a 200-s transient at an average 0.47-s time step at a speed 1.8 times faster than real time.

C. Test L6-3 (Excessive-Load Increase)

Table II shows that the TRAC steady-state calculation again closely approximates the initial conditions for Test L6-3. The code also calculates the main events (Table V) well except for the pressurizer-heater operation because of a discrepancy between the measured and the calculated system pressures near 50 s. Also, this pressure discrepancy causes the pressurizer spray to turn on momentarily. The spray is not observed in the experiment.

Figure 16 compares the calculated and the measured core powers. The agreement between the calculation and the data is excellent, with the increased core power predicted accurately. Again, the discrepancy between the calculation and the test data after the reactor scram may be exaggerated because the measurement is within the dead-band range of the detector.

TABLE V

TEST L6-3 SEQUENCE OF EVENTS

Event	Test Time (s)	Calculated Time (s)
MSFCV started to open	0.0[a]	0.0
Pressurizer cycling heaters turned on	--[a]	7.3
Pressurizer backup heaters turned on	10.2	11.9
Reactor scrammed	15.6	16.0
MSFCV started to close	17.8[b]	16.0
HPIS initiated	26.4	36.6
HPIS terminated	66.5[c]	76.7
Pressurizer backup heaters turned off	105.4	53.7
Pressurizer cycling heaters turned off	154.9	54.7
Pressurizer spray turned on	--[d]	57.7
Pressurizer spray turned off	--[d]	59.2
Code calculation terminated	--	500.0[e]

[a]Not reported in Ref. 2. However, the trip set points are such that the cycling heaters must come on before the backup heaters and must turn off after the backup heaters.

[b]The MSFCV should have started to close immediately after the reactor scram in response to the trip that controls the valve operation after the reactor scram.

[c]Reference 2 reports that the HPIS pumps were shut off ~50 s; however, the residual flow continued until 66.5 s.

[d]Not observed in the experiment.

[e]The experiment was completed at 700 s. However, between 500 and 700 s, the operators manually turned on and off the pressurizer heaters, sometimes in reverse order from that dictated by their trip set statuses. Because of this operator intervention, the automatic heater-control capability in the TRAC model could not be used beyond 500 s. Also, the primary events of interest occurred by 500 s. Therefore, the code calculation was terminated at 500 s.

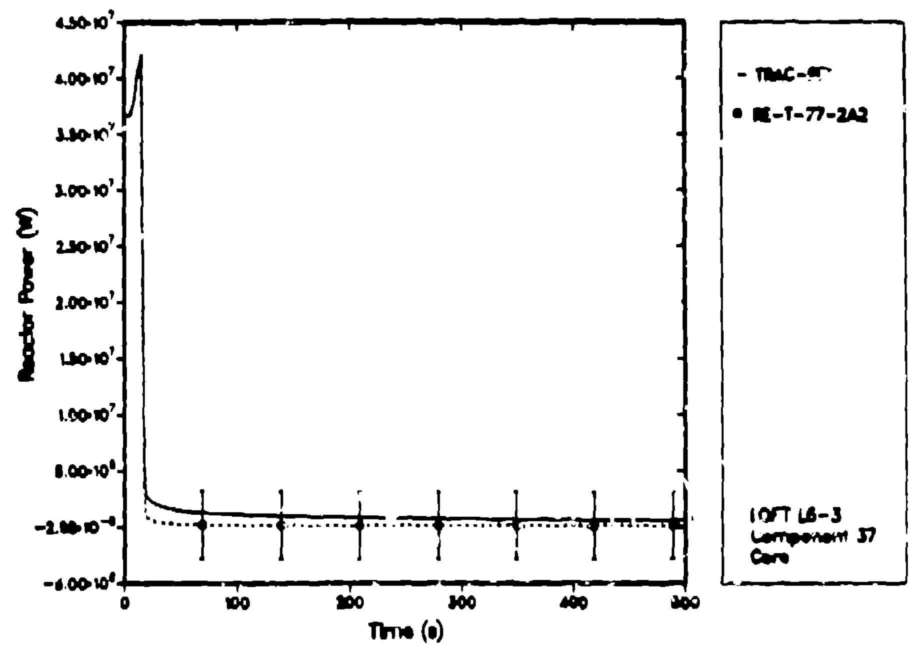

Fig. 16.
Comparison of the TRAC-calculated and the measured core powers for Test L6-3.

Figure 17 compares the TRAC-calculated and the measured pressurizer pressures. The calculation is within the uncertainty of the measurement except near 50 s when the calculation shows faster system repressurization rate due to HPIS injection compared to the data. A lower pressurizer vapor volume in the TRAC model, a higher HPIS flow in the TRAC model, or a lower condensation rate calculated by TRAC may have caused the faster repressurization. As a result of this rapid pressure increase in the calculation, the pressurizer spray comes on at 57.7 s momentarily in the calculation, which suddenly reduces the pressure, and near 70 s the calculation again falls back within the uncertainty of the measurement.

Figure 18 compares the steam-generator secondary-side pressures. The calculation generally is within the measurement uncertainty. However, a lower repressurization rate in the calculation after ~70 s points to the lower primary-to-secondary heat transfer.

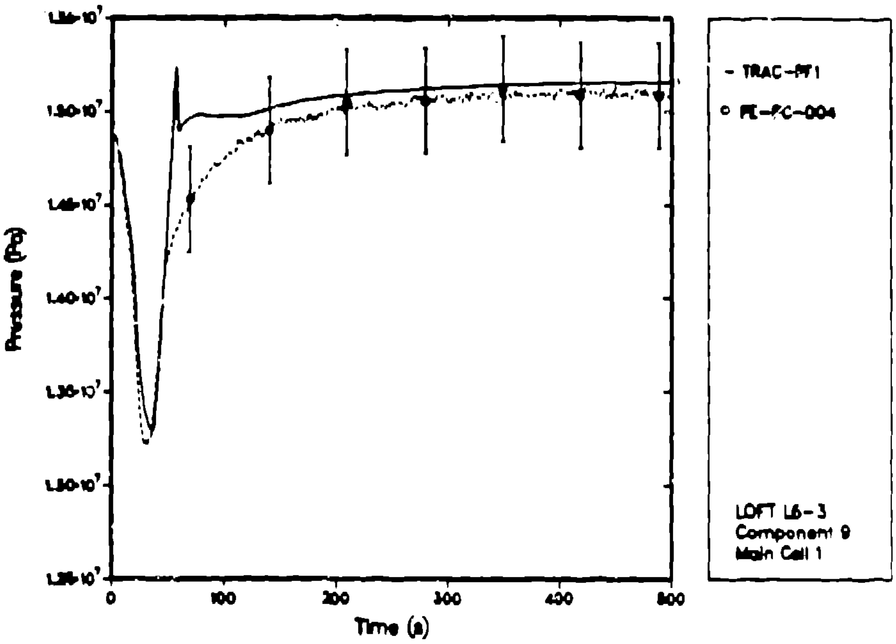

Fig. 17.
Comparison of the TRAC-calculated and the measured pressurizer pressures for Test L6-3.

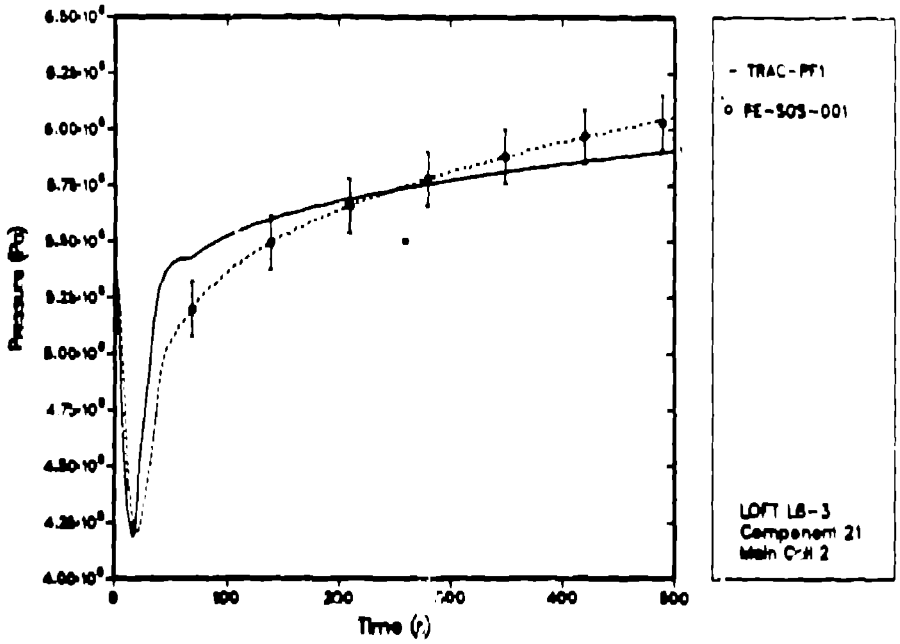

Fig. 18.
Comparison of the TRAC-calculated and the measured secondary-side pressures for Test L6-3.

Figures 19 and 20 compare the TRAC-calculated and the measured steam-generator secondary-side feedwater and steam mass flows, respectively. Both the feedwater and the steam-flow controller operations in the TRAC model function satisfactorily. The quantitative agreement also is excellent, and the calculation is significantly within the data uncertainty except for the steam mass flow after the MSFCV is fully closed because of an unknown amount of leakage through the valve.

Figure 21 compares the TRAC-calculated and the measured pressurizer liquid-level histories. The agreement between the calculation and the data is good until 70 s, when the two curves diverge. However, the maximum discrepancy is only about twice the magnitude of the data uncertainty. This slower filling of the pressurizer in the calculation again may have been caused by a slightly lower condensation rate in the pressurizer during an insurge, or by a slightly lower pressurizer vapor-volume in the TRAC model compared to the data.

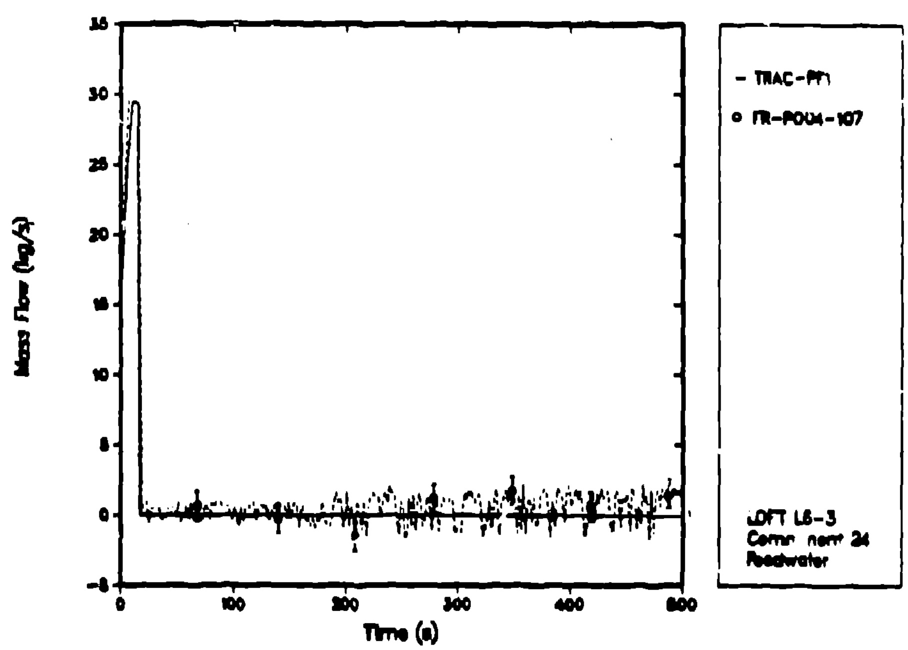

Fig. 19.
Comparison of the TRAC-calculated and the measured steam-generator secondary-side feedwater mass flows for Test L6-3.

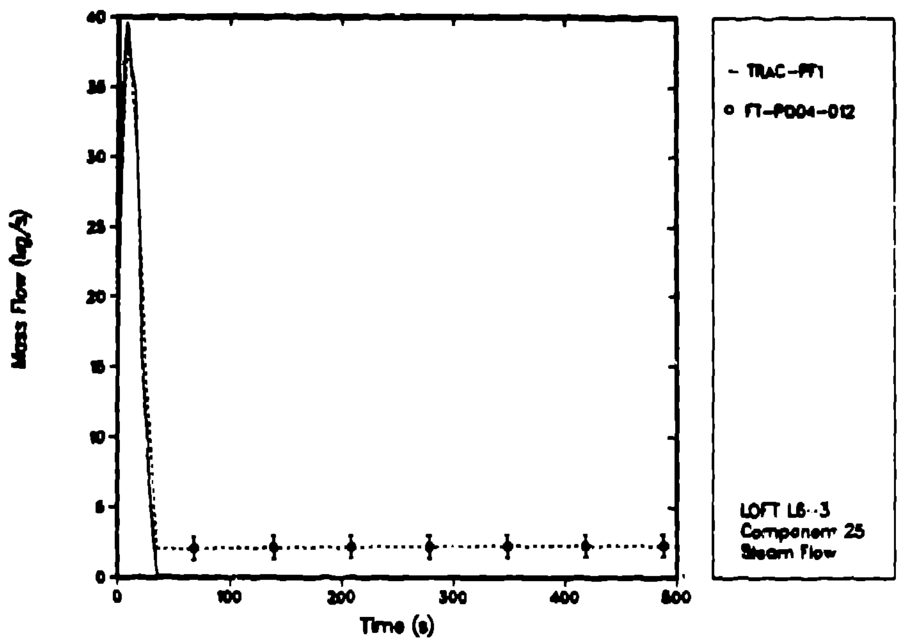

Fig. 20.
Comparison of the TRAC-calculated and the measured steam-generator secondary-side steam mass flows for Test L6-3.

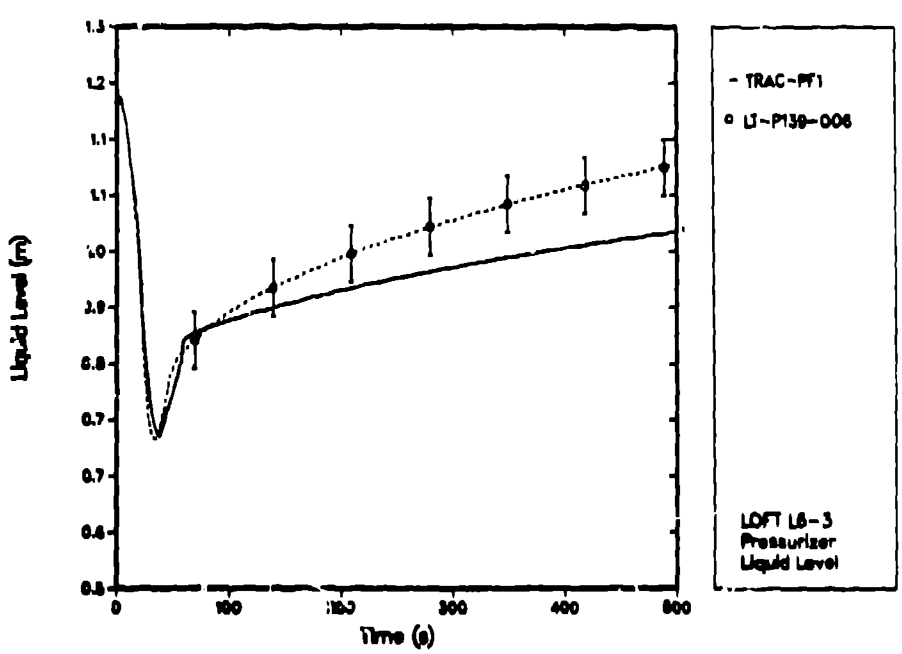

Fig. 21.
Comparison of the TRAC-calculated and the measured pressurizer liquid-level histories for Test L6-3.

The Cray-1 CPU time required to simulate a 500-s system transient was 185 s at an average 0.70-s time step at a speed 2.7 times faster than real time.

VI. CONCLUSIONS

The TRAC-PF1/MOD1 models predict accurately the slow-transient thermal-hydraulic phenomena during anticipated loss-of-steam load, loss-of-primary coolant flow, and excessive-load increase accidents. Most comparisons between the TRAC-PF1/MOD1 results and test data are excellent. This conclusion was based on comparisons of the primary- and secondary-side pressures, the loop mass flows, the pressurizer liquid levels, and the steam-generator secondary-side feedwater and steam mass flows. The pressurizer condensation model under spray conditions works well, as observed in the Test L6-1 system-pressure comparison plot (Fig. 5). The point-kinetics calculation with reactivity feedback provides good core-power predictions. All major events are predicted at approximately the correct times and in the correct sequence except for the following.

1. The pressurizer heaters in Test L6-2 turn off too early in the calculation because of the slightly higher system pressure.
2. Because of a faster system repressurization calculated during the HPIS injection in Test L6-3, the pressurizer heaters turn off early and the pressurizer spray, which is not observed in the experiment, occurs momentarily.

The trip and control logic in TRAC-PF1/MOD1 is sufficiently general to allow modeling of most anticipated or operational transients.

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