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QUICK LOOK REPORT FOR SEMISCALE MOD-2B EXPERIMENT S-SG-2

G. G. Loomis
C. P. Fineman
W. A. Owca

Idaho National Engineering Laboratory
Operated by the U.S. Department of Energy

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QUICK LOOK REPORT FOR SEMISCALE MOD-2B
EXPERIMENT S-SG-2

Authors: G. G. Loomis — Date: 9/21/83

C. P. Fineman — Date: 9/21/83

W. A. Owca — Date: 9/21/83

Reviewed: J. S. Martinell, Supervisor, Experiment Planning and Analysis — Date: 9/29/83

Approved: R. L. Benedetti, WRRTF Branch Manager — Date: 9/30/83

ABSTRACT

Results of a preliminary analysis of the second test performed in the Semiscale Mod-2B Steam Generator Tube Rupture Series are presented. Test S-SG-2 simulated a pressurized water reactor accident initiated by a double-ended offset shear of five cold side steam generator tubes. The transient included an initial 10-minute period during which only automatic plant protection system response to the initiating event occurred. This period was followed by an operator-induced recovery procedure to establish an unaffected steam generator feed and steam condition, pressurizer PORV cycling to reduce primary pressure, and HPIS cycling to maintain liquid inventory. The test results provided a measured evaluation of the effectiveness of a controlled secondary side steam and feed in Semiscale, the effectiveness of pressurizer PORV operation in controlling primary pressure, and the effect of the high pressure injection system operation on the Semiscale response to a five tube steam generator tube rupture. The test showed that the prescribed limited operator response was adequate to recover the Semiscale system from a simulated five-tube rupture.

SUMMARY

This report presents a preliminary analysis of the Semiscale MOD-2B Steam Generator Tube Rupture Series (SG) Test S-SG-2. S-SG-2 is the second test of the SG series to be conducted. The test series is designed to study not only the effect of the number of tubes ruptured (break size), but also the effect of limited operator responses to the accident following an initial 10-minute simulated identification period.

Test S-SG-2 simulates a pressurized water reactor transient initiated by a double-ended offset shear of five cold side steam generator tubes. Data from this experiment will be examined to evaluate event signatures, event severities in Semiscale and recovery procedures, with the principal objective of providing data to benchmark computer code calculations.

Test S-SG-2 was designed in two parts: (a) an initial 600 s period in which only automatically functioning plant protection systems were assumed to operate, followed by (b) an operator controlled recovery period including an unaffected loop steam generator feed and bleed, pressurizer power operated relief valve (PORV) operation and termination of safety injection (SI).

The signature of a five-tube rupture is characterized by a relatively rapid decrease of the primary coolant system pressure to a saturation condition in the hot legs as primary coolant system fluid flows through a simulated five-tube break conical flow tube into the affected loop steam generator secondary. Automatic protective actions that influence the pressure response during this early period are core scram and main steam isolation valve (MSIV) closure. Both are initiated by a low pressurizer pressure trip at 13.1 MPa (1900 psia). Main coolant pump trip, feedwater termination, auxiliary feedwater start, and safety injection start are all initiated on a safety injection signal at a pressurizer pressure of 12.5 MPa (1814 psia). Part of the pressure response during this early period is a rapid increase in secondary pressure in both loops as primary-to-secondary heat transfer raises the pressure of the secondaries

after MSIV closure. Accompanying this secondary pressure increase was a lifting of the atmospheric dump valve in the affected, but not the unaffected, steam generator. The five-tube break flow was sufficient to leave the vessel upper head collapsed liquid level near the vessel hot leg at the end of 600 s. Following the attainment of saturation conditions in the hot legs the primary and secondary system pressures remained fairly constant as safety injection (SI) fluid entered the primary and break flow left the primary system to the affected loop steam generator secondary. Decay heat was removed by natural circulation.

The recovery procedure in S-SG-2 was not initiated until 600 s to simulate a period for operators to identify the tube rupture. Operator response at 600 s included operating the unaffected loop atmospheric dump valve (ADV) in an attempt to depressurize the unaffected loop secondary at 0.227 MPa/5 min. (33 psia/5 min.) and thus increase the loop heat sink. Pressurizer PORV operation was used to aid in primary depressurization. SI was terminated on pressurizer and vessel level trips. The test was terminated when the primary pressure reached 4.22 MPa (600 psi).

The overall system response to the combined recovery methods including unaffected loop feed and bleed, PORV operation, and SI termination was to cause a slow depressurization ($\sim 3.13 \times 10^{-4}$ MPa/s (163 psi/hr)) of the primary system. The combined effects of unaffected loop steam and feed, break flow, and subcooling due to SI, caused the primary pressure to decrease. A momentary pressurization of the primary occurred as SI pumped against a nearly liquid full system. The effect of the PORV on system depressurization was, by itself, minimal, but this operation caused the pressurizer to fill with liquid, leading-to a primary pressurization from SI pumping against a nearly full system.

A comparison of the system pressure response for one- and five-tube rupture experiments (S-SG-1 and S-SG-2, respectively) shows similar responses except for the timing of events. The system mass inventory for the five-tube break, however, indicates a more severe case than the one-tube break and could cause more concern to the operator to maintain

adequate core cooling. However, the influence of pressurizer filling on system recovery with SI during a one tube break is expected to be stronger than for a five tube break because of the minimal primary coolant system voiding.

Certain differences in assumed and actual operator action, including unaffected loop ADV and SI operation, precluded a direct comparison of data and RELAP5 calculations. RELAP5 calculations showed similar phenomenological response to the operator actions with mainly timing of events being different. Posttest calculations with actual operator response modeled are expected to give excellent agreement between code and data.

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1. INTRODUCTION

This report documents preliminary results from Semiscale Mod-2B test S-SG-2, the second experiment in the Semiscale Steam Generator Tube Rupture (SG) Test Series.[1] The test series includes experiments designed to investigate both tube rupture initiated transients and transients otherwise induced but concurrent with tube rupture. Data from these experiments will be examined to evaluate event signatures, event severities in Semiscale, and recovery procedures, with the objective of providing data to assess computer code calculations. Although inherent scaling distortions and facility limitations preclude interpreting the results of the SG Test Series as precise replications of pressurized water reactor response, the experiments are designed to provide thermal-hydraulic behavior that will be representative of PWR behavior. Subsequent references in this document on simulation of a full-scale PWR address the design of the experiment rather than the quantitative results.

Test S-SG-2 simulated a pressurized water reactor transient initiated by a double-ended offset shear of five cold side steam generator tubes. The test was designed in two parts, an initial 600 s period in which only automatically functioning plant protection systems were assumed to operate, and a subsequent operator controlled recovery period, which included steaming and feeding of the unaffected loop steam generator secondary, operation of the pressurizer PORV, and cycling of safety injection (high pressure injection and charging pumps). Automatically occurring events included safety injection (SI), main steam isolation valve closure, core scram, main feedwater secural, auxiliary feedwater actuation, main coolant pump trip, and deenergization of pressurizer heaters. Recovery operations were initiated at 600 s after the occurrence of the break. (A time of 600 s is within the range of transient identification and response times that have occurred, or are expected to occur, in actual plant transients.) For S-SG-2, the recovery involved steaming the unaffected loop secondary system through the atmospheric dump valve (ADV) and feeding with auxiliary feedwater. The ADV was cycled in an attempt to decrease primary system pressure by enhancing the heat sink during a controlled, 2.76 MPa/hr (400 psi/hr) secondary cooldown. After sufficient time had elapsed to

determine the effect of the unaffected loop secondary sink on primary system depressurization, SI was cycled to maintain primary system inventory. When the system pressure stabilized below the accumulator injection setpoint of 4.22 MPa (612 psia), the test was terminated.

A preliminary analysis of test S-SG-2 is presented in the following sections. Section 2 describes the system configuration and test conduct. Section 3 presents results from test data analysis. Section 4 presents a comparison of test data to the RELAP5 pretest analysis, and Section 5 summarizes conclusions drawn from the preliminary analysis.

2. SYSTEM CONFIGURATION AND TEST CONDUCT

2.1 System Configuration

The Semiscale Mod-2B system configuration is illustrated in Figure 1. The system is scaled from a reference four-loop PWR system based on the core power ratio, 2(MW)/3411(MW).[2,3] Component elevations, dynamic pressure heads, and liquid distribution were maintained as similar as practical. The two-loop test configuration consisted of the vessel with a 25-rod electrically heated core with external downcomer, tube-and-shell steam generators and associated loop piping with circulation pumps. The affected loop (the loop in which the steam generator tube rupture occurs) is scaled to represent one loop of a four-loop PWR and the unaffected loop represents three loops of a four-loop PWR. The Semiscale Steam Generator Tube Rupture Experiment Operating Specification[1] gives more detail about the specific components.

Special modifications to the Semiscale Mod-2B system are incorporated to properly control and measure boundary conditions for the steam generator tube rupture series. These include condensing systems and catch tanks to accurately measure system effluent from the steam generator secondaries, special effluent flow controls in the steam generator secondaries to give properly scaled steam relief flow rates, and a tube-rupture break assembly to simulate the primary to secondary flow path created by the tube rupture.

In both the unaffected and affected loop, a simulated power operated atmospheric dump valve (ADV) and a staged safety relief valve (SRV) system are situated on the main steam line. They represent scaled ADV and SRV flow capacities and operation.[3]

The SRV orifice is designed to pass a scaled flow corresponding to only the first stage of relief of the SRV in a PWR (PWR SRV's typically have 5 stages of relief). The ADV orifice is designed to pass scaled flow corresponding to ADV operation in a PWR. On a PWR, the pressure relief setpoint for the ADV stage is encountered before the various multistaged SRV relief setpoints. Figure 2 shows the orientation used in Semiscale to

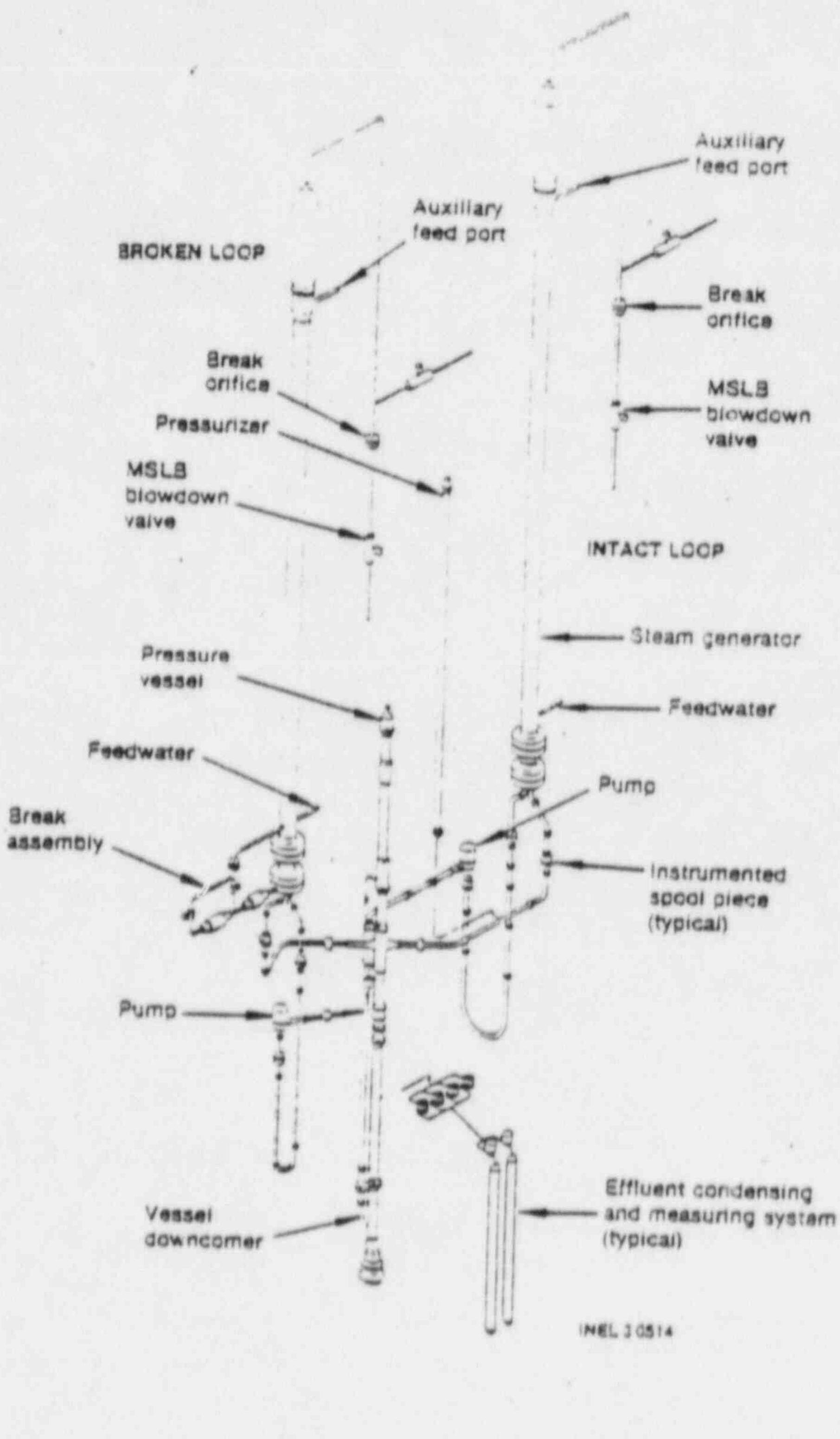


Figure 1 Semiscale Mod-2B system as configured for the SG test series.

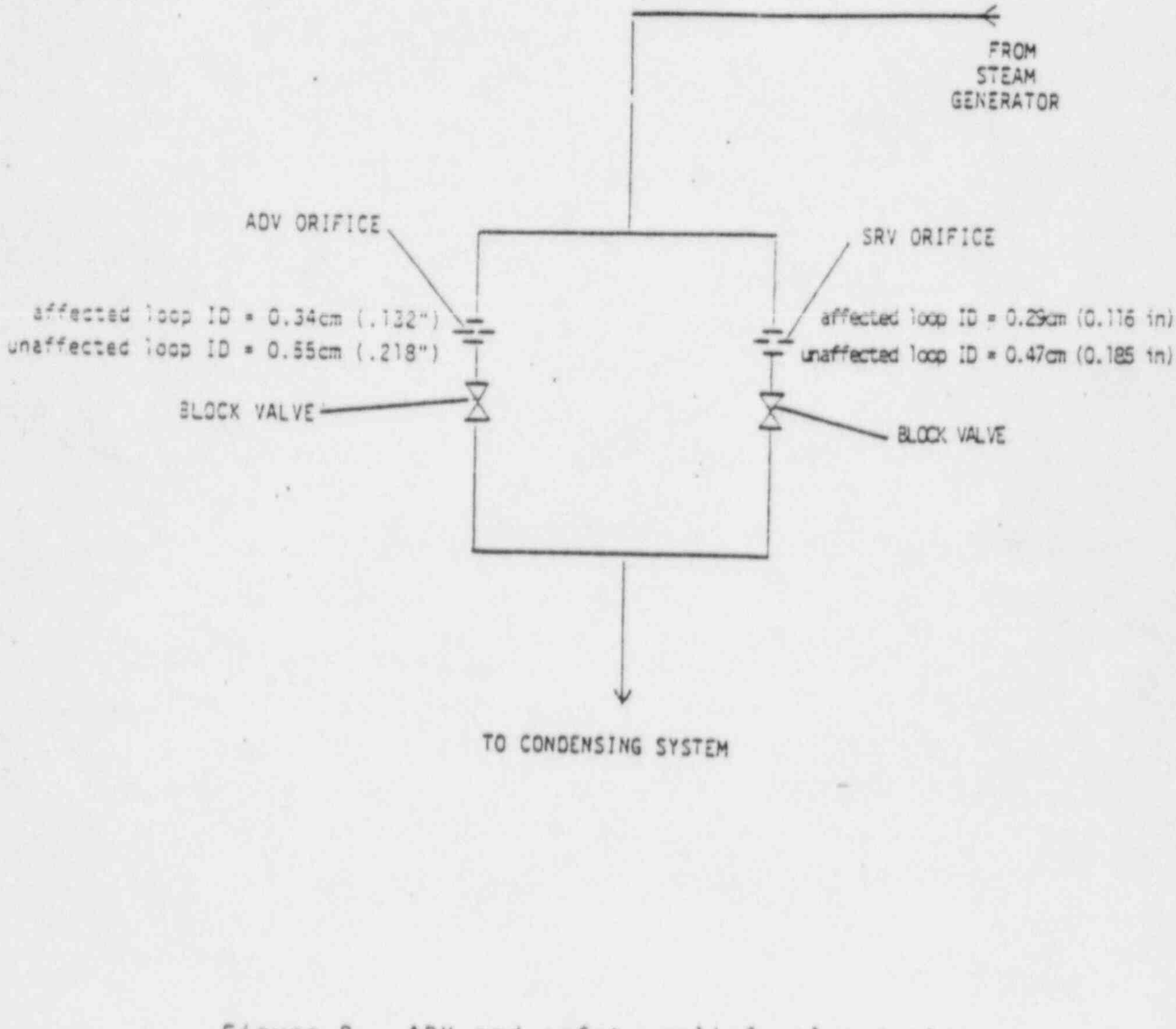


Figure 2. ADV and safety relief valve system.

simulate this operation in both the affected and unaffected loops. The parallel flow path arrangement allows ADV flow through the ADV block valve and orifice, and stage one SRV flow through the combination of both block valves and orifices. The block valves operate in an open or shut mode only, with the orifices controlling the flow rates. The ADV block valve opens automatically at the ADV pressure setpoint. If the pressure continues to rise after the ADV opens, the SRV block valve opens automatically at the SRV pressure setpoint. As the pressure decreases, the block valves close automatically, 69 KPa (10 psi) below their respective pressure setpoints. In Semiscale, the ADV relief setpoint is 5.85 MPa (848 psia) in the affected loop and 6.55 MPa (949 psia) in the unaffected loop. The first stage SRV relief setpoint is 5.94 MPa (861 psia) in the affected loop and 6.74 MPa (977 psia) in the unaffected loop.[a] Figures 3 and 4 show mass flow rate versus pressure for ADV and SRV operation for the affected and unaffected loops, respectively. The ADV can also be latched open manually during the recovery procedure with the SRV block valve shut.

The pressurizer PORV provides a means of manually relieving primary system pressure from the top of the pressurizer. Semiscale uses a single valve with a flow control orifice to simulate the two PORV's of a full scale PWR. A 0.141 cm (0.055 in.) sharp edged orifice was sized to pass 0.03 kg/s (0.069 lb/s) at 16.2 MPa (2350 psia). The scaling criteria are presented in Appendix A of Reference 1.

The tube rupture break assembly connects the primary coolant system with the secondary side in the vicinity of the affected loop steam generator tube sheet (see Figure 5). The break assembly can be connected to either the hot leg or cold leg side of the primary at the broken loop steam generator plenum, 57.1 cm (22.5 in) below the top of the tube sheet. The break assembly connects to the secondary at one location, 36.5 cm

a. The ADV and SRV relief setpoints were set to different values for the two steam generators, and artifically low, to ensure ADV operation during the transient. The scaling of these relief setpoints is discussed in detail in Reference 1.

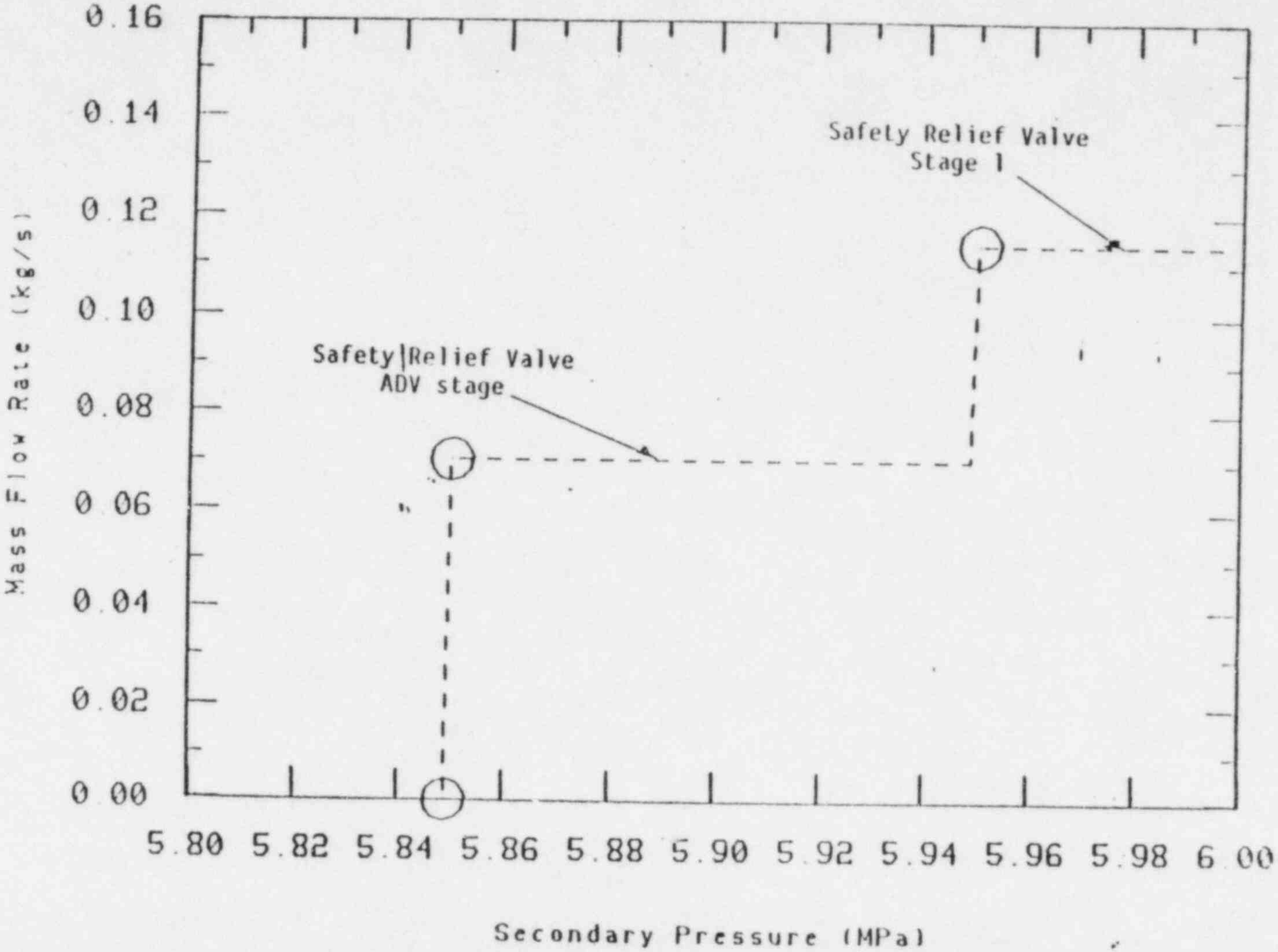


Figure 3. Broken loop steam generator safety relief valve operation.

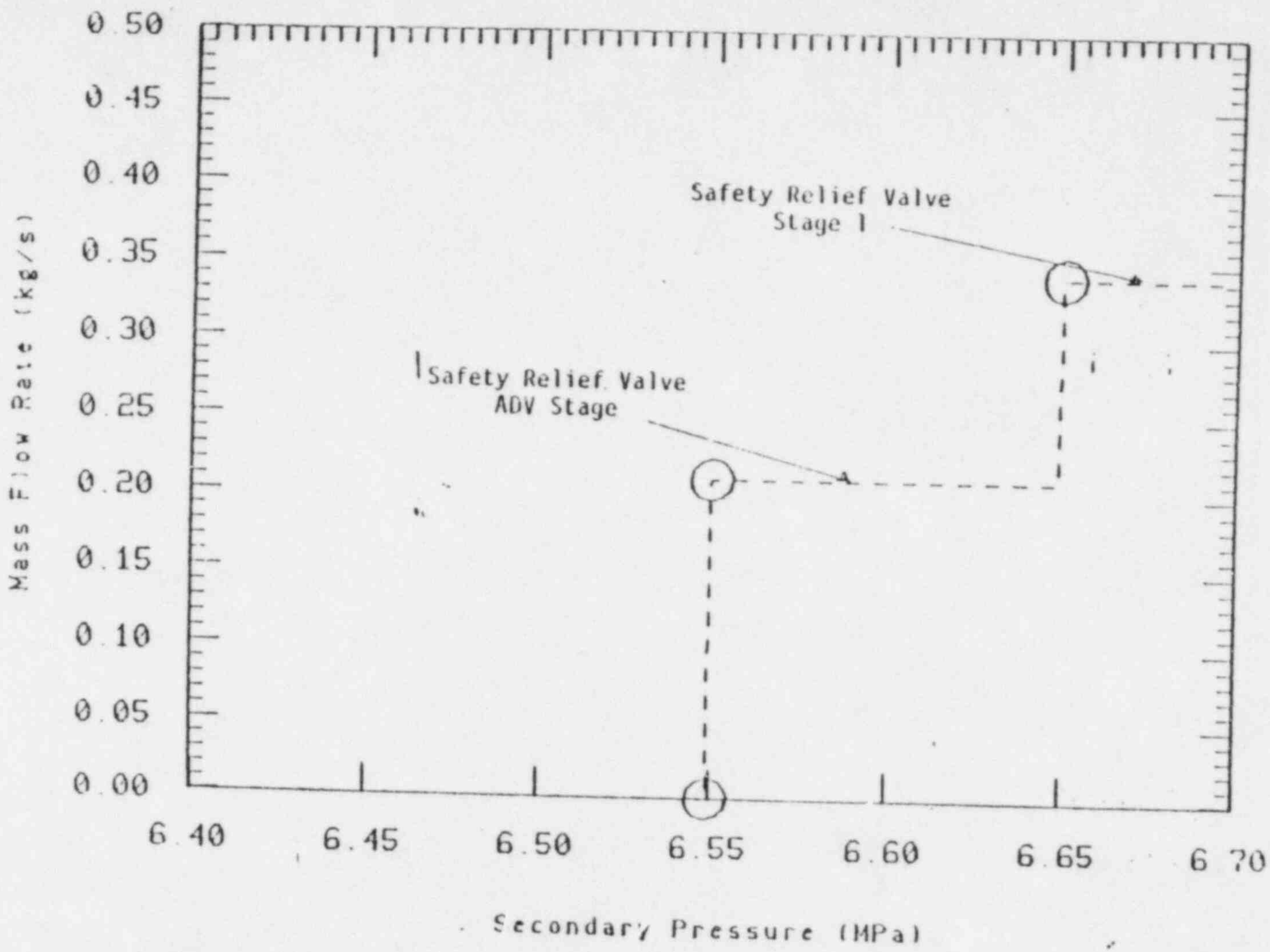


Figure 4. Intact loop steam generator safety relief valve operation.

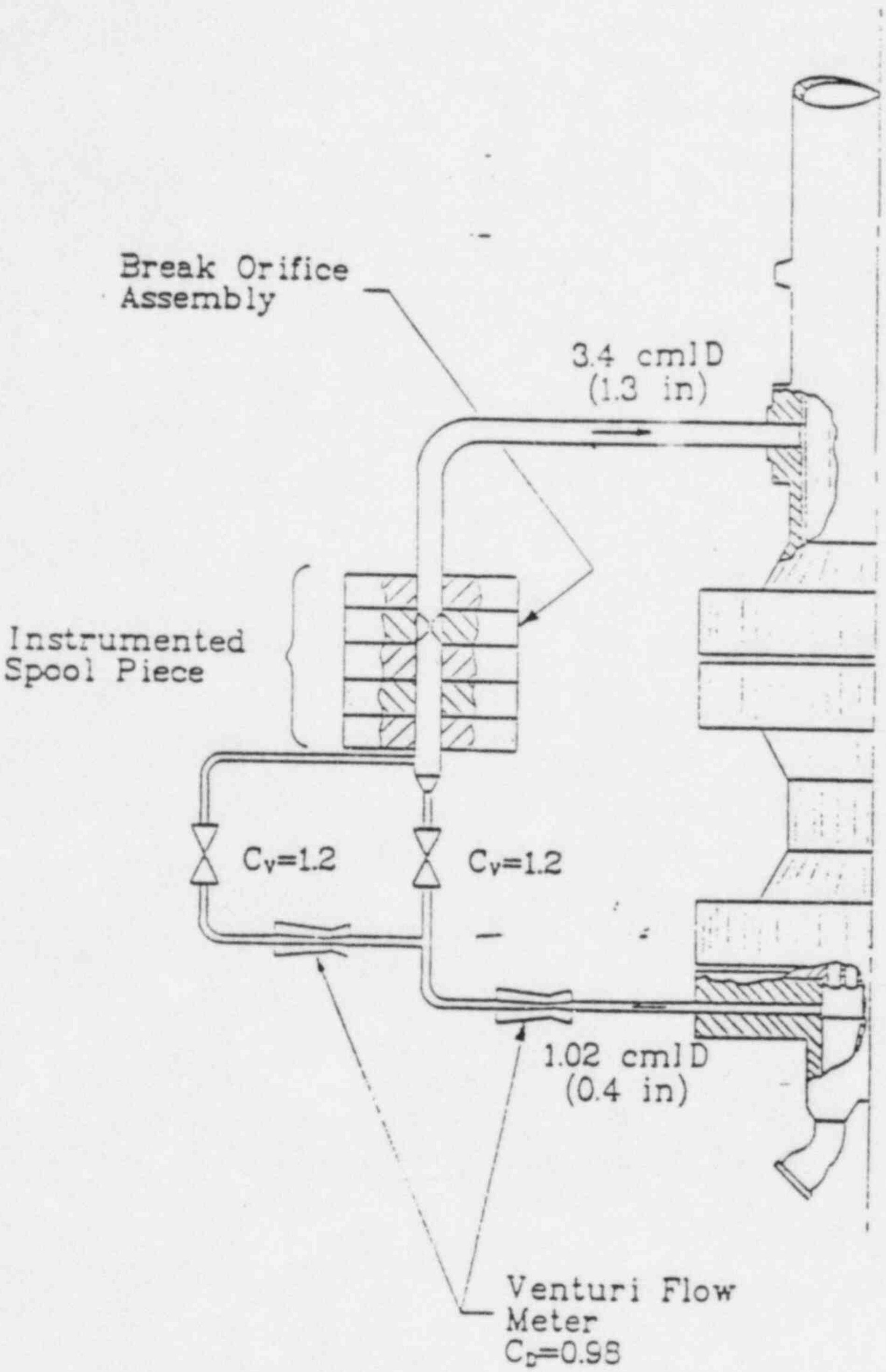


Figure 5. Semiscale tube-rupture break assembly.

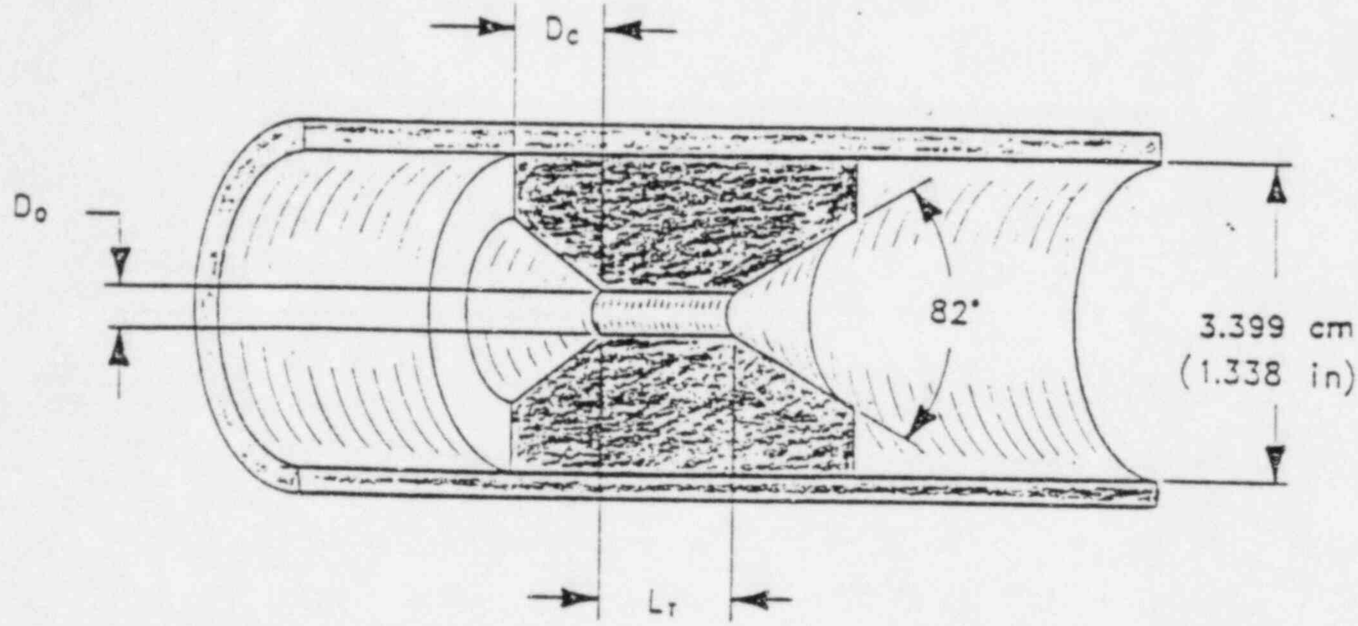
(14.4 in) above the top of the tube sheet on the cold leg side of the generator. For test S-SG-2, the break assembly was on the cold leg side of the primary. The break assembly consists of a break orifice and venturi flow meters to measure single phase break mass flow rate. The break orifice is a symetrical conical flow tube as depicted in Figure 6. The break orifice is interchangeable. Figure 6 shows the dimensions for a 1-, 5-, and 10-tube break orifice. Test S-SG-2 used the 5-tube break orifice with a 0.175 cm (0.0689 in) ID. The flow tube was calibrated in single phase water and can be used to monitor break mass flow rate.

Heat loss makeup in the Semiscale system is accomplished by using external heaters distributed fairly uniformly throughout the Semiscale system. These heaters are controlled by six separate power supplies including: vessel, hot legs, cold legs, unaffected loop pump suction, affected loop pump suction and pressurizer. The total power provided by these heaters is about 47 kW. An additional 20 kW of heat loss makeup was provided by augmenting core power throughout the transient. Control of the heaters is as follows: If the maximum allowable temperature level (900 K) is reached on the inside surface of the pipe insulation, external power to that component is reduced by half. If the temperature trip limit continues to be exceeded, power to that component is terminated. Pressurizer external heaters were not used in S-SG-2, and the upper three heater banks on the vessel were turned off at the initiation of the transient.

2.2 Test Conduct

The system was filled with demineralized water and vented to ensure a liquid full system. Instrumentation was calibrated and zeroed as necessary. The system was heated to initial conditions using core power and forced flow with the primary coolant pumps running. Specified and measured initial conditions are listed in Table 1.

The test was initiated at t = 0 by opening a block valve in the break assembly allowing primary fluid to flow into the affected loop secondary. Table 2 contains a sequence of significant events for S-SG-2. The first 600 s involved automatically occurring events such as core scram, main



TUBE RUPTURE	D_o		L_T		D_c	
	cm	in	cm	in	cm	in
1 TUBE	.079	.0308	.198	.078	1.473	.662
5 TUBE	.175	.0689	.439	.173	1.372	.709
10 TUBE	.249	.0975	.622	.245	1.270	.745

Figure 6. Semiscale conical break orifice.

TABLE 1. INITIAL CONDITIONS FOR S-SG-2

	Specified	Measured
Primary Cold Leg Flow Rate (Nominal)		
Affected Loop	2.7 ℓ/s (43 gpm)	3.33 l/s (52.3 gpm)
Unaffected Loop	8.1 ℓ/s (128 gpm)	9.60 l/s (152.2 gpm)
Pressurizer Pressure	15.6 ± 0.14 (2250 ± 20 psig)	15.5 (2248 psia)
Pressurizer Liquid Volume	0.0102 ± 0.0008 m^3 (0.36 ± 0.028 ft^3)	0.00957 m^3 (0.338 ft^3)
Core Power	2.0 ± 0.01 MW	2.010 MW
Loop to Loop Cold Leg Fluid Temperature Differential	2.0 K (3.6°F)	0.5 K (0.9°F)
Core Fluid Temperature Rise	37 ± 1.5 K (66.6 ± 3°F)	38.5 K (69.3°F)
Steam Generator Pressure		
Affected Loop	5.55 ± 0.07 MPa (793 ∓ 10 psig)	5.55 MPa (805 psia)
Unaffected Loop	5.55 ∓ 0.07 MPa (793 ∓ 10 psig)	5.42 MPa (786 psia)
Steam Generator Secondary Fluid Mass[a]		
Affected Loop	100^{+40}_{-20} kg	118 Kg[b] (260 lbm)
	(220^{+88}_{-44} lbm)	136 Kg[c] (300 lbm)
Unaffected Loop	100^{+40}_{-20} kg	103 Kg[d] (227 lbm)
	(220^{+88}_{-44} lbm)	118 Kg[b] (260 lbm)
		135 Kg[c] (298 lbm)
		100 Kg[d] (220 lbm)

TABLE 1. (continued)

	Specified	Measured
Primary Leakage at t = 0	<0.006 kg/s (<0.0132 lbm/s)	0.004 kg/s (0.008 lbm/s)

a. These values were determined from data acquisition system levels following main steam isolation valve closure. Initial conditions were established using process indicated levels which have a high uncertainty in a steaming condition; however the specified process levels where achieved prior to test initiation.

b. Measured with LIS 1117 + 51 for unaffected loop or LBS 1117 + 51 for affected loop.

c. Measured with LIS 1117 + 836 for unaffected loop or LBS 1117 + 836 for affected loop.

d. Measured with LIS 1117 + 825 for unaffected loop or LBS 1117 + 825 for affected loop.

TABLE 2. SEQUENCE OF EVENTS FOR TEST S-SG-2

Event	Time (s)
Blowdown initiated; break flow indicated	0
Pressurizer low pressure trip, 13.1 MPa (1900 psia)	18
Main steam isolation valve closure, both loops	18
Core power trip	18
Safety injection signal low pressure trip, 12.5 MPa (1814 psia); HPI initiated	20
Feedwater off; both loops	20
Auxiliary feedwater initiated; both loops	20
Primary coolant pumps tripped	22
Primary coolant pumps coastdown completed; both loops	50
Affected loop auxiliary feedwater terminated	55
Recovery procedure commenced	600

	Time On (s)	Time Off (s)
Unaffected loop auxiliary feedwater operation		2739
	3000	3582
	4634	--[a]
HPIS operation		4382
	5104	5539

	Time open (s)	Time closed (s)
PORV Operation	1574	1704
	1730	1845
	1955	2015
	2052	2068
	2095	2130
	2245	2260
Test terminated, accumulator injection setpoint, 4.22 MPa (612 psia)	7900	

a. Operating at test termination.

steam isolation valve closure, auxiliary feedwater start and main feedwater stop, main coolant pump trip and HPIS/charging flow initiation. The initiating events for these actions were a low pressurizer pressure trip (13.1 MPa (1900 psia)) and SI signal (12.51 MPa (1814 psia)). The recovery procedure for S-SG-2 involved initiation of intact loop steam and feed, operation of the pressurizer PORV, and cycling of SI. SI included both high pressure injection flow and charging pump flow as described in Reference 1. The recovery procedure started at 600 s, the simulated time required for operator identification of the tube rupture. Unaffected loop auxiliary feed was controlled by maintaining the secondary water level between 800 and 1050 cm (315 and 413 in.). Affected loop auxiliary feed was terminated prior to 600 s on a 1050 cm (413 in.) level trip.

The unaffected loop ADV was used to produce a controlled 2.76 MPa/hr (400 psi/hr) secondary side depressurization rate. Figure 7 illustrates acceptable operating bands for unaffected secondary depressurization. At 980 s, the secondary depressurization rate slowed and manual ADV cycling was initiated. ADV cycling continued until 6300 s, at which time the ADV was no longer able to maintain the specified depressurization rate and was latched open to produce the maximum depressurization.

The pressurizer PORV was cycled to maintain a primary system depressurization rate equal to that of the unaffected loop secondary system. Manual PORV cycling was initiated at 1575 s and continued until 2260 s, when the pressurizer level exceeded 475 cm (187 in.). The valve was then latched shut.

SI was terminated at 4380 s, after pressurizer and vessel level requirements were satisfied, to examine the influence of SI on system pressure. The vessel level then fell to a point requiring restart of SI flow at 5000 s. The required levels were reestablished and SI was again (and finally) terminated at 5450 s. The test was terminated at 7900 s when the primary system pressure fell below the accumulator injection setpoint of 4.22 MPa (612 psia). Pressurizer external heaters were not used, and the upper three vessel external heater banks were tripped off at test

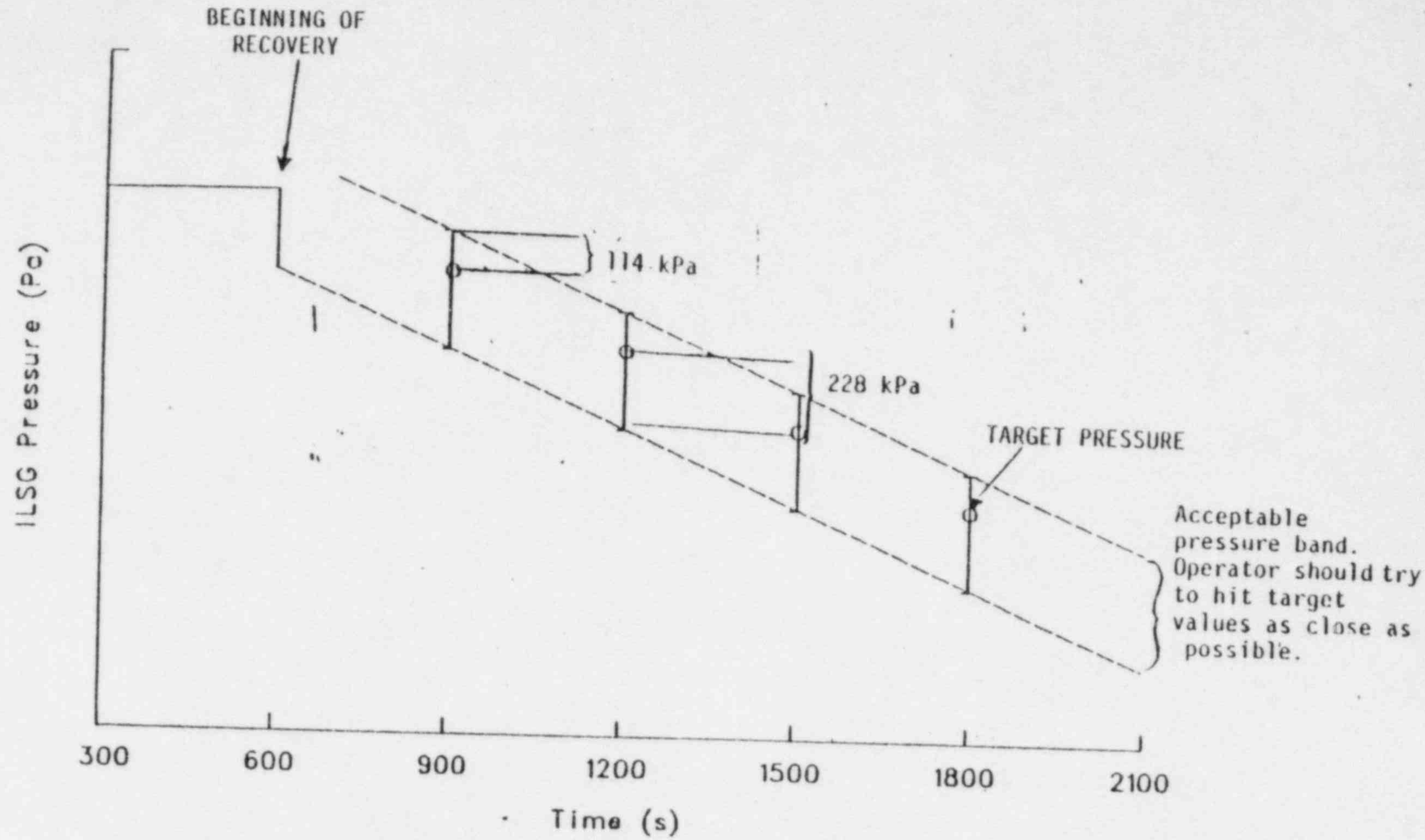


Figure 7. Unaffected loop steam generator pressure control during recovery.

initiation. All other external heater power for heat loss makeup remained on for the entire transient. No external temperature limits were exceeded.

3. RESULTS

This section discusses the overall thermal-hydraulic response of the Semiscale system during Test S-SG-2. Test S-SG-2 was a simulation of a double-ended offset-shear of five steam generator tubes on the cold side of the steam generator near the tube sheet. The discussion is organized into three areas: the early response to automatically occurring events (0 to 600 s), the recovery period involving operator actions (600 to 8000 s) and a comparison of the response for a 1-tube (Test S-SG-1) and 5-tube (Test S-SG-2) break experiment.

3.1 System Behavior--Tube Rupture Signature Early in Time (0 to 600 s)

The occurrance of a 5-tube rupture event during normal operation in a PWR has a very distinctive signature response, as shown in the comparison of primary and secondary pressure in Figure 8. The tube rupture (occurring in the affected loop steam generator) initiated the transient at 0 s. Primary fluid originally at 15.6 MPa (2250 psia) flowed through the conical flow tube break orifice into the affected loop steam generator originally at 5.5 MPa (797 psia). The loss of mass from the primary loop caused a fairly steady primary depressurization until about 12.5 s, at which time a marked increase in depressurization occurred. This increase in depressurization rate is thought to be due to a reduction in the free surface area of the fluid in the pressurizer. The resulting reduction in flashing led to a more rapid depressurization rate (see Appendix A for details). The primary depressurization following this point was fairly steady until the low pressurizer pressure setpoint of 13.1 MPa (1900 psia) was achieved at about 20 s. Prior to achieving the low pressurizer pressure trip, both the affected and unaffected loop steam generator pressures remained fairly constant as core power was removed via normal secondary steaming conditions with the primary loop pumps running (see Figure 9). The energy addition to the affected loop secondary from break flow was small enough to cause a negligible pressure rise during this period. At the low pressurizer pressure trip point, two prominent events

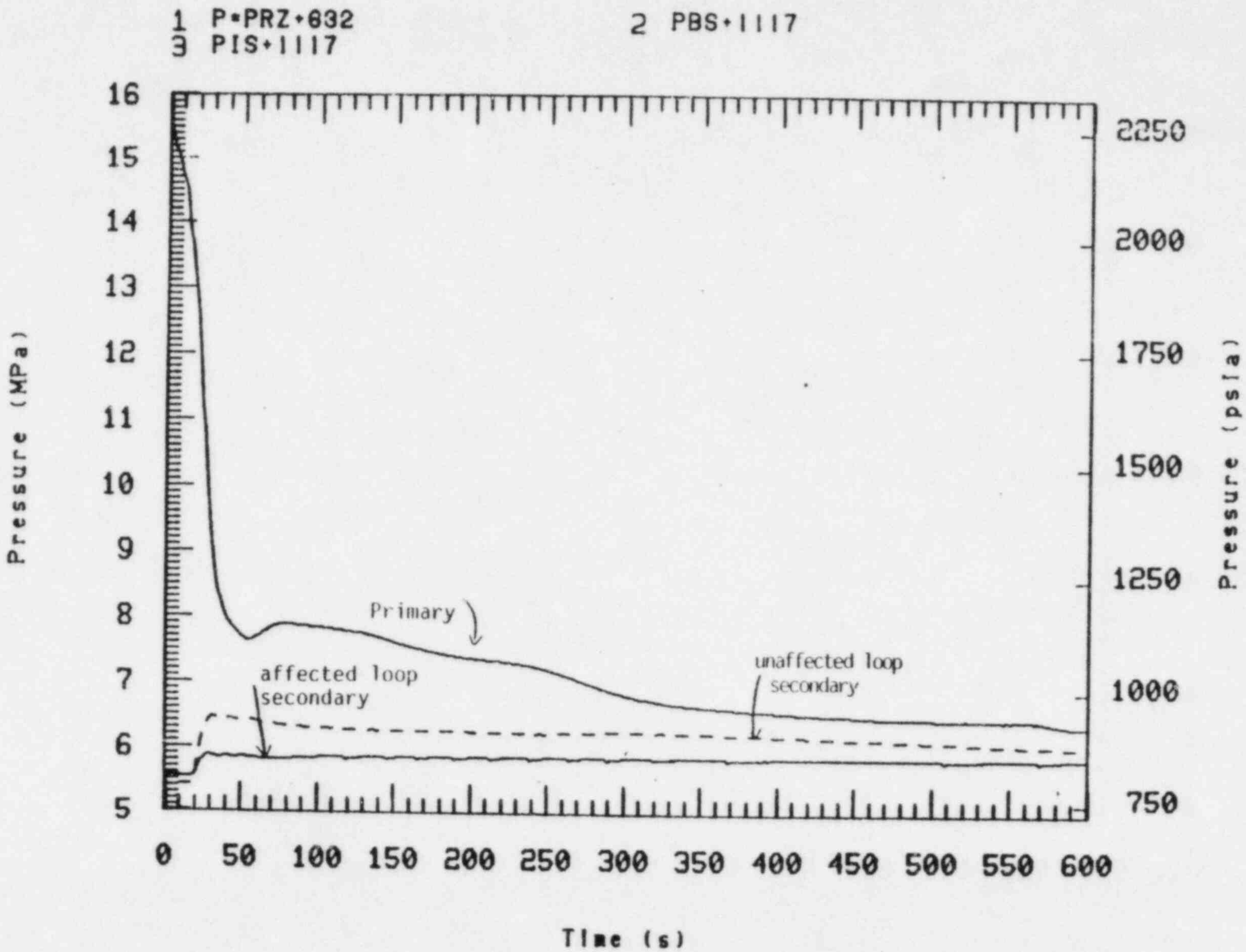


Figure 8. Comparison of primary and secondary pressure during a five tube rupture transient (S-SG-2).

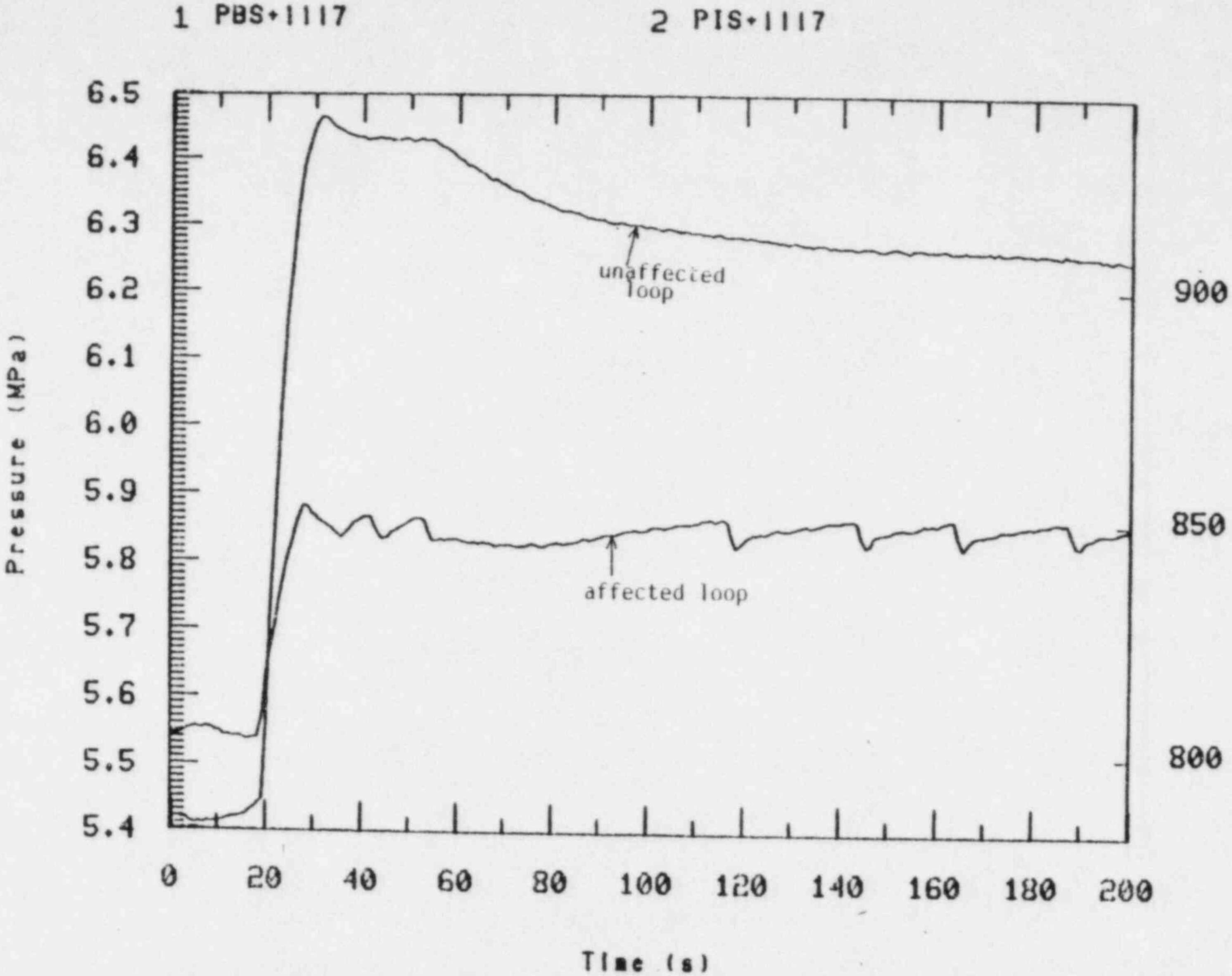


Figure 9. Comparison of affected loop and unaffected loop secondary pressure during a five tube rupture transient (S-SG-2).

occurred which greatly affected the depressurization rate: the core power was scrammed to the ANS decay power curve and the main steam isolation valves were closed on the steam generators.

Upon MSIV closure, the heat transfer to both the affected and unaffected loop steam generator secondaries caused a rapid pressurization of the secondaries as shown in Figure 9. The secondary pressure in the unaffected loop steam generator ultimately decreased without achieving the ADV setpoint of 6.55 MPa (950 psia). A high metal mass-to-system liquid volume ratio, and thus too great a heat sink, is thought to be the cause of this decrease in pressure. The affected loop secondary pressure achieved the ADV setpoint of 5.85 MPa (848 psia) and cycled several times during this early period.

Following the core scram at 13.1 MPa (1900 psia), the system pressure showed an increased depressurization rate as the system liquid shrunk due to primary to secondary heat transfer (see Figure 8). The safety injection signal was achieved at 12.51 MPa (1814 psia) and initiated:
(a) terminating power to the primary coolant pumps, (b) starting SI flow, and (c) terminating main feedwater and starting auxiliary feedwater to the secondaries. No major change in depressurization rate occurred from these events as the effect of these events were overshadowed by the effect of core scram. Following pump trip and coastdown, the loop flow reduced to typical natural circulation values[4] as shown on Figure 10. Eventually, the primary system depressurization was sufficient for the hot leg fluid to reach a saturation condition at about 40 s (Figure 11). Flashing in the system then caused a major reduction in the depressurization rate. Primary pressure remained above both secondary system pressures for the entire 600 s period, causing a primary-to-affected loop secondary mass flow.

The primary-to-secondary break flow persisted throughout the initial period as shown on Figure 12. As long as break flow exceeded total SI flow primary system mass inventory depleted. Figure 13 shows the pressurizer collapsed liquid level essentially depleted after the initial 50 s. The vessel upper head collapsed liquid level[a] fell to near the level of the hot leg within the first 200 s as shown in Figure 14. The steam generator

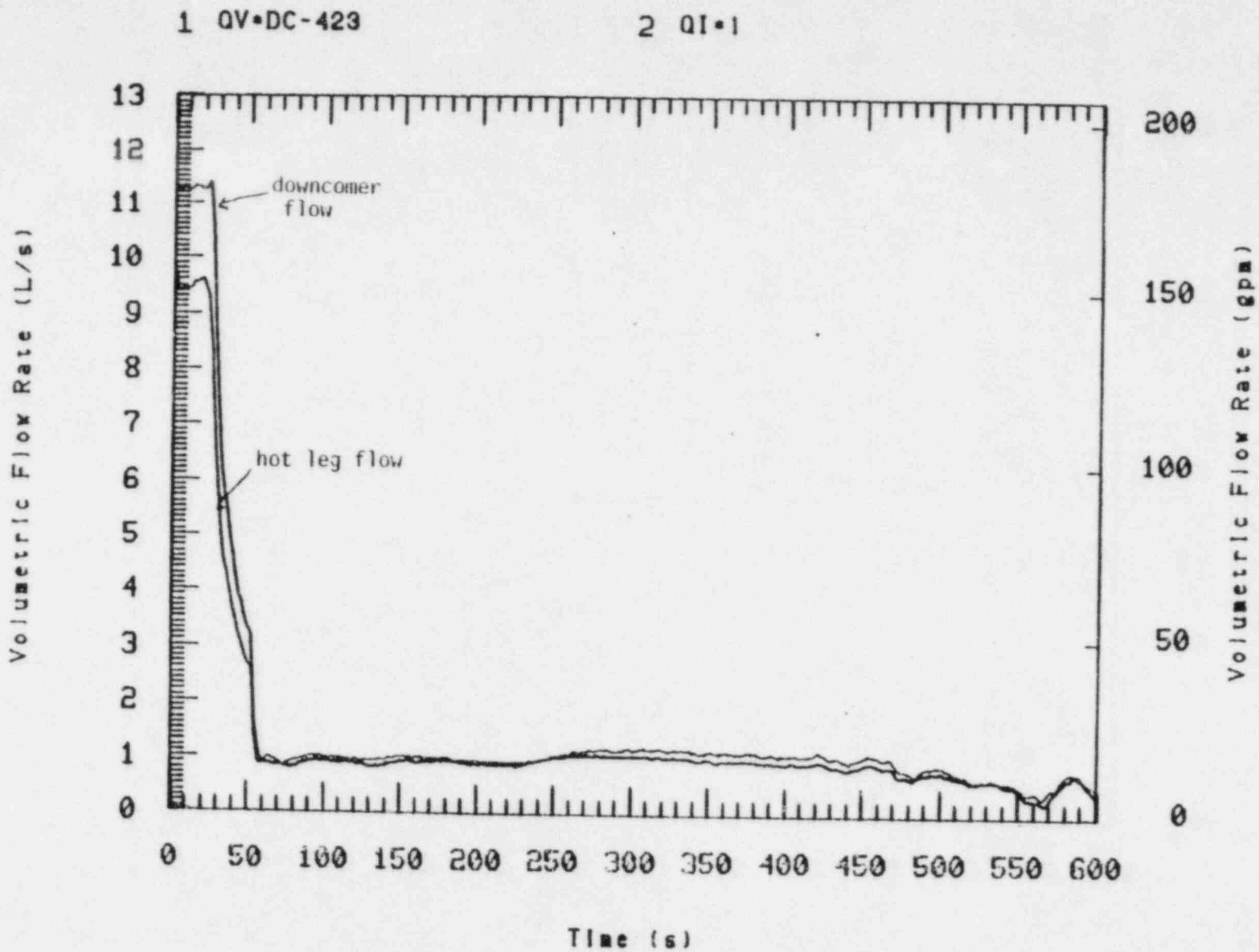


Figure 10. Change to natural circulation in the unaffected loop during a five tube rupture transient (S-SG-2).

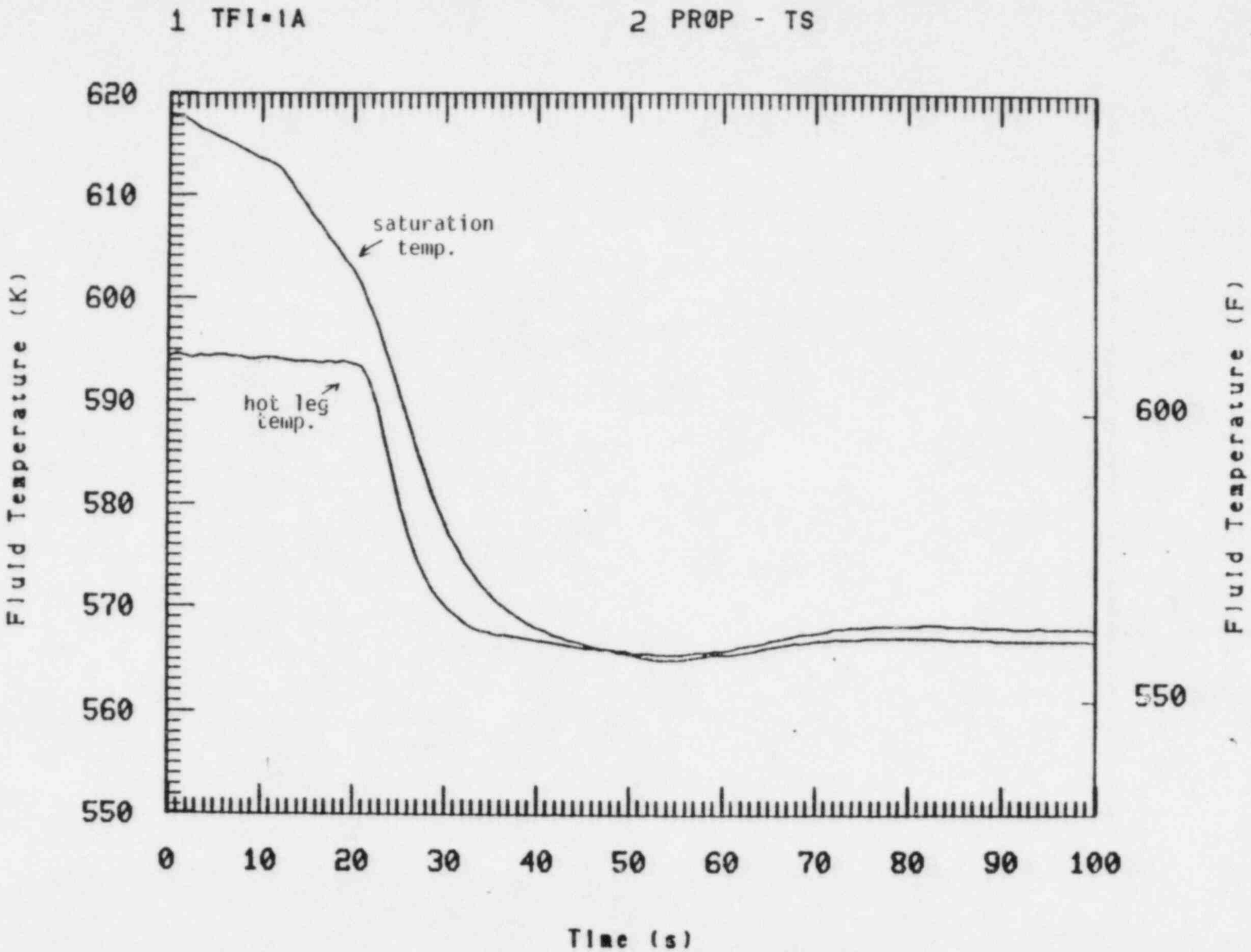


Figure 11. Comparison of hot leg fluid temperature and saturation temperature during a five tube rupture transient (S-SG-2).

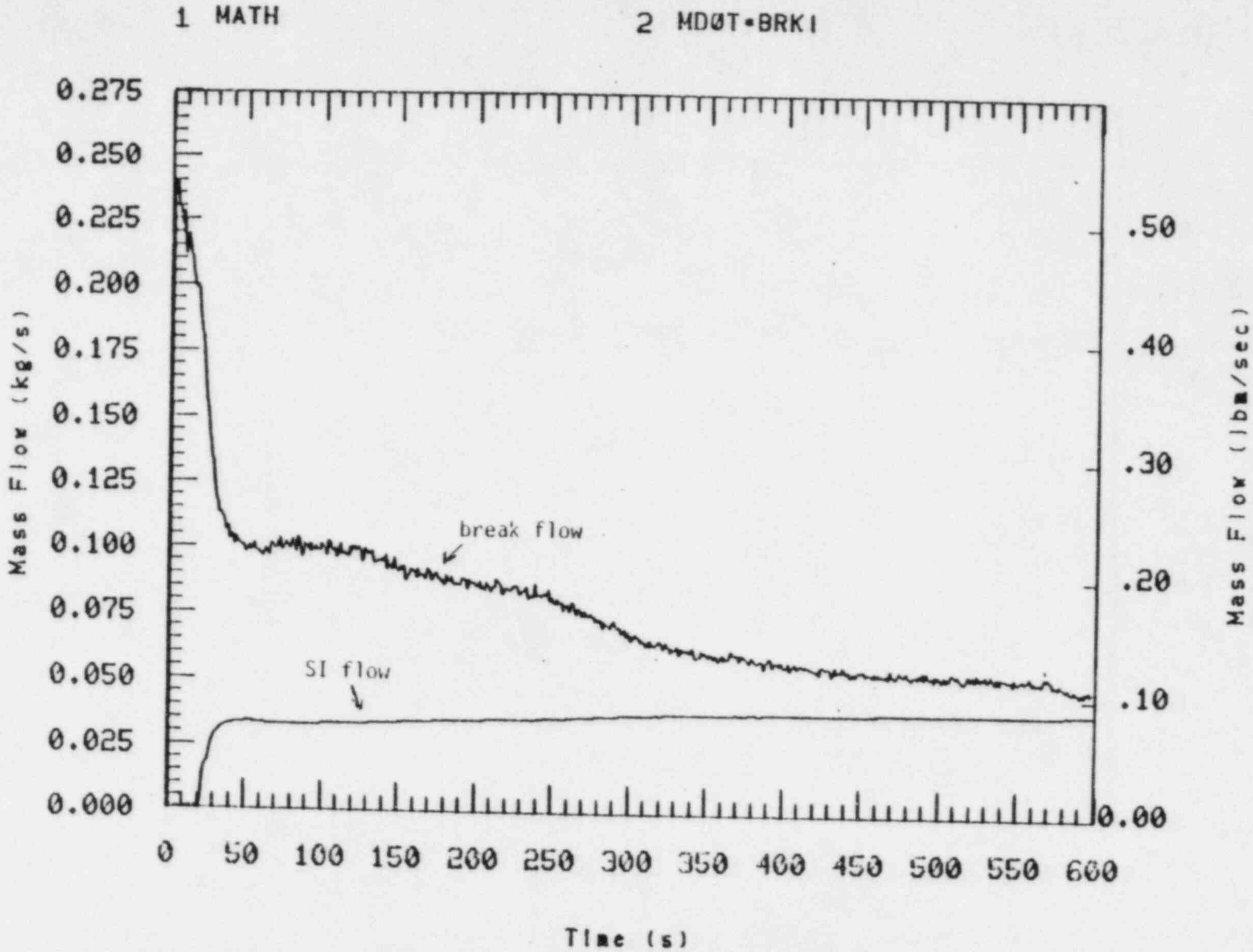


Figure 12. Comparison of break flow and SI flow during a five tube rupture transient (S-SG-2).

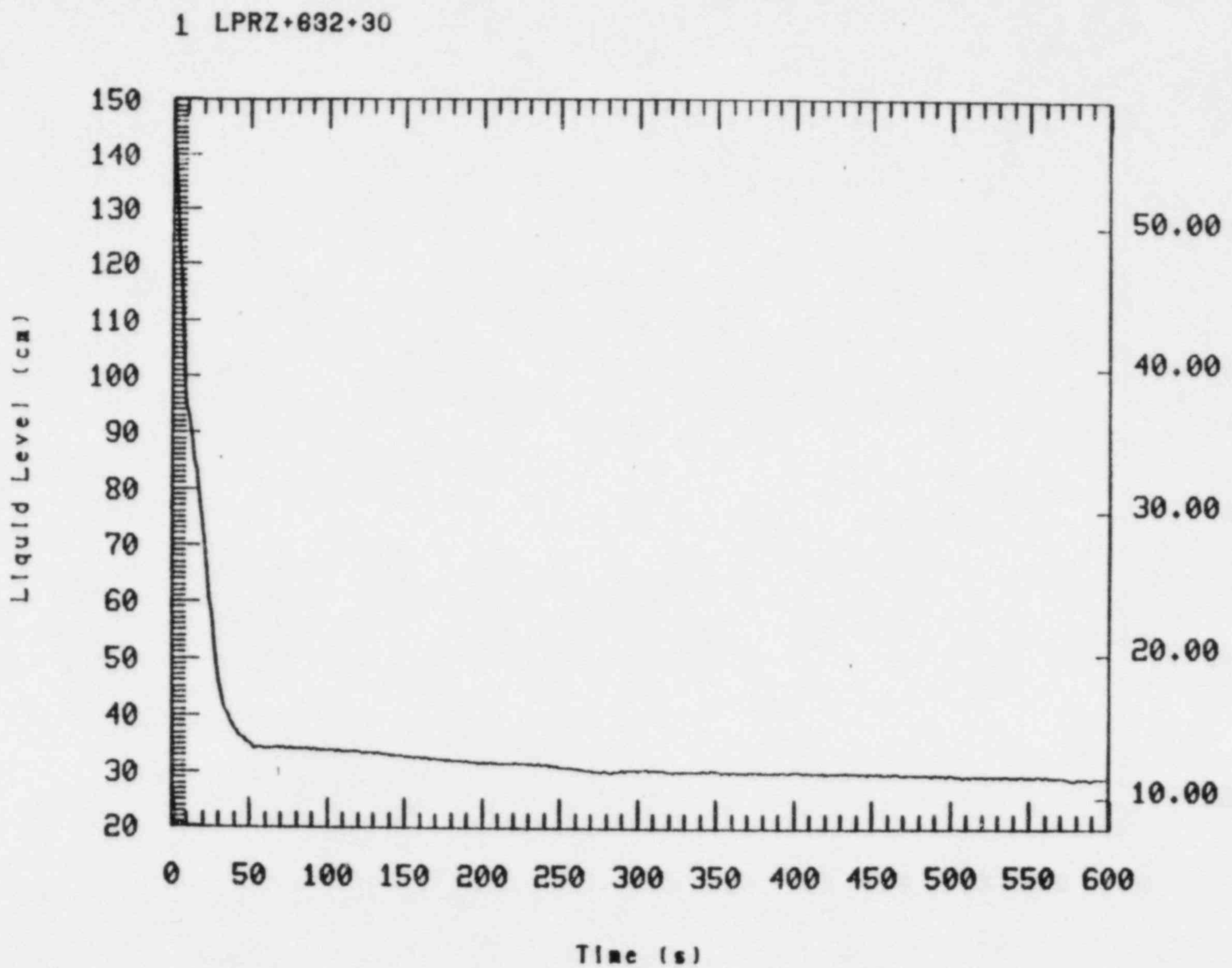


Figure 13. Pressurizer collapsed liquid level during a five tube rupture transient (S-SG-2).

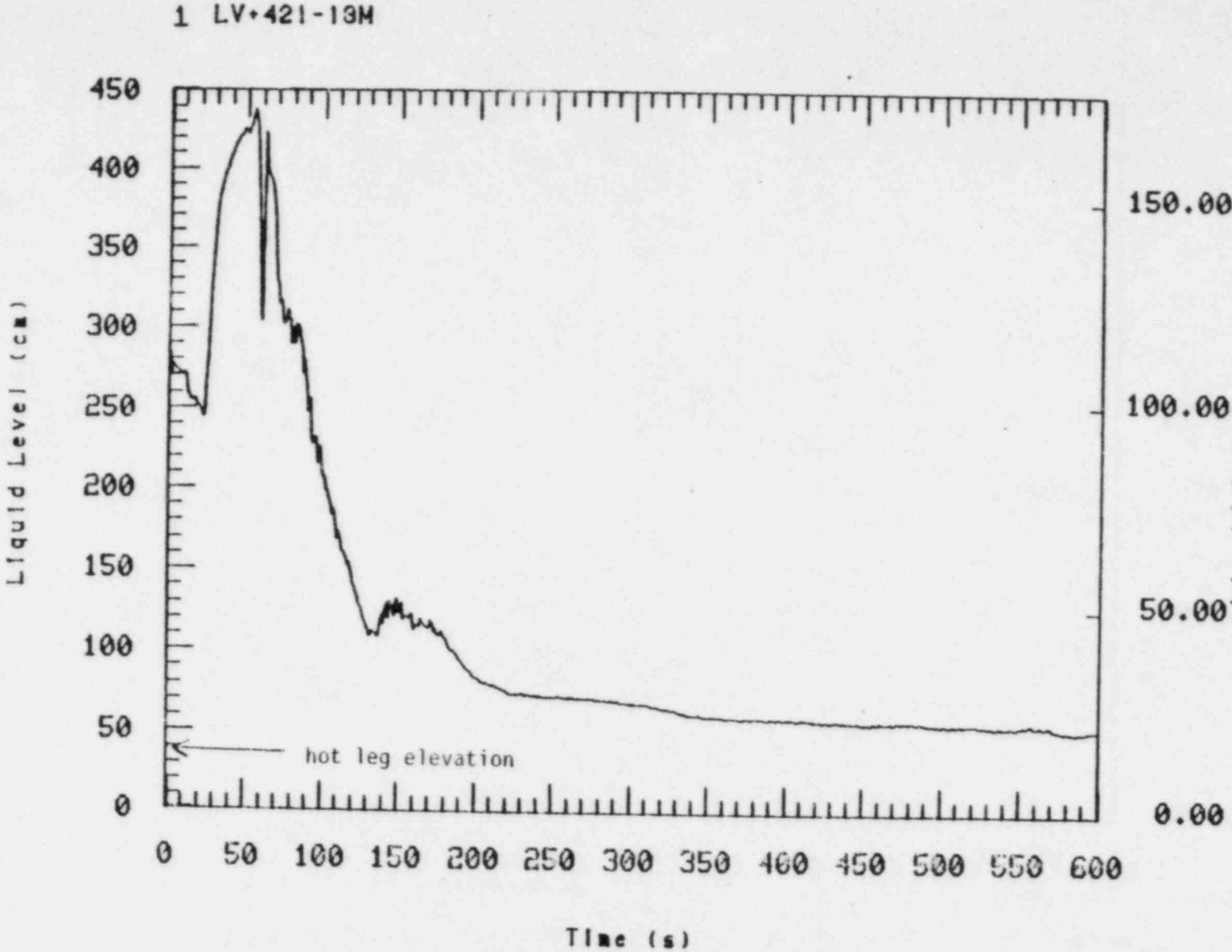


Figure 14. Vessel upper head collapsed liquid level during a five tube rupture transient (S-SG-2).

U-tube primary side collapsed liquid levels are shown on Figure 15. The readings showed essentially full tubes once the flow effects of pumped flow were removed, indicating there was little draining of the U-tubes due to break flow.

During the initial 600 s, the steam generator collapsed liquid level was affected by ADV flow and auxiliary feed flow in the unaffected loop; and break flow, ADV flow, and auxiliary feed flow in the affected loop. Figure 16 shows the collapsed liquid level in both the unaffected and affected loops. Following main steam isolation valve closure, the liquid level settled to a pool-type condition of about 900 cm (354 in.) in the unaffected loop steam generator and about 960 cm (377 in.) in the affected loop steam generator.[b] The affected steam generator collapsed liquid level continued to increase until about 600 s, when it was near the top differential pressure measurement tap [1117 cm (439 in.)]. Figure 17 shows that the break flow dominated the affected loop mass balance. There was a slight increase in unaffected steam generator liquid level during the initial 600 s period (Figure 16) as auxiliary feed flow added mass with no depletion due to lack of ADV operation (see Figure 18).

3.2 Recovery Phase Signature

The system recovery in Test S-SG-2 involved unaffected loop steam and feed, PORV operation, and termination of SI. Recovery in this sense meant reducing the primary pressure to the accumulator setpoint pressure, 4.22 MPa (612 psia). Recovery operation commenced at 600 s by operating the unaffected loop ADV to maintain a 0.227 MPa (33 psia) per 5 min. secondary depressurization rate as shown on Figure 7. This

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a. The indicated level during the first 50-100 s was influenced by frictional pressure drops and velocity effects on the differential pressure measurement. Once the loop pumps coasted down these flow effects were removed.

b. Prior to main steam isolation valve closure the liquid level was affected by flow affects in the secondary.

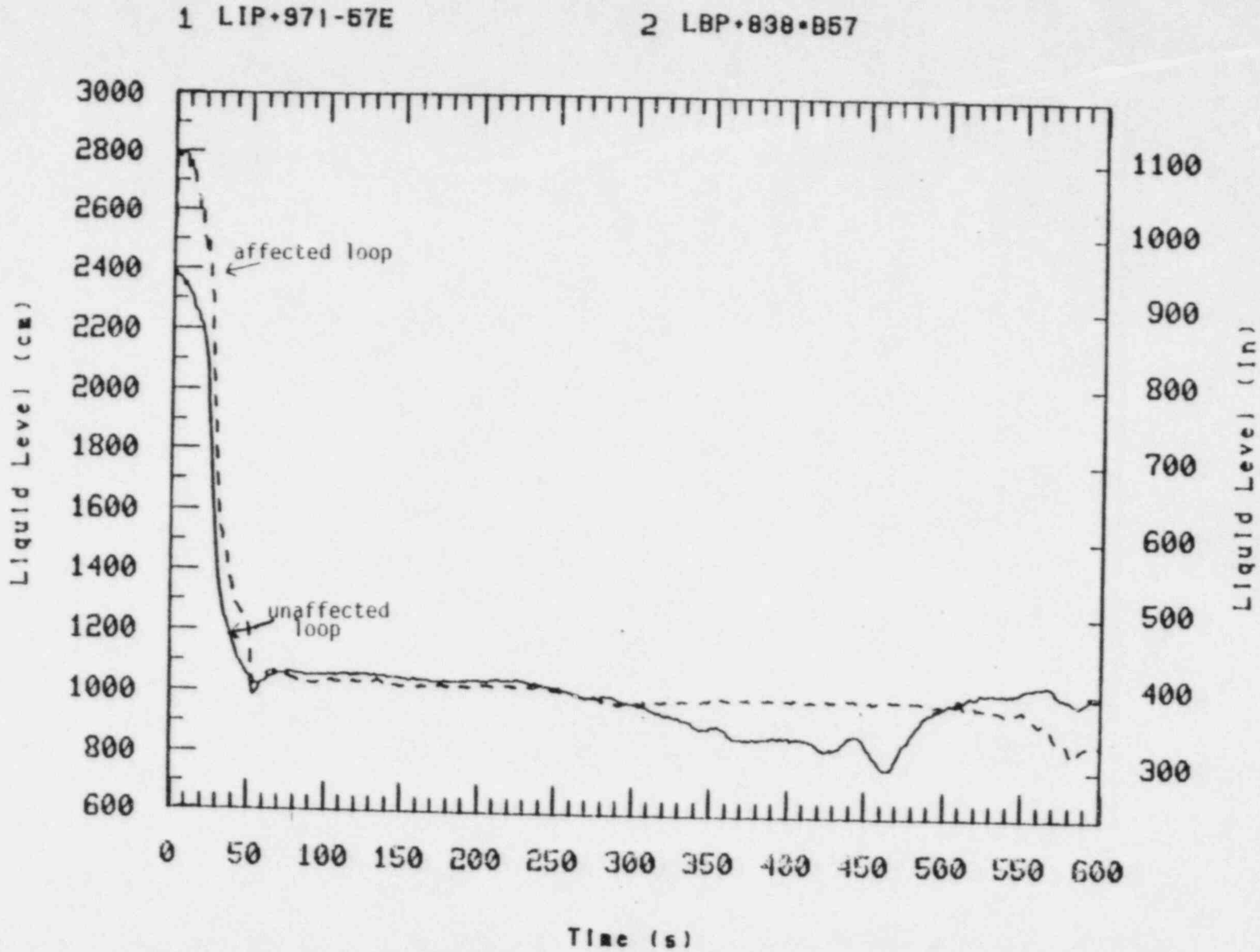

Figure 15. Affected and unaffected loop steam generator primary tube collapsed liquid level during a five tube rupture transient (S-SG-2).

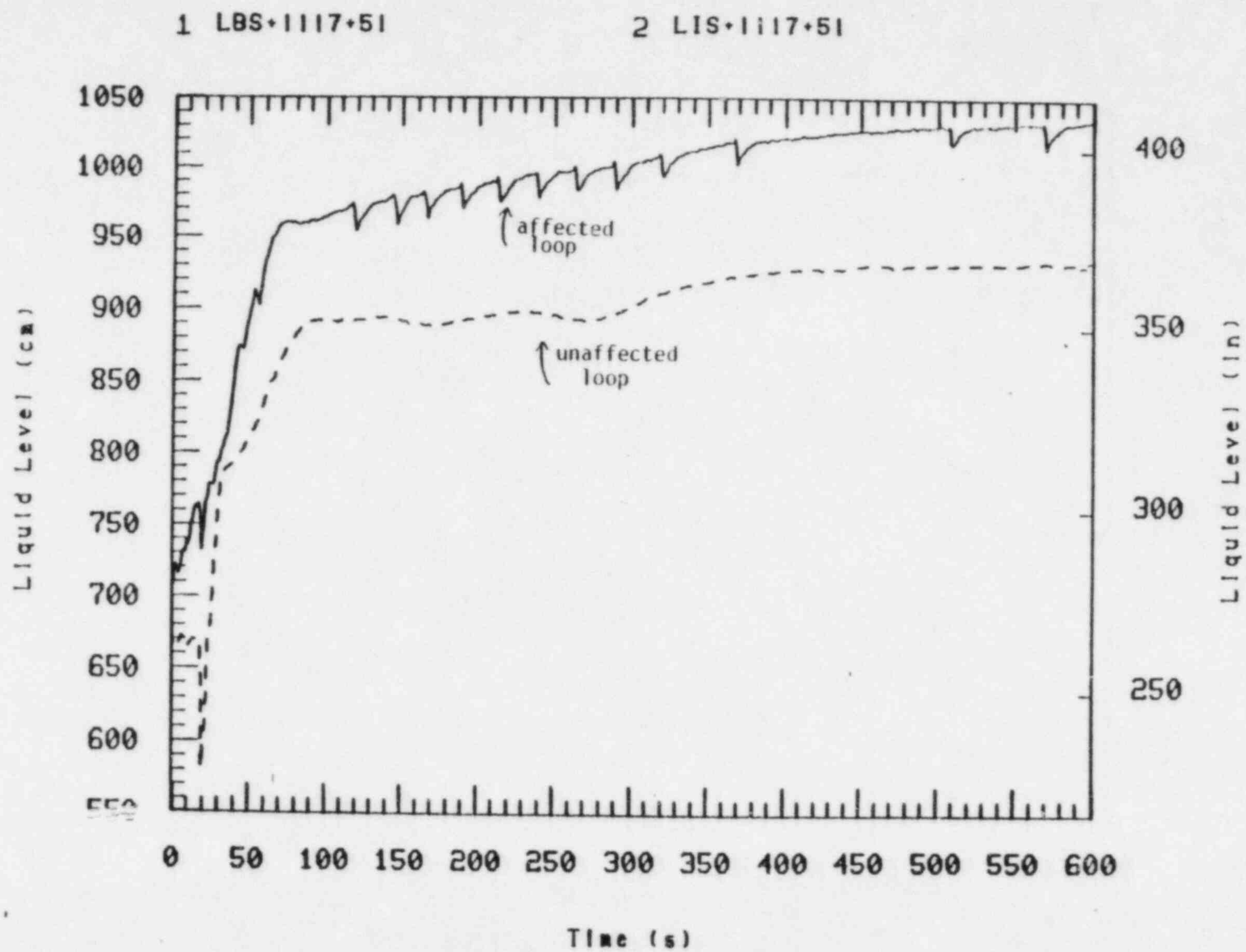

Figure 16. Collapsed liquid level in the affected and unaffected loop secondary during a five tube rupture transient (S-SG-2).

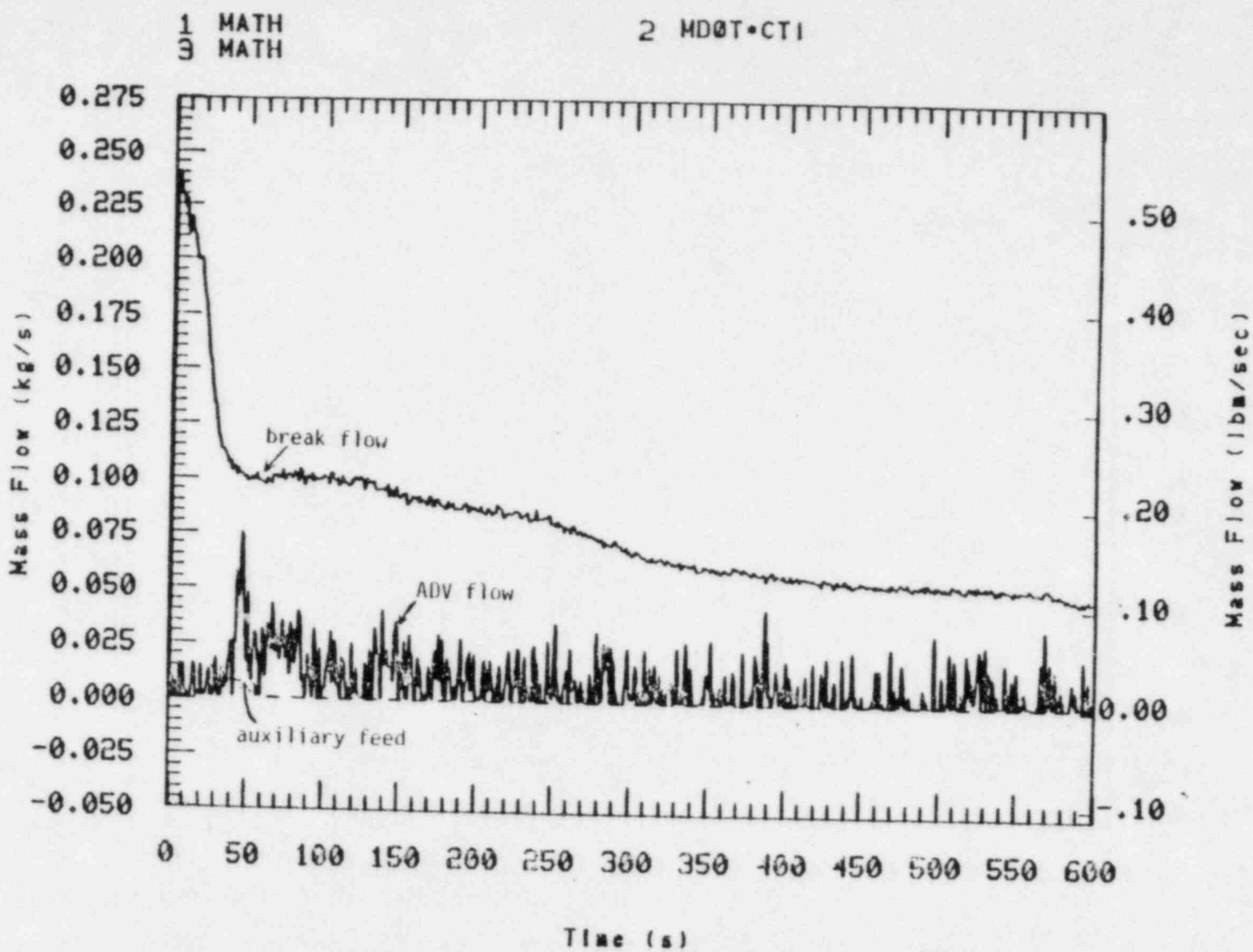

Figure 17. Comparison of break flow auxiliary feed and ADV flow in the affected loop steam generator during a five tube rupture transient (S-SG-2).

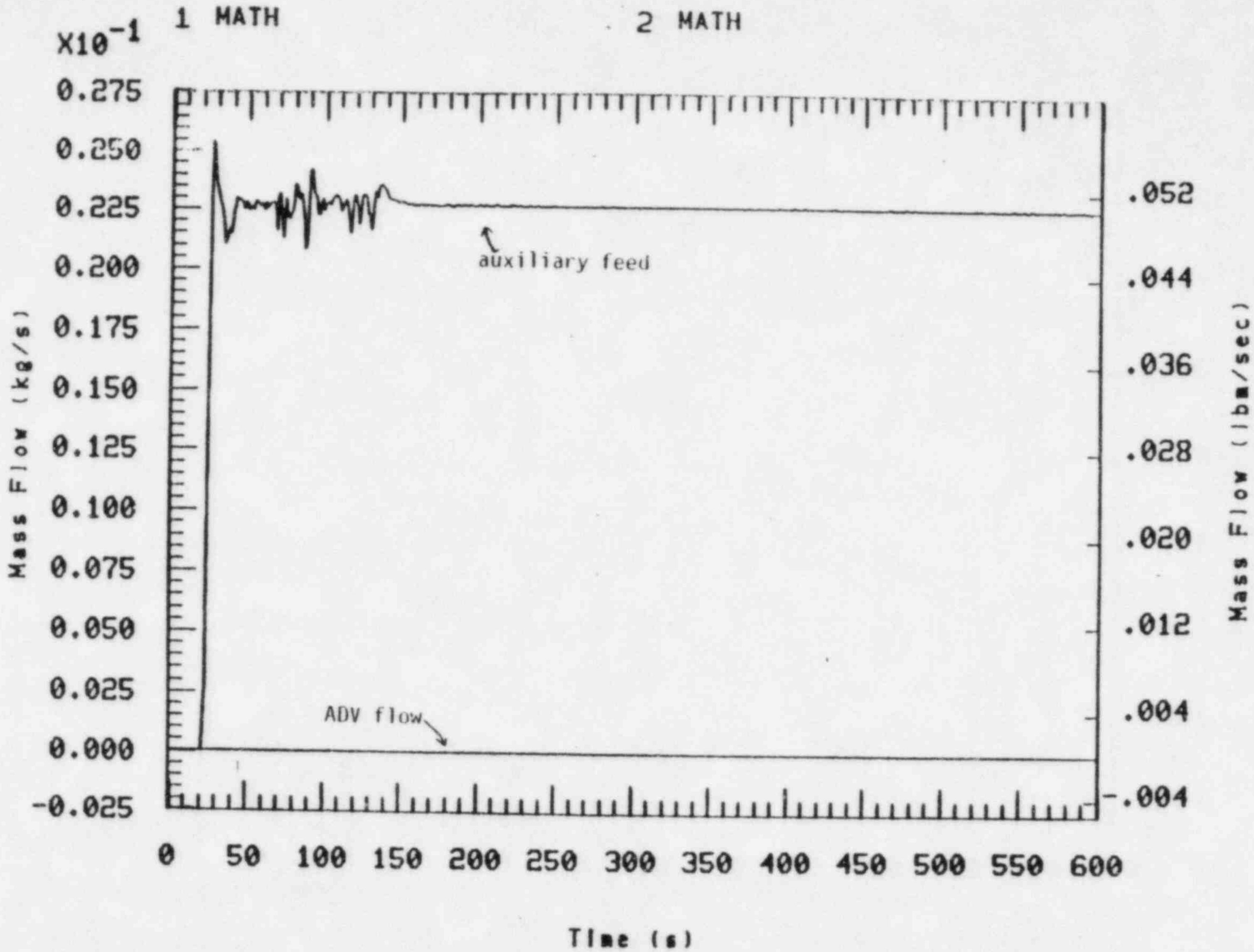

Figure 18. Comparison of auxiliary feed and ADV flow in the unaffected loop secondary during a five tube rupture transient (S-SG-2).

depressurization increased the heat sink between the primary and secondary and thus hastened the primary depressurization rate. To aid in this operation, pressurizer PORV operation commenced when the unaffected loop secondary pressure was 0.344 MPa (50 psi) less than the primary pressure. The PORV was closed if the primary pressure was reduced to within 0.206 MPa (30 psi) of the unaffected loop secondary pressure. This operation persisted until the pressurizer collapsed liquid level reached 475 cm (187 in.). SI was terminated in the test when the vessel level was above 291 cm (115 in.). The test was terminated when the primary pressure dropped to 4.22 MPa (612 psia).

3.2.1 Overall System Response to the Combined Recovery Methods

The overall system response to the combined recovery methods, including unaffected loop steam and feed, pressurizer PORV operation, and SI termination, was a slow depressurization ($\sim 3.13 \times 10^{-4}$ MPa/s (163 psi/hr)) of the primary system (see Figure 19). Figure 19 shows that the unaffected loop secondary depressurized at the specified 0.227 MPa (33 psia) per 5 min. rate while the primary system and affected loop secondary essentially depressurized together.

Two possible explanations exist for the close coupling of primary and affected loop secondary pressure: (a) the two systems were hydraulically coupled as a single liquid-filled system by the break, the depressurization being caused by primary-to-unaffected loop secondary heat transfer, and/or (b) core decay heat was exactly removed by primary-to-unaffected loop secondary heat transfer, while affected loop secondary heat loss caused a secondary depressurization which provided the heat sink for a long term primary depressurization.

The affected steam generator secondary level was above the 1117 cm (439 in.) level measurement tap for most of the recovery procedure (see Figure 20). It was possible, therefore, that the primary and affected loop secondary systems were nearly liquid solid for much of the transient. However, the increase in primary pressure occurring at about 2300 s was not followed by the affected loop secondary pressure, suggesting that the two

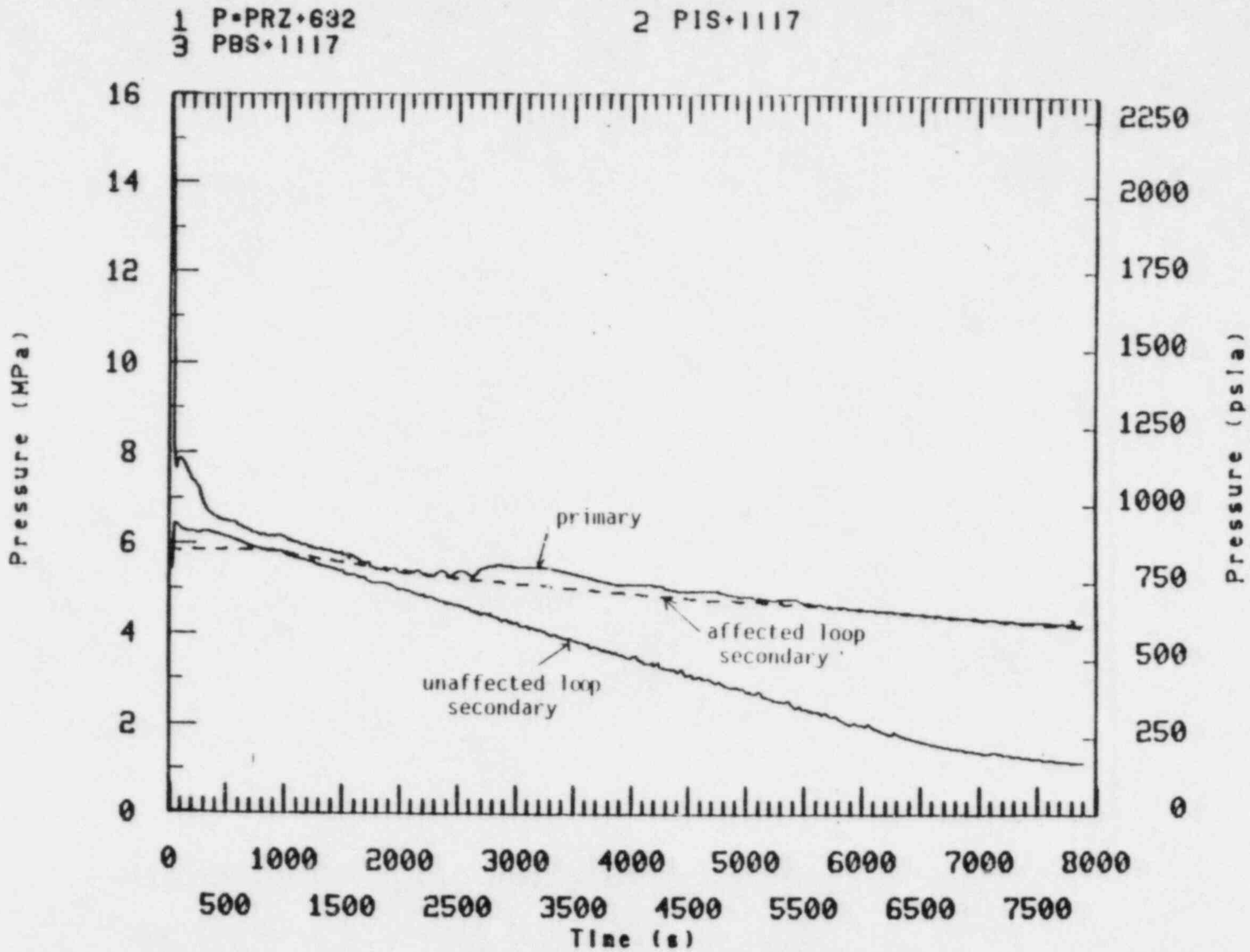

Figure 19. Comparison of primary and secondary pressure during a five tube rupture transient (S-SG-2).

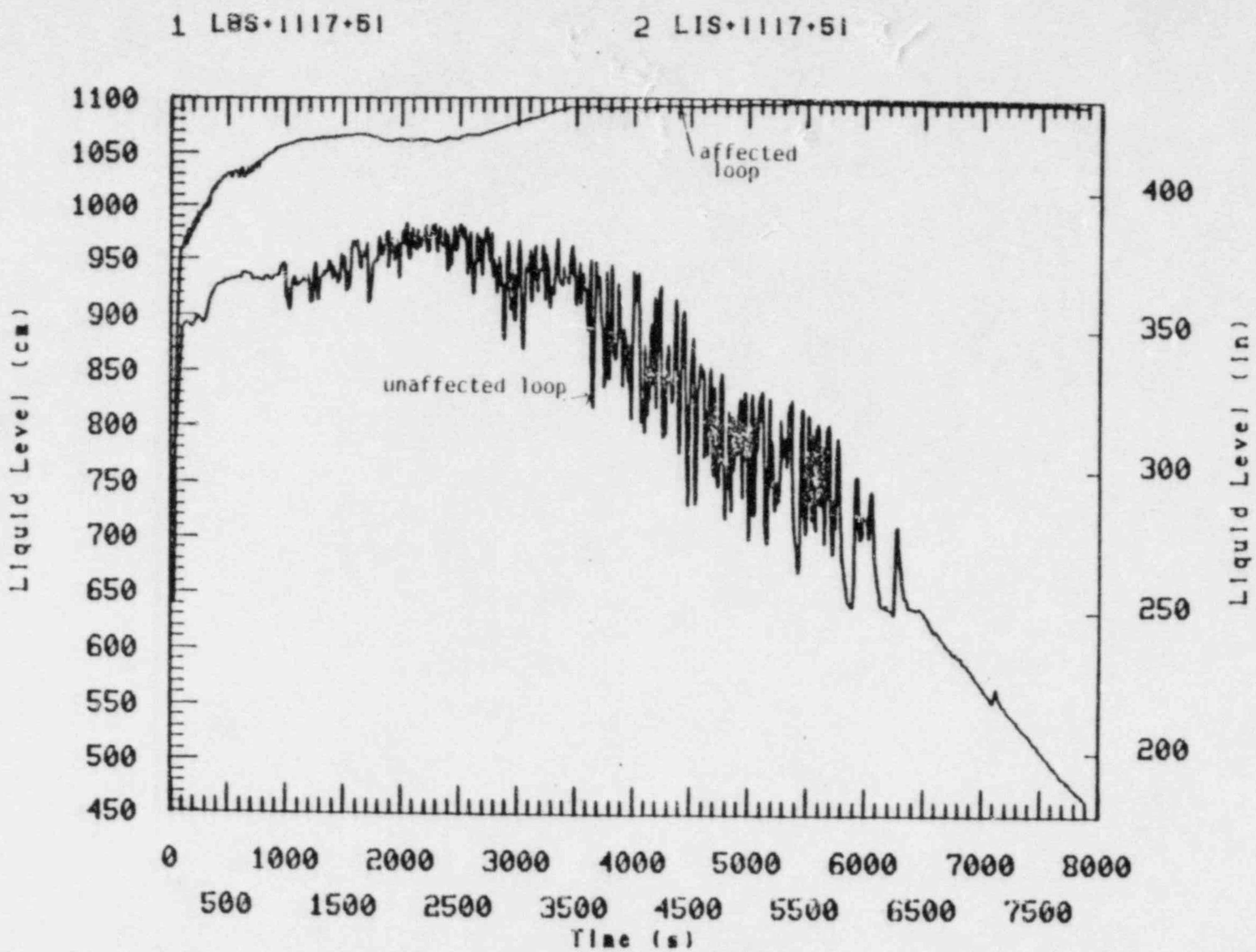

Figure 20. Comparison of affected and unaffected loop steam generator secondary collapsed liquid levels for a five tube rupture transient (S-SG-2).

systems were not strongly coupled. Explanations for the degree of coupling between primary and affected loop secondary pressures will be examined in the post series analysis.

The individual effects of unaffected loop steam and feed, PORV operation, and SI termination will be discussed in detail in the following sections.

3.2.2 Effect of Unaffected Loop Steam and Feed on Primary System Depressurization

At 600 s, a controlled depressurization of the unaffected loop secondary at 0.227 MPa (33 psia)/5 min. was initiated (see Figure 21). This depressurization rate was accomplished by operating the ADV as necessary. Because the initial unaffected loop secondary depressurization rate was approximately 0.227 MPa (33 psia)/5 min., the first ADV operation wasn't required until several hundred seconds later. Prior to the initial unaffected loop ADV operation at about 950 s, the primary pressure seemed to follow the decrease in the unaffected loop secondary pressure (see Figure 22). The unaffected loop secondary pressure was being reduced by secondary heat loss (approximately 7 kW[5]) and injection of cold auxiliary feedwater. Duing this same period, the primary pressure was reduced by a combination of break flow to the affected loop secondary, SI injection of subcooled water, and primary-to-secondary heat transfer in both steam generators.

At about 950 s, a series of unaffected loop ADV operations commenced. The primary pressure continued to follow the unaffected loop secondary pressure during this period of ADV operation until PORV operation commenced at 1574 s. Although it is clear that unaffected loop ADV operation influenced the primary depressurization, the depressurization was also influenced by break flow, SI, and affected loop primary to secondary heat transfer. Further analysis is required to determine the precise role of unaffected loop depressurization alone.

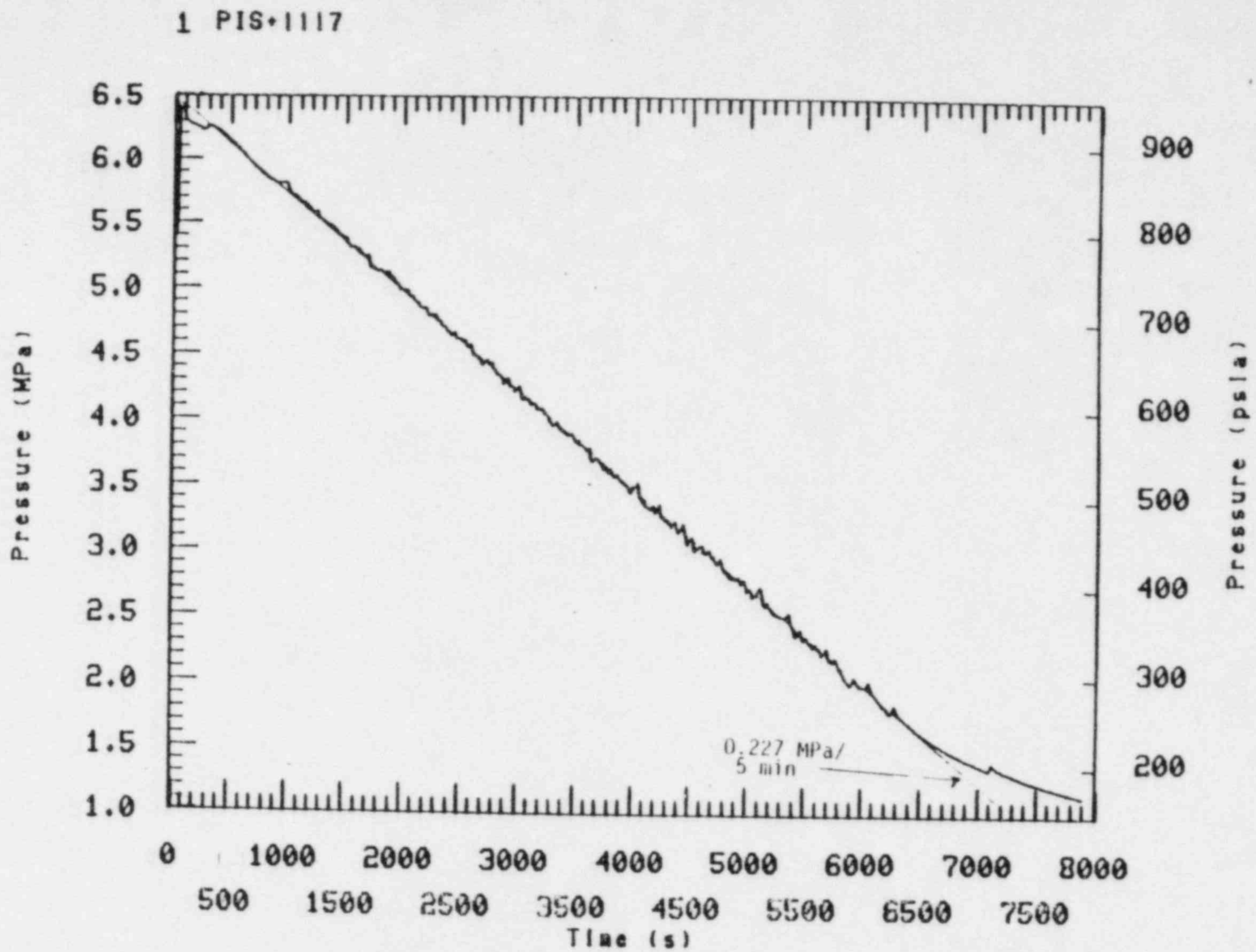

Figure 21. Comparison of desired and actual unaffected loop depressurization for a five tube rupture transient (S-SG-2).

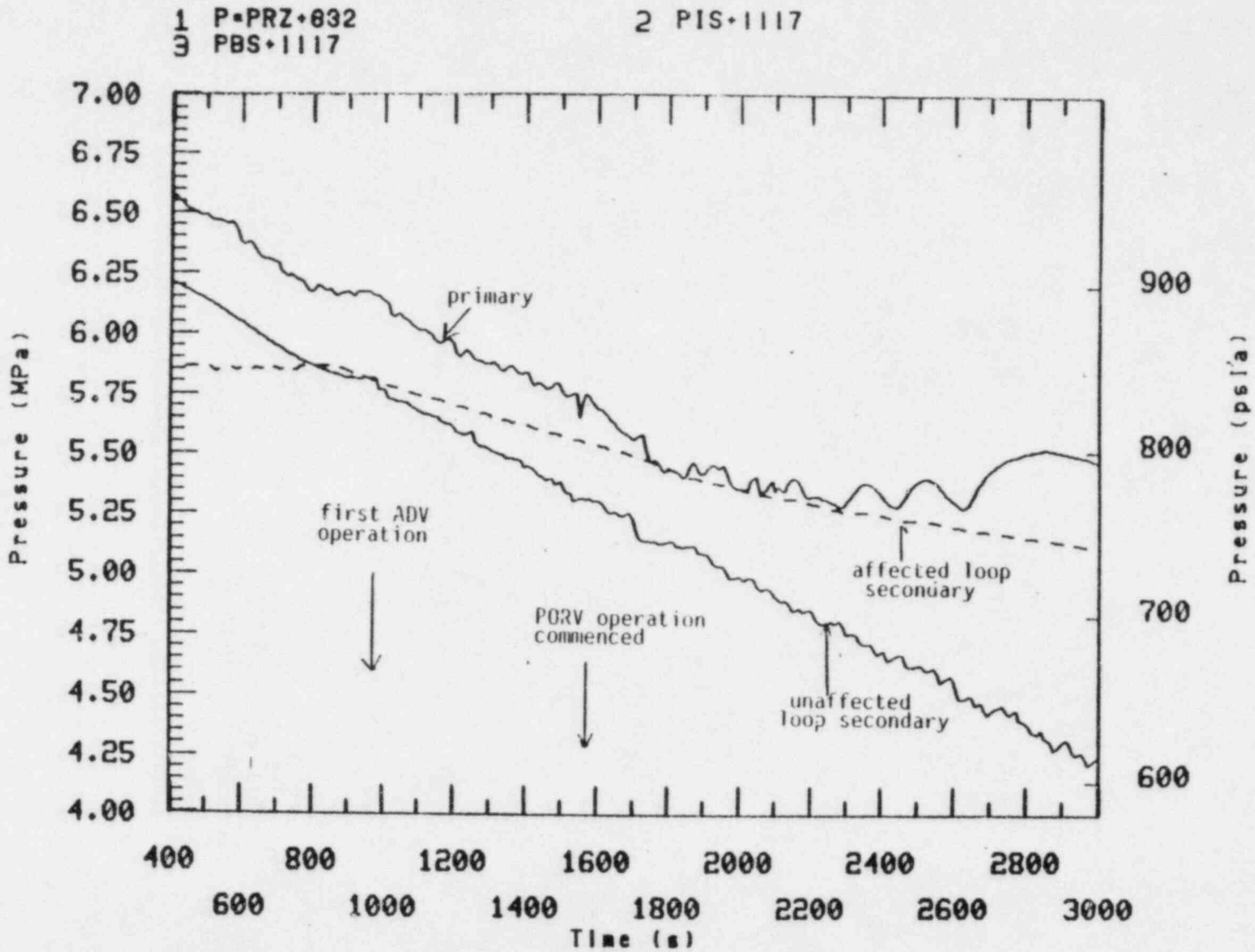

Figure 22. Comparison of primary and secondary pressure during unaffected loop secondary feed and bleed (S-SG-2).

3.2.3 Effect of Pressurizer PORV Operation on System Depressurization

The pressurizer PORV operation was specified to maintain the primary pressure within 0.206-0.344 MPa (30-50 psi) of the unaffected loop secondary pressure. In addition, PORV operation was to be terminated if the pressurizer collapsed liquid level was above 475 cm (187 in.).

The main effect of PORV operation on the system response was to fill the pressurizer, which eventually led to a primary system pressurization. Figure 23 shows that following PORV opening at 1574 s, the primary pressure showed only a slight increase in depressurization rate as steam flowed out the top of the pressurizer. With SI dominating the system mass balance and PORV flow in the pressurizer, the pressurizer quickly filled with liquid as shown in Figure 24. PORV flow was terminated at about 2260 s. During this period, the primary pressure dropped below the affected loop secondary pressure and caused backflow from the affected loop generator to the primary (see Figure 25).

Continued SI flow compressed the steam bubble in the pressurizer and the vessel upper head, which led to a system pressurization as discussed in the next section. It is not clear that PORV operation actually aided the overall recovery because the rapid filling of the pressurizer led to a pressurization of the primary system.

3.2.4 Effect of SI on Primary System Pressure

SI operation dominated the system mass balance and had a large effect on system pressure during the recovery phase. Figure 26 compares primary pressure and affected loop secondary pressure during a time period when SI was terminated and restarted. The figure shows a pressurization of the primary system, starting at about 2200 s, caused by SI pumping against a nearly liquid-full system. Figure 27 shows the collapsed liquid level in the pressurizer and vessel upper head during this same period. As the presssurizer level approached 500 cm (197 in), at about 2200 s, the primary pressure began to increase as SI flow compressed the bubble in both the vessel upper head and pressurizer.

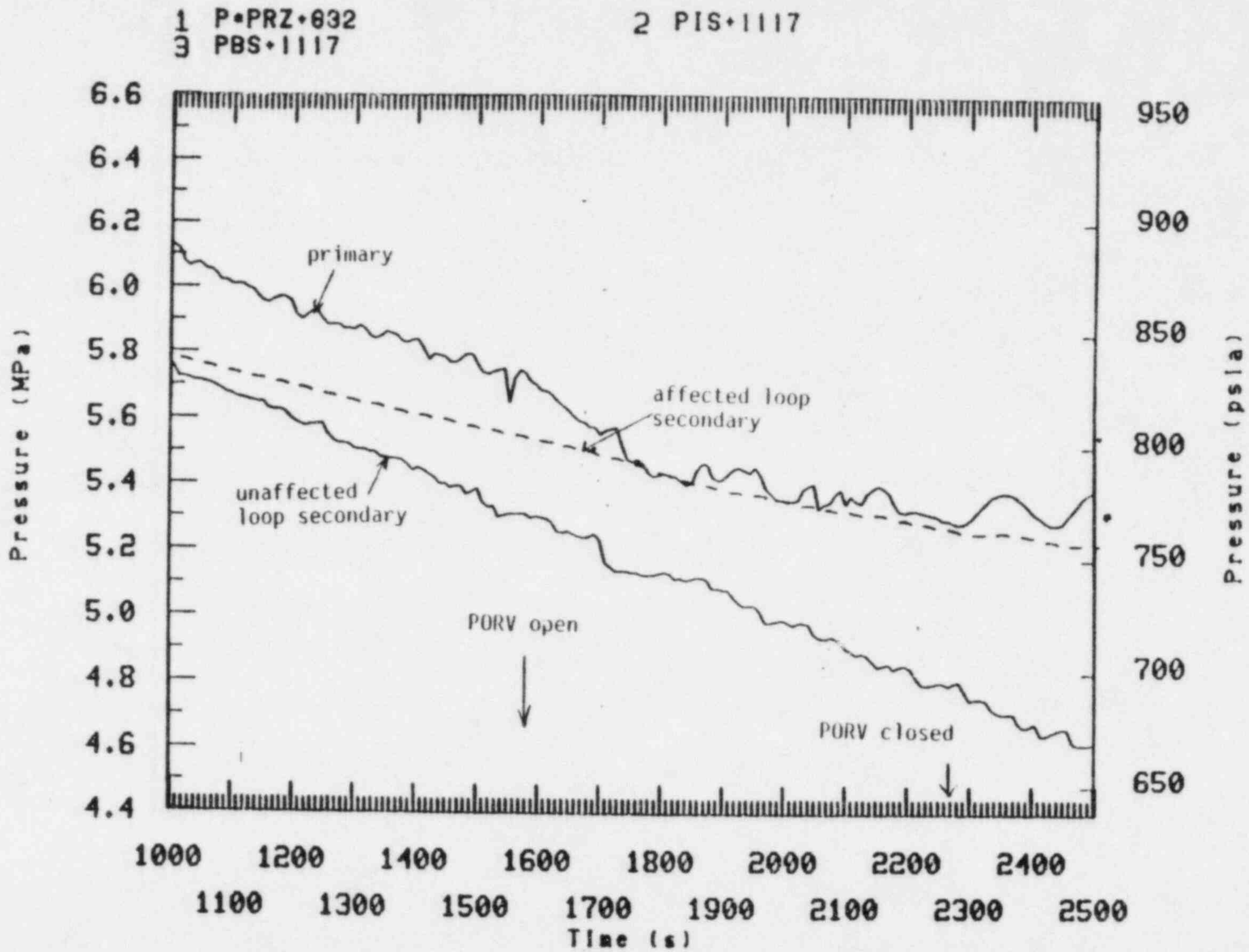

Figure 23. Comparison of primary and secondary pressures during PORV operation (S-SG-2).

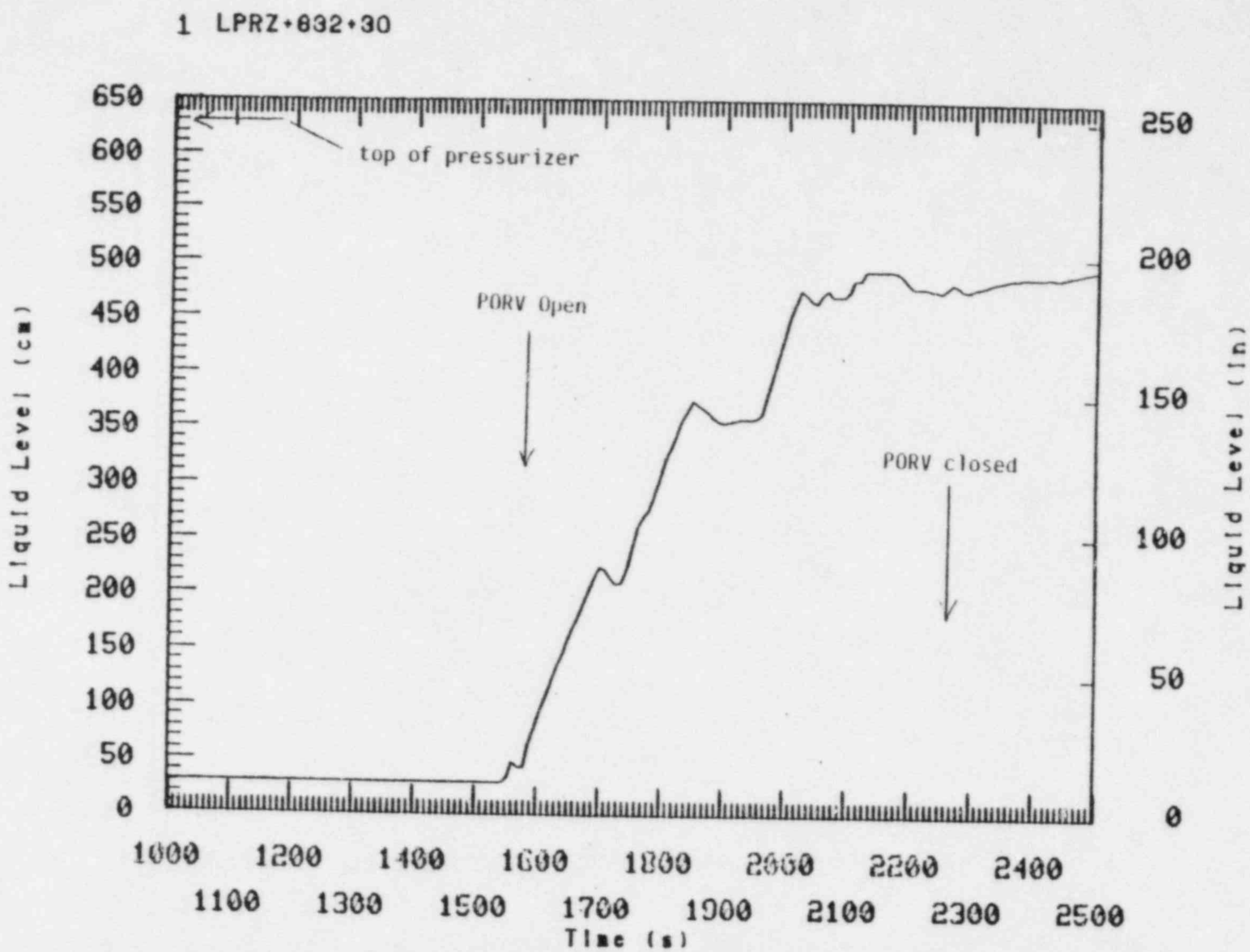

Figure 24. Pressurizer collapsed liquid level (S-SG-2).

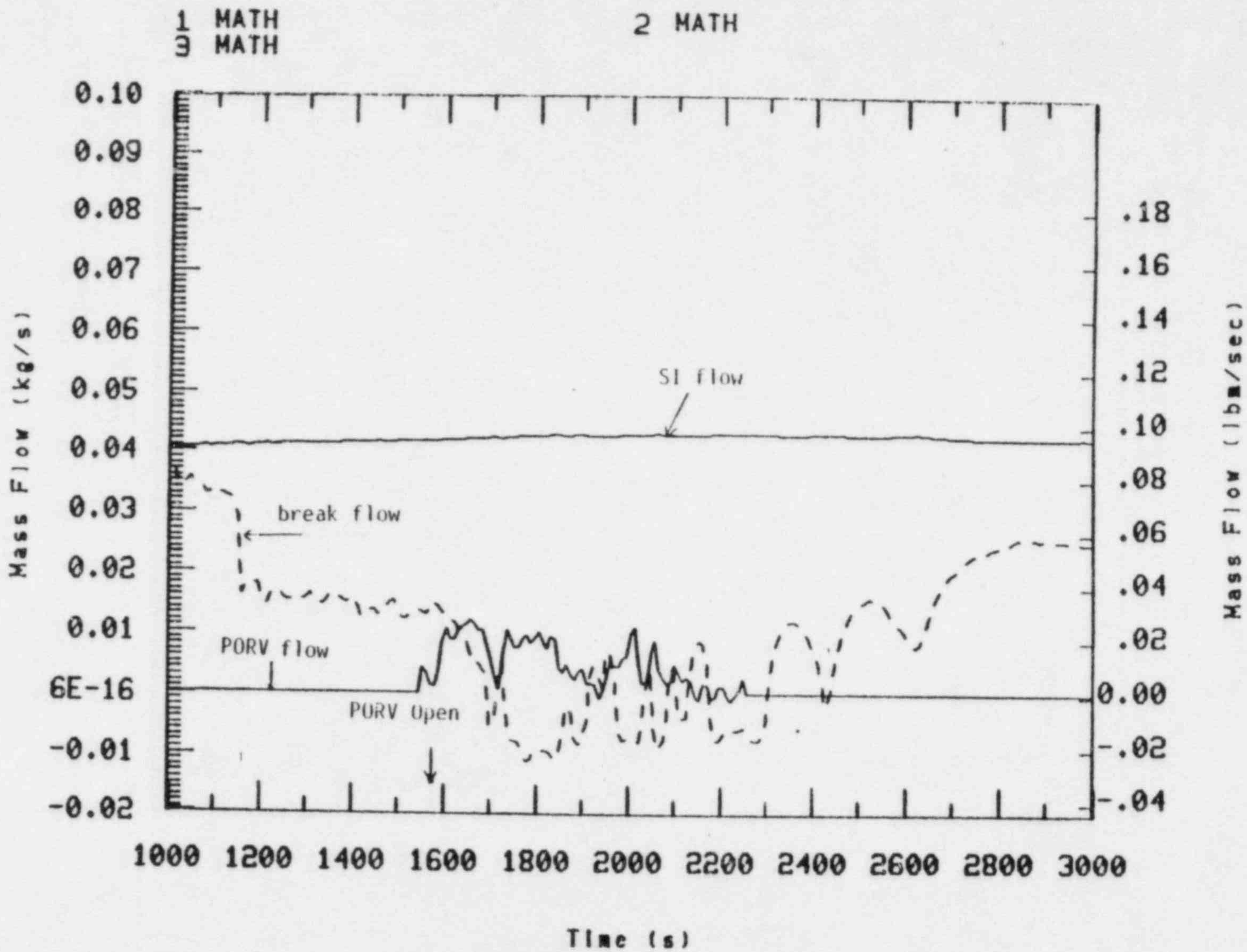

Figure 25. Comparison of break flow, SI flow, and PORV flow during S-SG-2 (S-SG-2).

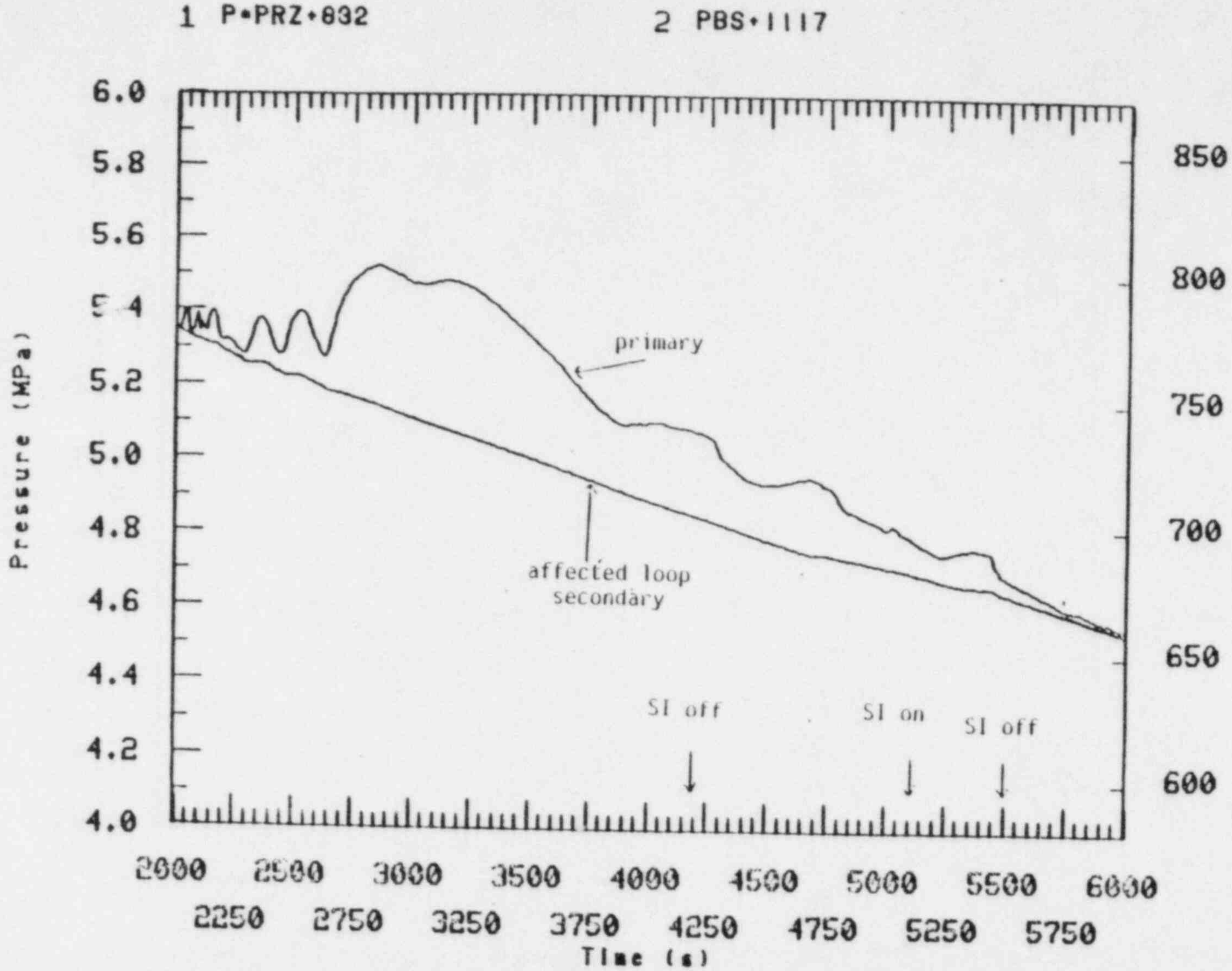

Figure 26. Comparison of primary and affected loop secondary pressure during SI termination (S-SG-2).

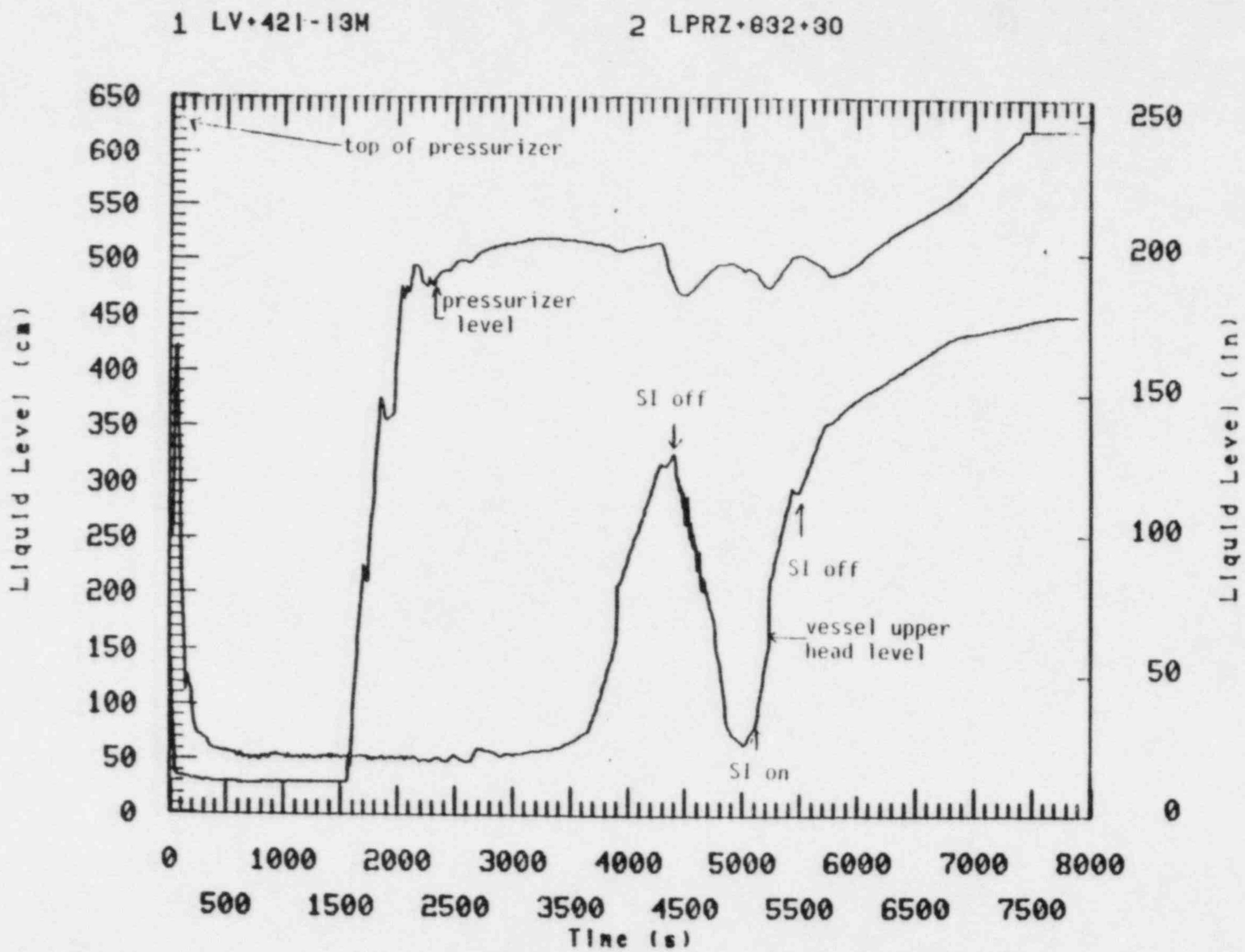

Figure 27. Pressurizer and vessel upper head collapsed liquid level (S-SG-2).

Prior to terminating SI, the system pressure began decreasing (see Figure 26) during a period of an increasing vessel upper head level (see Figure 27). By itself, the increasing vessel upper head level would have caused a primary system pressurization. However, positive break flow was reestablished (see Figure 28). The combined effects of SI subcooling and break flow apparently were sufficient to cause the pressure decrease. Terminating SI at 4382 s on a simultaneous high pressurizer and high vessel upper head level resulted in no change in primary depressurization (see Figure 26), but led to a relatively rapid decrease in vessel upper head level. The vessel level dropped because of positive break flow depleting the primary inventory. When the vessel upper head had depleted to near the level of the hot leg, SI was turned on and caused an immediate increase in vessel upper head level (see Figure 27). At 5539 s, SI was terminated and remained off for the remainder of the experiment. Both the vessel and upper head levels continued to increase as primary pressure had decreased to below the affected loop secondary pressure, allowing secondary fluid to flow into the primary as shown on Figure 28. During this period of negative break flow, the primary and affected loop secondary pressures both decreased to the 4.22 MPa (612 psia) accumulator setpoint. This decrease in pressure was caused by the unaffected loop secondary heat sink and natural circulation in the unaffected loop.

Overall, SI eventually caused a primary pressurization once the primary inventory had increased to the point where there was only a small steam space to compress in both the pressurizer and vessel upper head. Termination of SI allowed a decrease in primary pressure to the accumulator setpoint pressure of 4.22 MPa (612 psia).

3.3 Comparison of System Response for a One and Five Tube Break (0 to 600 s)

This section compares the early-in-time response (0 to 600 s) of system pressures and mass inventories in the one-tube (S-SG-1B)[6] and five-tube (S-SG-2) rupture experiments. Initial conditions in the two experiments were nearly identical except for steam generator secondary mass inventories. S-SG-1B (1-tube) had in excess of 188 kg in each generator,

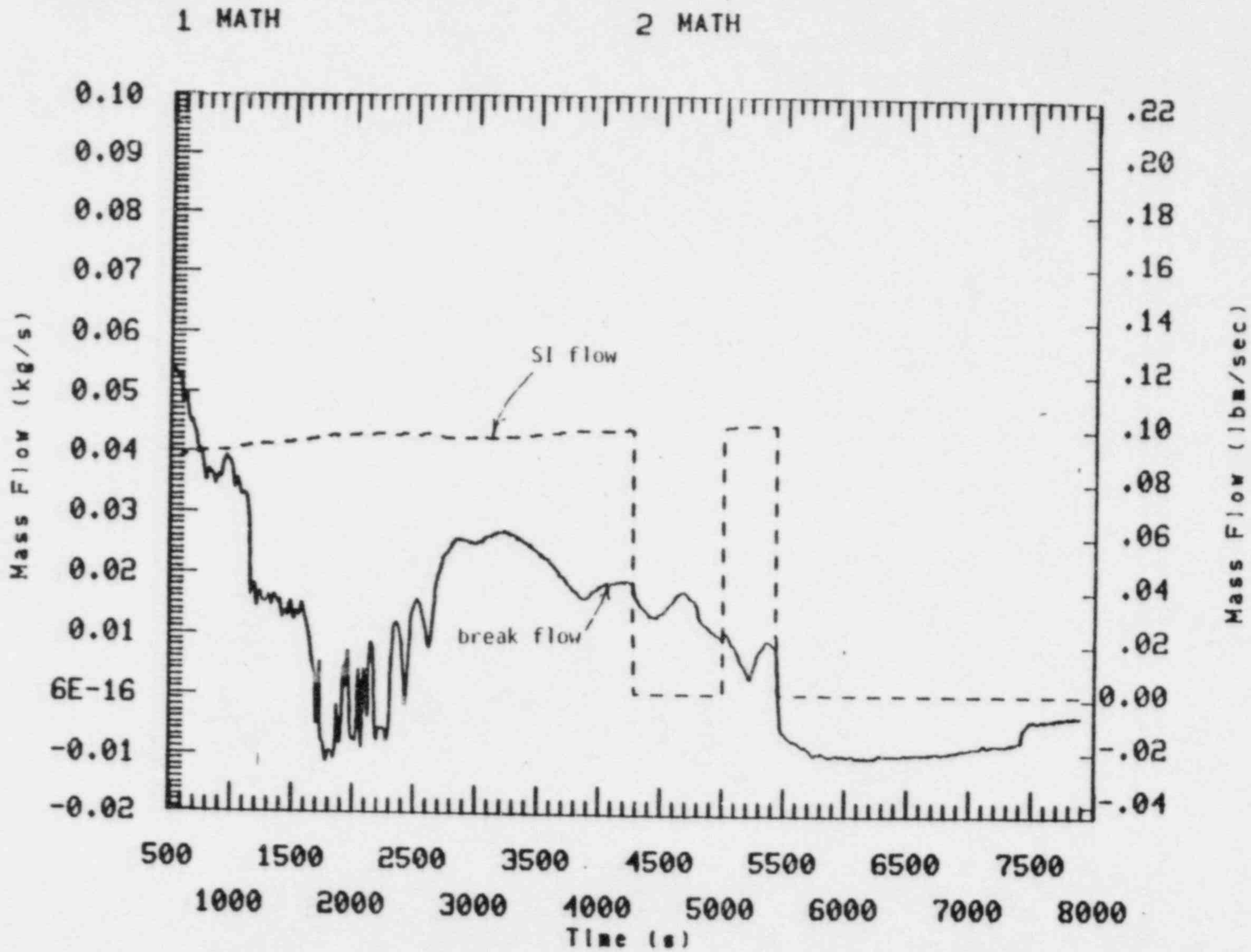

Figure 28. Comparison of break flow and SI during a five tube rupture transient (S-SG-2).

whereas S-SG-2 had between 100 and 136 kg in each generator. These differences are not considered significant enough to impair comparison between the basic signature responses.

The overall system responses of a one-tube and a five-tube rupture are quite similar. The influence of break size on the early primary system pressure response was principally one of timing, as shown in Figure 29. As expected, the five-tube rupture showed a more rapid depressurization, but a pressure response with the same characteristic shape as the one-tube rupture. The similarity in response was also seen in the pressurizer collapsed liquid level (Figure 30) and the secondary pressures in the steam generators (Figure 31).

The fundamental difference between the one-tube and five-tube ruptures was the relationship between break flow and SI flow. Figure 32 compares the vessel upper head collapsed liquid level for the one- and five-tube cases showing an essentially empty upper head for the five-tube case and a nearly full upper head for the one-tube case. The more extensive voiding observed with the five-tube rupture was a direct result of the break flow exceeding SI flow for the entire 600 s period preceding direct operator action (see Figure 33). In contrast, Test S-SG-1 showed SI flow exceeding break flow approximately 90 s after the rupture occurred.[6] The effect of the difference in break flow was a minimal amount of system voiding in S-SG-1 and a much earlier influence of the pressurizer as it started to refill from SI. Subsequent recovery of the Semiscale system during one tube breaks with SI are therefore more influenced by pressurizer filling than five tube breaks. Posttest analysis will address the comparison of early-in-time pressurizer response for various break sizes.

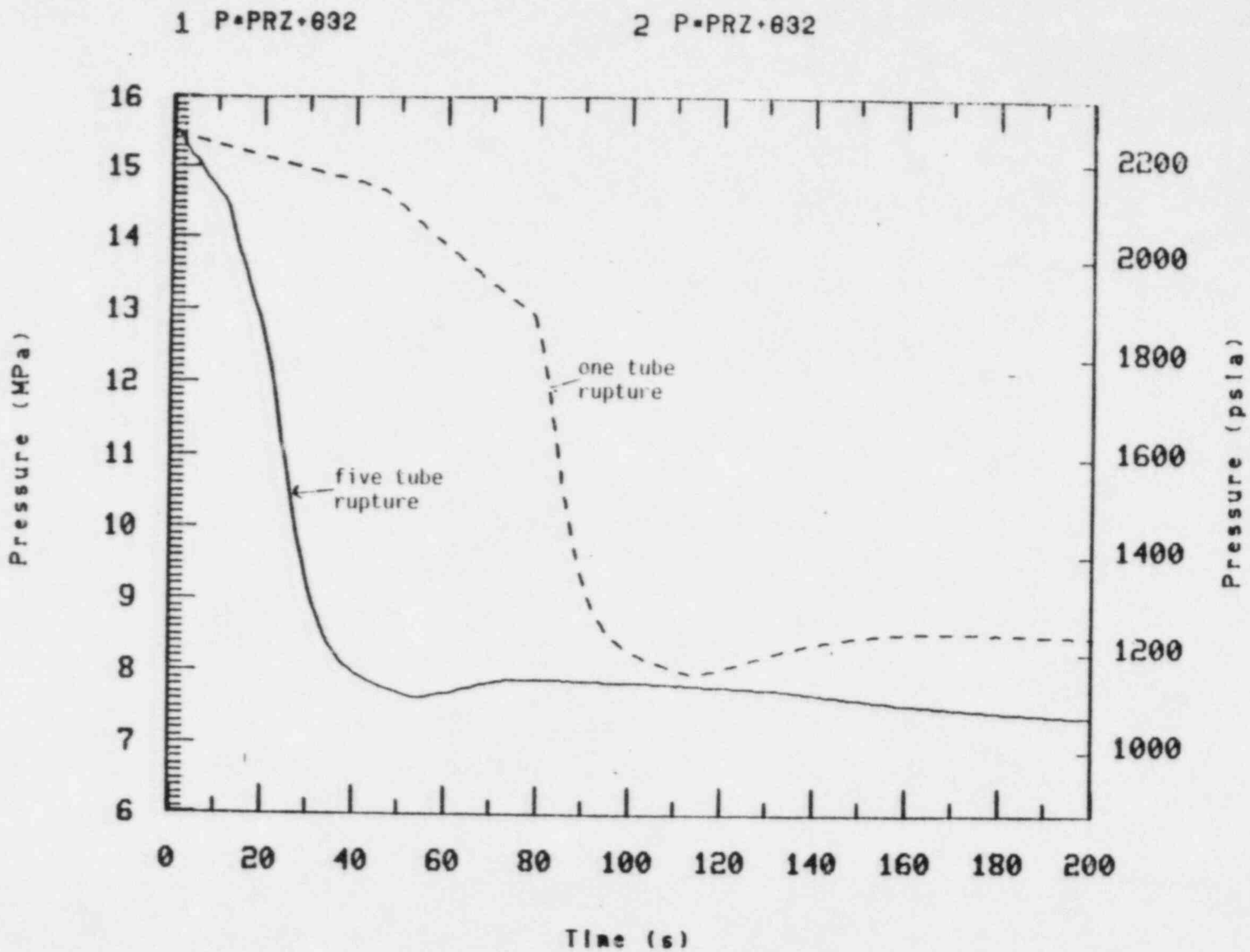

Figure 29. Comparison of primary pressure response for a one tube (S-SG-1) and five tube (S-SG-2) rupture transient.

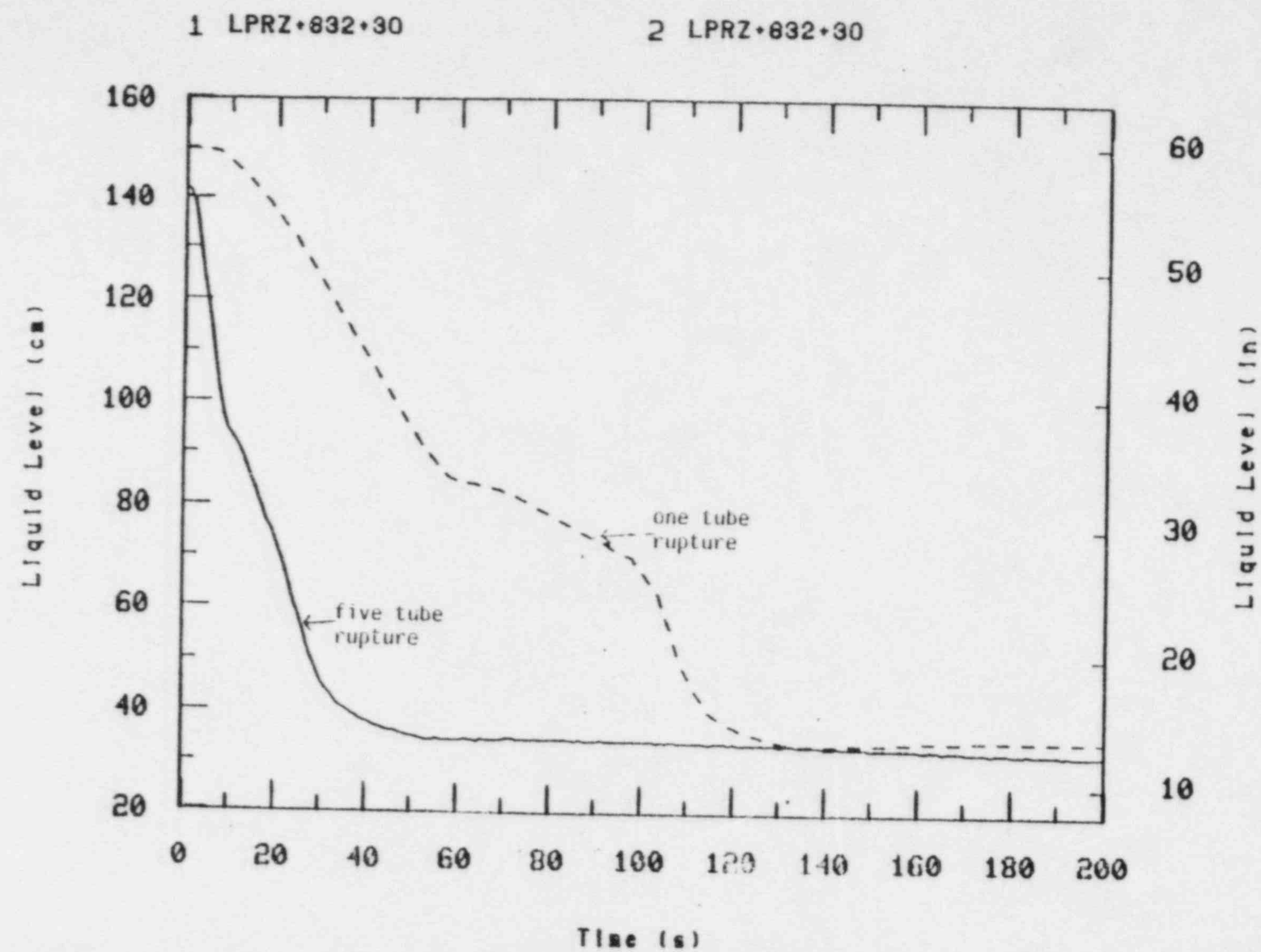

Figure 30. Comparison of pressurizer collapsed liquid level for a one tube (S-SG-1) and five tube (S-SG-2) rupture transient.

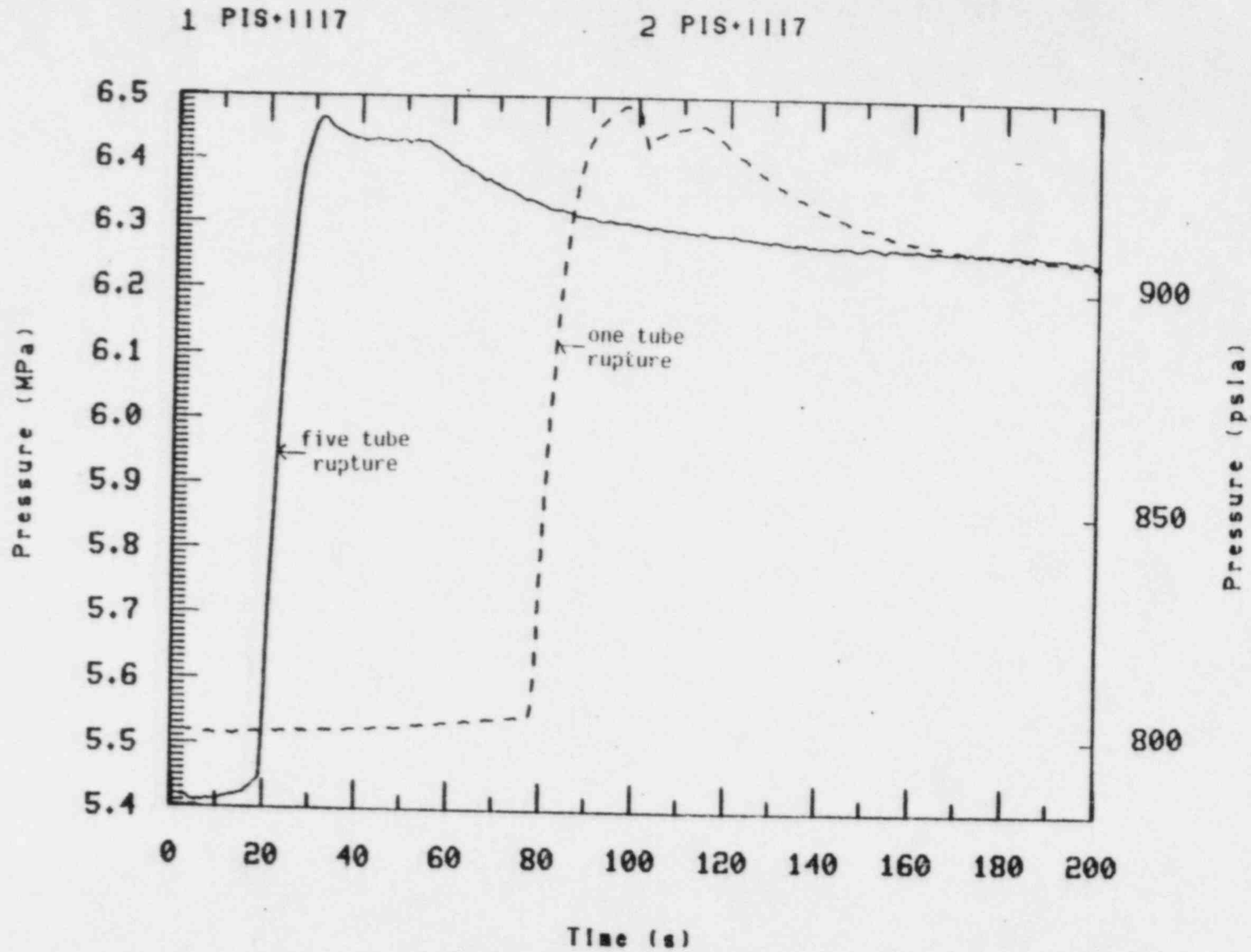

Figure 31. Comparison of the unaffected loop secondary pressure for a one tube (S-SG-1) and five tube (S-SG-2) transient.

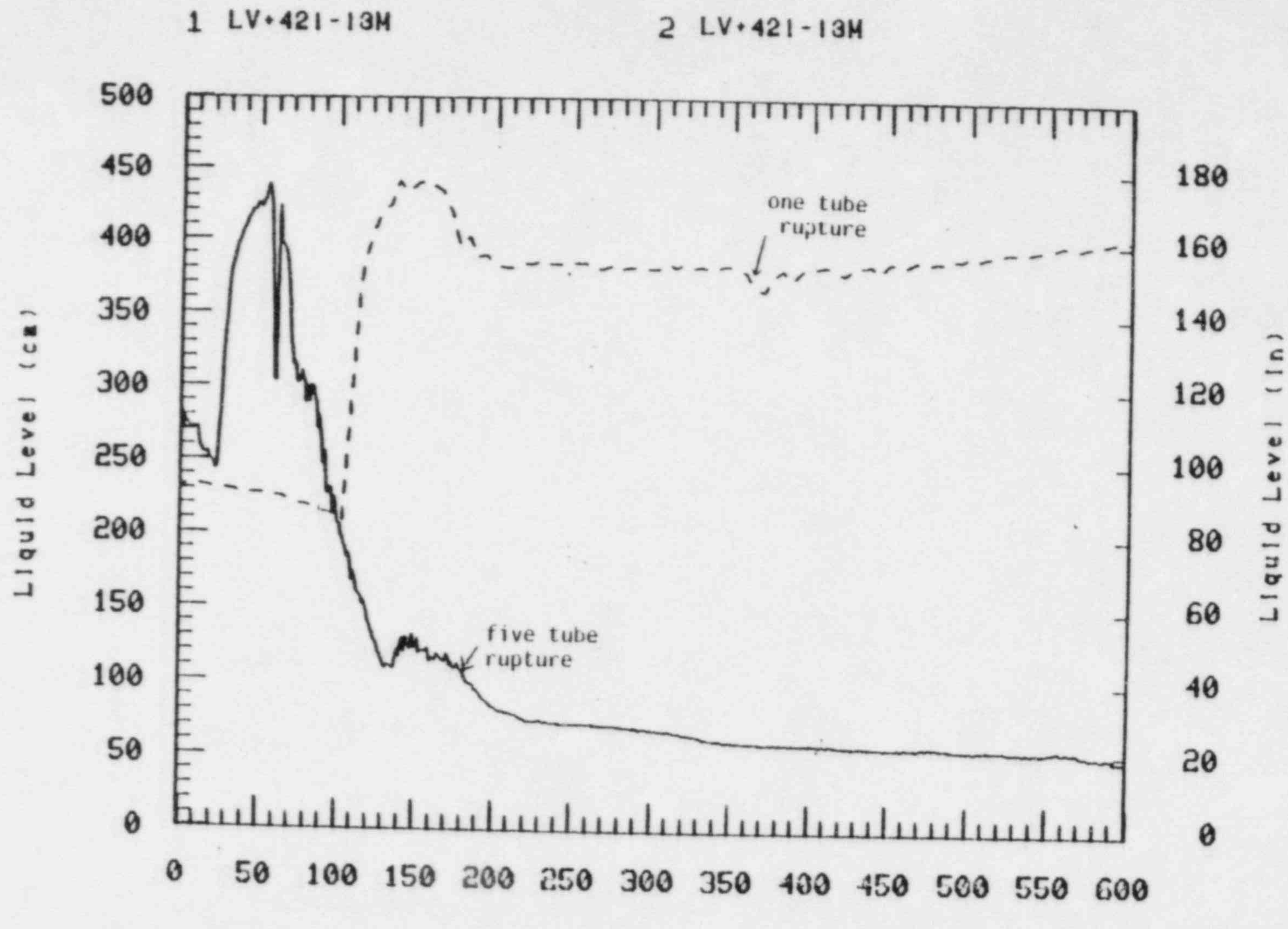

Figure 32. Comparison of the vessel upper head collapsed liquid level for a one tube (S-SG-1) and five tube (S-SG-2) rupture transient.

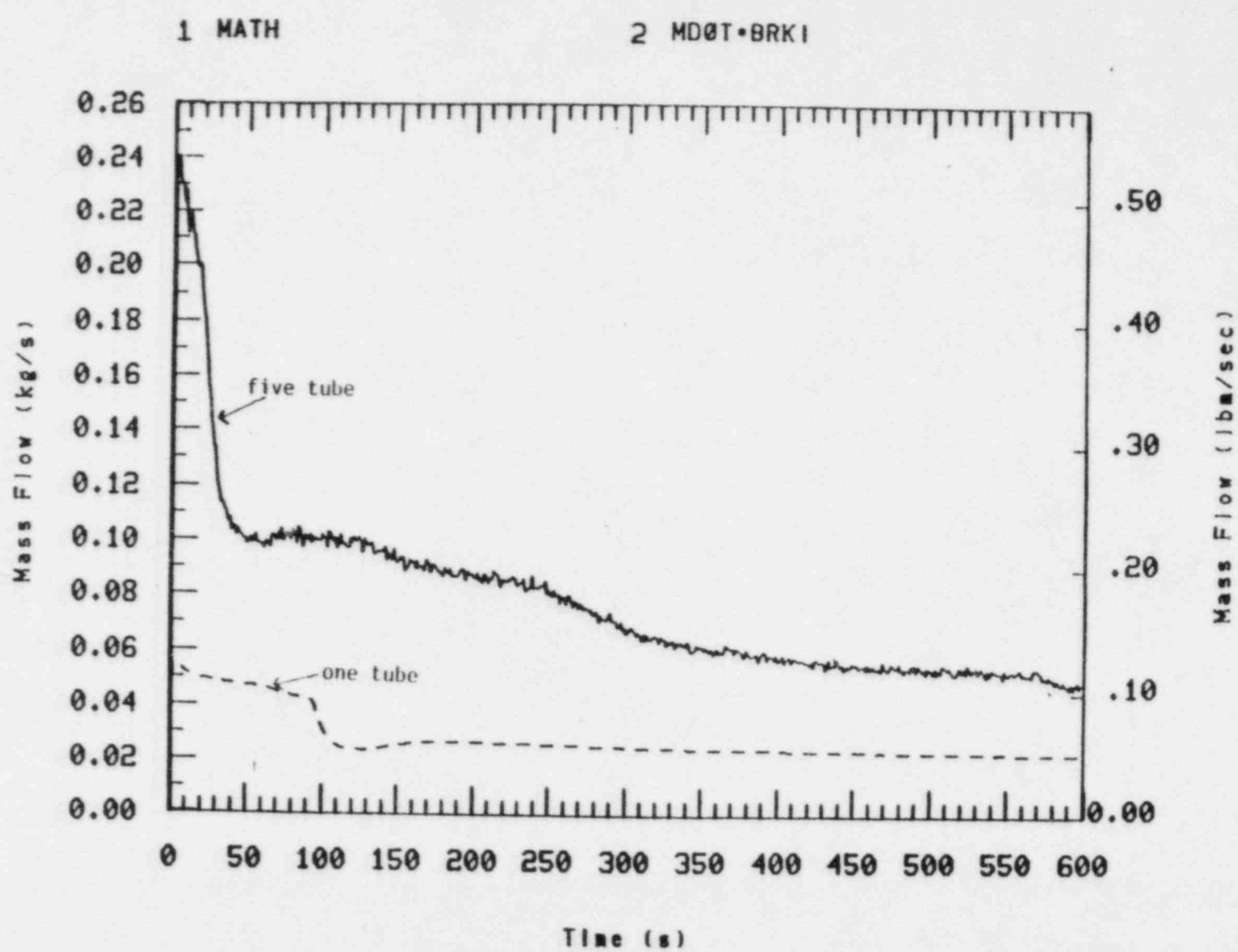

Figure 33. Comparison of break flow for a one (S-SG-1) and five tube (S-SG-2) rupture transient.

4. COMPARISON TO THE PAD CALCULATION

This section compares the test results to the PAD calculation[7] for Test S-SG-2. Included in this section is a comparison of the calculation and test results for the first 600 s of the experiment when only automatic plant responses were functioning, as well as the calculated and experimental results during the recovery phase. Table 3 compares the actual and calculated initial conditions and Table 4 compares the actual and calculated sequence of events.

4.1 Operator Diagnostic Period--0 to 600 s

The early primary system pressure response in the test and the calculation were different. During the first 50 s, the test data showed the system depressurized more rapidly than in the calculation (see Figure 34). As a result, scram and SI occurred at 18 s and 20 s in the test compared to 26 s and 30 s in the calculation. As discussed in Appendix A, there was a change in the primary depressurization rate during the test at 12.5 s when the pressurizer level decreased to the top of the pressurizer surge line. The change in the interphase surface area resulted in less vapor generation in the pressurizer and a more rapid depressurization. This area change was included in the RELAP5 model of the system, but little effect on the calculated system depressurization rate was seen as the level decreased to the level of the surge line. Posttest analysis is needed to better understand the experimental and calculated results during this period.

The magnitude of the initial pressure drop as well as the magnitude of the slight repressurization at 70 s were calculated well by RELAP5 as shown in Figure 34. From 100 s to 300 s, the experimental pressure was approximately 0.5 MPa higher than the calculated pressure, but from 300 s to 600 s, there was excellent agreement between the calculation and the test.

The calculated break flow had a larger initial peak than in the experiment (see Figure 35). After the initial peak, the differences in

TABLE 3. COMPARISON OF ACTUAL AND CALCULATED INITIAL CONDITIONS

Parameter	Calculated	Measured
Pressurizer pressure	15.52 MPa (2251 psia)	15.5 MPa (2248 psia)
Core temperature differential	36.0K (64.8°F)	39.5K (69.3°F)
Initial core power	2.0 MW	2.010 MW
Pressurizer liquid volume	0.0104 m^3 (0.37 ft^3)	0.00957 m^3 (0.338 ft^3)
Nominal primary flowrates[a]		
Unaffected loop	9.6 ℓ/s (152 gpm)	9.6 ℓ/s (152.2 gpm)
Affected loop	3.5 ℓ/s (55 gpm)	3.33 ℓ/s (52.3 gpm)
SG secondary pressure		
Affected loop	5.54 MPa (804 psia)	5.55 MPa (805 psia)
Unaffected loop	5.54 MPa (804 psia)	5.42 MPa (786 psia)
SG secondary mass		
Unaffected loop	100.1 kg (220.7 lbm)	118-136 kg (260-300 lbm)
Affected loop	99.3 kg (218.9 lbm)	100-135 kg (220-298 lbm)

a. Varied to maintain the 37K (67°F) core temperature differential.

TABLE 4. COMPARISON OF ACTUAL AND CALCULATED SEQUENCE OF EVENTS

Event	Time (s) Calculated	Actual
Transient initiation	0	0
Scram	26.5	18
Pressurizer emptied	30.0	50
SIS	30.3	20
PCP pump coastdown completed	68	50
Recovery began	600	600
PORV open	600	1574
PORV closed	1400	2260
HPIS terminated	3400	5539
Accumulator injection setpoint reached	12200	7900

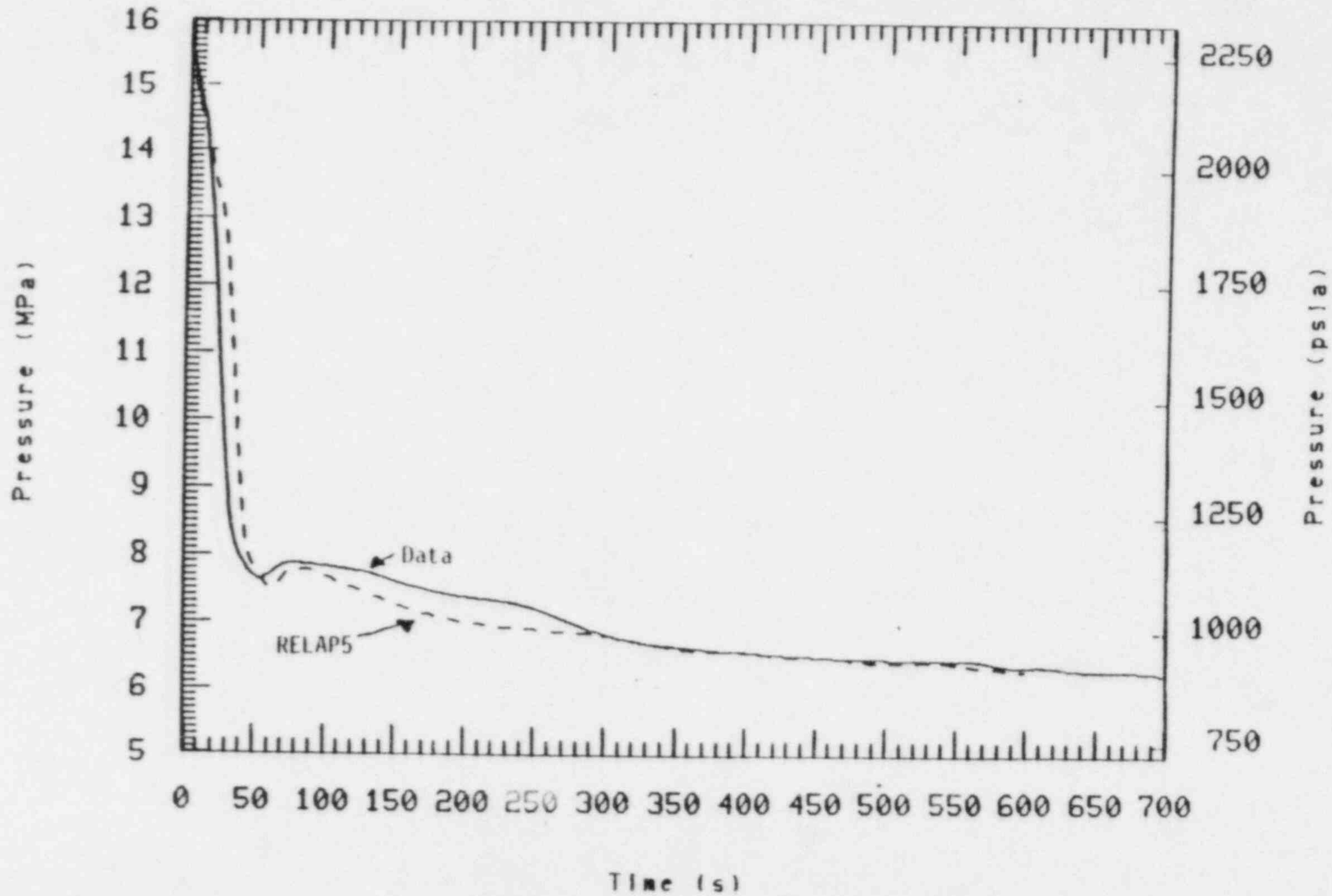

Figure 34. Comparison of RELAP5 calculated and experimental primary pressure during a five tube rapture transient (S-SG-2).

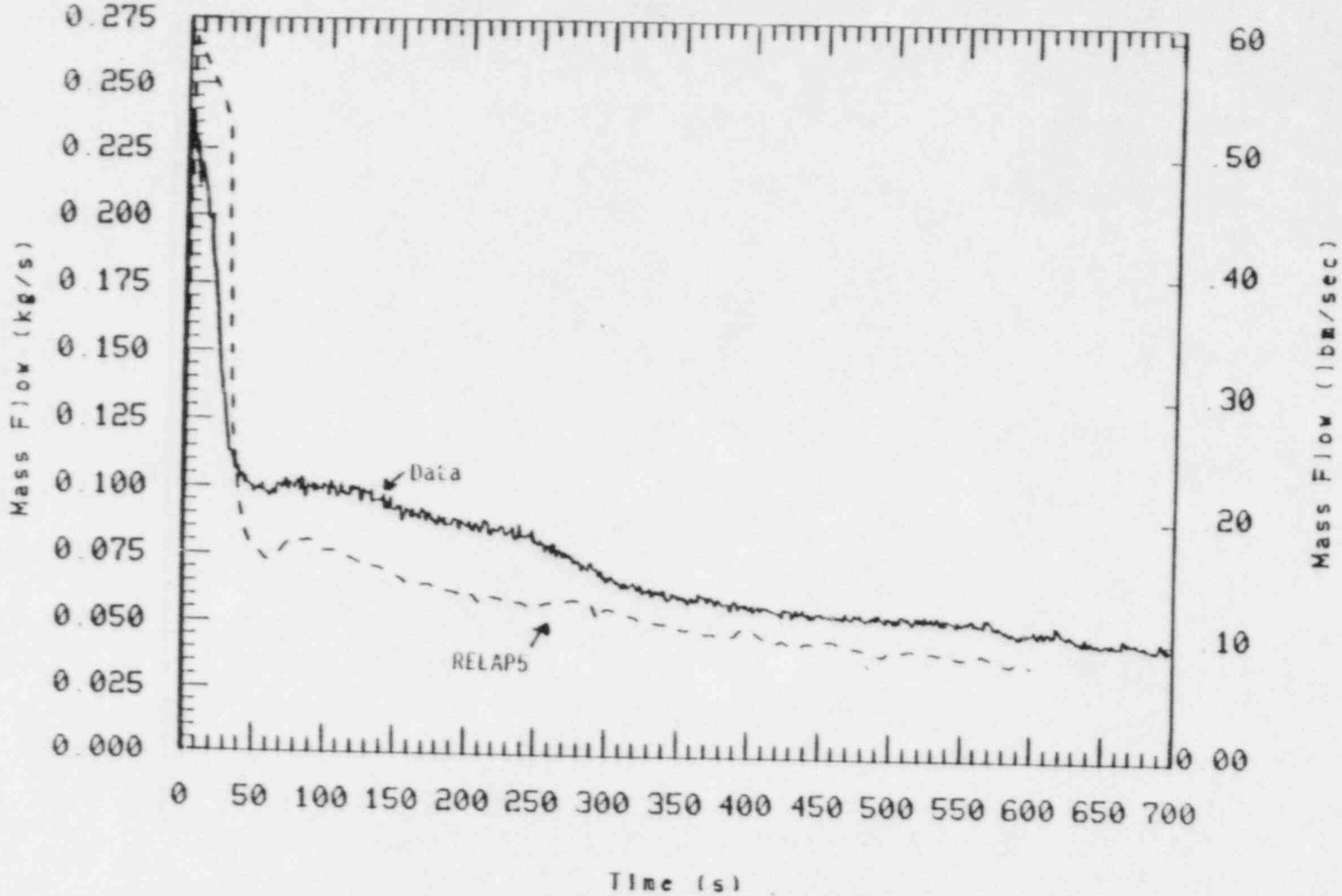

Figure 35. Comparison of RELAP5 calculated and experimental break flow during a five tube rupture transient (S-SG-2).

break flow corresponded to differences in primary pressure until 300 s. After 300 s, although the primary pressures agreed, the calculated break flow was lower than the measured break flow. This was attributed to density differences upstream of the break in the test and the calculation, as shown in Figure 36.

Qualitatively the calculated and measured pressure response of the unaffected loop steam generator secondary was similar during the first 600 s of the test (see Figure 37). In the calculation, the unaffected loop ADV opened once at approximately 40 s, while in the test the pressure remained below the ADV setpoint because of the initial, lower unaffected secondary pressure. In both the calculation and experiment, the pressure declined from the initial peak, then increased slightly before cooldown due to auxiliary feedwater injection. However, the timing of the events was different. In the affected loop secondary, the initial pressure peak was also higher in the calculation than the test (see Figure 38). The first stage of the affected loop secondary relief valve was needed in addition to the ADV to control the pressure in the calculation. The ADV alone was sufficient in the experiment. This was probably due to the higher primary pressure and break flow in the calculation compared to the test during this period. After the initial peak the affected loop secondary ADV was sufficient to control the pressure at the ADV setpoint in both the calculation and the experiment.

The pressurizer level response was similar, with both the calculated and measured levels dropping out of the pressurizer by approximately 40 s (see Figure 39). The change in the rate of decrease in the measured pressurizer level at 12.5 s was due to the change in the vaporization rate when the level decreased to the top of the pressurizer surge line as discussed in Appendix A.

4.2 Plant Recovery Phase--600 s to Test Termination

Plant recovery in Test S-SG-2 began at 600 s and was achieved by an unaffected loop secondary steam and feed assisted by cycling the pressurizer PORV. Beginning at 600 s, the unaffected loop steam generator

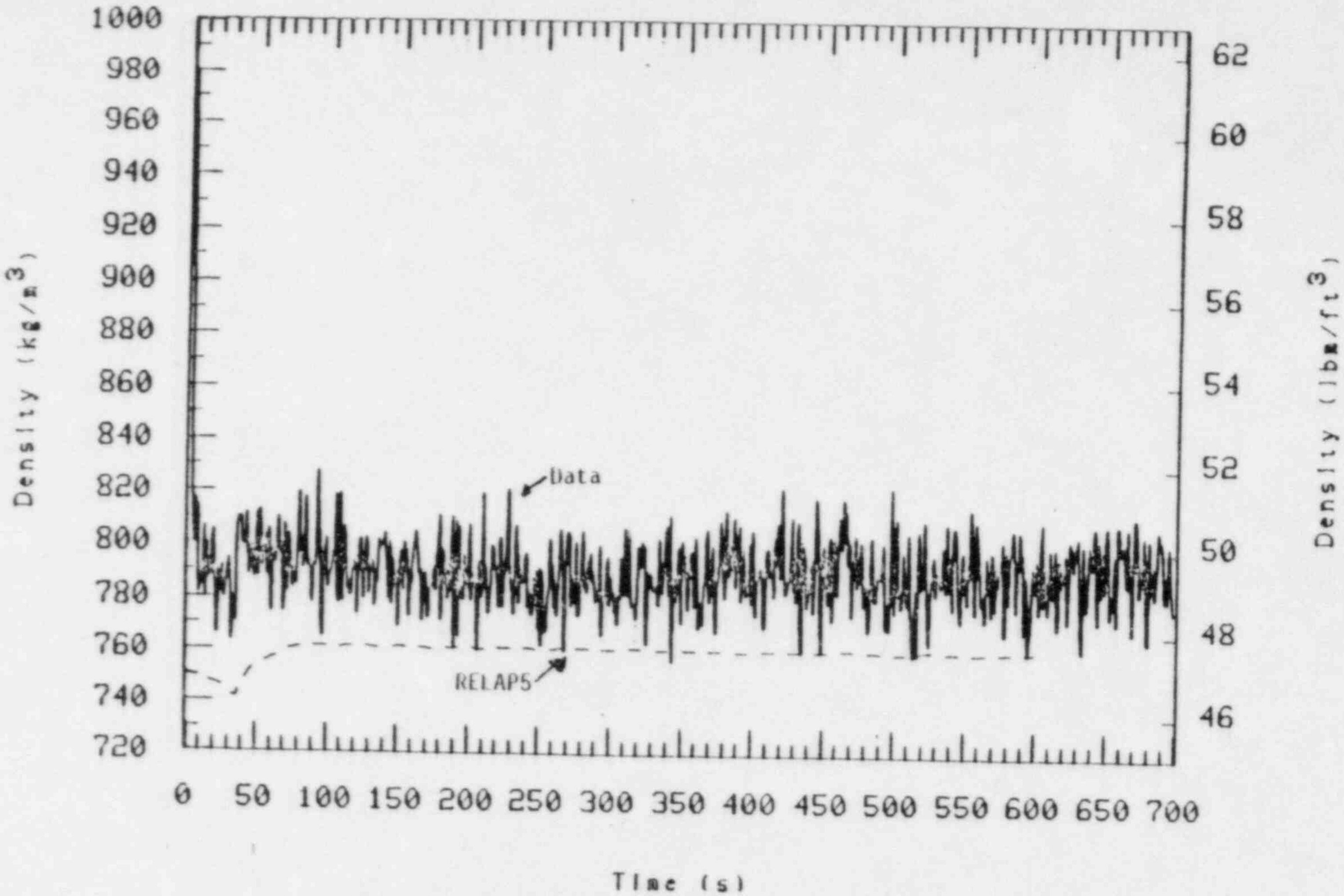

Figure 36. Comparison of RELAP5 calculated and experimental density upstream of the break during a five tube rupture transient (S-SG-2).

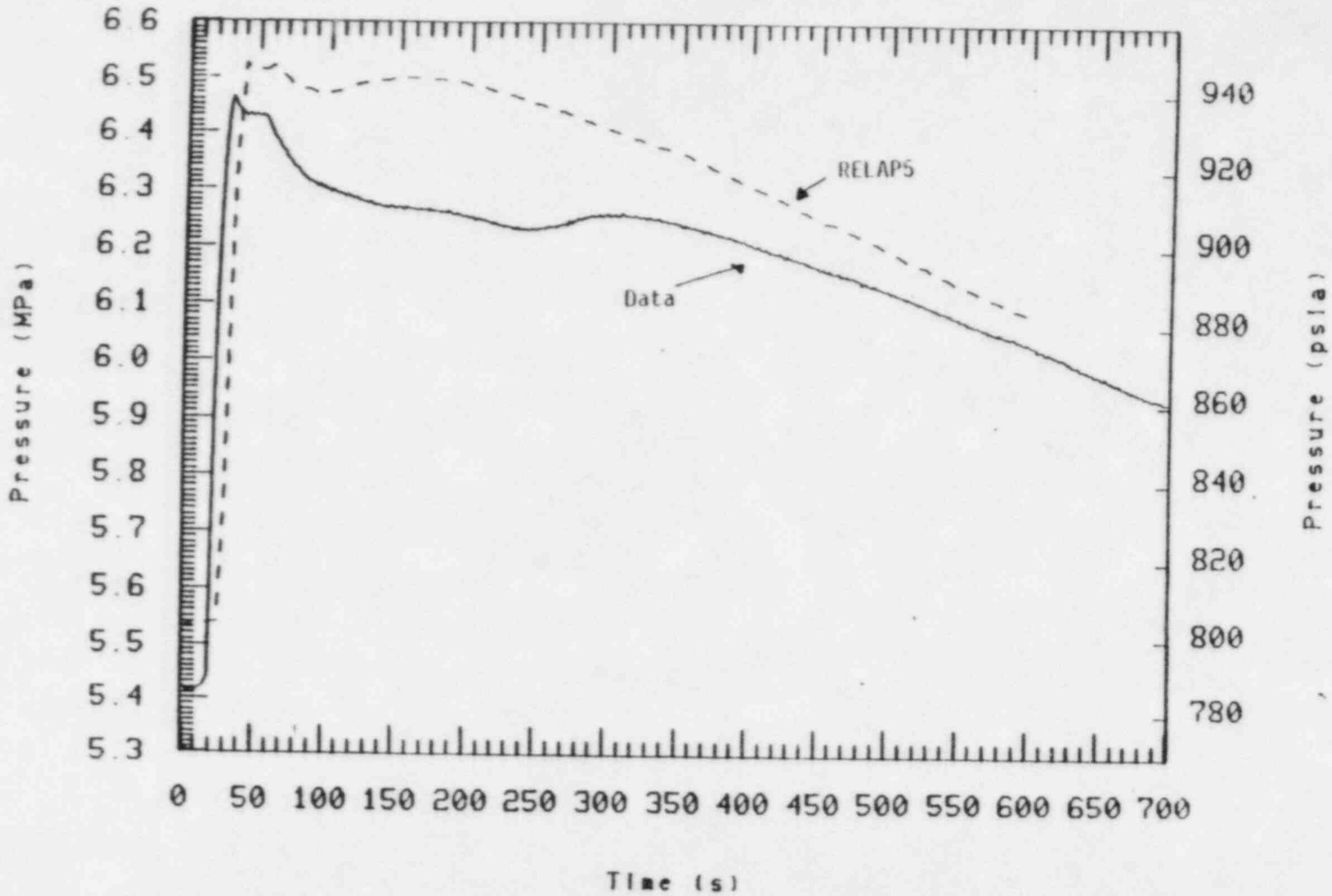

Figure 37. Comparison of RELAP5 calculated and experimental unaffected loop secondary pressure during a five tube rupture transient (S-SG-2).

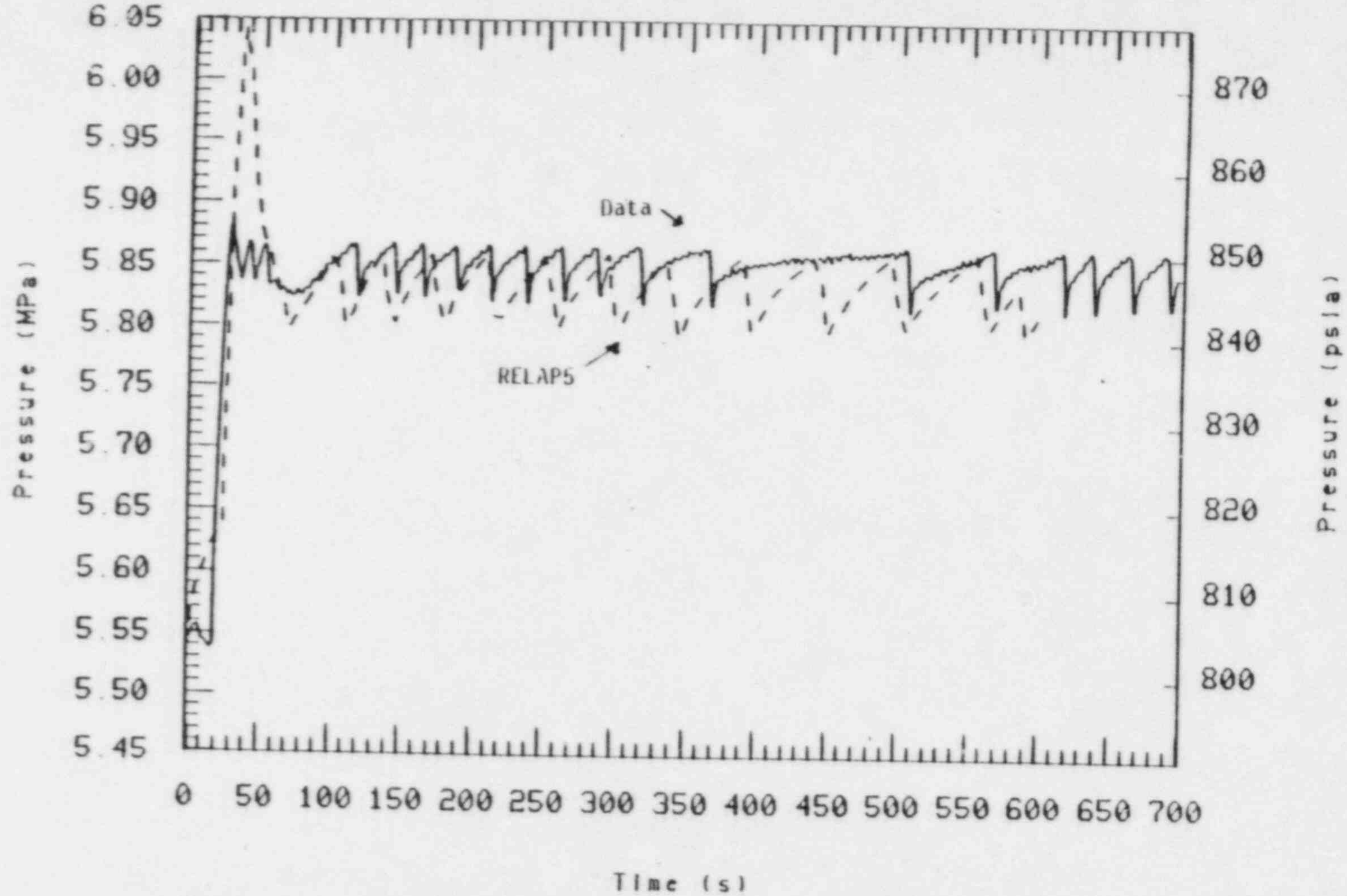

Figure 38. Comparison of RELAP5 calculated and experimental affected loop secondary pressure during a five tube rupture transient (S-SG-2).

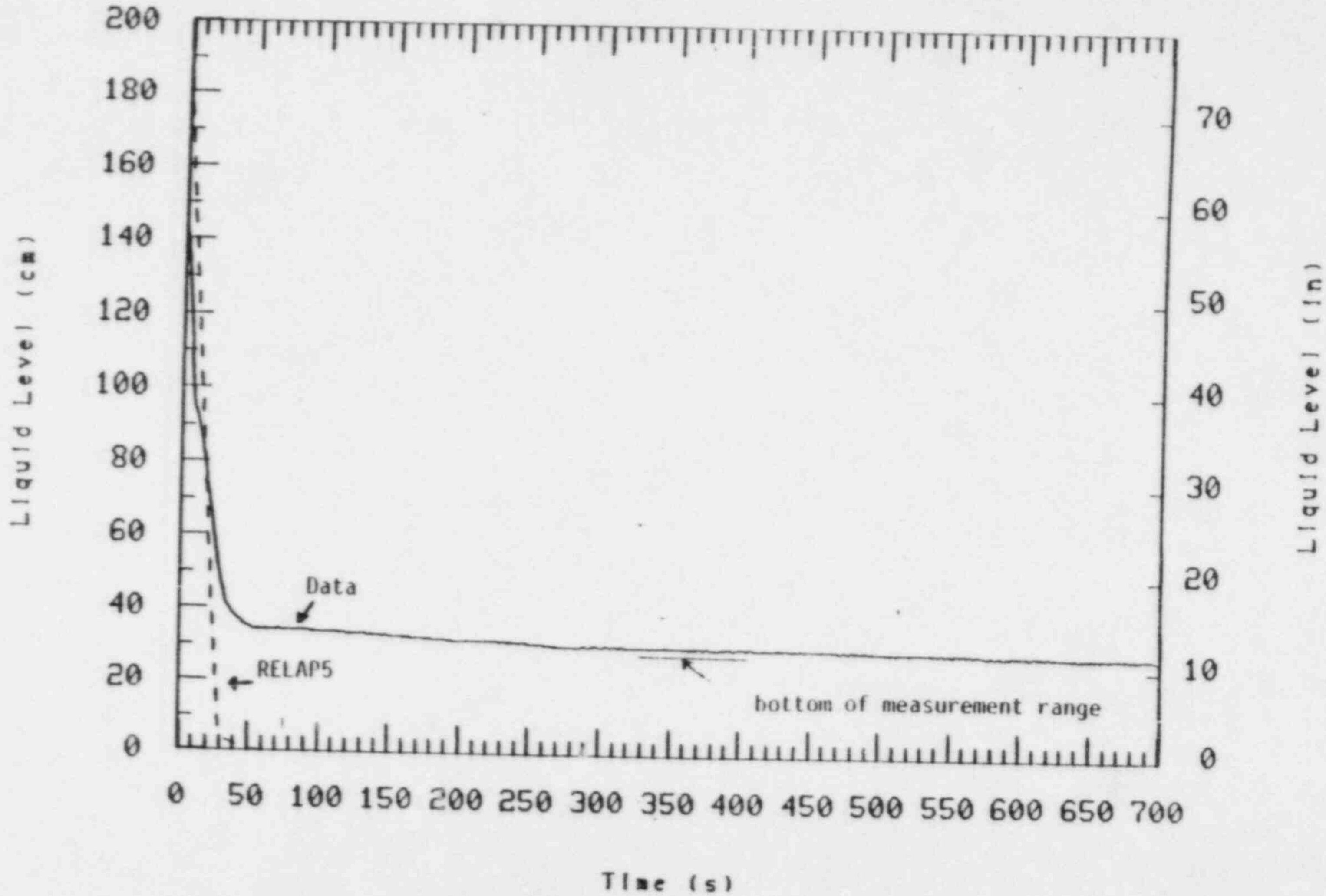

Figure 39. Comparison of RELAP5 calculated and experimental pressurizer level during a five tube rupture transient

was to be depressurized at a rate of 2.76 MPa/hr (400 psi/hr) using the unaffected loop ADV to take discrete 228 kPa/5 min (33 psi/5 min) steps. The pressurizer PORV was to be cycled to keep the primary pressure within 207 to 350 kPa (30 to 50 psi) of the unaffected loop secondary pressure. If the pressurizer collapsed liquid level increased to above 475 cm (187 in.), however, the PORV would be closed.

The early portion of the recovery phase in the calculation differed from the test because of a difference in implementing the 2.76 MPa/hr (400 psi/hr) depressurization. In the calculation, the unaffected loop ADV was opened at 600 s and the secondary depressurized 228 kPa (33 psi) even though the unaffected loop secondary was already depressurizing at a rate of 2.76 MPa/hr (400 psi/hr) (see Figure 40). The 228 kPa (33 psi) was enough to increase the pressurizer-to-unaffected loop secondary pressure difference to greater than 350 kPa (50 psi) and allow the PORV to open. Continued operation of the unaffected loop ADV in the calculation resulted in continued PORV operation. The pressurizer filled to the maximum level for PORV operation [475 cm (187 in.)] by 1400 s as shown in Figure 41. In the test, the unaffected loop ADV was left closed at 600 s because the secondary was depressurizing at the specified rate. The unaffected loop ADV was not opened until approximately 1000 s, and the pressurizer-to-unaffected loop secondary pressure difference did not exceed 350 kPa (50 psi) until 1480 s. Rather than performing a 228 kPa (33 psi) pressure drop at the beginning of each 5 min period, as was assumed in the calculation, the test operator provided a linear depressurization rate of 2.76 MPa/hr (400 psi/hr). The PORV cycled several times from 1480 to 2200 s, as the pressurizer filled to 475 cm (187 in.) (see Figure 41). After PORV closure, the test operator continued to provide a linear depressurization rate of 2.76 MPa/hr (400 psi/hr), while the calculation continued to use a 228 kPa (33 psi) depressurization at the start of each five minute interval. In the calculation the ADV was closed after each 228 kPa depressurization with the result that the unaffected loop secondary repressurized. The ADV was cycled in the calculation when the secondary pressure increased to 114 kPa (16.5 psi) above the ideal, linear depressurization rate. As a result, the unaffected loop secondary in the

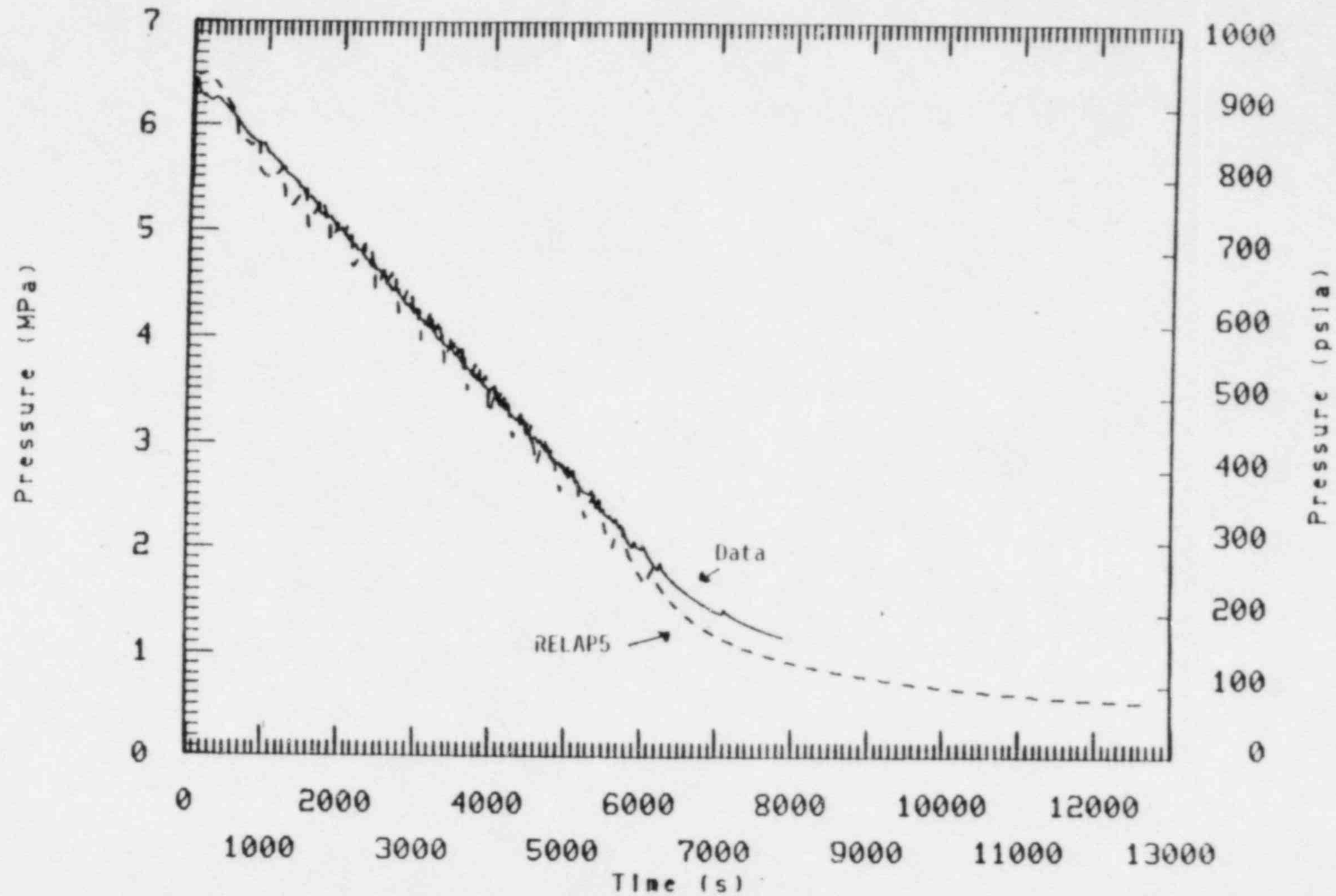

Figure 40. Comparison of RELAP5 calculated and experimental unaffected loop pressure during a five tube rupture transient (S-SG-2).

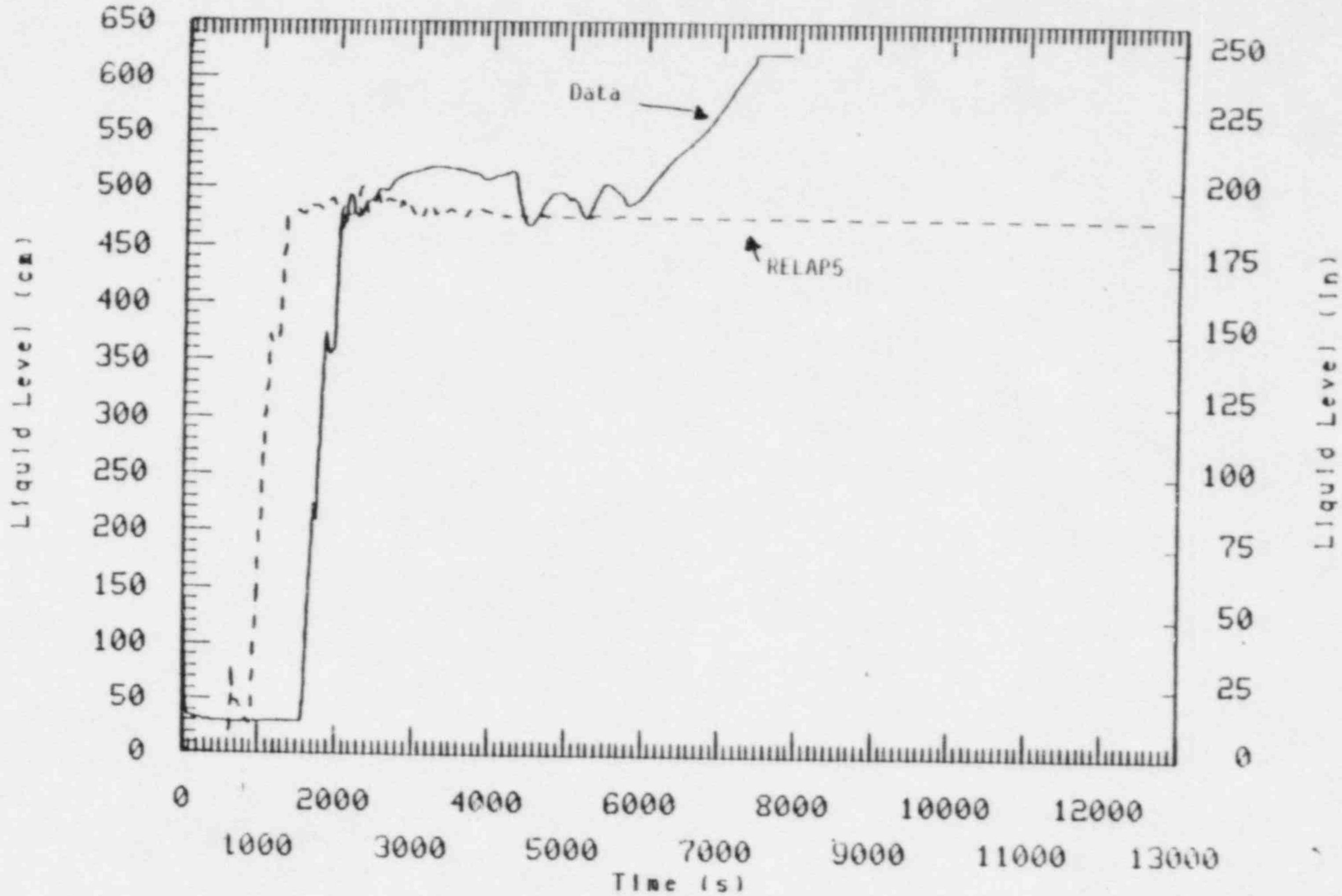

Figure 41. Comparison of RELAP5 calculated and experimental pressurizer liquid level during a five tube rupture transient (S-SG-2).

test, as shown in Figure 40, underwent a relatively smooth depressurization while in the calculation the unaffected loop secondary pressure oscillated between the upper and lower limits of the allowed operating band.

The difference in the unaffected loop ADV/PORV operation discussed above affected the comparison of primary system pressures as shown in Figure 42. The opening of the PORV at 600 s resulted in the calculated pressure dropping below the measured pressure until PORV closure at 1400 s. Opening the PORV at 1480 s in the test resulted in the measured pressure being lower than the calculated pressure until PORV closure at 2200 s. After 2200 s in the test, the system repressurized slightly until the measured and calculated primary pressures were approximately equal at 3000 s. After 3000 s, the measured primary system pressure decreased at a faster rate than calculated. As a result, the test termination criterion to depressurize the primary system to the accumulator injection setpoint (4.22 MPa (612 psia)) was reached at 7900 s, compared to 12,200 s in the calculation. The primary pressure in the calculation was only 0.5 MPa higher than the measured pressure at 7900 s, but the calculated depressurization rate was so slow that an additional 4300 s was required to bring the system down to the accumulator injection setpoint. Reasons for this difference in depressurization, as well as for the more rapid affected loop steam generator depressurization (see Figure 43), are discussed below.

As discussed above, the difference in the timing of the unaffected loop ADV/PORV resulted in the pressurizer filling at 1400 s in the calculation and 2200 s in the test. The difference in the time of pressurizer filling affected the amount of SI injected in the calculation and the test. SI was not to be terminated until the pressurizer level exceeded 381 cm (150 in.) and the upper plenum/upper head level exceeded 291 cm (115 in.). Therefore, once the pressurizer filled, the termination of SI was based solely on the upper plenum/upper head level. In both the calculation and the experiment the upper head did not begin to refill until the PORV closed (see Figure 44). Because PORV closure in the experiment was delayed compared to the calculation, there was a longer period of SI injection in the test than in the calculation . As a result, there was approximately 100 kg more mass injected by SI in the test than in the

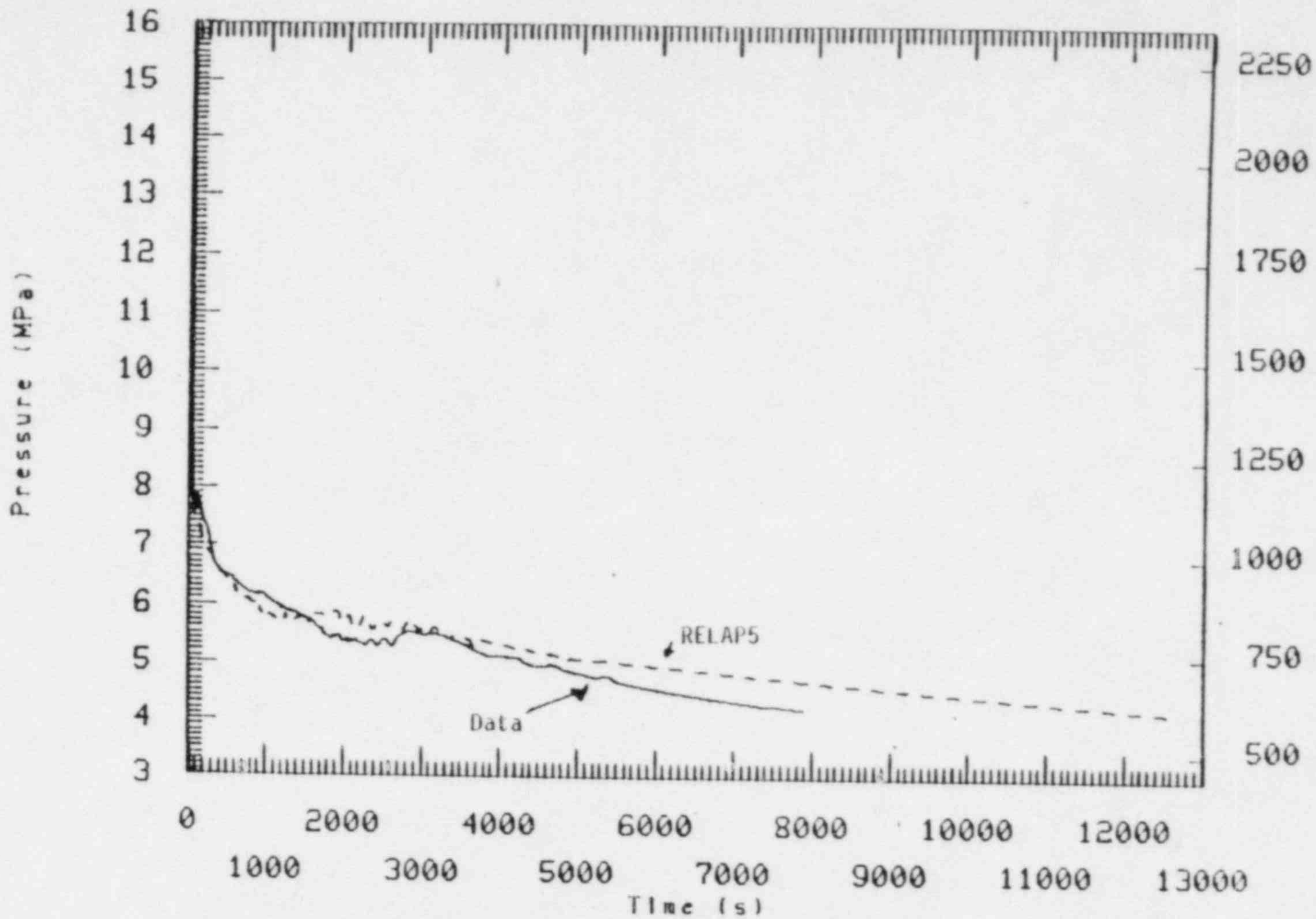

Figure 42. Comparison of RELAP5 calculated and experimental primary pressure during a five tube rupture transient (S-SG-2).

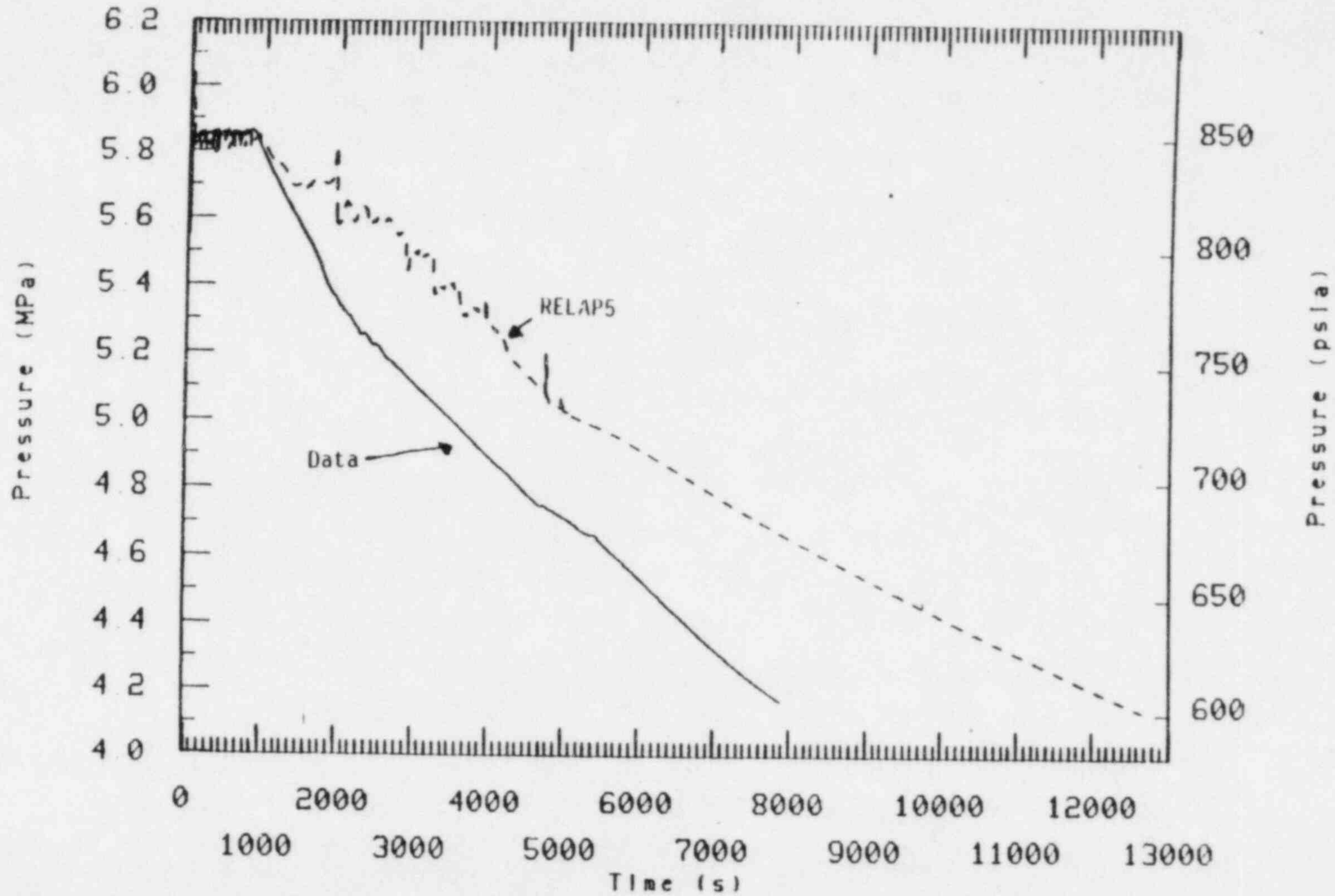

Figure 43. Comparison of RELAP5 calculated and experimental affected loop secondary pressure during a five tube rupture transient (S-SG-2).

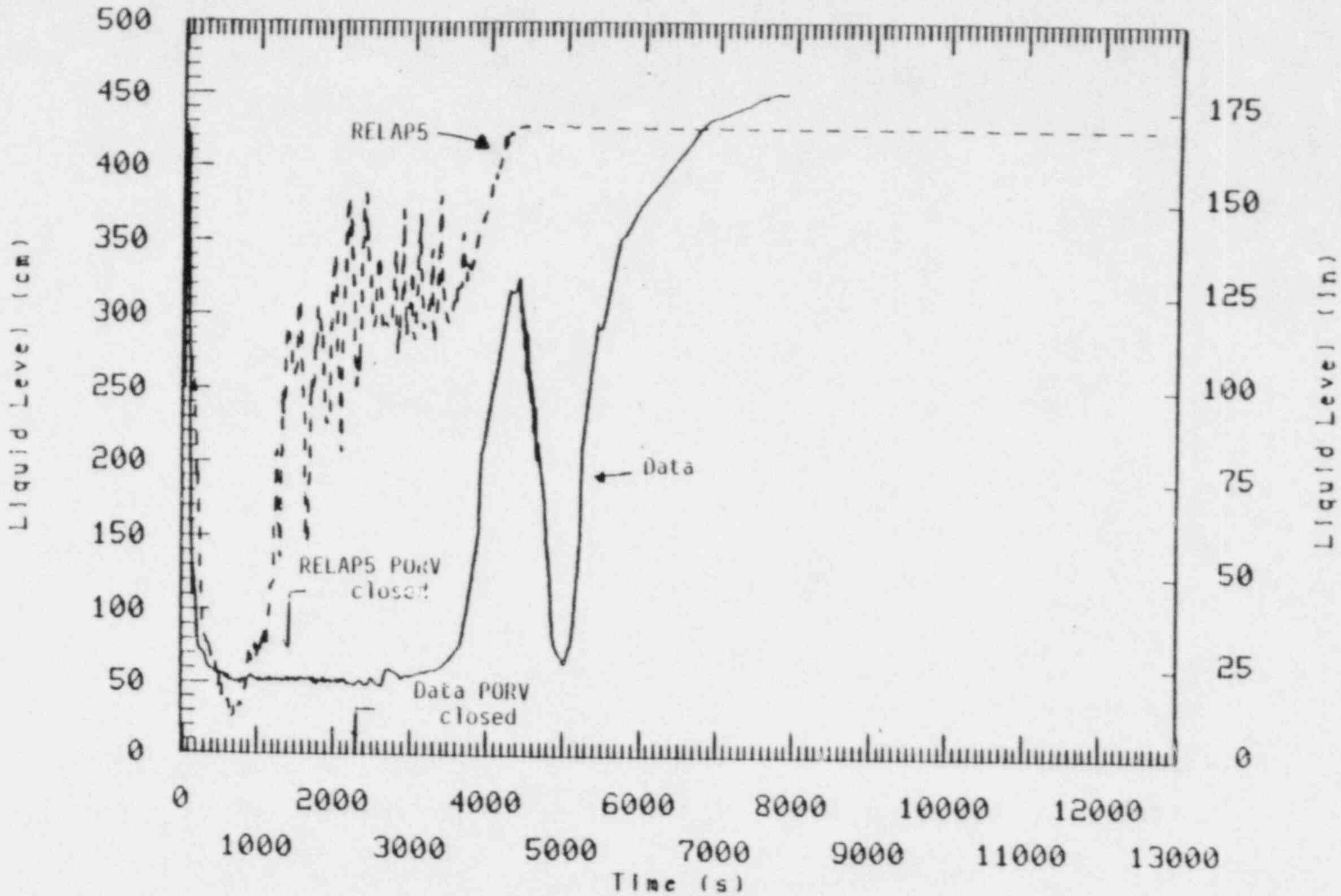

Figure 44. Comparison of RELAP5 calculated and experimental vessel upper head liquid level during a five tube rupture transient (S-SG-2).

calculation. The SI was cycled on and off from 2000 to 3400 s in the calculation because the upper plenum/upper head level oscillated about the 291 cm (115 in.) level. This level was used as an on/off switch for SI operation. Operation of SI in the test was somewhat different because once the level in the upper plenum/upper head exceeded 291 cm (115 in.), and SI was turned off, it was not turned on again until the level dropped to almost the level of the hot leg. It then remained on until the 291 cm (115 in.) level was exceeded again. It is also noted the upper plenum/upper head refilled more quickly and the refilling was more oscillatory in the calculation than in the test. Reasons for this will be investigated in posttest analysis.

The differences in the unaffected loop ADV/PORV and SI operation all contribute to the differences in the long term break flow comparison shown in Figure 45. Early PORV operation in the calculation resulted in negative break flow at 1000 s in the calculation versus 1700 s in the test. Also, earlier termination of SI in the calculation (3400 s) compared to the test (5500 s) resulted in an earlier initiation of sustained, negative break flow (approximately 3500 s in the calculation and 5500 s in the experiment). Oscillations in the calculated break flow from 1400 s to 3500 s were due to primary pressure oscillations as the upper head was refilling and HPIS was turning on and off.

There was a significant difference in the depressurization rate of the primary and the affected loop steam generator. This resulted in test termination at 7900 s versus 12,200 s in the PAD calculation. Preliminary analysis of the test data and the calculation indicated several factors which could have had a bearing on this difference. First, 100 kg more cold water was injected by the SI in the test compared to the calculation. This additional cold water would have had the effect of cooling the primary system and reducing the pressure in the test compared to the calculation. A second possible effect of the additional SI injection was that it served to keep the system liquid continuous and hydraulically coupled via the break. This allowed the whole system to cool down (depressurize) due to unaffected loop feed and steam as discussed in Section 3. Without the 100 kg being injected in the calculation, voids existed in the affected

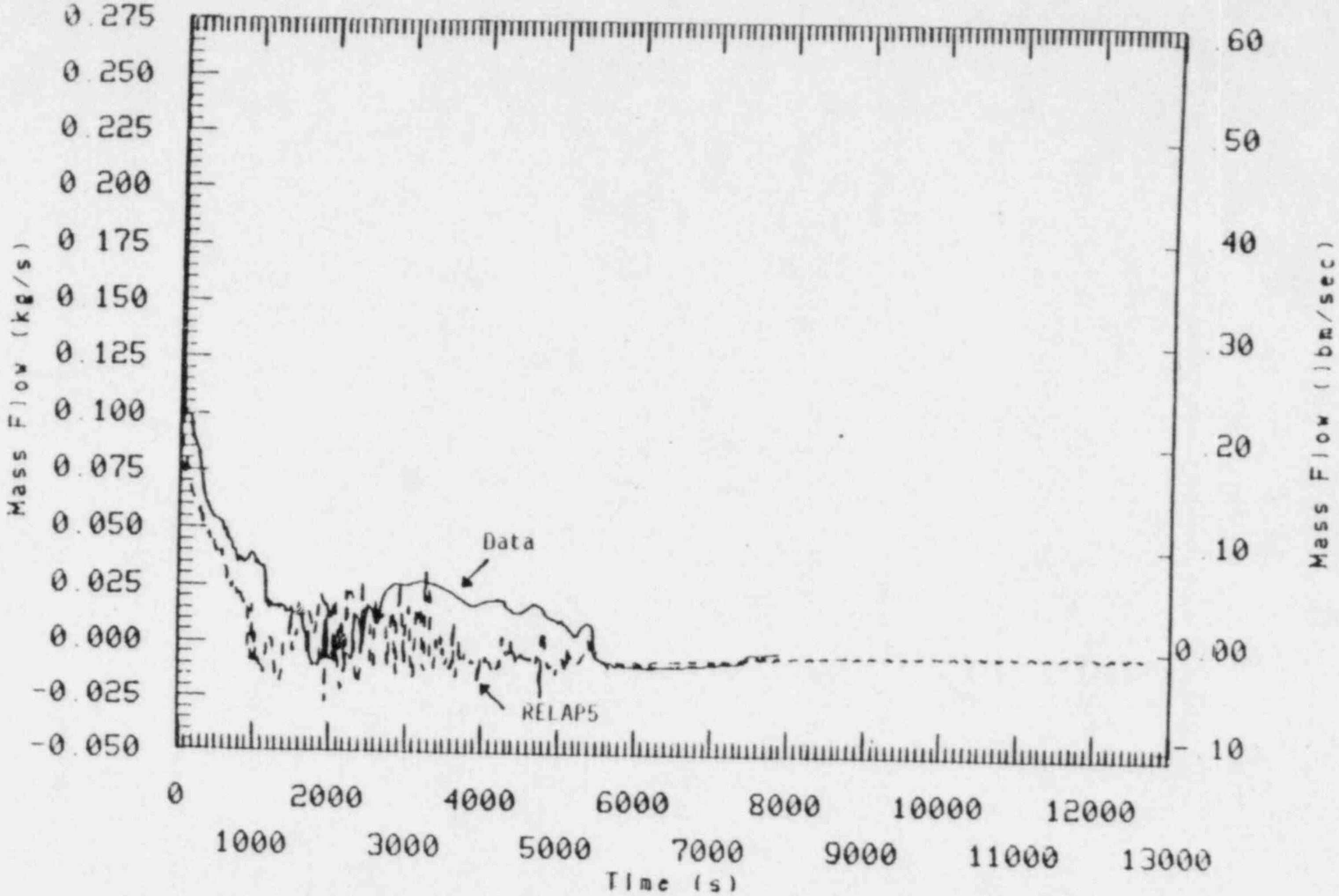

Figure 45. Comparison of RELAP5 calculated and experimental break flow during a five tube rupture transient (S-SG-2).

loop steam generator tubes and broken loop pump suction downflow during most of the recovery phase. Therefore, the system was not liquid continuous and the loops did not cool down together, extending the recovery phase in the calculation to 12,200 s. Finally, the difference between the measured and calculated affected loop steam generator pressures at 7900 s was 0.5 MPa (the same as the difference in the primary pressures). Hand calculations have shown that a difference of less than 1 kW in the energy balance of the affected loop steam generator (break flow, heat loss, primary to secondary heat transfer, etc.) during the 7900 s of the test would have been sufficient to cause a 0.5 MPa difference in the affected loop steam generator pressure at 7900 s. If the affected loop steam generator had an effect on the system depressurization rate, then this indicates that even a fairly small difference in the affected loop steam generator energy balance between the test and the calculation could have resulted in the fairly significant difference noted between the experiment and the calculation in the timing of test termination. Further posttest analysis is needed in order to understand the difference in the timing of test termination.

4.3 Summary

Differences between the assumed and actual operator actions during the test precluded a direct comparison between the RELAP5 calculation and data. However, the phenomena calculated by RELAP5 compared well with data with the major difference being the timing of events. These differences in operator actions also resulted in 100 kg more SI being injected in the experiment compared to the calculation. In spite of these differences, much of the same behavior was seen in the calculation and the experiment. Unaffected loop ADV/PORV operation reduced the primary pressure in both the calculation and experiment. In both cases, PORV operation resulted in a rapid filling of the pressurizer, so that the PORV was removed from the recovery procedure early in the recovery phase. Continued unaffected loop steam generator feed and steam, in both the calculation and the experiment, cooled the primary. In both cases, the upper head did not refill until the PORV closed.

The initial comparison of the test and the PAD calculation has shown that further posttest analysis is needed. This analysis will lead to a better understanding of the difference in the depressurization rate between the test and the calculation and an improved calculation.

5. CONCLUSIONS

The following conclusions have been drawn based on a preliminary analysis of both S-SG-2 (five tube rupture) and S-SG-1 (one tube rupture).

1. The combined effect of unaffected loop steam generator feed and bleed, pressurizer PORV operation, and termination of safety injection, was sufficient to recover the Semiscale facility from a five-tube steam generator cold side rupture.

   Recovery included reducing the system pressure to the accumulator injection setpoint (4.22 MPa (600 psi)) without uncovering the core. The vessel collapsed level remained above the hot legs during the entire five steam generator tube rupture transient.

2. Operation of the pressurizer PORV during the recovery phase did not directly affect the primary system depressurization rate, but instead led to the pressurizer filling.

   Continued SI operation during the period of PORV operation supported the filling of the pressurizer and pressurization of the primary system.

3. Despite differences between assumed and actual operator actions during S-SG-2, RELAP5 pretest calculations agreed qualitatively with experimental data.

   The assumed differences resulted in significant differences in the timing of many events.

   Posttest calculations including actual operator response during the recovery phase are expected to result in excellent agreement between code and data.

4. The larger break flow during a Semiscale five tube rupture transient (S-SG-2) left the system with less mass inventory early in the transient than a one tube rupture transient (S-SG-1).

   With more primary coolant system mass inventory in the one tube transient, the effect of the pressurizer filling under the influence of SI had a greater affect on system recovery than in the five tube transient.

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APPENDIX A

EFFECT OF PRESSURIZER GEOMETRY ON SYSTEM DEPRESSURIZATION

An increase in primary system depressurization rate was observed early in the transient in both S-SG-1[A-1] and S-SG-2, and has been found to be related to pressurizer level depletion and geometry. Figure A-1 compares the primary pressure for S-SG-1 and S-SG-2. A knee in the depressurization rate occurred at approximately 65 s and 12.5 s for S-SG-1 and S-SG-2 respectively. Figure A-2 shows the interfacial or pool level in the pressurizer for S-SG-1 and S-SG-2. Upon tube rupture, the level declines until it reaches the lower differential pressure tap, and goes off scale at approximately 0 cm. No level measurement was made below the tap. The dotted portions of Figure A-2 illustrate the level decreasing at the same rate after it goes off scale. The level of the surge line entrance is -25 cm (-9.8 in). Therefore the interfacial level was estimated to enter the surge line at 65 s and 12.5 s for S-SG-1 and S-SG-2 respectively, coinciding with the depressurization knees shown on Figure A-1. The vessel interfacial area is 49.70 cm^2 (7.704 $in.^2$), whereas the surge line interfacial area is 2.40 cm^2 (0.37 $in.^2$). The greatly reduced interfacial area caused a large decrease in vapor generation, and resulted in an increased system depressurization rate.

APPENDIX A REFERENCE

A-1. G. G. Loomis, R. A. Shaw, Quick Look Report for Semiscale Mod-2B Experiment S-SG-1, EGG-SEMI-6395, September 1983.

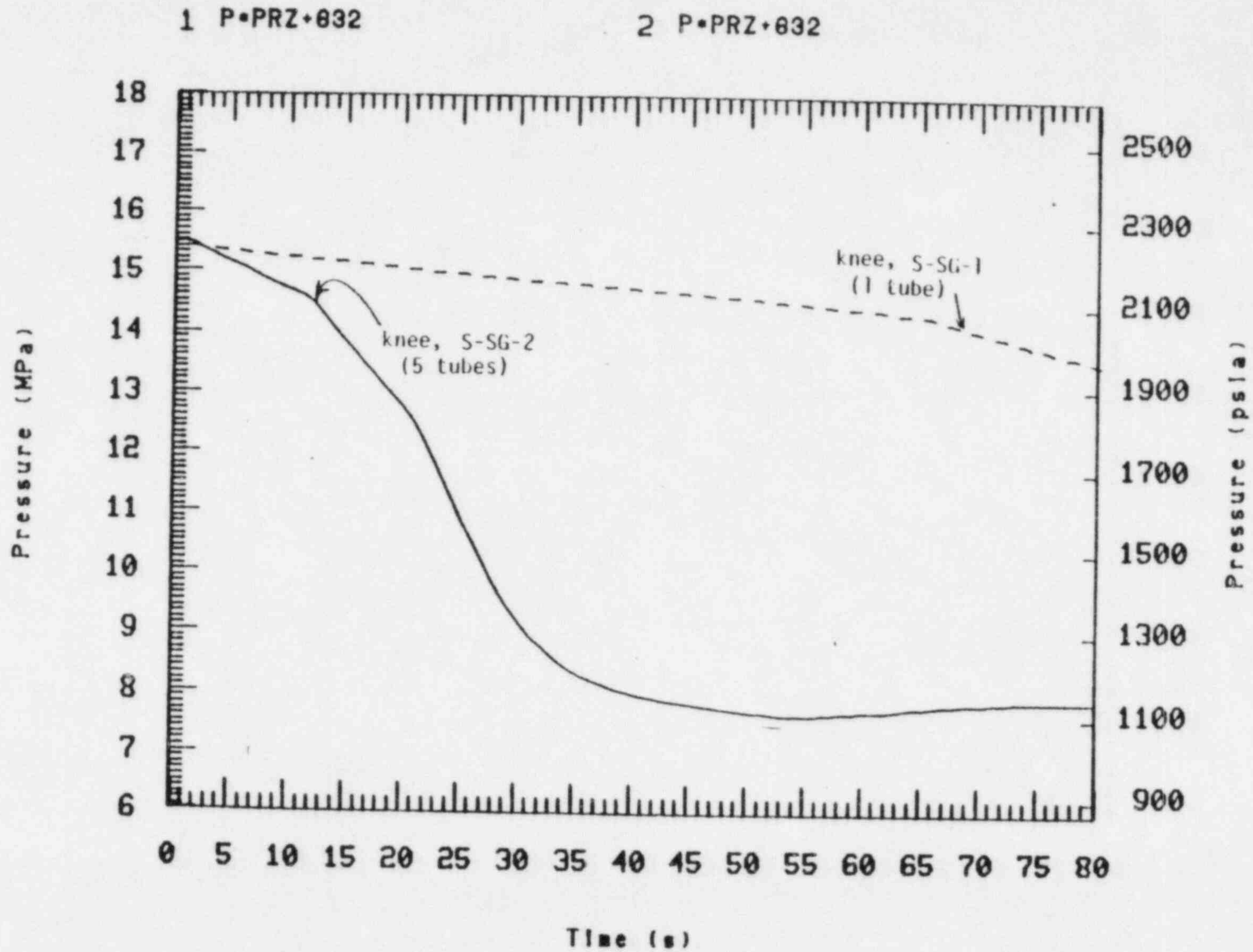

Figure A-1. Comparison of primary pressure response for a one and five tube rupture experiment.

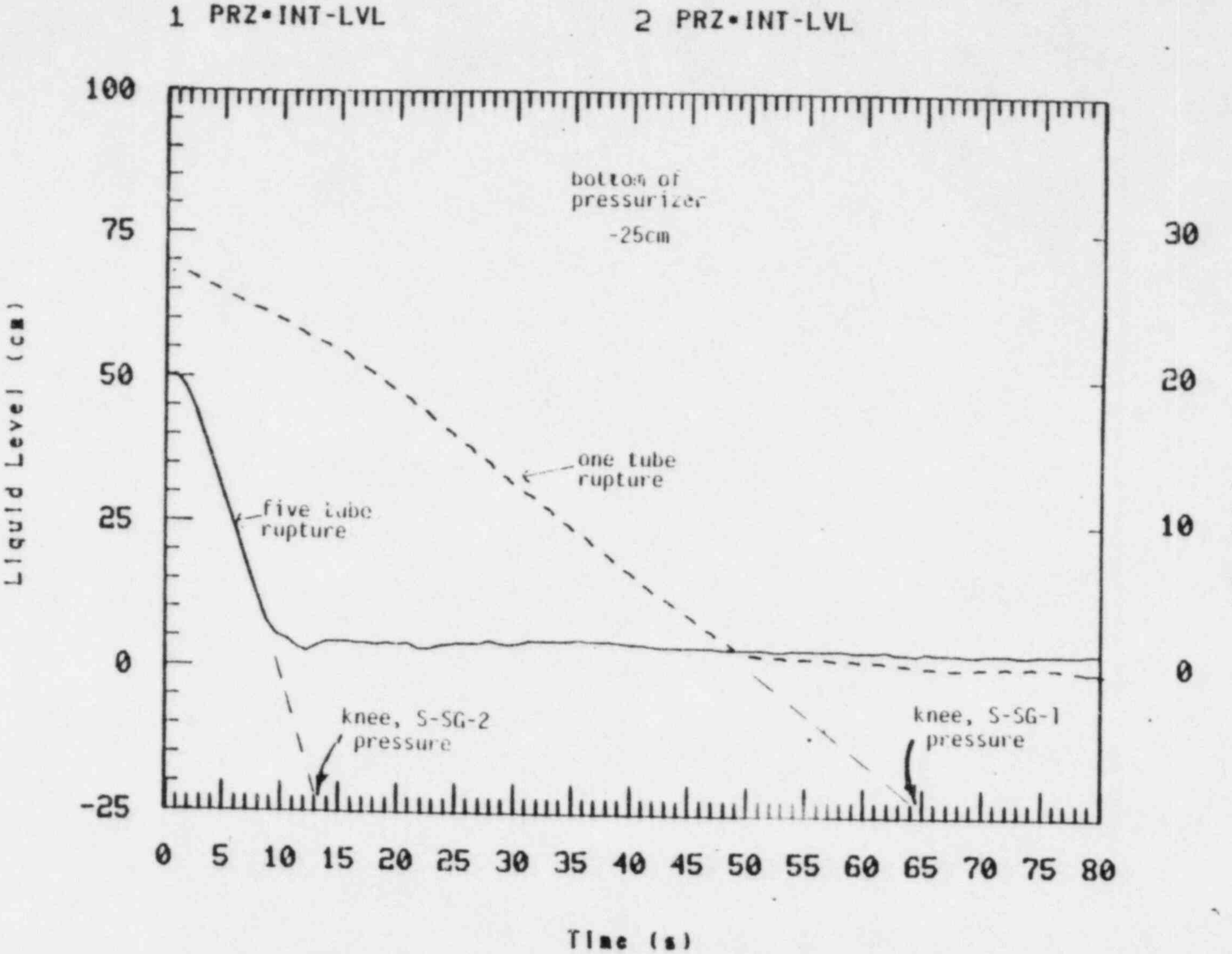

Figure A-2. Pressurizer interfacial level for S-SG-1 and S-SG-2.

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Results of a preliminary analysis of the second test performed in the Semiscale Mod-2B Steam Generator Tube Rupture Series are presented. Test S-SG-2 simulated a pressurized water reactor accident initiated by a double-ended offset shear of five cold side steam generator tubes. The transient included an initial 10-minute period during which only automatic plant protection system response to the initiating event occurred. This period was followed by an operator-induced recovery procedure to establish an unaffected steam generator feed and steam condition, pressurizer PORV cycling to reduce primary pressure, and HPIS cycling to maintain liquid inventory. The test results provided a measured evaluation of the effectiveness of a controlled secondary side steam and feed in Semiscale, the effectiveness of pressurizer PORV operation in controlling primary pressure, and the effect of the high pressure injection system operation on the Semiscale response to a five tube steam generator tube rupture. The test showed that the prescribed limited operator response was adequate to recover the Semiscale system from a simulated five-tube rupture.

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