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QUICK LOOK REPORT FOR SEMISCALE MOD-2B EXPERIMENT S-SG-8

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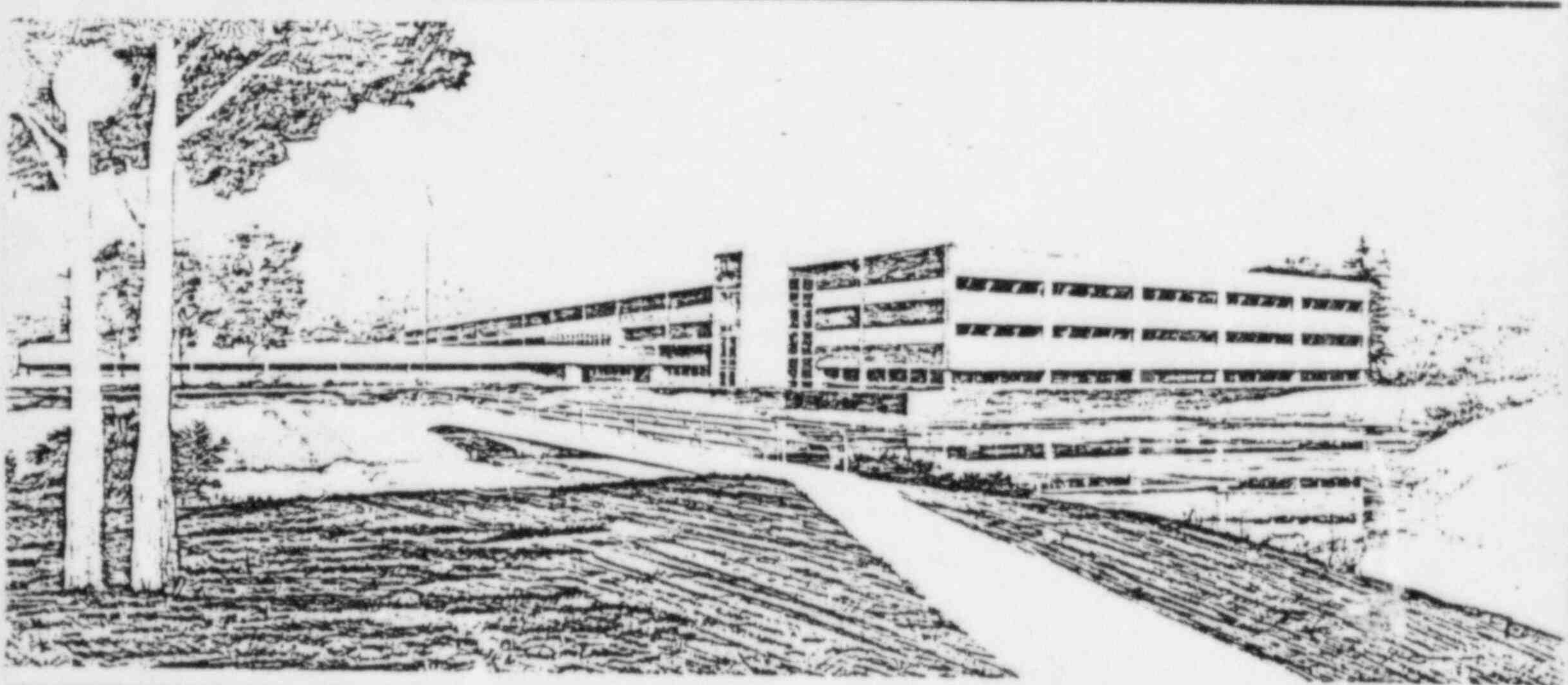

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QUICK LOOK REPORT FOR SEMISCALE
MOD-2B EXPERIMENT S-SG-8

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ABSTRACT

Results of a preliminary analysis of the fifth test performed in the Semiscale Mod-2B Steam Generator Tube Rupture Series are presented. Test S-SG-8 simulated a pressurized water reactor accident initiated by a double-ended offset shear of one cold side steam generator tube. The transient included an initial 600-second 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 a primary feed and bleed with the PORV assumed stuck in an open position, followed by intact loop secondary steam and feed operation. The test results provided a measured evaluation of the impact of a stuck open PORV on primary inventory and system recovery as well as the effectiveness of intact loop secondary steam and feed in reducing primary system pressure. The test showed that the prescribed limited operator response was adequate to recover the Semiscale system from a simulated one-tube rupture.

SUMMARY

This report presents a preliminary analysis of the Semiscale MOD-2B Steam Generator Tube Rupture Series (SG) Test S-SG-8. S-SG-8 is the fifth test of the SG series to be conducted. The test series is designed to study the effect of the number of tubes ruptured (break size), the location of the rupture (hot side or cold side of the steam generator) and the effect of limited operator responses to the accident following an initial 10-minute simulated identification period.

Test S-SG-8 simulates a pressurized water reactor transient initiated by a double-ended offset shear of one cold side steam generator tube. 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-8 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 a primary feed and bleed with a simulated stuck open PORV, and an intact loop secondary steam and feed operation.

The signature of a single-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 single-tube break conical flow tube into the broken 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. Following the attainment of a saturation condition in the hot legs the primary and secondary system pressures remained fairly constant as safety injection (SI) fluid enters the primary, and break flow leaves the primary system to the broken loop steam generator secondary. Decay heat is removed by natural circulation.

The recovery procedure in S-SG-8 was not initiated until 600 s, so as to simulate a period necessary for operators to identify the tube rupture. At 600 s the simulated pressurizer PORV operation was initiated in an attempt to depressurize the system using a primary feed and bleed operation. The simulated PORV was latched open to simulate the condition of a stuck open PORV. A quasi-steady state primary feed and bleed condition was established followed by an intact loop secondary steam and feed to further reduce primary pressure. Upon opening the PORV, primary pressure dropped to a point just above the secondary pressures. The vessel level fell to the top of the core, and the pressurizer filled. A quasi-steady primary feed and bleed condition was established with combined PORV flow and break flow matched by SI flow, and steady liquid levels in the vessel and pressurizer. A cyclic primary mass distribution developed with the broken loop U-tubes filling and dumping which resulted in flow into the vessel. Primary pressure gradually dropped until intact loop steam and feed was initiated. The intact loop secondary pressure then dropped rapidly, with the primary pressure following closely. The test was terminated after an extended intact loop steam and feed, and primary pressure reduced to the accumulator injection setpoint.

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1. INTRODUCTION

This report documents preliminary results from Semiscale Mod-2B test S-SG-8, the fifth experiment performed in the Semiscale Steam Generator Tube Rupture (SG) Test Series.[1] S-SG-8 was performed December 21, 1983. 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 capability. 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-8 simulated a pressurized water reactor transient initiated by a double-ended offset shear of one cold side steam generator tube. The test was designed in two parts, an initial 600 s period in which only automatically functioning plant protection systems were assumed to operate, followed by an operator induced recovery period, which included SI operation, latching open the pressurizer PORV, and steaming and feeding the intact loop secondary. Automatic signals started safety injection (SI), closed main steam isolation valves, turned off main feedwater, started auxiliary feedwater, tripped the main coolant pumps, and shut off 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.) The S-SG-8 recovery consisted of primary feed and bleed with a simulated stuck open PORV, and intact loop secondary steam and feed operation. The primary feed and bleed consisted of feeding with SI and bleeding through the pressurizer PORV which was latched open to simulate a stuck open condition. A quasi-steady state primary feed and bleed was established and maintained for 1000 s. During

this period, pressurizer and vessel levels, and primary pressure remained stable, while PORV and break flow were matched by SI flow. Intact loop secondary steam and feed was established late in recovery using auxiliary feedwater and ADV operation to further reduce primary system pressure. The test was terminated after primary pressure was reduced to the accumulator setpoint, and intact loop steam and feed had been maintained for 1000 s.

A preliminary analysis of test S-SG-8 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[a] with external downcomer, tube-and-shell steam generators and associated loop piping with circulation pumps. The broken loop (the loop in which the steam generator tube rupture occurs) is scaled to represent one loop of a four-loop PWR and the intact 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 intact and broken loops, 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

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a. For Test S-SG-8, only 22 rods were powered.

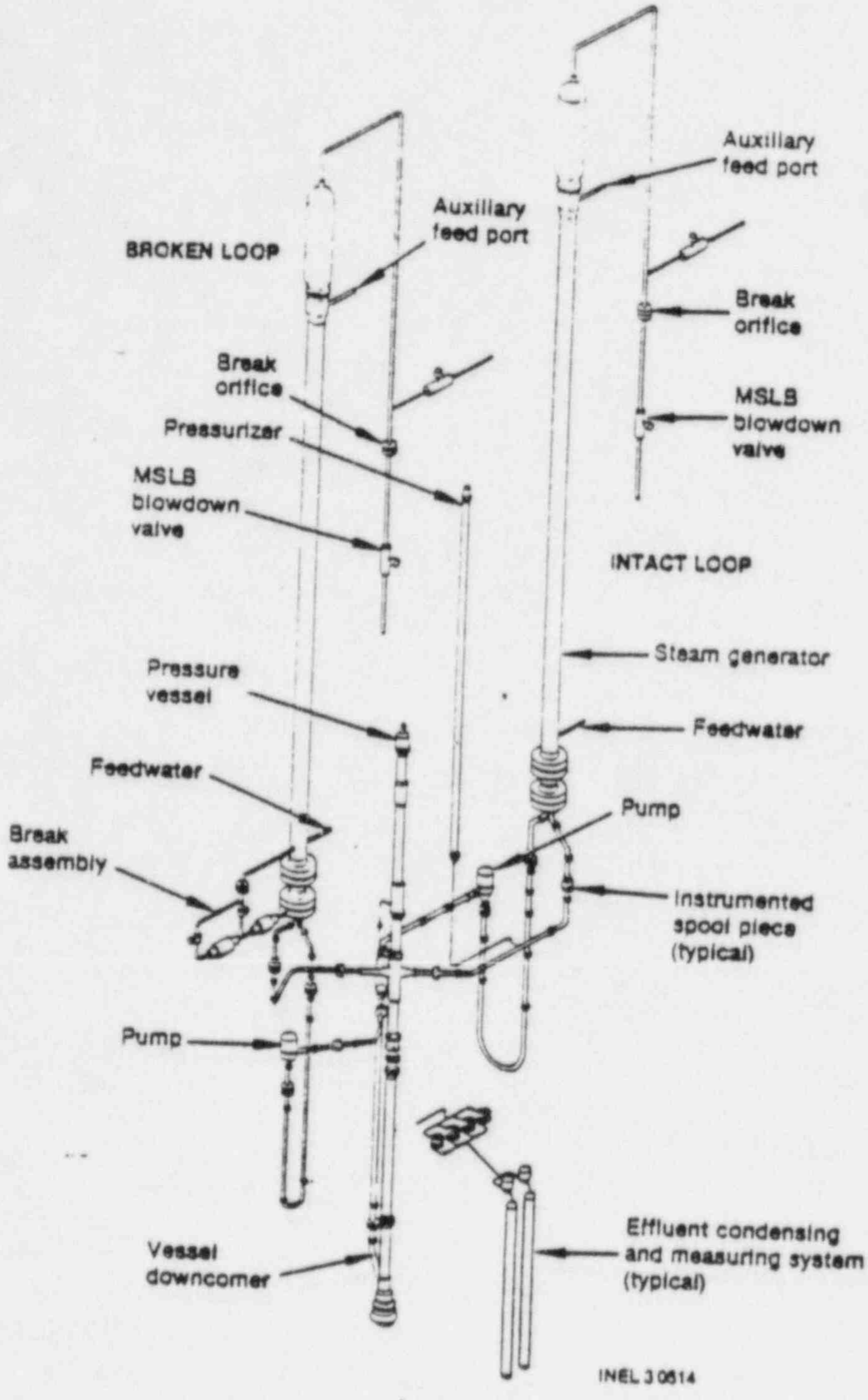

Figure 1. Semiscale Mod-2B system as configured for the SG test series.

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 simulate this operation in both the broken and intact 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 broken loop and 6.55 MPa (949 psia) in the intact loop. The first stage SRV relief setpoint is 5.94 MPa (861 psia) in the broken loop and 6.74 MPa (977 psia) in the intact loop.[a] Figures 3 and 4 show mass flow rate versus pressure for ADV and SRV operation for the broken and intact 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) of saturated steam 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 broken 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

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

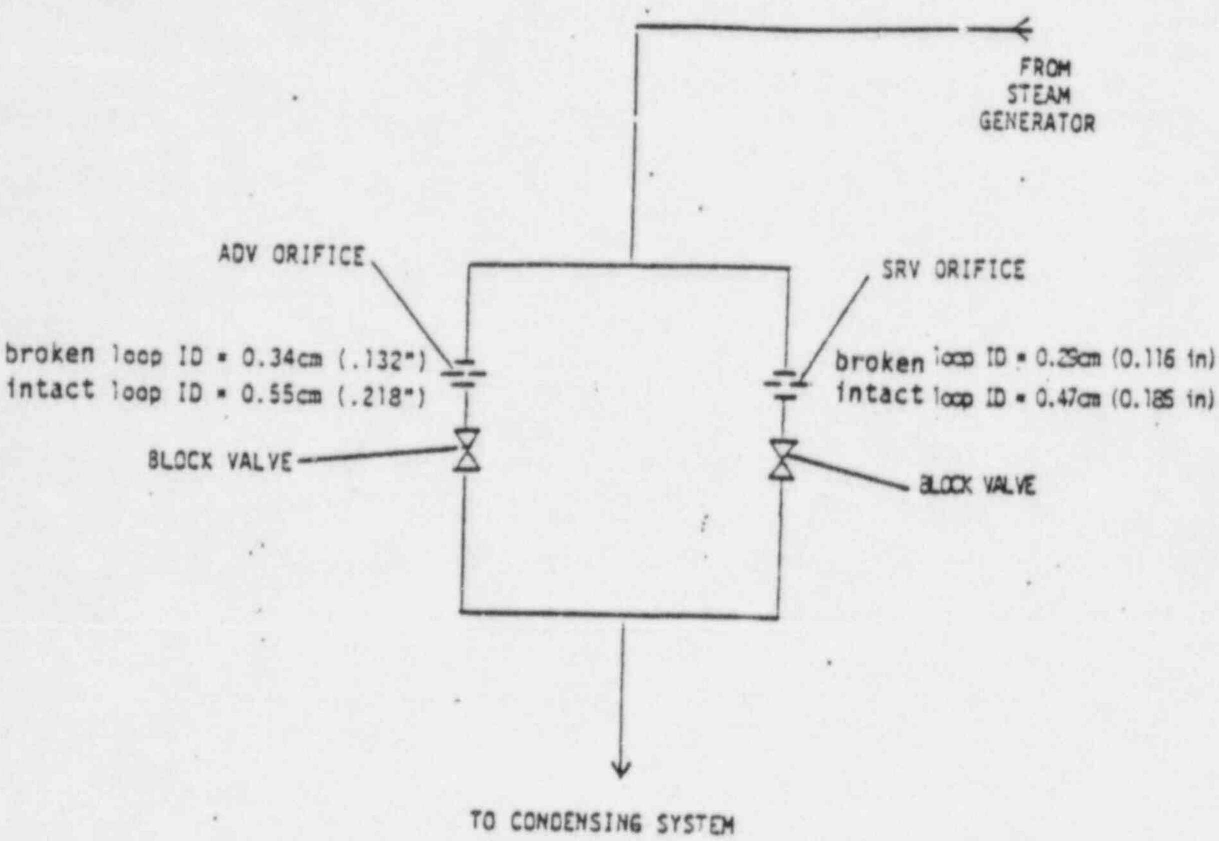


Figure 2. ADV and safety relief valve system.

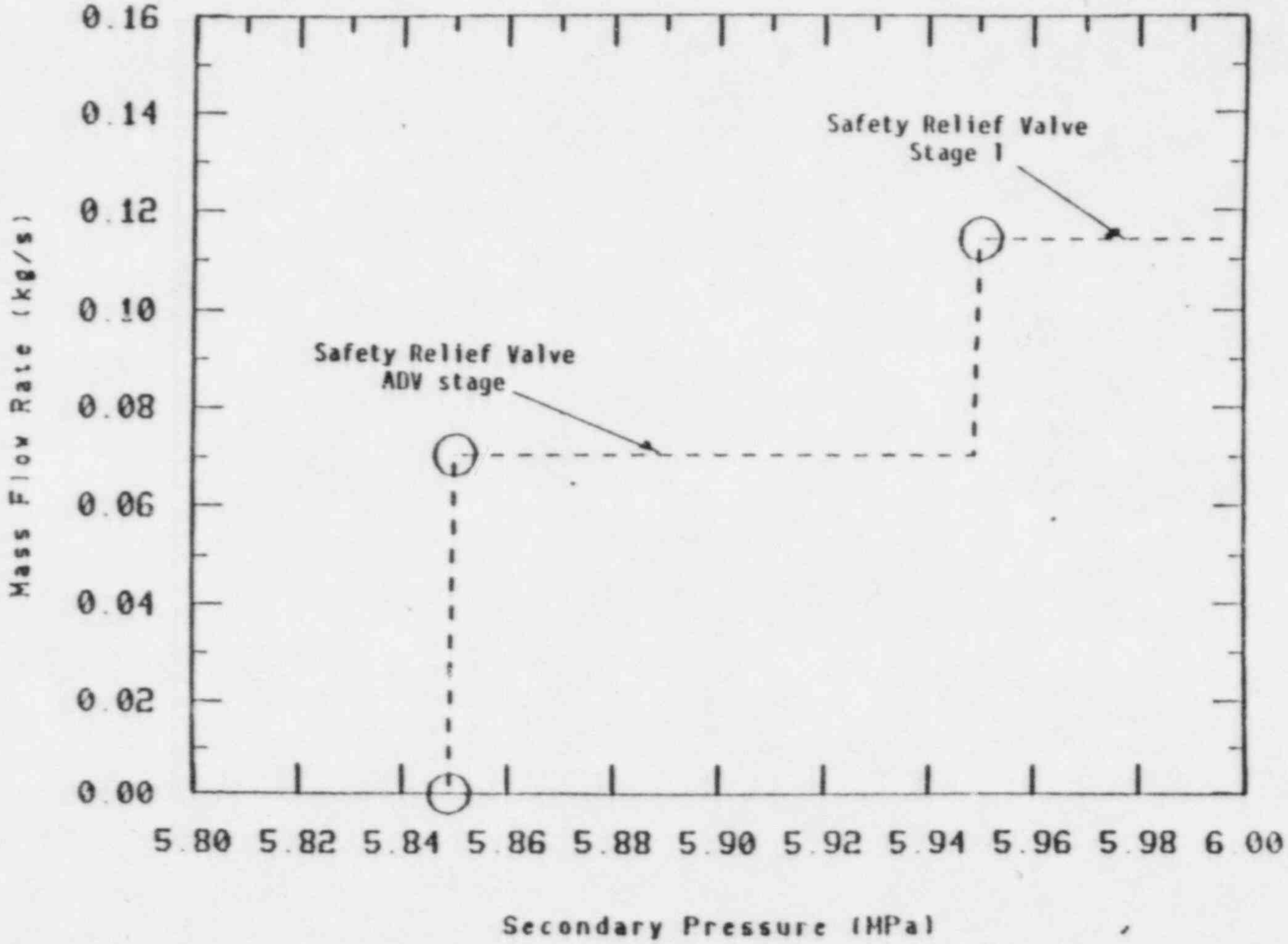


Figure 3. Broken loop steam generator safety relief valve operation.

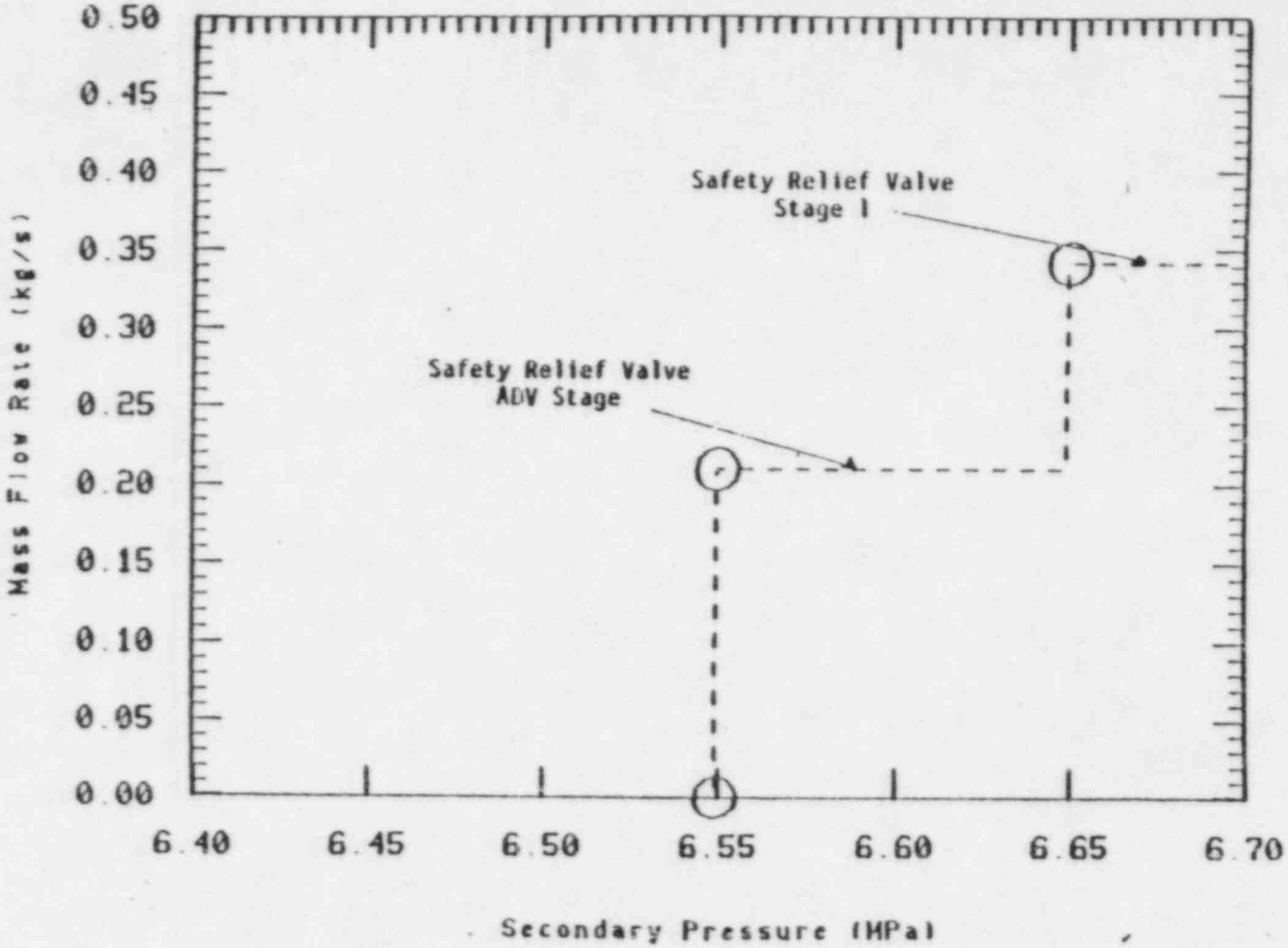


Figure 4. Intact loop steam generator safety relief valve operation.

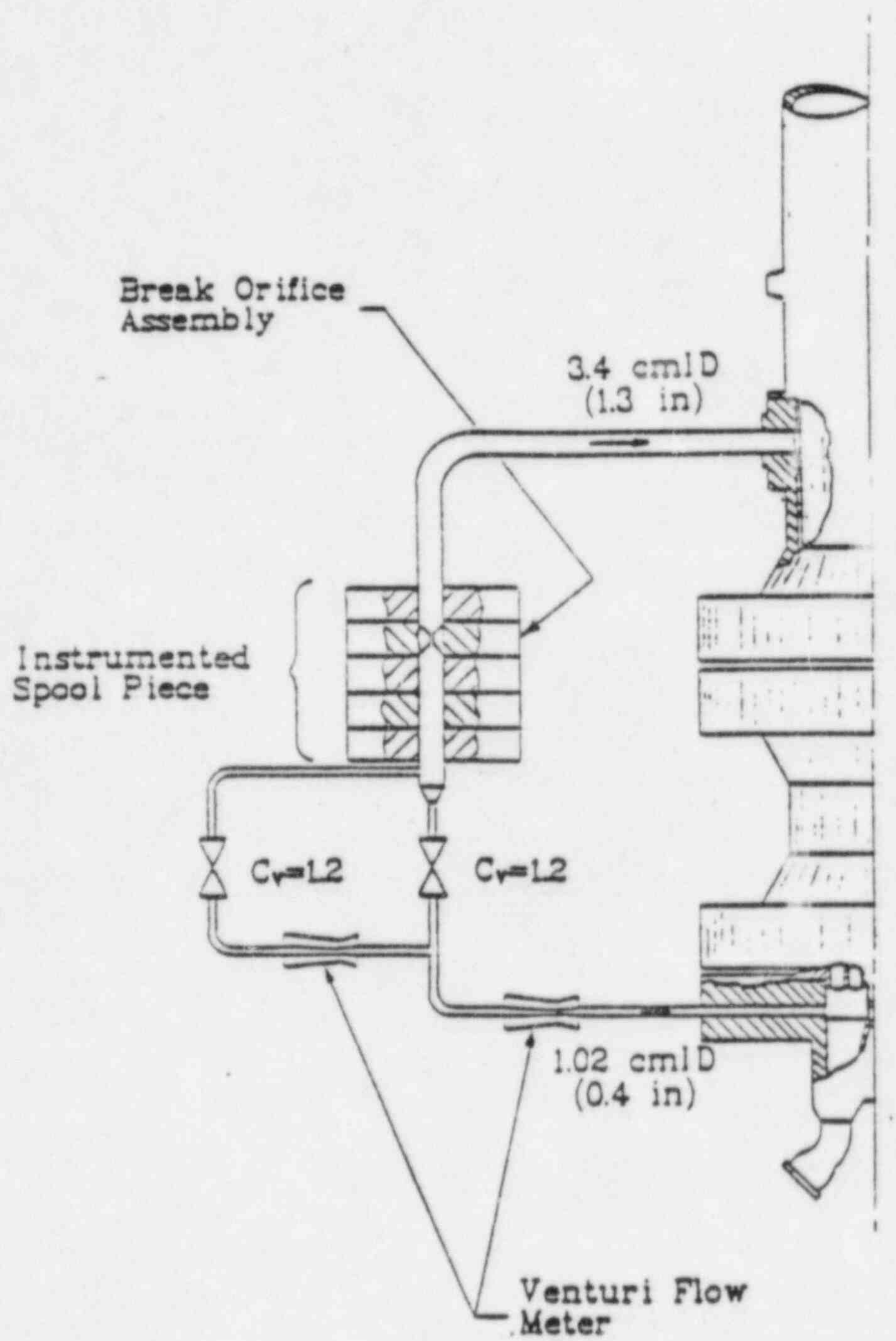
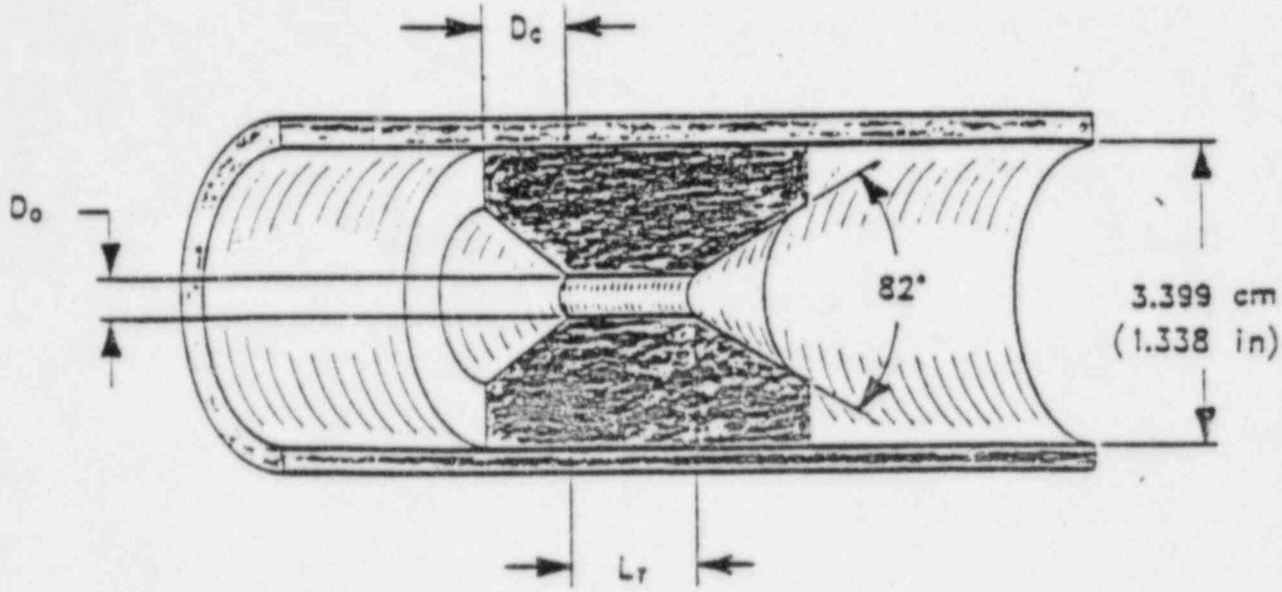


Figure 5. Semiscale tube-rupture break assembly.

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 (14.4 in) above the top of the tube sheet on the cold leg side of the generator. For test S-SG-5, 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 an interchangeable symmetric conical flow tube as depicted in Figure 6. Figure 6 shows the dimensions for a 1-, 5-, and 10-tube break orifice. Test S-SG-8 used the 1-tube break orifice with a 0.079 cm (0.0308 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, intact loop pump suction, broken 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-5. Power to the vessel upper head and upper plenum heater banks was terminated when the indicated liquid level fell below 20% of full for the portion of the vessel covered by the particular heater.

Pressurizer internal heaters were used in the following manner during S-SG-8 to establish initial conditions. Three types of pressurizer heaters were used, back-up heaters, variable heaters, and warm-up heaters. The back-up heaters were operated in an on/off mode only, supplying a total maximum power of 1170 watts from 2 heater rods. These heaters were controlled automatically to energize when the primary pressure decreased to 15.3 MPa (2219 psia) and to turn off when pressure returned to 15.4 MPa (2233 psia). The variable heaters supplied up to 1185 watts total power



TUBE RUPTURE	Do		LT		Dc	
	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.

from 2 heater rods. The controller was set to maintain primary pressure at 15.6 ± 0.14 MPa (2262 ± 20 psia). These heaters were energized at 5.6 MPa (812 psia), and as the primary pressure decreased, the power increased to a maximum at 15.4 MPa (2233 psia). As the pressure rose, power was reduced until it was terminated at 15.74 MPa (2282 psia). Warm-up heaters were controlled manually and supplied up to 14 kW total power from 6 rods if back-up and variable heaters were unable to maintain pressure control.

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 broken loop secondary. Table 2 contains a sequence of significant events for S-SG-8. The first 600 s involved automatically occurring events such as core scram, main 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-8 involved primary feed and bleed, and intact loop secondary steam and feed. 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. Intact loop auxiliary feed was controlled by maintaining the secondary water level between 800 and 1050 cm (315 and 413 in.). Broken loop auxiliary feed was terminated at 600 s in an attempt to isolate the secondary. The pressurizer PORV was latched open at 600 s to simulate the condition of a stuck open PORV. It was not shut until test termination. SI was also

TABLE 1. INITIAL CONDITIONS FOR S-SG-8

	Specified	Measured
Primary Cold Leg Flow Rate (Nominal)		
Broken Loop	2.7 ℓ/s (43 gpm)	3.03 l/s (48 gpm)
Intact Loop	8.1 ℓ/s (128 gpm)	8.65 l/s (137 gpm)
Pressurizer Pressure	15.6 ± 0.14 (2263 ± 20 psia)	15.54 MPa (2253 psia)
Pressurizer Liquid Volume	0.0102 ± 0.0008 m^3 (0.36 ± 0.028 ft^3)	0.0105 m^3 (0.3708 ft^3)
Core Power	2.0 ± 0.01 MW	1.99 MW
Loop to Loop Cold Leg Fluid Temperature Differential	2.0 K (3.6°F)	0.7 K (1.3°F)
Core Fluid Temperature Rise	37 ± 1.5 K (66.6 ± 3°F)	37.8 K (68.0°F)
Steam Generator Pressure		
Broken Loop	5.55 ± 0.07 MPa (805 ± 10 psia)	5.58 MPa (809 psia)
Intact Loop	5.55 ± 0.07 MPa (805 ± 10 psia)	5.49 MPa (796 psia)
Steam Generator Secondary Fluid Mass[a]		
Broken Loop	100 + 40, - 20 kg (220 + 88, - 44 lbm)	97 kg[b] (214 lbm)
Intact Loop	100 + 40, - 20 kg (220 + 88, - 44 lbm)	88 kg[b] (194 lbm)
Primary Leakage at t = 0	<0.006 kg/s (<0.0132 lbm/s)	0.002 kg/s (0.004 lbm/s)

a. These values were determined from data acquisition system levels following main steam isolation valve closure.

b. Measured with LIS 1117 + 51 for intact loop or LBS 1117 + 51 for broken loop.

TABLE 2. SEQUENCE OF EVENTS FOR TEST S-SG-8

Specified Criteria	Actual Time (s)	Event
0 s	0	Break flow initiated
0 s	0	Pressurizer internal heaters off
P_{PRZ} = 13.1 MPa (1900 psia)	146	SCRAM
SCRAM	148	Core power shut off
SCRAM	149	MSIV closure
P_{PRZ} = 12.5 MPa (1814 psia)	152	SIS
SIS	153	Main feedwater secured
SIS	153	Auxiliary feedwater initiated
SIS	153	SI turned on
SIS	154	Pumps off
600 s	600	PORV is opened
$m_{HPIS} = m_{PORV}$	3000	Quasi-steady state primary feed and bleed condition established
Steady state + 1000 s	4000	Intact loop steam generator steam and feed initiated
P_p < 4.22 MPa (612 psia) intact loop secondary steam and feed for 1000 s	5100	Test terminated

maintained throughout the test. An extensive period was allowed during the primary feed and bleed operation to assess the effect on primary pressure and inventory. The intact loop steam and feed was initiated at 4000 s, by opening the ADV. Auxiliary feedwater was used in an attempt to maintain secondary level. The test was terminated at 5100 s when the primary pressure fell below the accumulator injection setpoint of 4.22 MPa (612 psia), and intact loop steam and feed had continued over the minimum 1000 s. Pressurizer external heaters were not used. The vessel upper head and upper plenum external heaters were shut off at 650 s and 780 s respectively as these vessel sections voided. All other external heater power for heat loss makeup remained on for the entire transient. No external heater temperature limits were exceeded.

3. RESULTS

This section discusses the overall thermal-hydraulic response of the Semiscale system during Test S-SG-8. Test S-SG-8 was a simulation of a double-ended offset-shear of one steam generator tube 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 effect of primary feed and bleed (600 to 4000 s), and the effect of intact loop steam and feed (4000 to 5100 s).

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

The occurrence of a one-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 7. The tube rupture (occurring in the broken loop steam generator) initiated the transient at 0 s. Primary fluid originally at 15.54 MPa (2253 psia) flowed through the conical flow tube break orifice into the broken loop steam generator originally at 5.58 MPa (809 psia). The loss of mass from the primary loop caused a fairly steady primary depressurization until the pressurizer emptied at approximately 134 s. The pressure then fell faster until the low pressurizer pressure setpoint of 13.1 MPa (1900 psia) was achieved at about 146 s. Prior to achieving the low pressurizer pressure trip, both the broken and intact 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 8). The energy addition to the broken 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 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 broken and intact loop steam generator secondaries caused a rapid pressurization of the

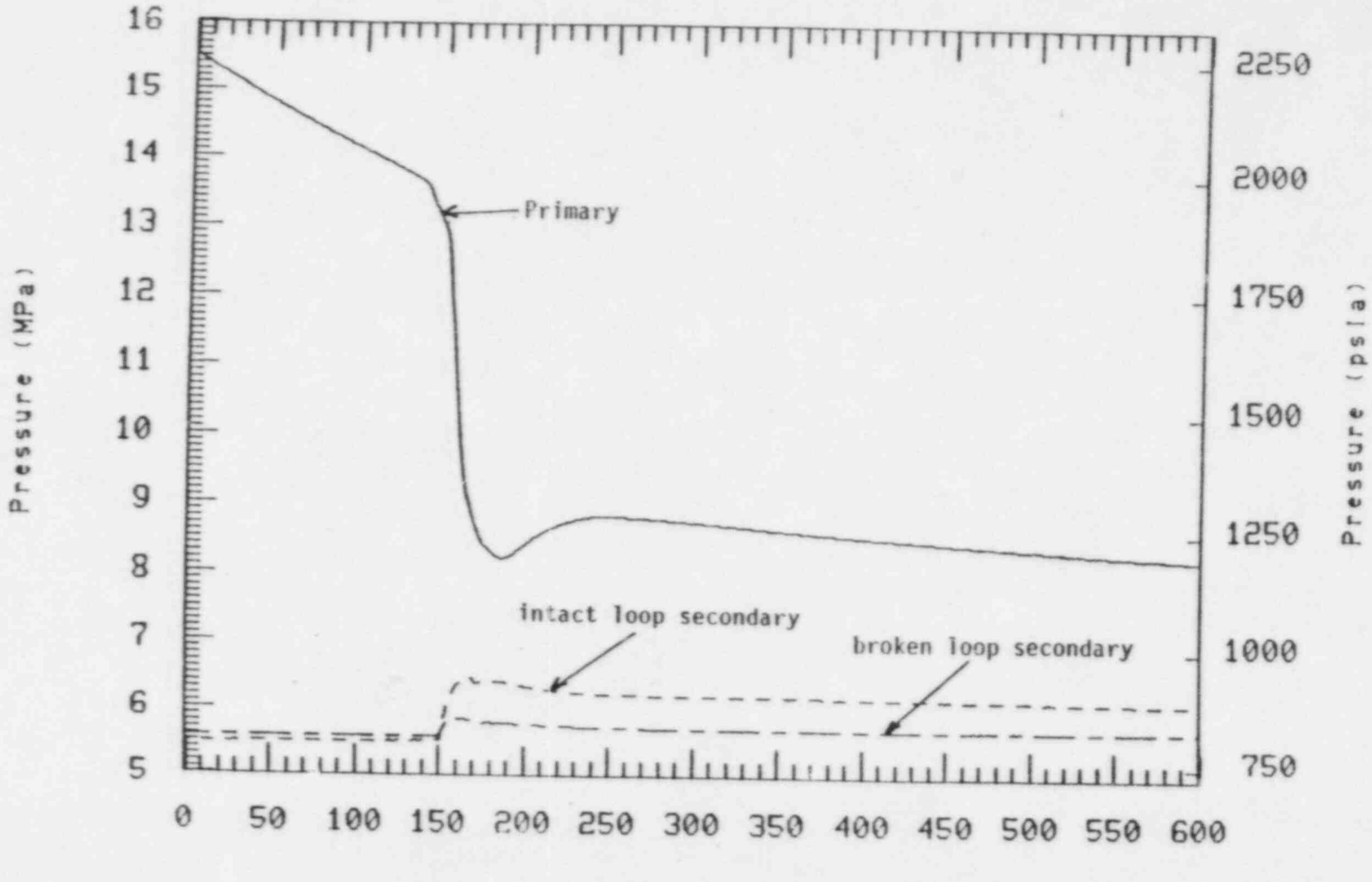


Figure 7. Comparison of primary and secondary pressure during a cold side, one-tube rupture transient, (S-SG-8).

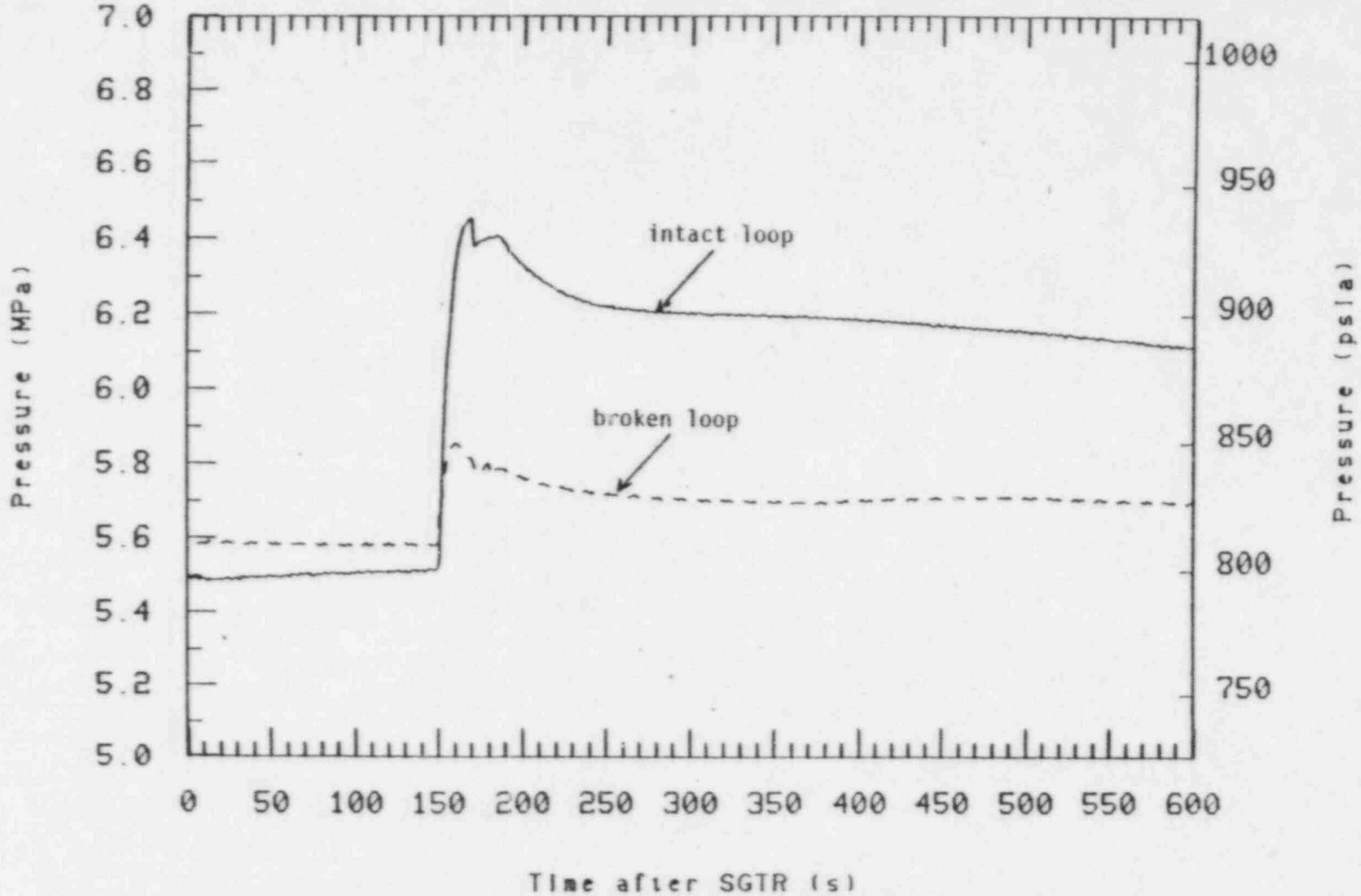


Figure 8. Comparison of broken loop and intact loop secondary pressure during a cold side, one-tube rupture transient (S-SG-8).

secondaries as shown in Figure 8. The secondary pressure in the intact loop steam generator achieved the ADV setpoint of 6.55 MPa (950 psia) cycling the ADV once. The broken loop secondary pressure achieved the ADV setpoint of 5.85 MPa (848 psia) and cycled twice 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 7). The safety injection signal was achieved at 12.51 MPa (1814 psia): (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 9. Eventually, the primary system depressurization was sufficient for the hot leg fluid to reach a saturation condition at about 220 s (Figure 10). Flashing in the system then caused a major reduction in the depressurization rate. The primary pressure made a slight recovery between 190 and 240 s. This repressurization was likely caused by superheated steam in the pressurizer (Figure 10), flashing in the reactor vessel, and reduced heat transfer to the secondaries. Primary pressure remained above both secondary system pressures for the entire 600 s period, causing a primary-to-broken loop secondary mass flow.

The primary-to-secondary break flow persisted throughout the initial period as shown on Figure 11. As long as break flow exceeded total SI flow primary system mass inventory depleted. Figure 12 shows the pressurizer interfacial liquid level essentially depleted after the initial 130 s. By 170 s SI flow exceeded break flow and the primary inventory started to recover. The vessel upper head collapsed liquid level[a] showed little

a. The indicated level during the first 200 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.

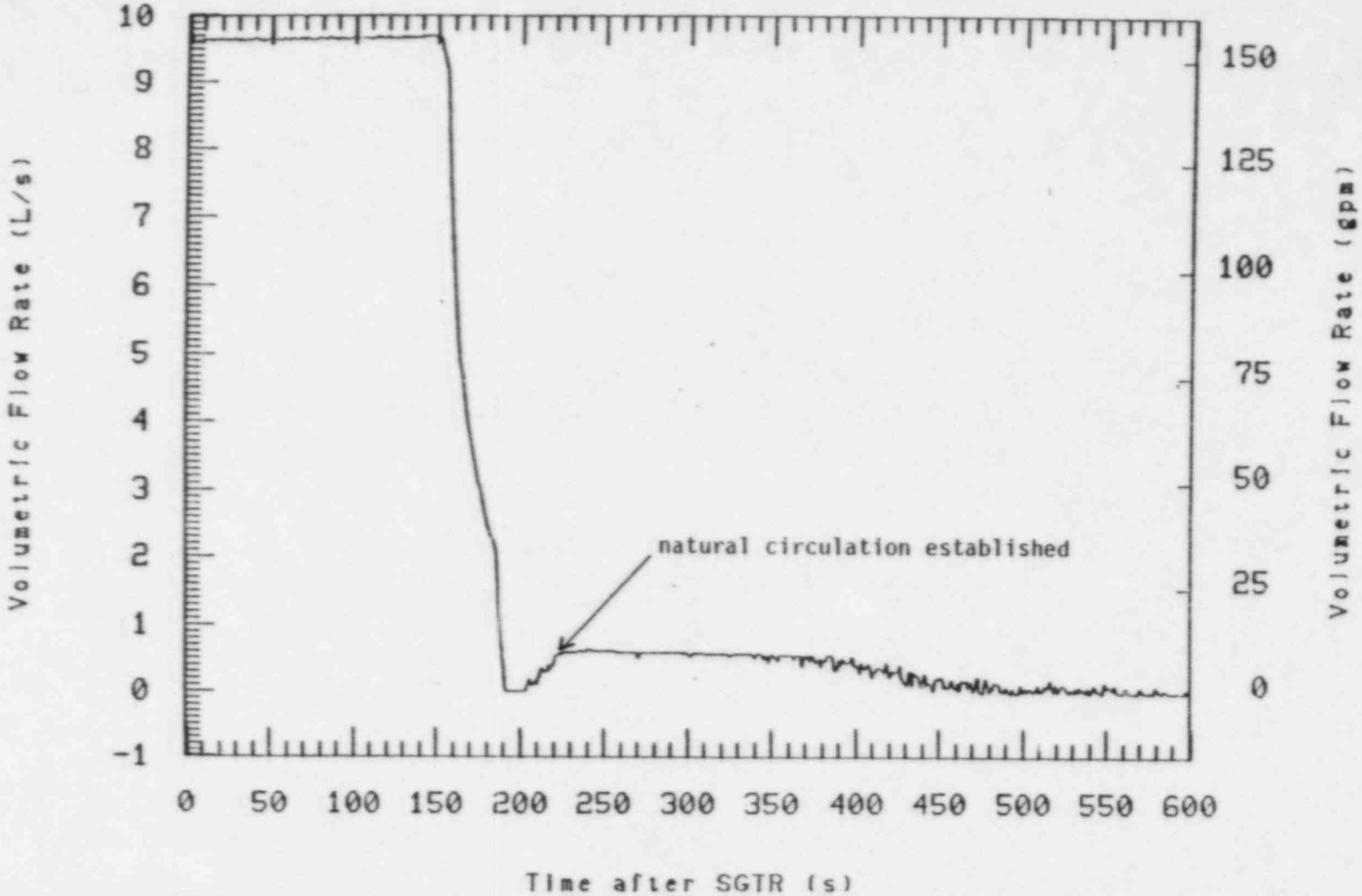


Figure 9. Change to natural circulation in the intact loop during a cold side, one-tube rupture transient (S-SG-8).

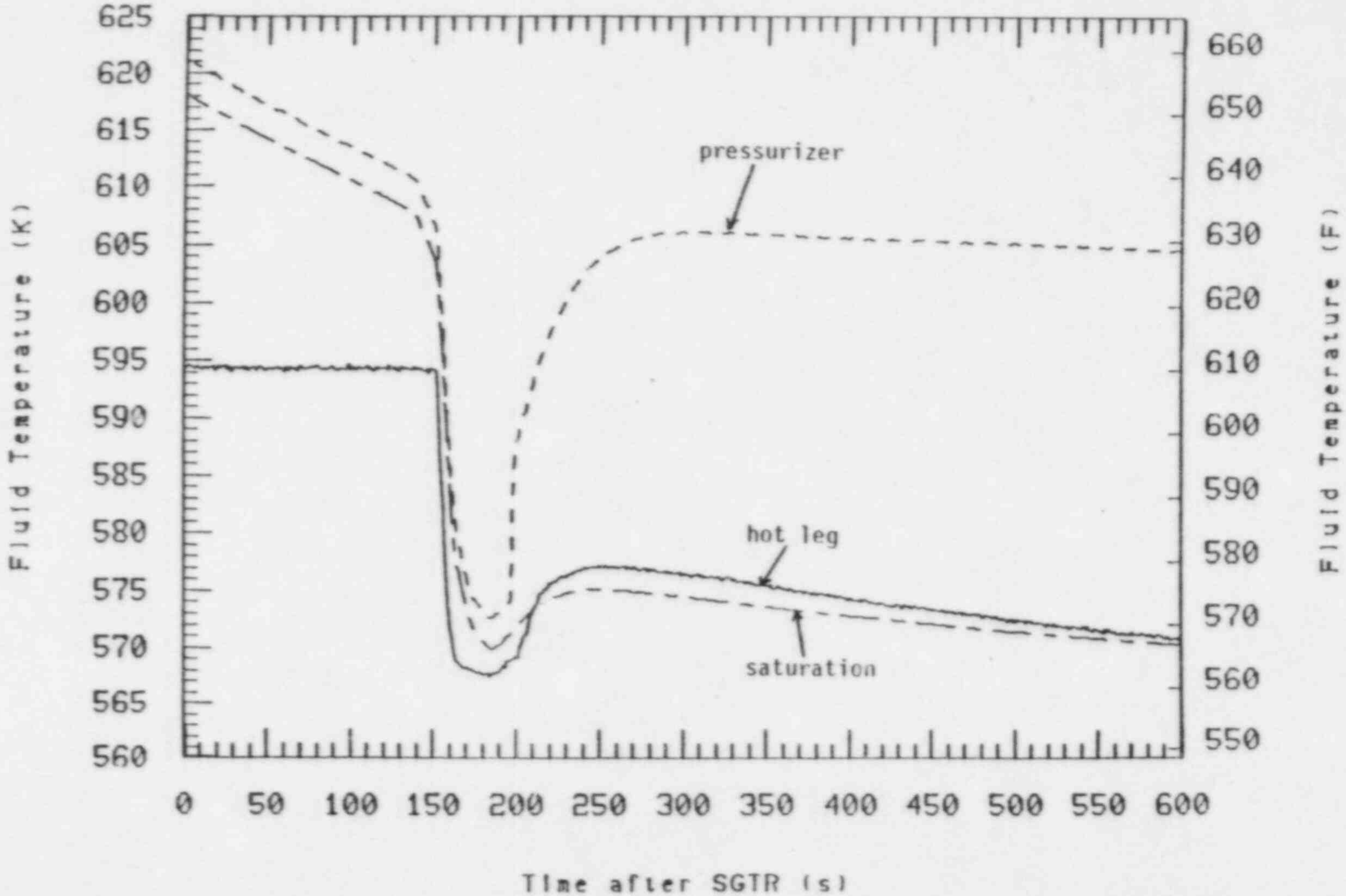


Figure 10. Comparison of fluid temperatures and saturation temperature for a cold side, one-tube rupture transient (S-SG-8).

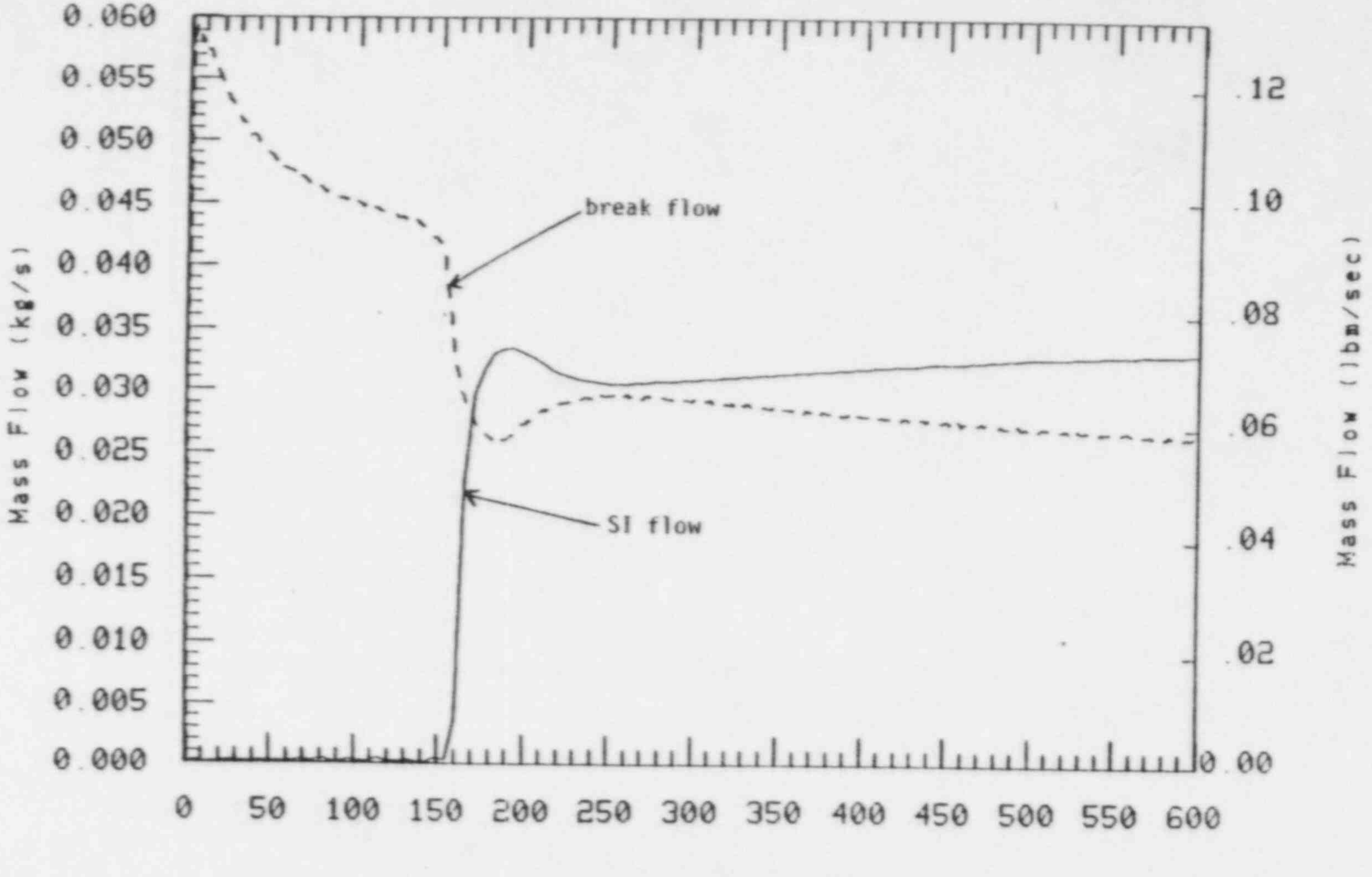


Figure 11. Comparison of break flow and SI flow during a cold side, one-tube rupture transient (S-SG-8).

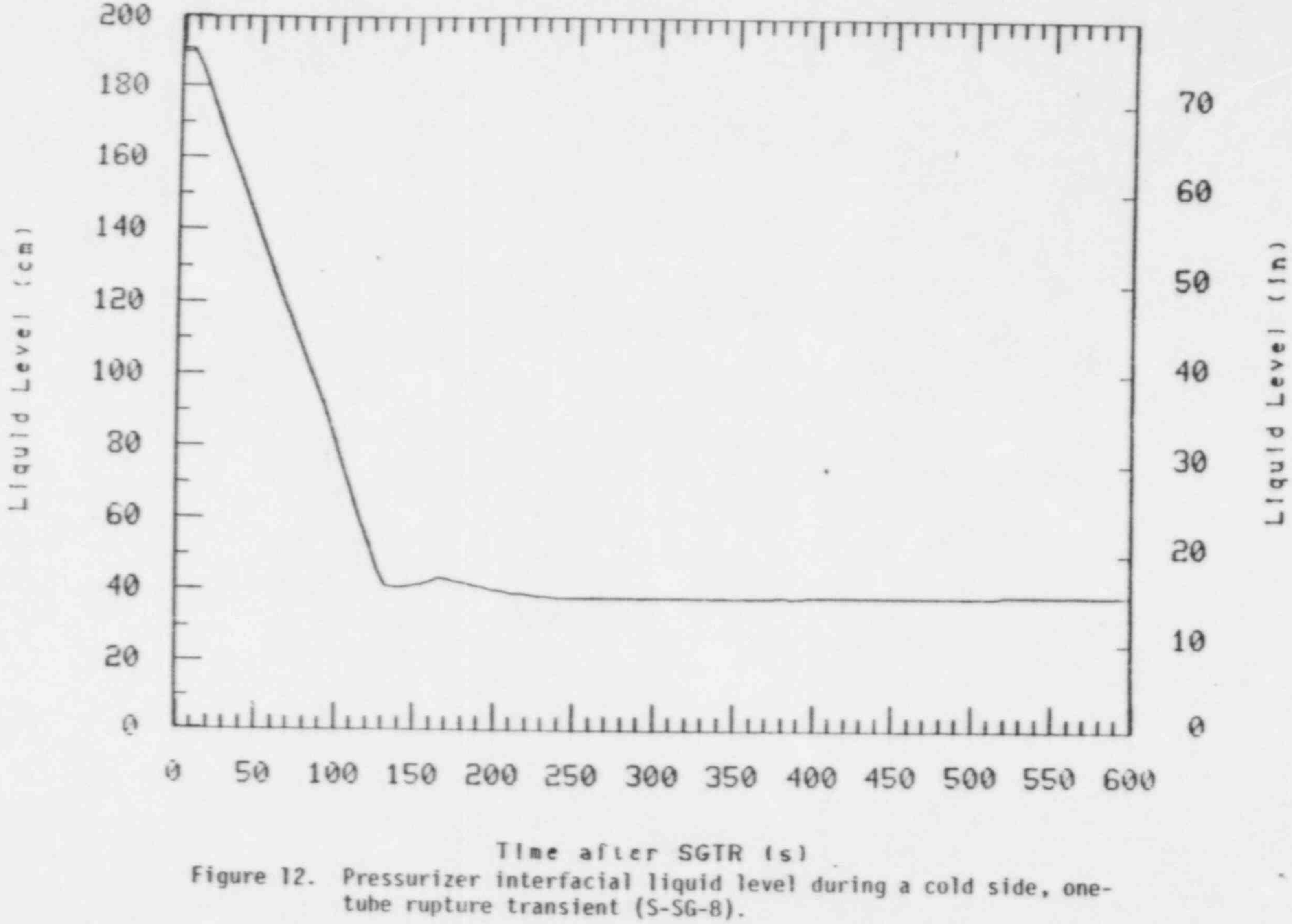


Figure 12. Pressurizer interfacial liquid level during a cold side, one-tube rupture transient (S-SG-8).

voiding in the first 600 s (Figure 13). The steam generator U-tube primary side collapsed liquid levels are shown on Figure 14. 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 intact loop; and break flow, ADV flow, and auxiliary feed flow in the broken loop. Figure 15 shows the collapsed liquid level in both the intact and broken loops. Following main steam isolation valve closure, the collapsed liquid level settled to 800 cm (315 in.) in the intact loop steam generator and about 990 cm (390 in.) in the broken loop steam generator.[a] The broken loop steam generator collapsed liquid level continued to increase until about 600 s. Figure 16 shows that the break flow dominated the broken loop mass balance. There was a slight increase in intact steam generator liquid level during the initial 600 s period (Figure 15) as auxiliary feedwater flow added mass with little depletion due to ADV operation (see Figure 17).

3.2 Recovery Phase Signature

The system recovery in S-SG-8 involved a primary feed and bleed followed by an intact loop steam and feed operation. Recovery in this case meant the operation of intact loop steam and feed for a minimum of 1000 s and reduction of primary pressure to 4.22 MPa (612 psia).

Recovery operation commenced at 600 s when the pressurizer PORV was latched open in an attempt to reduce primary pressure. The PORV was assumed stuck in the open position and remained so for the duration of the test. A quasi-steady state primary feed and bleed resulted from the combined PORV flow and safety injection. Intact loop steam and feed was initiated at 4000 s and maintained until test termination at 5100 s.

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

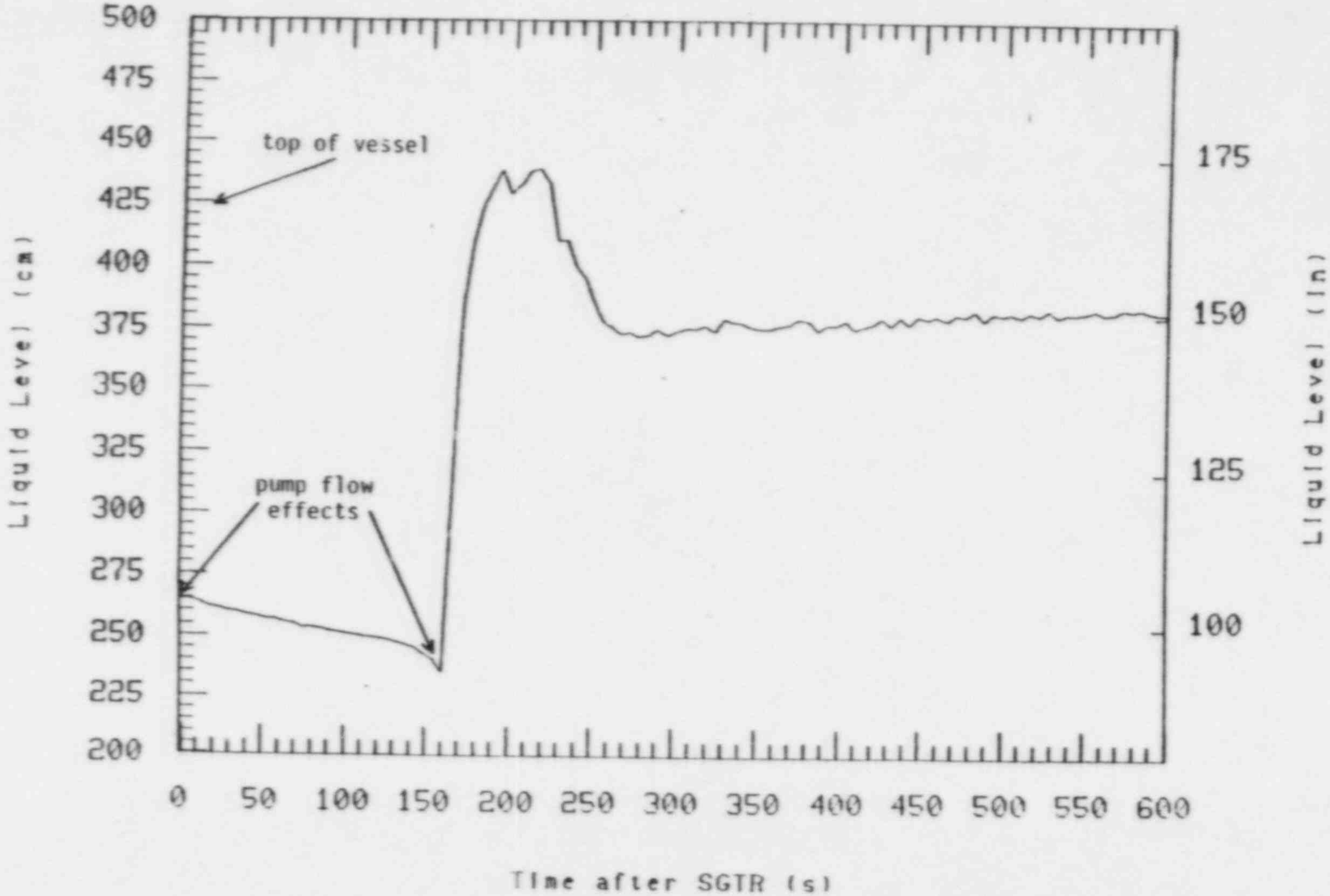

Figure 13. Vessel upper head collapsed liquid level during a cold side, one-tube rupture transient (S-SG-8).

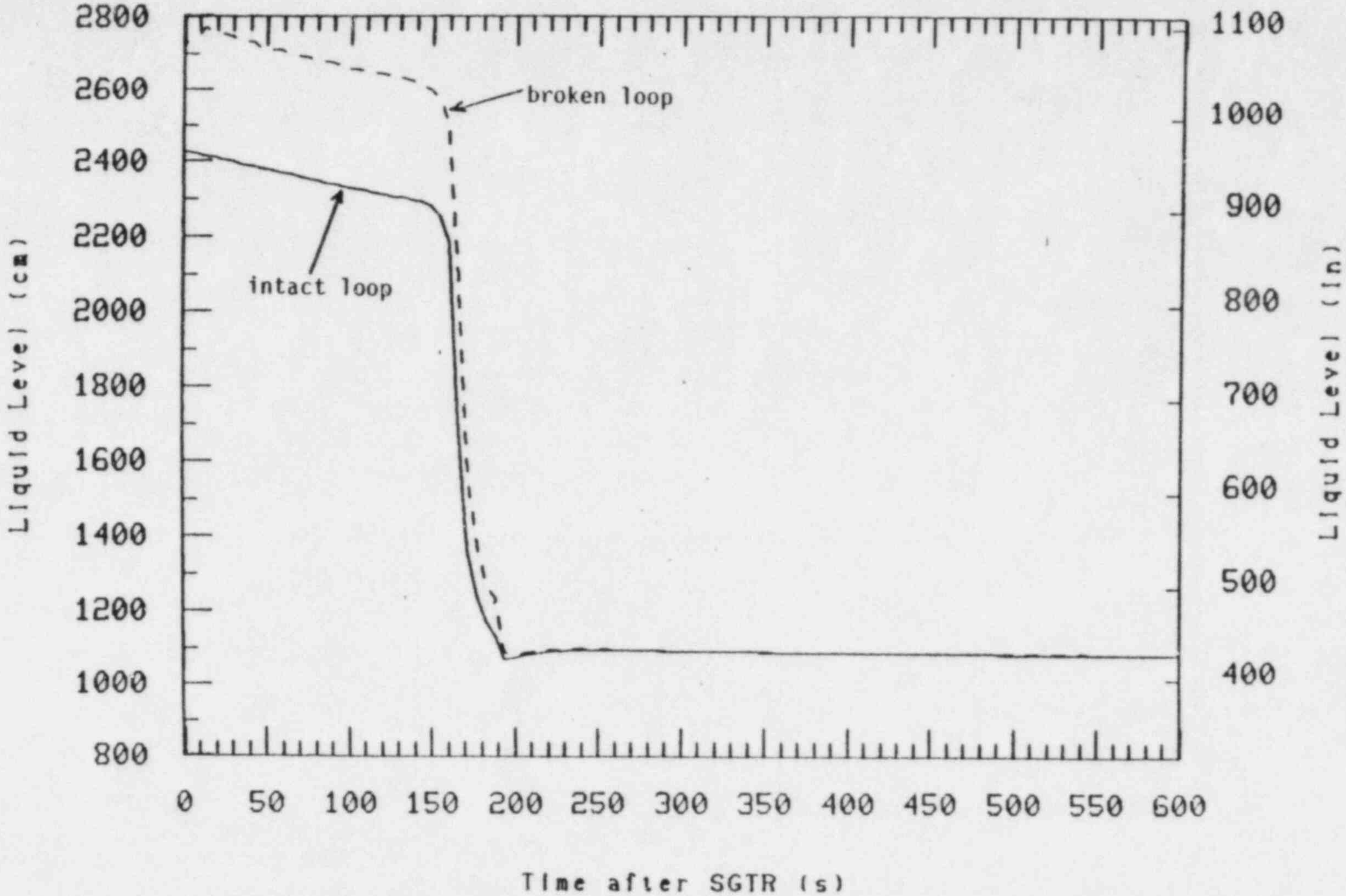

Figure 14. Broken and intact loop steam generator primary tube collapsed liquid level during a cold side, one-tube rupture transient (S-SG-8).

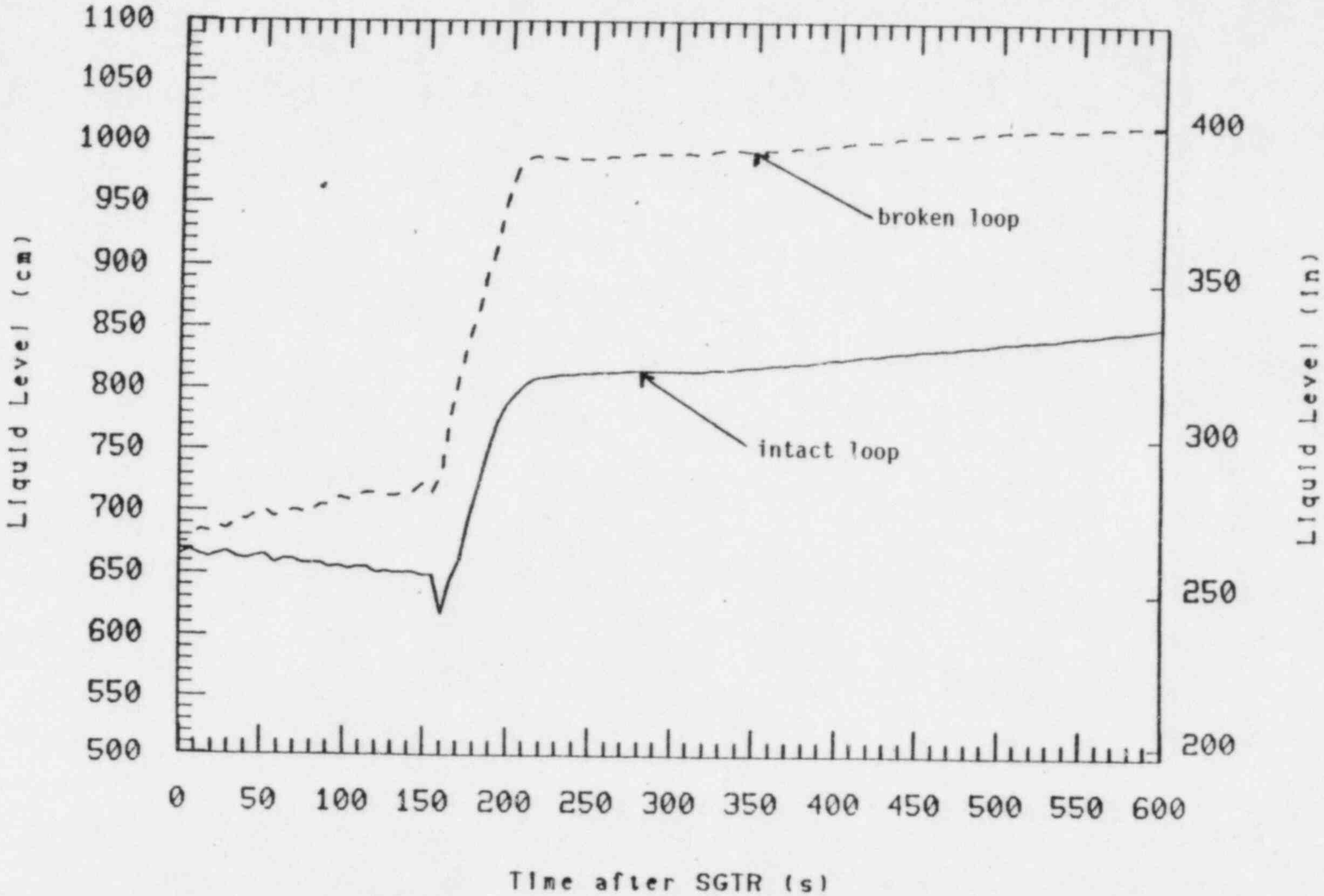

Figure 15. Collapsed liquid level in the broken and intact loop secondary during a cold side, one-tube rupture transient (S-SG-8).

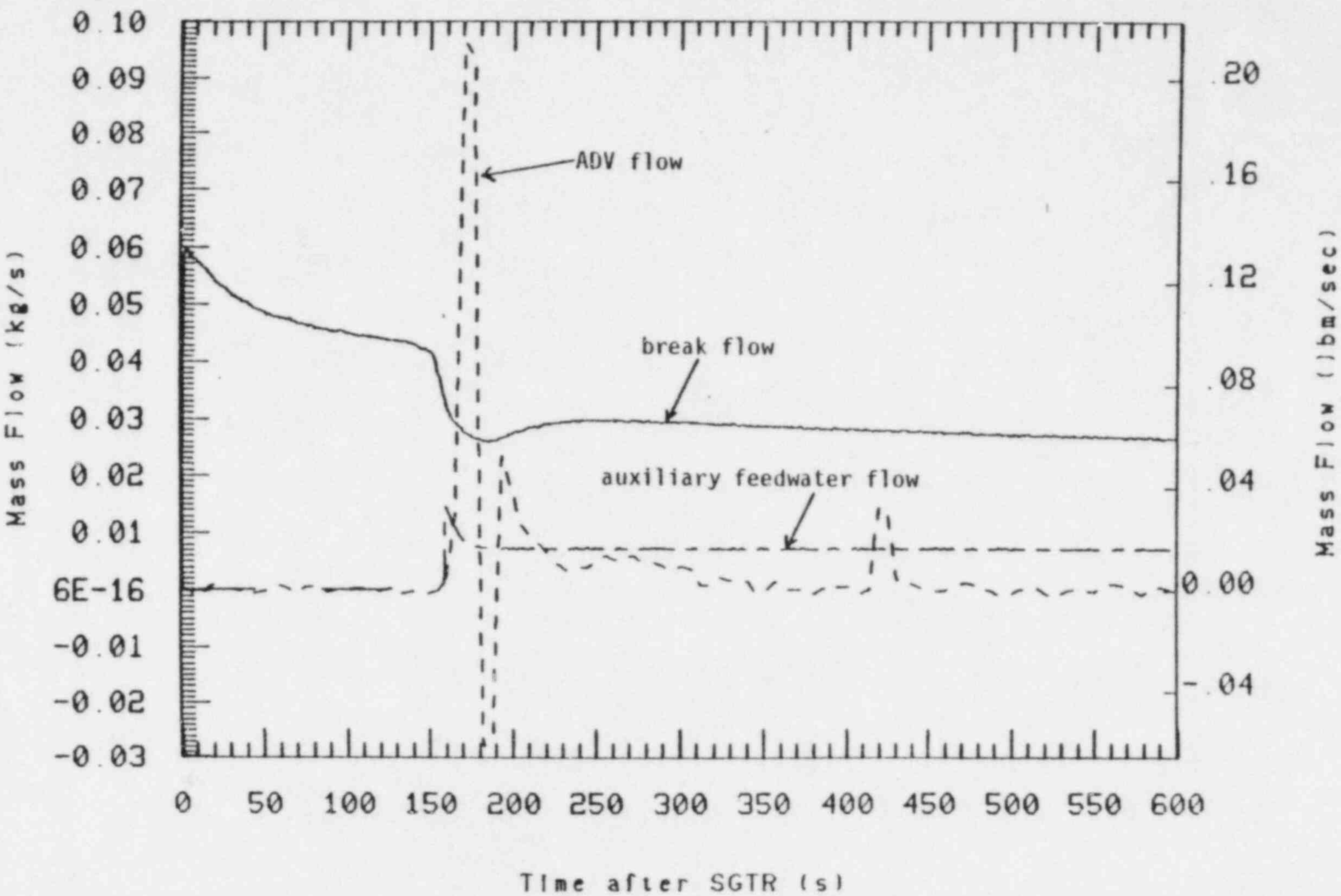

Figure 16. Comparison of break flow, ADV flow, and auxiliary feed flow in the broken loop steam generator during a cold side, one-tube rupture transient (S-SG-8).

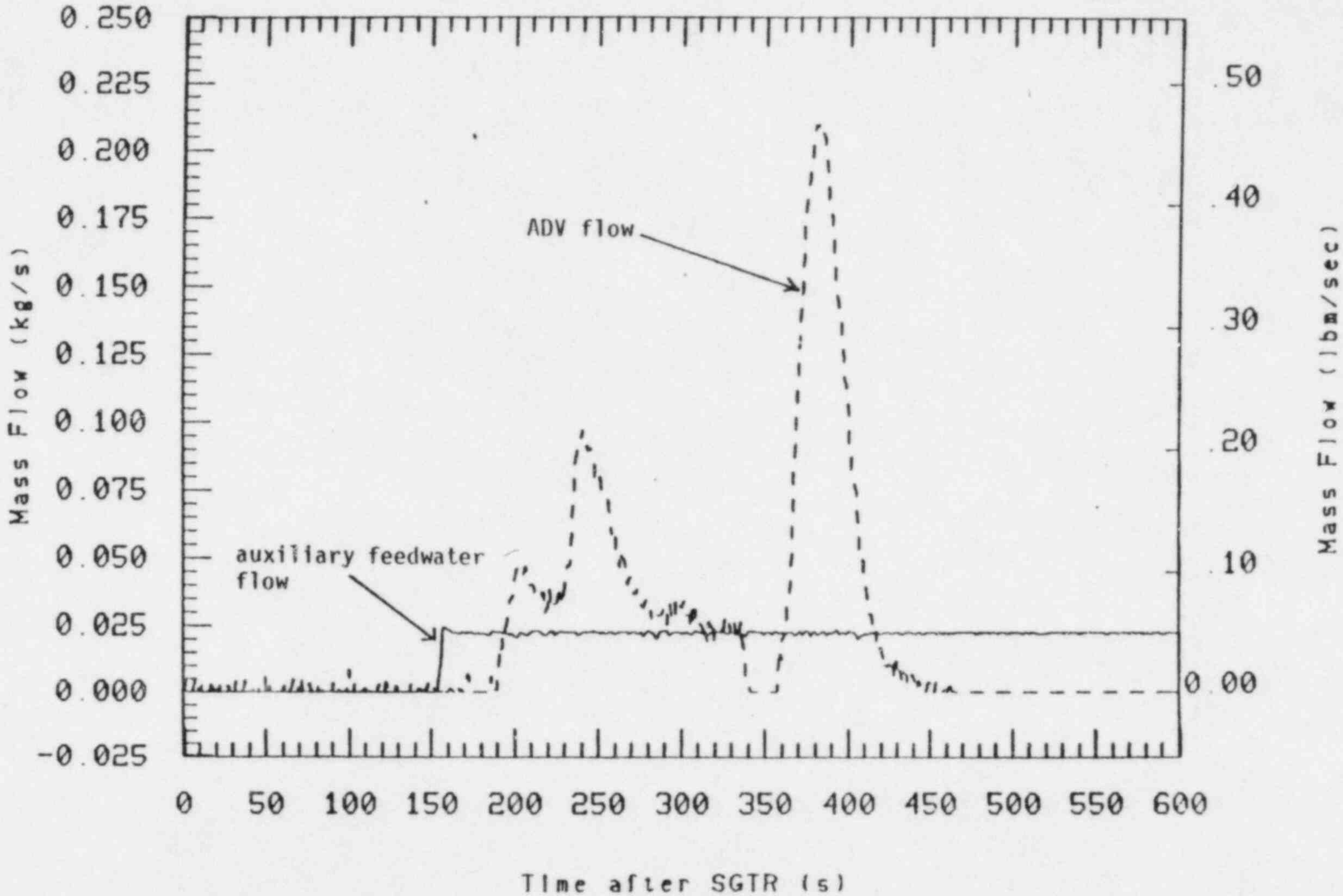

Figure 17. Comparison of auxiliary feed and ADV flow in the intact loop secondary during a cold side, one-tube rupture transient (S-SG-8).

3.2.1 Overall System Response to the Combined Recovery Methods

The overall system response to the combined recovery methods, including primary feed and bleed and intact loop steam and feed, was a rapid initial primary depressurization which gradually slowed, followed by a rapid pressure drop upon intact loop steam and feed operation. Figure 18 shows the primary and secondary pressure response to the recovery operations. The primary pressure drops rapidly as the pressurizer fills removing superheated steam. The depressurization then slows until intact loop steam and feed operation again rapidly drops the pressure. The secondary pressure drop slowly due to environmental heat loss, until intact loop steam and feed rapidly reduces intact loop pressure. Figure 19 shows the pressurizer interfacial liquid level rising from the PORV opening at 600 s, until the pressurizer is full at about 1100 s. The level then remained stable until the system mass redistribution, induced by intact loop steam and feed, dropped the level. SI then refilled the pressurizer. Upon PORV opening, the vessel level dropped to about the top of the core as shown in Figure 20. The level then stabilized and the vessel slowly filled as SI flow slightly exceeded the combined PORV flow and break flow. Intact loop steam and feed produced a rapid increase in core level and a slow filling of the vessel upper head. Secondary levels are shown in Figure 21. The intact loop secondary collapsed liquid level rose consistently until auxiliary feedwater was terminated at about 3100 s. Intact loop steam and feed dropped the level rapidly and auxiliary feedwater was restarted at 4200 s. The broken loop secondary collapsed liquid level rose gradually as break flow filled the secondary. The intact loop steam and feed dropped primary pressure below the broken loop secondary, resulting in back flow from the broken loop secondary to the primary system and a subsequent drop in secondary level.

3.2.2 Effects of Primary Feed and Bleed on System Pressure and Mass Distribution

The primary feed and bleed consisted of feeding with Safety Injection and bleeding through the latched open pressurizer PORV. Opening the PORV at 600 s caused a significant primary system mass redistribution

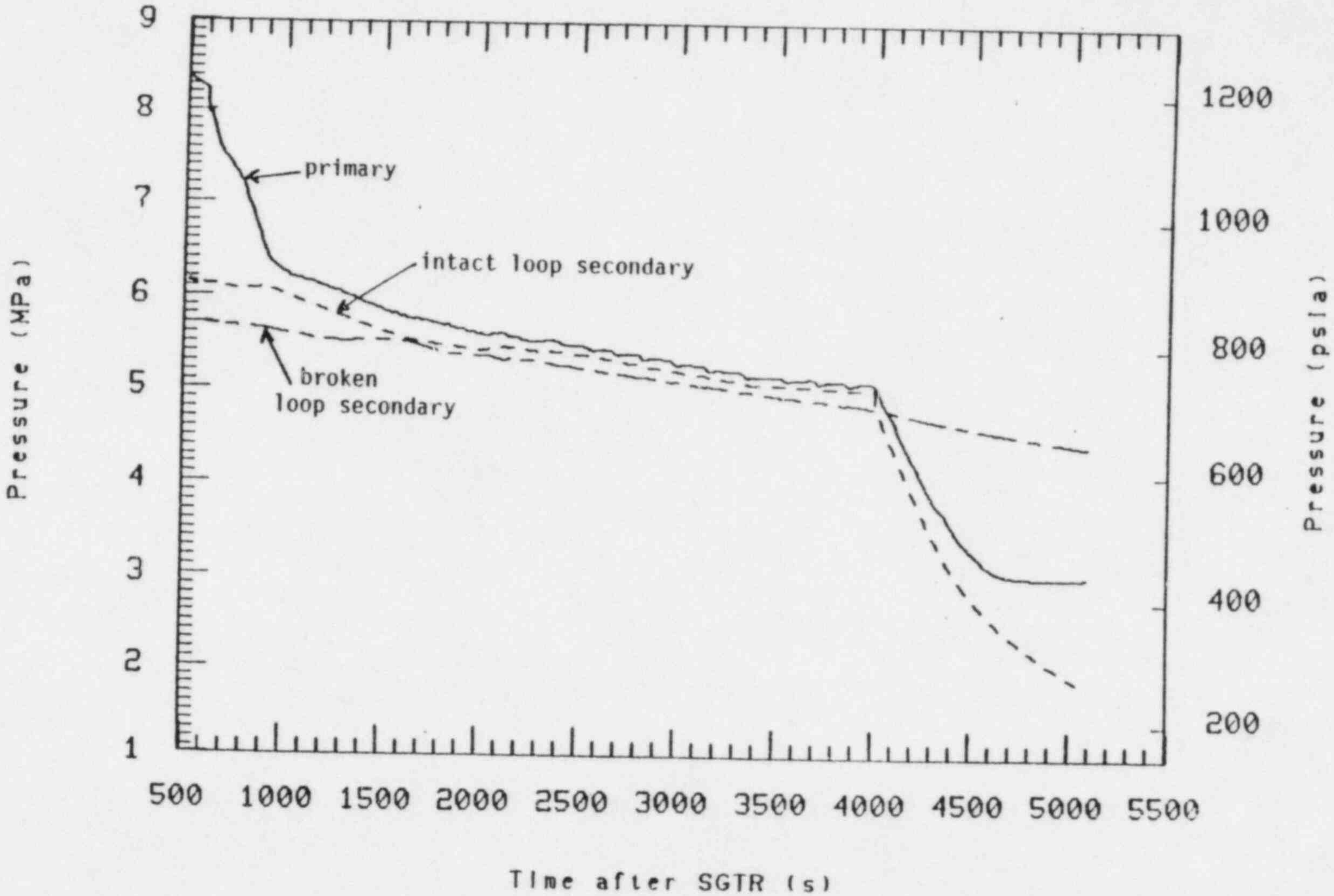

Figure 18. Comparison of primary, intact loop secondary, and broken loop secondary pressures during a cold side, one-tube rupture transient (S-SG-8).

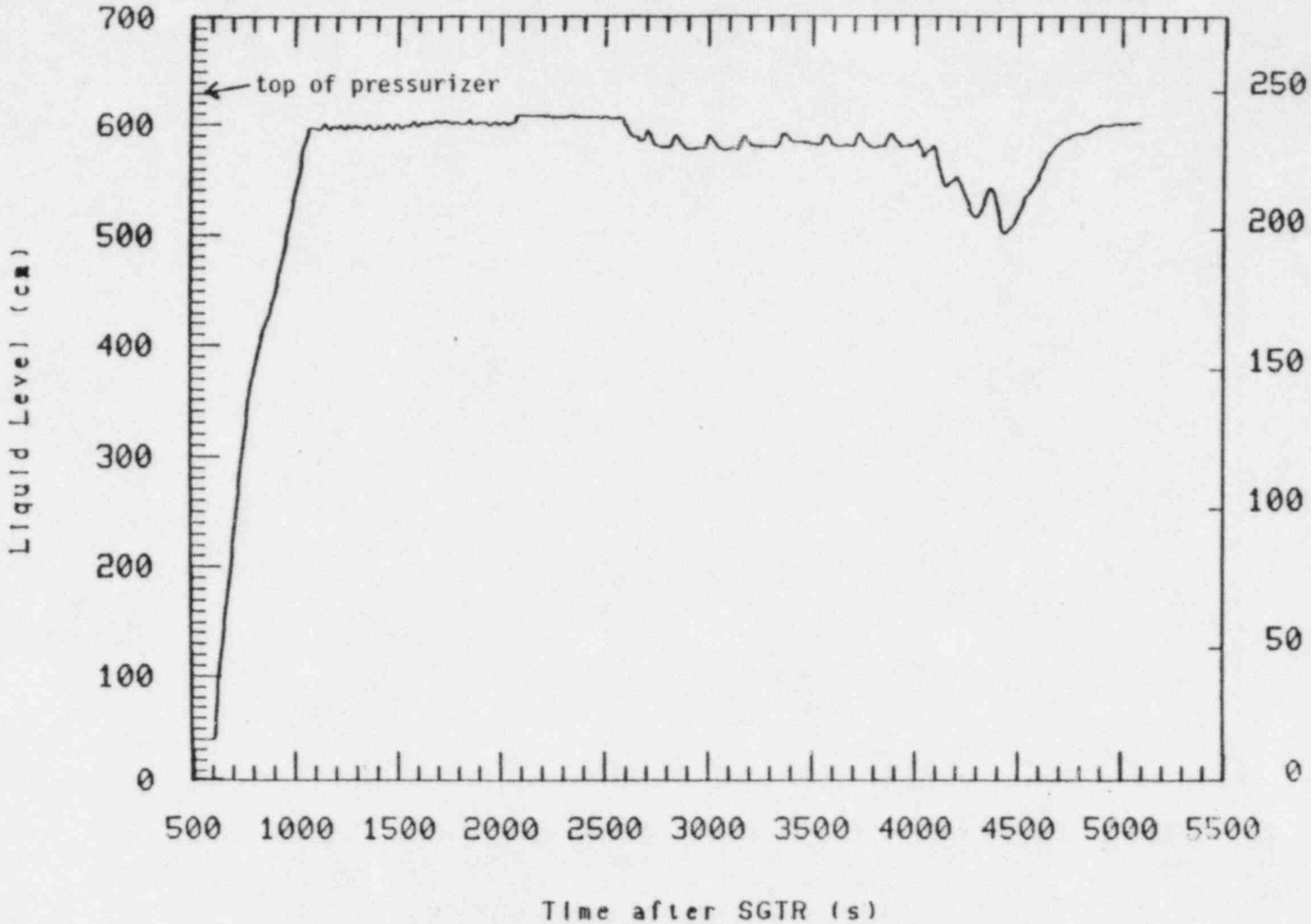

Figure 19. Pressurizer collapsed liquid level during a cold side, one-tube rupture transient (S-SG-8).

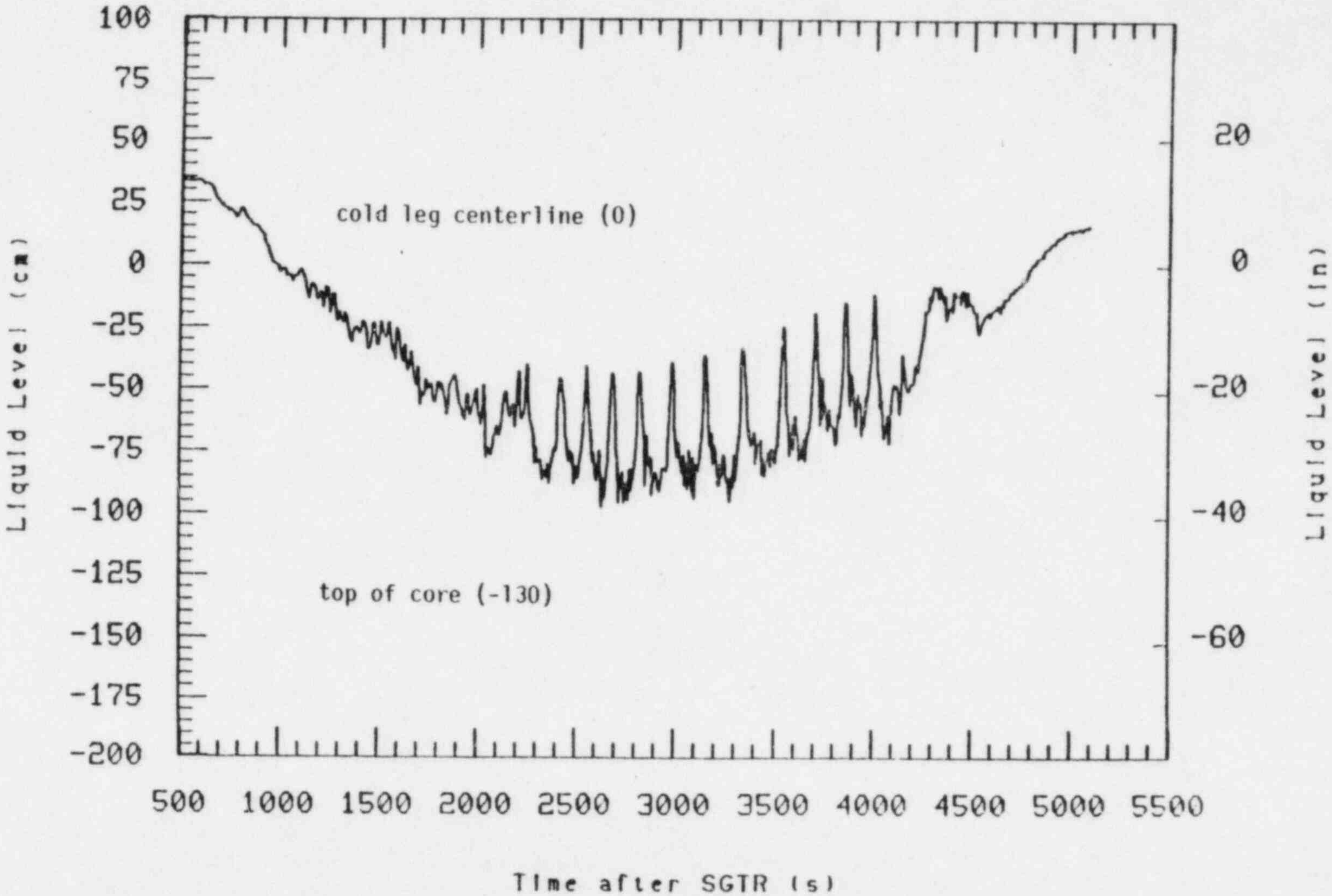

Figure 20. Vessel collapsed liquid level during a cold side, one-tube rupture transient (S-SG-8).

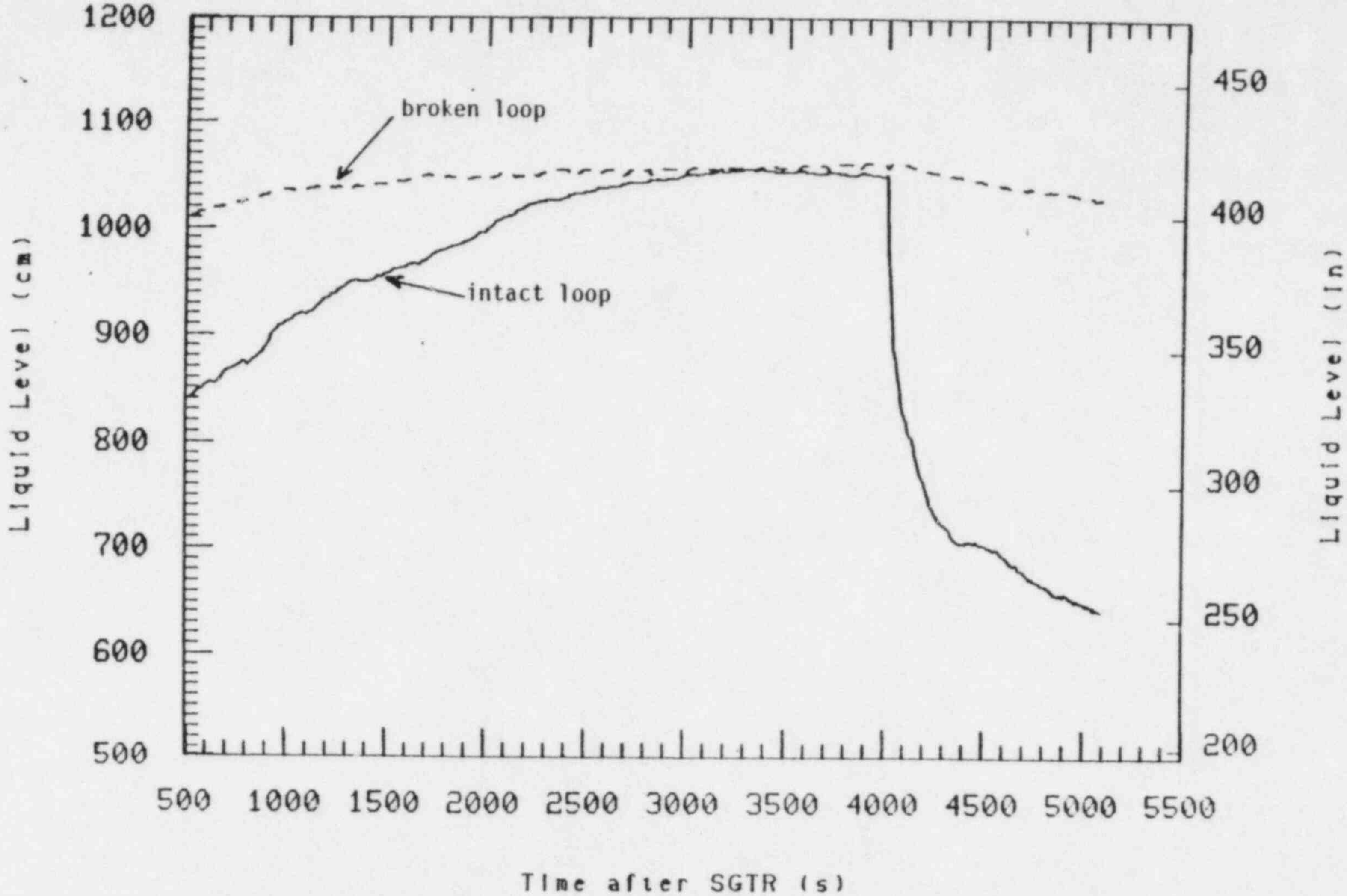

Figure 21. Broken and intact loop secondary collapsed liquid level during a cold side, one-tube rupture transient (S-SG-8).

characterized by dropping pressure, vessel level, and steam generator U-tube level, and pressurizer filling. Subsequently a quasi-steady state condition developed, characterized by cycling yet stable vessel, pressurizer, and broken loop U-tube levels, and a very slow primary pressure drop.

PORV flow was the dominant factor in the primary system mass redistribution, and was the most variable factor in the quasi-steady state feed and bleed portion of recovery. Figure 22[a] shows PORV flow and SI flow during the primary feed and bleed. Initially the PORV passed single phase, saturated steam, but as the pressurizer level rose (Figure 19), the PORV passed a two-phase mixture, then single phase liquid flow as the pressurizer filled. Single phase steam flow existed between about 600 and 1100 s. Between 1100 and 2100 s the pressurizer was almost full. However, a small steam space remained at the PORV exit, and a two-phase mixture was passed. The pressurizer then became liquid solid and only single phase liquid is passed. At about 2600 s a cycling level close to the top of the pressurizer began, and continued until 4000 s. This cycling pressurizer level produced a cycling two-phase flow rate out the PORV as the fluid quality changed at the valve entrance. The cyclic nature of the primary feed and bleed will be discussed later in this section. Fluid redistribution occurred when the intact loop steam and feed began and dropped the pressurizer level, resulting in a temporarily reduced PORV flow. Flow returned to single-phase liquid when the pressurizer level was reestablished. The stuck open position of the PORV did not cause a significant primary inventory loss and no core temperature excursion resulted (Figure 23).

Safety injection was operated from SIS until test termination in an attempt to maintain primary system inventory. SI flow increased rapidly from SIS to 1000 s when the primary pressure stabilized. The flow then

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a. A gap exists in the data between 2600 and 3000 s. The duration of PORV flow necessitated a drain of the PORV catch tank which was done during this period.

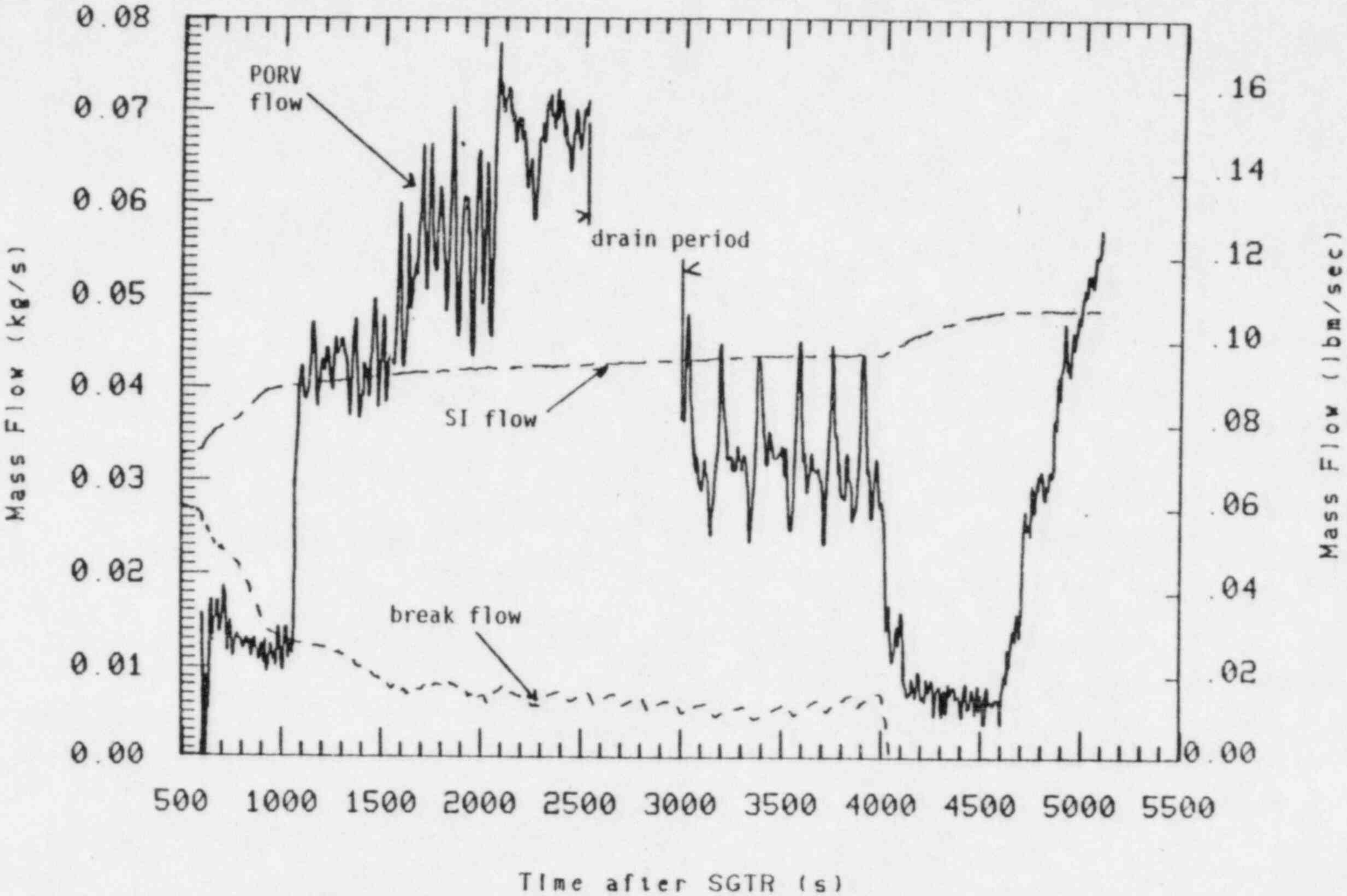

Figure 22. Comparison of SI, PORV, and break flow during a quasi-steady state primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

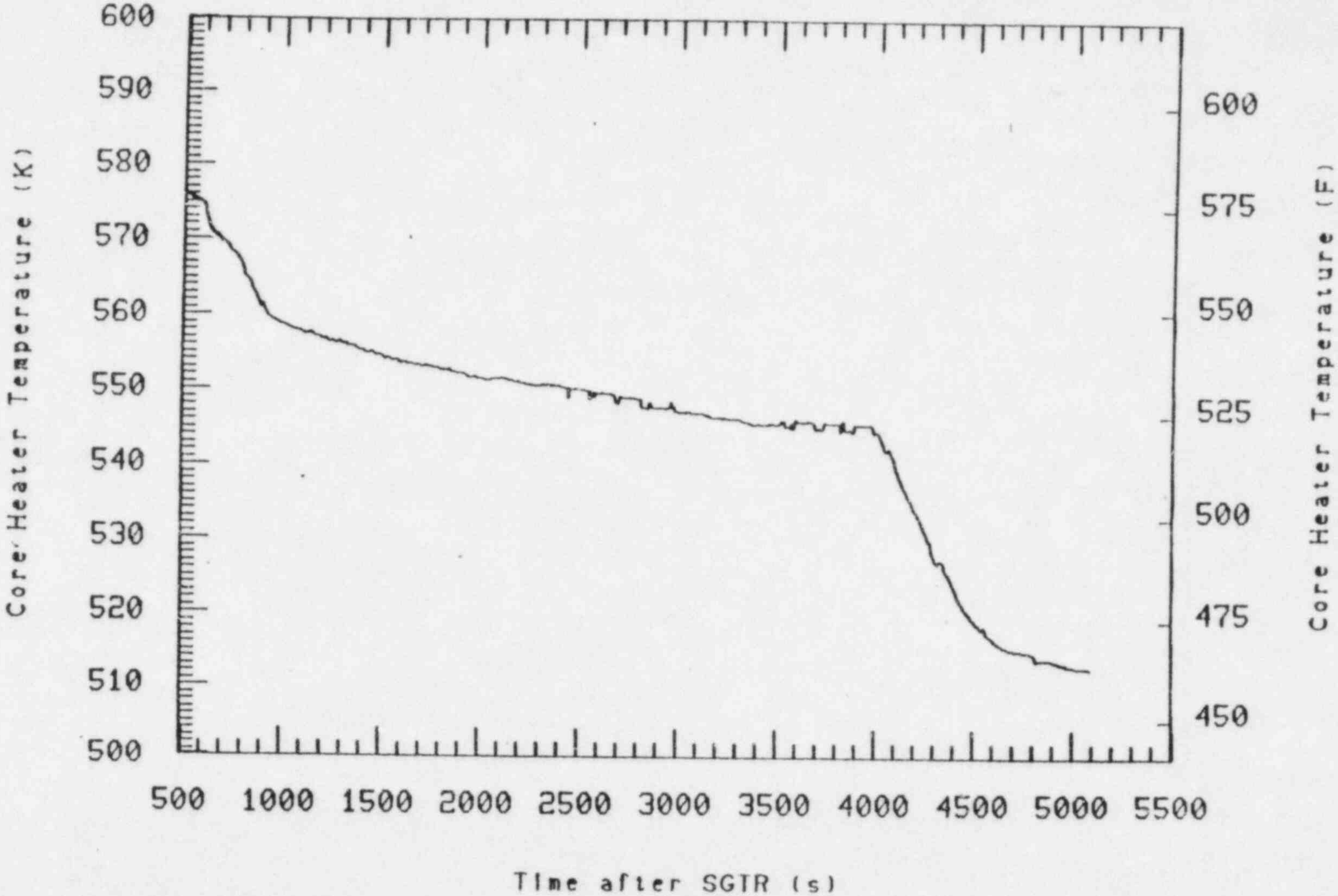

Figure 23. Core temperature during a quasi-steady state primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

increased very slowly until 4000 s. During the quasi-steady state period, 2500 to 4000 s, primary pressure stabilized at a point where SI flow was balanced by the combined PORV and break flow (Figure 22). Stable pressurizer, vessel and steam generator U-tube levels resulted. The intact loop steam and feed reduced primary pressure which increased SI flow. The vessel level then rose covering the core and partially filling the upper head.

A quasi-steady state condition was first established at approximately 2400 s and continued until 4000 s of the primary feed and bleed period. This condition was evidenced by a cycling of vessel, pressurizer, and U-tube levels and PORV flow. These cyclic phenomena were caused by a periodic mass redistribution and appear similar to those previously observed in Test S-PL-3, Reference 5. The phenomena enables the primary system to slowly cool and reduce pressure as shown in Figure 24. The system response is as follows. The broken loop steam generator U-tubes slowly condense steam from the vessel until liquid spills over the top of the U-tube, Figure 25. The spillover increases the gravitational head on the fluid in the down side of the U-tube, forcing liquid into the downcomer and raising the vessel level, Figure 26. The increase in vessel level forces steam out of the vessel and into both primary loops. Figures 27 and 28 are the broken loop hot leg density and volumetric flow respectively, showing steam flow from the vessel to the U-tubes. The steam flow in the broken loop restarts the cycle. Steam in the intact loop hot leg forces fluid into the pressurizer compressing what steam space exists, causing liquid flow out the PORV. This is reflected as a sharp increase in PORV mass flow, Figure 29. A manometric settling follows as the gravitational balance is reestablished between the broken loop U-tube level and the vessel level.

3.2.3 Effect of Intact Loop Steam and Feed on Primary Pressure

An intact loop steam and feed, consisting of latching open the ADV and feeding with auxiliary feedwater, was initiated 4000 s after the tube rupture. At that time, the intact loop primary piping was voided, except for the pump suction, and the U-tubes were voided. The broken loop primary

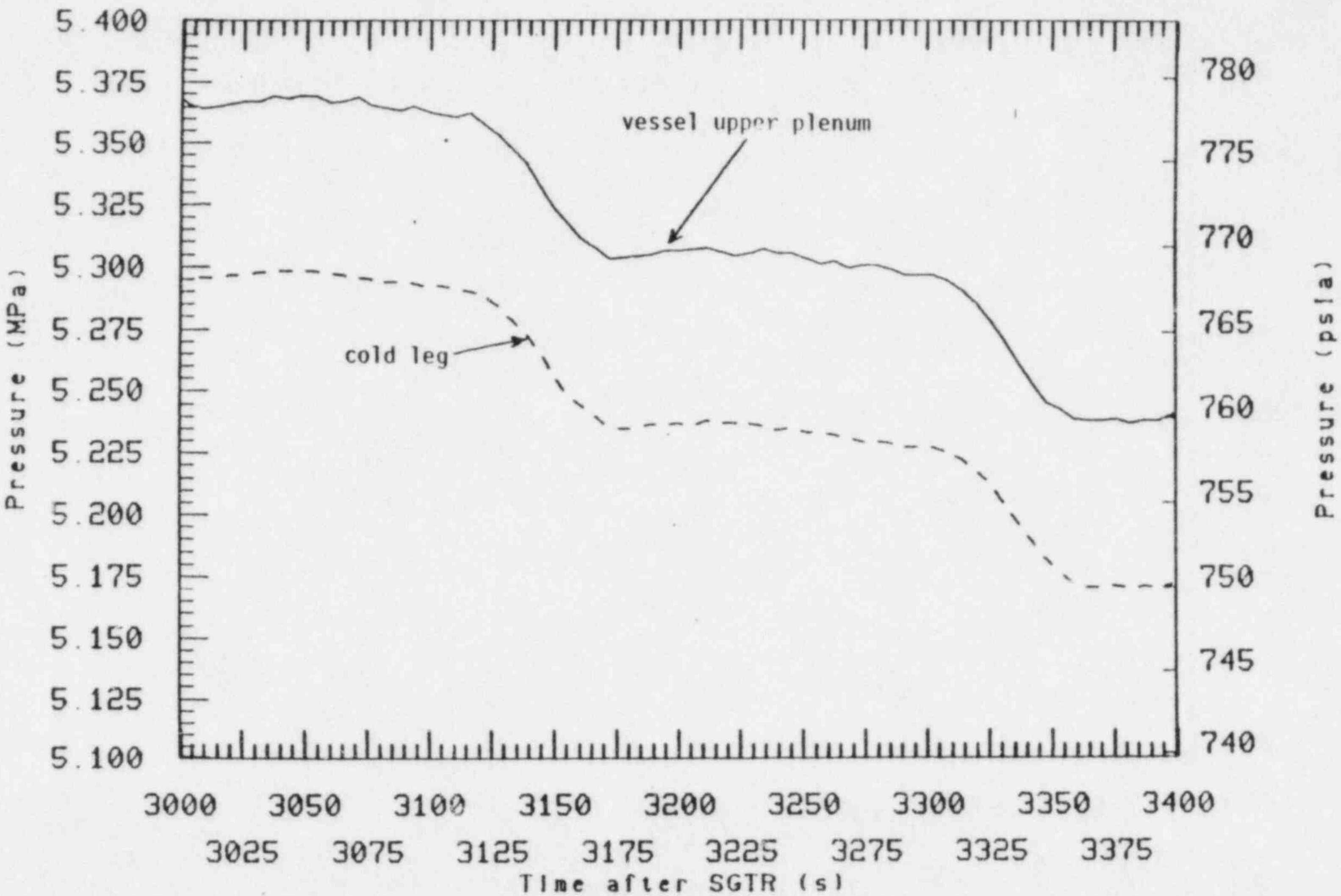

Figure 24. Vessel and cold leg pressure during a quasi-steady state primary feed and bleed with a cold side, one-tube rupture transient (S-SG-8).

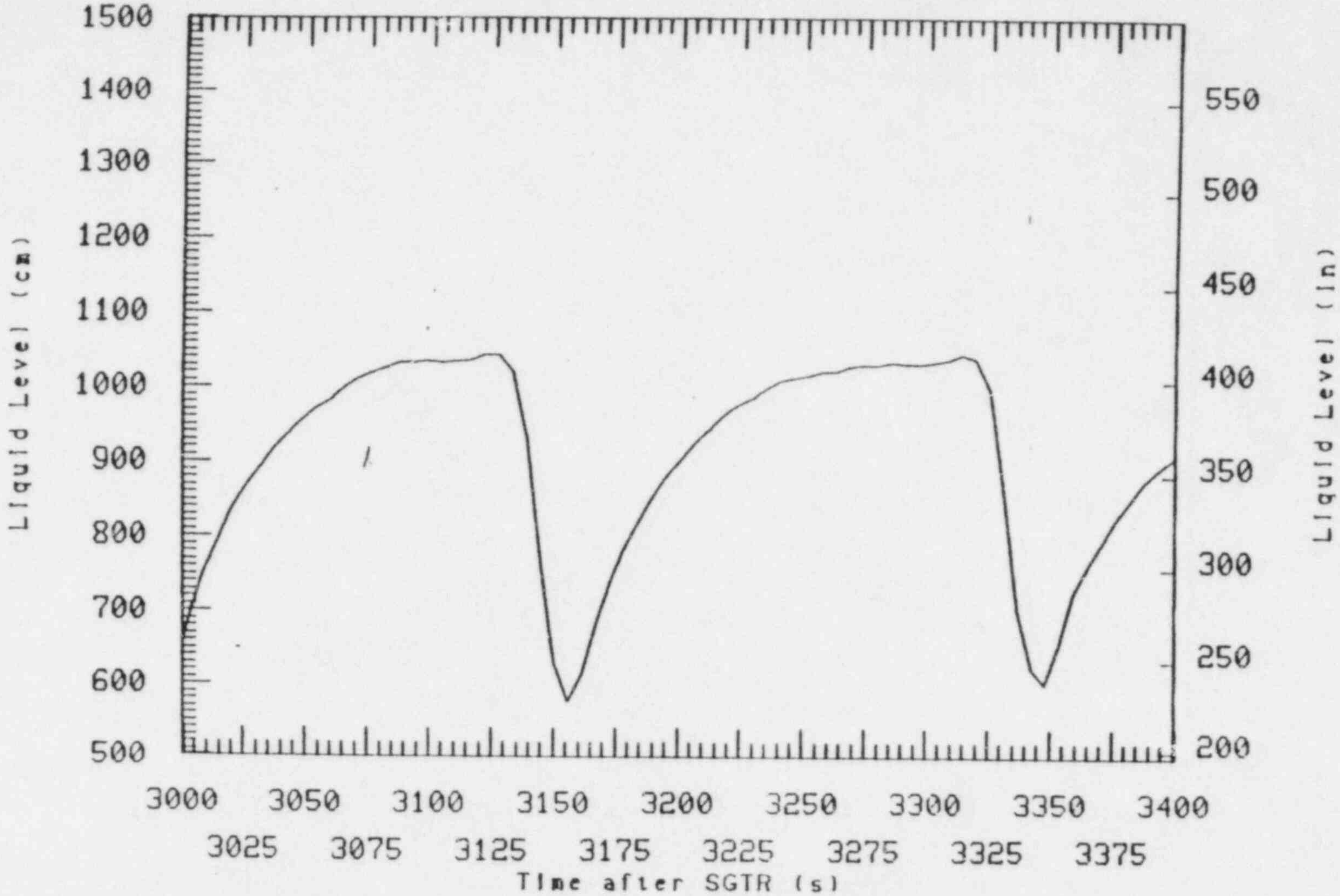

Figure 25. Primary U-tube collapsed liquid level in the broken loop during a quasi-steady state primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

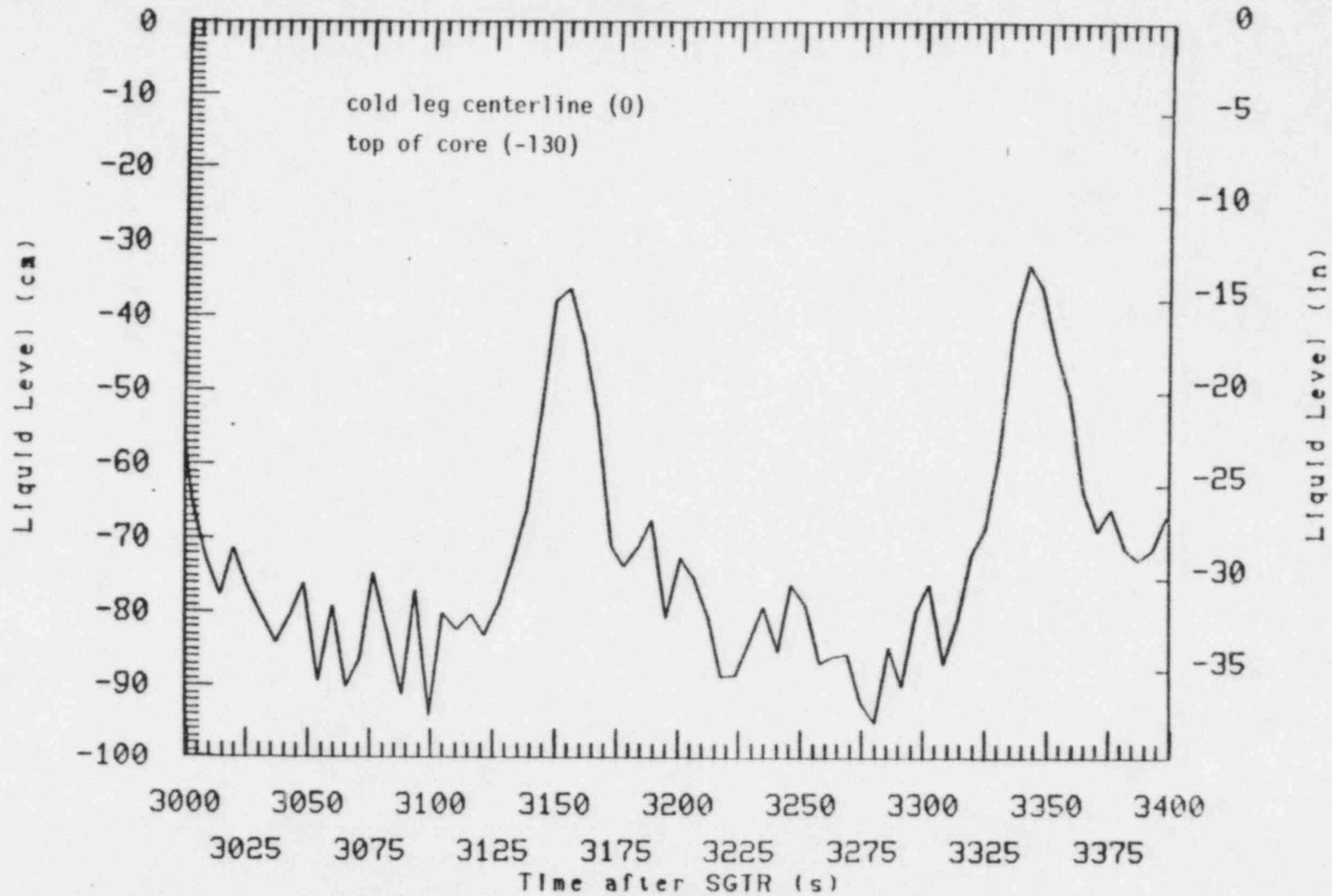

Figure 26. Vessel collapsed level during a quasi-steady state primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

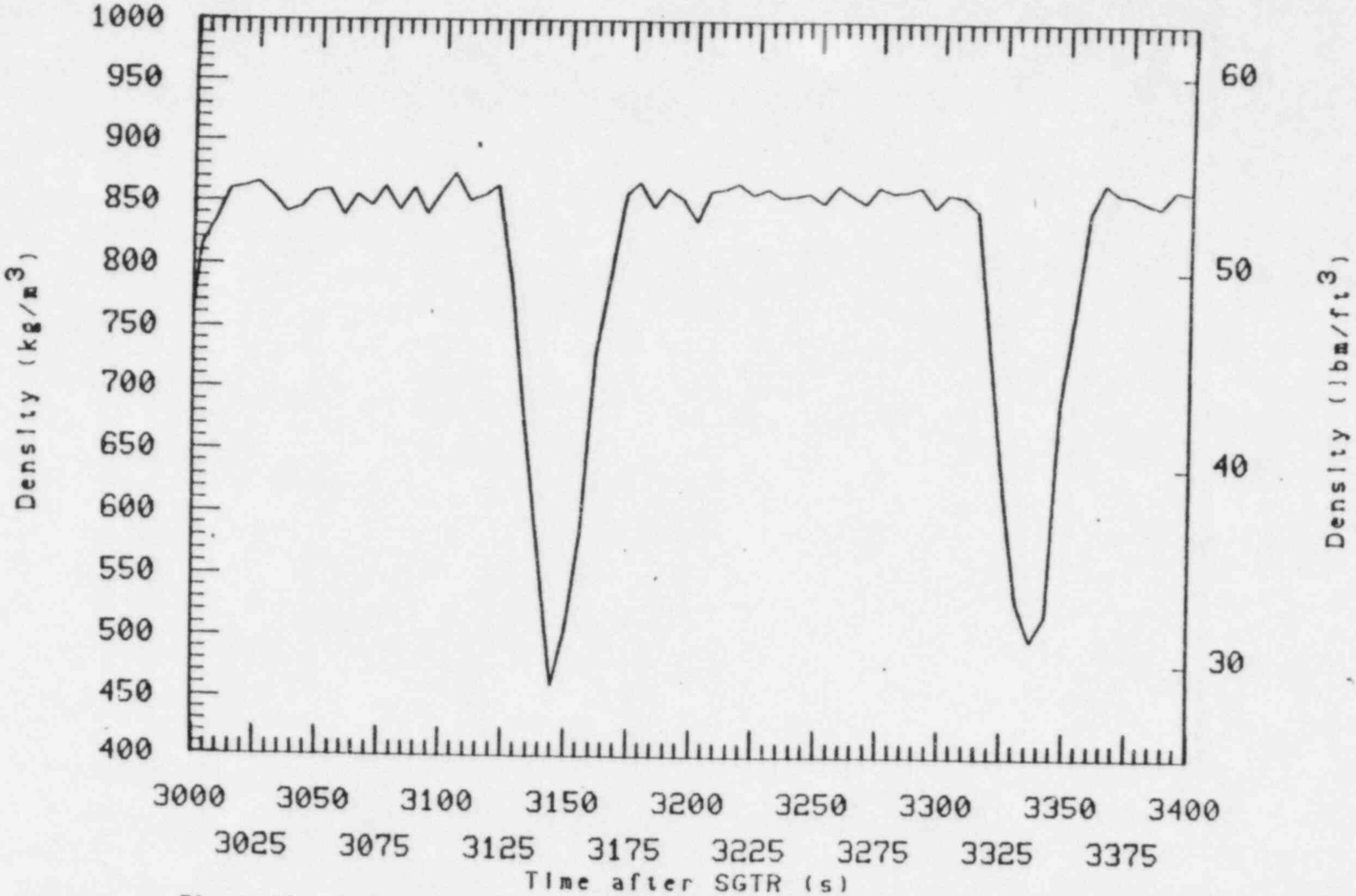

Figure 27. Broken loop hot leg fluid density during a quasi-steady state primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

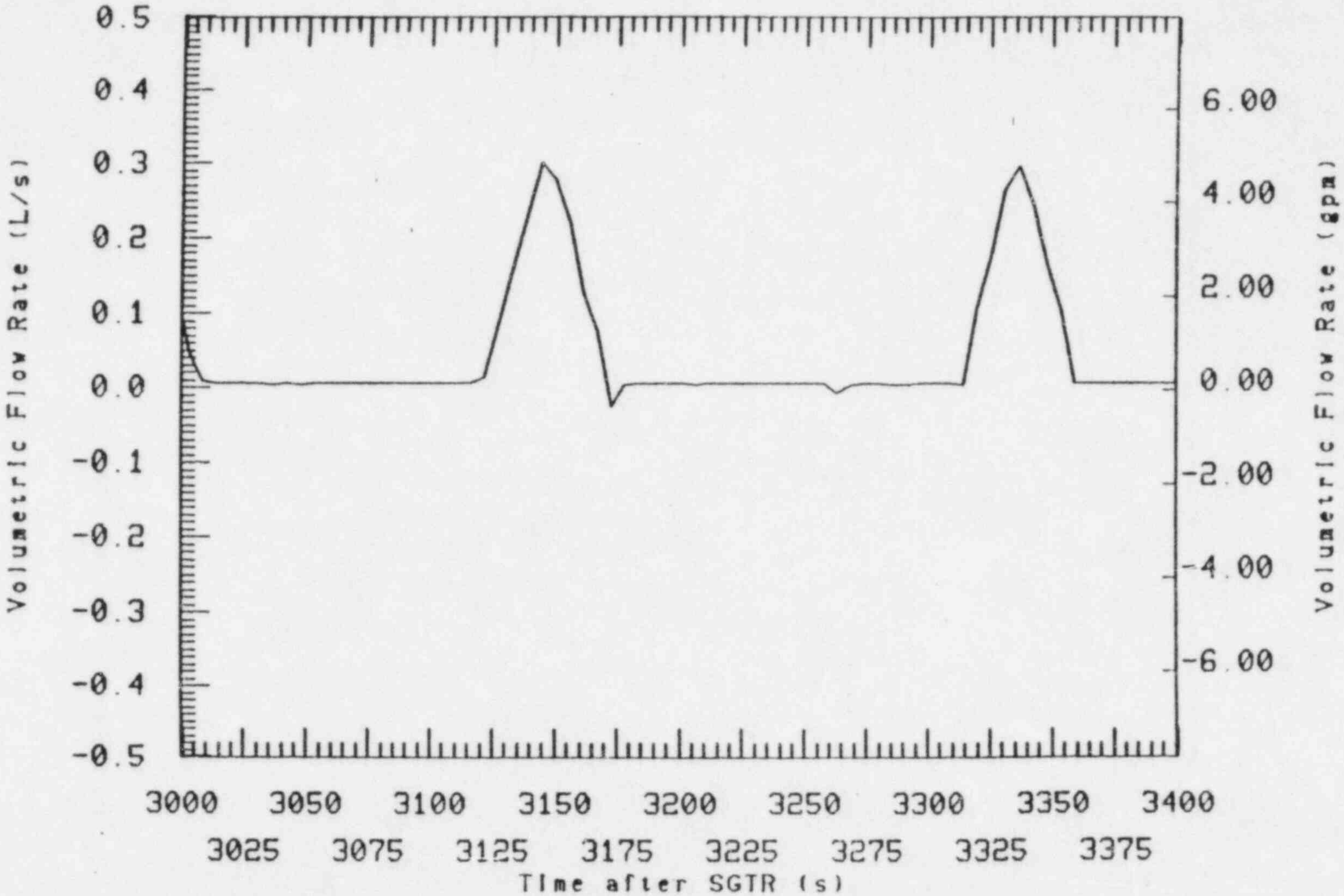

Figure 28. Broken loop hot leg volumetric flow during a quasi-steady state primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

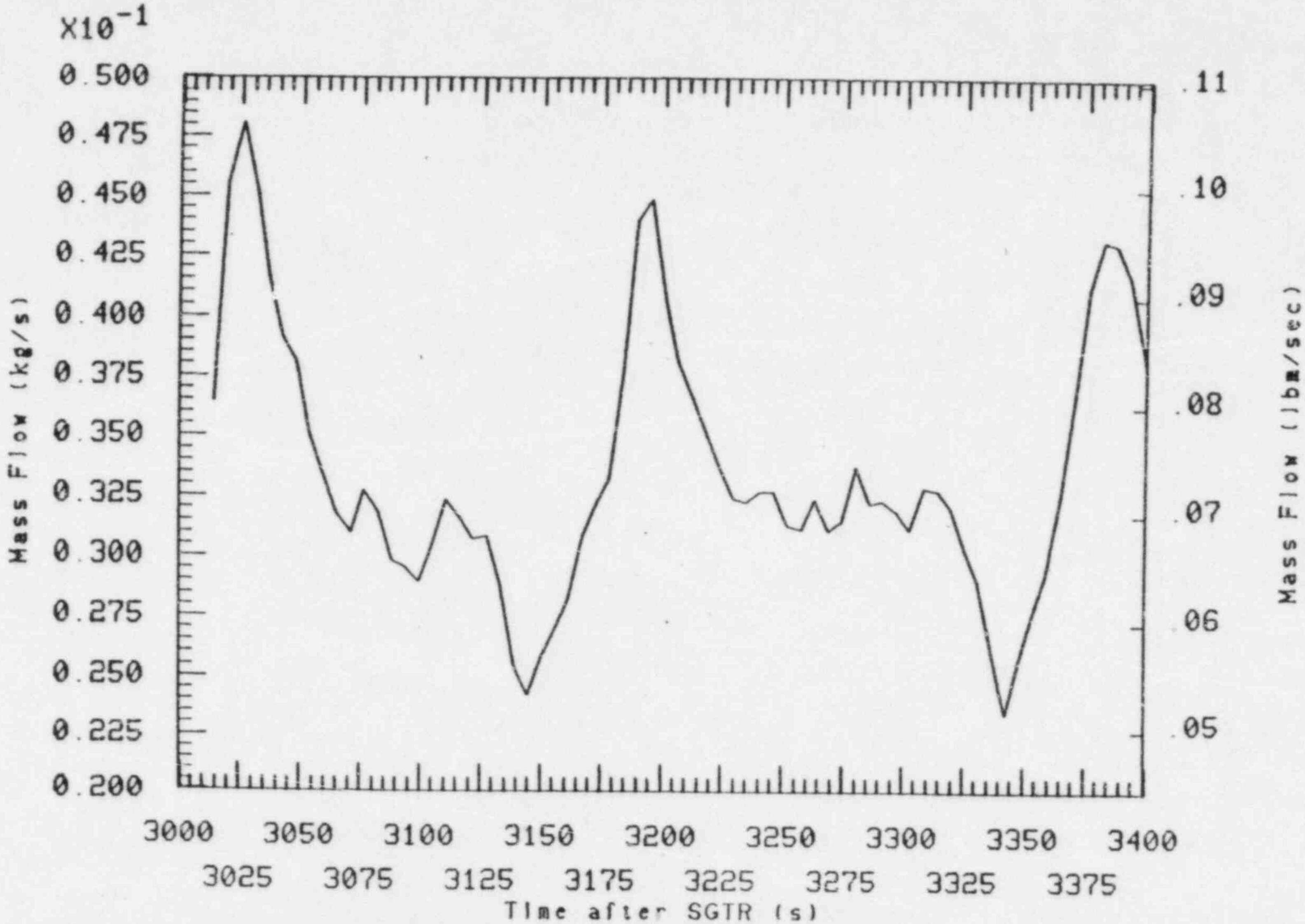

Figure 29. Mass flow rate out the PORV during a quasi-steady state primary feed and bleed recovery from a cold side, single-tube rupture transient (S-SG-8)

piping was mostly filled with liquid, voids occurring only in the hot leg and at the top of the U-tubes. Upon initiating steam and feed, the intact loop piping and U-tubes filled while the broken loop U-tubes drained (Figure 30). The mechanism for filling the intact loop primary consisted of condensing steam in the U-tubes, resulting in a localized low pressure region at the top of the U-tubes. Fluid from high pressure regions, including the pressurizer and broken loop U-tubes, moved into the low pressure region. Concurrently, fluid flow from the pressurizer into the hot leg lowered the collapsed liquid level, and produced an increased steam flow out the PORV. The transition to high quality steam flow resulted in a much lower mass flow out the PORV (Figure 31). SI flow between 4000 and 4600 s was significantly higher than the combined PORV and break flow (Figure 31), resulting in an increased primary system inventory. This mass flow differential was great enough to fill the intact loop primary during this time period. Typical natural circulation values for both the single-phase and two-phase regimes were established as the intact loop primary transitioned from mostly steam to subcooled liquid conditions, Figure 32.

The steam and feed operation produced significant cooling and depressurization in the primary system as shown in Figures 33 and 34. The cold leg temperature in Figure 33 was affected by SI flow upstream of the measurement until 4150 s when natural circulation refilled the intact loop primary piping with saturated liquid from the vessel. During the first 600 s of steam and feed, hot leg temperatures were reduced 30 K (54°F) with significant subcooling noted in the cold legs, and primary pressure dropped 2 MPa (290 psia). The primary system pressure drop reversed the break flow, resulting in further filling of the primary. At 5100 s the primary pressure was well below the accumulator injection setpoint, and the test was terminated.

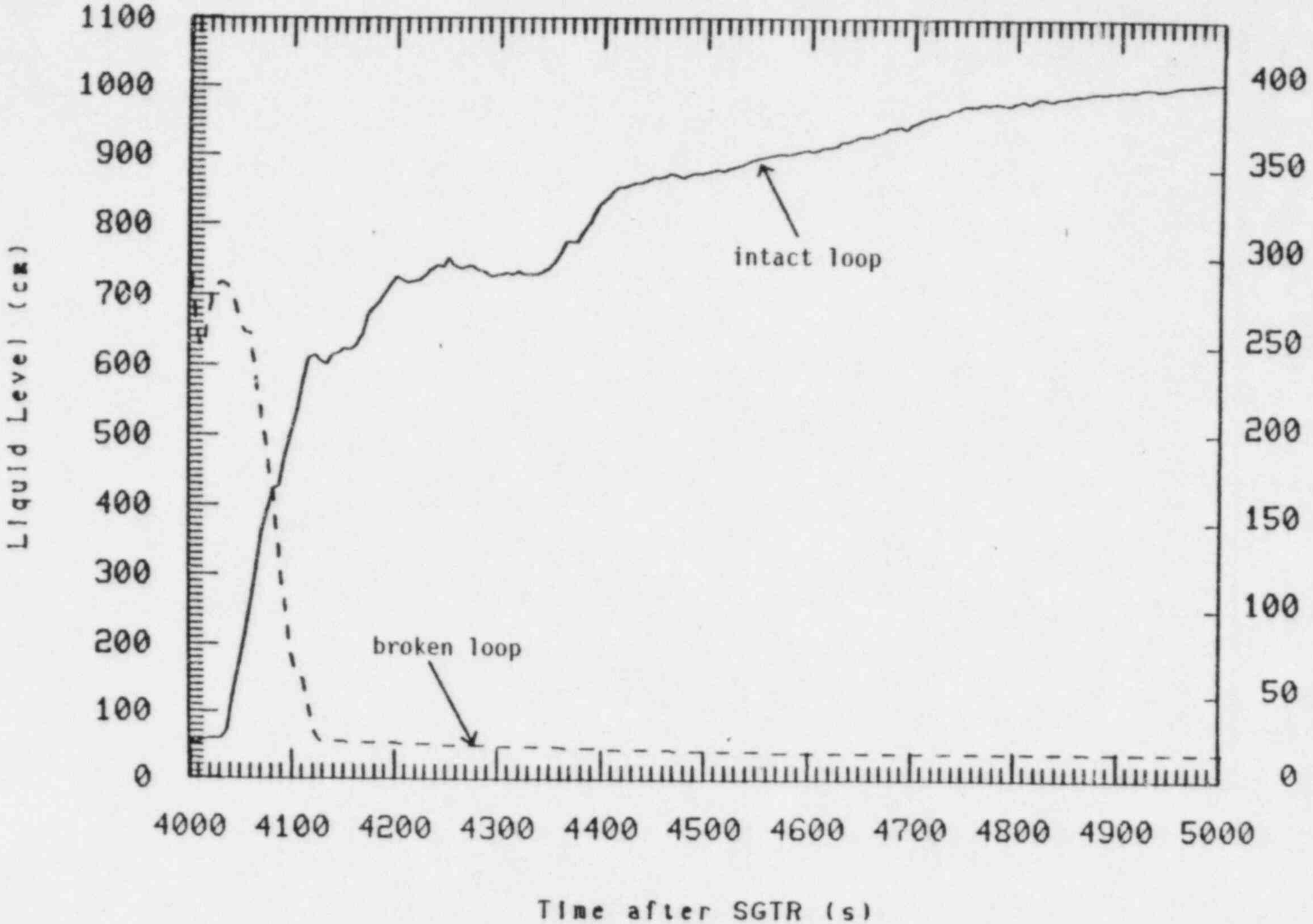

Figure 30. Broken and intact loop U-tube collapsed liquid level during intact loop steam and feed and primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

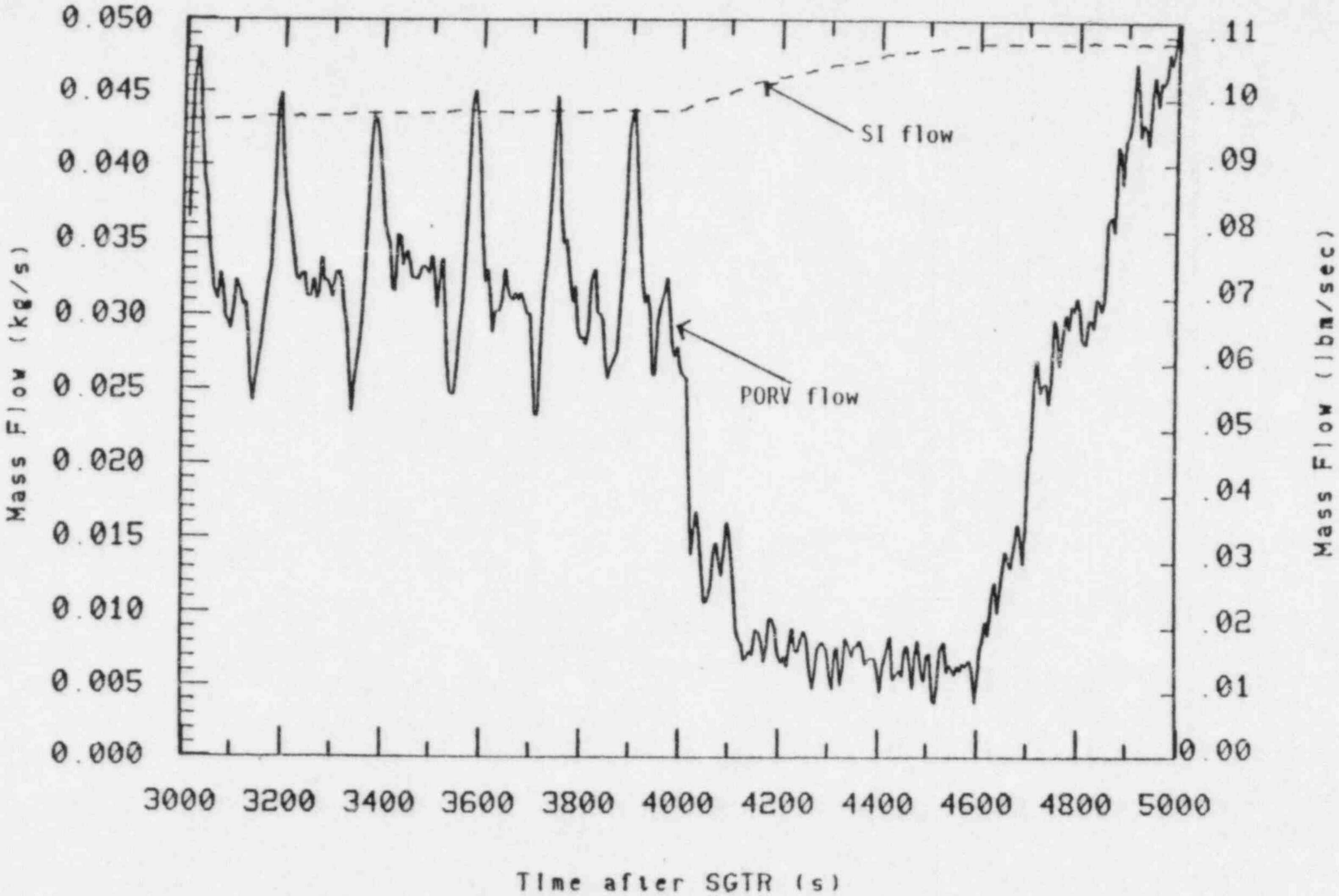

Figure 31. Mass flow rate through the PORV and SI flow during intact loop steam and feed and primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

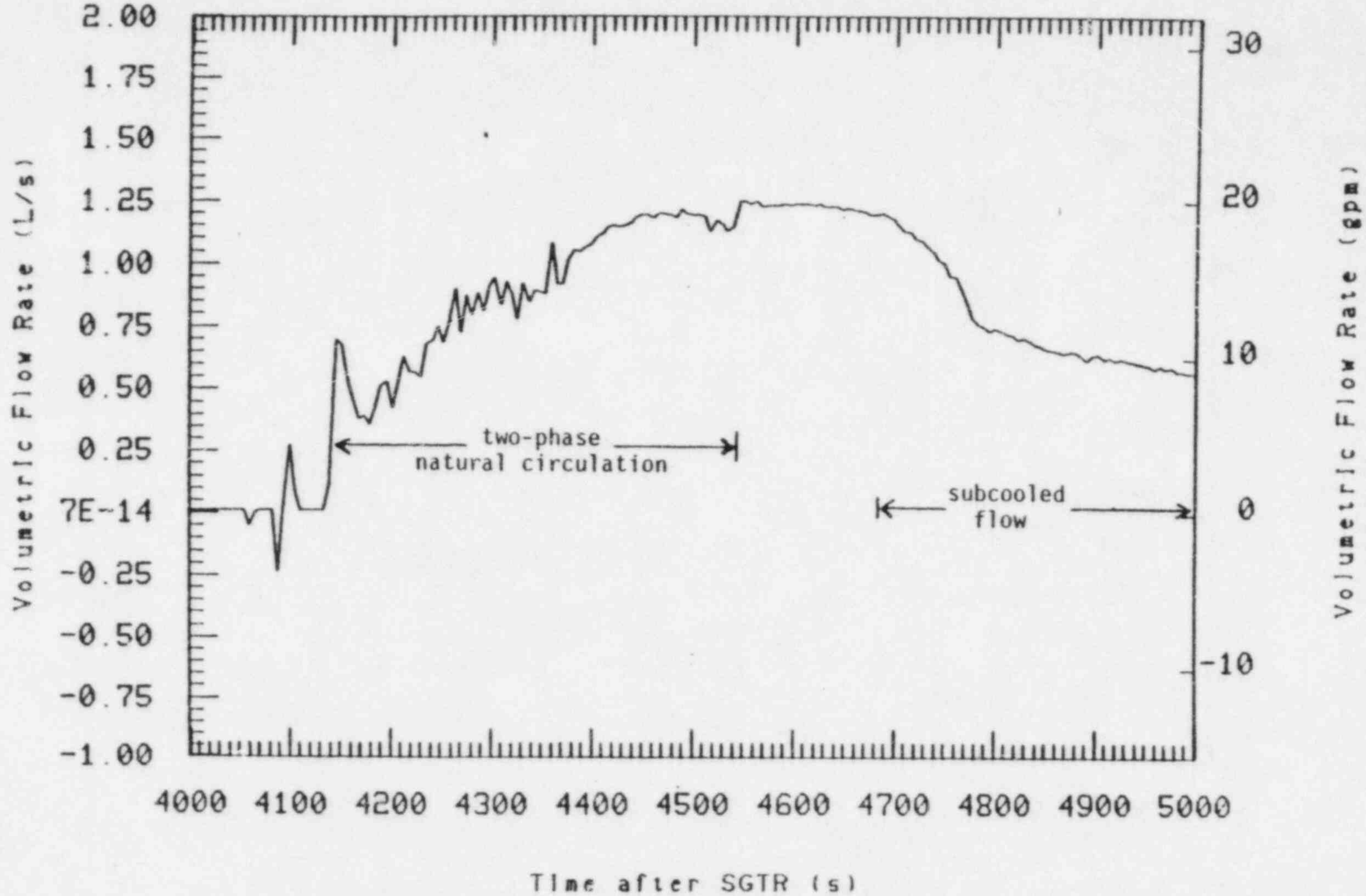

Figure 32. Intact loop cold leg volumetric flow during intact loop steam and feed and primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

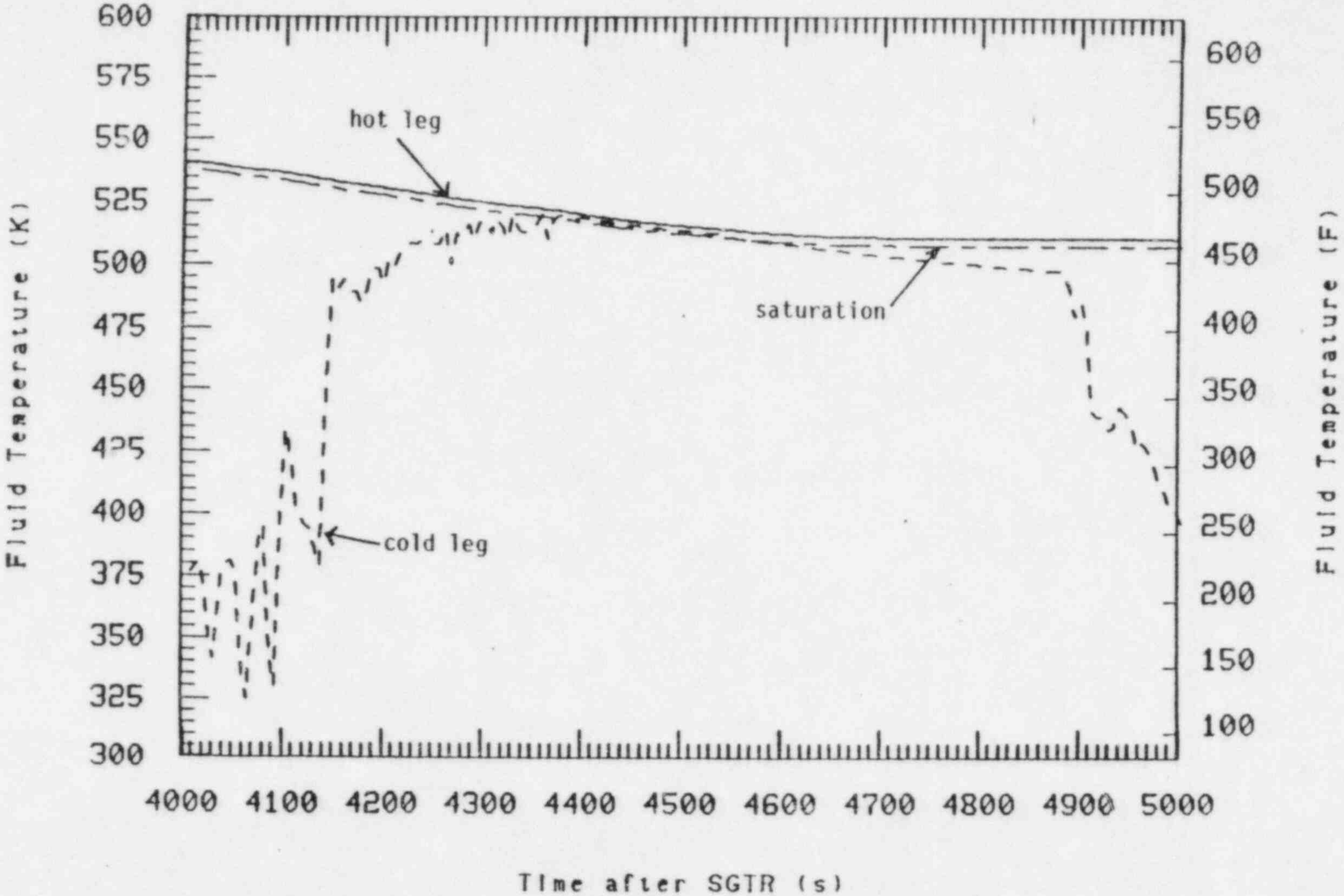

Figure 33. Comparison of intact loop hot leg, cold leg, and saturation temperature during intact loop steam and feed and primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

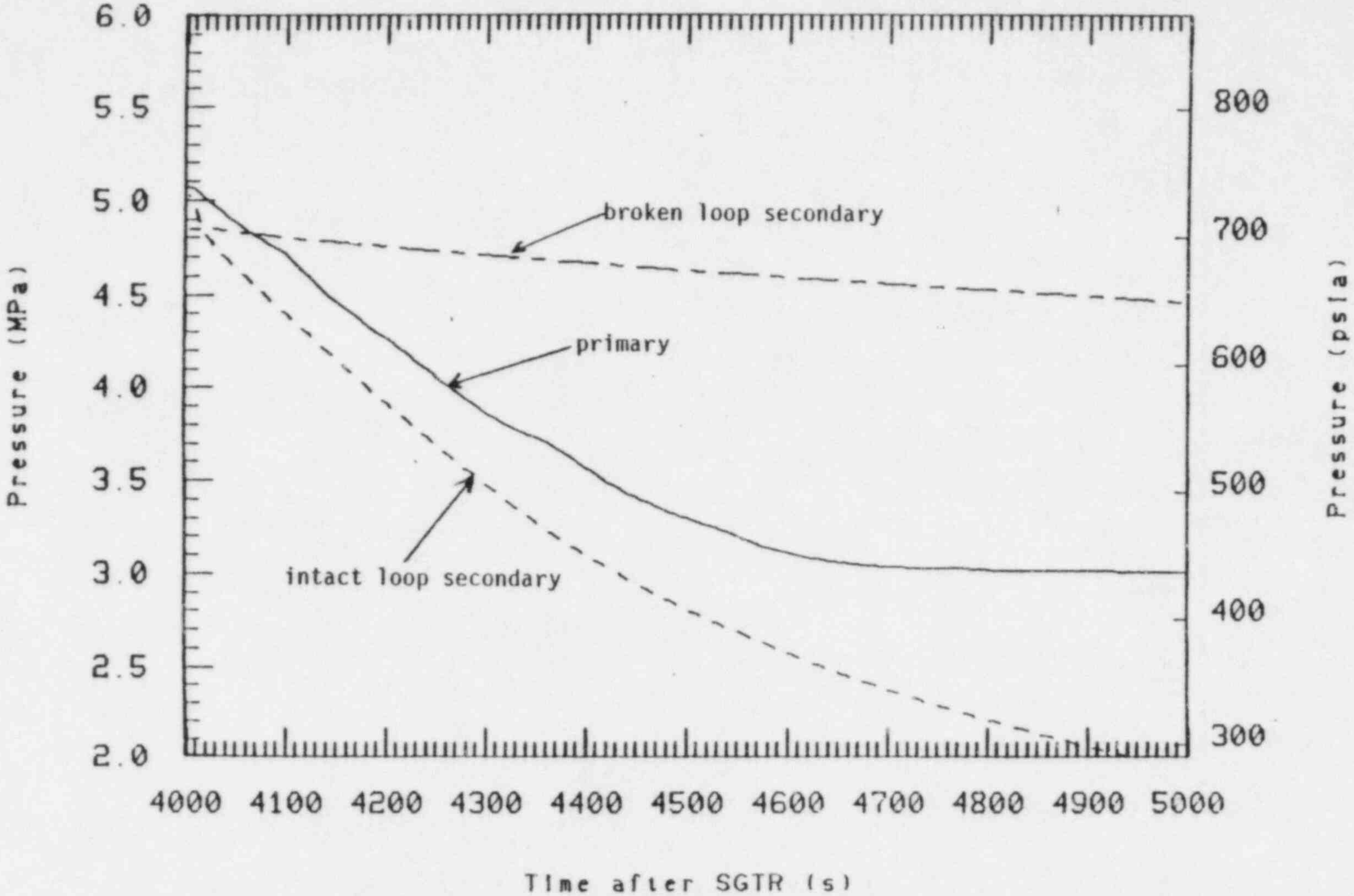

Figure 34. Comparison of primary and secondary pressures during intact loop steam and feed and primary feed and bleed recovery from a cold side, one-tube rupture transient (S-SG-8).

4. COMPARISON OF PRETEST CALCULATION TO TEST DATA

This section compares the S-SG-8 test results to the best-estimate calculation documented in the S-SG-8 Pretest Analysis Document.[6] Discussion of the calculated and test results comparisons are presented in the following three subsections: Operator Diagnostic Period (4.1), Plant Recovery (4.2), and Summary and Recommendations (4.3). Table 3 compares the actual and calculated sequence of events.

4.1 Operator Diagnostic Period (0-600 s)

This section discusses comparisons of the calculated and test results from time of tube rupture (time 0) through 600 s. Table 4 presents the actual and calculated initial conditions. All of the calculated and actual initial conditions, with two exceptions, agreed well enough that the subsequent transient responses were not significantly affected by any differences. One exception is the initial water mass in the ILSG which was 12.3 kg (27 lbm) less in the test than in the calculation. Its effect is discussed later in this section. The other exception is the intact and broken loop hot leg flow rates which were 0.97 ℓ/s (15.4 gpm) and 0.36 ℓ/s (5.7 gpm) less, respectively, than in the calculation. Although the test flow rates were lower, the core power was essentially the same, as seen by the higher core temperature rise.

Two methods are used to compute liquid levels in this report, collapsed and interfacial, but only the interfacial level is used in Section 4. The collapsed level method assumes that the entire differential pressure between two points is due to saturated liquid and is calculated by

$$LL_c = \frac{\Delta P}{\rho_{fsat} g} ,$$

TABLE 3. COMPARISON OF PREDICTED AND MEASURED EVENT TIMING

Event	Calculated Time (s)	Actual Time (s)
Break flow initiated	0	0
Pressurizer internal heaters off	0	0
SCRAM	125	146
Core power shut off	125	148
MSIV closure	125	149
SIS	129.5	152
Main feedwater secured	129.5	153
Auxiliary feedwater initiated		
Intact Loop	129.5	153
Broken Loop	Off	153
SI turned on	129.5	153
Pumps off	129.5	154
PORV is opened	600	600
Quasi-steady state primary feed and bleed condition established	3000	3000
Intact loop steam generator steam and feed initiated	3740	4000
Test terminated	5060	5100

TABLE 4. COMPARISON OF PREDICTED AND MEASURED INITIAL CONDITIONS

Parameter	Calculated	Actual
Pressurizer pressure	15.53 MPa (2252 psia)	15.54 MPa (2253 psia)
Core temperature[a] differential	36.1 K (65.0°F)	37.8 K (68.0°F)[a]
Cold leg fluid temperature loop to loop difference--max	0.42 K (0.76°F)	0.7 K (1.3°F)
Initial core power	2.0 MW	1.99 MW
Pressurizer liquid volume	0.0102 m^3 (0.36 ft^3)	0.0105 m^3 (0.3708 ft^3)
Cold leg flowrates[b]		
Intact loop	9.62 ℓ/s (152 gpm)	8.65 ℓ/s (137 gpm)
Broken loop	3.39 ℓ/s (54 gpm)	3.03 ℓ/s (48 gpm)
SG secondary pressure		
Intact loop	5.55 MPa (804 psia)	5.49 MPa (796 psia)
Broken loop	5.54 MPa (804 psia)	5.58 MPa (809 psia)
SG secondary water mass		
Intact loop	100.3 kg (221.1 lbm)	88 kg (194 lbm)
Broken loop	100.3 kg (221.1 lbm)	97 kg (214 lbm)
Primary leakage at t = 0	0.006 kg/s (0.013 lbm/s)	0.002 kg/s (0.004 lbm/s)

a. These temperature differentials are based on total system flows (core flows + bypass flows) and are the difference between averaged hot leg temperatures and averaged cold leg temperatures. The calculated flow rates were adjusted to obtain a temperature rise of 37 K (66.6°F) between the core inlet and outlet for the core flow only.

b. Varied to achieve 37 K core temperature differential.

where

ΔP = pressure at lower tap minus pressure at upper tap,

ρ_{fsat} = the density of saturated liquid, and

g = the acceleration of gravity.

The interfacial level represents the position of the liquid-vapor interface assuming the two phases are completely separated in the region of interest. The interfacial level is the sum of the product of the liquid fraction and volume length and is calculated by

$$LL_I = \sum_{i=1}^{n} (1 - \alpha_i) L_i \quad ,$$

where n is the number of individual volumes in the region of interest, and L and α are their length and void fraction, respectively. The physical interpretation of collapsed and interfacial liquid levels are the same for the data and the code calculations, although the equations used to reduce the measured DP readings to an interfacial level are not the same as those described above for the RELAP5 analysis.

The pressurizer interfacial levels are compared in Figure 35 which shows the calculated level dropping faster than the test level. This is due to the higher calculated break flow between 20 and 125 s (Figure 36). The calculated pressurizer pressure fell faster than the test pressure (Figure 37) due to the faster expansion of the steam volume resulting in earlier scram, SIS and related events (Table 3). Figure 35 shows the test pressurizer level falling only to 29.7 cm (11.7 in) at approximately 200 s. This is the elevation of the lower ΔP tap and therefore is the lower limit for the test level measurement. The level however did continue to drop and the pressurizer did empty completely as determined by ΔP measurement LPRZ+30-28.

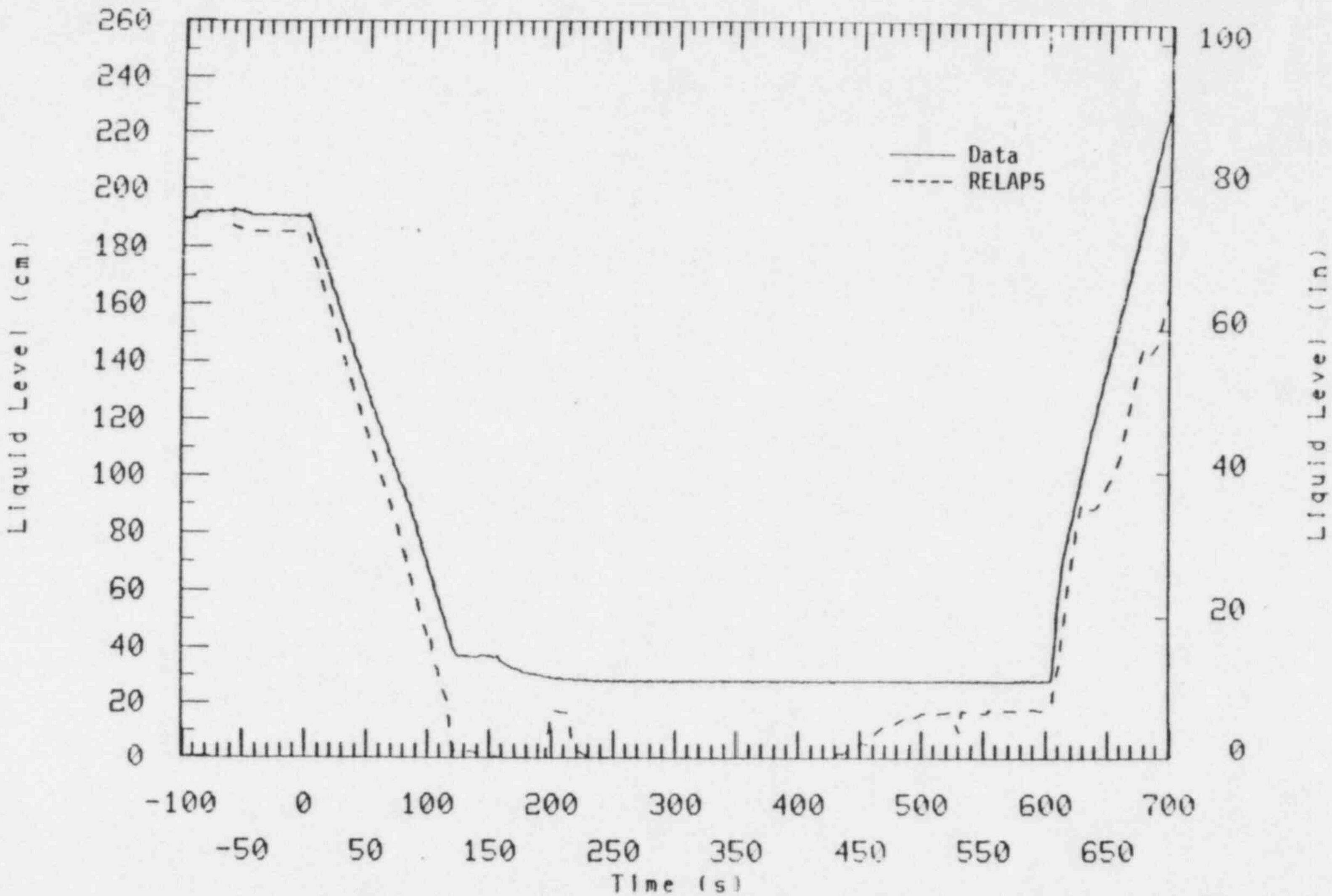

Figure 35. Pressurizer interfacial liquid level comparison-diagnostic period.

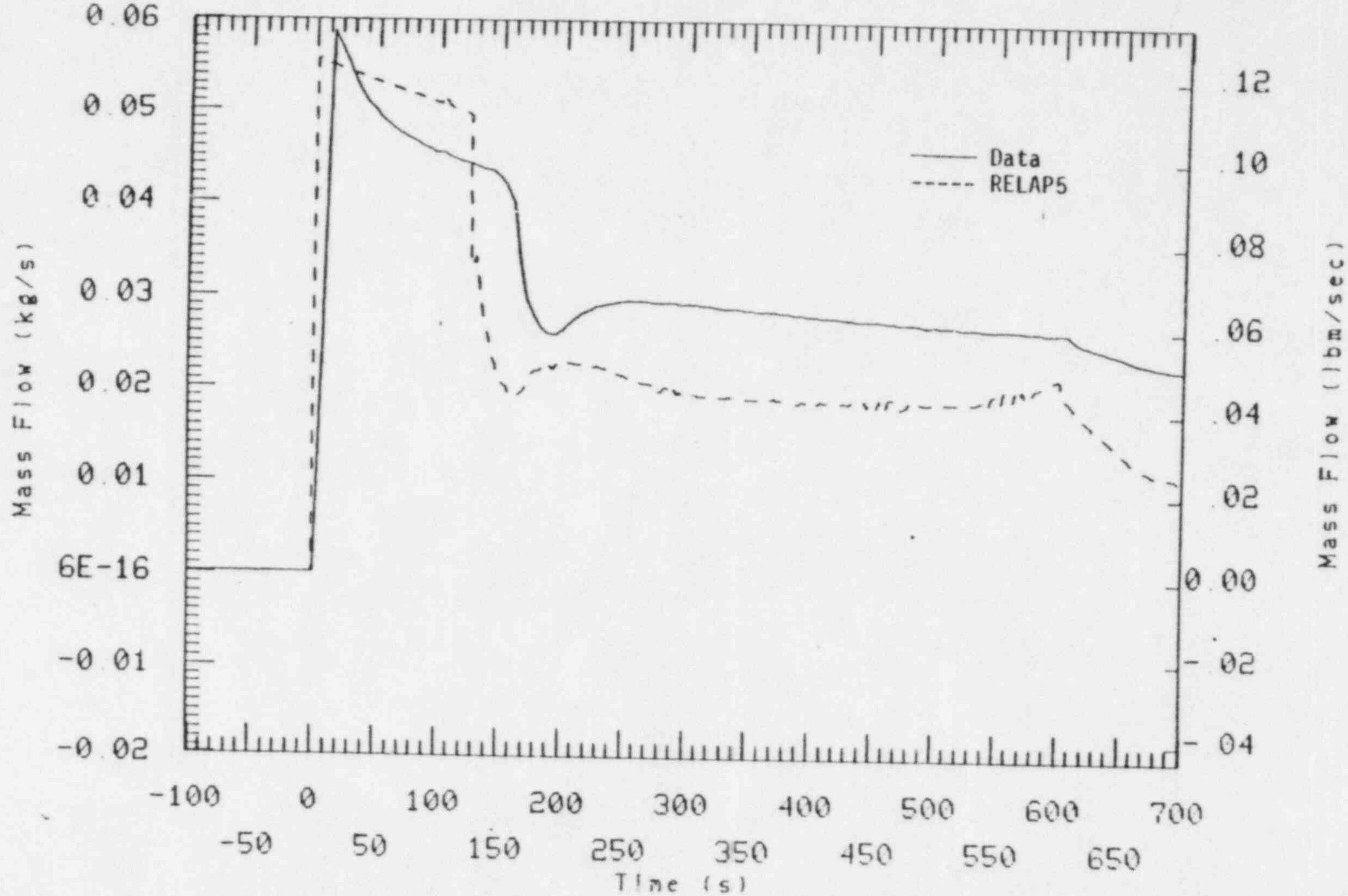

Figure 36. Break flow comparison - diagnostic period.

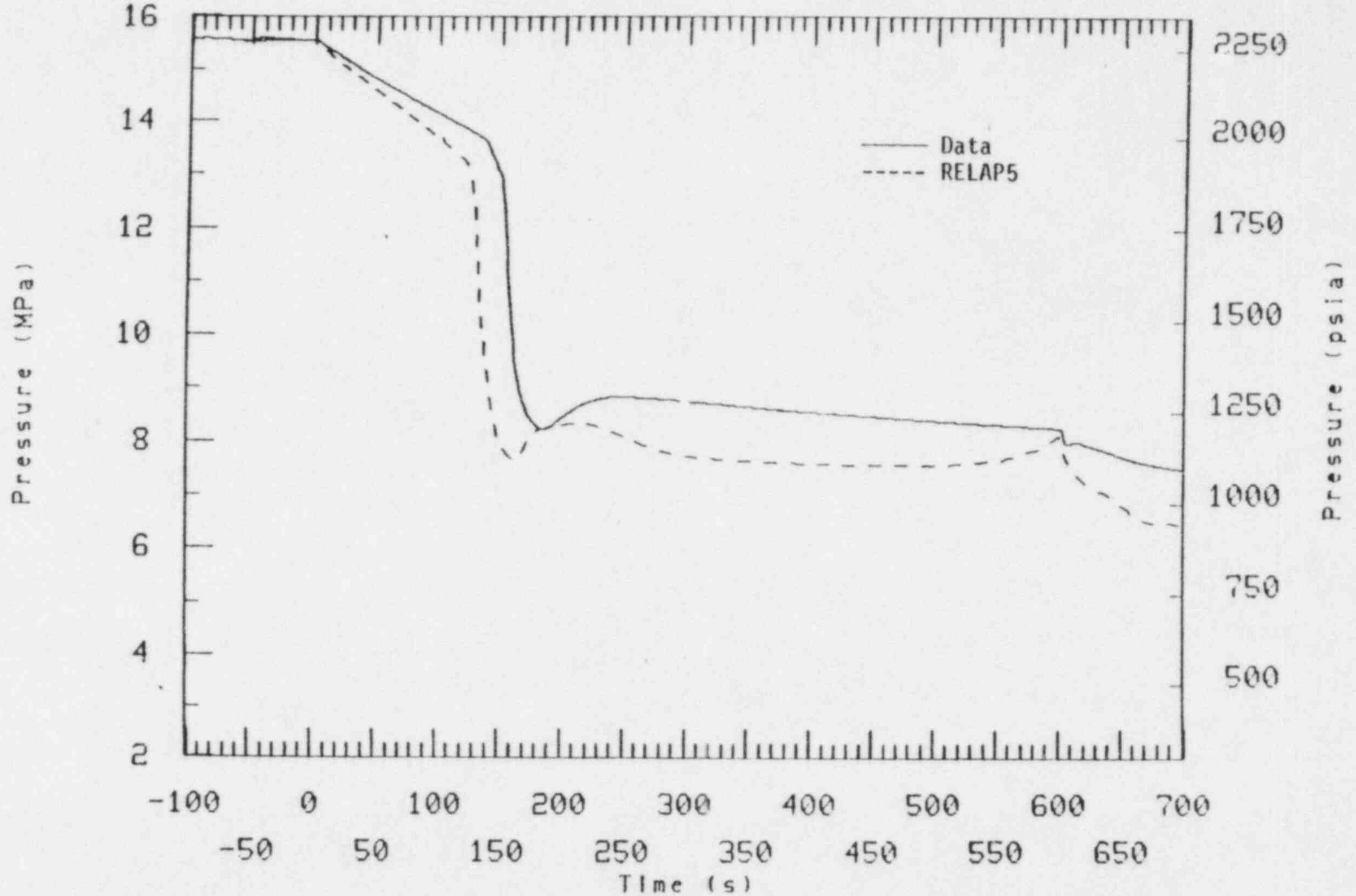

Figure 37. Pressurizer pressure comparison - diagnostic period.

After scram, the PCS pressure fell rapidly to the saturation pressure in the upper plenum, which began to rise as the pumps coasted to a stop and the loop flows slowed to natural circulation values. It is noted that the test pressure rose to a maximum of 8.8 MPa (1276 psia) at 250 s, but the calculated pressure only rose to 8.35 MPa (1211 psia) at 215 s. This was due to higher core inlet and outlet temperatures in the test (Figures 38 and 39) than in the calculation.

Figures 40 and 41 compare the Intact Loop Steam Generator (ILSG) and Broken Loop Steam Generator (BLSG) test and calculated pressures. It is noted that the ILSG calculated pressure rose almost to the ADV setpoint of 6.55 MPa (950 psia) upon closure of the main steam isolation valve and then fell off as auxiliary feedwater flow began. The test pressure did not go quite as high but did lift the ADV before falling off. The lower test pressure after isolating the steam generator was initially due to a difference in the ADV trip logic between the test and the calculation. The ADV trip pressure during the test was sensed at the bottom of the downcomer, whereas the calculation used steam dome pressure. This difference was about 0.074 MPa (11 psi) for 1000 cm (394 in) of liquid. Also, the smaller secondary water mass in the test had less total stored energy and therefore depressurized faster in response to condensation induced by cold auxiliary feedwater injection. The smaller mass was carried through the 600 s diagnostic period and beyond as shown by the lower downcomer interfacial liquid level after approximately 200 s (Figure 42). The calculated BLSG pressure rose high enough after steam generator isolation to open both the ADV and the SRV from 130 to 140 s. Thereafter, it rode the ADV setting of 5.86 MPa (850 psia) through and beyond the diagnostic period. The test ADV opened at a lower pressure than in the calculation, limiting the initial pressure rise as in the ILSG. Auxiliary feedwater in the test contributed to the faster depressurization. In the calculation, BLSG auxiliary feedwater was not initiated because the downcomer level was above 1050 cm (413 in), the upper limit which terminates auxiliary feedwater flow (Figure 43). The auxiliary feedwater flow will not restart until the level falls below 800 cm. This

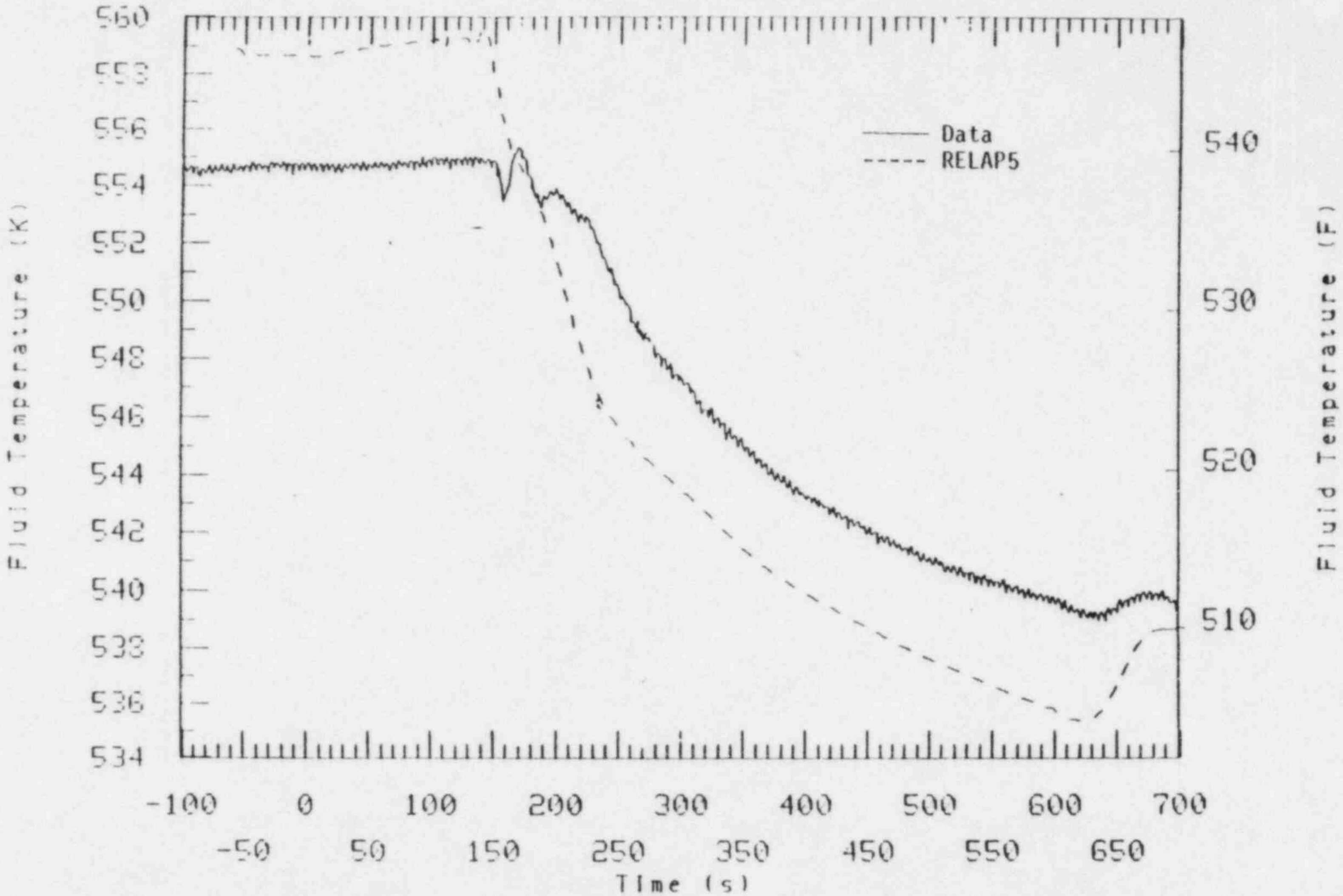

Figure 38. Core inlet temperature comparison -diagnostic period.

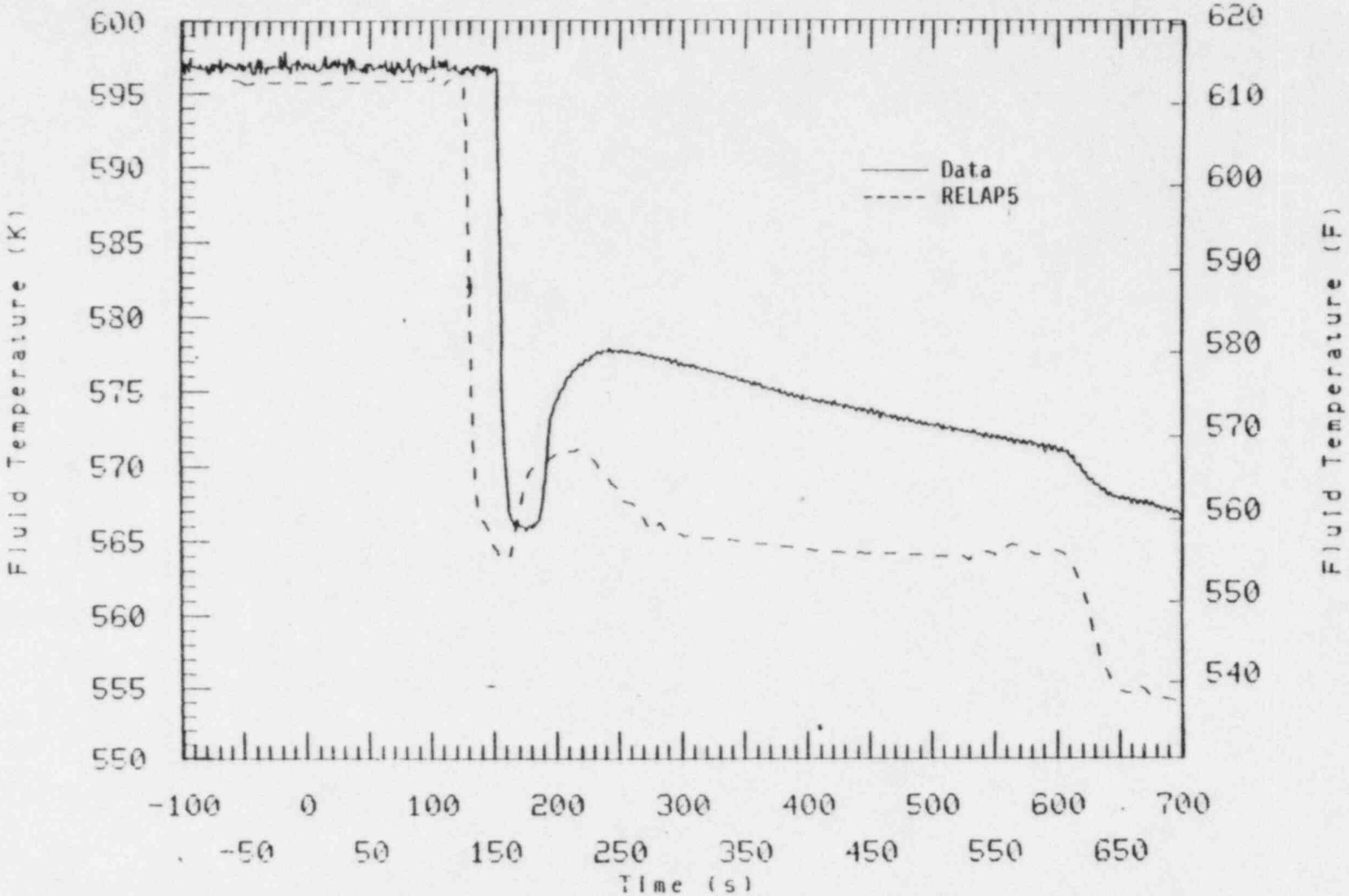

Figure 39. Core outlet temperature comparison - diagnostic period.

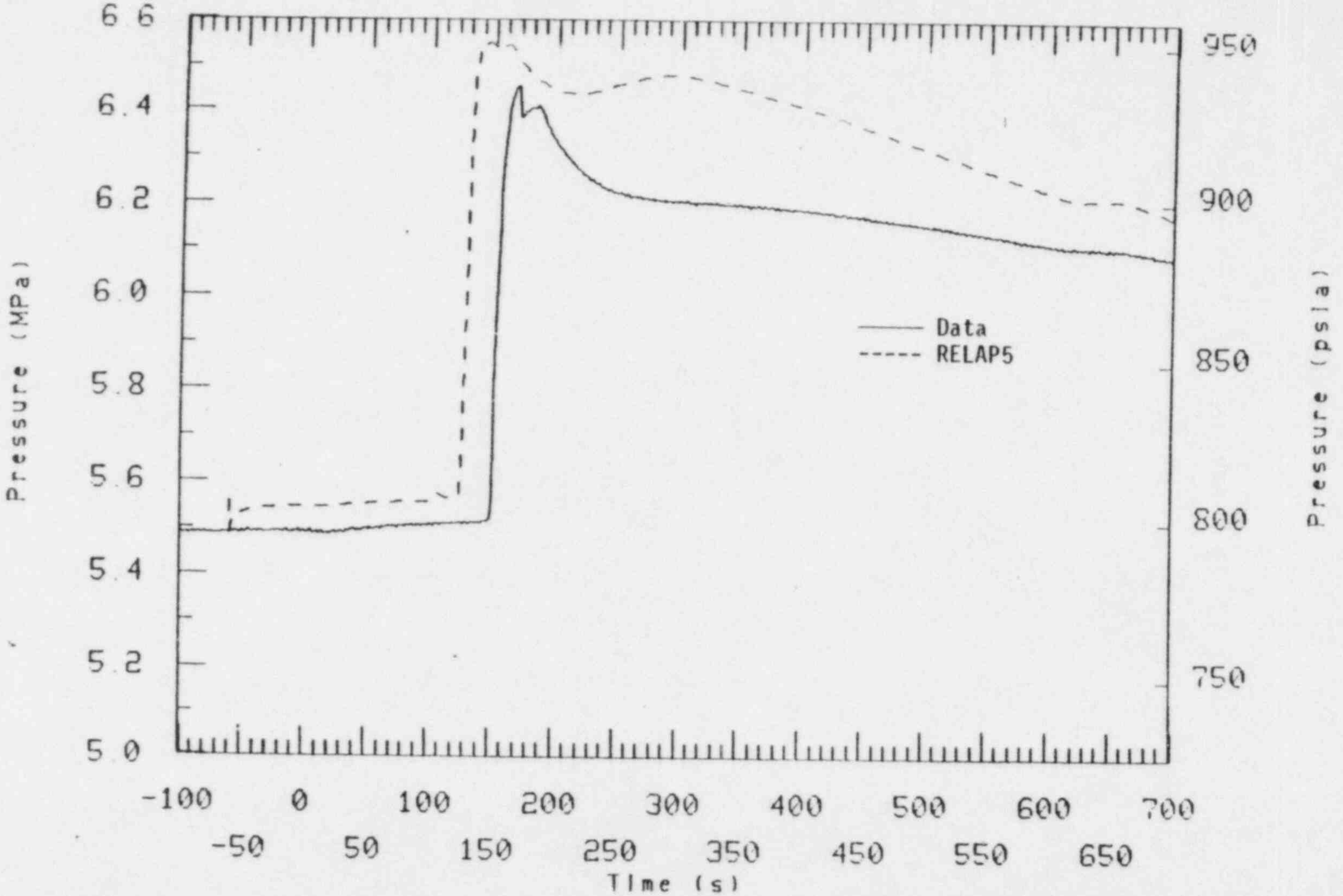

Figure 40. ILSG pressure comparison - diagnostic period.

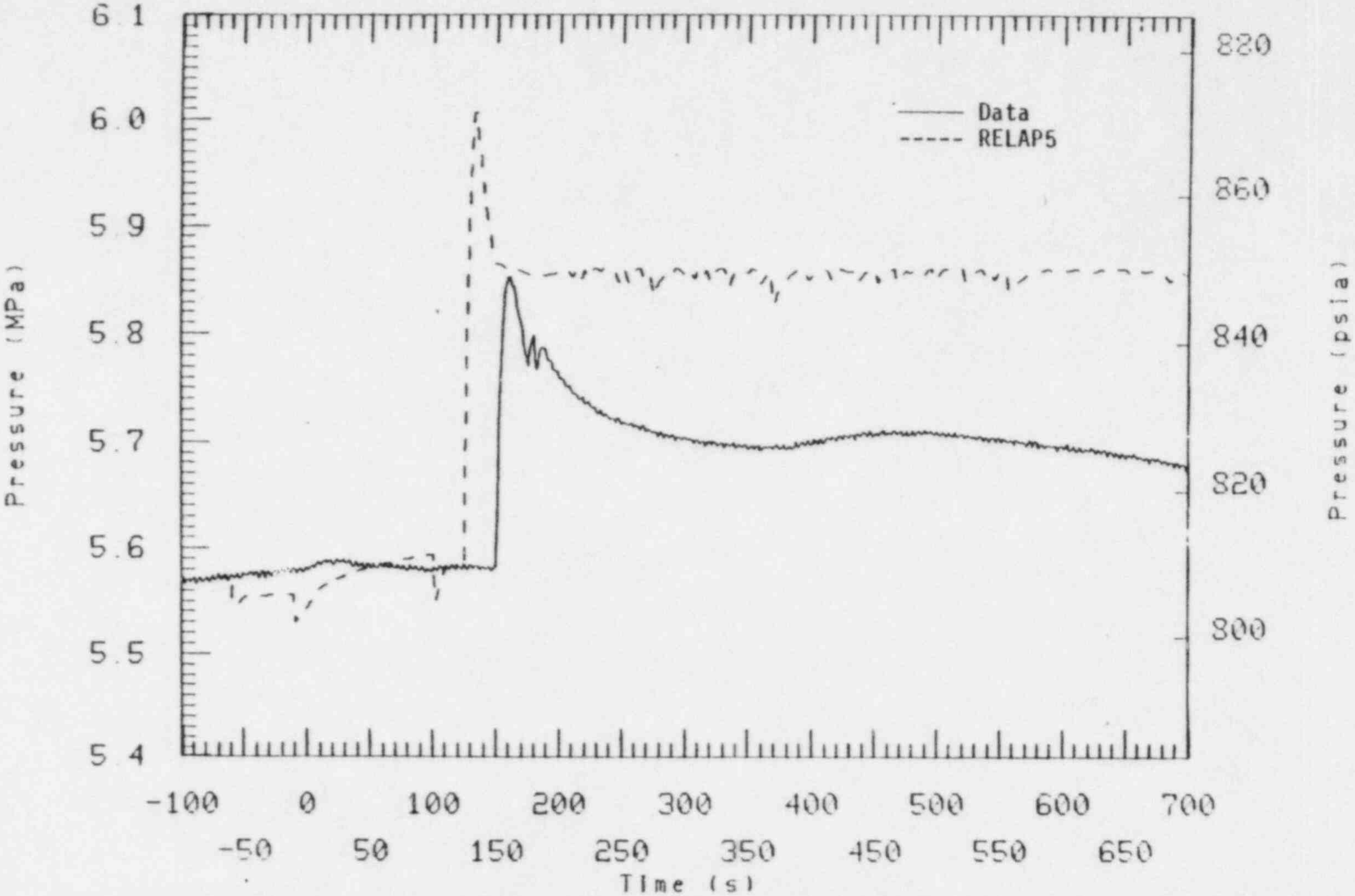

Figure 41. BLSG pressure comparison - diagnostic period.

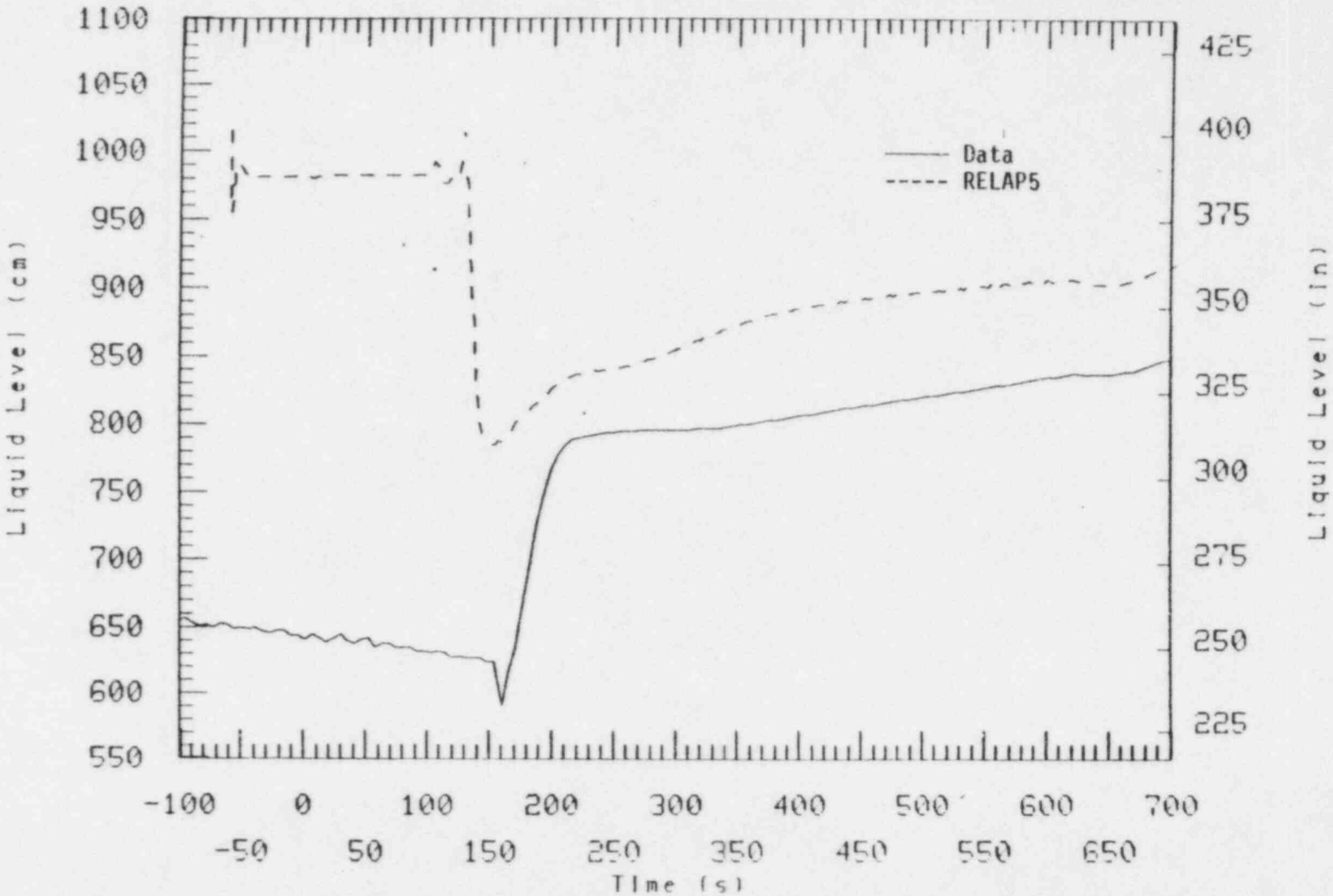

Figure 42. ILSG downcomer interfacial liquid level comparison - diagnostic period.

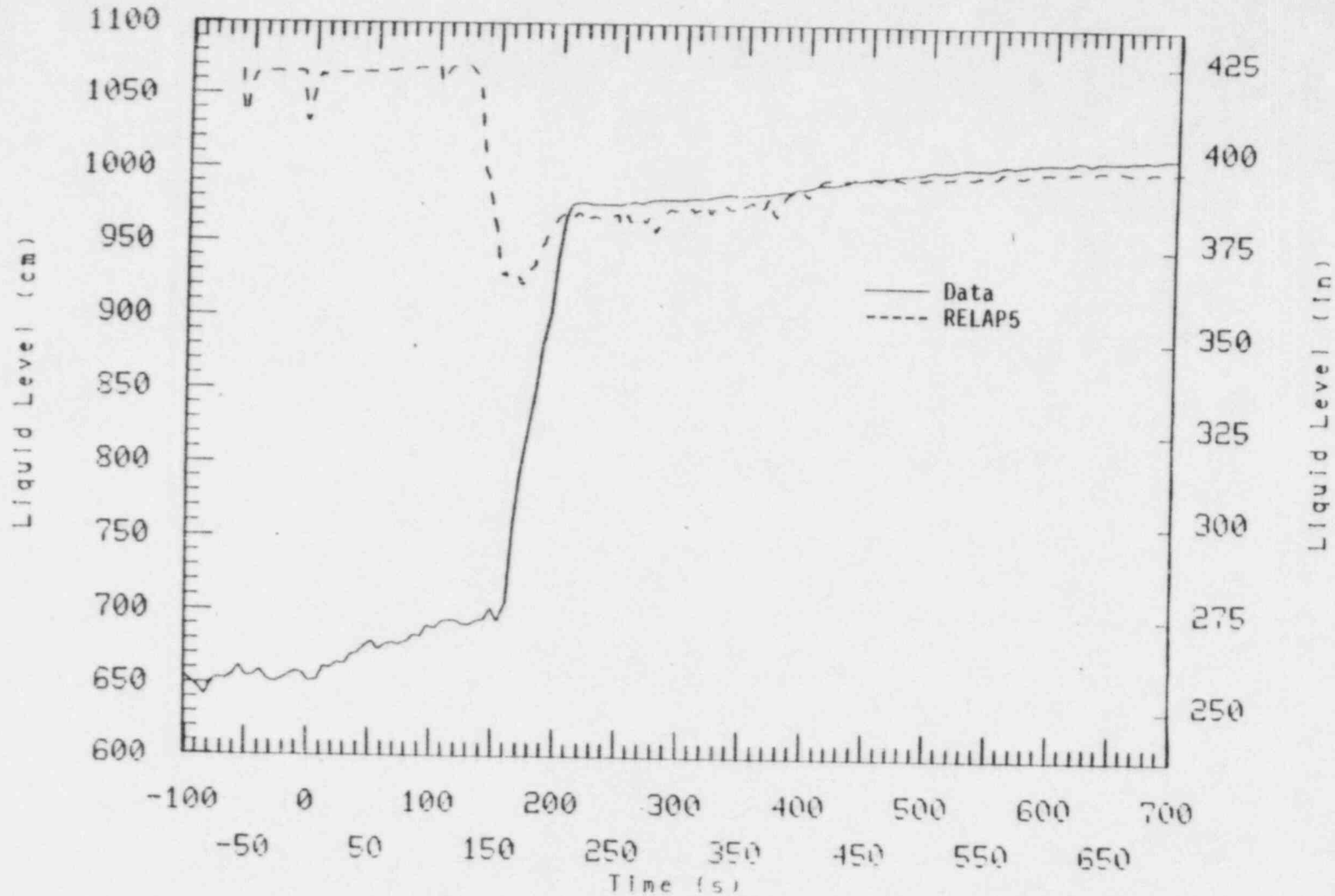

Figure 43. BLSG downcomer interfacial liquid level comparison - diagnostic period.

did not occur because the secondary mass was increasing due to the break flow. The lack of auxiliary feedwater flow in the calculation kept the calculated pressure high.

4.2 Plant Recovery Period

This section discusses comparisons of calculated and test results for the recovery phase of the transient. The test terminated at 5100 s and the calculation terminated at 5060 s so the comparisons will cover the total recovery period of each case.

Figure 44 is a comparison of pressurizer pressures. At the start of the recovery period (600 s), the pressurizer PORV was opened, and remained open until the end of the test. Both test and calculated pressures began to fall, with the calculated pressure falling more rapidly due to a smaller steam volume in the upper plenum/upper head region (Figure 45). Less voiding was calculated in the upper head/upper plenum region after scram when the calculated break flow became less than the test break flow (Figure 46). The pressurizer level in both cases began to rise immediately upon opening the PORV and both were completely full by 1070 s (Figure 47). PORV flows increased several fold as the pressurizer filled and two phase flow began (Figure 48).[a] Upper head/upper plenum voiding increased rapidly as the pressure dropped below the saturation level in the upper plenum and flashing began, forcing liquid into the pressurizer. The PCS depressurization rate decreased as the pressurizer became liquid full at 1070 s and reduced the liquid outflow from the upper head/upper plenum region.

At about 800 s, flashing began in the ILSG U-tubes, due to the declining heat sink in the steam generator. The U-tubes were empty by about 1900 s in the calculation and by about 2400 in the test (Figure 49). The BLSG U-tubes in the calculation began voiding at about 1900 s and were

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a. The test PORV flow was not measured between approximately 2500 and 3100 s as the catch tank was draining during this period.

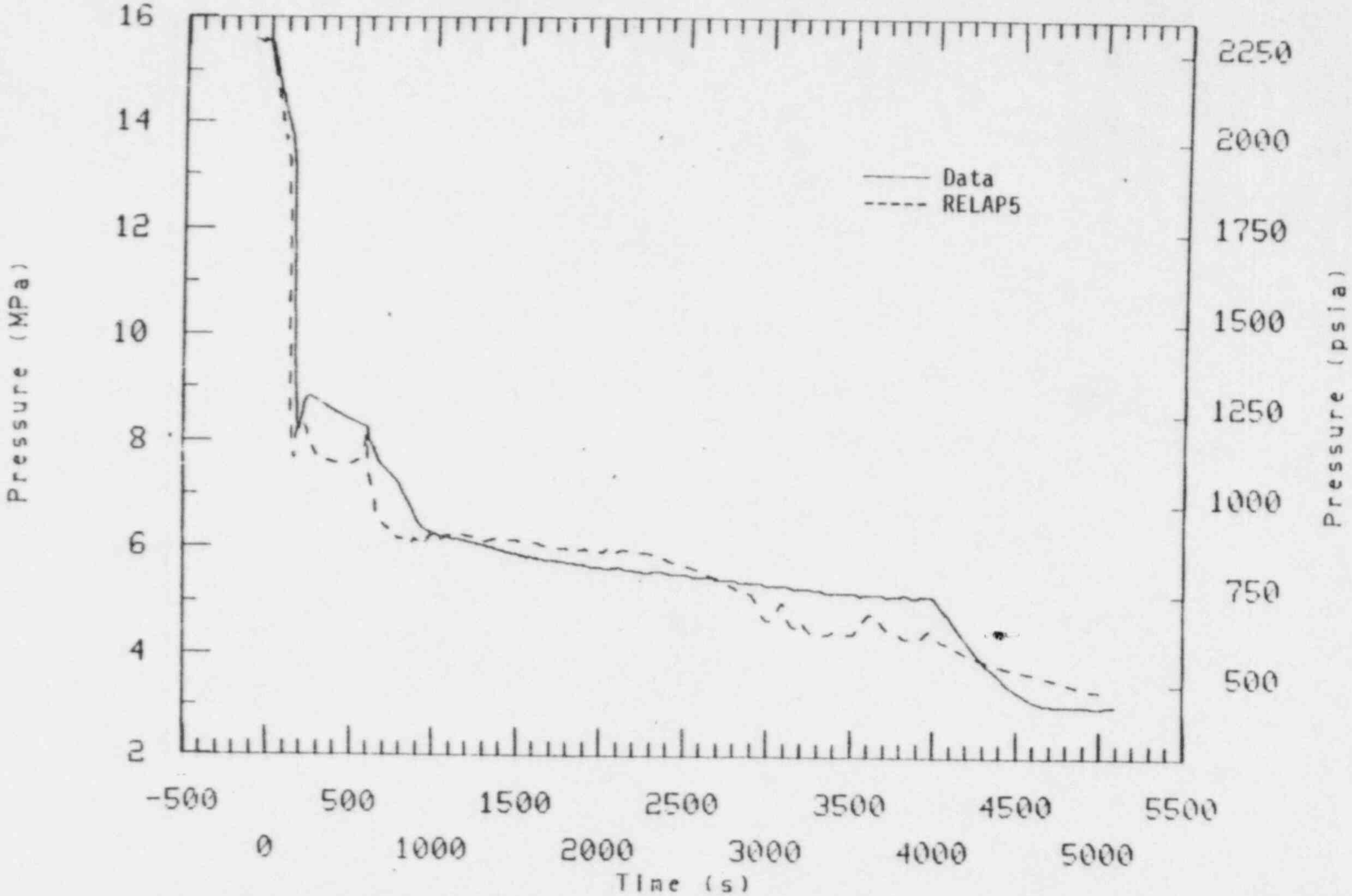

Figure 44. Pressurizer pressure comparison - recovery period.

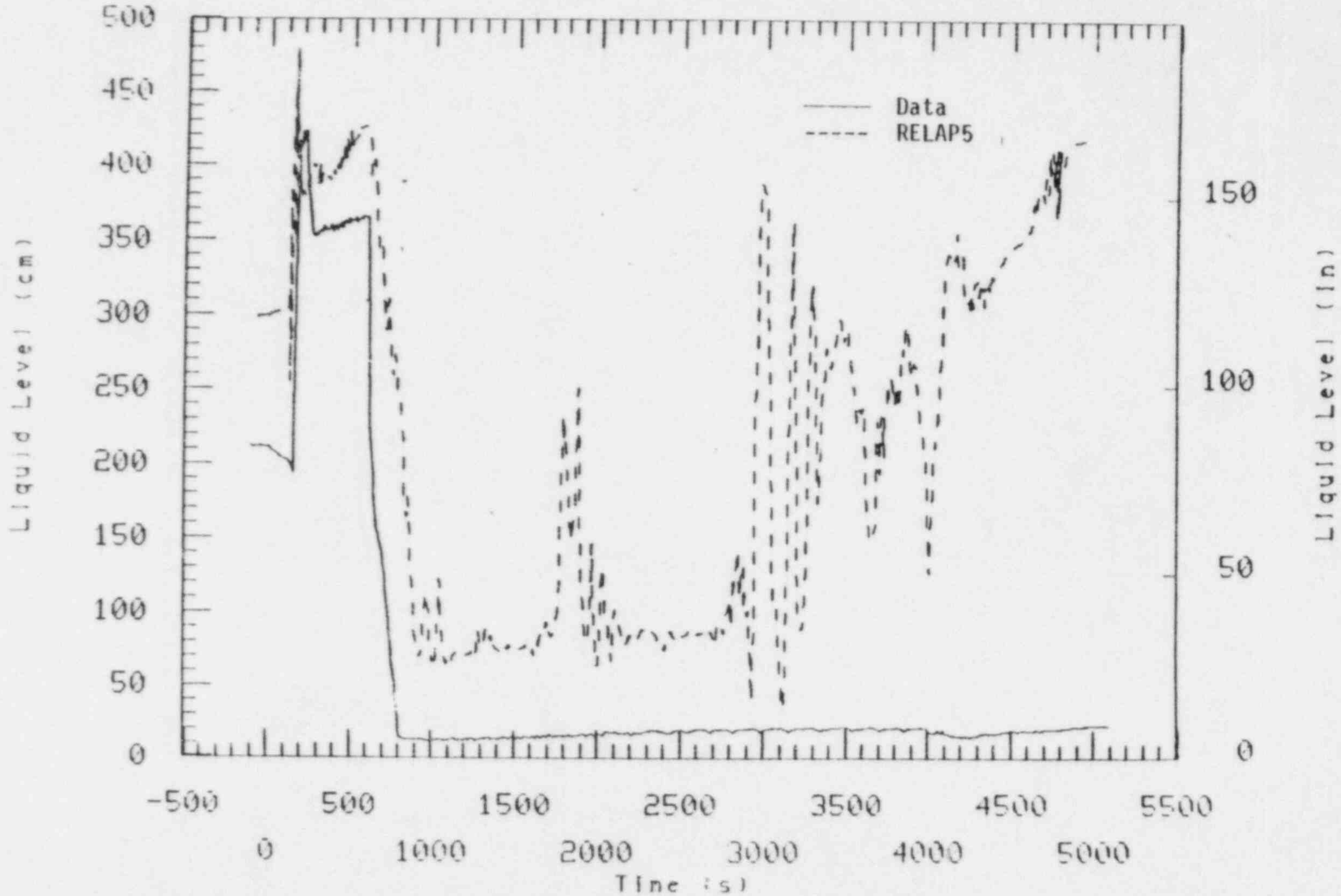

Figure 45. Upper-head/upper-plenum interfacial liquid level comparison referenced to the cold leg centerline.

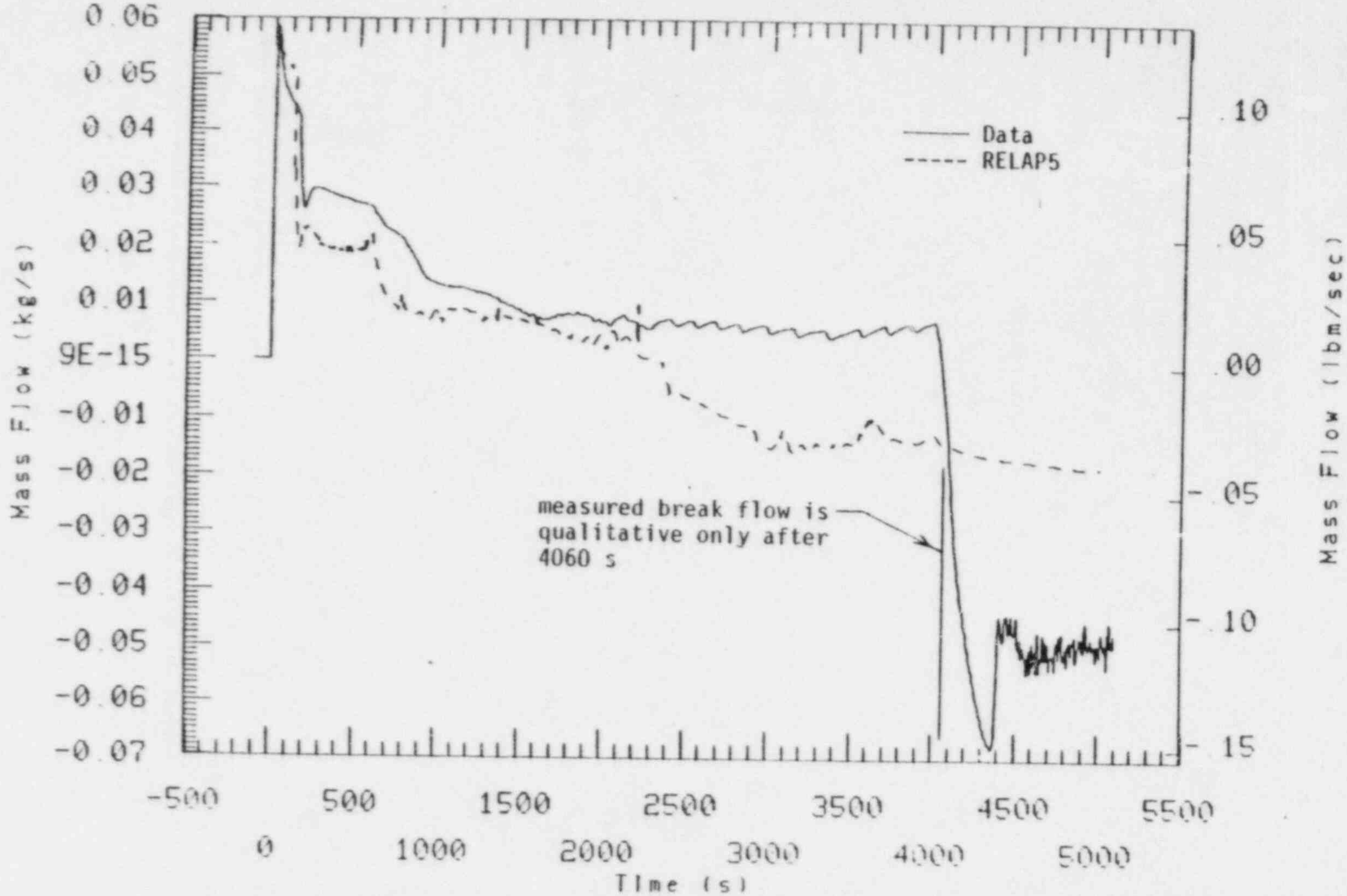

Figure 46. Break flow comparison - recovery period.

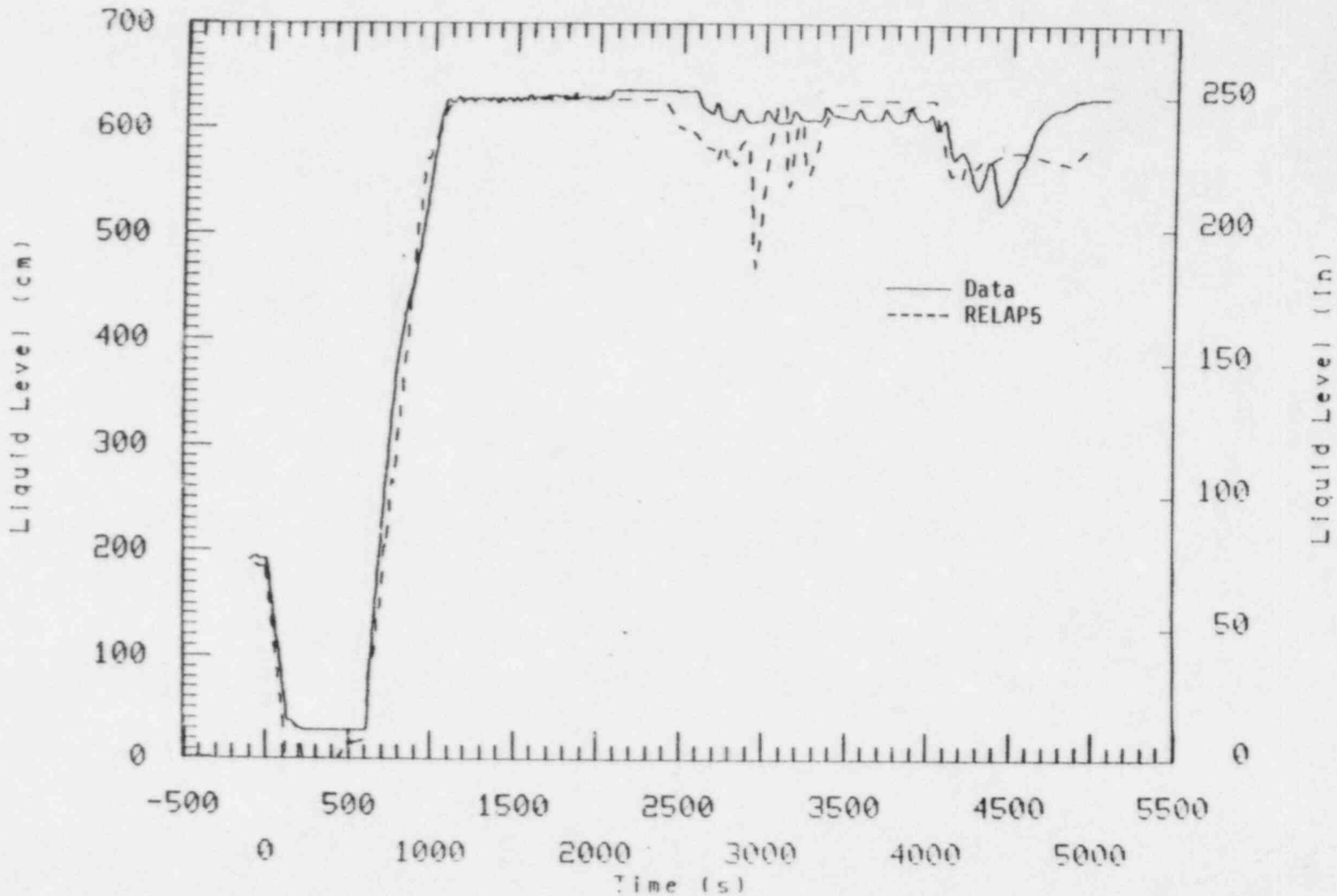

Figure 47. Pressurizer interfacial liquid level comparison - recovery period.

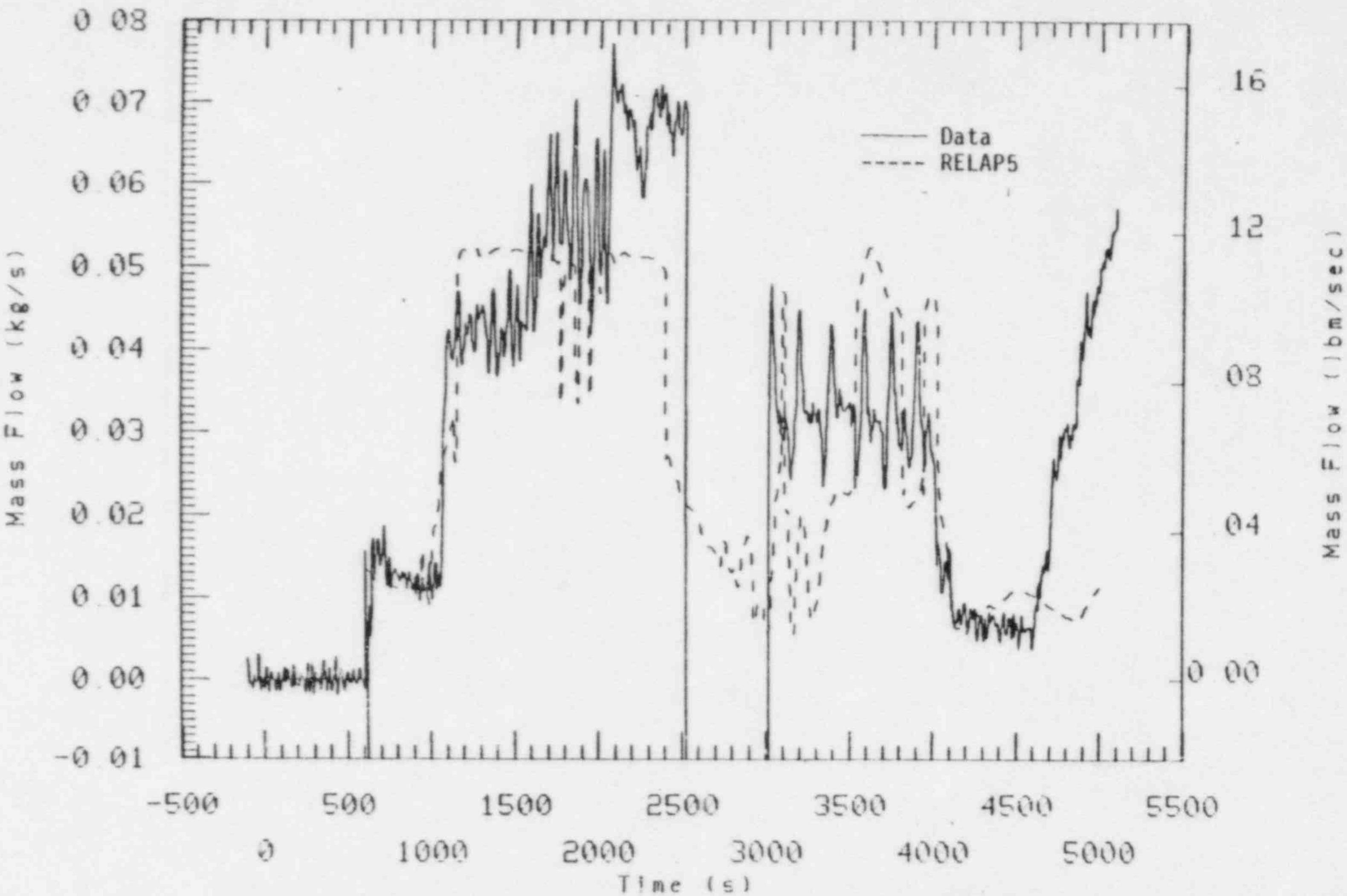

Figure 48. PORV flow comparison - recovery period.

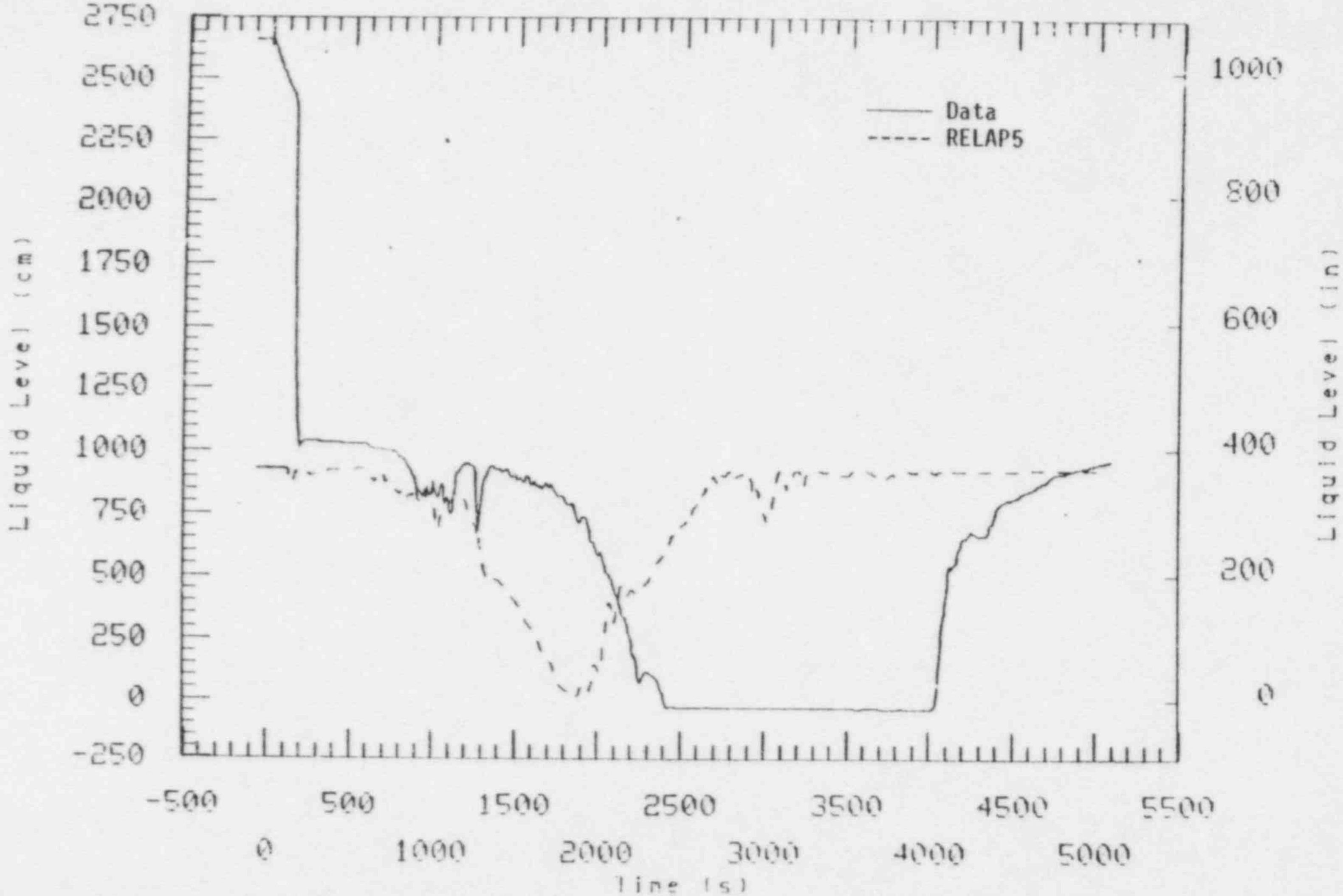

Figure 49. ILSG U-tube up leg interfacial liqiud level comparison.

empty by 2300 s. They remained empty until the end of the calculation. In the test, a cyclic filling and partial emptying down to approximately 500 cm (197 in) developed in the BLSG U-tubes (Figure 50), beginning at approximately 2200 s and lasting until 4000 s, when the ILSG ADV was opened. The U-tubes emptied by 4060 s and remained empty until the end of the test, due to loss of heat sink when PCS pressure fell below BLSG pressure. These cyclic BLSG phenomena were not predicted in the calculation.

4.2.1 Vessel Liquid Level

The calculated vessel interfacial liquid level fell about 30 cm (12 in) into the top of the core between 2000 and 2700 s (Figure 51). This was caused by the voids in both steam generator U-tubes blocking the PCS flows, resulting in loss of steam generator heat sinks to the PCS. Reflux natural circulation began in the ILSG with a high liquid column in the upflow tubes and a lower liquid column in the downflow tubes. At the same time the BLSG tubes were completely void and a column of liquid was standing in the broken loop pump suction up leg. Thus both loops were blocking liquid flow and causing a pressure differential between the hot and cold legs, created by safety injection induced condensation in both cold legs. This pressure differential resulted in a manometric level differential between the downcomer and vessel from 2000 to 2700 s. Cold auxiliary flow into the ILSG eventually condensed the voids in the tubes and liquid flow resumed at approximately 2700 s allowing the vessel level to rise.

In the test, the intact loop fluid flow was stopped by voiding in the steam generator tubes at approximately 1800 s and the ILSG heat transfer was by the reflux mode until the tubes refilled shortly before the end of the test. The tubes in the BLSG did not void completely and the cyclic condition mentioned earlier developed. This allowed periodic flow interruptions in the broken loop resulting in periodic core liquid level depressions of smaller magnitude (Figure 51) than that discussed above for the calculation. The BLSG tubes emptied completely after the break flow reversed at about 4060 s. The test interfacial liquid level fell

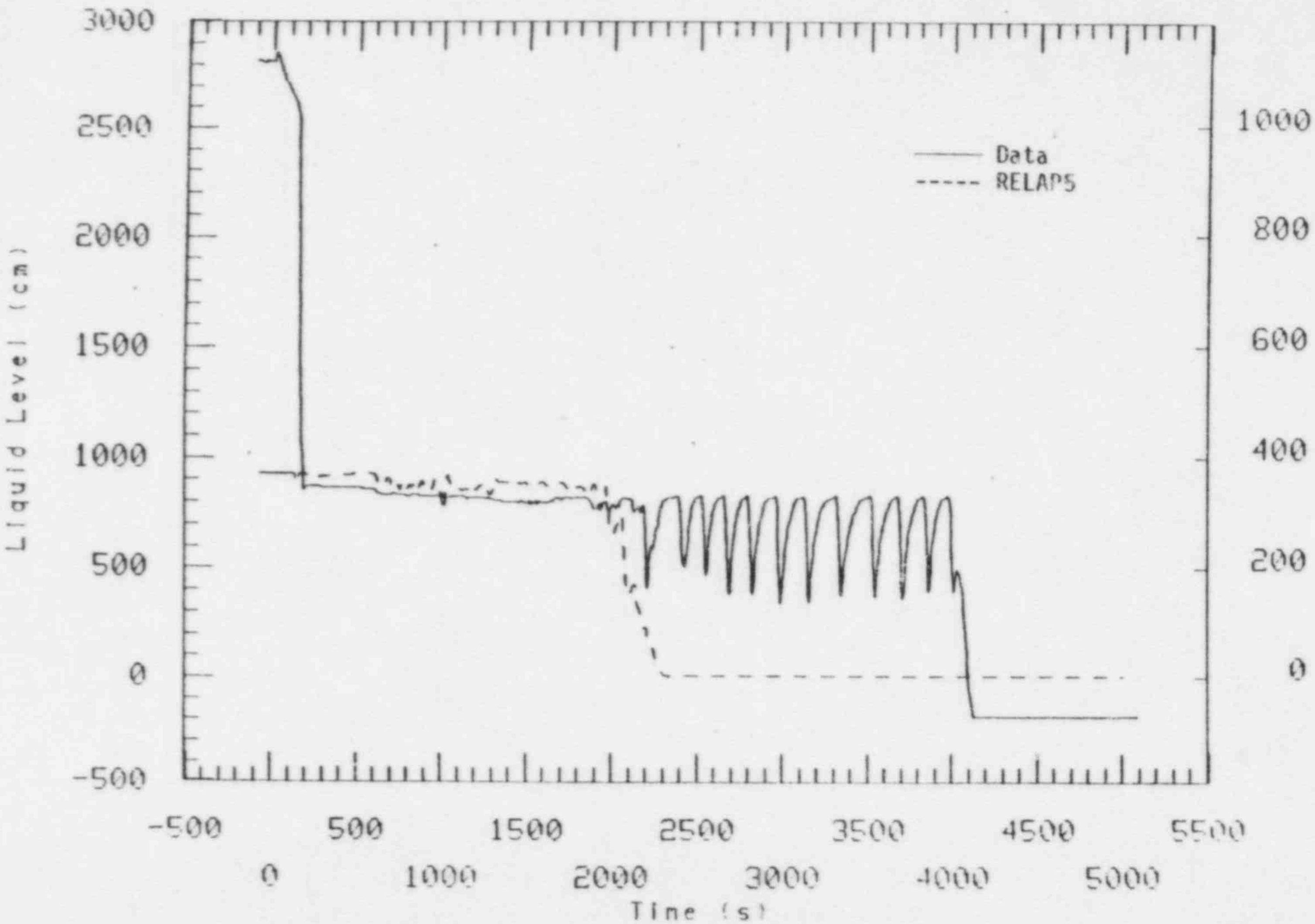

Figure 50. BLSG U-tube up leg interfacial liquid level comparison.

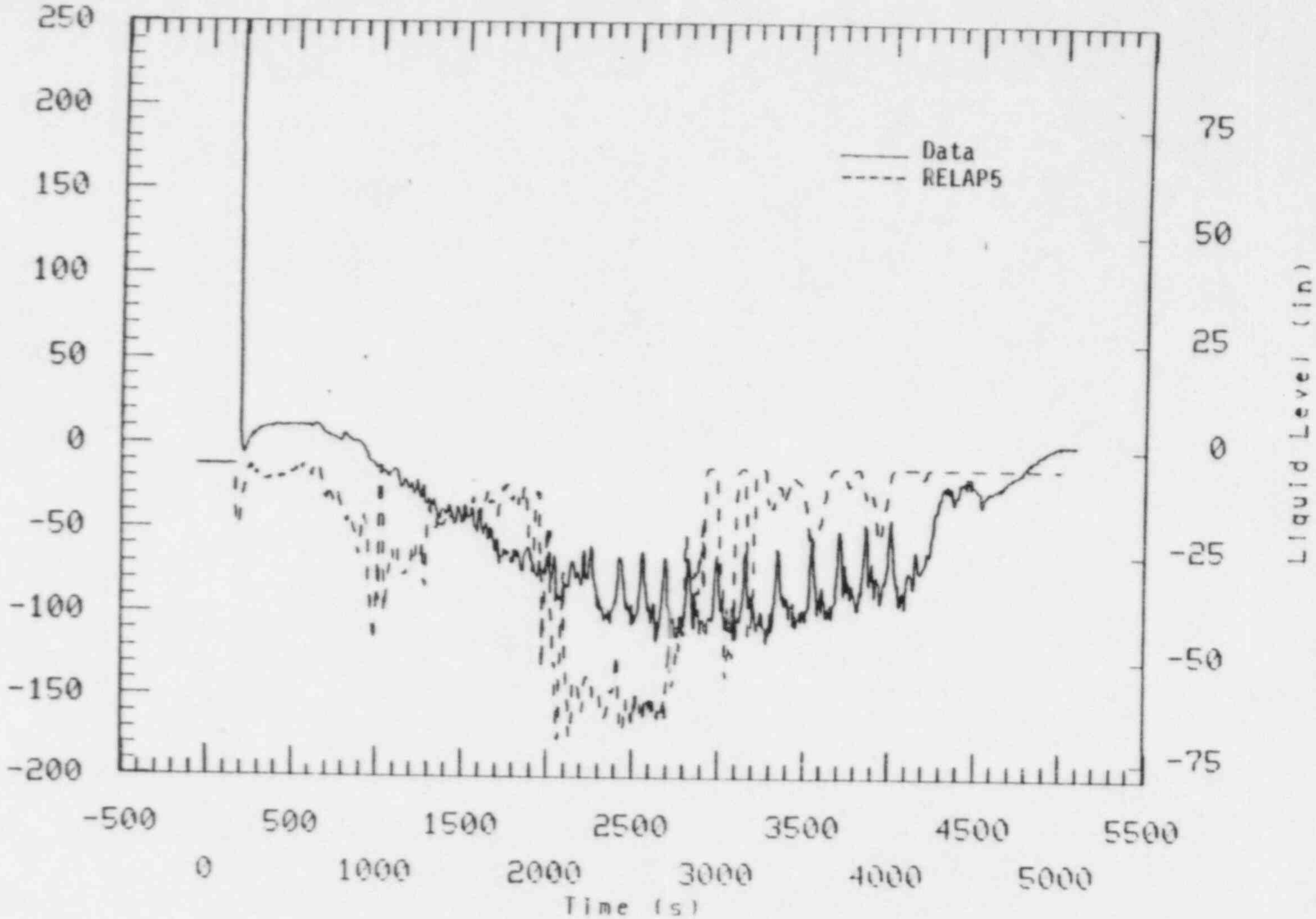

Figure 51. Vessel liquid level comparison, -13 cm to -57 cm referenced to cold leg centerline.

approximately to the top of the core from 2300 to about 3500 s. No heater rod temperature excursions were noted in either the test or the calculation.

4.2.2 Safety Injection (SI)

SI flows in the calculation cycled on and off after about 2900 s (Figure 52) due to the liquid level in the upper head rising above the 291 cm (115 in) upper head control limit (Figure 45). In the test, the HPIS flow remained on continuously, since the upper head did not refill (Figure 45). The fluctuations in calculated PCS pressure between 2900 and 4000 s were due to the cycling on and off of the SI flow affecting the core outlet temperature and therefore the saturation pressure. The test PCS pressure maintained a steady decline; the SI flow did not cycle as in the calculation.

In the calculation, a quasi-steady PCS condition with the PCS pressure below the BLSG ADV setpoint of 5.86 MPa (850 psia) had been achieved between 3000 and 3740 s with essentially stable liquid levels above the core. To enhance the PCS depressurization, the ILSG ADV was opened at 3740 s. The EOS, modified in response to this calculated steady condition, required a quasi-steady PCS condition for 1000 s before opening the ILSG ADV, resulting in the test ADV opening at 4000 s. A comparison of the ILSG calculation and test pressures is made in Figure 53 showing similar depressurization rates after ADV opening. The effect on the ILSG downcomer interface liquid levels is shown in Figure 54. In both test and calculation the auxiliary feedwater was terminated when the liquid levels reached the upper control limit of 1050 cm (413 in) and reinitiated after the ADV opening when the levels fell to the lower control limit of 800 cm (315 in). It is noted that the test level continued to fall after the auxiliary feedwater was reinitiated, whereas the calculated level climbed back up to 1050 cm and again terminated the feedwater. The auxiliary feedwater flow is much less than the ADV flow and therefore the level would be expected to continue falling as in the test. The discrepancy is felt to be related to the Semiscale RELAP5 model and sensitive to node size,

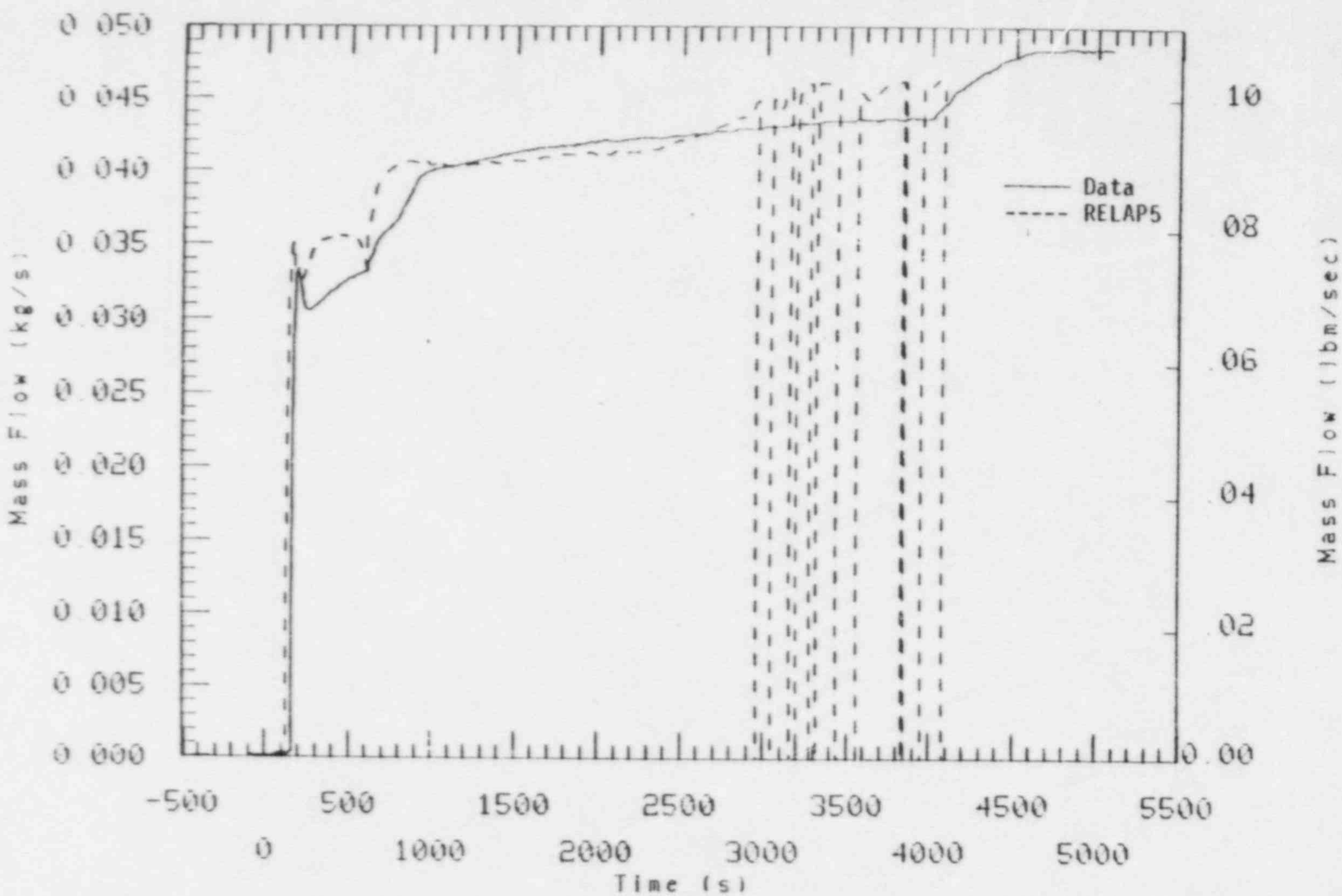

Figure 52. Total HPIS flow comparison.

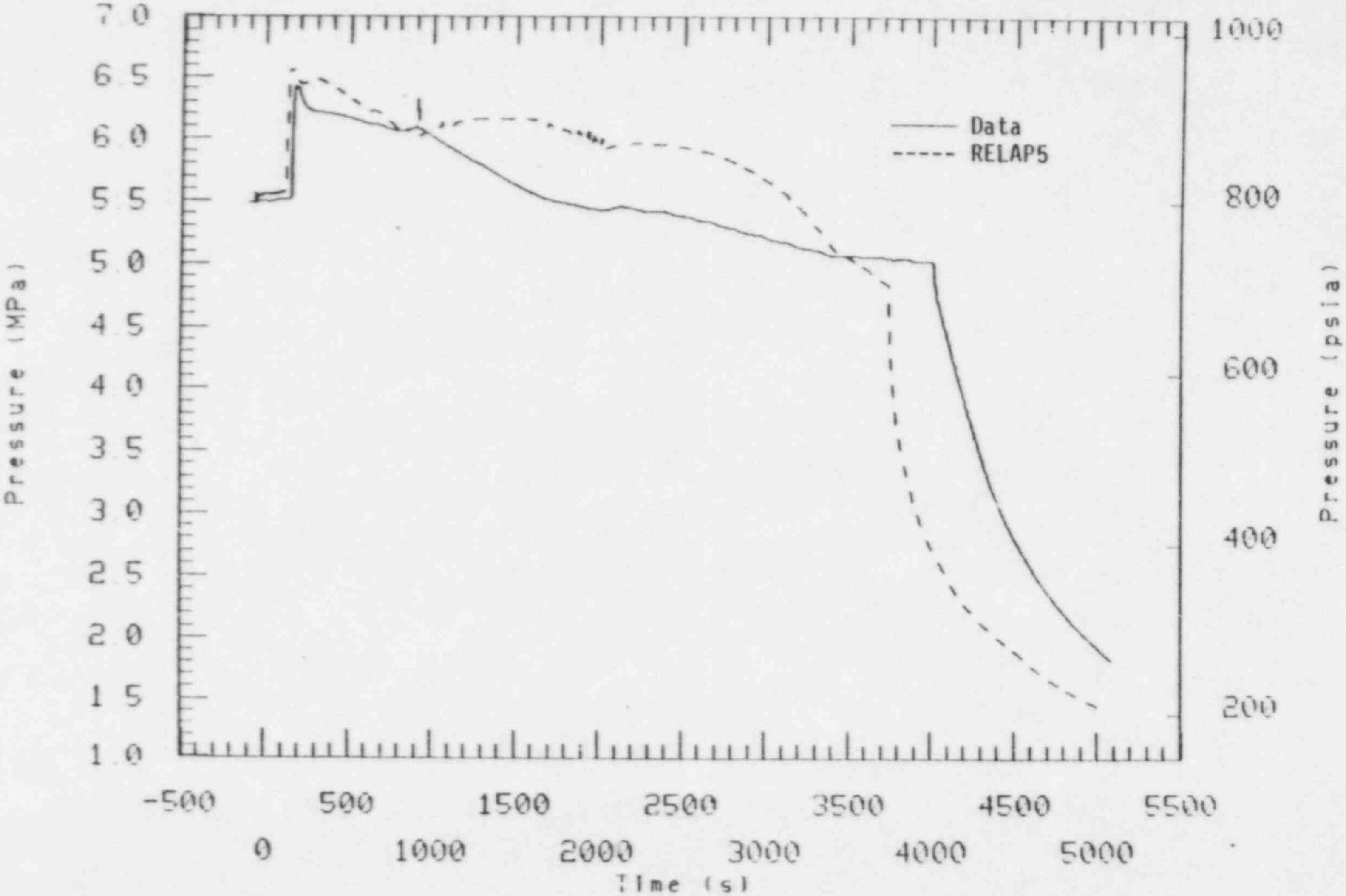

Figure 53. ILSG pressure comparison - recovery period.

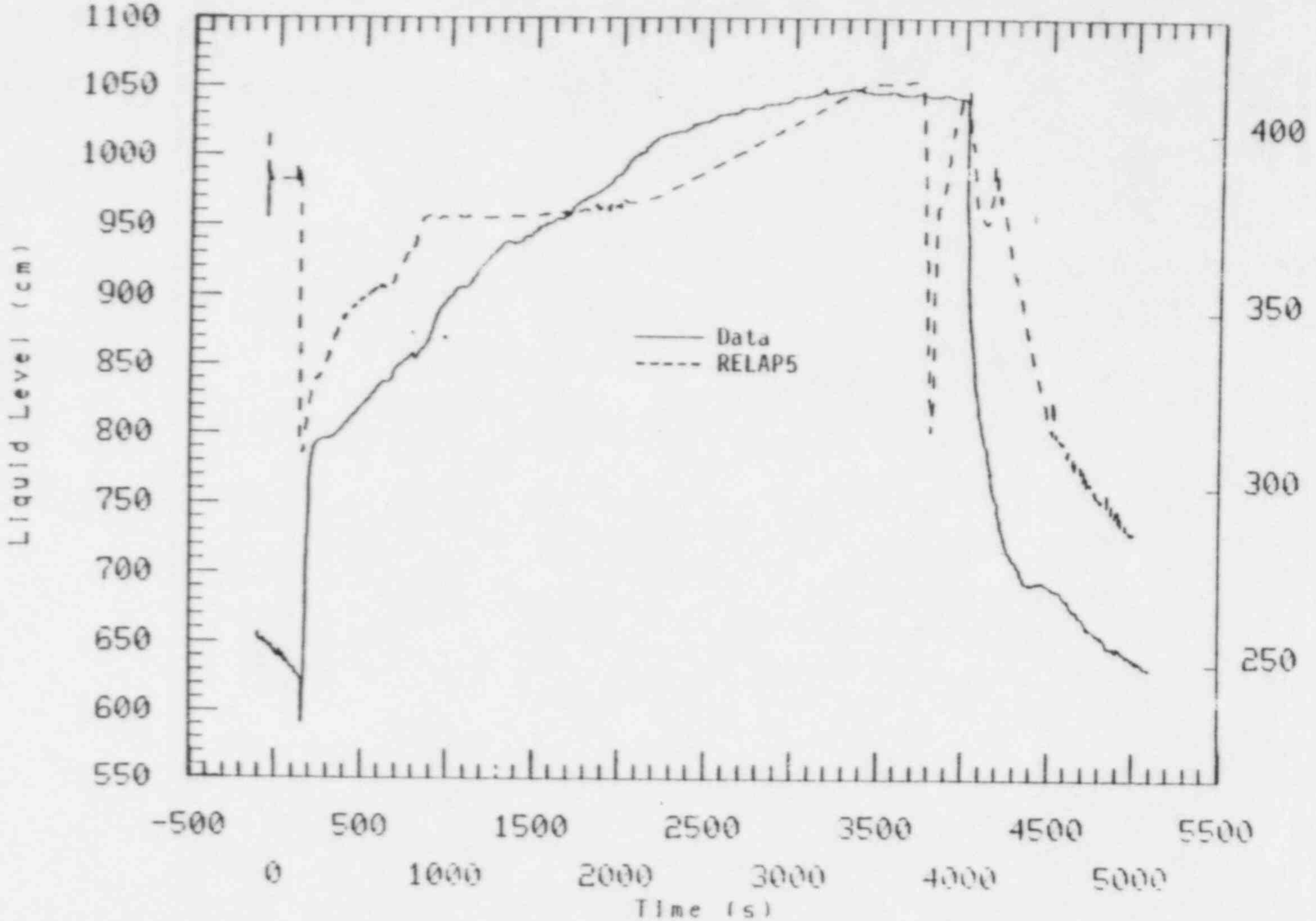

Figure 54. ILSG downcomer interfacial liquid level comparison - recovery period.

especially in the steam generator downcomer. Similar phenomena were observed in the S-SG-6 pretest calculation,[7] which was run after the S-SG-8 calculation was completed.

4.2.3 Break Flow Reversal

Figure 55 is a plot of pressurizer and steam dome test pressures in the two steam generators. It is seen that, after the ILSG ADV was opened at 4000 s, the PCS depressurization rate increased and the pressure fell below the BLSG pressure at 4060 s. At that time the break flow stopped and reversed directions, flowing from the steam generator into the PCS. Figure 46 shows the test break flow out to 4060 s, but upon reversal, the flow became two-phase and could not be computed accurately. For this reason, the measured break flow after 4060 s must be considered qualitative only. Figure 56 is a plot of pressurizer pressure and steam dome calculated pressures in the two steam generators. It is seen that the PCS pressure fell below the BLSG pressure at 2350 s and the flow reversed 1710 s earlier than in the test. The reason for this calculated early reversal can be seen in Figure 57, which shows calculated BLSG pressure holding nearly constant at the ADV setting until 2350 s when back flow from the BLSG commenced and its pressure began to drop. By contrast, the test BLSG pressure underwent a nearly continuous depressurization during the recovery period, approximately paralleling the PCS depressurization. It was not until after the ILSG ADV was opened at 4000 s, increasing the PCS depressurization rate, that the PCS pressure fell below the BLSG pressure and reversed the break flow. The reasons for the faster BLSG depressurization in the test than in the calculation are not fully understood at this time, but a contributing factor was the use of auxiliary feedwater[a] during the diagnostic period in the test, but not in the calculation.

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a. See Section 4.1.

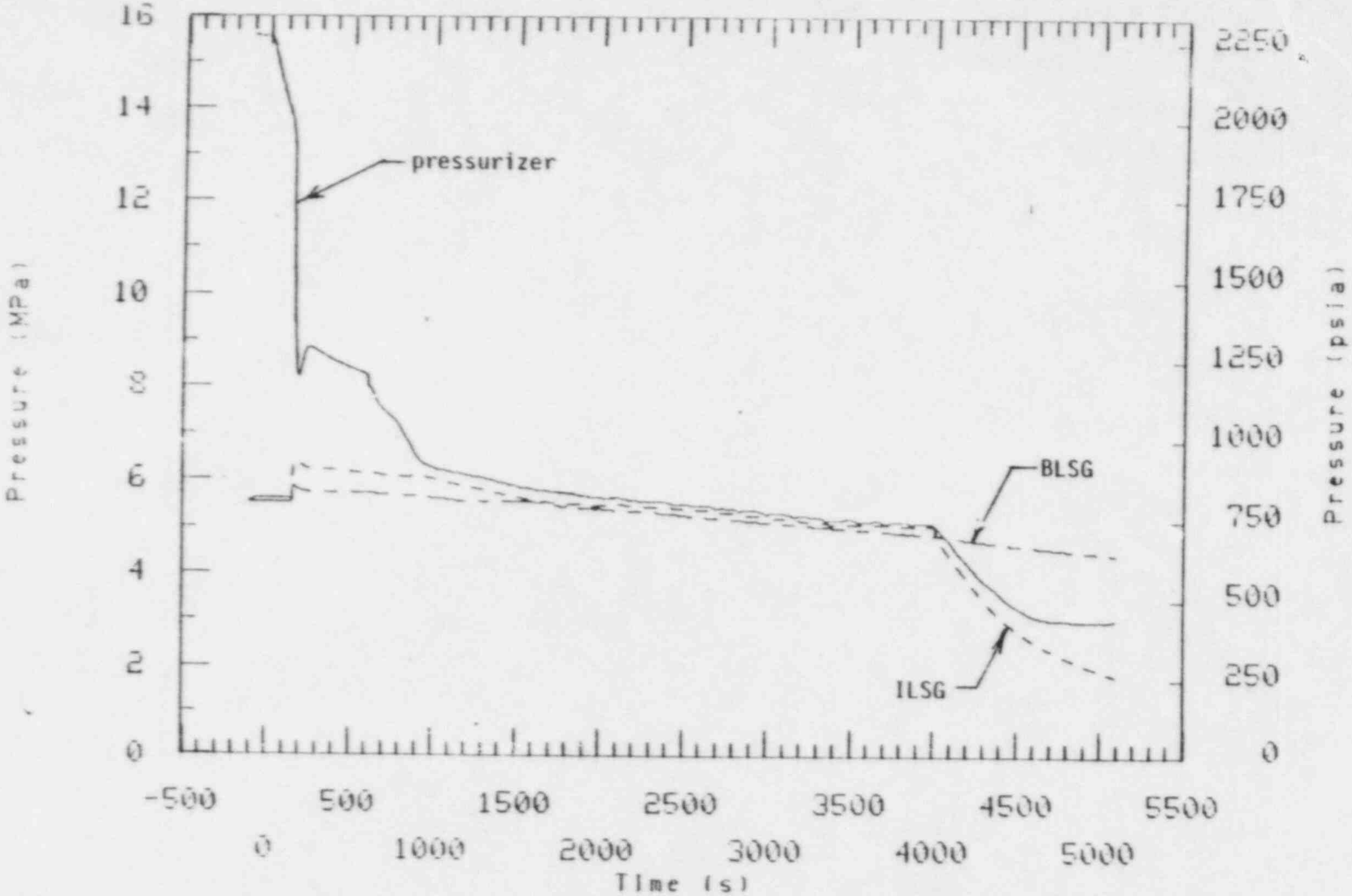

Figure 55. Pressurizer ILSG and BLSG pressures - test.

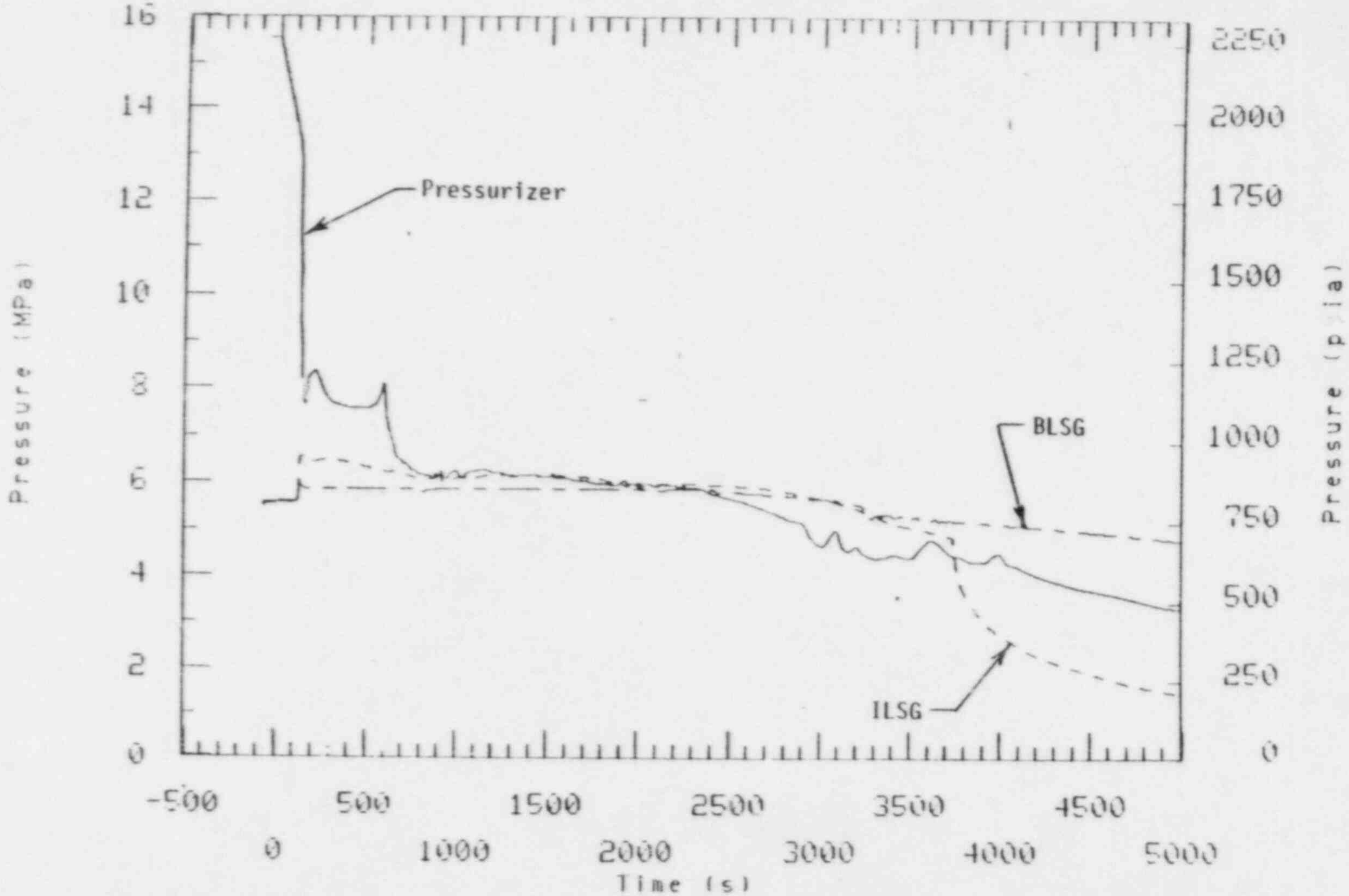

Figure 56. Pressurizer ILSG and BLSG pressures - calculation.

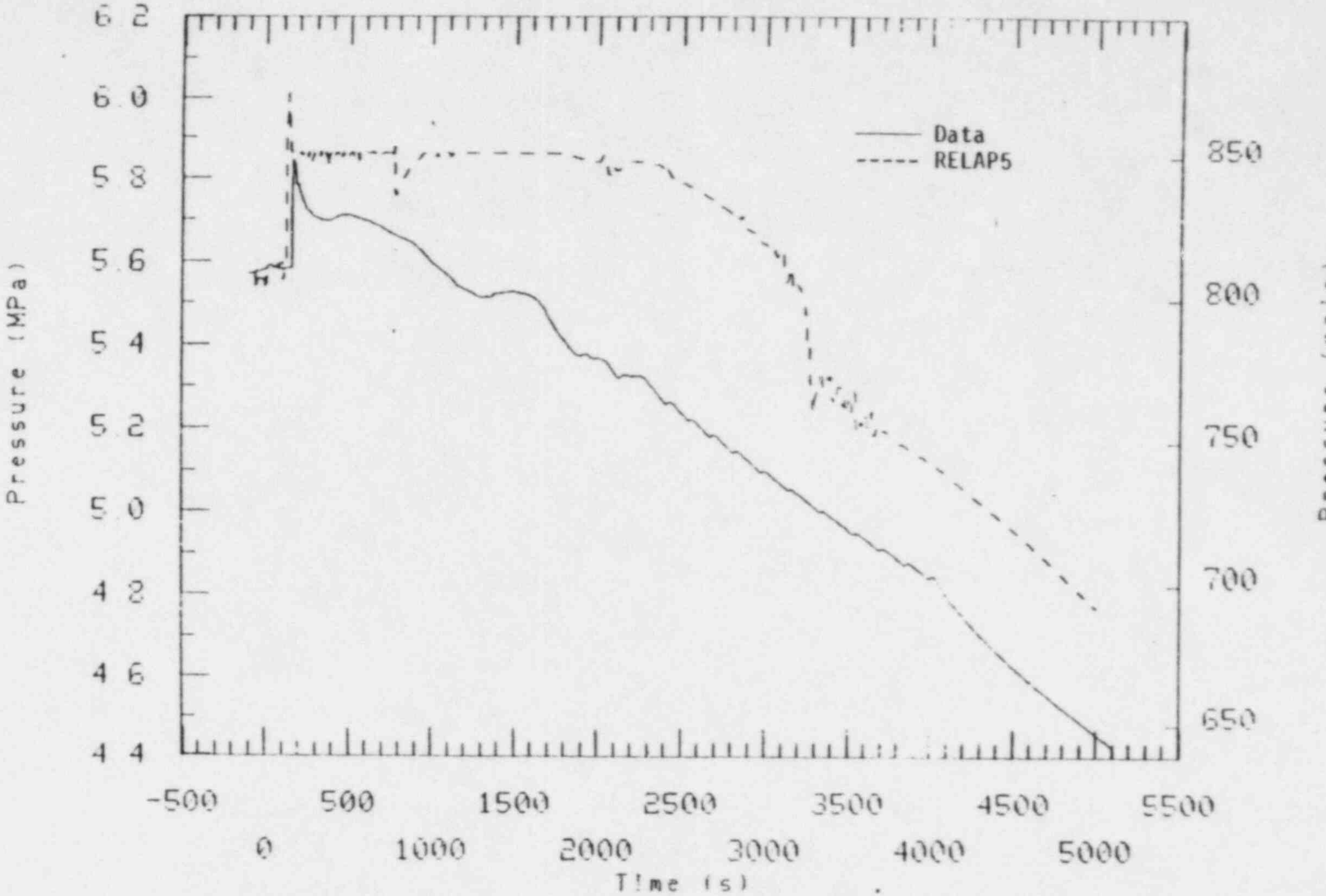

Figure 57. BLSG pressure comparison - recovery period.

4.2.4 Vessel Refill

The calculation overpredicted the vessel refill as shown in Figure 51. This is also seen in the upper head/upper plenum region (Figure 45) which shows the upper head full at 5000 s, but no significant increase in the test liquid level. The reason for the calculated faster vessel refill can be seen in Figure 46 which shows that the calculation underpredicted the break flow rate throughout the entire recovery period. The early break flow reversal in the calculation contributed significantly to the faster refill in the calculation.

4.3 Summary and Recommendations

The calculation predicted the main characteristics (signature) of a steam generator tube rupture during the 600 s diagnostic period, i.e.:

1. falling pressurizer level and pressure,

2. rising steam generator secondary level.

Major differences in the diagnostic period were:

1. The break flow was overpredicted prior to scram leading to faster PCS depressurization and early scram.

2. Steam generator ADV setpoints in the test were lower in the test than in the calculation, due to location of the pressure sense lines at the bottom of the downcomer, causing lower peak pressures after closure of the main steam isolation valves.

3. Smaller mass inventory in the test ILSG contributed to the continuing lower secondary pressure in the test.

4. BLSG auxiliary feedwater flow operation in the test contributed to the continuing lower secondary pressure in the test.

Major differences in the recovery period were:

1. The break flow was underpredicted following scram, leading to early vessel refill.

2. Complete voiding of the BLSG U-tubes was predicted by 2300 s, but a cyclic, partial void and refill condition developed in the test at 2200 s and continued to 4000 s before the U-tubes voided completely.

3. Safety injection (SI) cycled on and off after about 2900 s maintaining the upper head liquid level in the calculation, but remained on continuously in the test due to the voided upper head.

4. Steam generator secondary pressures were overpredicted leading to early reversal of the break flow.

5. The ILSG calculated liquid level in the downcomer climbed rapidly after reinitiation of auxiliary feedwater. In the test, the level continued to drop after reinitiation of the auxiliary feedwater.

The pressurizer refill time after opening of the PORV was well predicted. The calculated PORV and SI flow rates showed good agreement with test flow rates. The break flow model needs further study to improve benchmarking (see Reference 7). Also, the steam generator models need study to improve the level calculation comparison with data.

5. CONCLUSIONS

The following conclusions have been drawn based on a preliminary analysis of Test S-SG-8.

1. The prescribed operator response consisting of primary feed and bleed and intact loop secondary steam and feed was adequate to recover the Semiscale system from a single steam generator tube rupture. Recovery, in this case, meant reducing the primary pressure to the accumulator injection setpoint of 4.22 MPa (612 psia).

2. The stuck open pressurizer PORV did not cause significant primary inventory loss. The lowest vessel collapsed liquid level remained well above the level of the core. SI flow was greater than the combined break and PORV flow during most of the transient, maintaining primary inventory.

3. A quasi-steady state primary feed and bleed operation can be established to reduce primary pressure to stable and acceptable levels. The primary pressure stabilized below the broken loop ADV setpoint.

4. Intact loop steam and feed operation is very effective in reducing primary pressure during a feed and bleed operation.

5. The RELAP5 pretest calculation agreed qualitatively with the test data in predicting important events in the transient such as: scram, pressurizer refill after PORV opening, voiding in the upper head/upper plenum region, and break flow reversal. It did not predict, however, the cyclic partial void and refill condition that developed in the BLSG tubes between 2200 and 4000 s.

6. Break flow was overpredicted prior to scram and underpredicted following scram. This led to early scram and early

upper-plenum/upper-head refill. Steam generator secondary pressures were overpredicted leading to early break flow reversal. ILSG downcomer liquid level was predicted to climb with the ADV open after auxiliary feedwater was reinitiated, but the level continued to fall in the test.

7. Further study of the break model is needed to improve the accuracy of the flow calculation. Investigation of the many factors affecting the steam generator depressurization rates is needed to improve the accuracy of the steam generator pressure and downcomer liquid level predictions.

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16. ABSTRACT (200 words or less)

Results of a preliminary analysis of the fifth test performed in the Semiscale Mod-2B Steam Generator Tube Rupture Series are presented. Test S-SG-8 simulated a pressurized water reactor accident initiated by a double-ended offset shear of one cold side steam generator tube. The transient included an initial 600-second period during which only automatic plant protection system response to the initiation event occurred. This period was followed by an operator-induced recovery procedure to establish a primary feed and bleed with the PORV assumed stuck in an open position, followed by intact loop secondary steam and feed operation. The test results provided a measured evaluation of the impact of a stuck open PORV on primary inventory and system recovery as well as the effectiveness of intact loop secondary steam and feed in reducing primary system pressure. The test showed that the prescribed limited operator response was adequate to recover the Semiscale system from a simulated one-tube rupture.

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November 26, 1984

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Rec'd 11-29-84

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To Whom It May Concern:

Pursuant to the Freedom of Information Act, this is to request copies of any documents subsequent to 1980 describing the scope of work and results from projects completed, in the process of being conducted or planned by Westinghouse Electric Corporation or the Nuclear Regulatory Commission relating to tests or analyses of steam generator tube degradation in pressurized water reactors.

A waiver from any fees is requested on the grounds that the information is sought by a non-profit, public interest organization for use as part of the public dialogue. In the event a waiver from fees is not granted, please advise if any fees will be in excess of $50.

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by

PETER ANDERSON
President

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