EG&G Idaho, Inc

FORM EG&G-398
(Rev. 05-79)

INTERIM REPORT

Accession No.

Report No. EGG-SEMI-5431

Contract Program or Project Title:

Water Reactor Research Test Facilities Division

Subject of this Document:

Quick Look Report for Semiscale
Mod-2A Test S-UT-5

Type of Document:

Quick Look Report

Author(s): D. J. Shimeck
J. E. Blakeley
M. T. Leonard

NRC Research and Technical Assistance Report

Date of Document:

April 1981

Responsible NRC Individual and NRC Office or Division:

W. C. Lyon, Reactor Safety Research

THIS DOCUMENT CONTAINS POOR QUALITY PAGES

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

EG&G Idaho, Inc.
Idaho Falls, Idaho 83401

Prepared for the
U.S. Nuclear Regulatory Commission
Washington, D.C.
Under DOE Contract No. DE-AC07-76ID01570
NRC FIN No. A6038

INTERIM REPORT

8106170087

QUICK LOOK REPORT

FOR

SEMISCALE MOD-2A

TEST S-UT-5

NRC Research and Technical Assistance Report

by

D. J. Shimeck
J. E. Blakeley
B. W. Murri

April 1981

Approval: Gary W. Johnsen

G. W. Johnsen, Manager
WRRTF Experiment Planning
and Analysis Branch

Approval: Paul North.

P. North, Manager
Water Reactor Research
Test Facilities

ABSTRACT

Results are presented from a preliminary analysis of Semiscale Mod-2A Test S-UT-5. This test simulated a 2-1/2%, communicative break in the cold leg of a pressurized water reactor equipped with upper head emergency core coolant injection (UHI) capability. Initial conditions were typical of, or scaled from, a UHI plant. The primary objective of the test was to investigate the distribution of UHI water, and its influence on transient behavior, through comparison with Semiscale Mod-2A Test S-UT-4 which was similar but did not use UHI. Comparison shows that UHI had little effect on overall transient behavior.

CONTENTS

SUMMARY

This report presents the results of a preliminary analysis of data from Semiscale Mod-2A small break Test S-UT-5. This test simulated a loss-of-coolant accident resulting from a 2-1/2% communicative break in the cold leg of a pressurized water reactor (PWR). The break size for this test was 0.0613 cm^2 which is volumetrically scaled to represent an 11-cm diameter pipe break in a PWR. The Mod-2A system was configured to simulate a PWR with the capability to inject emergency core coolant (ECC) into the vessel upper head. The upper head accumulator was pressurized to a 8.6 MPa and the loop accumulator pressures were set at 2.86 MPa as is nominally specified for upper head injection (UHI) plants. Data from a previous test (S-UT-4) was used to establish the baseline response of the Mod-2A system for a 2-1/2% break without UHI for similar test conditions. Comparison of system responses between S-UT-4 and S-UT-5 allowed an evaluation of the influence of UHI.

Initial conditions for the test were equivalent to, or scaled from, typical PWR operating conditions. Following rupture of the pressure boundary, continuous depressurization took place and the system was observed to void predominantly from the upper elevations downward. The injection of UHI liquid into the vessel upper head caused a delayed and slower draining of the head. It also caused a more rapid depressurization during the duration of injection than was observed in Test S-UT-4. Measurements indicate that nearly all of the UHI liquid exited the upper head through the bypass line to the downcomer and cold legs and subsequently flowed out the break by 600 s. As the system voided, fluid in the pump suctions formed a seal which impeded steam flow around the loops. The formation of the suction seals had relatively little effect on the liquid level in the core. Once the intact loop pump suction had cleared the cold leg emptied, uncovering the break. The system then depressurized to the loop accumulator pressure of 2.86 MPa at 1277 s. At this time sufficient liquid still remained in the core to provide adequate cooling of the heater rods and no core uncovery and rod heatup was observed at any

time during the transient. The extra UHI fluid injected into the system did provide a slightly better margin against core uncovery than in Test S-UT-4.

After 1500 s, the system pressure, liquid distribution, and overall response was the same for both Test S-UT-4 and S-UT-5. Loop accumulator injection initiated a refilling trend in the system which continued throughout the remainder of the transient with HPIS flow. Results from Test S-UT-4 show that the system would have depressurized to the LPIS setpoint of 0.98 MPa at 5830 s.

Results of the RELAP5 pretest prediction calculation generally compared well with test data. The first 300 s of the transient was predicted well with respect to system depressurization, core temperatures and upper head drainage. The code calculated the intact loop pump suction to clear 150 s later than data indicated which, coupled with major differences in steam generator secondary mass, was a major influence in causing discrepancies between test data and the calculation results after 300 s. Posttest analysis improvements to the RELAP5 calculations should investigate these two factors as well as corrections in the break mass flow rate.

1. INTRODUCTION

Testing performed in the Semiscale Mod-2A system is part of the water reactor safety research effort directed toward assessing and improving the analytical capability of computer codes which are used to predict the behavior of pressurized water reactors (PWR's) during postulated accident scenarios. For this purpose, the Mod-2A system was designed as a small-scale model of the primary system of a four-loop PWR nuclear generating plant. The system incorporates the major components of a PWR including steam generators, vessel, pumps, pressurizer, and loop piping. One loop (intact loop) is scaled to simulate the three intact loops in a PWR, while the other (broken loop) simulates the single loop in which a break is postulated to occur in a PWR. Geometric similarity has been maintained between a PWR and Mod-2A, most notably in the design of a 25 rod, full-length (3.66 m), electrically heated core, full-length upper head and upper plenum, component layout, and relative elevations of various components. Equipment in the upper head of the Mod-2A vessel has been designed to simulate the fluid flow paths found in a PWR which has the capability of injecting emergency core coolant (ECC) into the upper head. The scaling philosophy followed in the design of the Mod-2A system (modified volume scaling) preserves most of the important first-order effects thought important for small break loss-of-coolant transients.[1]

This report presents a preliminary analysis of data from Semiscale Test S-UT-5, the fifth test conducted in the UT test series. The primary objective of the UT test series is to evaluate the capability of the upper head injection (UHI) system to provide an increased margin against core uncovery in the Semiscale system during small break transients. The test series will investigate transients for 2-1/2%, 5%, and 10% cold leg breaks. For each break size a test is first conducted which does not use UHI but does use loop accumulators pressurized to 2.86 MPa to establish baseline response data. These are followed by similar tests which do employ UHI. Tests results will provide applicable data for use in the assessment of computer codes used to predict the behavior of UHI systems.

Test S-UT-5 was a 2-1/2%, communicative, cold leg break loss-of-coolant experiment performed with upper head accumulator injection. This test provided information on the influence of upper head injection on system transient response which will be evaluated by comparison to a counterpart test (S-UT-4)[2] which was a 2-1/2% break experiment and did not have ECC injected into the upper head. An additional objective of Test S-UT-5 was to provide data concerning the effects of using external loop piping heaters to offset system heat loss to the ambient. Test S-UT-4 was the first experiment in which the heat loss makeup system was used. A previous test (S-UT-3)[3] was conducted to provide baseline data on Mod-2A response during a 2-1/2% cold leg break without compensation for heat loss.

The following sections present a preliminary analysis of Test S-UT-5. Section 2 describes the system hardware, test procedures, and initial conditions. Section 3 presents the results of the test data analysis including a comparison to Test S-UT-4. Section 4 compares the actual system response with the computer code pretest prediction and Section 5 presents conclusions drawn from a preliminary analysis of the data.

2. SYSTEM CONFIGURATION AND TEST CONDUCT

2.1 System Configuration

An isometric of the Semiscale Mod-2A system, as configured for Test S-UT-5, is shown in Figure 1 with major components identified. The break was located in the broken loop cold leg between the pump and the vessel and was communicative in nature. The break assembly and orifice are shown in detail in Figure 2. The break size was 0.0613 cm^2, which is volumetrically scaled to represent 2-1/2% of the area of a cold leg pipe in a PWR. The orifice was designed as bell-mouthed with a length-to-diameter ratio of 3.

Figure 3 is a plan view of the Mod-2A core for Test S-UT-5 showing its orientation with respect to the remainder of the system, the location of unpowered rods, and the distribution of internal cladding thermocouples monitored during the test. Internally heated electric rods are used to simulate the nuclear rods in a PWR. The rods are geometrically similar to nuclear rods with a heated length of 3.66 m and an outside diameter of 1.072 cm. The axial power profile for the rods is illustrated in Figure 4, showing the step cosine shape with a 1.55 peak-to-average power factor. All 23 heated rods were powered equally. The total core power was 2.0 MW which yielded a maximum linear heat generation rate of 36.85 kW/m. The relative locations of in-core instrumentation (gamma densitometers and core inlet drag screen) and grid spacers are indicated in Figure 5.

Figure 6 shows the configuration of the upper head region of the Mod-2A vessel. The internals of the upper head have been designed to simulate the flow paths found in a PWR with UHI capability. Penetrations into the upper head consist of a perforated ECC injection tube, a bypass line from the top of the downcomer, a simulated control rod guide tube, and two simulated support columns.

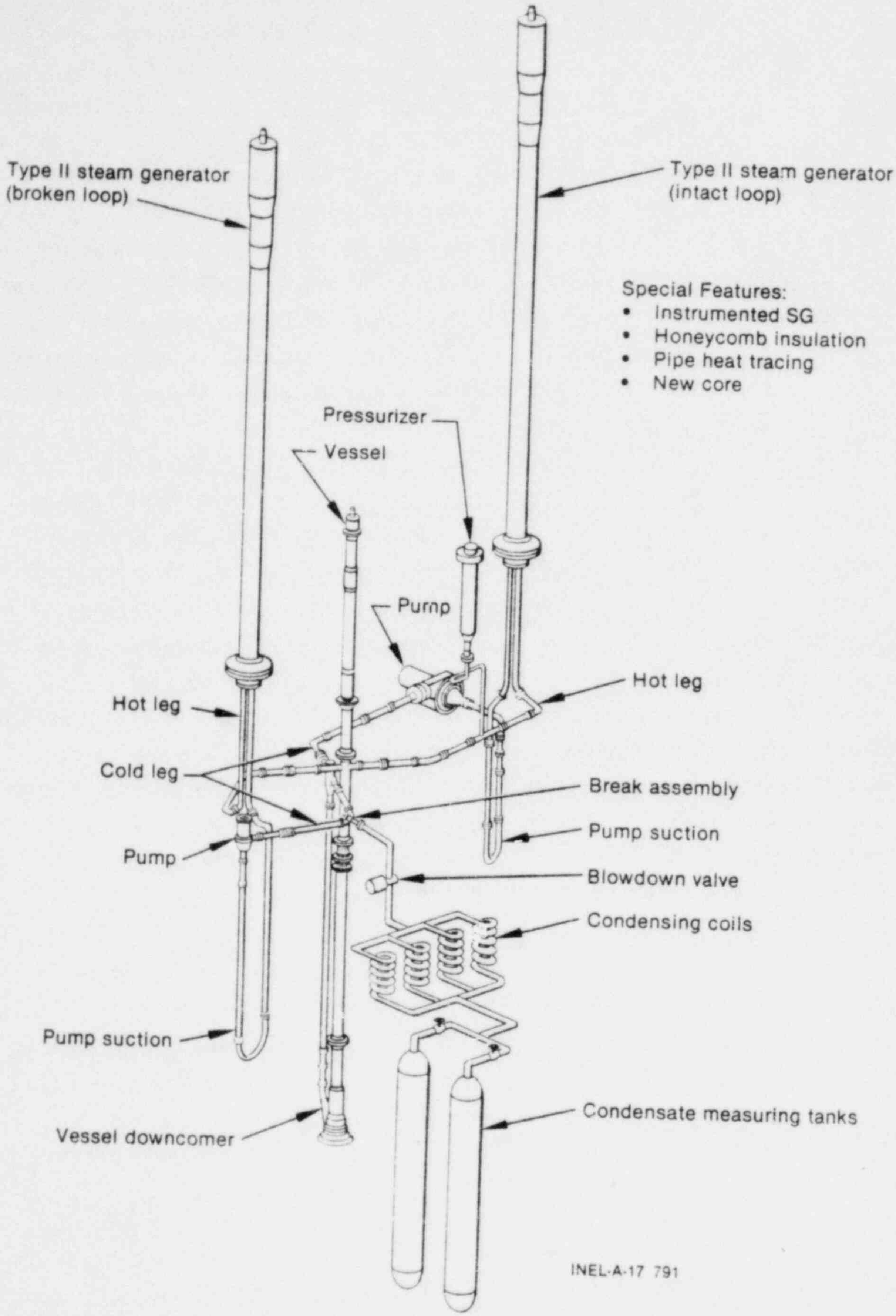


Figure 1. Semiscale Mod-2A system as configured for Test S-UT-5.

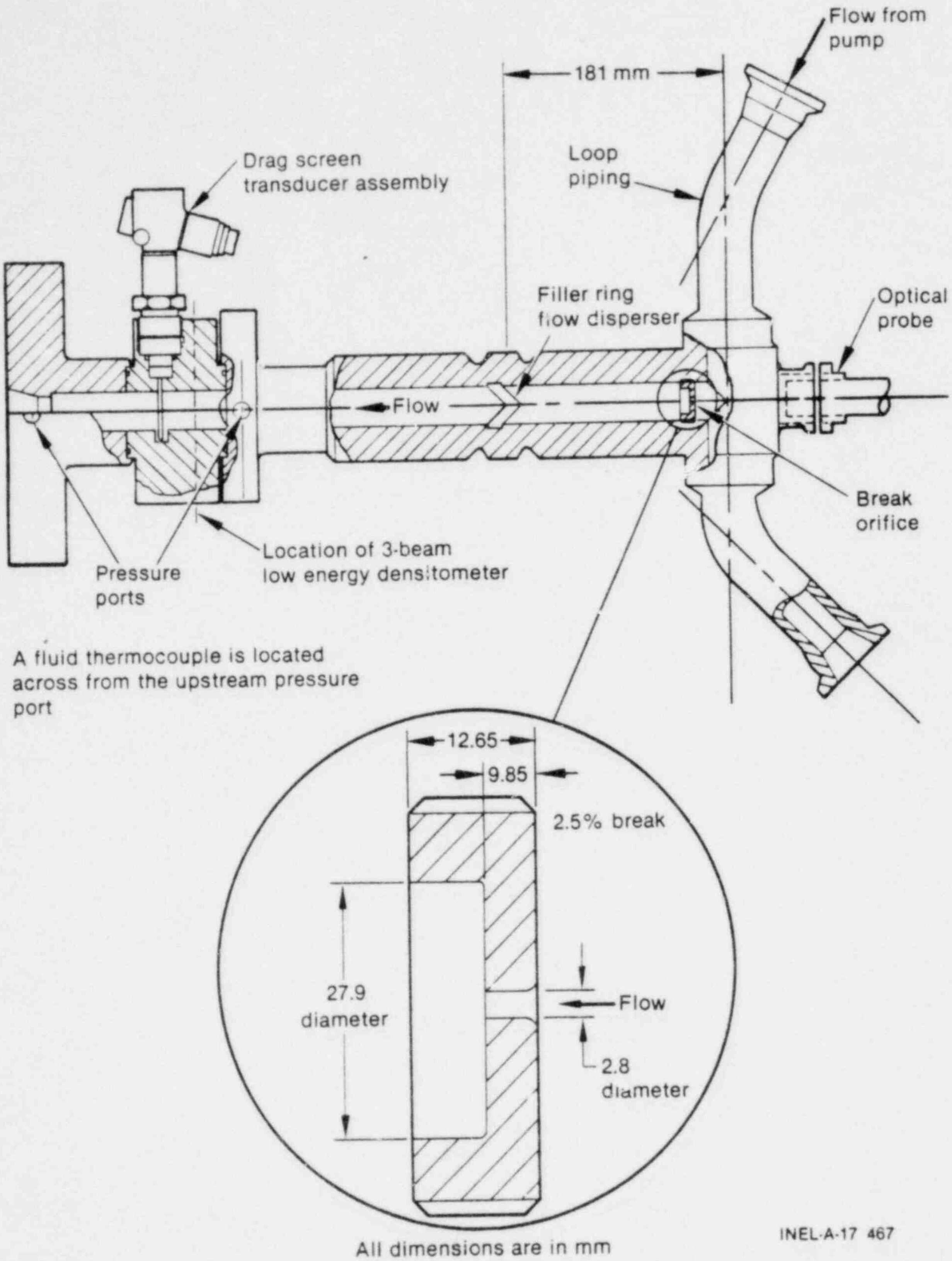


Figure 2. Communicative break assembly and orifice for 2-1/2% break.

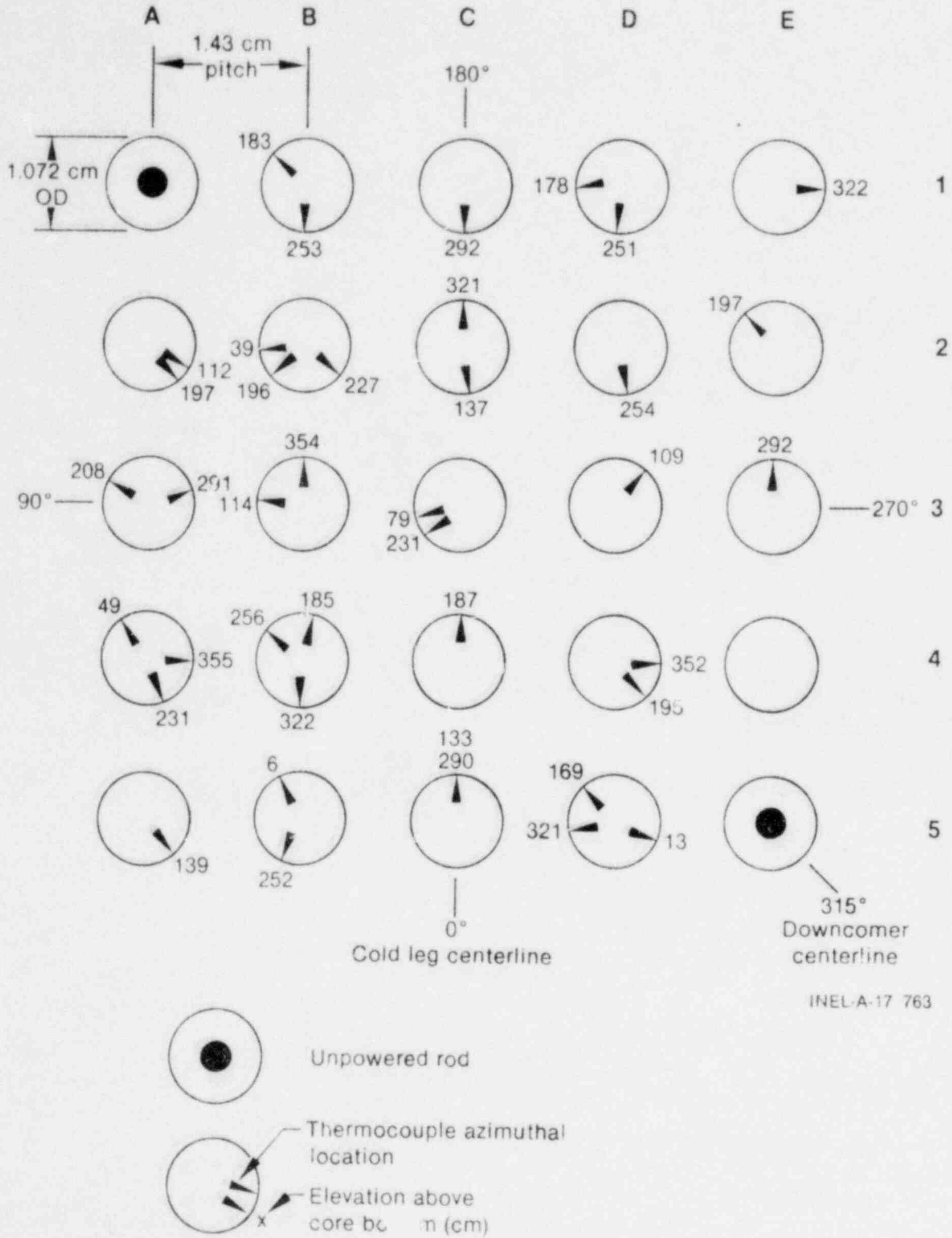


Figure 3. Plan view of the Mod-2A core showing heater rod thermocouple locations for Test S-UT-5.

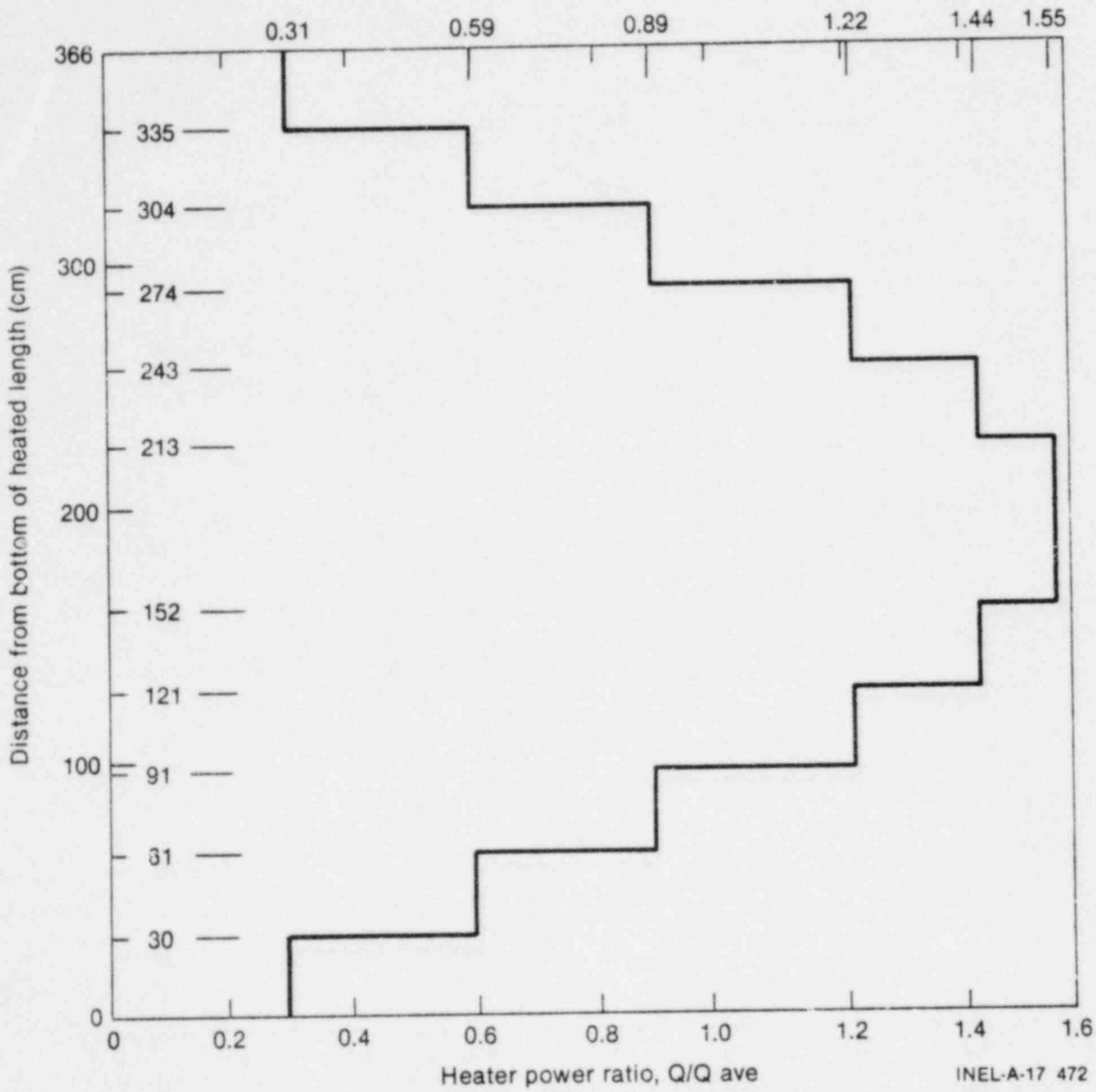


Figure 4. Semiscale Mod-2A heater rod axial power distribution.

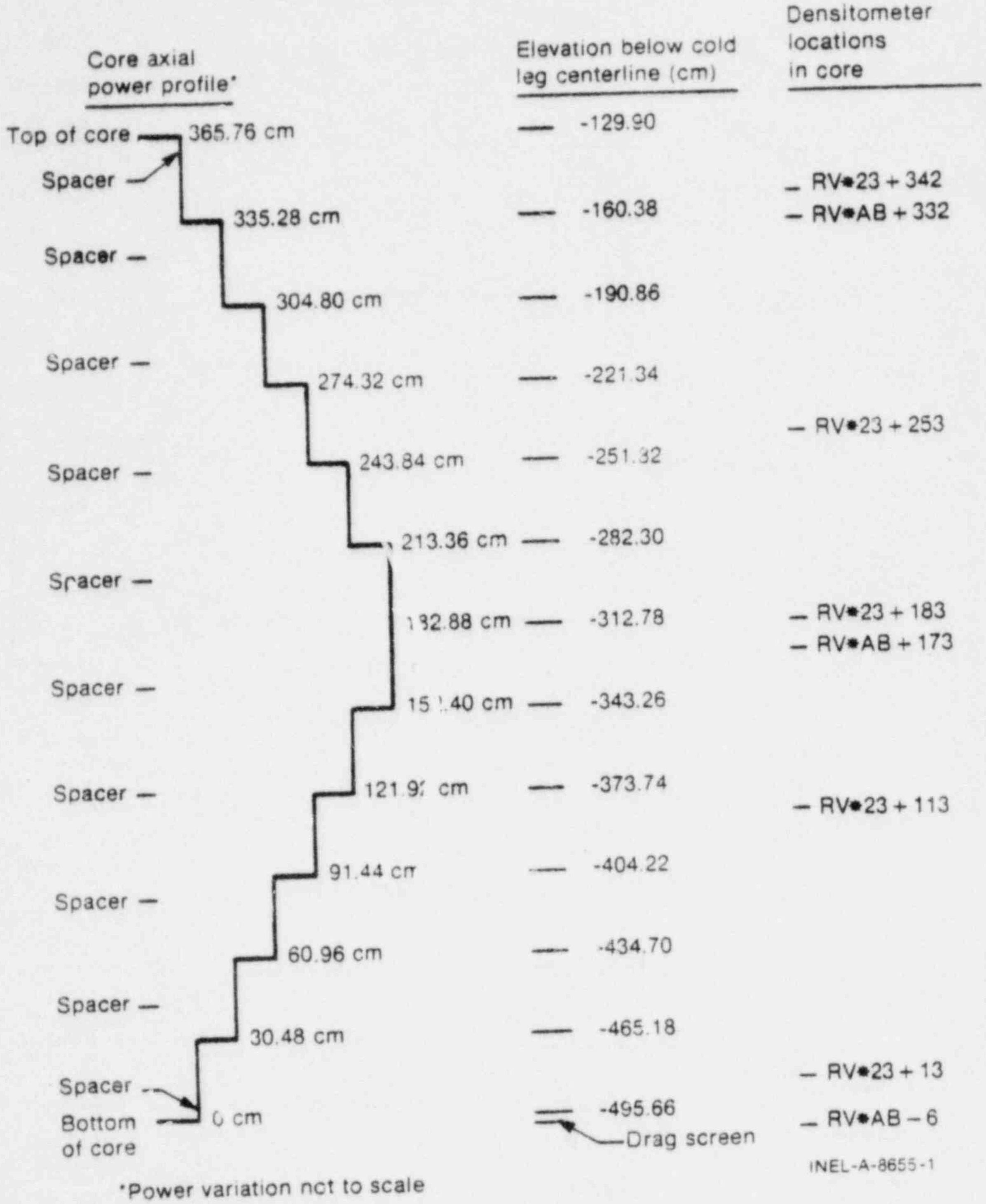


Figure 5. Vessel instrumentation in relation to core axial power profile.

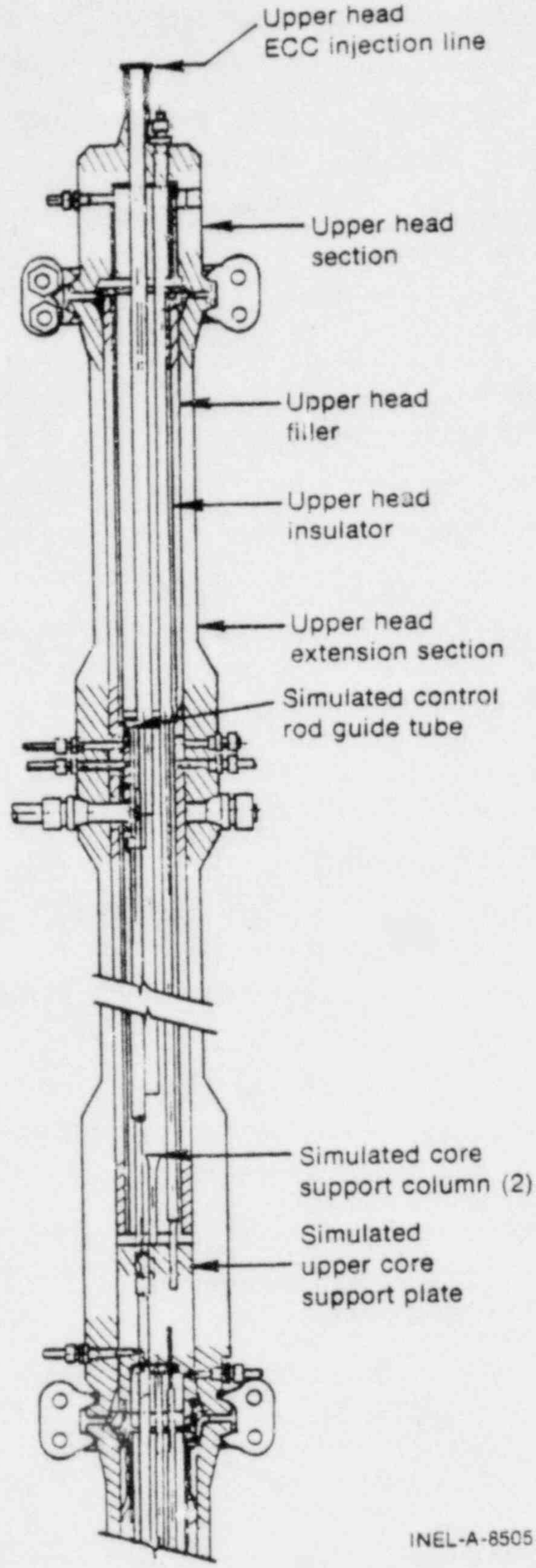


Figure 6. Upper head geometry for the Semiscale Mod-2A vessel.

The heat loss makeup system for the Mod-2A system is composed of numerous heater bands and tapes on the loop piping and five variable power supplies. Heater bands and tape have been installed on the piping where space allowed. The heaters are controlled in five power banks; intact loop hot leg, intact loop cold leg, intact loop pump suction, broken loop hot and cold leg, and broken loop pump suction. The total operating capacity of the system is approximately 51 kW. A more detailed description of the system may be found in Reference 4. A representation of the distribution of heaters may be seen in the computer code system model in the appendix.

The data acquisition system recorded measurements from approximately 275 instruments throughout the system. These measurements include fluid and metal temperatures, pressures, fluid densities, flow rates, liquid levels, and other system parameters. Figure 2 shows the communicative break assembly and one set of instrumentation used to measure break flow. A more detailed description of the Mod-2A system may be found in the Semiscale Mod-2A System Design Description.[4]

2.2 Test Procedures and Conditions

2.2.1 Preblowdown Activities

Prior to the initiation of the test, the Semiscale system was filled with demineralized water and vented to ensure a liquid-full system. Water in the steam generator feedwater tank was heated to the desired temperature. Accumulator water levels were established and the accumulators were pressurized with nitrogen gas to the desired pressure. The accumulators used in this test injected water into the upper head and the intact and broken loop cold legs. Instrumentation was calibrated and zeroed as necessary and a system hydrostatic test was performed.[a] After

a. The measured leak rate for Test S-UT-5 was 0.012 ℓ/s at initial conditions. This is much smaller than the break flow rate during the early portion of the transient. The leak rate generally decreases with system pressure and with increased system voiding.

the necessary protective trip controls and peripherial hardware controls (pumps, valves, etc.) had been set, the system was brought to initial conditions and the required levels were established in the steam generator secondary sides. Power for the external heaters on the loops was brought to specified conditions and the system was allowed to equilibrate.

When initial conditions were within specified tolerances, the test was initiated by opening a blowdown valve downstream of the break orifice to break the system pressure boundary.

2.2.3 Component Controls

Transient core power control and the intact and broken loop pump speed controllers were initiated by a pressure trip 3.4 s after the pressurizer pressure reached 12.9 MPa. Both intact and broken loop steam generator steam valves were sequenced to close when the pressure trip occurred. Both steam generator feedwater valves were sequenced to close 24 s later.[a] The core power curve and pump speed curves are shown in Figures 7 and 8 respectively. More discussion of how the core electric power curve was determined, and how other various component controls were selected, may be found in Reference 5.

The heaters on the intact and broken loop piping were controlled to offset system heat losses to the extent possible. The power to the heaters was determined by analysis of pretest scoping calculations which compared Mod-2A response for various control schemes against an ideal system with no heat losses. Heater band power was controlled on-line according to the data presented in Figure 9. The heaters are initially powered at 48.5 kW which is approximately the maximum system operating limit. Power was

---

a. The Mod-2A steam generators operate with a lower than desired secondary liquid level at initial conditions. Extra feedwater is injected for 24 s to ensure that the tubes are covered for the transient.

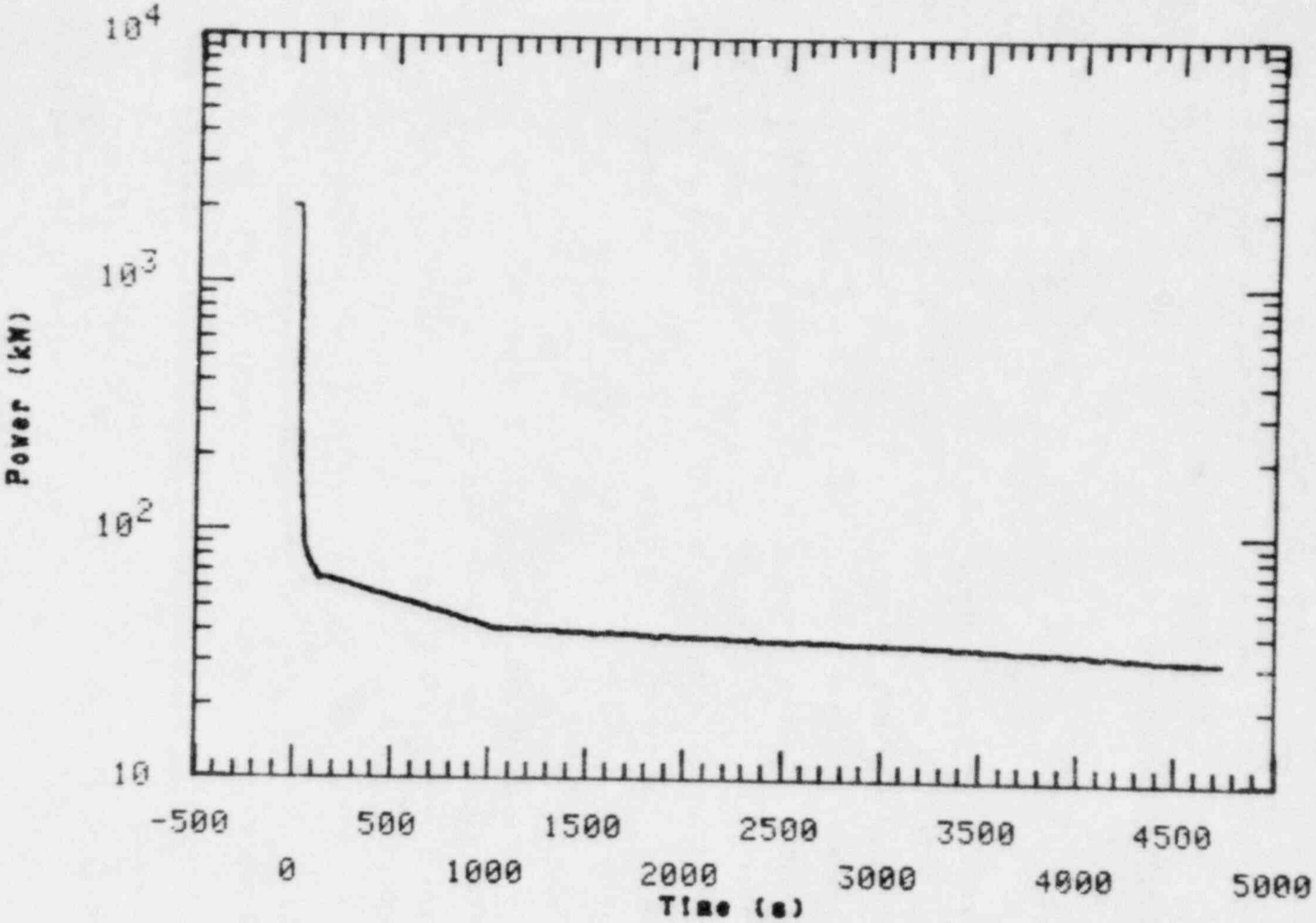


Figure 7. Core power for Test S-UT-5.

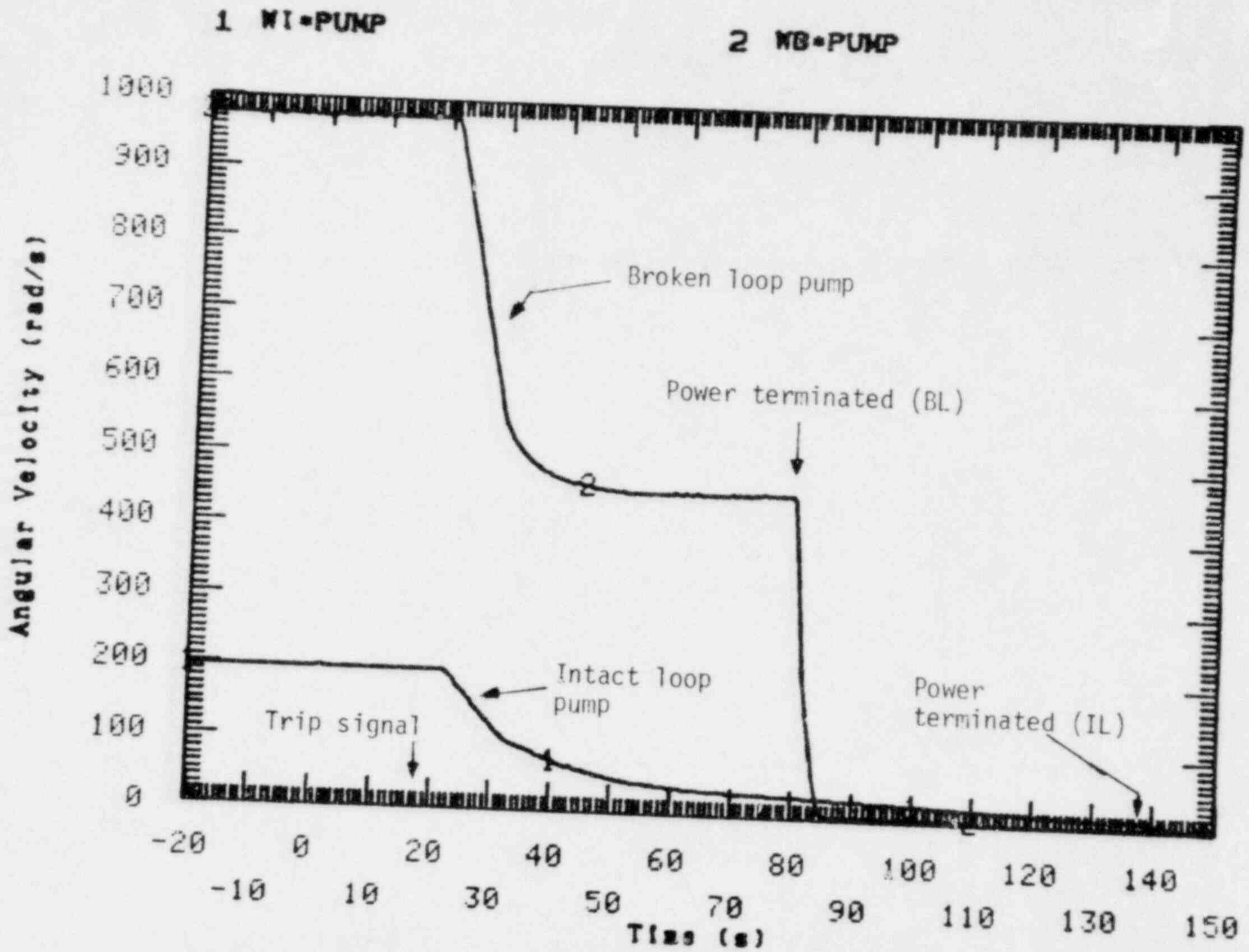


Figure 8. Intact and broken loop pump speed curves for Test S-UT-5.

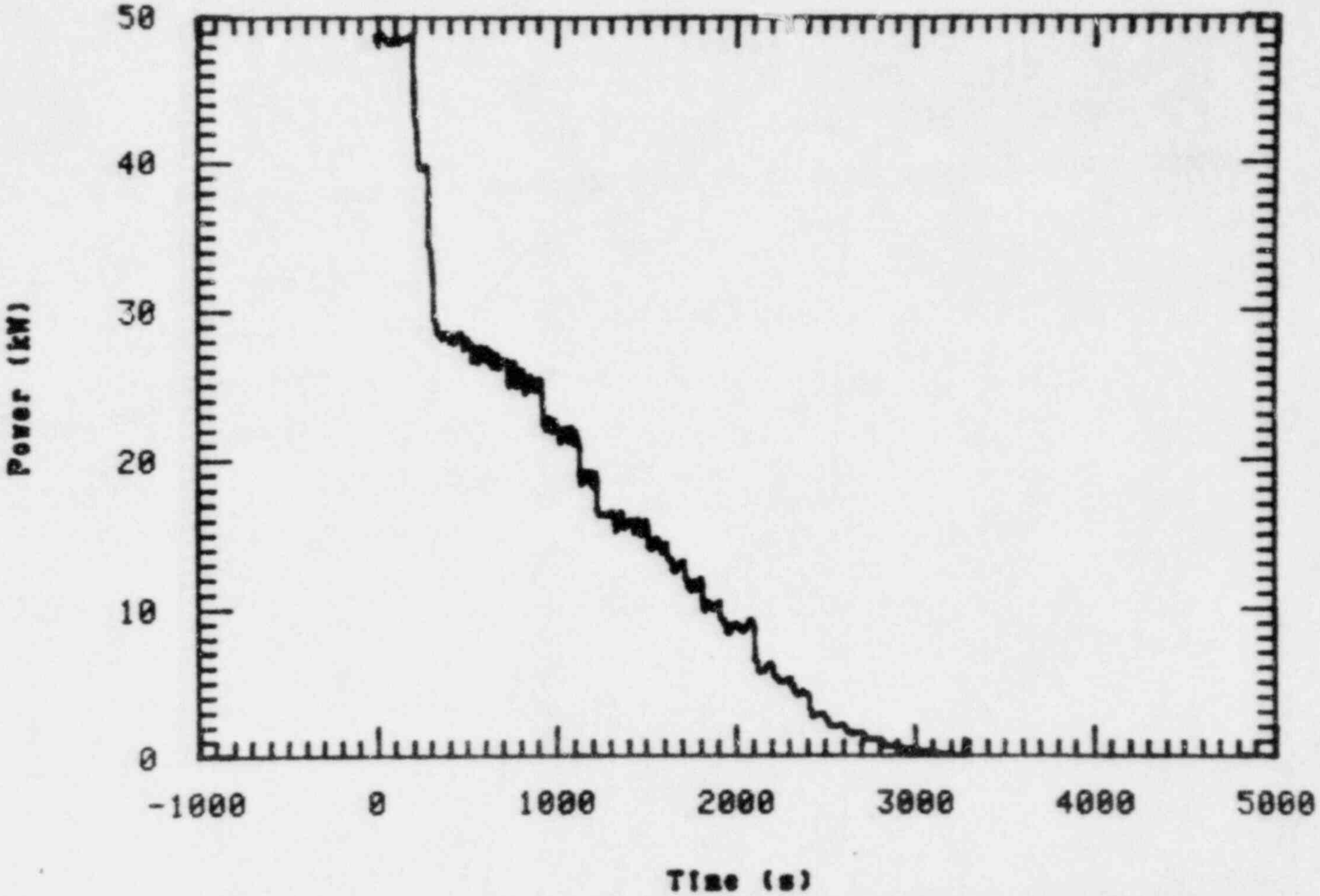


Figure 9. Loop piping heater power for Test S-UT-5.

decreased as the transient proceeded in response to the predicted voiding of the loops and resultant decreased fluid to pipe heat transfer.

The HPIS and LPIS injection rates were controlled on a flow rate versus system pressure basis to simulate the characteristics of a PWR plant. The specifications originally were made assuming one of two ECC and charging pump trains fail resulting in only 78% of the flow from two train operation. However, the broken loop ECC systems were mistakenly not operated in Test S-UT-3 and it was therefore decided to not use broken loop HPIS for Tests S-UT-4 and S-UT-5 in order to facilitate comparison. The intact and broken loop HPIS and LPIS flow rates versus pressure for the test are shown in Figure 10. The LPIS injection rate for the intact loop is simply added to the HPIS flow rate for pressures below 0.98 MPa.

2.2.3 Initial Conditions and ECC Parameters

The specified and actual test conditions for Test S-UT-5 are compared in Table 1. In general, the initial conditions and test parameters were judged as satisfactory to meet the test objectives. One notable difference was the broken loop steam generator secondary side conditions.

At the time of rupture the broken loop steam generator was operating at low pressure and liquid level (4 MPa and 230 cm). The low pressure caused the steam generator to be a greater heat sink than in Test S-UT-4 and to remain a sink until about 700 s versus 500 s in Test S-UT-4. This variance must be taken into account for posttest analysis; however, the major differences in system response between Tests S-UT-4 and S-UT-5 were dominated by phenomena related to the effects of UHI. The test was therefore deemed acceptable for meeting its primary objective of evaluating the effects of UHI.

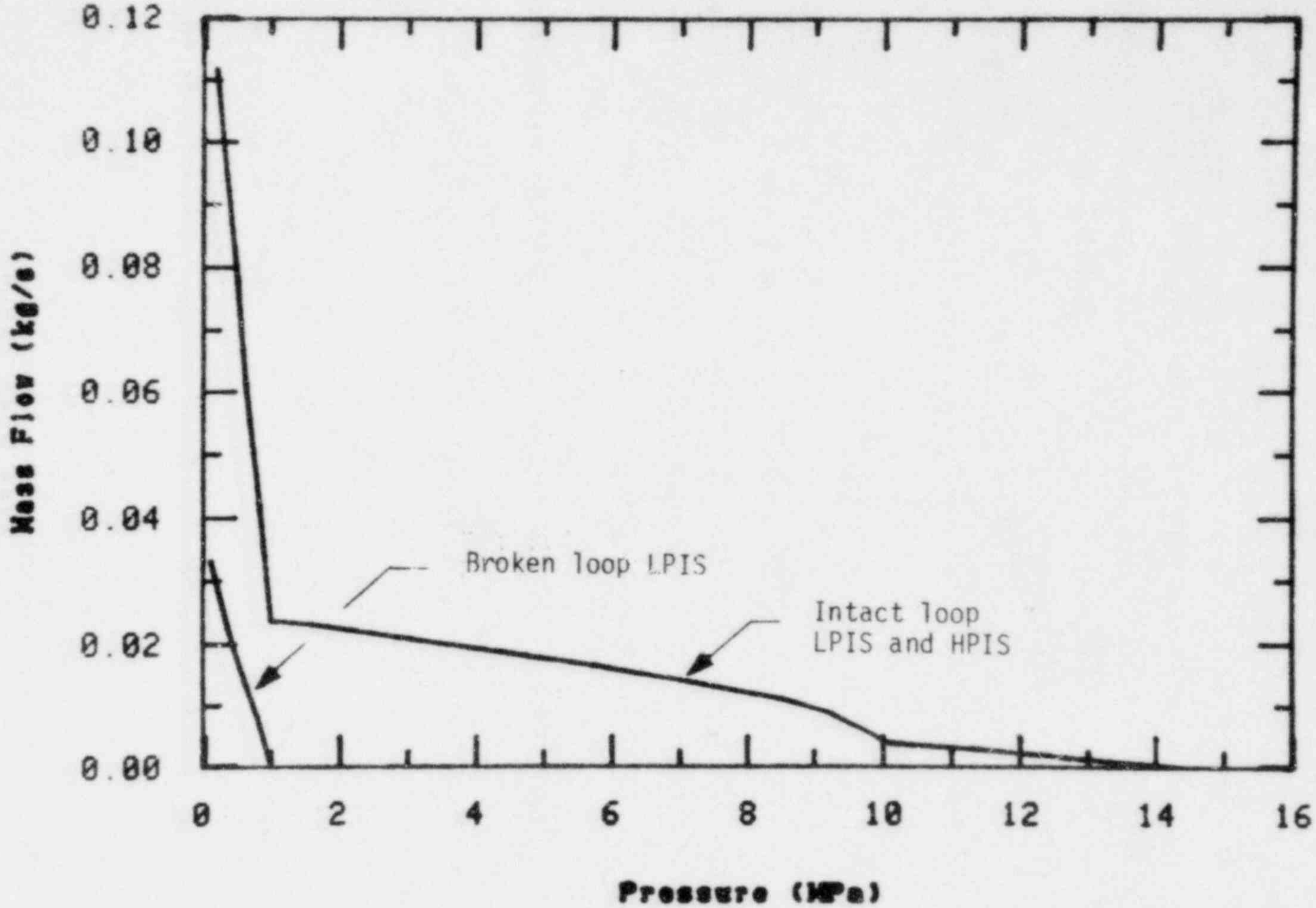


Figure 10. High and low pressure ECC injection system control for intact and broken loops.

TABLE 1. INITIAL CONDITIONS AND ECC REQUIREMENTS FOR TEST S-UT-5

Parameter	Specified Value	Actual Value
Initial Conditions		
Pressurizer pressure	15.5 ± 0.2 MPa	15.8 MPa
Hot leg fluid temperature	594 ± 2 K	595 K
Cold leg fluid temperature	557 ± 2 K	557 K
Total core power	2.0 ± 0.005 MW	2.0 MW
Radial power profile	Flat	
Core inlet flow rate	9.77 kg/s[a]	9.2 kg/s
Pressurizer liquid mass	10.4 ± 0.1 kg	10.3 kg[d]
S.G. secondary pressure	5.9 ± 0.2 MPa[b]	Intact loop 5.74 MPa Broken loop 3.98 MPa
S.G. feedwater temperature	495 ± 2 K	Intact loop 498 K Broken loop 497 K
S.G. steam dome temperature	547 ± 2 K[b]	Intact loop 544 K Broken loop 540 K
S.G. secondary water level		
Intact loop	Footnote b	1036 cm[e]
Broken loop	Footnote b	230 cm[e]
Configuration		
Break size	2.5%	
Break type	Communicative	
Break location	Cold leg	
Pressurizer location	Intact loop	
Pressurizer line resistance	5.9×10^8 m^{-4} [d]	
Upper Head Accumulator		
Actuation pressure	8.6 ±0.1 MPa	8.7 MPa
Liquid volume	0.0299 ± 0.0005 m^3	0.0299 m^3
Nitrogen volume	0.0299 ± 0.0005 m^3	0.0299 m^3
Volume of liquid injected	0.0166 ± 0.0005 m^3	0.0178 m^3
Temperature	300 ± 10 K	335 K
Line resistance	$2.69 \times 10^9 m^{-4}$	
ECC Injection		
Intact loop accumulator		
Actuation pressure	2.9 ± 0.1 MPa	2.95 MPa
Liquid volume	0.048 ± 0.0005 m^3	0.0395 m^3
Nitrogen volume	0.025 ± 0.0005 m^3	0.0335 m^3
Temperature	300 ± 10 K	298 K
Line resistance	8.59×10^8 m^{-4} [d]	

TABLE 1. (continued)

Parameter	Specified Value	Actual Value
Intact loop HPIS		
Actuation pressure	12.6 ± 0.1 MPa	12.9 MPa
Delay	25 ± 0.5 s	25 s
Injection rate	See Figure 10[c]	
Temperature	300 ± 10 K	298 K
Intact loop LPIS		
Actuation pressure	0.98 MPa ± 0.05 MPa	0.98 MPa
Injection rate	See Figure 10	Footnote f
Temperature	300 ± 10 K	298 K
Broken loop accumulator		
Actuation pressure	2.9 ± 0.1 MPa	2.9 MPa
Liquid volume	0.016 ± 0.0005 m^3	0.0134 m^3
Nitrogen volume	0.0083 ± 0.0005 m^3	0.0109 m^3
Temperature	300 ± 10 K	303 K
Line resistance	7.73 x 10^9 m^{-4} [d]	
Broken loop HPIS	Not used	Not used
Broken loop LPIS		
Actuation pressure	0.98 ± 0.05 MPa	0.98 MPa
Injection rate	see Figure 10	Footnote f
Temperature	300 ± 10 K	298 K

a. Approximate value; flow is adjusted to achieve required core ΔT.

b. Secondary side conditions will be adjusted to obtain required primary side temperature and ΔT.

c. Figure 10 shows the sum of the scaled flow rates for charging and safety injection pumps.

d. These values are determined by pretest calibrations or through use of process instrumentation.

e. The reported level is the height of hot water above the top of the tube sheets after the feedwater flow had stopped (24 s after the pressurizer pressure reached 12.9 MPa). The intact loop feedwater flow averaged 0.8[illegible] kg/s and the broken loop feedwater flow averaged 0.2[illegible] kg/s.

f. The test was terminated prior to reaching the LPIS setpoint.

3. TEST RESULTS

The following sections present a preliminary analysis of the results obtained from Test S-UT-5 data. First a discussion of general system behavior is given, followed by more detailed analyses of factors which influenced the response. Evaluation of the influence of upper head accumulator injection on system response was the primary objective of this test. It is evaluated by comparison to Test S-UT-4[2] which was conducted from similar initial conditions but without UHI in order to establish baseline response data for a 2-1/2% break.

3.1 General System Behavior

Table 2 presents a sequence of events, derived from test data, highlighting the important operations and thermal-hydraulic events which occurred. System response was characterized by a continuous depressurization and a voiding from the upper elevations downward. Vessel fluid inventory remained sufficient to provide adequate cooling of the core heater rods at all times during the transient and no temperature excursions were observed. The formation of liquid seals in the pump suction piping had little effect on the core liquid level. A slow boiloff of fluid in the vessel/downcomer began after the suctions had blown out[a] (at about 400 to 600 s), reaching a minimum prior to loop accumulator injection at 1277 s. The latter portion of the transient was characterized by a slow filling of the vessel and continuous depressurization. The injection of UHI liquid from 30 to 445 s caused a more rapid depressurization than was observed in Test S-UT-4 but had little effect on overall system behavior, relative to that observed in S-UT-4.

---

a. Pump suction liquid seal behavior is generally characterized by a depression of the downflow leg level to the bottom of the suction, a rapid "blowout" of about half the liqud in the upflow leg which first provides a steam flow path, followed by a long "clearing out" of the remaining liquid.

TABLE 2. SEQUENCE OF EVENTS FOR TEST S-UT-5

Event	Time (s)
Blowdown initiated	0
Pressurizer pressure = 12.9 MPa	16.6
Intact and broken loop main steam valves begin to close	16.6
Core power decay initiated	19.5
Intact and broken loop pump coastdown initiated	20.2
Upper plenum fluid saturates	21
Upper head accumulator injection begins	31.6
Entire system saturated	35
Intact and broken loop main feed-water valves begin to close	40.6
HPIS initiated	41.6
Pressurizer and surge line empty	46
Power to broken loop pump terminated	80
Broken loop pump stops	85
Power to intact loop pump terminated	143
Intact loop pump stops	144
Upper head drained	330
Upper head accumulator injection ends	450
Intact loop pump suction downflow leg clears out and break uncovers	450
Intact loop accumulator injection begins	1277
Broken loop accumulator injection begins	1362

TABLE 2. (continued)

Event	Time (s)
Broken loop pump suction downflow leg clears out	1630
Broken loop pump suction partially refills	3160
Broken loop accumulator liquid injection ends	3134
Intact loop accumulator liquid injection ends	4224
Test terminated	4800

3.2 Pressure Response

The vessel upper plenum pressures for Tests S-UT-5 and S-UT-4 are compared in Figure 11. The timing of events which influenced the system depressurization in S-UT-5 are also indicated in the figure. After the initiation of the transient, the pressure drop was very rapid until 35 s when fluid in the entire system became saturated at about the initial cold leg temperature. The saturation of the system fluid is shown in Figure 12, which compares the system saturation temperature to the hot leg (core outlet) and cold leg temperatures. Bulk flashing of the fluid is sufficient to slow the system pressure decrease because the break is covered with high density fluid.

The primary pressure is compared to the secondary pressures in Figure 13 for both tests. As discussed in Section 2.2.3 the broken loop secondary side conditions were substantially different between the two tests. The broken loop steam generators remained a heat sink for an additional 200 s in Test S-UT-5. While this certainly had some impact on system response it will be noted in Sections 3.3 and 3.6 that the main reason for the differences in depressurizations was the influence of UHI liquid on break conditions. Figure 11 shows that the system depressurized faster in Test S-UT-5 from 100 to 450 s which was the period of upper head accumulator injection. The clearing of the vessel upper head at about 350 s in Test S-UT-5 caused a sharp drop in the system pressure resulting in the greatest divergence between the two pressures. Once UHI had terminated and the loop pump suction seals had cleared the two pressures converge. This resulted from the system mass inventories and distributions being nearly identical for the two tests for the period after 600 s. The steam generation rates in the core were therefore similar for both tests, which governed the depressurization.

The initiation of loop accumulator injection (approximately 2.86 MPa system pressure) again slows the depressurization, as can be seen in Figure 11. This occurs because of a partial refilling of the core with

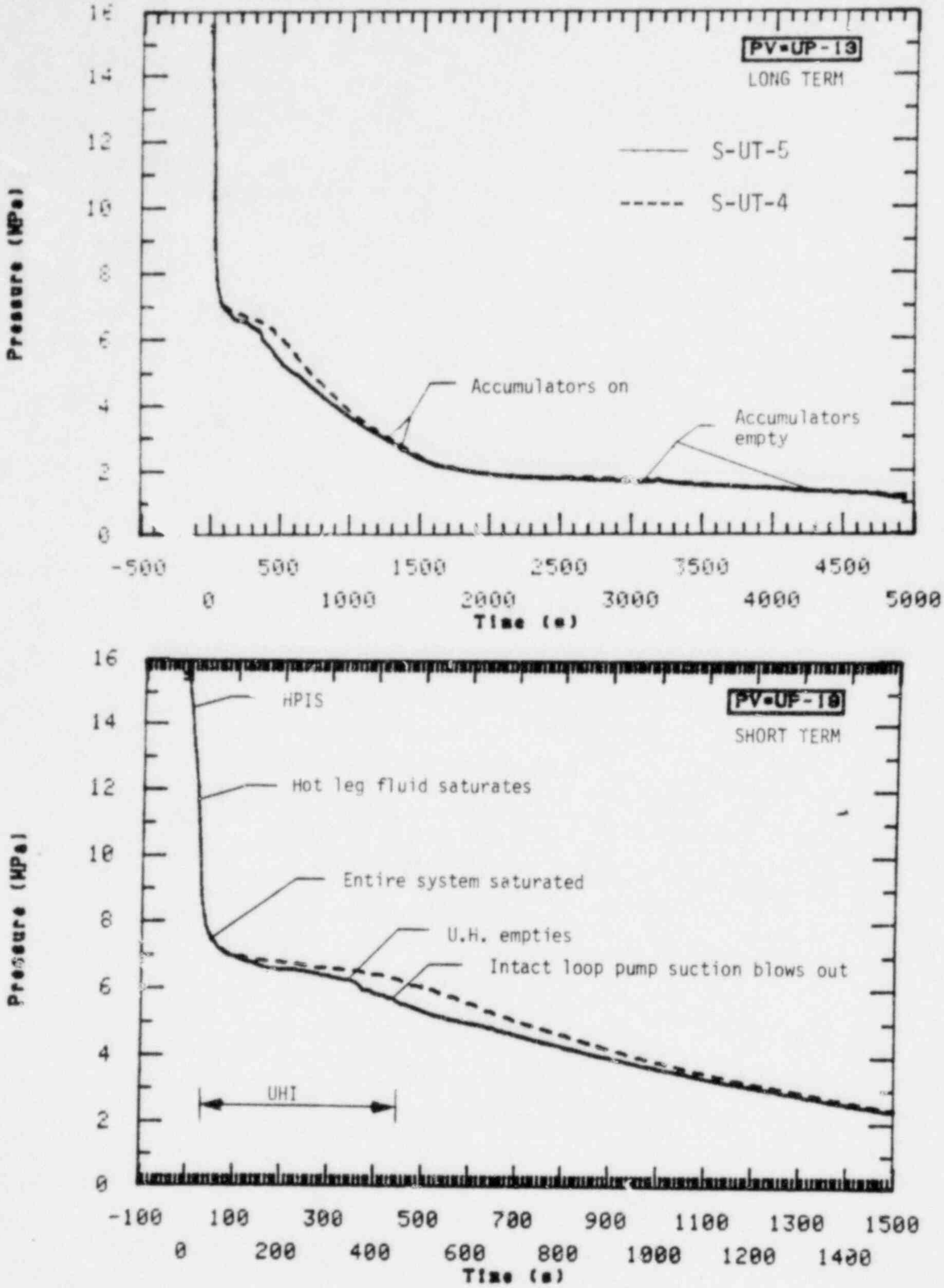


Figure 11. Comparison of system pressures for Tests S-UT-4 and S-UT-5. Events indicated are for Test S-UT-5.

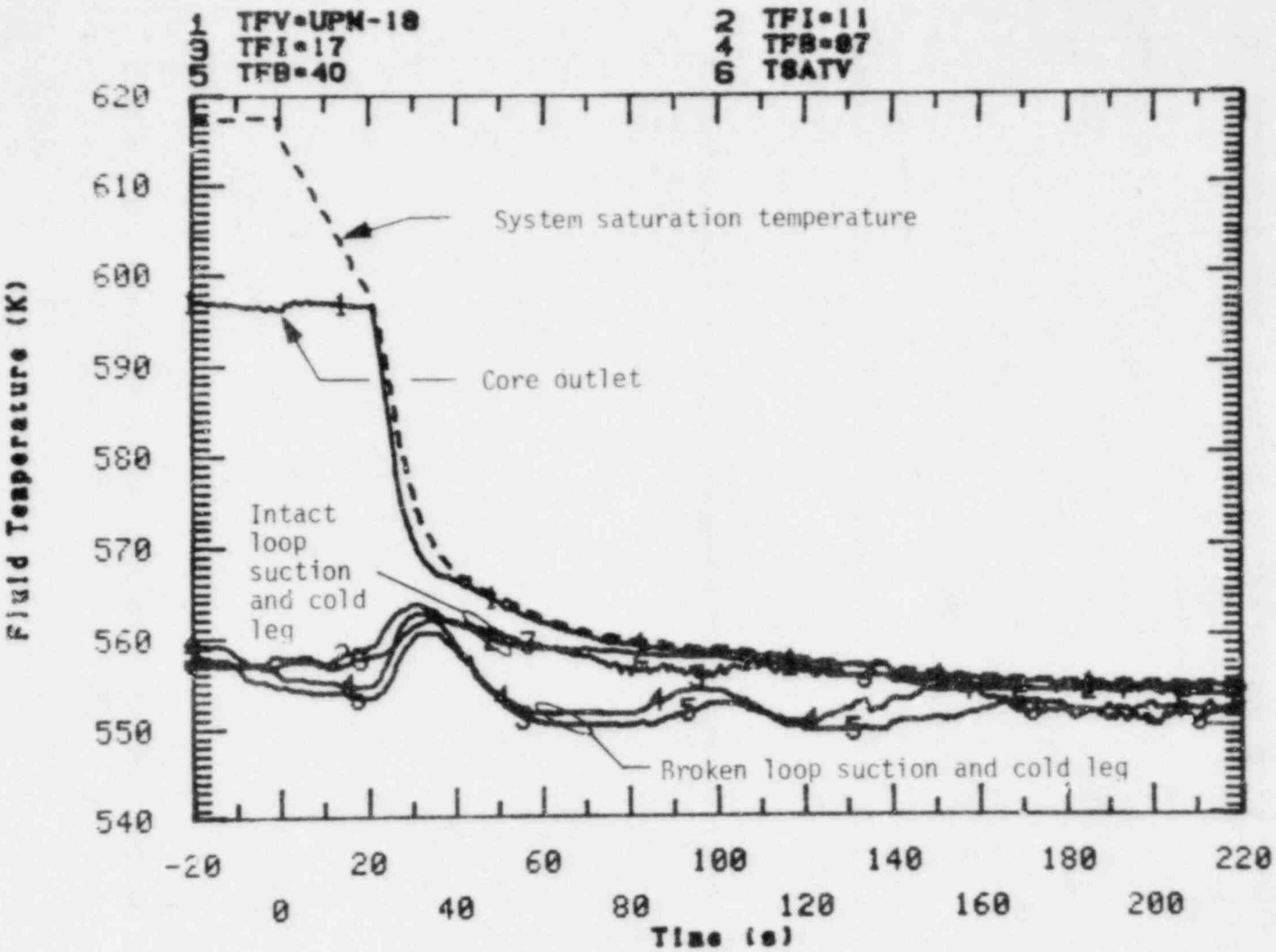


Figure 12. Comparison of selected system fluid temperatures to saturation temperature.

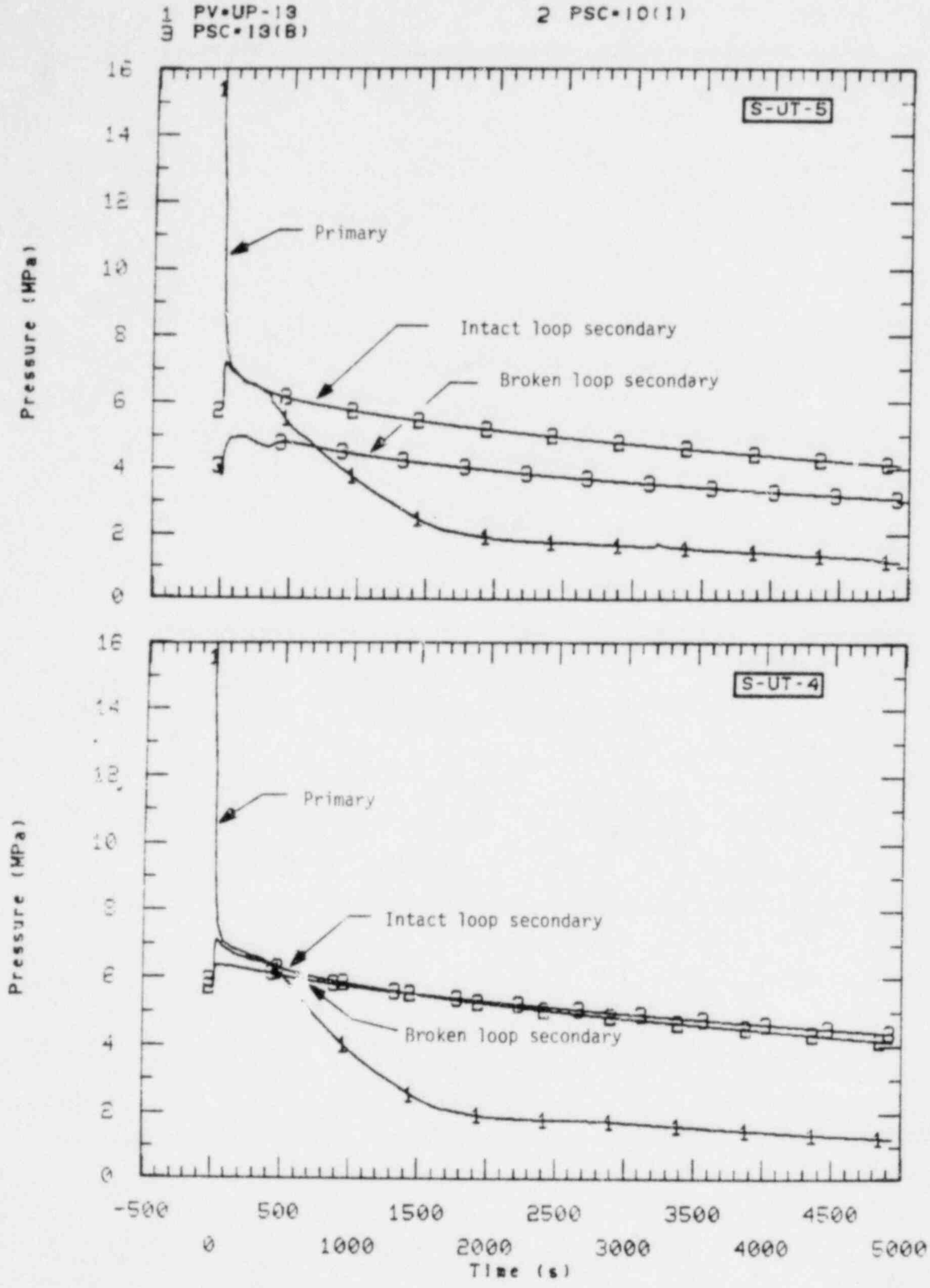


Figure 13. Comparison of primary and secondary side pressures for Tests S-UT-4 and S-UT-5.

accumulator liquid and the resultant increased steam generation. By the time the accumulators have emptied of liquid at 3600 and 4200 s the break flow is on the order of the HPIS flow as seen in Figure 14 and the depressurization continues at only a slightly faster rate.

While Test S-UT-5 was terminated at 4943 s, Test S-UT-4 was continued out to 7000 s to verify that the system would depressurize to the LPIS setpoint without core uncovery. This was found to be the case, with the pressure decreasing at a rate on the order of 19.5 kPa per 100 s and reaching the LPIS setpoint of 1 MPa at 5830 s. By 7000 s the pressure had decreased to 0.8 MPa and conditions appeared to be very stable. Since system conditions were nearly identical between the two tests after 1500 s, the results from Test S-UT-4 are directly applicable to Test S-UT-5.

3.3 Break Flow

As indicated in Figure 1, a break flow condensing and catch tank system was used to measure total flow out the break during Test S-UT-5. This section presents preliminary break flow rates as calculated from the catch tank measurements along with a brief discussion of break conditions during the transient.

Figure 15 compares the mass flow rates out the break for Tests S-UT-4 and S-UT-5. These were calculated by differentiating the liquid level (differential pressure) measurements in the catch tanks. The initial large break flow spike was not measured accurately because of the time lag of the system; however, all the break effluent did go into the catch tanks. After about 200 s, the break flows were nearly steady and the catch tank measurement is considered to be a good indication of the break flows.

The break flow is characterized as follows. A large mass flow of subcooled fluid existed until 35 s when the cold leg becomes saturated. A period of relatively high mass flow (saturated high density fluid) continued until 350 to 450 s when the break uncovered. When the break

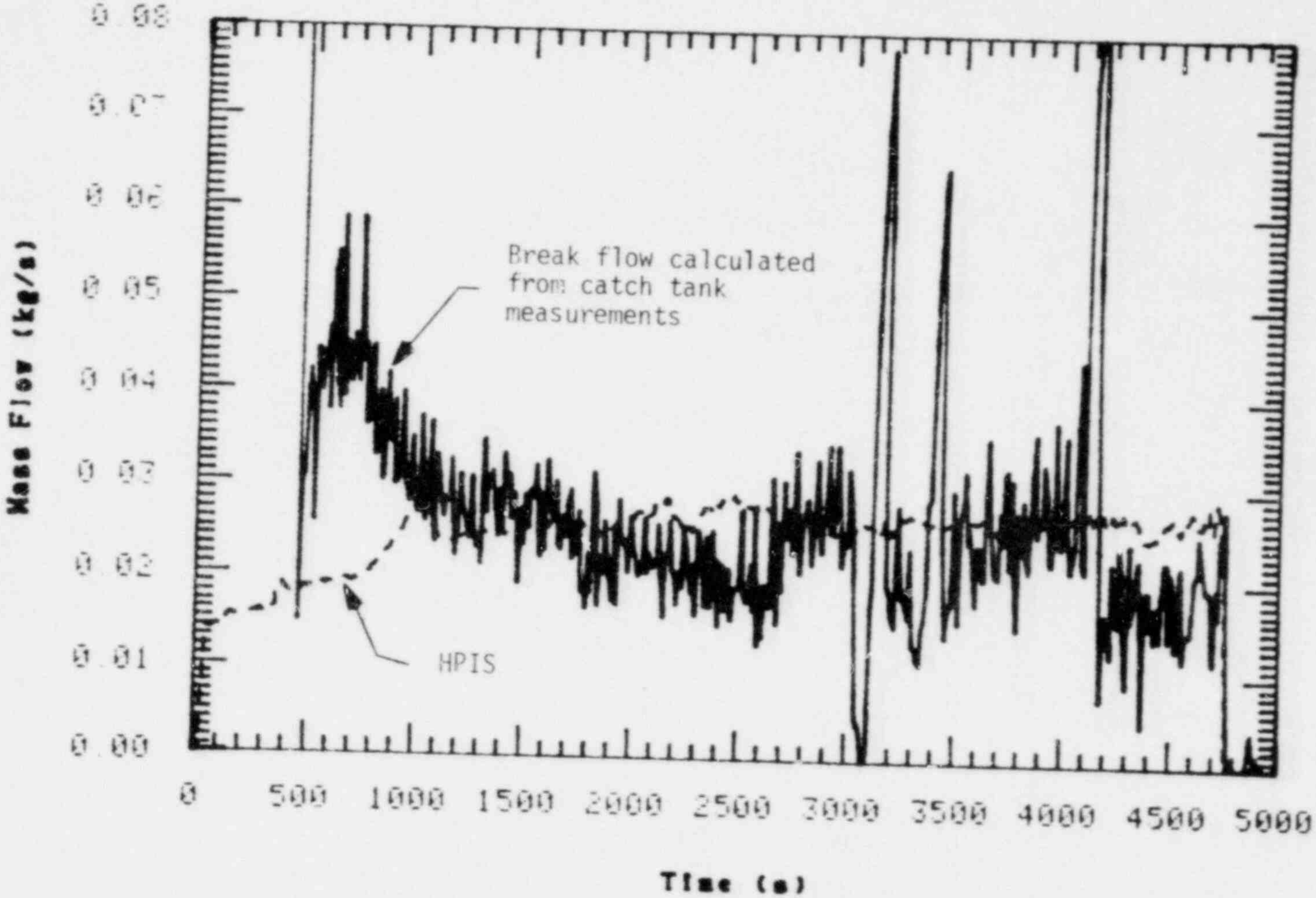


Figure 14. Comparison of break flow rate to HPIS flow rate for Test S-UT-5.

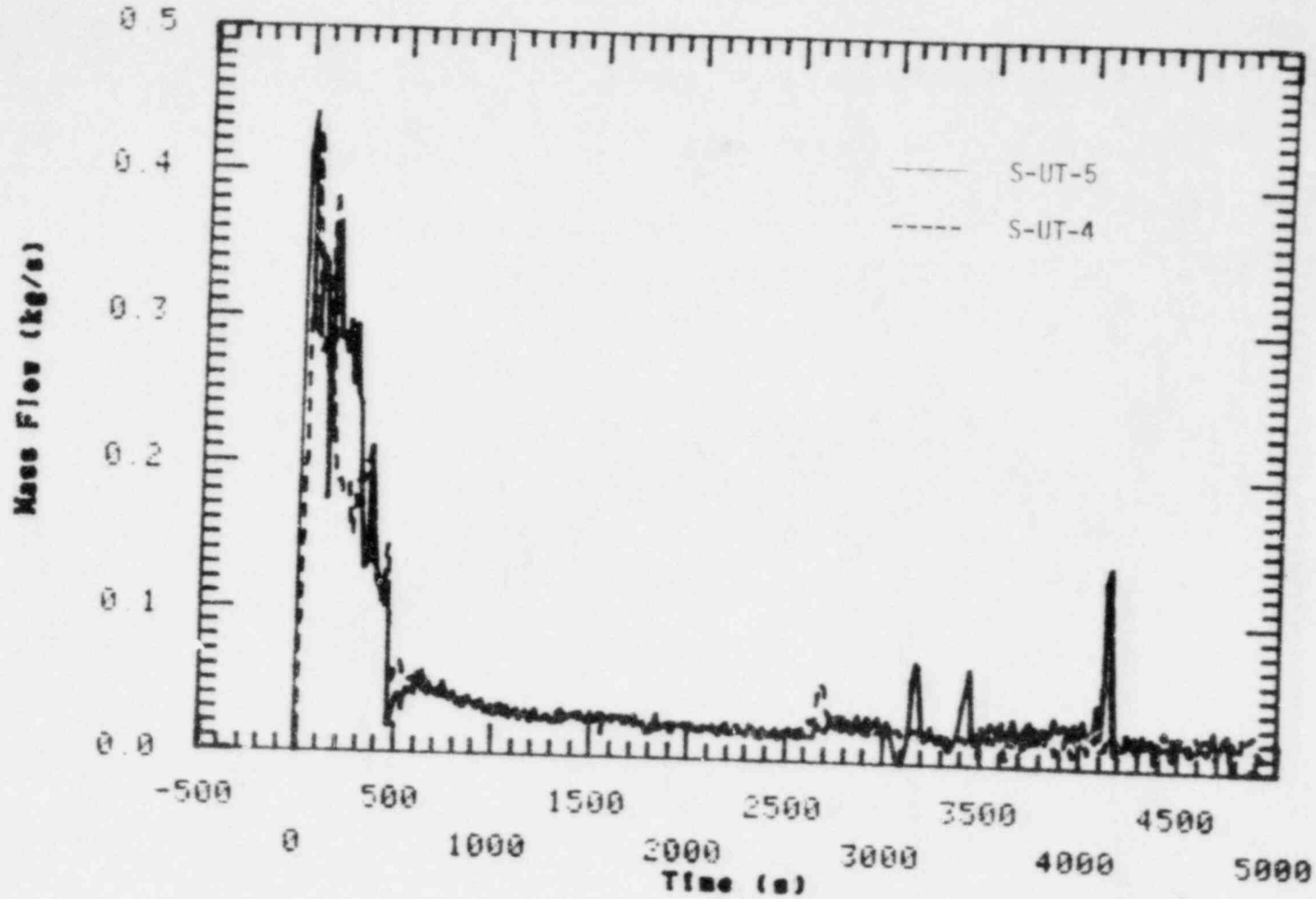


Figure 15. Comparison of break flows for Tests S-UT-4 and S-UT-5.

uncovered, there was a sharp decrease in mass flow, but an increase in energy flow, causing system pressure to drop at a faster rate. Figures 16 and 17 shows the fluid density measurements in the two spool pieces upstream of the break orifice. The density shots show that the piping upstream of the break remained predominantly full of liquid until the intact loop pump suction blew out at about 370 s.

The difference in the break flow rates in Figure 15 is illustrated more clearly in Figure 18 which compares the integrated break flow rates for the first 600 s. It is seen from this figure that the difference in break flow corresponds almost exactly with the amount of UHI liquid injected into the system (17.8 ℓ). The analysis in Section 3.6 will show that it was apparently the case that nearly all of the UHI liquid injected exited the vessel upper head through the bypass line to the downcomer and cold legs. The increased energy removal through the break was the reason for the more rapid depressurization in Test S-UT-5 as discussed in Section 3.2.

The curves in Figure 14 showed that after 1600 s the break flow rate was on the order of the HPIS injection rate. The slow depressurization during this period resulted in very slow accumulator injection rates, averaging about 25 mℓ/s. The slow injection therefore did not result in a large rise in the liquid level in the cold leg. For most of the remainder of the transient the density measurements, as well as video tapes of the break orifice taken through a Storz lens, showed that a small layer of liquid remained in the bottom of the pipe upstream of the break. The break flow was predominantly steam with some apparent entrainment of droplets off the surface of the liquid.

3.4 Loop Hydraulic Response and Void Distribution

The first 300 s of the transient was characterized by the voiding of the upper elevations of the system with liquid collecting in the lower elevations. Figure 19 shows the collapsed liquid levels in the downflow side of the intact loop steam generator tubes and outlet piping for

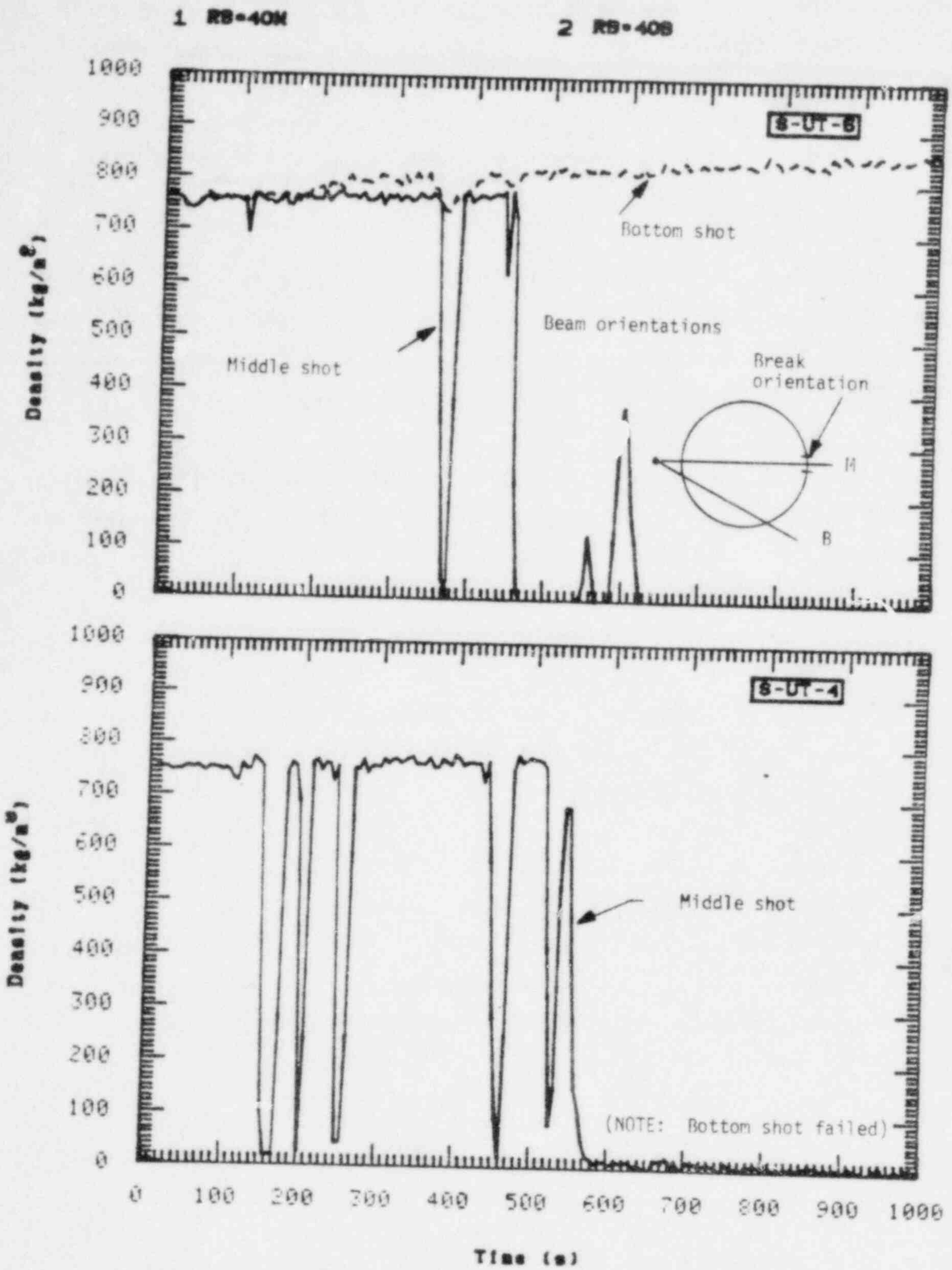


Figure 16. Comparison of fluid densities upstream of the break in spool piece 40 for Tests S-UT-4 and S-UT-5. (Refer to Figure 1 for location relative to break).

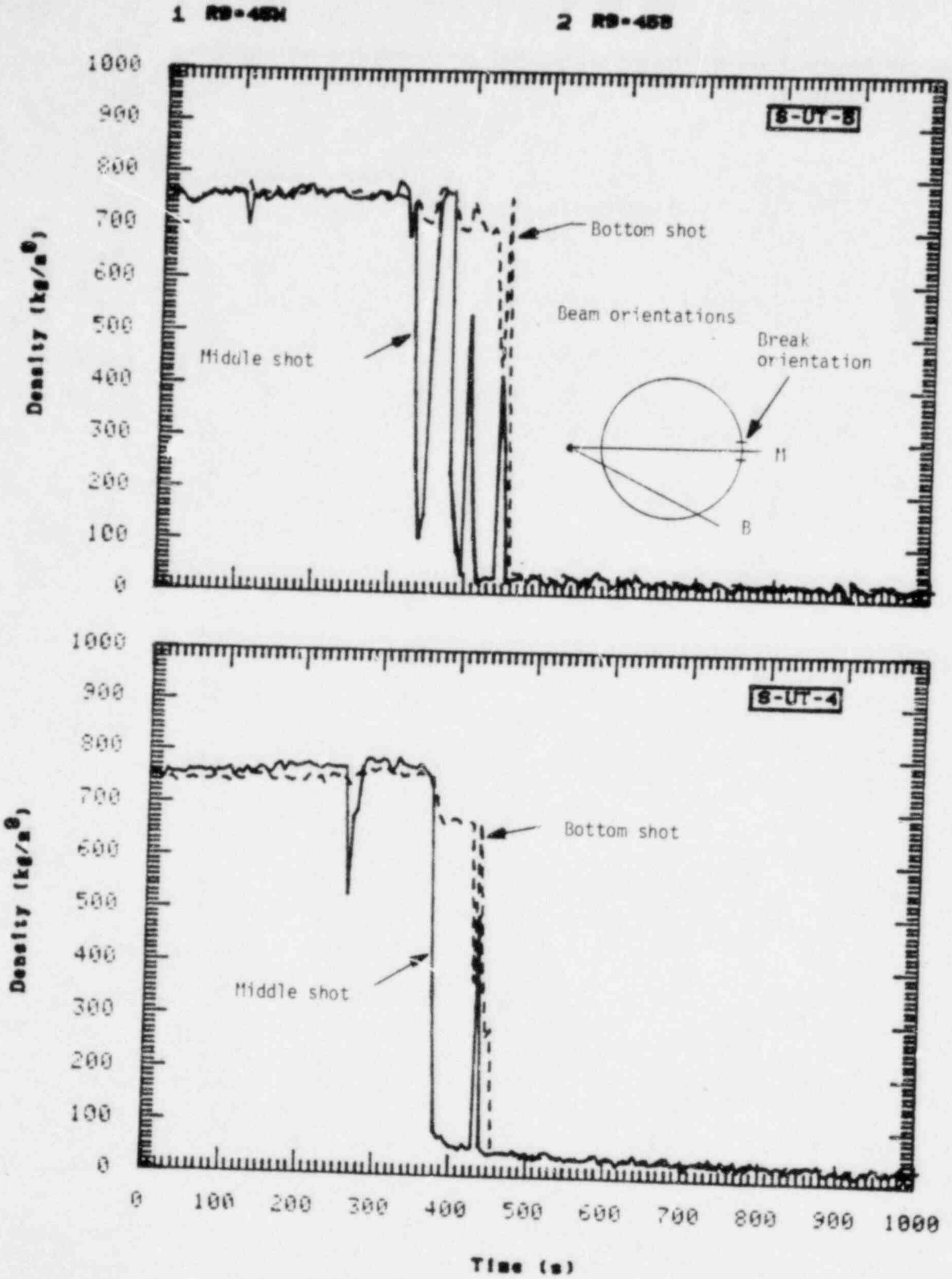


Figure 17. Comparison of fluid densities upstream of the break in spool piece 45 for Tests S-UT-4 and S-UT-5. (Refer to Figure 1 for location relative to break.)

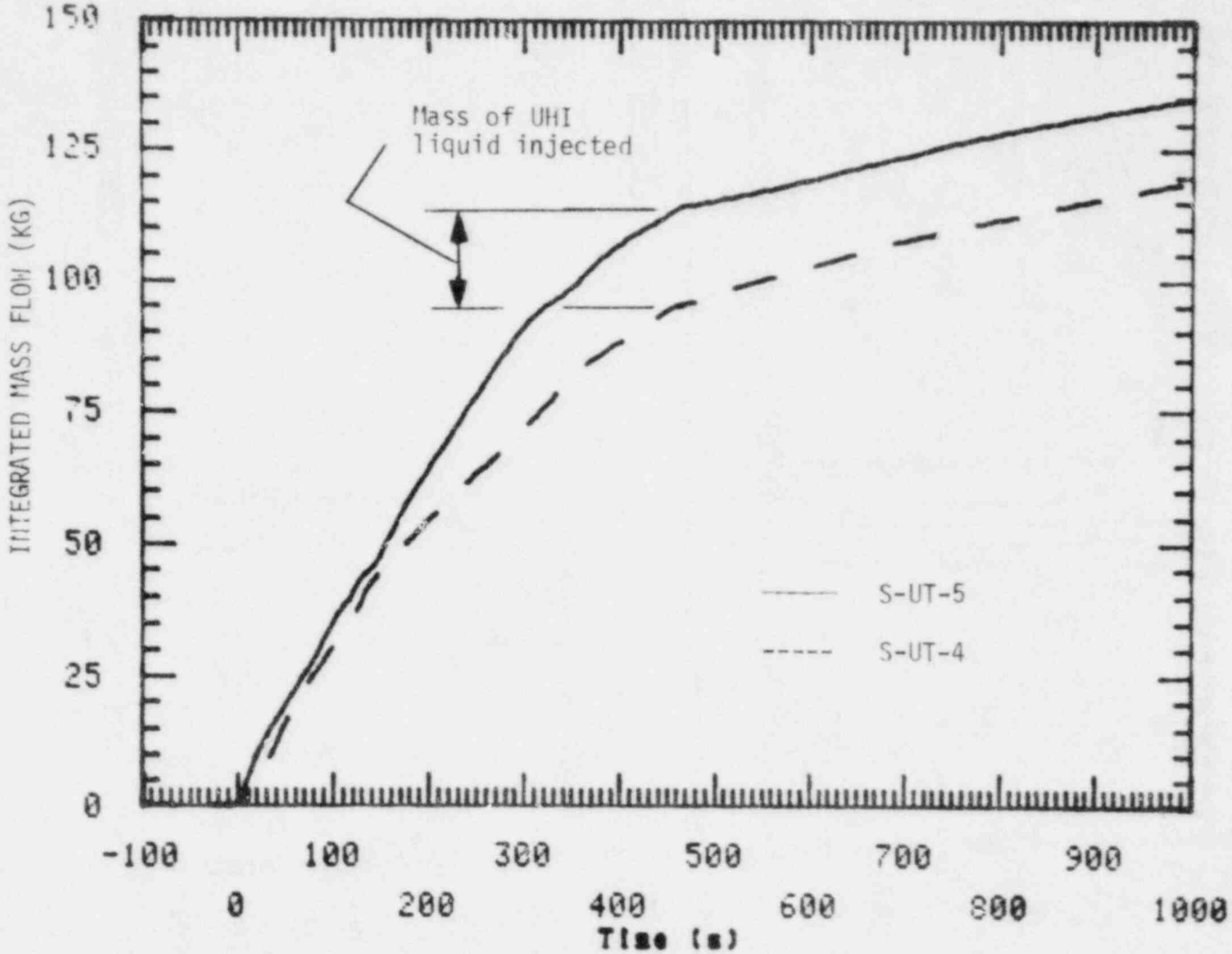


Figure 18. Integrated break mass flows for Tests S-UT-4 and S-UT-5.

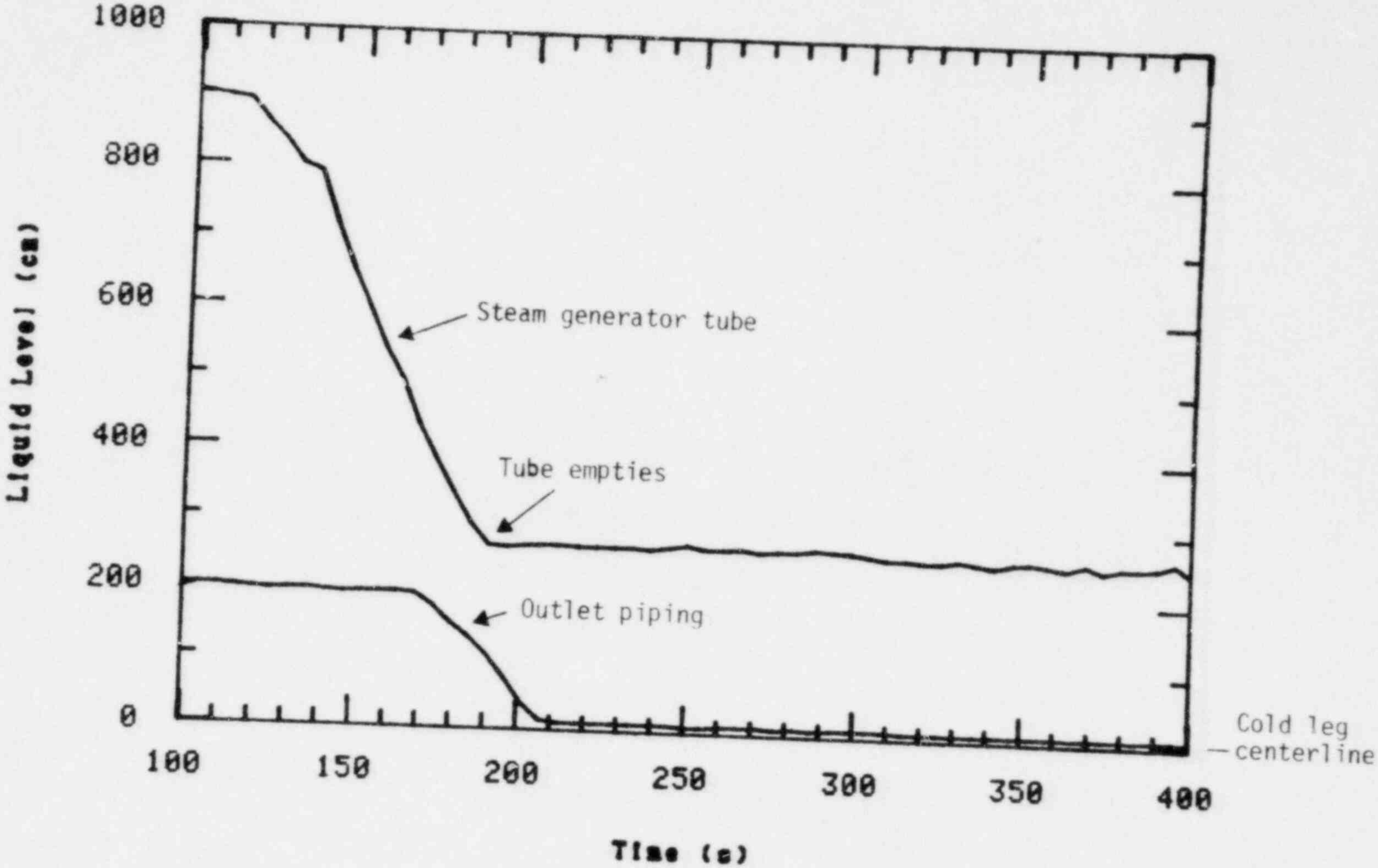


Figure 19. Collapsed liquid levels in the downflow side of the intact loop steam generator and outlet piping.

Test S-UT-5. Figure 20 shows the liquid level in the upflow side of the intact loop steam generator tubes and inlet piping. Comparison of Figures 19 and 20 shows that liquid drained down both sides of the inverted U-tubes into the hot leg and the pump suctio. The liquid level reached the hot leg elevation by about 210 to 235 s. Figure 21 shows the broken loop steam generator upflow side and outlet piping liquid level. Comparison with Figure 20 shows that the broken loop steam generator drained more slowly than the intact loop steam generator and was not voided down to the hot leg elevation until 615 s. Instrumentation showing liquid level in the broken loop steam generator downflow side failed, but the measurement in the downflow outleg piping indicates that the liquid level had dropped down out of the steam generator by 500 s, and by 570 s the liquid level reached the cold leg elevation.

Figures 22 and 23, respectively, show the liquid levels in the intact and broken loop pump suctions for Test S-UT-4 and S-UT-5. Liquid in the pump suction piping formed a seal which impeded steam flow around the loops, causing a back pressure in the core region and a slight depression of the core liquid level (discussed in Section 3.5). At 435 s the intact loop pump suction cleared enough to provide a steam path around the loop. The pressure equilization allowed the core liquid to rise. With the establishment of a relief path through the intact loop, the driving force to clear the broken loop pump suction was diminished. As a result, the broken loop suction did not completely clear until 2800 s. The behavior of the pump suction seals is not greatly influenced by UHI because the injection rate from the upper head accumulator (on the average of 43 mℓ/s) is small compared to both the break flow rate and the rate at which liquid is displaced from the suctions.

The intact and broken loop accumulators began injecting water into the cold legs at 1277 and 1362 s respectively. This water flowed into the downcomer and began filling the core region and downcomer. The system filled enough to have high density fluid in the intact loop hot leg by 1450 s, and in the broken loop hot leg by 1800 s. Some liquid also

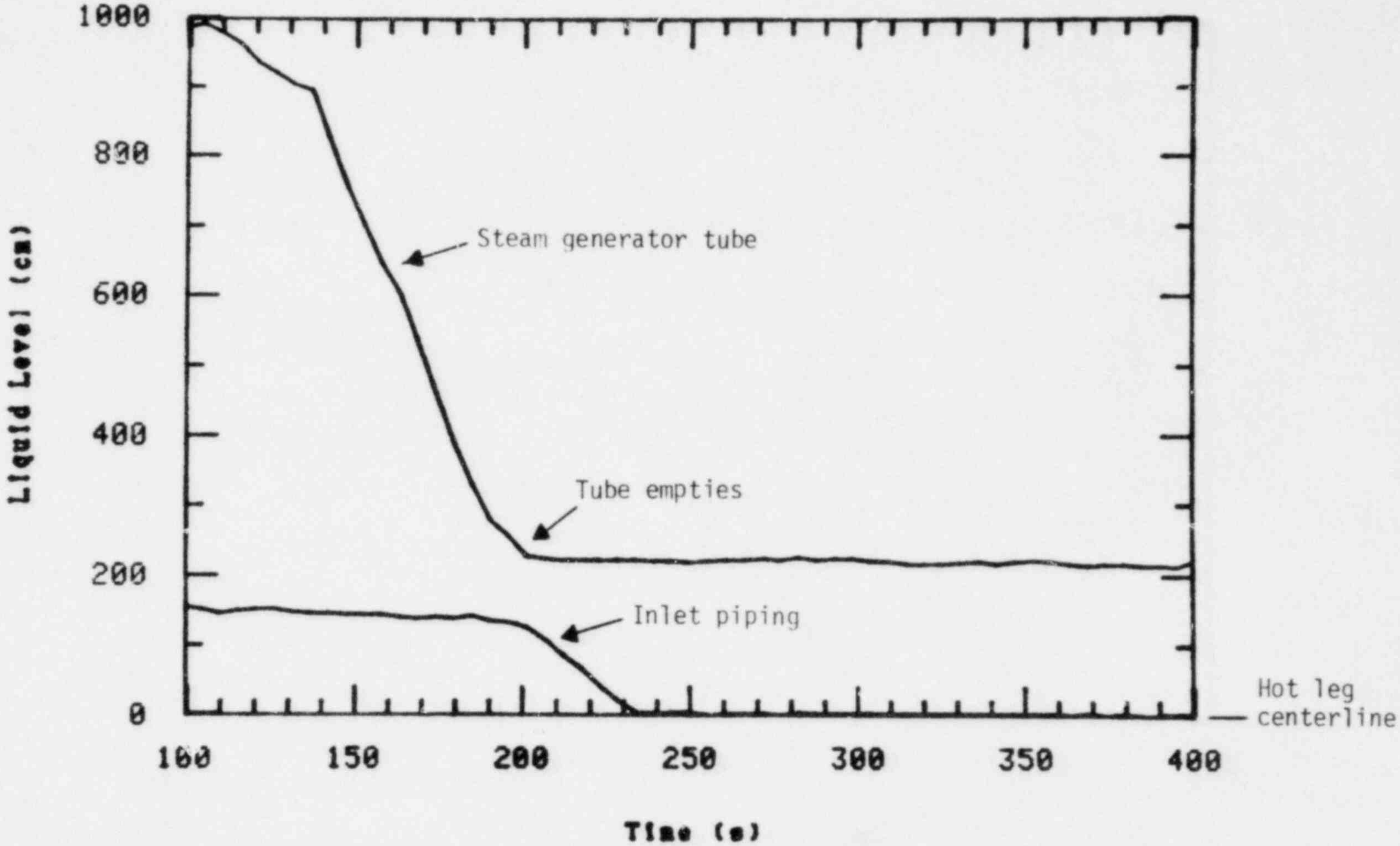


Figure 20. Collapsed liquid levels in the upflow side of the intact loop steam generator and inlet piping.

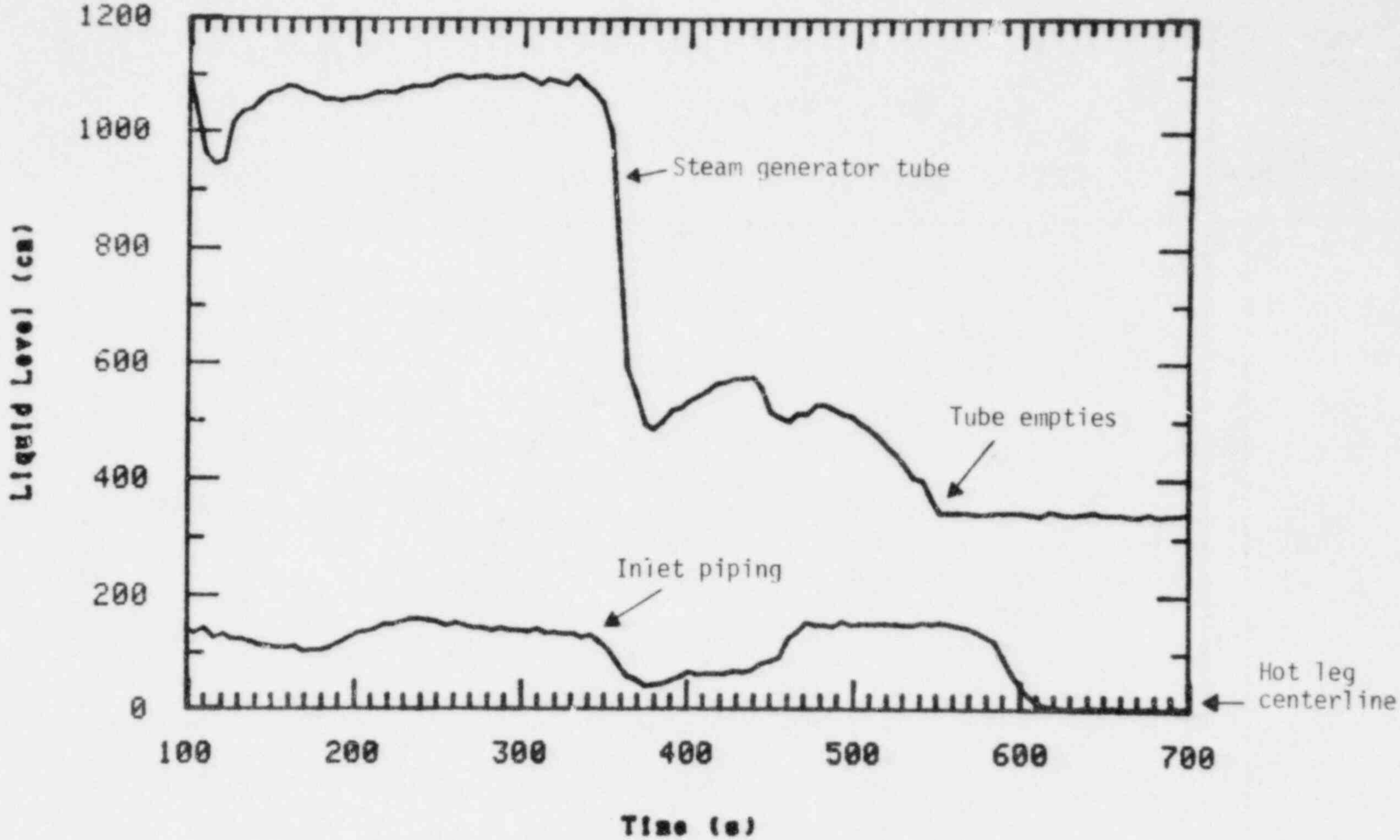


Figure 21. Collapsed liquid level in the upflow side of the broken loop steam generator and inlet piping.

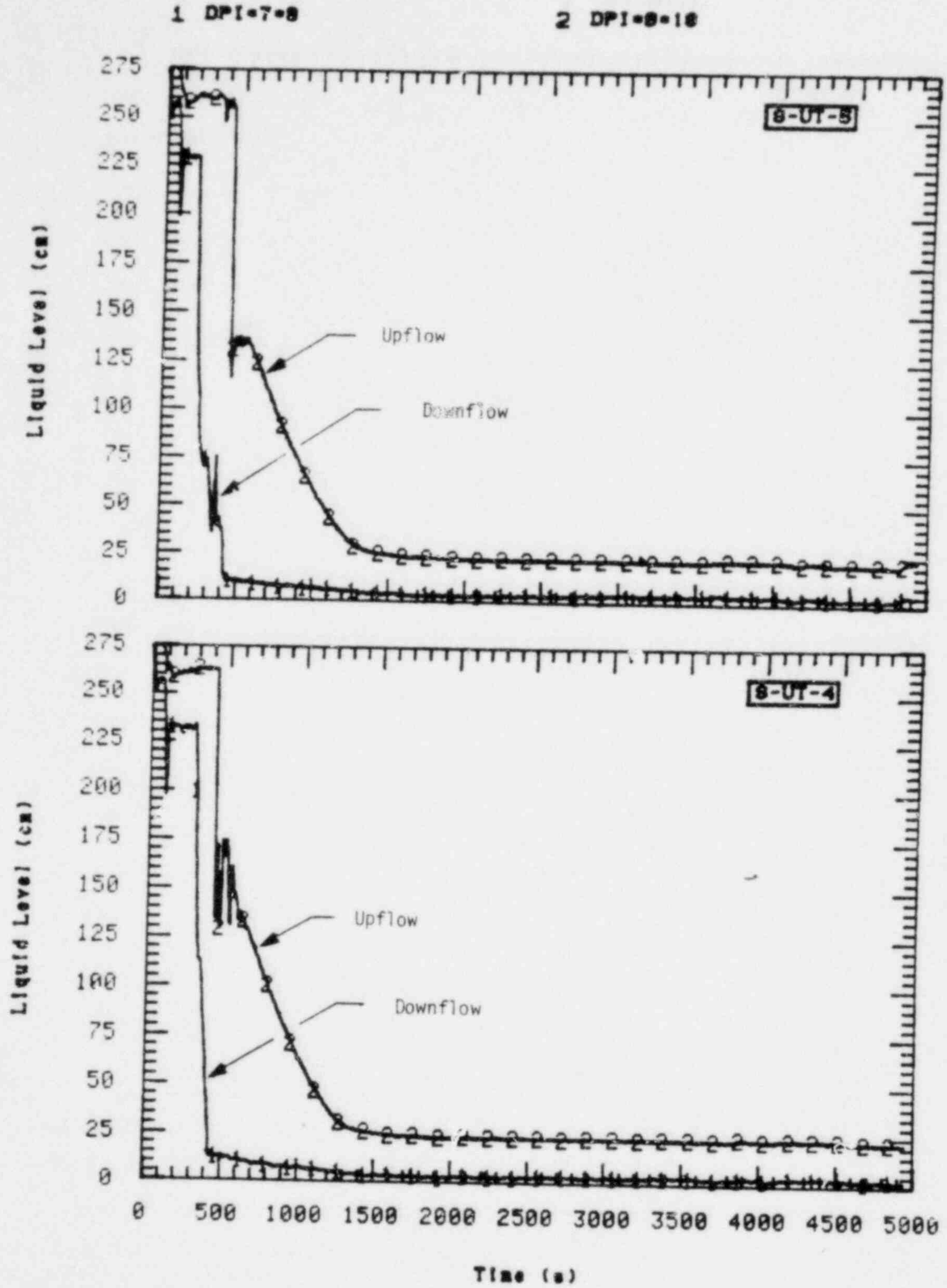


Figure 22. Comparison of liquid levels in the intact loop pump suction for Tests S-UT-4 and S-UT-5.

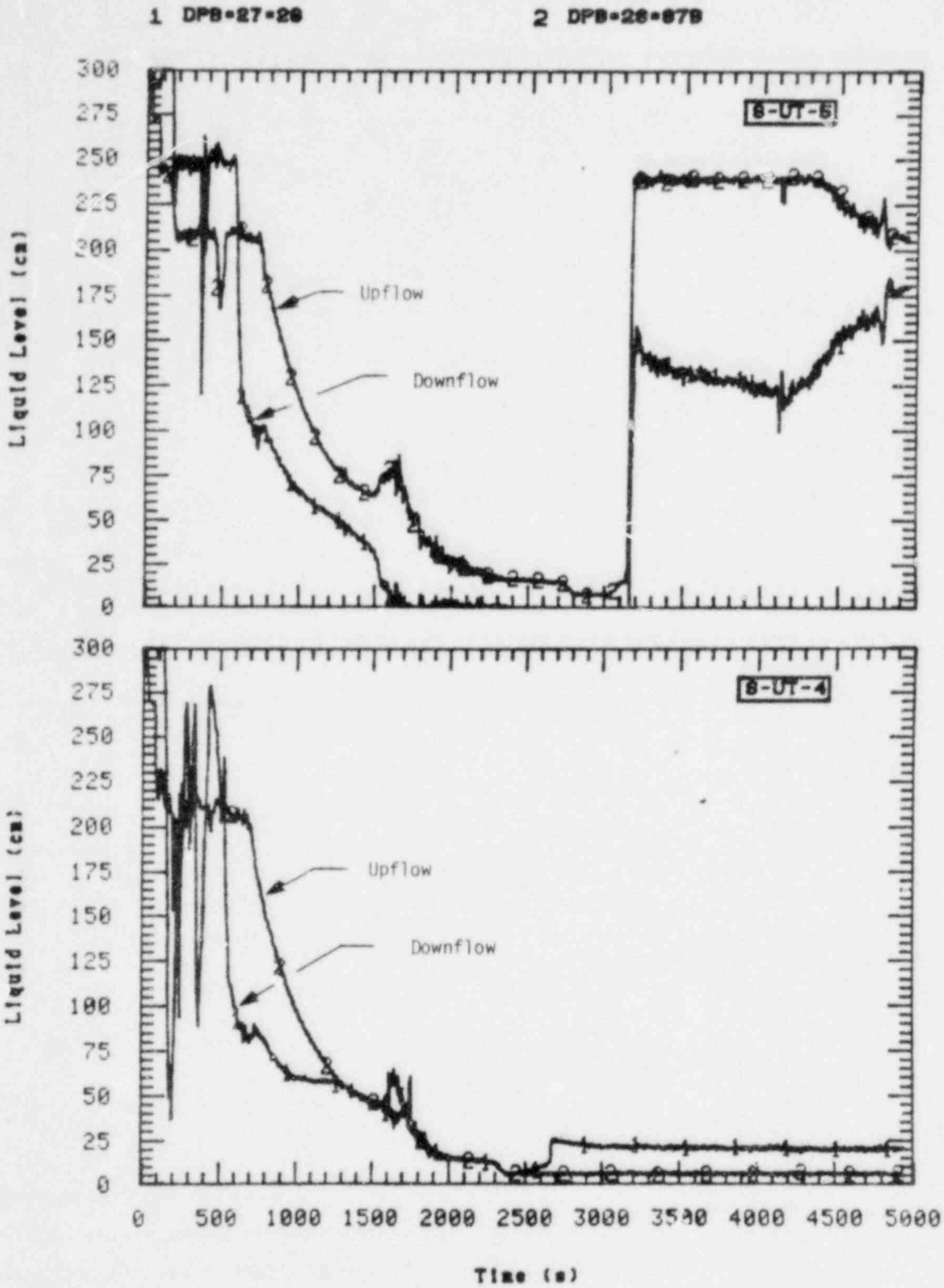


Figure 23. Comparison of liquid levels in the broken loop pump suction for Tests S-UT-4 and S-UT-5.

collected in the bottom of the upper head from 1800 to 2400 s. The refilling of the broken loop pump suction at 3150 s resulted from a surge of water out of the broken loop accumulator line. This occurs because the valves in the accumulator lines used to adjust the line resistances are nearer to the accumulator tanks than the system. Once the accumulator tank has emptied and the liquid in the line passes the valve the remainder of the liquid in the line rapidly surges out into the system. This may also be seen in Figure 24.

A preliminary attempt was made to perform an overall mass balance on the system by balancing the mass flow rates into and out of the system (all except the break flow are shown in Figure 24). The mass flow rate out of the system (break flow and leakage)[a] was subtracted from the flow into the system (HPIS and upper head, intact, and broken loop accumulator flows). This net mass flow rate was integrated and added to the 155 kg initial system mass. The result is shown in Figure 25 along with a computed value for the combined core, lower plenum, and downcomer mass for comparison. Comparison of the two curves shows that the loops had essentially completely voided in the first 1500 s and the remaining system liquid mass was in the vessel. It is also seen by comparison of the curves that the injection of UHI liquid did not result in any increase in system liquid inventory. The mass balance presented in Figure 25 is felt to provide a relatively good measure of minimum system liquid inventory and an indication of the refilling trend that followed the initiation of accumulator injection.

3.5 Core Behavior

The vessel liquid inventory throughout Test S-UT-5 remained sufficient to provide adequate cooling of the heater rods. No temperature increases

a. Most of the system leakage occurs through the intact loop pump suction seals. This leakage was collected for the entire test and an approximate rate estimated as shown in Figure 24.

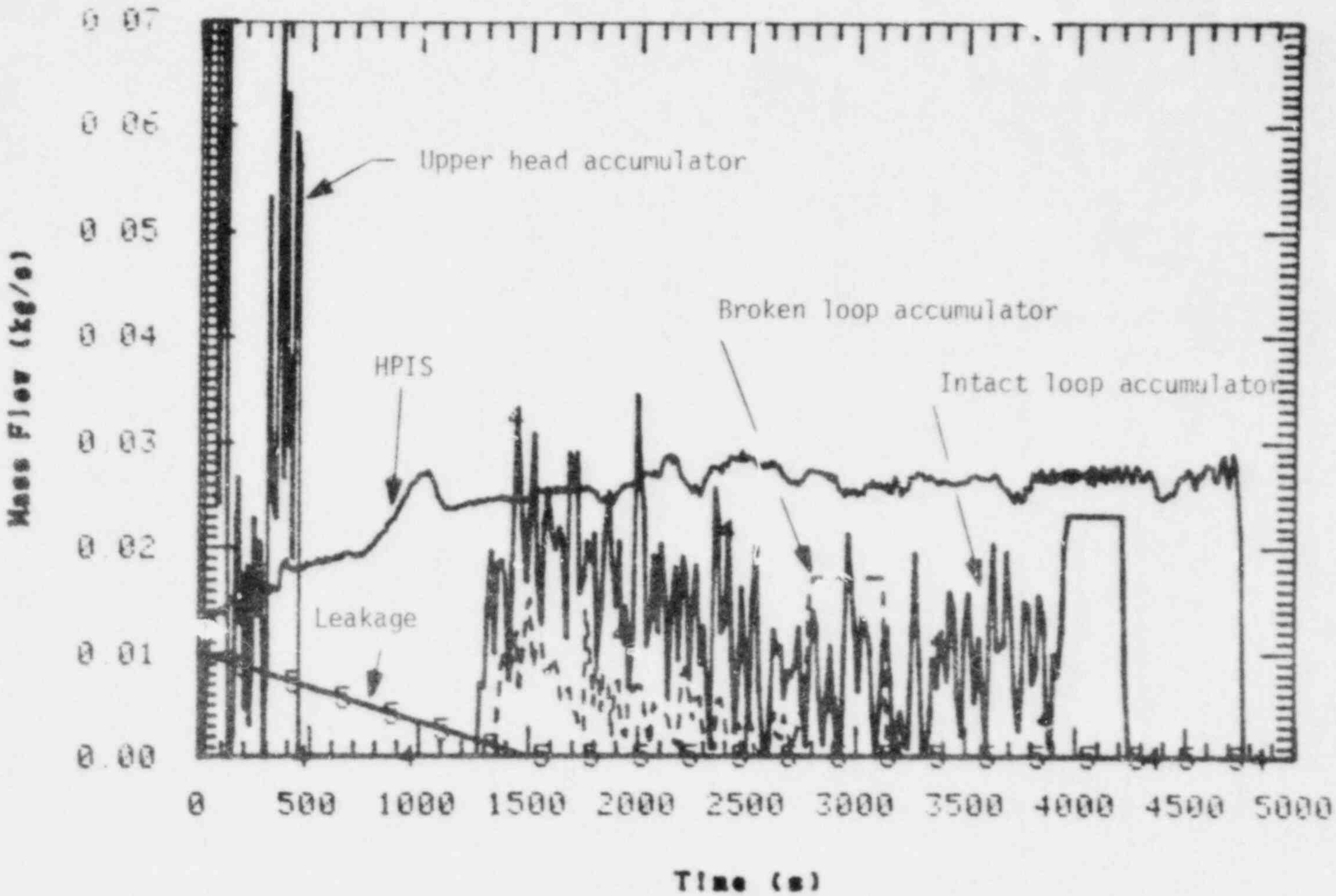


Figure 24. Components of system mass balance; system leak rate, HPIS flow rate, upper head, intact, and broken loop accumulator flow rates.

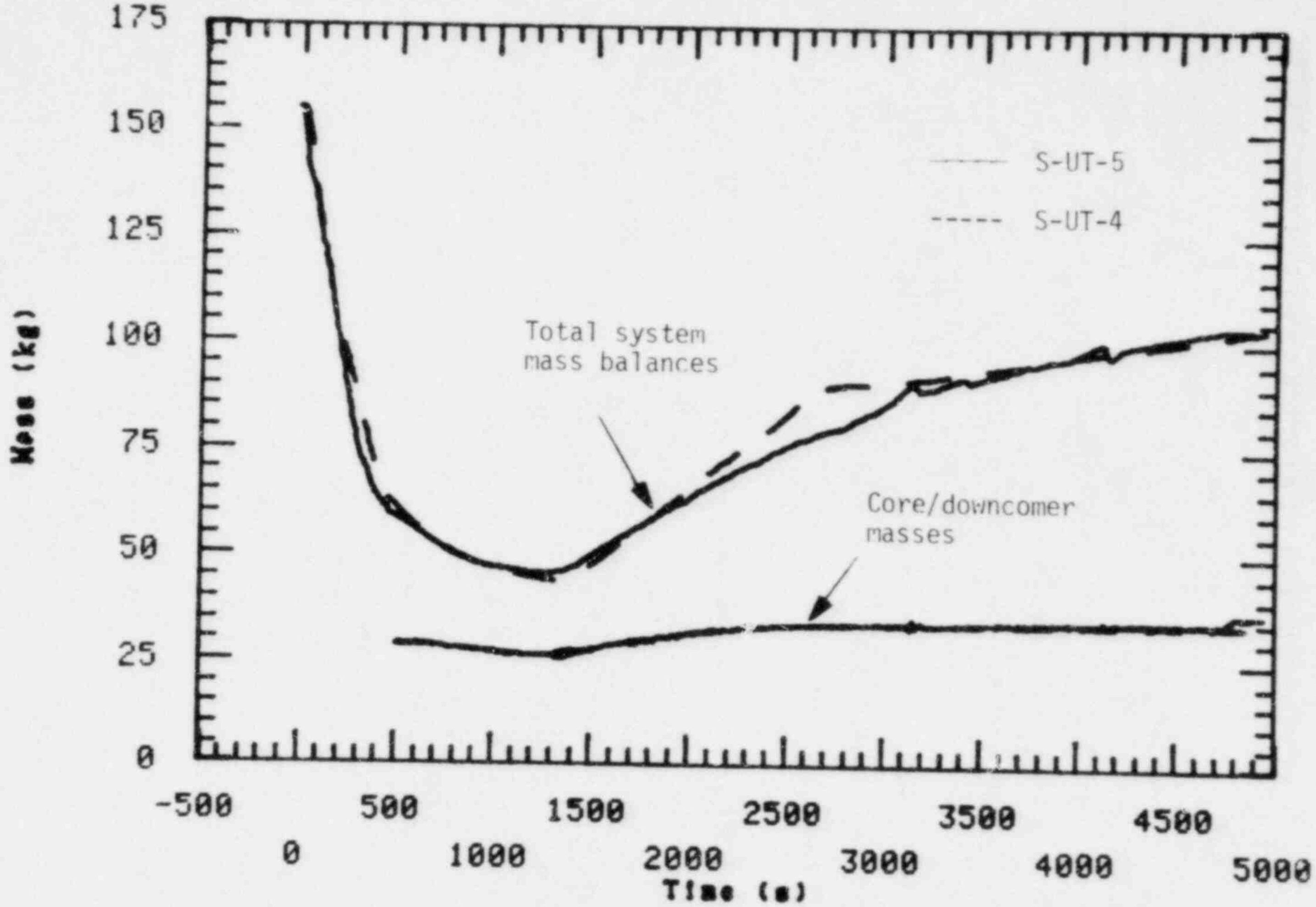


Figure 25. Comparison of system fluid masses and core/downcomer fluid masses for Tests S-UT-4 and S-UT-5.

were observed at any time as may be seen from Figure 26 which shows selected heater rod cladding thermocouple temperatures. Figure 27 shows the calculated collapsed liquid levels in the vessel and external downcomer and compares them to the levels from Test S-UT-4. Figure 28 shows the fluid densities at several axial levels in the core as measured by gamma densitometers. Following rupture it is seen that the core rapidly began to void and a large axial density gradient of two-phase fluid was established. The formation of liquid seals in the pump suctions and the pressure drop from flow around the loops produced a back pressure which resulted in a higher downcomer static head. From 200 to 300 s, the liquid level in the core in Test S-UT-4 stayed higher and more manometrically balanced with the downcomer level than in S-UT-5 because the upper head had emptied by this time (see following section) providing a small pressure relief path to the break. This relief path was not sufficient to finally prevent the depression of the core liquid level, however, as occurred at 300 s. In neither test did the formation of the loop seals cause a core liquid level depression low enough to result in any core dryout.

As seen in Figure 27, after the cold legs had voided (about 600 s) a slow boiloff of the vessel/downcomer liquid inventory began. But even with the low loop accumulator pressures in Test S-UT-4[a] and the low HPIS rates[b] in both tests the vessel fluid inventories remained sufficient to prevent core dryout. The extra UHI liquid which had been injected into the system in Test S-UT-5 apparently provided only a slight additional margin against core uncovery prior to loop accumulator injection. Once loop accumulator injection began a steady refilling of the core began. Slight manometric oscillations between the core and downcomer occurred beginning about 1600 s but had no effect on core cooling. After the loop

---

a. Non-UHI equipped PWR plants have loop accumulators pressurized to nominally 4.14 MPa.

b. As discussed in Section 2.2.3, broken loop HPIS flow was not used.

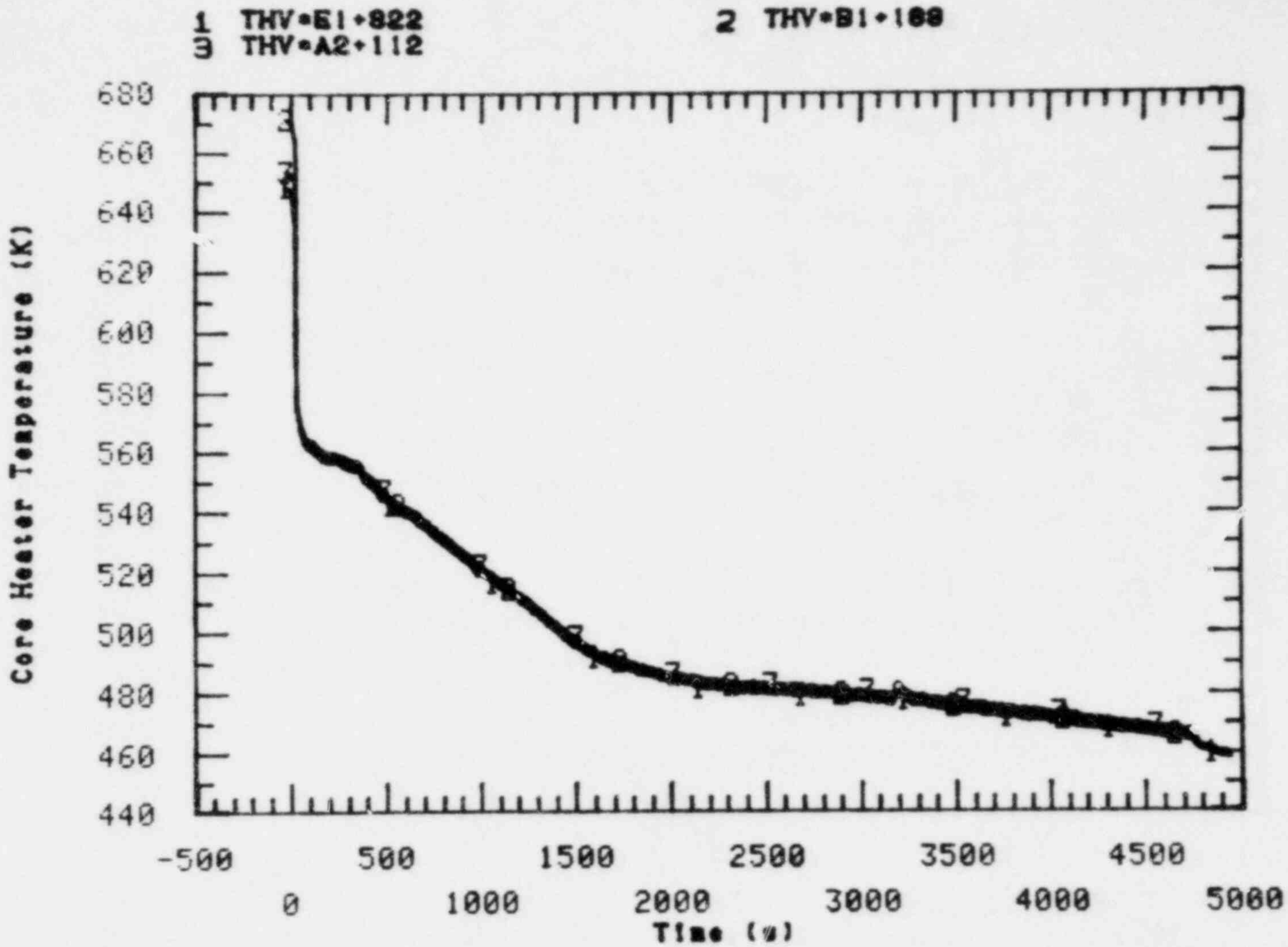


Figure 26. Selected heater rod cladding temperatures from Test S-UT-5.

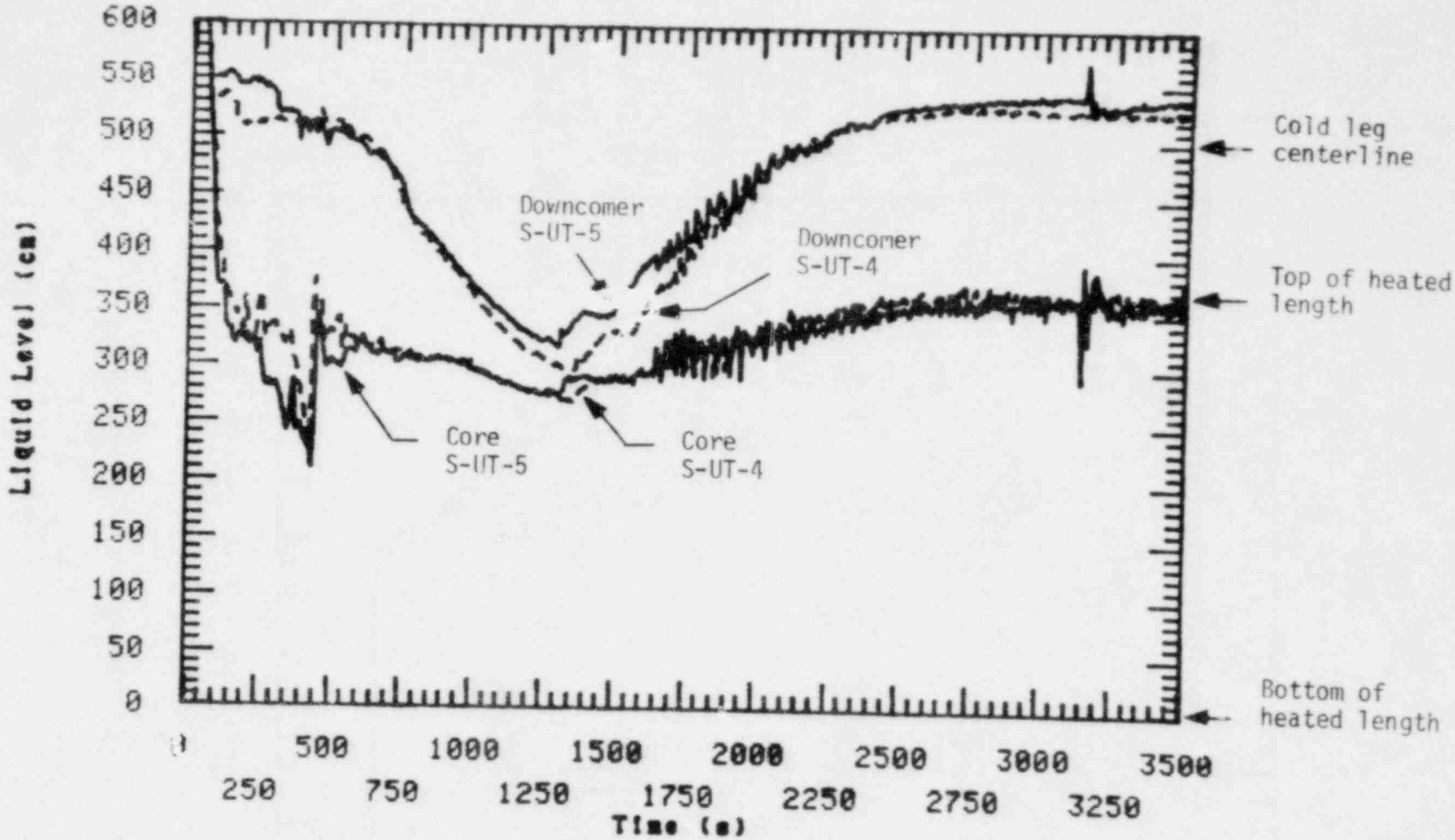


Figure 27. Comparison of collapsed liquid levels in the core and downcomer for Tests S-UT-4 and S-U7-5.

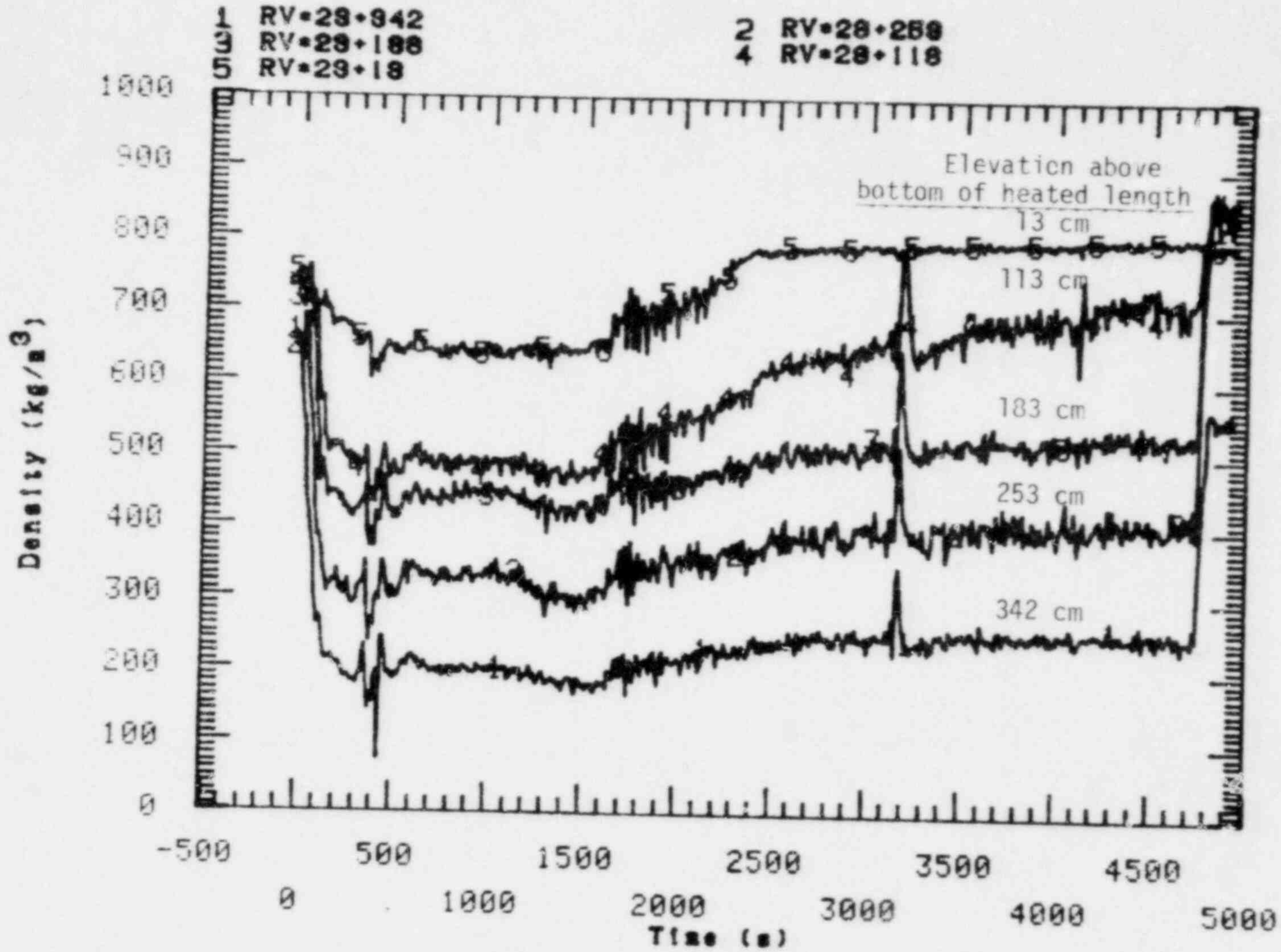


Figure 28. In-core fluid densities as measured by gamma densitometers for Test S-UT-5.

accumulators had emptied of liquid the HPIS injection rate adequately replenished core boiloff and maintained steady conditions.

3.6 Upper Head Fluid Behavior

The distribution in the system of the UHI fluid injected from the upper head accumulator is of particular interest in comparing Tests S-UT-4 and S-UT-5. The UHI injection rate was shown in Figure 24. Figure 29 compares the collapsed liquid levels in the upper head for the two tests. It is seen that the injection rate was not large enough to keep the upper head full, but did cause a delay in the time to drain the head of about 100 s.

Figures 30 through 33 compare the volumetric flow rates from Tests S-UT-4 and S-UT-5 through the various penetrations to the vessel upper head, these being; the downcomer to upper head bypass line, guide tube, and two support columns (see Figure 8). In both tests the first 80 seconds was characterized by a slow decay of the normal flow through the upper head as the pumps coasted down. The guide tube flow reversed direction as steam was drawn from the voided upper plenum to be condensed in the upper head. The higher volumetric flow rate in Test S-UT-5 is caused by the greater condensation potential induced by UHI. Figure 34 compares the fluid temperature distribution throughout the upper head for Tests S-UT-4 and S-UT-5.

Due to the slow upper head accumulator injection the flow of liquid down the support columns was a gravity-driven drain and was not much different between the two tests. The differences in the flow rates from about 150 to 350 s are the result of the different times that flashing began in the upper head. As seen in Figure 30 however, the differences in the bypass line flows indicates that nearly all of the UHI liquid injected in Test S-UT-5 exited the upper head through the bypass line to the top of the downcomer. Since the core liquid inventory and steam generation rate

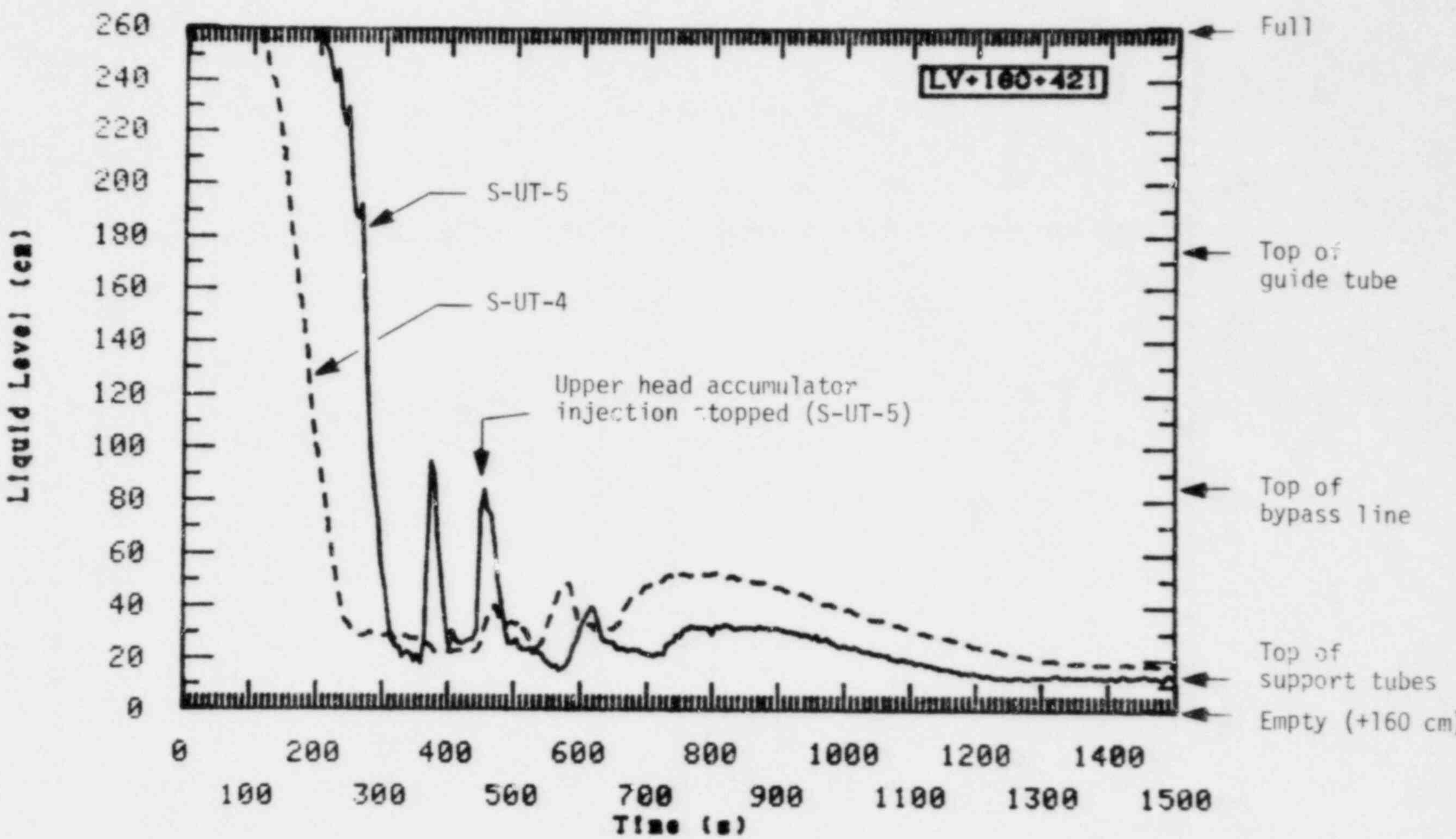


Figure 29. Comparison of vessel upper head collapsed liquid levels from Tests S-UT-4 and S-UT-5.

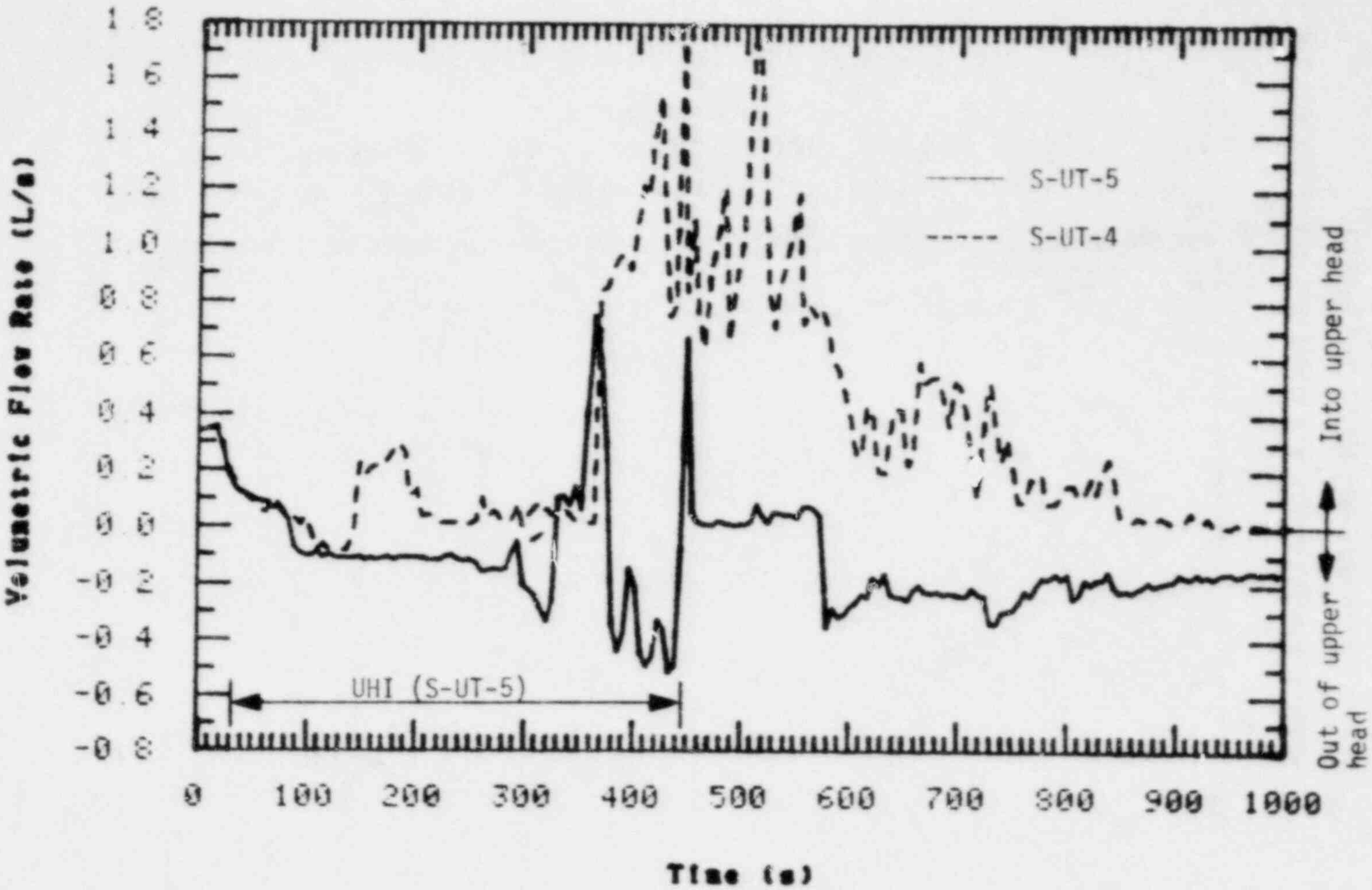


Figure 30. Comparison of vessel upper head bypass line flows for Tests S-UT-4 and S-UT-5.

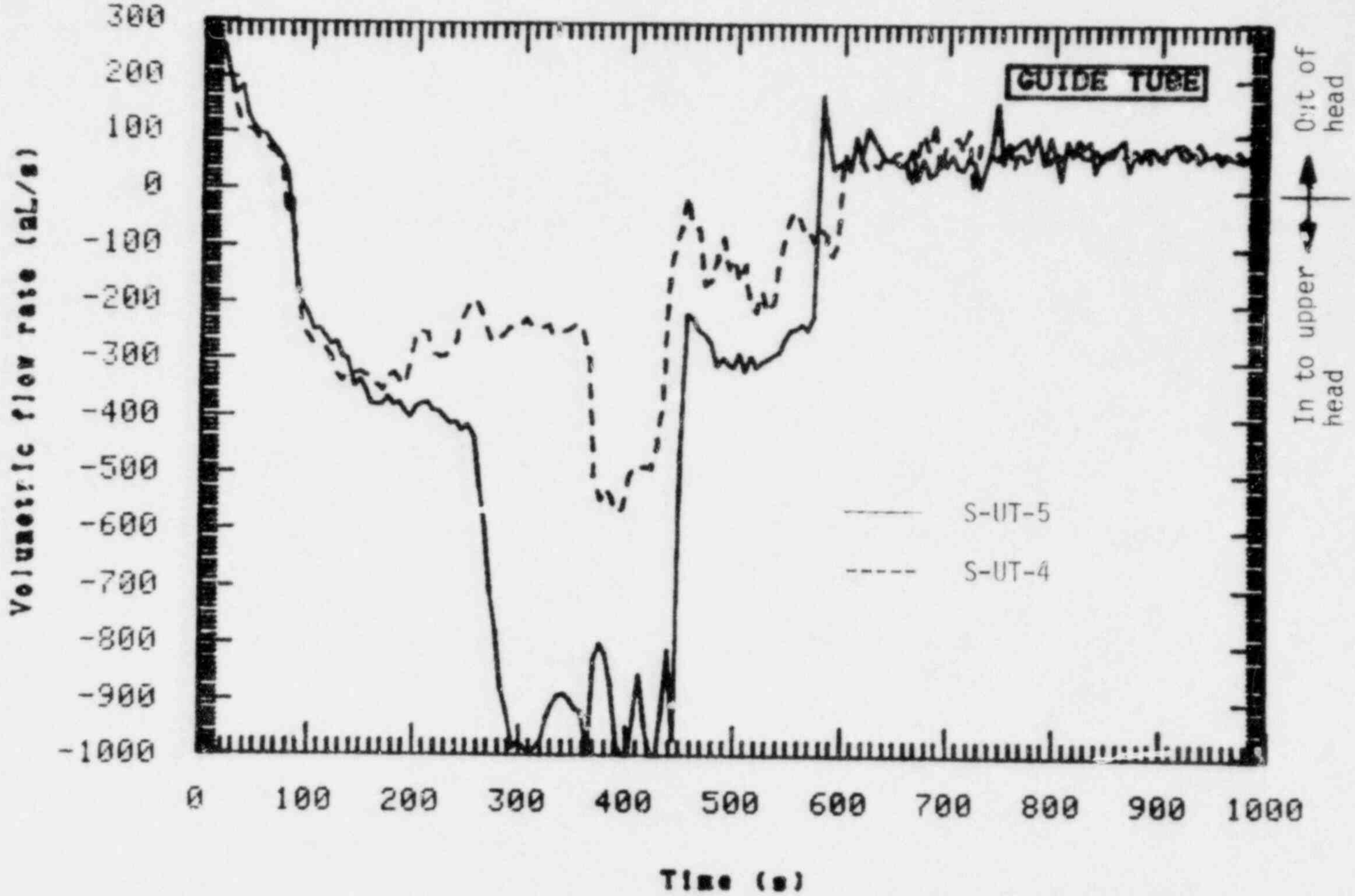


Figure 31. Flow through the upper head guide tube for Tests S-UT-4 and S-UT-5.

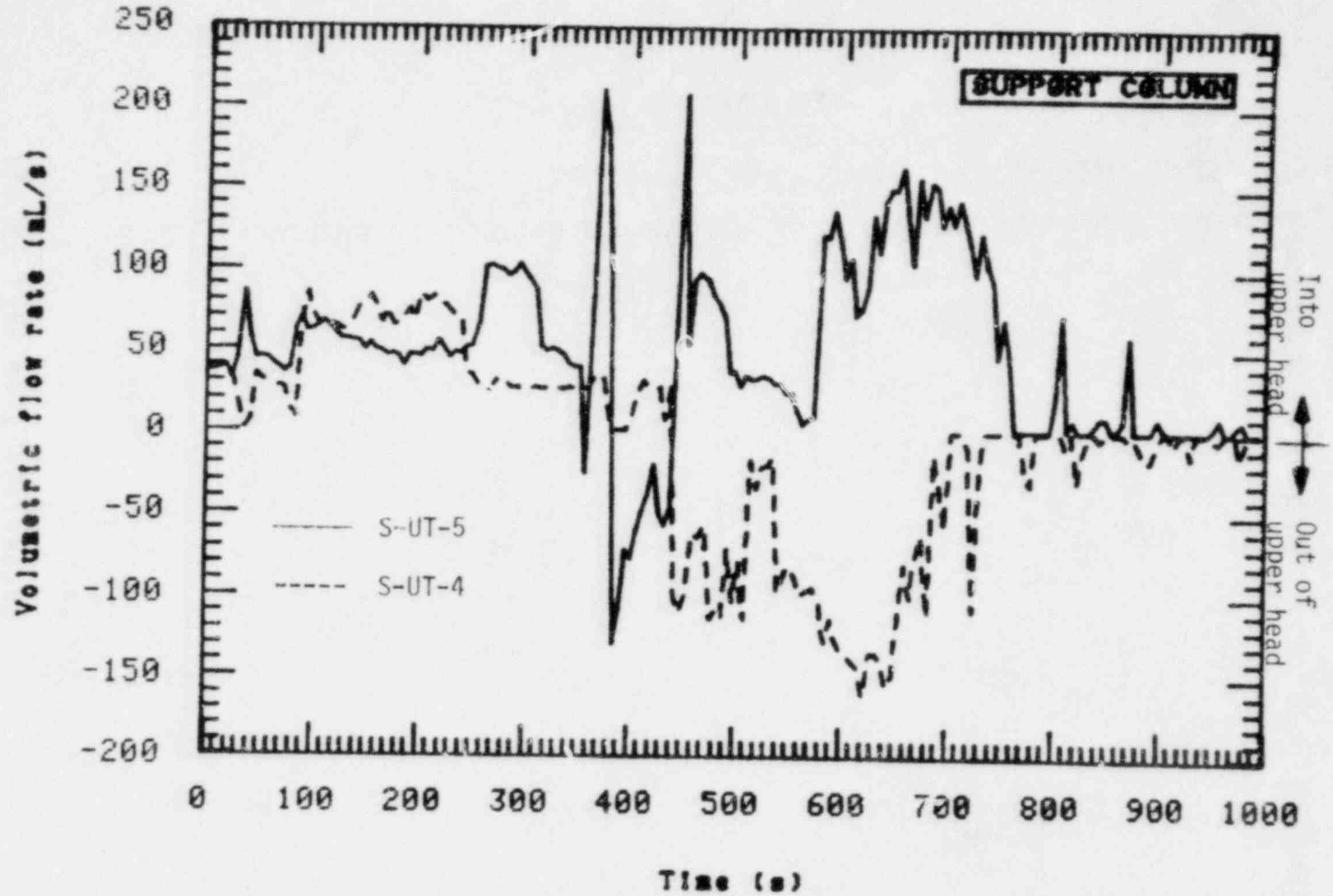


Figure 32. Flow through one of two upper head support columns for Tests S-UT-4 and S-UT-5.

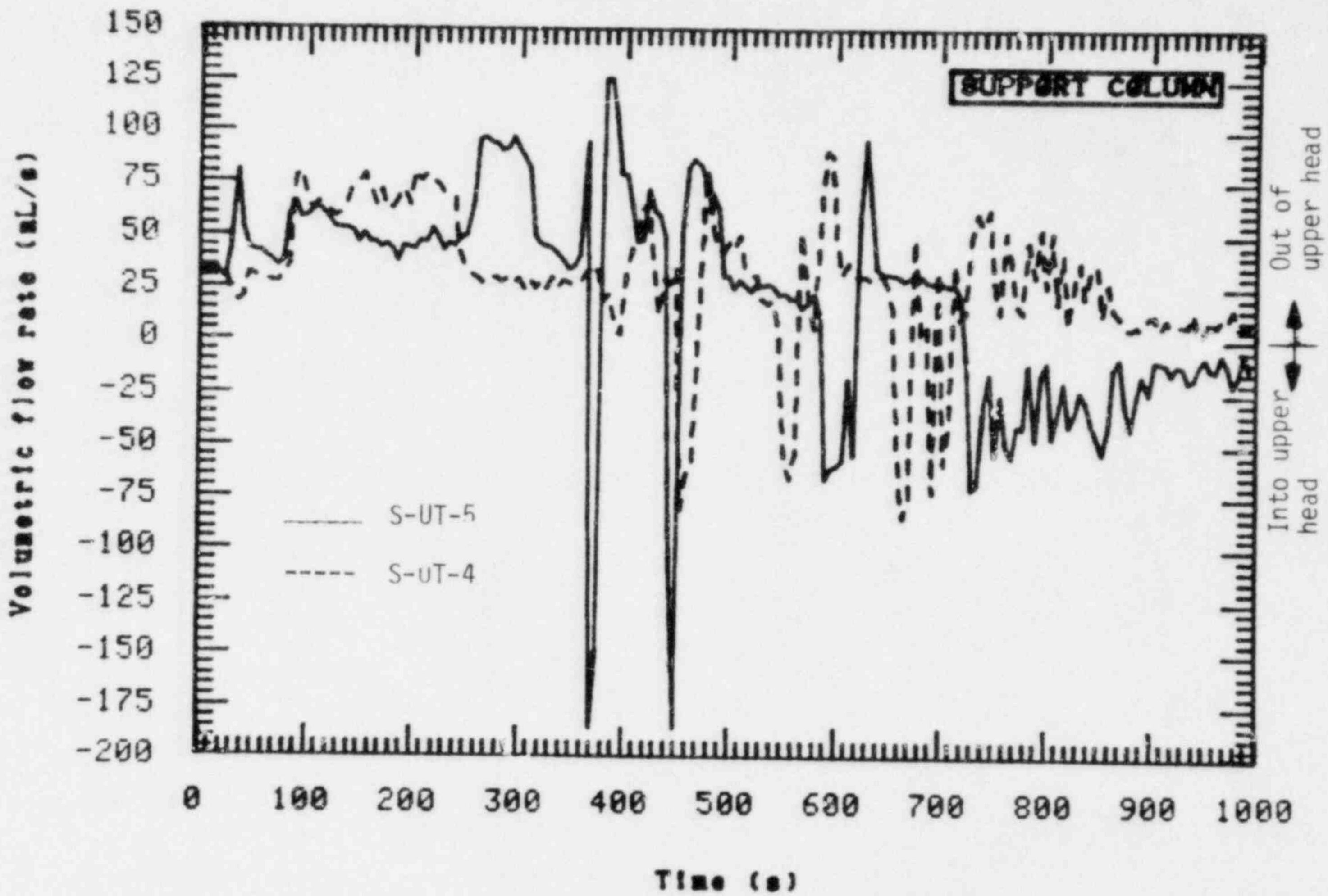


Figure 33. Flow through one of two upper head support columns for Tests S-UT-4 and S-UT-5.

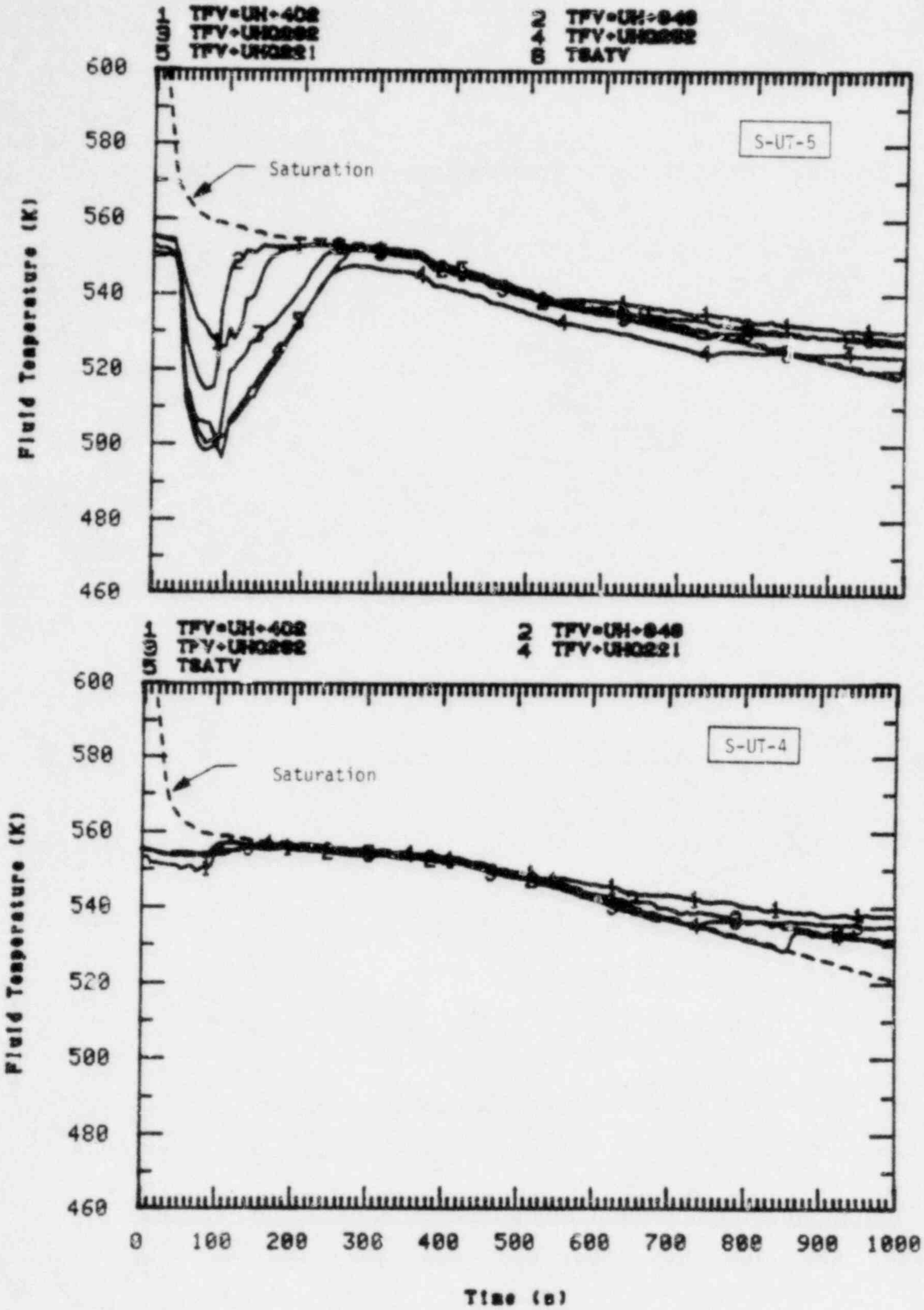


Figure 34. Upper head fluid temperatures and saturation temperatures for Tests S-UT-4 and S-UT-5.

were already sufficient to support a full head of downcomer liquid even in a test without UHI (S-UT-4) (see Figure 27) the UHI liquid predominantly went out the break.

It is concluded from the upper head fluid behavior presented above, the comparison of core liquid level behaviors in Section 3.5, the system depressurizations compared in Section 3.2, and the difference in break flows shown in Section 3.3 that the UHI liquid acted to remove energy from the system by directly increasing the break flow rate. The contribution of UHI fluid to core cooling mostly is the result of a longer period of liquid flow down the support columns and by simply providing a slightly greater liquid inventory in the system. The net effect was a slightly better margin against core uncovery.

4. COMPARISON OF SELECTED DATA TO PRETEST PREDICTION CALCULATION

A comparison of Test S-UT-5 data to results of the test prediction is presented in this section. The test prediction calculation was performed through the first 760 s of the transient using the RELAP5/MOD1 computer code (version 6). A detailed description of the results of the calculation is given in Reference 7. The system model used in the calculation is discussed in Appendix A. Comparisons presented in this section provide a basis for evaluating the capability of the present analytical model to predict the system response resulting from a 2-1/2% communicative cold leg break with UHI in the Semiscale Mod-2A facility. Table 3 compares the significant initial conditions specified, measured, and calculated for Test S-UT-5.

The primary system pressure response is compared to the test prediction in Figure 35. The calculation shows good agreement through 300 s of the transient, particularly during the subcooled depressurization (0 - 40 s). The rate of depressurization was under predicted, however, between 300 and 600 s, and over predicted after 600 s. Steam generator secondary pressures were calculated to be higher and more sustained than in the test data (Figure 36), which indicated a slow depressurization following coolant saturation temperatures. Between 300 and 600 s, the calculated difference in coolant pressure between the primary and secondary (Figure 37b) was significantly smaller than data (Figure 37a), primarily as a result of a lower experimental secondary mass in the broken loop. The calculated secondary conditions, therefore, were significantly less effective as heat sinks for the primary system. Since less core decay heat was being removed through the steam generators in the calculation, the loop cold leg temperatures were calculated to rise (Figures 38a and b), yielding a higher fluid saturation pressure than in the experiment. The increased rate of depressurization calculated after 600 s is a result of loop seal clearing which is discussed later.

TABLE 3. INITIAL CONDITIONS FOR TEST S-UT-5

	Specified	Actual	RELAP5
Nominal system pressure	15.5 ± 0.2 MPa	15.8	15.5
Hot leg fluid temperature	594 ± 2 K	595	594
Cold leg fluid temperature	557 ± 2 K	557	558
Total core power	2.0 ± 0.005 MW	2.0	2.0
Core inlet flow rate	9.77 kg/s[a]	9.1	9.31
Steam generator secondary pressure			
Intact loop	5.9 ± 0.2 MPa[b]	5.74	5.45
Broken loop	5.9 ± 0.2 MPa[b]	3.98	5.44
Steam generator secondary water level			
Intact loop	Footnote b	1036 cm	467
Broken loop	Footnote b	230 cm	677
Steam generator secondary feedwater Temperature			
Intact loop	495 ± 2 K	498	495
Broken loop	495 ± 2 K	497	495

a. Approximate value; flow is adjusted to achieve required core ΔT.

b. Secondary flow conditions will be adjusted to obtain required primary side temperature and ΔT.

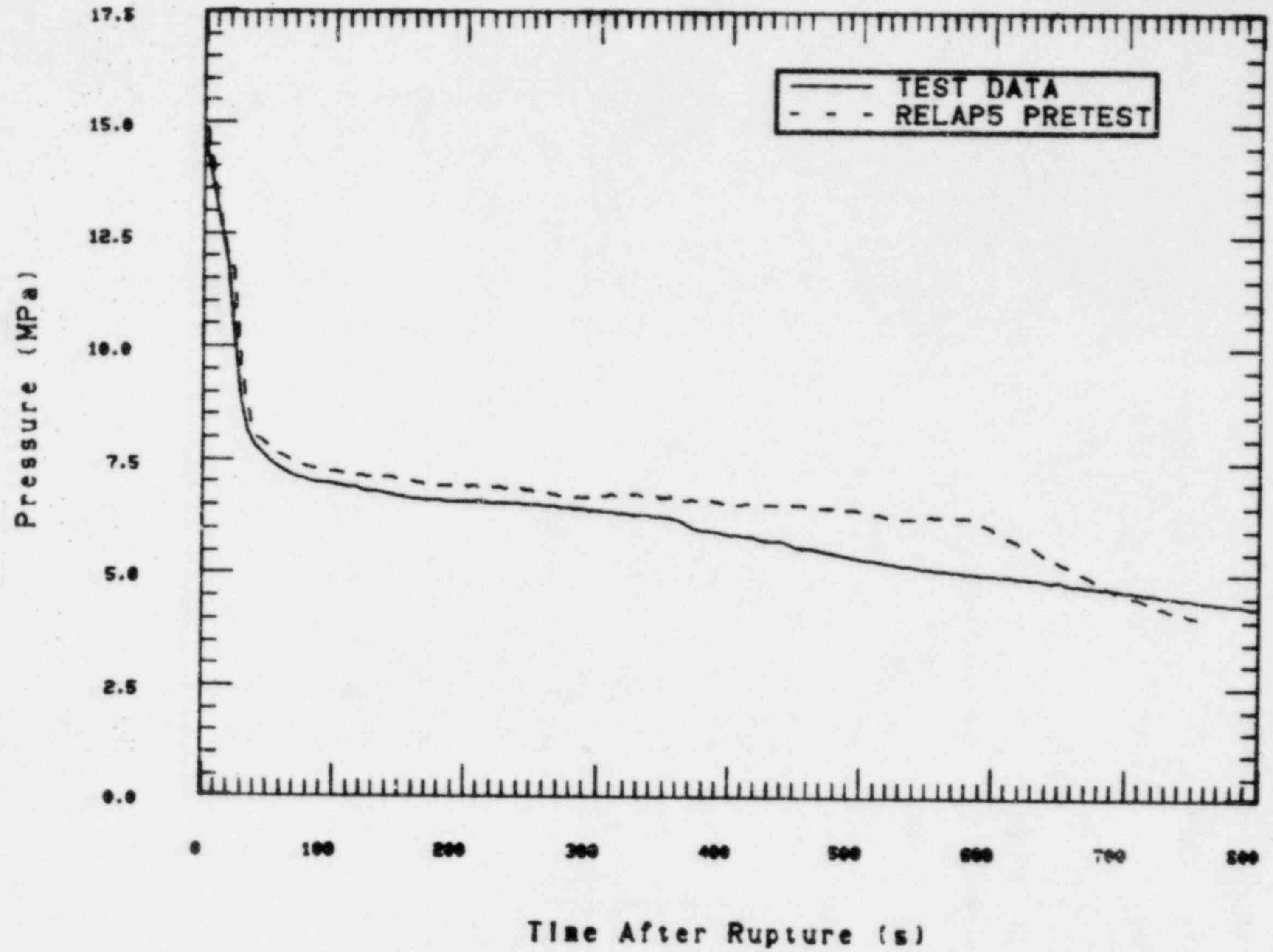


Figure 35. Upper plenum pressure.

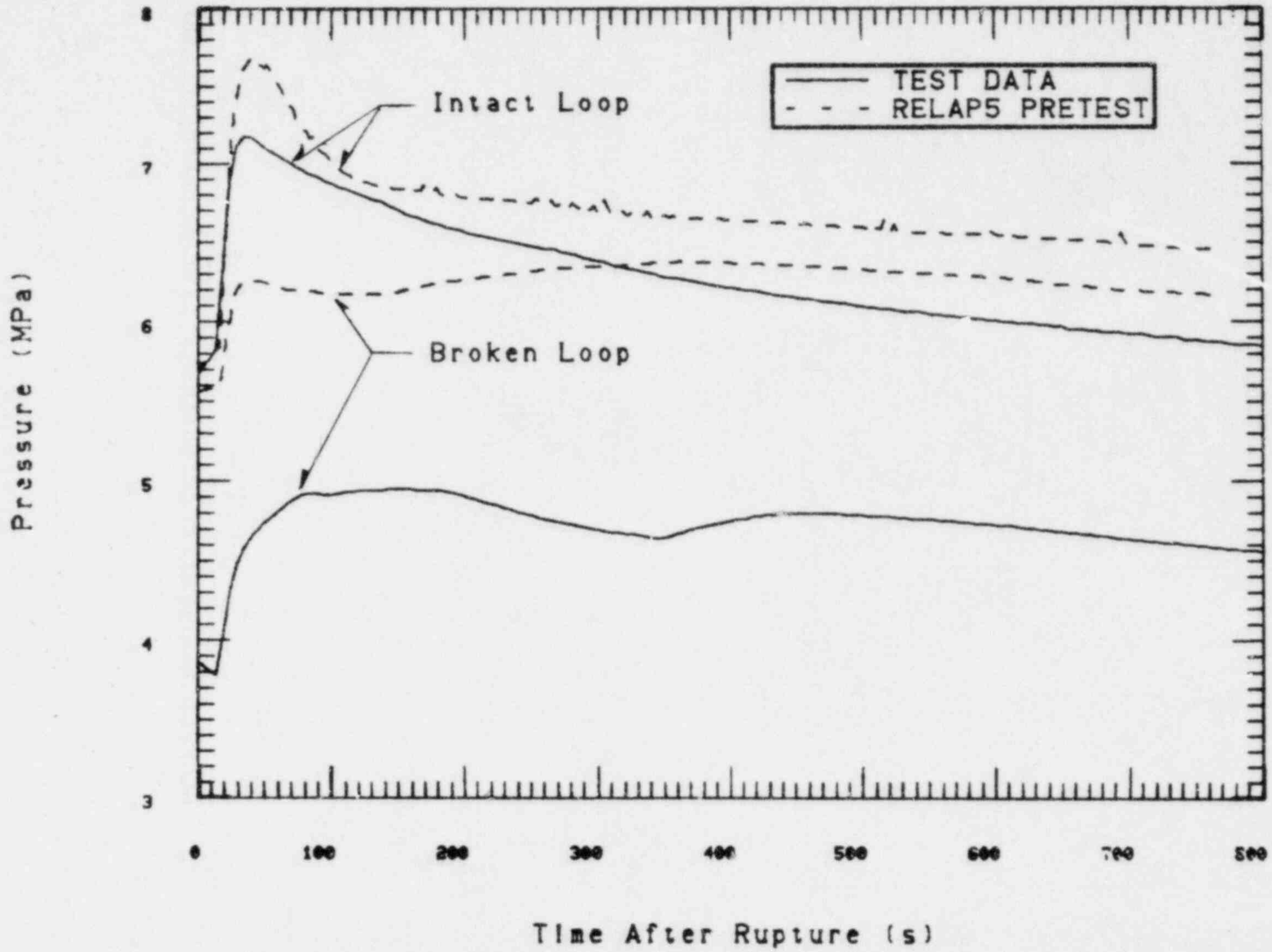


Figure 36. Steam generator secondary pressure.

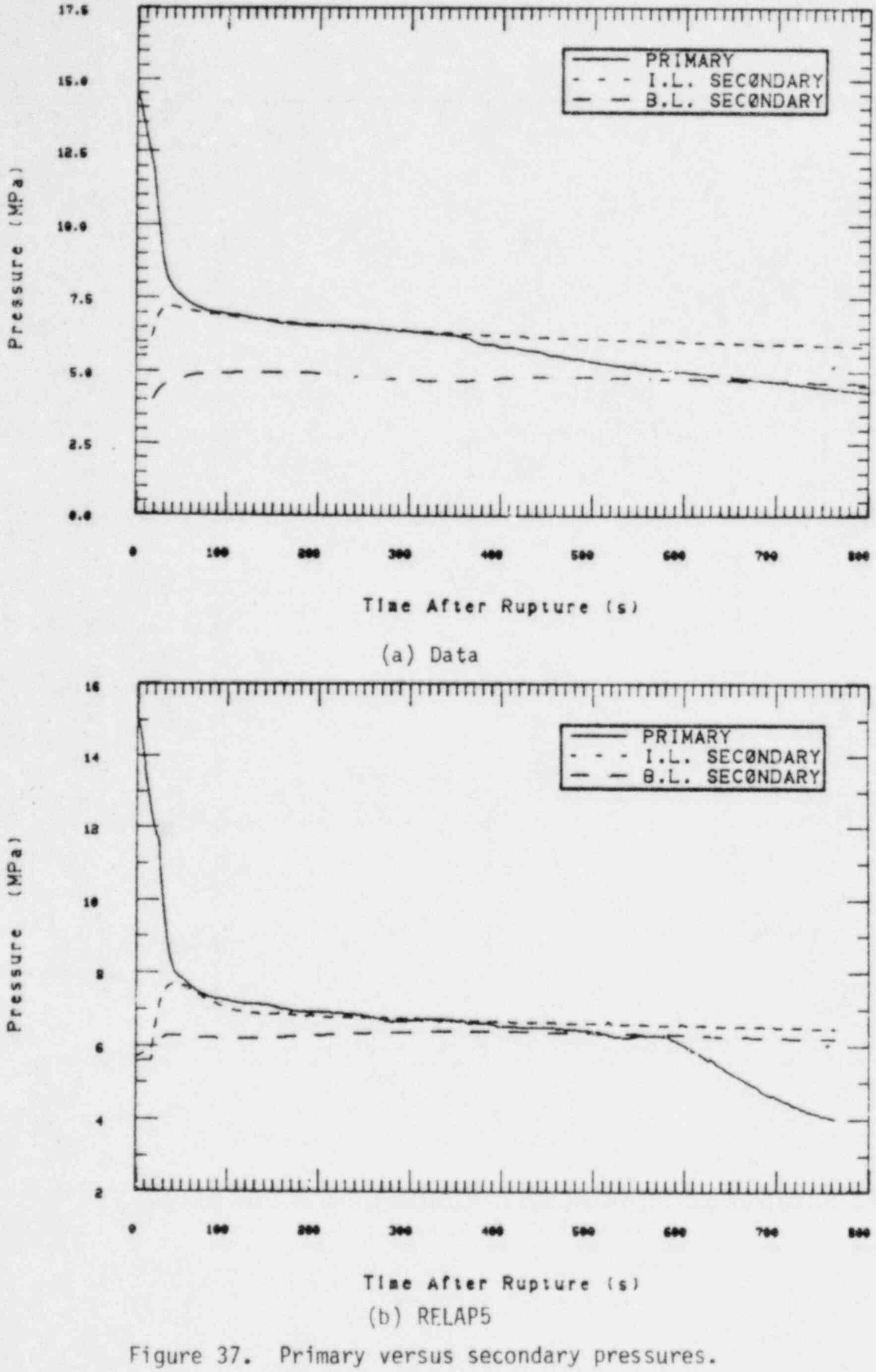
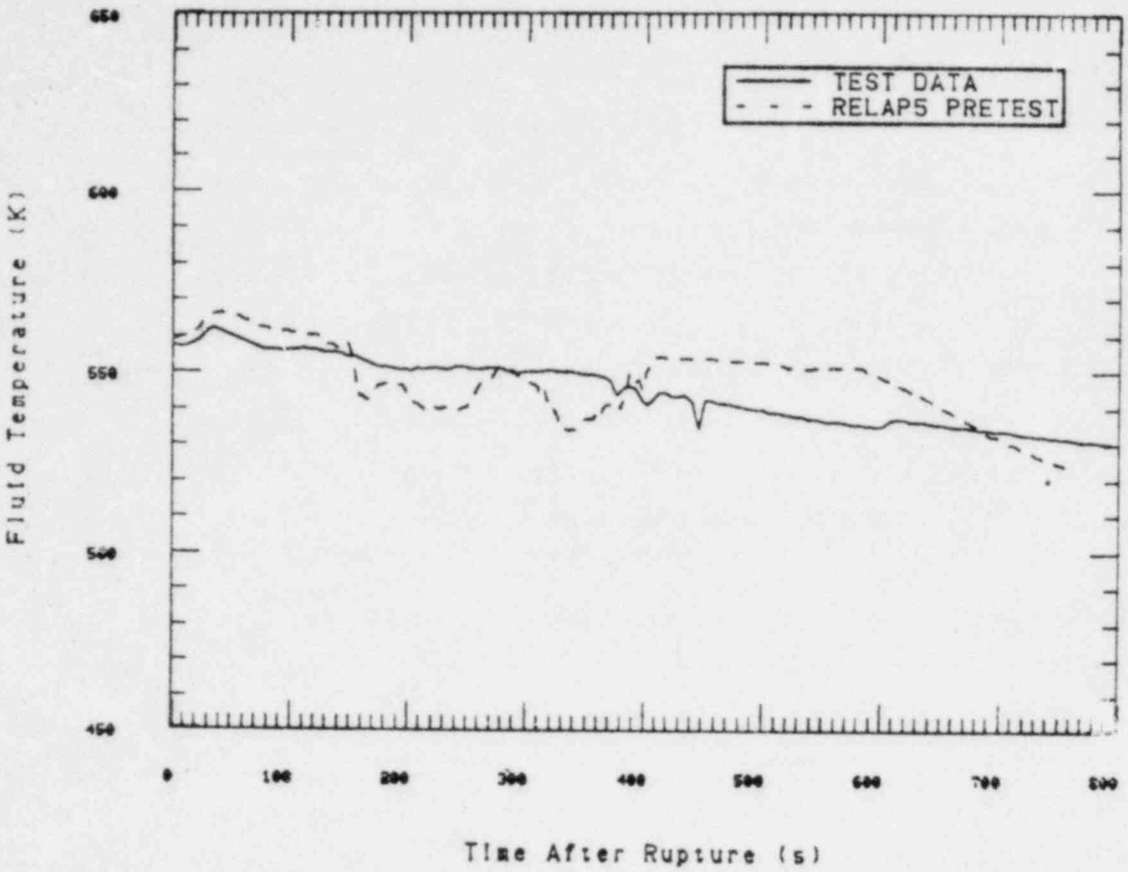
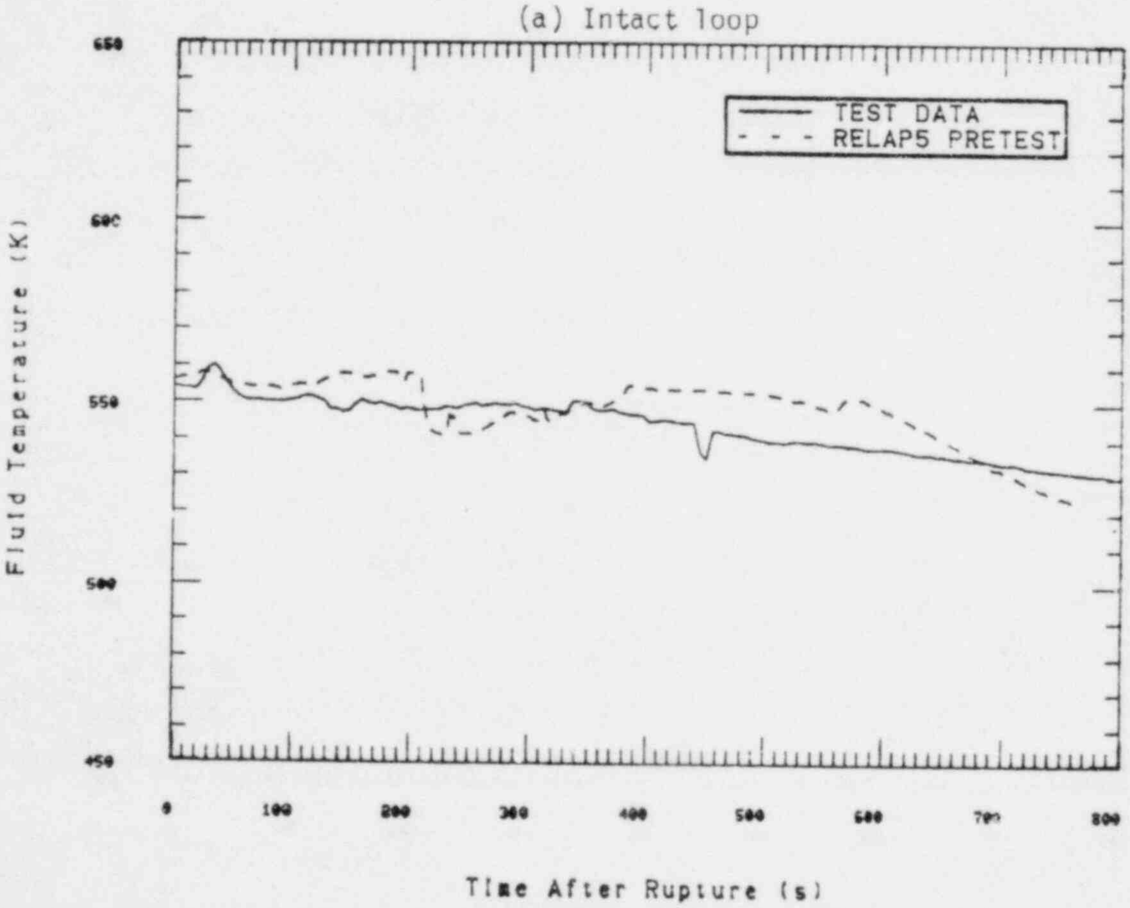


Figure 37. Primary versus secondary pressures.



(a) Intact loop



(b) Broken loop

Figure 38. Cold leg fluid temperatures.

Figure 39 compares the approximate system mass observed in the test to the pretest calculation result. The break mass flow rate was under predicted during the early portions of the transient and therefore contributed to the calculated system pressure stabilizing at a higher than observed value. The liquid mass in the core, however, was slightly under predicted, particularly during the core liquid level depression, as shown by the core collapsed levels in Figure 40a. The exaggerated core level depression, calculated by RELAP5, resulted in a brief dryout which was not observed in the test (Figure 40b). Significant changes in the calculated system mass inventory after 500 s are a result of an erratic mass flow rate from the UHI accumulator (discussed later). An increased UHI flow rate calculated at 600 s caused the system mass to increase.

The calculated depression of the core liquid level is a result of the formation of liquid seals in the pump suction legs. A comparison of collapsed liquid levels in the intact and broken loop pump suctions (downside and upside) is given in Figures 41 and 42. The order in which the loop seals cleared was predicted correctly, but the time of clearing was not calculated precisely. The intact loop was calculated to blowout approximately 150 s later than observed. This delay is the cause of the calculated depression in core liquid level. The calculated temporary voiding of the broken loop pump seal at 180 s was not observed in the test with the same magnitude. The time at which the broken loop seal begins to clear was calculated correctly. The test data indicated a slow clearing since the intact loop had already cleared completely, whereas the pretest calculation predicted a more rapid clearing. The rapid calculated clearing resulted in an over prediction in the rate of system depressurization after 600 s.

The predicted response of the upper head accumulator shows good agreement for the first 300 s of the transient. Drainage of the upper head compared well over the first 600 s of the calculation (Figure 43a) and the UHI accumulator response compares well especially over the first 300 s of the transient (Figure 43b). The calculated flow rates through the upper head bypass line, guide tube and support columns also demonstrate good

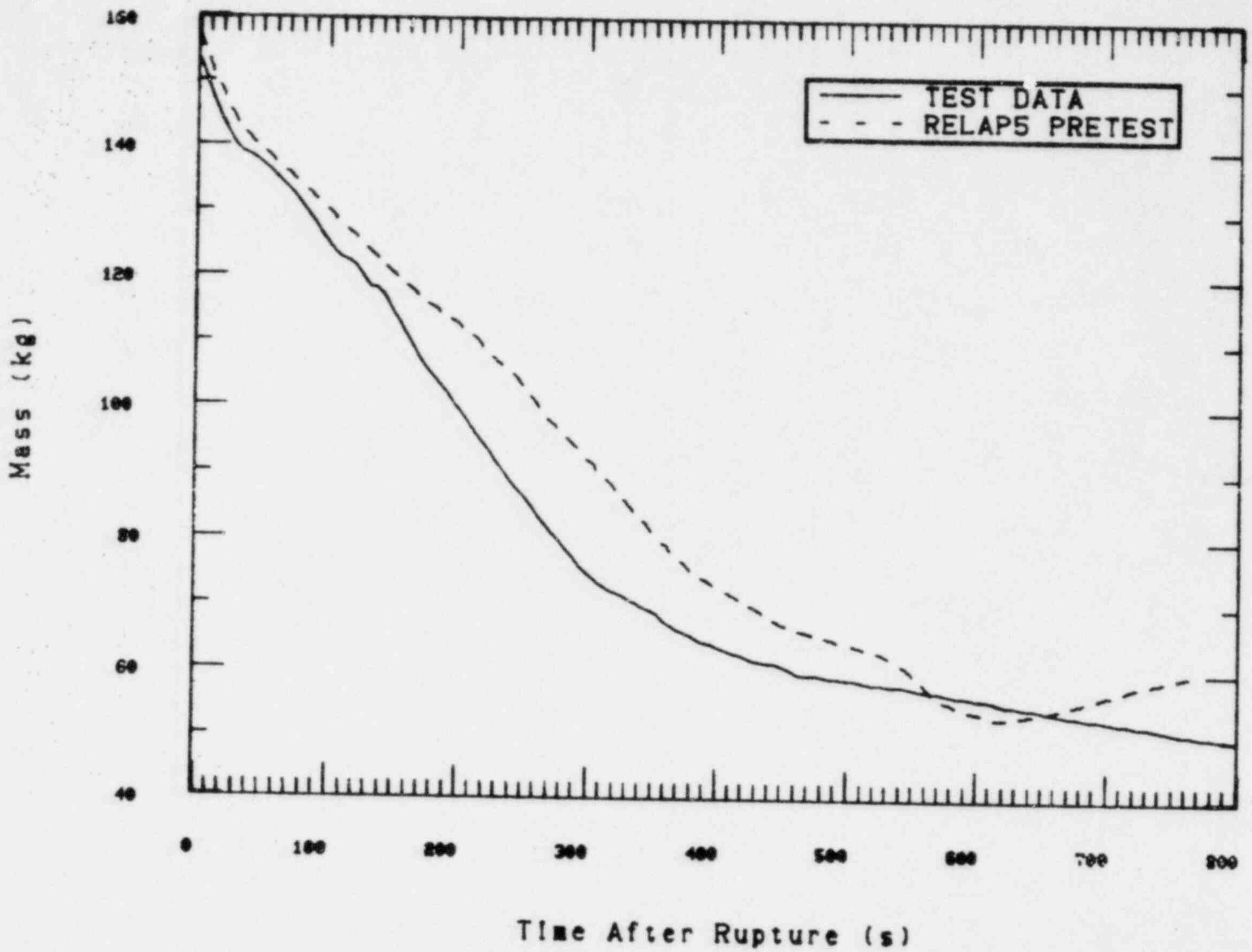


Figure 39. Total system mass.

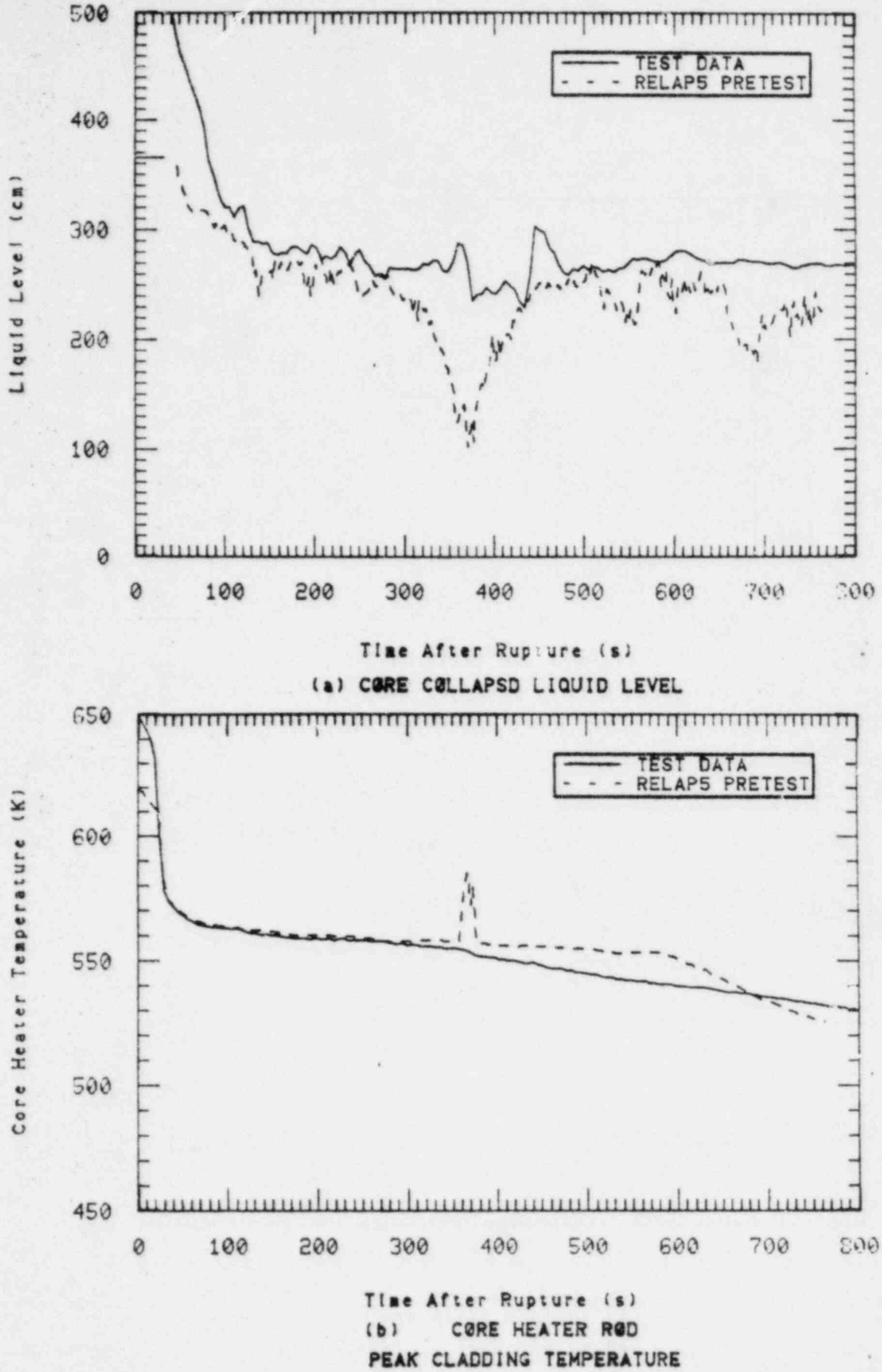
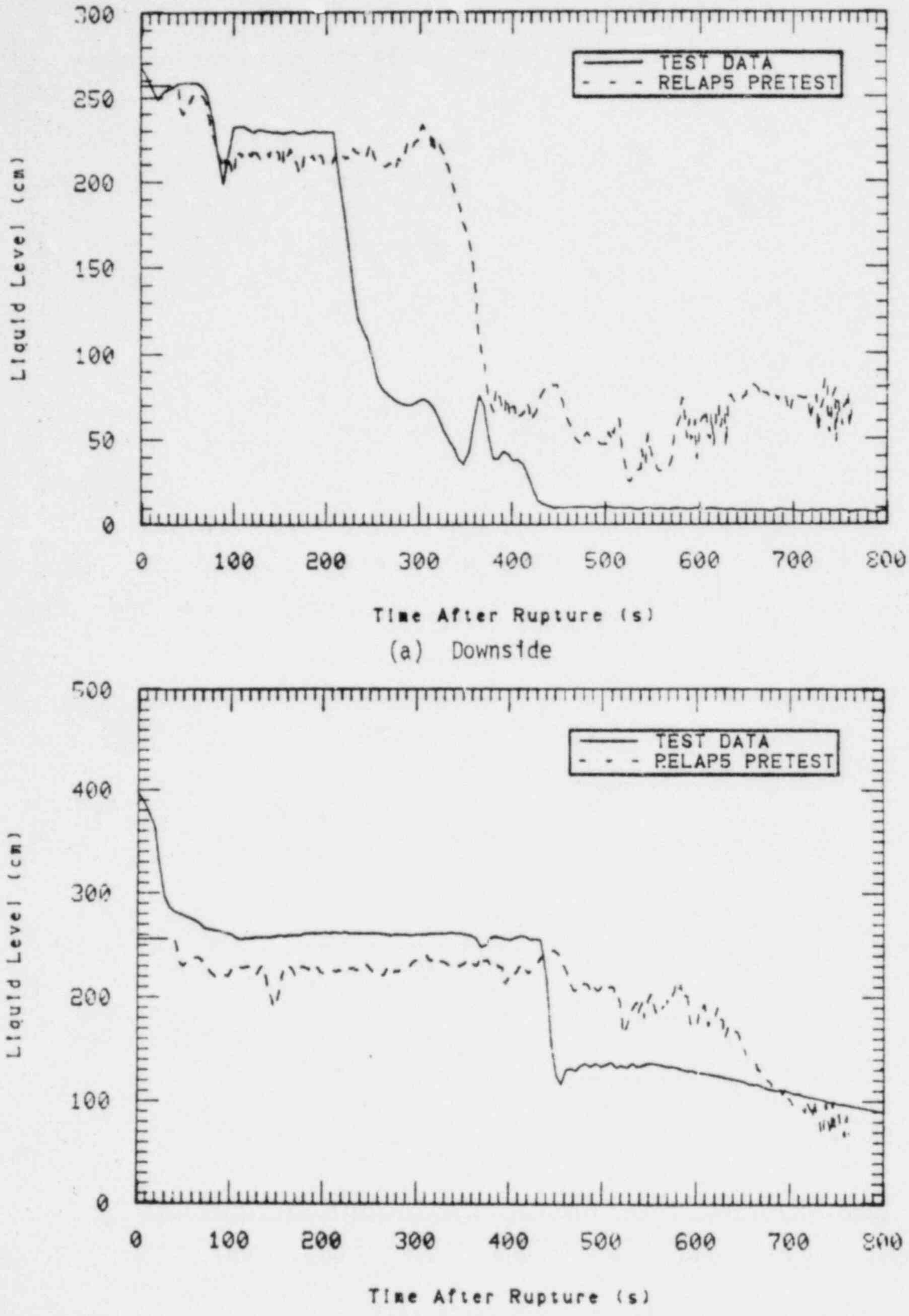


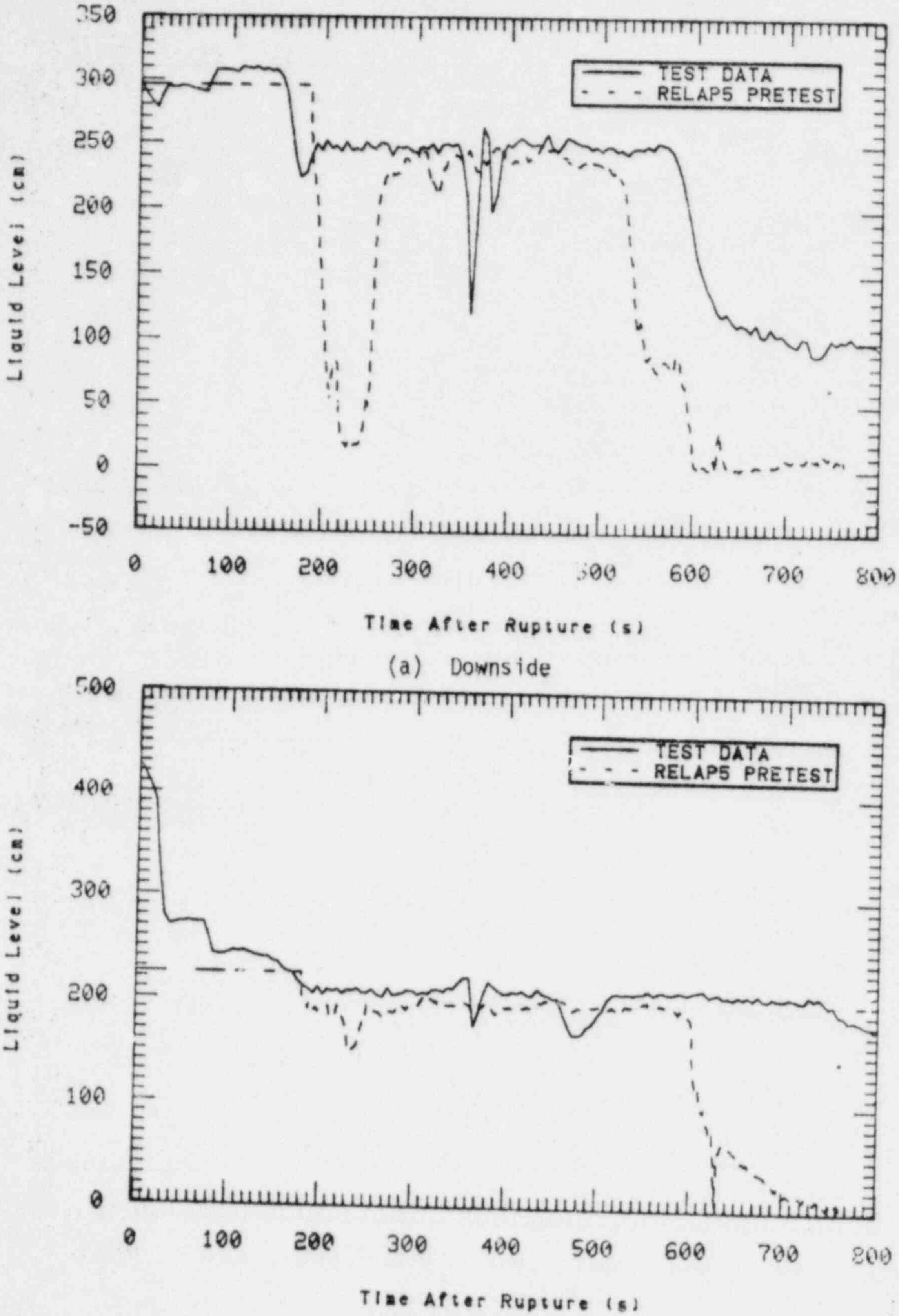
Figure 40. Core collapsed level and peak cladding temperature.



(a) Downside

(b) Upside

Figure 41. Intact loop pump suction collapsed liquid level.



(a) Downside

(b) Upside

Figure 42. Broken loop pump suction collapsed liquid level.

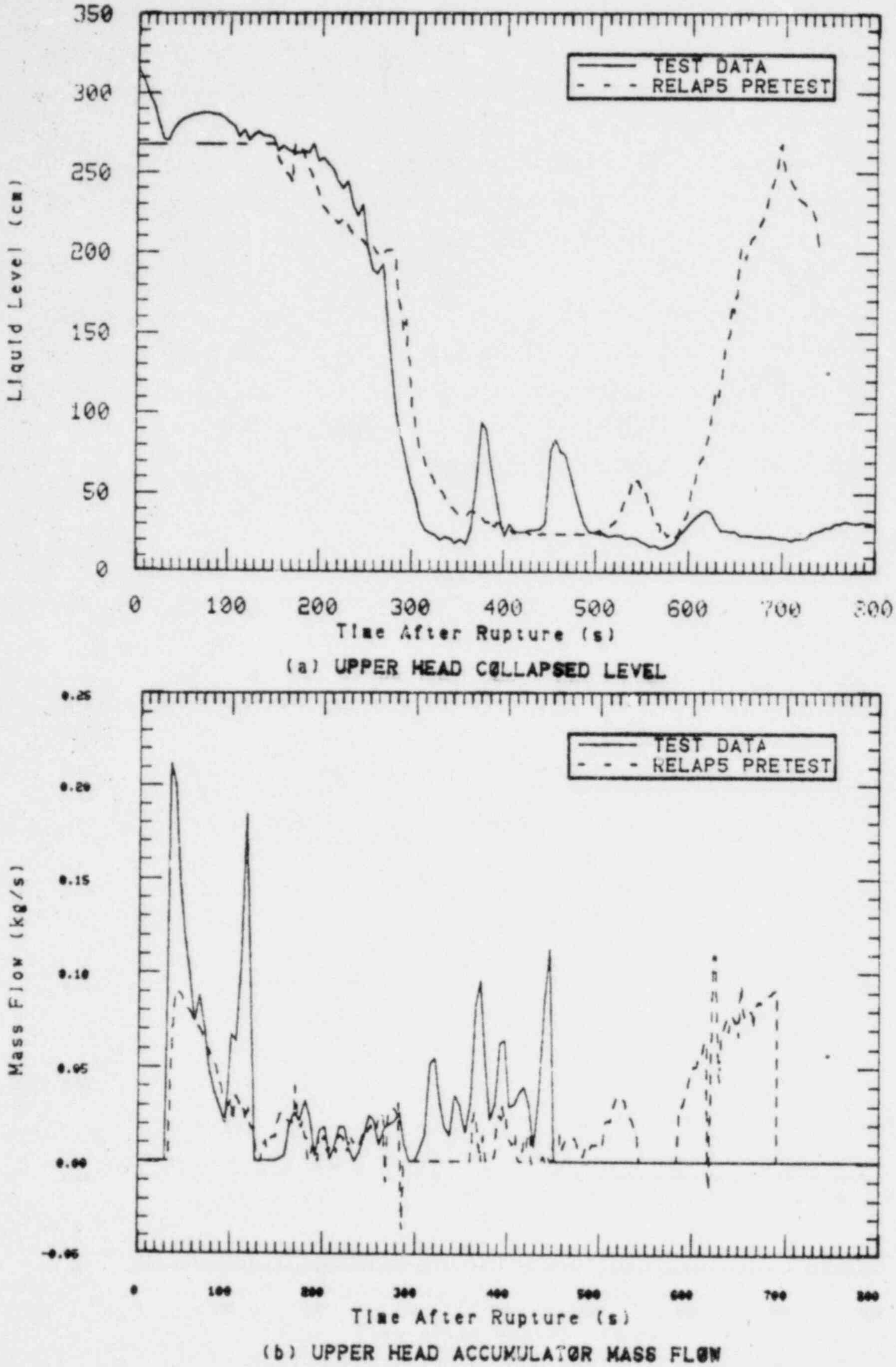


Figure 43. Upper head collapsed liquid level and accumulator flow rate.

agreement over this time (Figures 44, 45 and 46). After 300 s the calculated UHI flow rate does not compare well and is controlled by the over-predicted system pressure. The slow calculated rate of system depressurization between 300 and 600 s resulted in a small differential pressure between the UHI accumulator and the upper head. The higher calculated system pressure, therefore, prevented the UHI accumulator from injecting at the observed rate. The remaining accumulator mass injected continuously after 600 s in the calculation as the rate of system depressurization increased. When the broken loop pump suction cleared at 600 s a vapor path was opened to the break. By allowing more vapor to pass through the break the system pressure decreased at a more rapid rate, yielding at larger differential pressure between the UHI accumulator and the upper head, and the accumulator emptied.

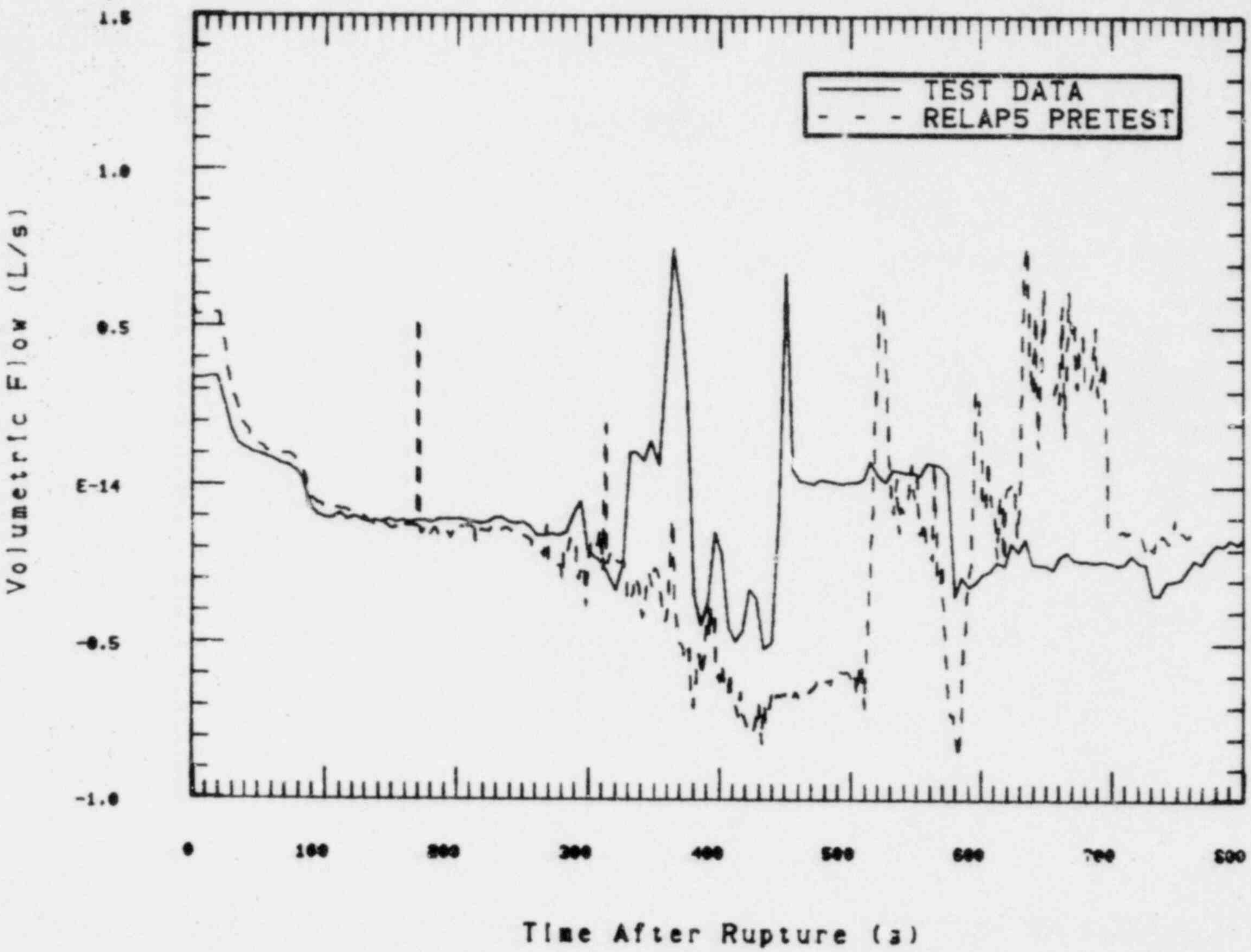


Figure 44. Upper head bypass flow rate.

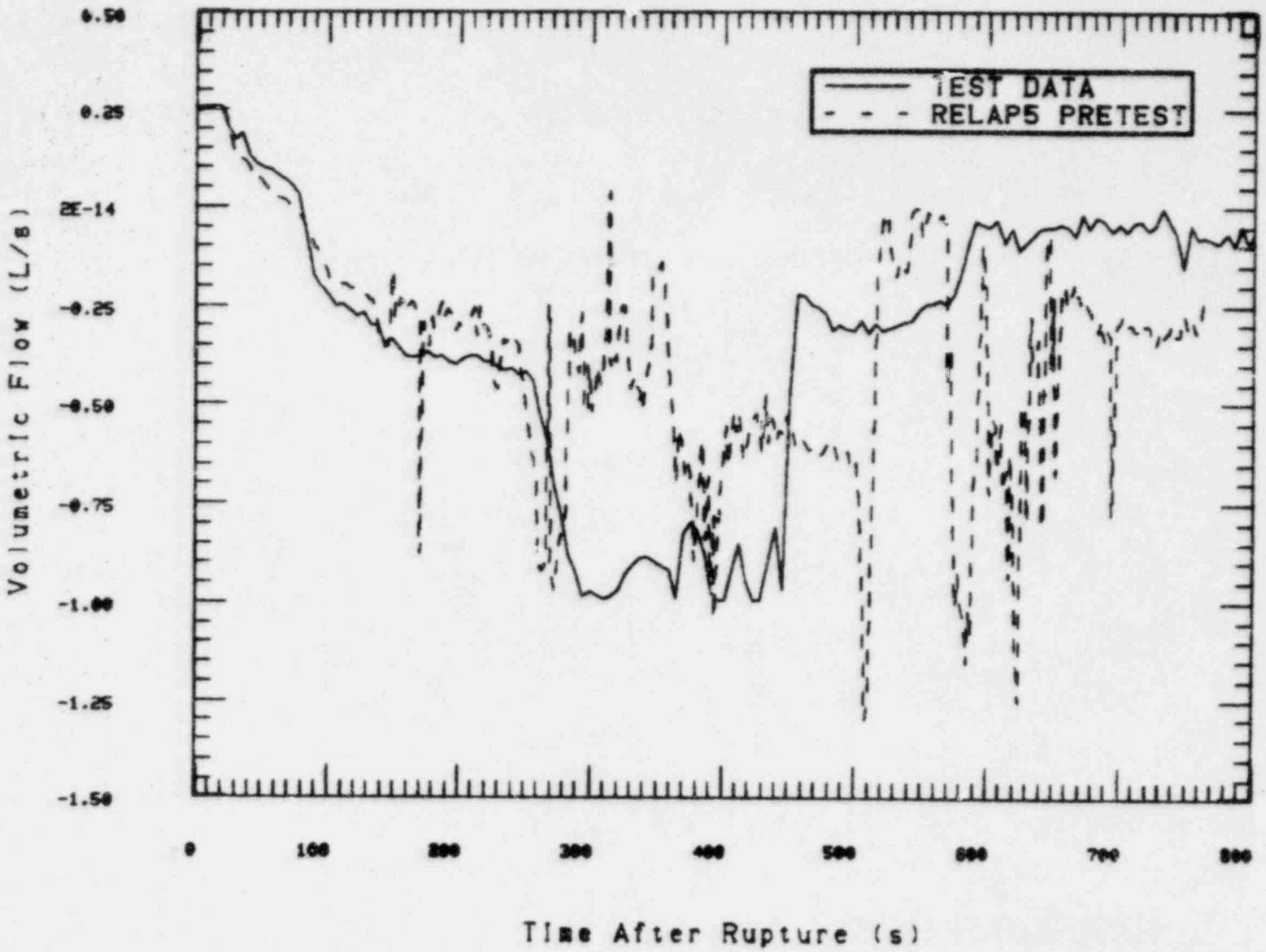


Figure 45. Guide tube mass flow rate.

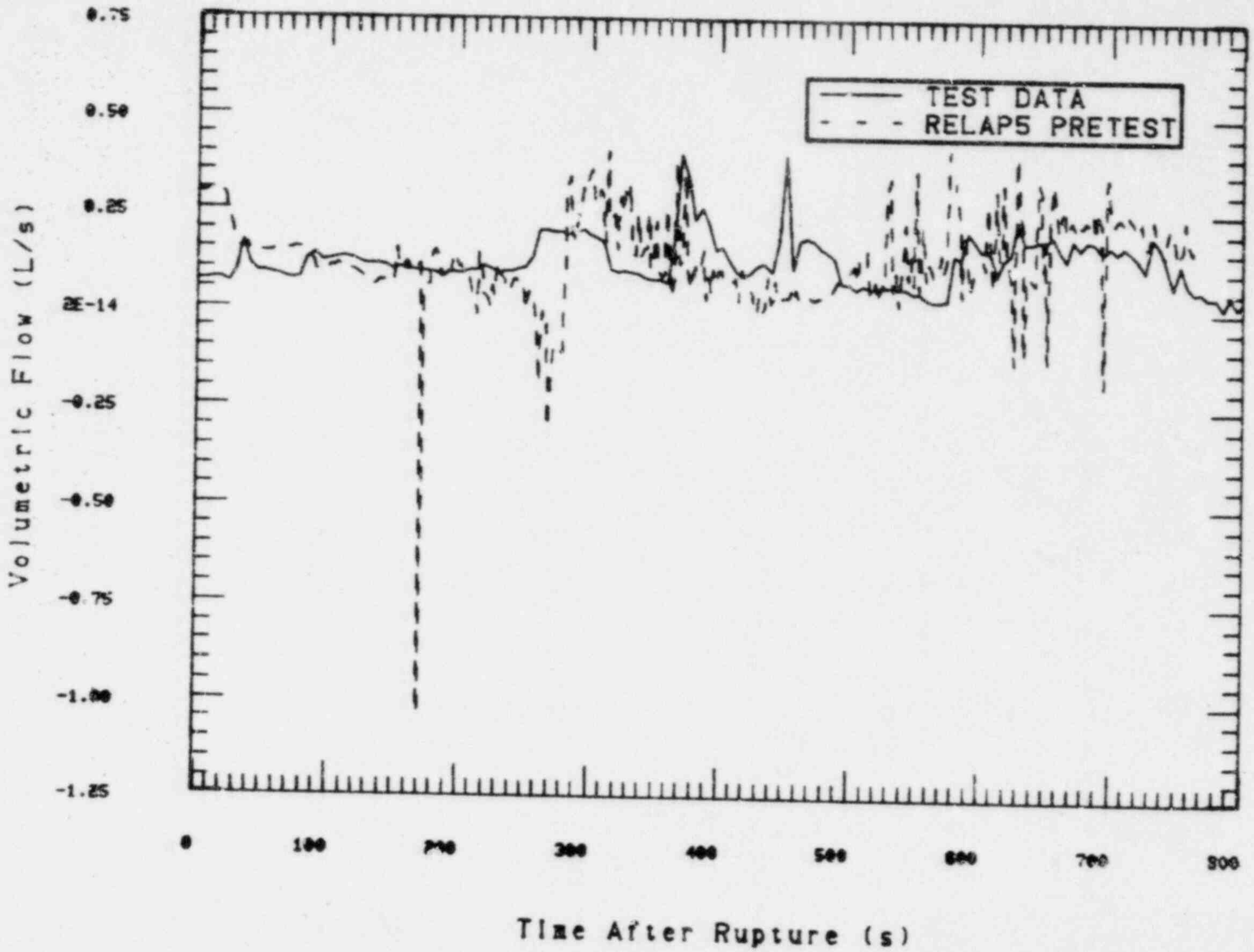


Figure 46. Support column(s) flow rate.

5. CONCLUSIONS

Results from Test S-UT-5 have provided information about system pressure response, fluid mass distribution, core coolability, and ECC injection effects for a 2-1/2%, communicative, cold leg break, loss-of-coolant experiment with upper head and cold leg ECC injection.

The test met its objective of providing thermal-hydraulic data to be used in assessing computer code performance.

Through comparison with results from Test S-UT-4 the influence of UHI on system behavior can be evaluated and further studied.

Injection of UHI fluid during a 2-1/2% cold leg break provides a slightly improved margin against core uncovery. The UHI fluid was found to predominatly flow out the break due to the already high core and downcomer levels during the period of injection.

Results of the RELAP5 pretest prediction calculation generally compared well with test data. Posttest analysis will be required to fully account for deficiencies in the calculation.

6. REFERENCES

1. T. K. Larson, J. L. Anderson, and D. J. Shimeck, Scaling Criteria and an Assessment of Semiscale Mod-3 Scaling for Small Break Loss-of-Coolant Transients, EGG-SEMI-5121, EG&G Idaho, Inc., March 1980.

2. D. J. Shimeck, J. E. Blakeley, and B. W. Murri, Quick Look Report for Semiscale Mod-2A Test S-UT-4, EG&G-SEMI-5429, EG&G Idaho, Inc., April 1981.

3. P. North letter to R. E. Tiller, Experiment Operating Specification (EOS) for Semiscale Mod-2A 2-1/2% Break Experiment, Test S-UT-3, PN-26-81, EG&G Idaho, Inc., March 11, 1981.

4. System Design Description for the Mod-3 Semiscale System (Revision B), EG&G Idaho, Inc., December 1980.

5. P. North letter to R. E. Tiller, Experiment Operating Specification for Semiscale Mod-2A 2-1/2% Break Experiment (S-UT-5), PN-29-81, EG&G Idaho, Inc., March 17, 1981.

6. G. G. Loomis, Summary Report, Semiscale Mod-2A Heat Loss Characteristization Test Series, to be published.

7. P. North ltr to R. E. Tiller, Test Prediction for Semiscale Mod-2A Small Break Test S-UT-5, PN-37-81, EG&G Idaho, Inc., April 6, 1981.

APPENDIX A

The pretest calculation for Semiscale Test S-UT-5[a] was performed using RELAP5/MOD1 (released version 6).[b] A model nodalization diagram used for the calculation is shown in Figure A-1. The model consists of 175 hydrodynamic volumes and 197 heat structures. All volume parameters are calculated with nonequilibrium code models. Break flow multipliers of 0.80 and 0.90 are used for subcooled and two-phase discharge coeffic ents, respectively. Information gained from the Heat Loss Characterization series tests concerning the magnitude and ditribution of system heat losses was incorporated into the model. System guard heaters are powered to offset environmental system heat losses.

---

a. Historical code configuration control number F0C196.

b. Historical code configuration control number F00181.

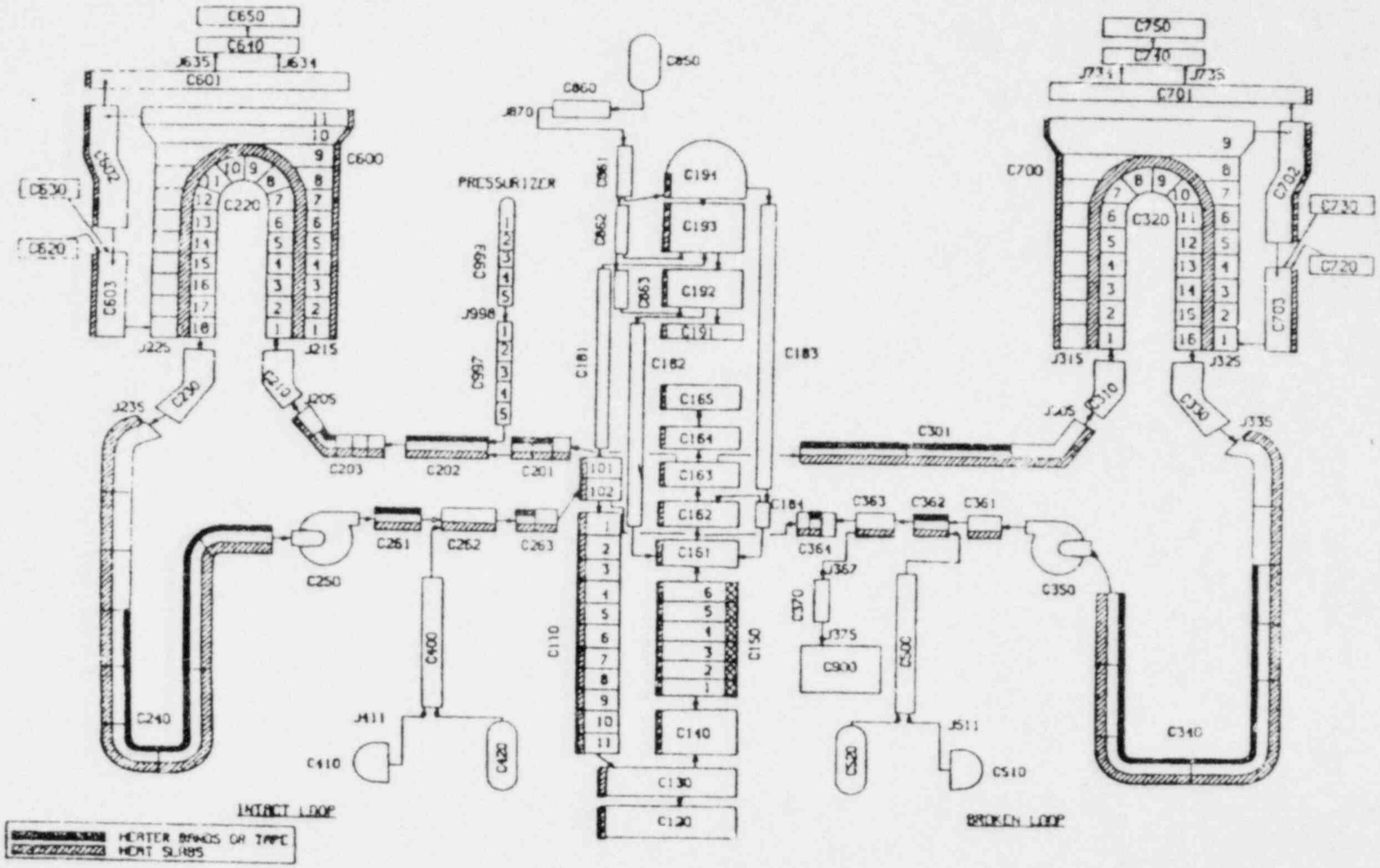


Figure A-1. RELAP nodalization diagram for the Semiscale Mod-2A system.