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# Multiloop Integral System Test (MIST): Final Report

## MIST Phase IV Tests

Prepared by G. O. Geissler/B&W

**Prepared for**
**U.S. Nuclear Regulatory Commission**
**and**
**Electric Power Research Institute**
**and**
**Babcock & Wilcox Owners Group**

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Author

G. O. Geissler

Prepared by

Babcock & Wilcox
Nuclear Power Division
3315 Old Forest Road
Lynchburg, VA 24506-0935

Babcock & Wilcox
Research and Development Division
Alliance Research Center
1562 Beeson Street
Alliance, OH 44601

Prepared for

Division of Systems Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
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Electric Power Research Institute
P.O. Box 10412
Palo Alto, CA 94303

Babcock & Wilcox Owners Group
P.O. Box 10935
Lynchburg, VA 24506-0935

ABSTRACT

The Multiloop Integral System Test (MIST) is part of a multiphase program started in 1983 to address small-break loss-of-coolant accidents (SBLOCAs) specific to Babcock & Wilcox designed plants MIST is sponsored by the U. S. Nuclear Regulatory Commission, the Babcock & Wilcox Owners Group, the Electric Power Research Institute, and Babcock and Wilcox. The unique features of the Babcock & Wilcox design, specifically the hot leg U-bends and steam generators, prevented the use of existing integral system data or existing integral facilities to address the thermal-hydraulic SBLOCA questions. MIST and two other supporting facilities were specifically designed and constructed for this program, and an existing facility--the Once-Through Integral System (OTIS)--was also used. Data from MIST and the other facilities will be used to benchmark the adequacy of system codes, such as RELAP5 and TRAC, for predicting abnormal plant transients.

The MIST Program is reported in 11 volumes. The program is summarized in Volume 1; Volumes 2 through 8 describes groups of tests by test type, Volume 9 presents inter-group comparisons, Volume 10 provides comparisons between the calculations of RELAP5/MOD2 and MIST observations, and Volume 11 presents the later Phase 4 tests. This Volume 11 pertains to MIST Phase IV tests performed to investigate risk dominant transients and non-LOCA events.

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# 1. INTRODUCTION

The Multiloop Integral System Test (MIST) Facility is a scaled 2-by-4 (two hot legs and four cold legs) model of the Babcock & Wilcox lowered-loop nuclear steam supply system. The project was sponsored by the Nuclear Regulatory Commission, the Electric Power Research Institute, the Babcock & Wilcox Owners Group, and Babcock & Wilcox. Experiments performed at the Babcock & Wilcox Alliance Research Center provide integral system data to be used in the verification of predictive best-estimate codes. The Phase III test program, performed from June 1986 through August 1987, examined the impact of the boundary systems, break size and location, feed-and-bleed cooling, steam generator tube rupture, noncondensible gas, and reactor coolant pumps on small-break loss-of-coolant accident (SBLOCA) transients. Additional tests in the Phase IV program explored the current operating procedures for mitigating various accident conditions and investigated possible alternative strategies.

The Phase IV test matrix, shown on Table 1.1., was composed of eight individual tests. The tests included (1) risk dominant transients, (2) steam generator performance, (3) plant transient scaling, and (4) SBLOCA transients.

The MIST facility required modifications for the performance of the Phase IV test matrix. These modifications included (1) adding a scaled low-pressure injection (LPI) system, (2) installing leak sites to simulate reactor coolant pump seal leakage, (3) increasing the cooling capacity at the cold leg discharge leak site and the range of the leak flow rate measurement to accommodate break sizes up to a scaled 100 cm$^2$, and (4) simulating main feedwater (MFW) for flows of approximately 7% of scaled full-power.

The MIST Phase IV testing was performed from September 1987 through December 1987. The Rancho Seco scaling transient was the initial Phase IV test that was conducted. This transient was a forced circulation test, used the reactor coolant pumps, and required the turbine flowmeters for flow rate measurement. These flowmeters were in use at the conclusion of the MIST Phase III Test Program, and since the Rancho Seco scaling transient was the only Phase IV test that required forced circulation, it was scheduled to be the first test performed. All loop modifications and the replacement of the turbine flowmeters with the venturi flowmeters were performed after the Rancho Seco test and before the remaining seven Phase IV tests were conducted.

The Phase IV test matrix provided on Table 1.1 identifies the test type, date conducted, and the test facility modification employed for the test. In addition, reference is made to the Immediate Report that was written for each individual test. The initial conditions for the MIST Phase IV transient tests are listed in Table 1.2 and the steady-state conditions for the steam generator performance test are provided in Table 1.3.

This report provides a description of the MIST test facility, test specifications, test conduct, observations obtained from each test, test comparisons, and a summary of the MIST Phase IV Test Program.

## Table 1.1. MIST Phase IV Test Matrix

| Test Number | Description | Type | Facility Modification Employed | Date Conducted | Immediate Report Number |
|---|---|---|---|---|---|
| 4NOML3 | Nominal Transient With Distorted Core Power | SBLOCA | Low-pressure injection | Nov. 17, 1987 | BAW-2017 |
| 41OAT3 | 10-$cm^2$ SBLOCA Without HPI ATOG Cooldown | Risk dominant and SBLOCA | Low-pressure injection | Nov. 12, 1987 | BAW-1973 |
| 41OBD1 | 10-$cm^2$ SBLOCA Without HPI Steam Generator Blowdown | Risk dominant and SBLOCA | Low-pressure injection | Dec. 1, 1987 | BAW-2019 |
| 4100B2 | Larger SBLOCA, 100 $cm^2$ | SBLOCA | Leak discharge system and low-pressure injection | Dec. 11, 1987 | BAW-2022 |
| 4SB011 | Station Blackout Transient | Risk dominant and SBLOCA | Leak location at reactor coolant pump | Nov. 24, 1987 | BAW-2018 |
| 4SGPF2 | Steam Generator Performance Test | Steam generator performance | Main feedwater | Nov. 19, 1987 | BAW-2025 |
| 4CR3T2 | Crystal River 3 Scaling Transient | Scaling | --- | Dec. 14, 1987 | BAW-202[illegible] |
| 4SEC02 | Rancho Seco Scaling Transient | Scaling | --- | Sept. 25, 1987 | BAW-2057 |

## Table 1.2. MIST Phase IV Test Initial Conditions

| | | 4NOML3 | 41OAT3 | 41OBD1 | 41OOB2 | 4SB011 | 4CR3T2 | 4SEC02 |
|---|---|---|---|---|---|---|---|---|
| **Primary Conditions** | | | | | | | | |
| Core power, kW | | 129.2 | 133.6 | 134.6 | 134.5 | 134.8 | 128.1 | 273.2 |
| Pressure, psia | | 1735 | 1730 | 1743 | 1743 | 2004 | 1908 | 2219 |
| Hot leg inlet temperature, F | Hot leg A | 591 | 592 | 593 | 593 | 594 | 587 | 594 |
| | Hot leg B | 591 | 592 | 594 | 594 | 595 | 589 | 594 |
| Core exit subcooling, F | | 23.4 | 22.6 | 24.2 | 24.1 | 42.8 | 41.7 | 55.0 |
| Reactor vessel inlet temperature, F | | 545 | 544 | 544 | 544 | 544 | 539 | 552 |
| Cold leg flow rate, lbm/h | Cold leg A1 | 1717 | 1747 | 1762 | 1763 | 1751 | 1710 | NA* |
| | Cold leg A2 | 1676 | 1708 | 1721 | 1716 | 1704 | 1673 | NA |
| | Cold leg B1 | 1814 | 1832 | 1836 | 1833 | 1838 | 1818 | NA |
| | Cold leg B2 | 1762 | 1784 | 1793 | 1790 | 1789 | 1774 | NA |
| Pressurizer level, ft | | 22.4 | 23.0 | 22.9 | 22.9 | 23.0 | 21.4 | 24.9 |
| **Secondary Conditions** | | | | | | | | |
| Pressure, psia | Steam generator A | 1014 | 1013 | 1013 | 1013 | 1013 | 986 | 1071 |
| | Steam generator B | 1015 | 1013 | 1013 | 1013 | 1012 | 985 | 1075 |
| Level, ft | Steam generator A | 3.5 | 4.0 | 5.4 | 4.6 | 5.1 | 9.9 | [illegible]7.6 |
| | Steam generator B | 3.5 | 4.2 | 5.2 | 4.7 | 5.4 | 10.0 | 9.6 |
| Feedwater flow rate lbm/h | Steam generator A | 159 | 165 | 170 | 171 | 167 | 160 | [illegible]3** |
| | Steam generator B | 165 | 172 | 173 | 173 | 172 | 162 | [illegible]37** |
| Feedwater temperature, F | Steam generator A | 122 | 119 | 120 | 123 | 113 | 120 | 459** |
| | Steam generator B | 123 | 121 | 121 | 124 | 113 | 121 | 459** |
| Steam flow rate, lbm/h | Steam generator A | 159 | 166 | 170 | 170 | 168 | 159 | 534 |
| | Steam generator B | 163 | 169 | 170 | 171 | 170 | 165 | 540 |
| Steam temperature, F | Steam generator A | 581 | 580 | 580 | 580 | 581 | 576 | 593 |
| | Steam generator B | 581 | 581 | 581 | 581 | 582 | 576 | 593 |

*Downcomer flow rate = 17036 lbm/h.

**Test 4SEC02 used main feedwater. The other tests in this table used auxiliary feedwater.

## Table 1.3. MIST Phase IV Test 4SGPF2 Steady-State Conditions

| | | Main Feedwater Tests | | | | Auxiliary Feedwater Tests | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SG Level 19 ft | SG Level 26 ft | SG Level 33 ft | SG Level 40 ft | SG Level 40 ft | SG Level 33 ft | SG Level 26 ft | SG Level 19 ft |
| **Primary Conditions** | | | | | | | | | |
| Core power, kW | | 258.8 | 259.1 | 258.8 | 259.4 | 258.7 | 259.5 | 258.6 | 259.3 |
| Pressure, psia | | 2246 | 2245 | 2245 | 2246 | 2246 | 2245 | 2245 | 2245 |
| Hot leg inlet temperature, F | Hot leg A | 629 | 617 | 610 | 602 | 603 | 605 | 607 | 607 |
| | Hot leg B | 629 | 616 | 610 | 602 | 603 | 605 | 606 | 607 |
| Core exit subcooling, F | | 22.5 | 35.1 | 40.9 | 48.6 | 47.2 | 45.2 | 44.2 | 43.3 |
| Reactor vessel inlet temperature, F | | 542 | 541 | 541 | 535 | 542 | 542 | 542 | 542 |
| Cold leg flow rate, lbm/h | Cold leg A1 | 1772 | 2124 | 2373 | 2502 | 2687 | 2608 | 2559 | 2525 |
| | Cold leg A2 | 1745 | 2083 | 2316 | 2445 | 2626 | 2545 | 2493 | 2470 |
| | Cold leg B1 | 1893 | 2215 | 2461 | 2576 | 2765 | 2674 | 2612 | 2573 |
| | Cold leg B2 | 1829 | 2172 | 2406 | 2522 | 2706 | 2614 | 2567 | 2503 |
| Pressurizer level, ft | | 24.4 | 22.0 | 24.1 | 22.2 | 22.3 | 22.2 | 22.1 | 21.9 |
| **Secondary Conditions** | | | | | | | | | |
| Pressure, psia | Steam generator A | 1015 | 1005 | 1012 | 1007 | 1009 | 1009 | 1012 | 1013 |
| | Steam generator B | 1009 | 1009 | 1009 | 1009 | 1008 | 1009 | 1009 | 1008 |
| Level, ft | Steam generator A | 19.2 | 26.1 | 33.3 | 40.0 | 40.0 | 33.2 | 26.3 | 19.5 |
| | Steam generator B | 19.[illegible] | 26.1 | 33.3 | 39.9 | 39.9 | 33.0 | 26.5 | 19.2 |
| Feedwater flow rate lbm/h | Steam generator A | 466 | 480 | 487 | 500 | 350 | 357 | 349 | 351 |
| | Steam generator B | 475 | 474 | 485 | 488 | 342 | 341 | 341 | 340 |
| Feedwater temperature, F | Steam generator A | 452 | 451 | 452 | 454 | 119 | 118 | 117 | 118 |
| | Steam generator B | 452 | 451 | 451 | 453 | 120 | 118 | 118 | 118 |
| Steam flow rate, lbm/h | Steam generator A | 467 | 481 | 486 | 501 | 353 | 352 | 352 | 353 |
| | Steam generator B | 485 | 485 | 492 | 497 | 354 | 352 | 353 | 350 |
| Steam temperature, F | Steam generator A | 630 | 617 | 609 | 593 | 579 | 579 | 577 | 577 |
| | Steam generator B | 630 | 617 | 608 | 592 | 583 | 583 | 583 | 583 |

# 2. FACILITY DESCRIPTION

## 2.1. Introduction

MIST was a scaled, 2-by-4 (2 hot legs and 4 cold legs) model of a B&W, lowered-loop, nuclear steam supply system (NSSS). MIST was designed to operate at typical plant pressures and temperatures. Experimental data obtained from this facility during post-SBLOCA testing are used for computer code benchmarking.

The reactor coolant system of MIST was scaled according to the following criteria, listed in order of descending priority: elevation, post-SBLOCA flow phenomena, component volume, and irrecoverable pressure drop. MIST consisted of two 19-tube, once-through steam generators; reactor; pressurizer; 2 hot legs; and 4 cold legs each with a scaled reactor coolant pump.

Other loop components in MIST included a closed secondary system, 4 simulated reactor vessel vent valves (RVVVs), a pressurizer power-operated relief valve (PORV), hot leg and reactor vessel upper-head vents, high-pressure injection, core flood system, and critical flow orifices for scaled leak simulation. Guard heaters, used in conjunction with passive insulation to reduce model heat loss, were included on the steam generator secondaries and on all primary coolant components. The system was also capable of noncondensible gas addition at selected loop sites.

The approximately 850 MIST instruments were interfaced to a computer-controlled, high-speed data acquisition system. MIST instrumentation consisted of measurements of temperature, pressure, and differential pressure. Fluid level and phase indications were provided by optical viewports, gamma densitometers, conductivity probes, and differential pressures. Mass flow rates in the circulation loop were measured using venturis or turbine meters and at the system boundaries using Coriolis flowmeters and weigh scales.

## 2.2. MIST Design

MIST was a scaled, full-pressure, experimental facility arranged to represent the B&W lowered-loop plant design. Like the plant, MIST was a 2-by-4 arrangement with 2 hot legs and 4 cold legs, as shown in Figure 2.1. MIST was designed for prototypical fluid conditions, with emphasis on being leak-tight and minimizing heat loss.

Scaling of MIST followed the approach and priorities used for OTIS[1]; that is, elevation, post-SBLOCA phenomenon, component and piping volumes, and irrecoverable pressure losses. MIST was at full elevation throughout. The only elevations compromised were the top of the pressurizer, the top plenum of the reactor vessel, the inlet and outlet of the steam generator plenums, and several incidental, stagnant fluid zones. Key interfaces were maintained -- these included the hot-leg, U-bend spillover; upper and lower tubesheets of the steam generator (secondary faces); cold-leg low point; pump discharge; cold- and hot-leg nozzles; core (throughout); and points of emergency core cooling system (ECCS) injection.

Two-phase behavior during voiding of the hot-leg U-bend and flow interruption was sufficiently prototypical; that is, both the plant and the model were expected to encounter phase separation early in the post-SBLOCA transient. Hot leg pipes in MIST were large enough to admit bubbly flow.

Fluid volume was 40% larger than power-to-volume scaling would dictate; the hot legs, cold legs, and upper downcomer were oversized. This atypicality was imposed by the previously described two-phase characteristics and by considering component irrecoverable pressure losses. The excess volume of the hot leg slowed the rate of level decrease for power-scaled draining and similarly retarded the rate of level increase for power-scaled injection. Although the excess volume of loop fluid delayed system heatup and cooldown, this effect was minor compared to the long-term impact on system energy of leak versus high-pressure injection (HPI) cooling. The concentration of excess volume in the piping runs decreased fluid velocities in the hot legs and cold legs and therefore lengthened the transit time of loop fluid. Irrecoverable pressure drops were well preserved.

The MIST core and steam generators were full-length subsections of their plant counterparts. As shown on Figure 2.2, the core consisted of a 7-by-7 array of 45 full-length, 0.430-inch-diameter heater rods and four simulated incore guide tubes. Plant-typical fuel pin pitch and grid geometry were used. The simulated rods were capable of full-scale power output but were limited to approximately 10% of scaled power for the planned MIST testing. (The ratio of plant power to MIST power was 1:817.) A fixed, axial heat flux profile (peak-to-average flux ratio ≈ 1.25) and a flat, radial heat flux profile were used.

The steam generators, shown in Figure 2.3, each contained 19 full-length tubes. The tubing diameter (5/8-inch OD), material, and tube bundle's triangular pitch (7/8 inch, tube centerline to centerline) were prototypical. The geometry of the tube support plant (TSP) was similar to the plant and provided equivalent characteristics of irrecoverable pressure loss.

The hot legs used 2.5-inch, schedule-80 piping (2.32 inch ID). This diameter admitted bubbly flow and approximated the irrecoverable pressure loss of a plant hot leg. With the schedule-80 piping, the metal-to-fluid volume ratio in MIST was only 20% greater than that of the plant. The horizontal runs in the hot leg, as noted in Figure 2.1, were approximately 1 foot long to accommodate the gamma densitometers. The hot-leg U-bend maintained pipe diameter; a 1.61-foot bend radius was used to conform to the model system layout. The elevation of the hot leg U-bend spillover was prototypical. Phase separation at the U-bend was predicted to occur at approximately 18% of full power versus 8% in the plant. Beyond the U-bend, the hot leg piping in the model extended 12 feet (versus 1.5 feet in the plant) to span the height of the plant steam generator's inlet plenum.

The four cold legs preserved elevation throughout. Two-inch, schedule-80 piping (1.939-inch ID) was used primarily to match irrecoverable pressure drop. This piping size also preserved the cold-leg Froude number, which influences the mixing of HPI and RVVV fluid streams. The cold leg horizontal piping runs were shortened, but the slope of the plant cold leg discharge piping was approximately maintained. HPI was injected into the sloping pipes at the appropriate elevation; the diameter of the model HPI nozzle was selected to preserve the ratio of fluid momentum between the cold leg and HPI.

A model reactor coolant pump was mounted in each cold leg. Suction and discharge orientations were prototypical. The pumps delivered single-phase scaled flows at plant-typical heads, allowed for simulated pump bumps by matching the plant pump spinup and coastdown times, and permitted operation under single- and two-phase conditions. However, the pumps preserved neither specific speed nor the two-phase degradation characteristics of the plant pumps.

The MIST reactor vessel employed an external annular downcomer, as shown in Figure 2.1. Cold-leg coupling was restricted by using fins in the downcomer annulus to form quadrants, as noted in Figure 2.4. The annular gap was 1.4 inches; the gap at each fin was 0.4 incnes. Each downcomer quadrant was connected to a separate RVVV simulation and cold leg. The two nozzles on the core flood tank were connected at the interface between two downcomer quadrants.

The geometry of the model downcomer was annular down to the elevation of the top of the core. Just above the top of the core, the downcomer was gradually reconfigured to form a single pipe for the remaining elevation. The lower downcomer region obtained roughly power-scaled fluid volume over the elevation of the core. Four model RVVVs were used to simulate eight plant valves.[2] The MIST RVVVs could be controlled individually or in unison. Individual controllers provided automatic actuation of the valves on the upper plenum to downcomer-quadrant pressure differences. The MIST RVVVs thus provided the head-flow response of the plant valves. But partially open operation was not possible in MIST; therefore, detailed valve dynamics of the plant flapper valves were absent.

The MIST pressurizer was power-to-volume scaled and contained heaters and spray. The lower pressurizer elevations were prototypical, as were those of the surge line. The model pressurizer height was reduced from that of the plant to increase the diameter, thus lessening atypical fluid stratification and the likelihood of spray impinging the vessel wall.

One core flood tank was used in MIST. This tank was power-to-volume scaled to represent the two plant tanks. The model tank was installed vertically, with the bottom of the tank at a prototypical elevation. The injection line from the tank to the nozzle on the downcomer was sized to preserve plant-typical irrecoverable losses, and the nozzle was sized to maintain the plant ratio of (core-flood) injected fluid momentum to the downcomer fluid momentum.

## 2.3. Boundary Systems

The MIST boundary systems were sized to power-scale the plant boundary conditions. HPI, LPI, and auxiliary feedwater (AFW) head-flow characteristics were based on composite plant characteristics. Scaled model vents were included in each hot leg and in the reactor vessel upper head. Controlled leaks were located in the cold leg suction and discharge piping and at the upper and lower elevations of steam generator B (for tube rupture simulation). The desired vent and leak flow rates were obtained using critical flow orifices of power-scaled areas.

## 2.4. Heat Losses and Guard Heaters

MIST was designed to minimize heat losses from the reactor coolant system. Fin effects (instrument penetrations through the insulation) were minimized by using 1/4-inch penetrations for most of the instrumentation. Heat losses due to conduction through component supports were minimized by designing the supports to reduce the cross-sectioned area and by placing ceramic blocks between load-bearing surfaces. The reactor coolant system piping and vessel were covered with passive insulation, guard heaters, and a sealed outer jacket (to prevent chimney effects). The insulation arrangement is illustrated in Figure 2.5. The guard heaters were divided into 42 zones, each controlled by a zonal temperature difference and a pipe metal temperature. This system provided a differential temperature control as a function of temperature. Detailed finite-difference analysis of the insulation system indicated that heat loss was strongly dependent on metal temperature and weakly related to fluid state. The control temperature difference required to minimize heat losses was determined experimentally at several loop temperatures.

However, the guard heaters did not compensate for all the loop heat losses. For example, large local losses at the gamma densitometers and viewports were not compensated. Had these local losses been compensated, the requisite increased metal temperature would have generated atypically large metal stored energy. The total MIST primary system heat loss at 650F was approximately 18 kW or 0.55% of scaled full power. This heat loss was attributable to the previously discussed uncompensated heat losses.

## 2.5. Instrumentation

The MIST instrumentation was selected and distributed based on the input from experimenters and code analysts. This instrument selection process considered the needs of code benchmarking, indication of thermal-hydraulic phenomena, and system closure.

The approximately 850 MIST instruments were interfaced to a computer-controlled, high-speed, data acquisition system. MIST instrumentation consisted of measurements of temperature, pressure, and differential pressure. Fluid level and phase indications were provided by optical viewports, conductivity probes, differential pressures, and gamma densitometers. Mass flow measurements at the system boundaries were made using Coriolis flowmeters and weigh scales. Mass flow rate measurements in the loop were performed with venturis or turbines. Tables 2.1 and 2.2 provide a summary of the MIST instrumentation by component and instrument type.

The largest grouping of instrumentation was in the two steam generators. About 250, or 30%, of the instruments were located in these two components. The steam generator instrumentation provided for the measurement of fluid temperature, metal and differential temperature, total guard heater power, differential pressure, gauge pressure, and conductivity (for void determination). The allocation of instruments to the steam generators resulted from the judgement that observations of AFW wetting effects and steam generator heat transfer were of major importance. Several other micro- and multidimensional phenomena were also of considerable interest: noncondensible gas blanketing of primary tubes, intermittent radial advancement of condensation fronts in the region of the AFW nozzle, and boiler-condenser heat transfer in the region of the secondary pool.

The core and RVVV instrumentation measured fluid temperature, metal and differential temperature, total guard heater and core power, conductivity (for void determination), and gauge and differential pressures. The core instrument distribution concentrated on the axially varying parameters. A flat, radial heat flux profile was used in the core, and radial maldistribution of inlet flow was expected to result in only minor variations of enthalpy. Therefore, the majority of the incore temperature instrumentation was located in a single, interior flow channel. Radial temperature variations at the core outlet were recorded, but with a limited number of instruments. The core instrument allocation provided core heat input, inlet and exit fluid properties, and fluid gradients within the reactor vessel. In addition, collapsed levels and regional void fractions were available. Single-phase vent valve mass flow rates were also available.

Downcomer instruments measured fluid temperature, metal and differential temperature, total guard heater power, and differential pressures. Forty fluid thermocouples were concentrated in the upper downcomer, detailing mixing information for the RVVV, core flood, and cold leg streams. Six additional fluid thermocouples were spaced uniformly in the lower downcomer to indicate the extent of mixing as the fluid left the upper downcomer. Downcomer flow rate was measured using a venturi.

Table 2.1. MIST Instrumentation by Component

| Component | Number of Instruments |
|---|---|
| Cold legs | 169 |
| Core flood | 7 |
| Hot legs | 121 |
| Pressurizer | 26 |
| Primary boundary systems | 75 |
| Reactor vessel and core | 155 |
| Steam generators | 259 |
| Steam generator feedwater and steam circuit | 44 |
| TOTAL | 856 |

Table 2.2 MIST Instrumentation by Measurement Type

| Measurement Type | Number of Instruments |
|---|---|
| Conductivity probes | 36 |
| Cooled thermocouple | 4 |
| Differential pressure | 136 |
| Differential temperature | 42 |
| Fluid temperature | 392 |
| Gamma densitometer | 12 |
| Limit switches | 80 |
| Mass flow | 9 |
| Metal temperature | 69 |
| Miscellaneous | 15 |
| Power | 48 |
| Pressure | 9 |
| Volumetric flow | 4 |
| TOTAL | 856 |

Cold leg instrumentation provided fluid and metal temperatures, differential temperatures, total guard heater power, and differential pressures. Gamma densitometers were also used. Cold leg flow rates were measured using venturis located in the suction piping of each cold leg. For tests requiring full forced flow, turbines were used in place of the venturis. In addition, the reactor coolant pump power, speed, and head rise were measured.

Special instrument groupings, thermocouple rakes, and gamma densitometers were installed in the cold legs upstream and downstream of the HPI injection points to indicate thermal stratification, density, and void fraction near the junction of the cold legs and downcomer.

Hot leg instrumentation measured fluid and metal temperatures, differential temperatures, total guard heater power, and differential pressures. Void measurements using gamma densitometers and conductivity probes were also made. In addition, viewports provided visual data to assess the local flow regime. The density of the hot leg instruments provided detailed fluid temperature gradients, local void fractions, and overall collapsed level. A conductivity probe, combined with local differential pressures in the U-bend region, provided additional information regarding loop refill and spillover. Gamma densitometers in the hot leg horizontals downstream of the reactor vessel's outlet nozzle and viewports in the 29-foot elevation and at the U-bend high points provided information regarding fluid state and flow conditions. A fifth and sixth viewport in the hot leg horizontals near the densitometers probed the developing flow regimes upstream of the vertical hot leg piping.

The boundary systems, which included HPI, LPI, leaks, vents, and gas addition, were provided with fluid thermocouples, absolute and differential pressure transmitters, mass flowmeters, and weigh scales. These instruments provided mass and energy closure for the facility. Additional information regarding the design and instrumentation of MIST may be found in the Facility Specification[3] and in the Instrument Report.[4]

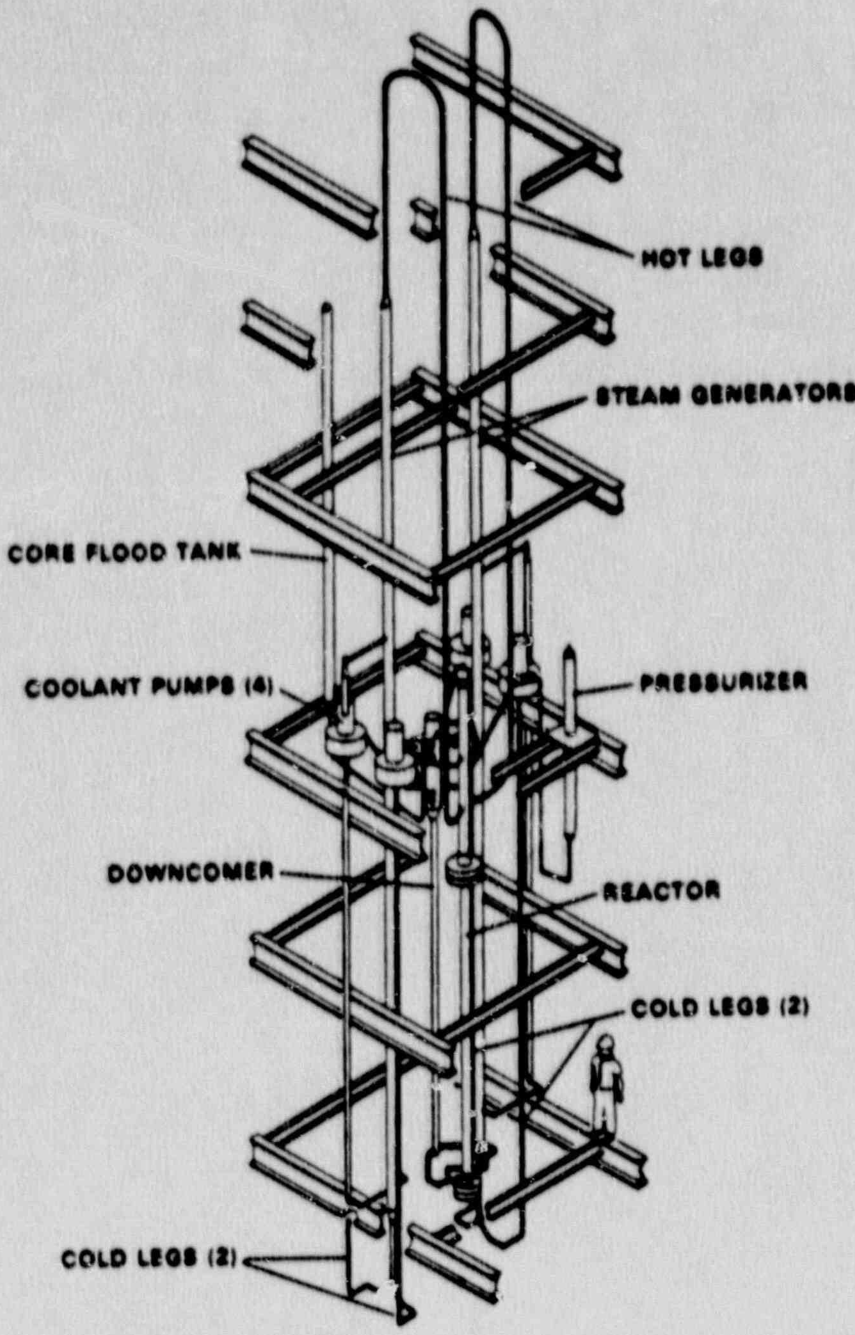



Figure 2.1. Reactor Coolant System -- MIST

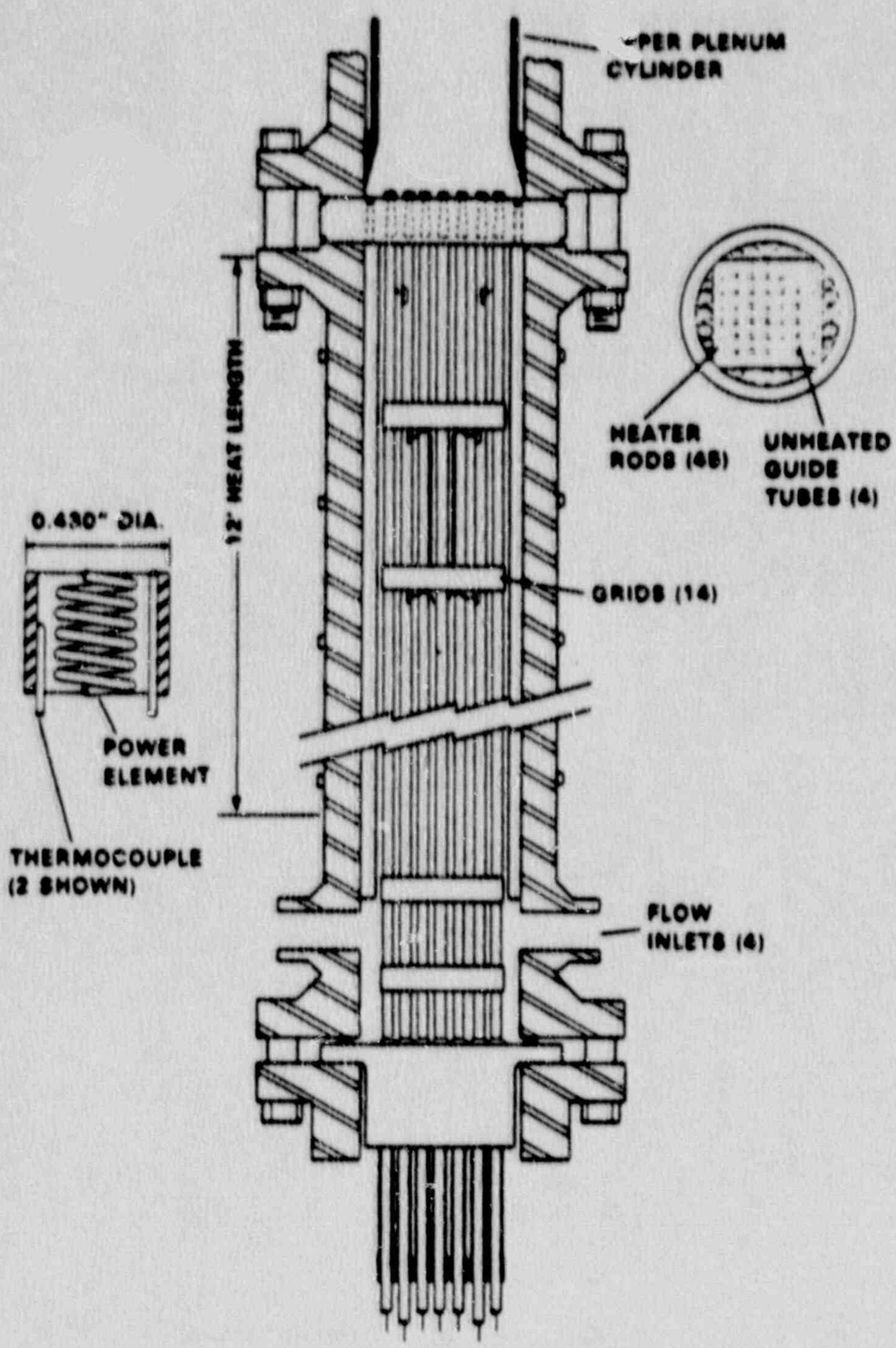



Figure 2.2. MIST Core Arrangement

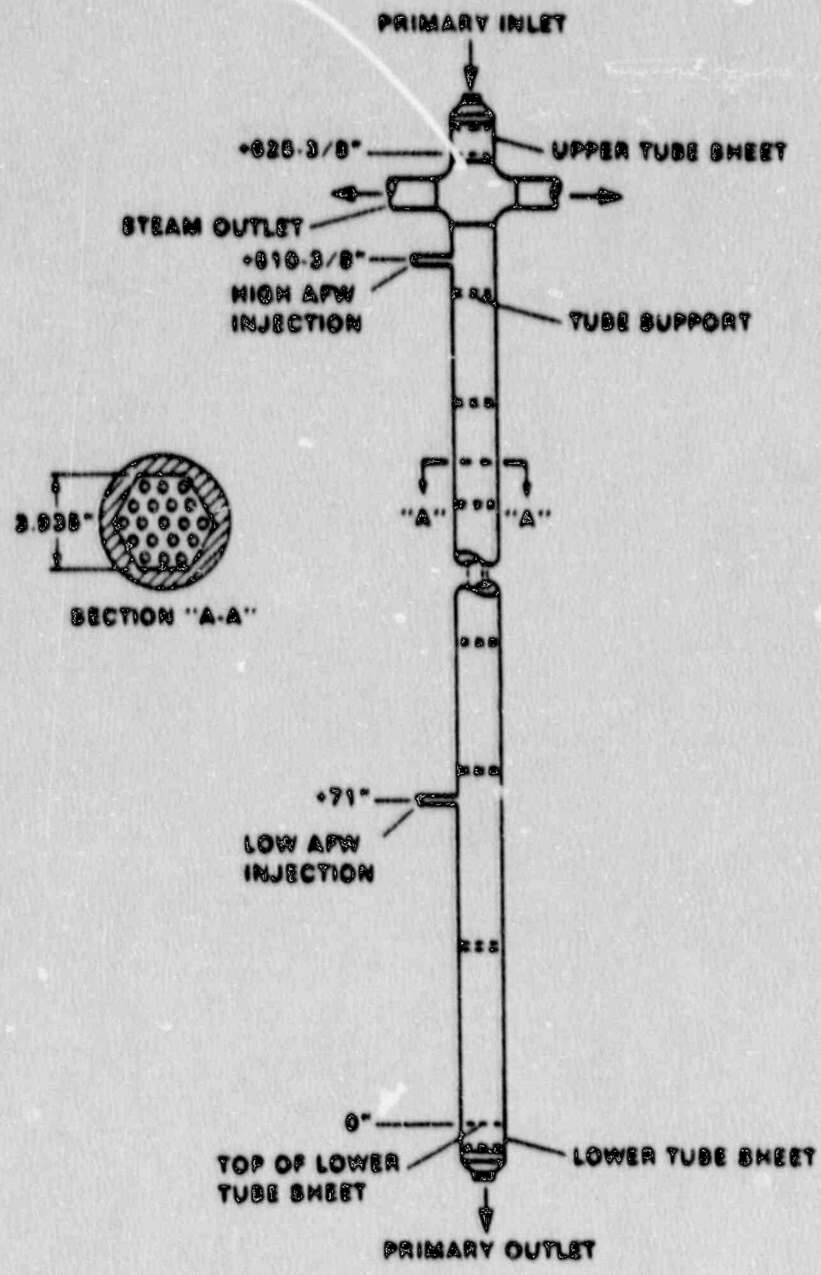



Figure 2.3. Nineteen-Tube, Once-Through Steam Generator

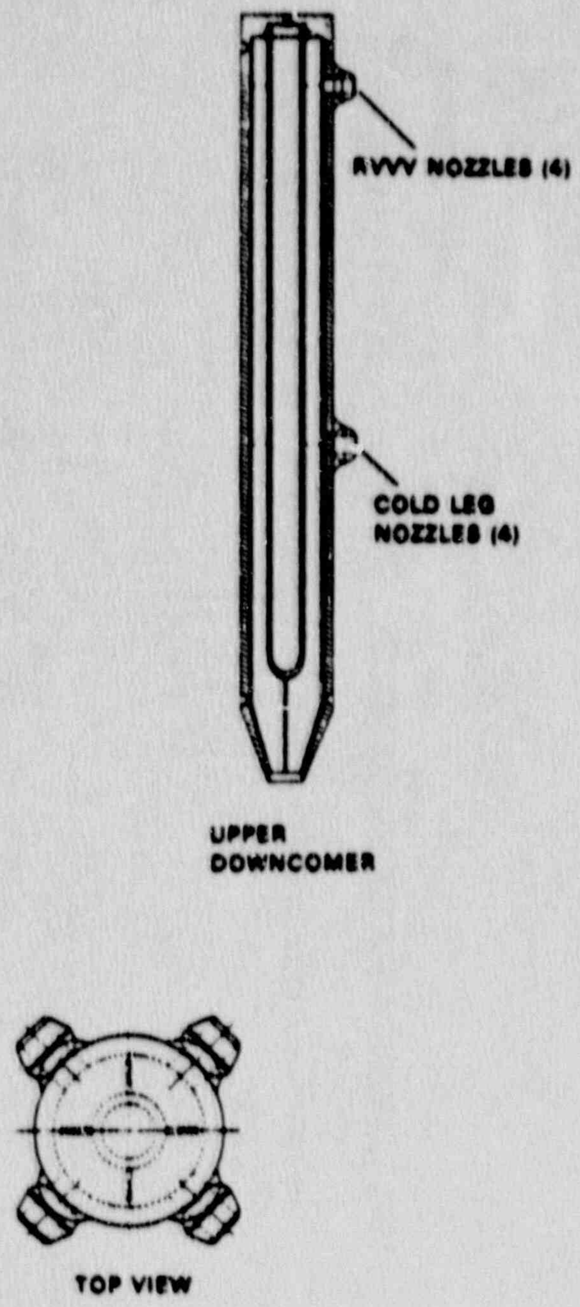



Figure 2.4. Upper Downcomer Arrangement

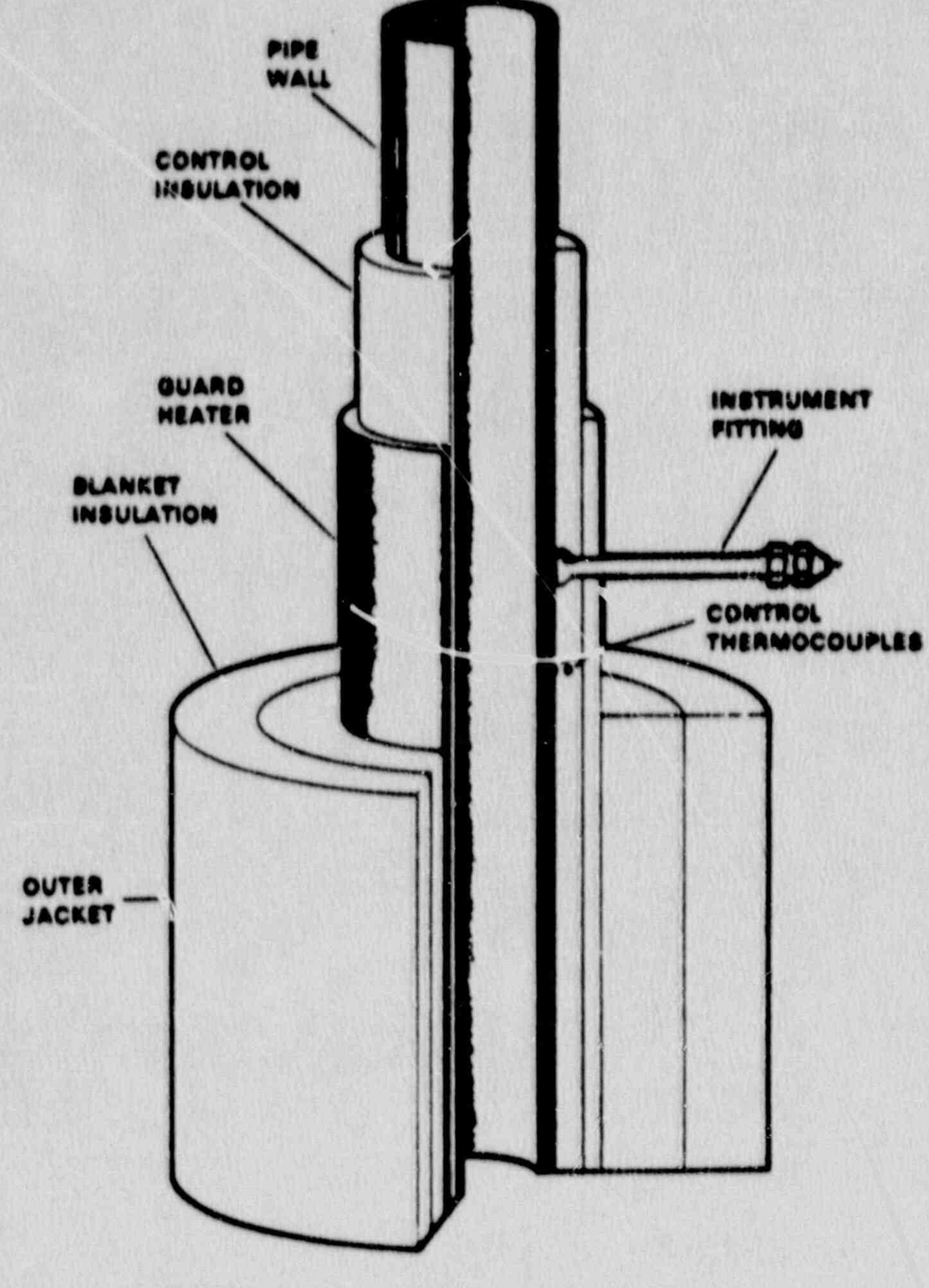



Figure 2.5. MIST Insulation Arrangement

# 3. TEST SPECIFICATIONS

The specifications for the MIST Phase IV tests have been extracted from the MIST Phase IV Test Specifications, BAW-2020, April 1988 (reference 5). The test specifications in this section are presented in the same order as the test observations are presented in section 5.

## 3.1. Test 4NOML3 -- Nominal Transient with Distorted Core Power

Test 4NOML3 is a repeat of the MIST Phase III Nominal Test with modified post-trip power and ATOG cooldown rates. This test complements the Phase III results, as well as the two scaling transient tests that feature the similar modified core power conditions. The LPI system, added to the MIST facility for Phase IV, will provide a more realistic simulation of the ECCS during low reactor coolant system (RCS) pressure than was previously available.

### 3.1.1. Purpose

This test provides data for a 10-cm$^2$ break LOCA. The test is to be initialized and performed so that the results can be compared to the MIST Nominal Test. The results will be useful in providing benchmarking data for the code analysts and will provide insight into the scaling compromises that are known to exist in the facility. In particular, the piping and steam generator metal masses, the total primary system volume, and AFW wetting atypicalities are believed to have the greatest likelihood of influencing the test results. In order to compensate for the excess primary fluid volume of the facility, a time distortion will be applied to the core power function. Many of the major post-SBLOCA phenomena are anticipated to be experienced. These phenomena include depressurization to saturation, intermittent and interrupted loop flow, BCM, refill, and post-refill cooldown. However, the timing for each phenomenon and the mechanisms by which the transient is concluded are expected to be dissimilar to those of the Nominal Test.

### 3.1.2. Steady-State Pretest Conditions

The loop is to be in the natural circulation testing configuration i.e., with the venturi flowmeters installed and the turbine meters removed. The system is to be held in steady state for 10 minutes or more prior to test initiation. The initial conditions for this steady-state period are listed in Table 3.1. Specified as well as derived conditions are provided. The derived conditions are for information only and should not be interpreted as control parameters. The primary is to be in subcooled natural circulation at 3.5% of full power plus 0.4% to offset the losses to ambient (see Table 3.2 for conversion factors). This augmentation is the same as was used in the Phase III Nominal test but different than that used in other Phase IV tests and will result in slightly different initial conditions. The secondary pressures are to be 1010 psia. The pressurizer is controlled to obtain approximately 1750 psia primary pressure with a 4.6-ft level within the pressurizer [22.6 ft relative to the secondary face lower tubesheet (SFLTS)]. The pressurizer spray control valve is manually closed. The PORV is in the automatic overpressure control mode as described in Appendix E of reference 6. The resulting primary flow rate will be approximately 4% of full primary flow with cold leg temperatures of approximately 550F. The primary boundary systems are inactive. The RVVVs are manually closed. The core flood tank is charged to 600 psia using nitrogen as a cover gas with a level of 42.8 ft and has been recirculated (the MIST core flood tank is kept isolated until the primary system depressurizes below 650 psia). The steam generator secondaries are initialized with auxiliary feedwater. The secondary levels are maintained at 3.5 ft, using the high-elevation minimum-wetting feedwater nozzles. The feedwater temperature is approximately 110F. The primary power-to-flow ratio will be approximately unity, obtaining a hot leg fluid temperature of about 595F. The initial primary subcooling is then the saturation temperature at 1750 psia (617F) less the hot leg temperature, or 22F. If the actual initial hot leg temperature results in an initial subcooling other than 22F, then the initial primary pressure is to be adjusted to obtain 22F subcooling. The surge line fluid temperature is to be within 5F of the hot leg temperature. As an indication of steady-state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively.

Table 3.1. Test 4NOML3. Initial Conditions

| Quantity | Specification | Tolerance (+/-) | Derived * |
|---|---|---|---|
| Core power** | 3.5% | 0.05 | |
| Primary flow | | | 4% |
| Primary pressure | | | 1750 psia |
| Hot leg inlet temperature | | | 595F |
| Cold leg exit temperature | | | 550F |
| Core exit subcooling | 22F | 2 | |
| Pressurizer level*** | 22.6 | 0.2 | |
| Surge line temperature | Hot leg temp., F | 5 | |
| Secondary flow | | | 2% |
| Secondary pressure | 1010 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary levels*** | 3.5 | 1 | |
| Core flood tank pressure | 600 psia | 10 | |
| Core flood tank level*** | 42.8 ft | 0.3 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.4% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

Table 3.2. Nominal Test Conversion Factors

| | | | |
|---|---|---|---|
| Core Power | 1% Scaled Full Power | = | 33 kW |
| Primary Flow | 1% Scaled Full Flow | = | 1660 lbm/h |
| Secondary Flow | 1% Scaled Full Flow | = | 138 lbm/h |

### 3.1.3. Initiation

The test is started after recording at least 10 minutes of steady-state data. The test is initiated by performing the following actions:

1. Open the 10-$cm^2$ B1 CLD leak. Use the same leak orifice as Test 3109AA.

2. Log the test initiation time.

3. Confirm that the pressurizer heaters have tripped on low level.

After the pressurizer has drained to 18.9 ft (SFLTS), the following actions should be performed as simultaneous as possible i.e., within an elapsed time of approximately 20 seconds.

1. Actuate the auxiliary feedwater system to raise the steam generator secondary levels to 31.6 ft.

2. Actuate the high-pressure injection system.

3. Actuate the core power decay ramp.

4. Switch control of the reactor vessel vent valves from manual to automatic "independent" control (open/close setpoints of 0.125/0.04 psi).

5. Actuate the ATOG secondary pressure control as described in Appendix C of reference 1 but with a cooldown rate of 74F/h when the temperature difference is greater than 0 but less than 50F. In addition, the depressurization rate whenever the temperature difference is less than 0F is to be 37 psi/min.

6. Actuate the low-pressure injection system.

7. Actuate constant secondary level control when secondary levels reach 31.6 ft.

The core power decay function (see Figure 3.1 and Table 3.3) is modified, distorting time by a factor of 1.36, which is the MIST-to-ideal primary fluid volume ratio.

### 3.1.4. Control During Testing

The boundary system simulations activated during test initiation are largely automated and will be identical to those used on the MIST Phase III Nominal Test, with the addition of the low-pressure injection system characterized by Figure 3.2 and Table 3.4. Manual control of the PORV after automatic

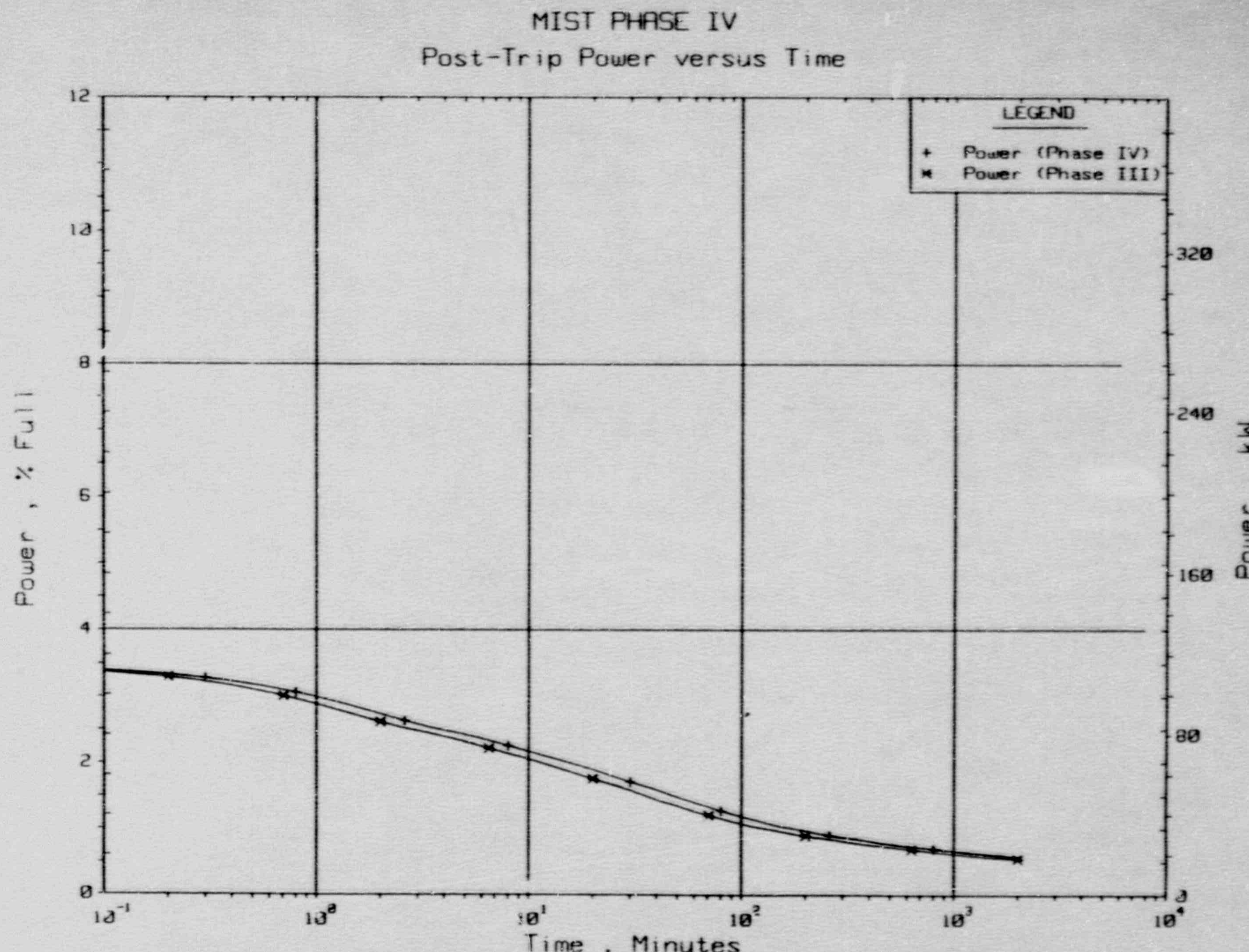



Figure 3.1 Post-Trip Power Vs Time

Tue Feb 16 11 31 40 1988

dh plot

Table 3.3. Test 4NOML3, Post-Trip Power

| Time (min) | Power (%) |
|---|---|
| 0.1 | 3.9101 |
| 0.2 | 3.7990 |
| 0.3 | 3.6993 |
| 0.4 | 3.6098 |
| 0.5 | 3.5293 |
| 0.6 | 3.4568 |
| 0.7 | 3.3912 |
| 0.8 | 3.3314 |
| 0.9 | 3.2764 |
| 1.0 | 3.2256 |
| 1.1 | 3.1784 |
| 1.2 | 3.1345 |
| 1.4 | 3.0555 |
| 1.6 | 2.9860 |
| 1.8 | 2.9237 |
| 2.0 | 2.8675 |
| 2.5 | 2.7496 |
| 3.0 | 2.6579 |
| 3.5 | 2.5867 |
| 4.0 | 2.5318 |
| 5.0 | 2.4583 |
| 6.0 | 2.3960 |
| 7.0 | 2.3369 |
| 8.0 | 2.2828 |

Table 3.3. Test 4NOML3, Post-Trip Power (Cont'd)

| Time (min)* | Power (%)** |
|---|---|
| 9.0 | 2.2340 |
| 10.0 | 2.1905 |
| 20.0 | 1.9123 |
| 40.0 | 1.6036 |
| 60.0 | 1.4076 |
| 80.0 | 1.2796 |
| 100.0 | 1.1912 |
| 200.0 | 0.96734 |
| 300.0 | 0.86843 |
| 400.0 | 0.81359 |
| 500.0 | 0.76772 |
| 600.0 | 0.74014 |
| 700.0 | 0.71849 |
| 800.0 | 0.69791 |
| 900.0 | 0.67932 |
| 1000.0 | 0.66385 |

*Time zero is actual decay power at 1 minute 40 seconds after reactor trip divided by 1.36.

**Power is calculated by the relationship

P = P (Time/1.36 + 1.667)

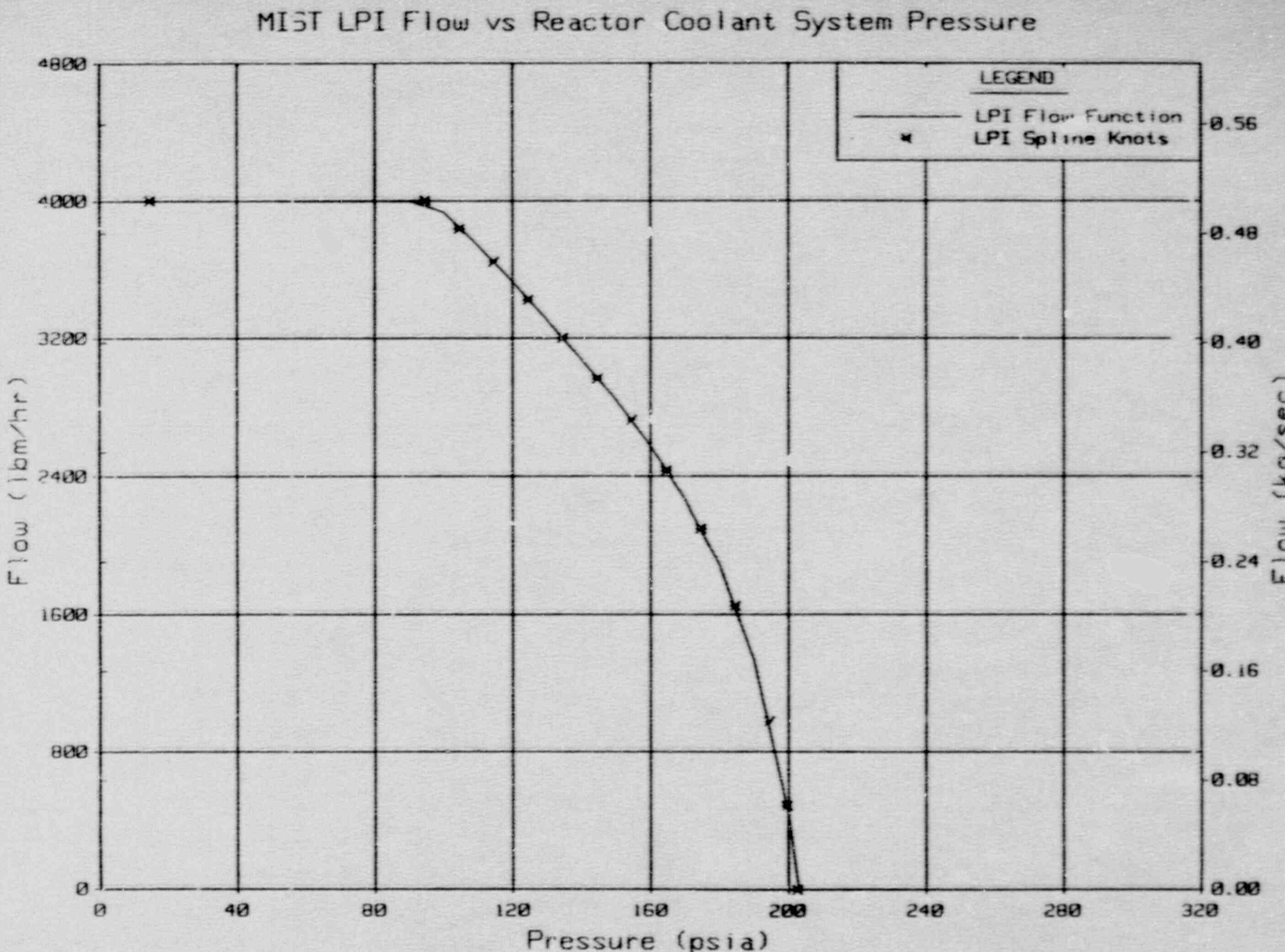



Figure 3.2 MIST LPI Flow Vs Reactor Coolant System Pressure

Table 3.4. MIST Low-Pressure Injection Characteristics

| RCS Pressure (psia) | LPI Flow (lbm/h) |
|---|---|
| 10 | 4002 |
| 20 | 4002 |
| 30 | 4002 |
| 40 | 4002 |
| 50 | 4002 |
| 60 | 4002 |
| 70 | 4002 |
| 80 | 4002 |
| 90 | 4002 |
| 100 | 3936 |
| 110 | 3736 |
| 120 | 3526 |
| 130 | 3306 |
| 140 | 3076 |
| 150 | 2840 |
| 160 | 2575 |
| 170 | 2267 |
| 180 | 1884 |
| 190 | 1333 |
| 200 | 441 |
| 203 | 0 |

opening, HPI throttling upon loss of subcooling margin (SCM), as well as core flood tank (CFT) isolation are to be performed as outlined in reference 6.

### 3.1.5. Termination

The test may be terminated based on specific loop conditions, but delayed at the discretion of the test engineer. The termination time is to be entered into the test log. The test may be terminated if any of the following conditions are satisfied:

1. If the RCS pressure is less than 200 psia continuously for 2 hours.
2. If 11 hours have passed since leak initiation.

The entire loop should be refilled prior to termination in order to complete the mass closure calculations. Therefore, if the second termination criterion is required, then refill of the loop should be attempted for 30 minutes using the available boundary system simulations. If refill is not achieved after 30 minutes, then the primary system is to be refilled without regard to the constraints of the boundary systems.

### 3.1.6. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.
2. Test initiation is performed as specified.
3. The specified boundary system control settings are maintained throughout the test.
4. Test termination is performed as specified.
5. All critical instrument data as specified in Appendix F of reference 6 and Table 3.5 are recorded at intervals of 10 seconds or less throughout the test.

Table 3.5. Additional Critical Instrumentation

| | | |
|---|---|---|
| LPLS01 | - | LPI isolation valve limit switch |
| LPMM01 | - | LPI total mass flow rate |
| LPMM21 | - | LPI total mass |
| LPTC01 | - | LPI fluid temperature |

## 3.2. Test 410AT3 -- 10-$cm^2$ SBLOCA Without HPI, ATOG Cooldown

Test 410AT3 examines an SBLOCA transient without the benefit of the high-pressure injection system (HPI). The ultimate refill and stabilization of the loop must be accomplished by the core flood and LPI system, which has been added to the MIST facility for Phase IV testing. The Phase IV test matrix includes two tests of this type. The first test, 410AT3, will include a 10-$cm^2$ leak and utilize standard abnormal transient operating guideline (ATOG) control schemes i.e., constant steam generator secondary level and ATOG secondary pressure control. In the second test, 410BD1, a different steam generator secondary pressure strategy will be employed. The operator will start a 50-psi/min blowdown of the secondary system 30 minutes after test initiation.

### 3.2.1. Purpose

This test examines the impact of the absence of HPI system flow on the MIST Nominal Test i.e., a 10-$cm^2$ B1 CLD leak, full auxiliary feedwater (AFW) and LPI, no noncondensible gas (NCG), reactor coolant pumps (RCPs) not available, automatic RVVV actuation on differential pressure, automatic guard heater control, constant steam generator level control (after steam generator refill), and symmetric steam generator cooldown. The test is to be initialized and performed so that the results can be compared to the MIST Nominal Test. Many of the major post-SBLOCA phenomena are anticipated to be experienced. These phenomena include depressurization to saturation, intermittent and interrupted loop flow, BCM, refill, and post-refill cooldown. However, the timing for each phenomenon as well as the mechanisms by which the transient is concluded are expected to be dissimilar to those of the Nominal Test.

### 3.2.2. Steady-State Pretest Conditions

The loop is to be in the natural circulation testing configuration i.e., with the venturi flowmeters installed and the turbine meters removed. The system is to be held in steady state for 10 minutes or more prior to test initiation. The initial conditions for this steady-state period are listed in Table 3.6. The primary is to be in subcooled natural circulation at 3.5% of

Table 3.6. Test 410AT3, Initial Conditions

| Quantity | Specification | Tolerance (+/-) | Derived * |
|---|---|---|---|
| Core power** | 3.5% | 0.05 | |
| Primary flow | | | 4% |
| Primary pressure | | | 1750 psia |
| Hot leg inlet temperature | | | 595F |
| Cold leg exit temperature | | | 550F |
| Core exit subcooling | 22F | 2 | |
| Pressurizer level*** | 22.6 ft | 0.2 | |
| Surge line temperature | Hot leg temp., F | 5 | |
| Secondary flow | | | 2% |
| Secondary pressure | 1010 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary levels*** | 5 ft | 1 | |
| Core flood tank pressure | 600 psia | 10 | |
| Core flood tank level*** | 42.8 ft | 0.3 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

full power plus 0.57% to offset the losses to ambient (see Table 3.2 for conversion factors). This augmentation is greater than that used in the Phase III Nominal Test (0.4%) and will result in slightly different initial conditions. The secondary pressures are to be 1010 psia. The pressurizer is controlled to obtain approximately 1750 psia primary pressure with a 4.6-ft level within the pressurizer (22.6 ft relative to SFLTS). The pressurizer spray control mode is described in Appendix E of reference 6. The resulting primary flow rate will be approximately 4% of full primary flow, with cold leg temperatures of approximately 550F. The primary boundary systems are inactive. The RVVVs are manually closed. The core flood tank is charged to 600 psia using a nitrogen cover gas with a level of 42.8 ft and has been recirculated (the MIST core flood tank is kept isolated until the primary system depressurizes below 650 psia). The steam generator secondaries are initialized with auxiliary feedwater. The secondary levels are maintained at 5 ft using the high-elevation minimum-wetting feedwater nozzles. The feedwater temperature is approximately 110F. The primary power-to-flow ratio will be approximately unity, obtaining a hot leg fluid temperature of about 595F. The initial primary subcooling is then the saturation temperature at 1750 psia (617F) less the hot leg temperature, or 22F. If the actual initial hot leg temperature results in an initial subcooling other than 22F, then the initial primary pressure is to be adjusted to obtain 22F subcooling. The surge line fluid temperature is to be within 5F of the hot leg temperature. As an indication of steady state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively.

### 3.2.3. Initiation

The test is started after recording at least 10 minutes of steady-state data. The test is initiated by performing the following actions:

1. Open the 10-cm$^2$ B1 CLD leak.
2. Log the test initiation time.
3. Confirm that the pressurizer heaters have tripped on low level.

After the pressurizer has drained, the following actions should be performed as simultaneous as possible i.e., within an elapsed time of approximately 20 seconds.

1. Actuate the auxiliary feedwater system to raise the steam generator secondary levels to 31.6 ft.

2. Actuate the core power decay ramp.

3. Switch control of the reactor vessel vent valves from manual to automatic "independent" control (open/close setpoints of 0.125/0.04 psi).

4. Actuate the ATOG secondary pressure control as described in Appendix C of reference 6.

5. Actuate the low-pressure injection system.

6. Actuate constant secondary level control.

3.2.4. Control During Testing

The boundary system simulations activated during test initiation are largely automated and will be identical to those used on the MIST Nominal Test, with the addition of the low-pressure injection system characterized by Figure 3.2 and Table 3.4.

3.2.5. Termination

The test may be terminated based on specific loop conditions, but delayed at the discretion of the test engineer. The termination time is to be entered into the test log. The test may be terminated if any of the following conditions are satisfied:

1. If the RCS pressure is less than 200 psia continuously for 2 hours.

2. If 7 hours have passed since leak initiation.

For the second condition, the HPI system should be activated to fill the loop before data acquisition is interrupted in order to complete mass closure calculations. If HPI is required to accomplish refill, then the MIST HPI simulation as described in Appendix B of reference 6 should be employed. Refill of the loop should be attempted for 30 minutes using the available boundary systems simulations. If refill is not achieved after 30 minutes, then the primary system is to be refilled without regard to the constraints of the boundary systems.

3.2.6. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.

2. Test initiation is performed as specified.

3. The specified boundary system control settings are maintained throughout the test.

4. Test termination is performed as specified.

5. All critical instrument data as specified in Appendix F of reference 6 and Table 3.5 are recorded at intervals of 10 seconds or less throughout the test.

## 3.3. Test 410BD1 -- 10-cm$^2$ SBLOCA Without HPI, Steam Generator Blowdown

Test 410BD1 is the second of two tests that examine an SBLOCA transient without the benefit of the HPI system. The ultimate refill and stabilization of the loop must be accomplished by the core flood and LPI system, which has been added to the MIST facility for Phase IV testing. The first test, 410AT3 described in Section 3.2, included a 10-cm$^2$ leak and utilized standard ATOG control schemes i.e., constant steam generator secondary level and ATOG secondary pressure control. In Test 410BD1, a different steam generator secondary control strategy will be employed. The operator will start a 50-psi/min blowdown of the secondary system 30 minutes into the transient. The 30-minute wait approximates the time required for a plant operator to determine that HPI will not be available and that an alternative cooldown strategy is necessary. A reactor coolant pump bump will be simulated at the end of the test to enhance the current information on this procedure.

### 3.3.1. Purpose

This test examines the impact of a more aggressive depressurization of the secondary system in place of the normal ATOG secondary pressure control scheme following a 10-cm$^2$ B1 CLD leak. The test is similar to the MIST Nominal Test in that a 10-cm$^2$ B1 CLD leak with full AFW and LPI, RCPs initially unavailable, automatic RVVV actuation, and constant steam generator level control (after steam generator refill) will be simulated. However, HPI flow will be unavailable as in Test 410AT3. The test is to be initialized and performed so that the results can be compared to the MIST Nominal Test. Many of the major post-SBLOCA phenomena are anticipated to be experienced. The phenomena include depressurization to saturation, intermittent and interrupted loop flow, BCM, refill and post-refill cooldown. However, the timing for each phenomenon and the mechanisms by which the transient is concluded are expected to be dissimilar to those of the Nominal Test.

### 3.3.2. Steady-State Pretest Conditions

The loop is to be in the natural circulation testing configuration i.e., with the venturi flowmeters installed and the turbine meters removed. The system is to be held in steady state for 10 minutes or more prior to test initiation. The initial conditions for this steady-state period are listed in Table 3.7. The primary is to be in subcooled natural circulation at 3.5% of full power plus 0.57% to offset the losses to ambient (see Table 3.2 for conversion factors). This augmentation is greater than that used in the Phase III Nominal Test (0.4%) and will result in slightly different initial conditions. The secondary pressures are to be 1010 psia. The pressurizer is controlled to obtain approximately 1750 psia primary pressure with a 5.0-ft level within the pressurizer (23.0 ft relative to SFLTS). The pressurizer spray control valve is manually closed. The PORV is in the automatic overpressure control mode as described in Appendix E of reference 6. The resulting primary flow rate will be approximately 4% of full primary flow, with cold leg temperatures of approximately 550F. The primary boundary systems are inactive. The RVVVs are manually closed. The core flood tank is charged to 600 psia using a nitrogen cover gas with a level of 42.8 ft and has been recirculated (the MIST core flood tank is kept isolated until the primary system depressurizes below 650 psia). The steam generator secondaries are initialized with auxiliary feedwater. The secondary levels are maintained at 5 ft using the high-elevation minimum-wetting feedwater nozzles. The feedwater temperature is approximately 110F. The primary power-to-flow ratio will be approximately unity, obtaining a hot leg fluid temperature of about 595F. The initial primary subcooling is then the saturation temperature at 1750 psia (617F) less the hot leg temperature, or 22F. If the actual initial hot leg temperature results in an initial

Table 3.7. Test 410BD1, Initial Conditions

| Quantity | Specification | Tolerance (+/-) | Derived* |
|---|---|---|---|
| Core power** | 3.5% | 0.05 | |
| Primary flow | | | 4% |
| Primary pressure | | | 1750 psia |
| Hot leg inlet temperature | | | 595F |
| Cold leg exit temperature | | | 550F |
| Core exit subcooling | 22F | 2 | |
| Pressurizer level*** | 23.0 ft | 0.2 | |
| Surge line temperature | Hot leg temp., F | 5 | |
| Secondary flow | | | 2% |
| Secondary pressure | 1010 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary levels*** | 5 ft | 1 | |
| Core flood tank pressure | 600 psia | 10 | |
| Core flood tank level*** | 42.8 ft | 0.3 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

subcooling other than 22F, then the initial primary pressure is to be adjusted to obtain 22F subcooling. The surge line fluid temperature is to be within 5F of the hot leg temperature. As an indication of steady state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively.

### 3.3.3. Initiation

The test is started after recording at least 10 minutes of steady-state data. The test is initiated by performing the following actions:

1. Open the 10-$cm^2$ B1 CLD leak.
2. Log the test initiation time.
3. Confirm that the pressurizer heaters have tripped on low level.

After the pressurizer has drained, the following actions should be performed as simultaneous as possible i.e., within an elapsed time of approximately 20 seconds.

1. Actuate the auxiliary feedwater system to raise the steam generator secondary levels to [illegible] ft.
2. Actuate the core power decay ramp.
3. Switch control of the reactor vessel vent valves from manual to automatic "independent" control (open/close setpoints of 0.125/0.04 psi).
4. Actuate the ATOG secondary pressure control as described in Appendix C of reference 6.
5. Actuate the low-pressure injection system.
6. Actuate constant secondary level control.

### 3.3.4. Control During Testing

The boundary system simulation for this test will differ from prior tests only by the steam generator pressure control procedure. Previously, the ATOG pressure control logic was followed. That is, when the core exit temperature is greater than the secondary saturation temperature by less than 50F, the secondary pressure is controlled to maintain a cooldown rate of 100F/h for the primary system. When the core exit temperature falls below the secondary saturation temperature (reverse primary to secondary heat transfer) then a

50-psi/min depressurization is started until positive heat transfer is re-established. If the core exit temperature is greater than the secondary saturation temperature by over 50F, then a constant secondary pressure is maintained. In this test, the normal ATOG control procedure will be followed for 30 minutes, at which time the 50-psi/min blowdown of the secondary pressure of both steam generators will be started regardless of the core exit-to-secondary saturation temperature difference. The remaining boundary system simulations activated during test initiation are largely automated and will be identical to those used on the MIST Nominal Test, with the addition of the low-pressure injection system characterized by Figure 3.2 and Table 3.4.

After LPI flow has been injected into the loop for the first time, the primary and secondary steam generator levels are to be monitored for the occurrence of pool BCM cooling phenomena. If BCM occurs, then a 1-hour countdown should be started after the primary pressure has stabilized for 5 minutes. At the end of the 1-hour period, if the primary pressure is above 203 psia, then the power-operated relief valve (PORV) is to be opened until LPI flow is indicated. The PORV should then be closed and returned to the automatic mode. At this point in the test, one or more reactor coolant (RC) pumps are to be bumped (A1 and B1). The first pump to be bumped is in the loop with the highest steam generator secondary level. Fifteen minutes later, the opposing pump (B1 or A1) is to be bumped. If only one primary loop is interrupted, then the pump in the interrupted loop is to be bumped. The pump bump procedure shall be the same as utilized in Test 360199 performed in Phase III of the MIST program.

If additional BCM phenomena occur, then 5 minutes following primary pressure stabilization a 30-minute countdown should be started. At the end of this period, perform one of the following:

1. If the PORV was not opened in the prior BCM occurrence, then the PORV should be opened until LPI flow is indicated. The PORV should then be closed and returned to the automatic mode. After the primary pressure has stabilized and a pool BCM has existed in both steam generators for 30 minutes, a second pump bump is to be performed using the same procedure as outlined above.

2. If the PORV was opened in the prior BCM occurrence, then perform a second pump bump of one or more RC pumps outlined above.

### 3.3.5. Termination

The test may be terminated based on specific loop conditions, but delayed at the discretion of the test engineer. The termination time is to be entered into the test log. The test may be terminated if any of the following conditions are satisfied:

1. If the RCS pressure is less than 200 psia continuously for 2 hours.
2. If 11 hours have passed since leak initiation.

For the second condition, the HPI system should be activated to fill the loop before data acquisition is interrupted in order to complete mass closure calculations. If HPI is required to accomplish refill, then the MIST HPI simulation as described in Appendix B of reference 6 should be employed. Refill of the loop should be attempted for 30 minutes using the available boundary systems simulations. If refill is not achieved after 30 minutes, then the primary system is to be refilled without regard to the constraints of the boundary systems.

### 3.3.6. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.
2. Test initiation is performed as specified.
3. The specified boundary system control settings are maintained throughout the test.
4. Test termination is performed as specified.
5. All critical instrument data as specified in Appendix F of reference 6 and Table 3.5 are recorded at intervals of 10 seconds or less throughout the test.

## 3.4. Test 4100B2 -- Larger SBLOCA, 100 cm$^2$

Test 4100B2 is a 100-cm$^2$ SBLOCA transient. The test complements the spectrum of leak sizes performed in Phase III and the break size is large enough to be considered a large-break loss-of-coolant accident (LOCA). The LPI system, added to the MIST facility for Phase IV, will provide a more realistic simulation of the ECCS during low RCS pressure than was previously available. Earlier tests with 50-$cm^2$ leak sizes displayed reverse heat transfer in the steam generators due to the rapid depressurization of the primary. However, the large leak size used in this test will clearly dominate the mass and energy depletion of the loop. The test is described in detail in the following sections.

### 3.4.1. Purpose

This test provides data for a 100-$cm^2$ break LOCA. The test is to be initialized and performed so that the results can be compared to the MIST Nominal Test. Many of the major post-SBLOCA phenomena are anticipated to be experienced. These phenomena include depressurization to saturation, intermittent and interrupted loop flow, Boiler-Condenser Mode (BCM), refill, and post-refill cooldown. However, the timing for each phenomenon and the mechanisms by which the transient is concluded are expected to be dissimilar to those of the Nominal Test.

### 3.4.2. Steady-State Pretest Conditions

The loop is to be in the natural circulation testing configuration i.e., with the venturi flowmeters installed and the turbine meters removed. The system is to be held in steady state for 10 minutes or more prior to test initiation. The initial conditions for this steady-state period are listed in Table 3.8. Specified as well as derived conditions are provided. The derived conditions are for information only and should not be interpreted as control parameters. The primary is to be in subcooled natural circulation at 3.5% of full power plus 0.57% to offset the losses to ambient (see Table 3.2 for conversion factors). This augmentation is greater than that used in the Phase III Nominal Test (0.4%) and will result in slightly different initial conditions. The secondary pressures are to be 1010 psia. The pressurizer is controlled to obtain approximately 1750 psia primary pressure with a 5.0-ft level within the pressurizer (23.0 ft relative to the SFLTS). The pressurizer spray control valve is manually closed. The PORV is in the automatic overpressure control mode as described in Appendix E of reference 6. The resulting primary flow rate will be approximately 4% of full primary flow, with cold leg temperatures of approximately 550F. The primary boundary systems are inactive. The reactor vessel vent valves (RVVVs) are manually

Table 3.8. Test 4100B2, Initial Conditions

| Quantity | Specification | Tolerance [+/-] | Derived * |
| --- | --- | --- | --- |
| Core power** | 3.5% | 0.05 | |
| Primary flow | | | 4% |
| Primary pressure | | | 1750 psia |
| Hot leg inlet temperature | | | 595F |
| Cold leg exit temperature | | | 550F |
| Core exit subcooling | 22F | 2 | |
| Pressurizer level*** | 23.0 ft | 0.2 | |
| Surge line temperature | Hot leg temp., F | 5 | |
| Secondary flow | | | 2% |
| Secondary pressure | 1010 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary levels | 5 ft | 1 | |
| Core flood tank pressure | 600 psia | 10 | |
| Core flood tank level | 42.8 ft | 0.3 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

closed. The core flood tank is charged to 600 psia using nitrogen as a cover gas with a level of 42.8 ft and has been recirculated (the MIST core flood tank is kept isolated until the primary system depressurizes below 650 psia). The steam generator secondaries are initialized with auxiliary feedwater. The secondary levels are maintained at 5 ft using the high-elevation minimum-wetting feedwater nozzles. The feedwater temperature is approximately 110F. The primary power-to-flow ratio will be approximately unity, obtaining a hot leg fluid temperature of about 595F. The initial primary subcooling is then the saturation temperature at 1750 psia (617F) less the hot leg temperature, or 22F. If the actual initial hot leg temperature results in an initial subcooling other than 22F, then the initial primary pressure is to be adjusted to obtain 22F subcooling. The surge line fluid temperature is to be within 5F of the hot leg temperature. As an indication of steady-state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively.

### 3.4.3. Initiation

The test is started after recording at least 10 minutes of steady-state data. The test is initiated by performing the following actions:

1. Open the 100-$cm^2$ B1 cold leg discharge (CLD) leak.
2. Log the test initiation time.
3. Confirm that the pressurizer heaters have tripped on low level.

After the pressurizer has drained, the following actions should be performed as simultaneous as possible i.e., within an elapsed time of approximately 20 seconds.

1. Actuate the auxiliary feedwater system to raise the steam generator secondary levels to 31.6 ft.
2. Actuate the high-pressure injection system.
3. Actuate the core power decay ramp.
4. Switch control of the reactor vessel vent valves from manual to automatic "independent" control (open/close setpoints of 0.125/0.04 psi).
5. Actuate the ATOG secondary pressure control as described in Appendix C of reference 6.

6. Actuate the low-pressure injection system.

7. Actuate constant secondary level control.

3.4.4. Control During Testing

The boundary system simulations activated during test initiation are largely automated and will be identical to those used on the MIST Nominal Test, with the addition of the low-pressure injection system characterized by Figure 3.2 and Table 3.4.

3.4.5. Termination

The test may be terminated based on specific loop conditions, but delayed at the discretion of the test engineer. The termination time is to be entered into the test log. The test may be terminated if any of the following conditions are satisfied:

1. If the RCS pressure is less than 200 psia continously for 2 hours.
2. If 7 hours have passed since leak initiation.

The entire loop should be refilled prior to termination in order to complete the mass closure calculations. Therefore, if the second termination criterion is required, then refill of the loop should be attempted for 30 minutes using the available boundary system simulations. If refill is not achieved after 30 minutes, then the primary system is to be refilled without regard to the constraints of the boundary systems.

3.4.6. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.
2. Test initiation is performed as specified.
3. The specified boundary system control settings are maintained throughout the test.
4. Test termination is performed as specified.
5. All critical instrument data as specified in Appendix F of reference 6 and Table 3.5 are recorded at intervals of 10 seconds or less throughout the test.

## 3.5. Test 4SB011 -- Station Blackout

Test 4SB011 examines the Station Blackout (SBO) transient. This transient is characterized as an SBLOCA accompanied by the loss of all AC power. As a result, no HPI or LPI emergency core cooling is available. The auxiliary feedwater system capacity is reduced by one half, with flow provided by the steam-driven pump. With the loss of power, the plant operator must rely on the station batteries to provide power to the plant's critical instrumentation. Normal battery life is postulated to be from 2 to 4 hours, after which time the operator cannot effectively monitor system conditions (flows, temperatures, and pressures) and thus is assumed to make no further adjustments to control valve positions. As a result, all controls are to be left in a static position anticipating DC power depletion. In this test, a battery life will not be assumed. Instead, the primary system will be controlled until one or both loops interrupt, at which time the relevant control valves will be maintained in fixed positions. After 8 hours, the AC power is assumed to be restored and all ECCS functions are assumed to be enabled. The SBO test is described in detail in the following sections.

### 3.5.1. Purpose

This test provides data as well as insight into the thermal-hydraulic behavior of an SBO transient. The test will replicate, as closely as practical, the postulated event and one possible procedure for mitigating it. Many of the major post-SBLOCA phenomena are anticipated to be experienced. These phenomena include depressurization to saturation, and intermittent and interrupted loop flow. At the conclusion of the station blackout test and prior to loop refill, additional data on the effect of pump "bumps" will be obtained.

### 3.5.2. Steady-State Pretest Conditions

The loop is to be held in steady state for 10 minutes or more prior to test initiation. The initial conditions for this steady-state period are listed in Table 3.9. The primary is in subcooled natural circulation at 3.5% of full power plus 0.57% to offset the losses to ambient (see Table 3.2 for conversion factors). The secondary pressures are 1010 psia. The pressurizer is controlled to obtain approximately 2000 psia primary pressure with a

Table 3.9. Test 4SB011, Initial Conditions

| Quantity | Specification | Tolerance | Derived* |
|---|---|---|---|
| Core power** | 3.5% | 0.05 | |
| Primary flow | | | 4% |
| Primary pressure | 2000 psia | | |
| Hot leg inlet temperature | | | 595F |
| Cold leg exit temperature | | | 550F |
| Pressurizer level*** | 23.0 ft | 0.2 | |
| Surge line temperature | Hot leg temp., F | 5 | |
| Secondary flow | | | 2% |
| Secondary pressure | 1010 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary levels | 5 ft | 1 | |
| Core flood tank pressure | 600 psia | 10 | |
| Core flood tank level | 42.8 ft | 0.3 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

5.0-ft level within the pressurizer (23.0 ft relative to SFLTS). The pressurizer spray control valve is manually closed. The PORV, as described in Appendix E of reference 6, is in the automatic overpressure control mode. However, the opening and closing setpoints are modified for this test and will be 2100 and 2050 psia, respectively. The modified PORV setpoints in conjunction with maintaining secondary pressure above 400 psia will prevent excessive primary-to-secondary differential pressure on the steam generator tubes. The primary flow rate will be approximately 4% of full flow with cold leg temperatures of approximately 550F (derived quantities). The primary boundary systems are inactive. The RVVVs are manually closed. The core flood tank is charged to 600 psia with a level of 42.8 ft and has been recirculated (the MIST core flood tank is kept isolated until the primary system depressurizes below 650 psia). The steam generator secondaries are initialized with auxiliary feedwater. The secondary levels are maintained at 5 ft using the high-elevation minimum wetting feedwater nozzles. The feedwater temperature is approximately 110F. The primary power-to-flow ratio will be approximately unity, obtaining a hot leg fluid temperature of about 595F. The surge line fluid temperature is to be within 5F of the hot leg temperature. As an indication of steady state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively.

### 3.5.3. Initiation

The test is started after recording at least 10 minutes of steady-state data. The test is initiated by performing the following actions as close to simultaneous as possible i.e., within an elapsed time of approximately 20 seconds:

1. Open the two 0.25-cm$^2$ B1 and A2 RCP leaks. This leak size will result in a leak flow of approximately 40 gpm/site at nominal plant cold leg conditions.

2. Manually trip the pressurizer heaters.

3. Actuate the auxiliary feedwater system to raise the steam generator secondary levels to 20.7 ft (50% of the startup range).

4. Actuate the core power decay ramp.

5. Switch control of the reactor vessel vent valves from manual to

automatic "independent" control (open/close setpoints of 0.125/0.04 psi).

6. Log the test initiation time.

### 3.5.4. Control During Testing

The boundary system simulations activated during test initiations are largely automated and many will be identical to those used on the MIST Nominal Test, with the addition of the low-pressure injection system characterized by Figure 3.2 and Table 3.4. The core post-trip power, RVVV, guard heater, steam generator constant level, secondary pressure, core flood system, and HPI simulations are as described in reference 6. The core flood tank is not to be isolated until at least 8 hours after test initiation, when required conditions are met. This test will consist of two different periods. In the first period, which lasts for 8 hours, the loss of AC power will be simulated. During this time, the HPI and LPI systems are inactive. The AFW is available at one half of normal capacity (see Figure 3.3 and Table 3.10). At the beginning of this period, the steam generator level is controlled to a constant 20.7 ft (50% of plant operate range) until the subcooled margin decreases below 20F, at which time the control level is increased to 31.6 ft (95% of plant operate range). The secondary pressure control is set to a constant 1010 psia. For this test, the secondary pressure will be prevented from decreasing below 400 psia in order to protect the facility from excessive primary-to-secondary differential pressure. In the event that one loop should interrupt and stay interrupted for a 10-minute period during the initial 8-hour period, a one-loop cooldown should be initiated through the following actions:

1. Adjust the secondary pressure control valve of the interrupted loop to its position prior to the onset of interruption to establish steam flow.
2. Decrease the AFW flow to the steam generator in the interrupted loop to approximately 76 lbm/h (125 gpm scaled).
3. Decrease the secondary pressure of the non-interrupted loop by 100 psi from 1010 to 910 psia.

The characteristics of interrupted loop flow will be indicated by one or more of the following:

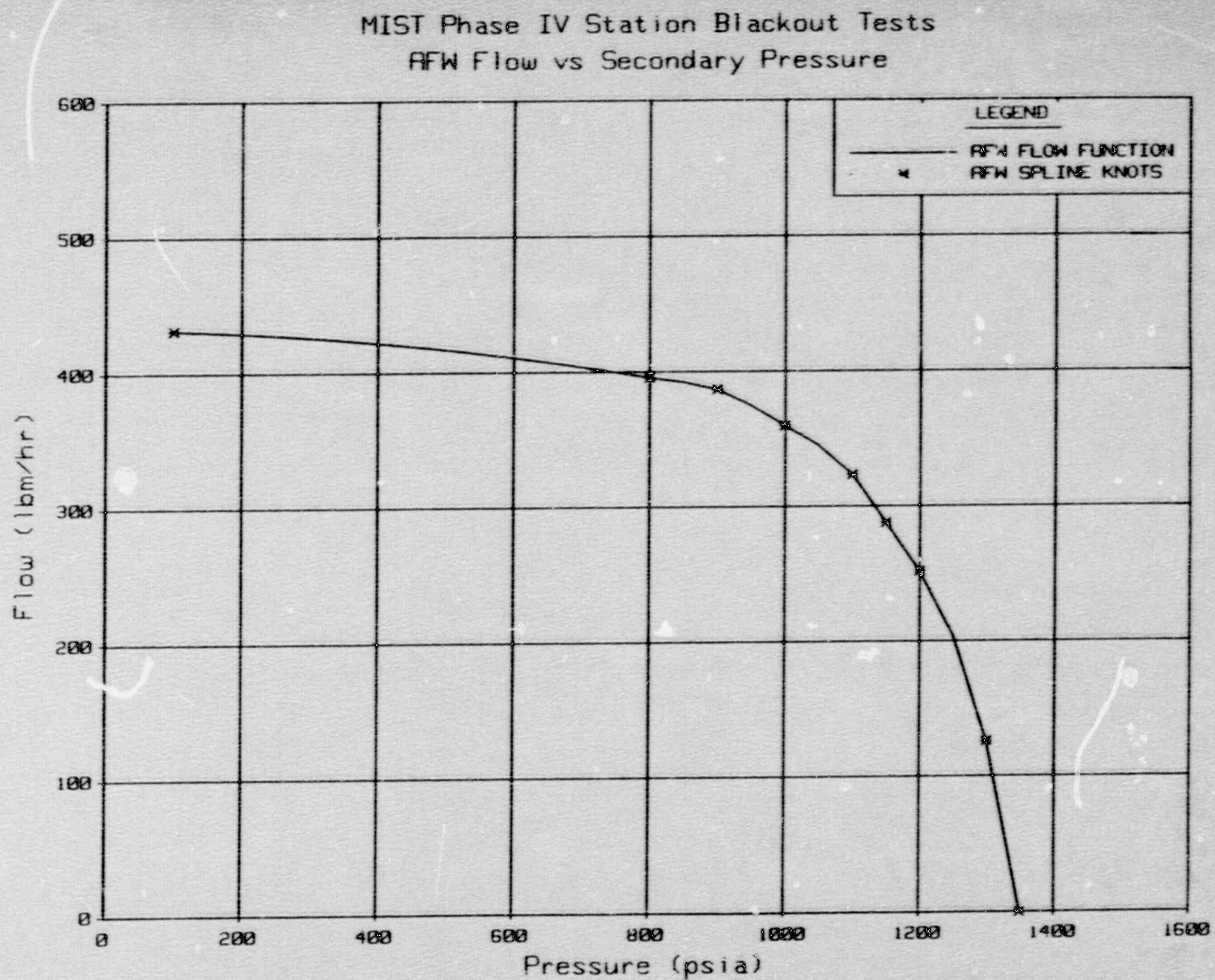



Figure 3.3 AFW Flow Vs Secondary Pressure

Table 3.10. Test 4SB011, Auxiliary Feedwater Characteristics

| Secondary Pressure (psia) | AFW Flow (lbm/h)* |
|---|---|
| 100.0 | 432.0 |
| 150.0 | 431.0 |
| 200.0 | 429.8 |
| 250.0 | 428.3 |
| 300.0 | 426.5 |
| 350.0 | 424.6 |
| 400.0 | 422.4 |
| 450.0 | 419.9 |
| 500.0 | 417.2 |
| 550.0 | 414.3 |
| 600.0 | 411.1 |
| 650.0 | 407.7 |
| 700.0 | 404.0 |
| 750.0 | 400.1 |
| 800.0 | 396.0 |
| 850.0 | 392.7 |
| 900.0 | 387.0 |
| 950.0 | 375.2 |
| 1000.0 | 360.0 |
| 1050.0 | 345.6 |
| 1100.0 | 324.0 |
| 1150.0 | 288.0 |
| 1200.0 | 252.0 |
| 1250.0 | 204.0 |
| 1300.0 | 126.0 |
| 1350.0 | 0.0 |

*The SBO AFW flow table is one-half of the MIST Phase III AFW table values.

1. The decoupling of the cold leg temperatures (C1TC06 and C3TC06 for loop A, C2TC06 and C4TC06 for loop B) from the corresponding steam generator saturation temperature.

2. The decrease in AFW flow to the interrupted loop.

3. A decrease in secondary pressure control valve modulation for the interrupted loop.

The uninterrupted loop will be indicated by one or more of the following:

1. An increasing temperature difference between the hot and cold legs.

2. An increase in loop flow (corresponding to qualitative indication available to the plant operator).

3. An increase in AFW flow to the uninterrupted loop.

These observations are to be indicated by the instruments listed in Table F.18 of reference 6.

Following these actions, the remaining automated systems i.e., the steam generator level and secondary pressure controls of the uninterrupted loop, should be placed in the manual mode. The controls should be adjusted to maintain approximately constant conditions. The AFW flow rate to the active steam generator should be adjusted to maintain a constant level. The change from automatic to manual control should be performed as quickly as possible with a minimum number of valve motions to facilitate code modeling. After these adjustments, no further adjustments to the secondary pressure and AFW flow control valves in either loop are to be made. For the remainder of the test period, until 8 hours after leak opening, the secondary pressure and steam generator level should be allowed to drift from the previously established control points.

If both loops interrupt during the initial phase of the test or one-loop natural circulation cannot be maintained, then steps 1 and 2 as described for the one-loop cooldown shall be performed on both steam generators.

Eight hours following leak opening or in the event that the MIST core limits are exceeded, the first test period is ended and the second test phase is started. The following actions should be taken:

1. Isolate the two 0.25-$cm^2$ leaks.

2. Activate the LPI system.

3. Perform an RC pump "bump."

The RC pump selected is dependent on whether one or both primary loops were interrupted at the end of the first test period. If one-loop circulation exists, then a pump in the interrupted loop is to be used (RCP A1 or B1). If both loops are interrupted, then a pump from the loop with the highest secondary level will be selected. The bump procedure i.e., the duration of current applied to the pump motor, should be the same as performed on the MIST Phase III Group 36 Tests. Fifteen minutes following the initial RC pump bump, a pump from the opposing loop will be bumped (RCP B1 or A1). Fifteen minutes following the second bump, the HPI system with MIST nominal characteristics should be initiated to refill the loop.

### 3.5.5. Termination

The test may be terminated based on specific loop conditions, but delayed at the discretion of the test engineer. The termination time is to be entered into the test log. The test may be terminated if any of the following conditions are satisfied:

1. The loop has refilled and both the hot leg inlet temperature and the RCS pressure are continuously 50F subcooled and less than 400 psia, respectively, for 2 hours.

2. If 11 hours have passed since leak initiation.

The entire loop should be refilled prior to termination in order to complete the mass closure calculations. Therefore, if the second termination criterion is required, then refill of the loop should be attempted for 30 minutes using the available boundary system simulations. If refill is not achieved after 30 minutes, then the primary system is to be refilled without regard to the constraints of the boundary systems.

### 3.5.6. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.

2. Test initiation is performed as specified.

3. The specified boundary system control settings are maintained throughout the test.

4. Test termination is performed as specified.

5. All critical instrument data as specified in Appendix F of reference 6 and Table 3.5 are recorded at intervals of 10 seconds or less throughout the test.

## 3.6. Test 4SGPF2

Test 4SGPF2 examines the steam generator performance characteristics. This test will supplement the current understanding of high-elevation auxiliary feedwater heat transfer characteristics, as well as provide data on main feedwater operation. Additional data are needed in order to understand the primary and secondary interactions when using auxiliary feedwater under the variety of conditions known to exist during an SBLOCA transient. These data are important in developing code models of the B&W once-through steam generator (OTSG) with its complicated geometry and AFW flow patterns. The test is described in detail in the following sections.

### 3.6.1. Purpose

This test provides steady-state steam generator performance data with either the main or auxiliary feedwater systems. The test will be performed in two parts: The first will utilize the main feedwater system while the second part will use the high-elevation minimum-wetting auxiliary feedwater. Each part will consist of a series of steady-state measurements at varying secondary levels while the primary side is in subcooled natural circulation. With all other conditions held constant, the data will directly correlate feedwater and wetting conditions to primary natural circulation flow. In the first part of the test, data will be accumulated using the main feedwater system, which has not been utilized in prior MIST testing.

### 3.6.2. Test Description

The loop is to be in the natural circulation testing configuration i.e., with the venturi flowmeters installed and the turbine meters removed. The primary system will be initialized and maintained in subcooled natural circulation throughout the test (see Table 3.11). All primary boundary systems (leak,

Table 3.11. Test 4SGPF2, Initial Conditions

| Quantity | Specification | Tolerance [+/-] | Derived* |
| --- | --- | --- | --- |
| Core power** | 7.25% | 0.05 | |
| Primary pressure | 2200 psia | 50 | |
| Cold leg exit temperature | | | 550F |
| Secondary pressure | 1010 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Main feedwater temperature | 460F | 10 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

HPI, LPI, and vents) are inactive. The guard heaters are in automatic. Core power will be held constant at 7.25% of full power plus 0.57% to offset the losses to ambient (see Table 3.2 for conversion factors). This augmentation is greater than that used in the Phase III Nominal Test (0.4%) and will result in slightly different initial conditions. The pressurizer is controlled to obtain approximately 2200 psia primary pressure. The pressurizer spray control valve and reactor vessel vent valve controls are manually closed. The secondary side pressures are to be 1010 psia.

In the first part of the test, the main feedwater system is to be used. The aspirator flow circuit is active. The main feedwater temperature is approximately 460F, or the maximum obtainable temperature. The secondary side of the steam generator is set to the minimum level, which still maintains the primary loop in stable natural circulation conditions and steady-state data are to be recorded for 30 minutes at 10-second intervals. As an indication of steady state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively. The control level is then raised to approximately 26, 33, and 40 ft and data are recorded for 30 minutes at each level.

In the second phase of the test, the minimum-wetting high-elevation auxiliary feedwater system will be used with a feedwater temperature of approximately 110F. The steam generator secondary level will be initially 40 ft. The loop is held in steady state for at least 30 minutes and data are collected at 10-second intervals. The control level is then decreased to 33 and 26 ft and at least 30 minutes of steady-state data are obtained at each level. The level is to be decreased further to the minimum, which maintains the core exit temperature 22F subcooled and data are recorded for 30 minutes.

### 3.6.3. Control Systems

The boundary system simulations used during the test i.e., constant secondary level and steam generator pressure controls, are largely automated and will be identical to those used on the MIST Nominal Test. The single- and two-phase leak monitoring, reactor vessel vent valve control, core flood tank, and PORV systems are not required. Similarly, the high- and low-pressure injection simulations are not required.

### 3.6.4. Acceptance Criteria

1. At least 30 minutes of steady-state data are recorded at each specified condition.
2. The specified boundary system control settings are maintained throughout the test.
3. All critical instrument data as specified in Appendix F of reference 6 are recorded at intervals of 60 seconds or less throughout the test. The instrumentation in the systems not used during this test i.e., single- and two-phase leak, continuous vent, core flood tank, gas addition, leak enthalpy, and HPI systems, may be excluded from the critical instrument list.

## 3.7. Test 4CR3T2 -- Crystal River 3 Scaling Transient

The Phase IV test matrix includes two tests that simulate actual plant transients. These tests are the Crystal River Unit 3 Loss-of-Offsite Power Event of June 16, 1981 and the Rancho Seco Loss-of-ICS Power Event of December 26, 1985 (see section 3.8). These transients have been selected for two reasons. First, because they are well documented (reference 7 and 8) and second, because they can be simulated without the addition of hardware and control systems to the present facility. The Crystal River Unit 3 event will be simulated in this test specification.

### 3.7.1. Purpose

This test simulates, as closely as possible, a plant transient on the scaled MIST facility. The results of the test will be useful in providing bench-marking data for the code analysts and will provide insight into the scaling compromises that are known to exist in the facility. In particular, the pipe and steam generator metal masses, total primary system volume, and AFW wetting atypicalities are believed to have the greatest likelihood of influencing the results of this test. In order to compensate for the excess primary system volume of the MIST facility, a time "distortion" will be applied to the post-trip power function and the operator control actions.

### 3.7.2. Background

The Crystal River Unit 3 event occurred on June 16, 1981 with the reactor at 100% full power and the integrated control system (ICS) in the automatic mode of operation. All station power was being supplied by the Unit 3 startup transformer except the reactor coolant pumps, which were powered by the unit auxiliary transformer. At 23:38:08, lightning struck the 230-kV feeder line between the fossil plant switchyard and the Unit 2 startup transformer, causing the breakers to open and a loss of the 4160 VAC unit and 4160 VAC ES power buses. As a result, power was lost to the control rod drives that led to a reactor and turbine trip. The turbine trip caused a loss of the 6900-VAC feed to the RC pump buses and with the alternate supply (startup transformer) already tripped, a loss of primary system flow occurred. The RC pumps coasted for approximately 3 minutes and natural circulation flow was established. A loss of instrument air to the steam generator startup control valves resulted in excessive auxiliary feedwater flow, and both generators were overfilled. The secondary levels were raised to approximately 80% on the operating range (28.0 ft relative to the SGLTS). The plant operators manually throttled the emergency feedwater block bypass valves to control the secondary levels. Following the overfill, the steam-driven AFW pump was terminated and feedwater was supplied by the motor-driven pump alone. HPI flow was manually initiated to prevent the loss of pressurizer level. The HPI flow exceeded the contracting rate, causing primary pressure to increase to the PORV setpoint of 2450 psig. The PORV opened and closed four or five times over a 20-minute period. The transient portion of the event lasted approximately 1 hour and was followed by an 8-hour period of stable natural circulation cooldown. The reactor coolant pumps were re-started 9 hours after the initial loss of power, and the plant was maintained in normal hot standby conditions. Table 3.12 contains a partial list of the key events and milestones of the transient. Plots of the available data are presented on Figures 3.4 through 3.12.

### 3.7.3. Steady-State Pretest Conditions

The loop is to be in the natural circulation testing configuration i.e., with the venturi flowmeters installed and the turbine meters removed. The system is to be held in steady state for 10 minutes or more prior to test initiation.

Table 3.12. Test 4CR3T2, Key Events and Actions

| Event* | Time** Min. | Sec. |
|---|---|---|
| Loss of offsite power.<br>CRDs trip.<br>Reactor/turbine trip.<br>RC pumps start coastdown. | | 0 |
| 4160V engd. safeguards bus. A energized.<br>(AFW pumps assumed to start.) | | 17 |
| Letdown flow terminated. | ~2 | |
| HPI pump A started. | 3 | 25 |
| 4160V engd. safeguards bus. B energized. | 4 | 18 |
| Steam-driven AFW pump terminated.<br>(Flow to steam generator B decreased.) | ~4 | |
| HPI flow verified.<br>(HPI pump C started.) | 4 | 27 |
| AFW block valve closed.<br>AFW block bypass valves opened and throttled.<br>(AFW flow to steam generator B increased.) | ~7 | |
| AFW flow terminated to steam generator A. | ~8 | |
| HPI pump C terminated. | 11 | 29 |
| AFW flow to steam generator B terminated. | ~13 | |
| PORV opens (first of four or five times). | 20 | 18 |
| PORV reopens three or four times. | ~25-40 | |

*Events were extracted from "Transient Assessment Program Report on Crystal River Unit 3 Reactor Trip on June 16, 1981," Report No. CR-3-81-10, prepared by Florida Power Corporation, B&W No. 12-1127044-00.

**Times are relative to the initiating event i.e., loss-of-offsite power on June 16, 1981 at 23:38:08.

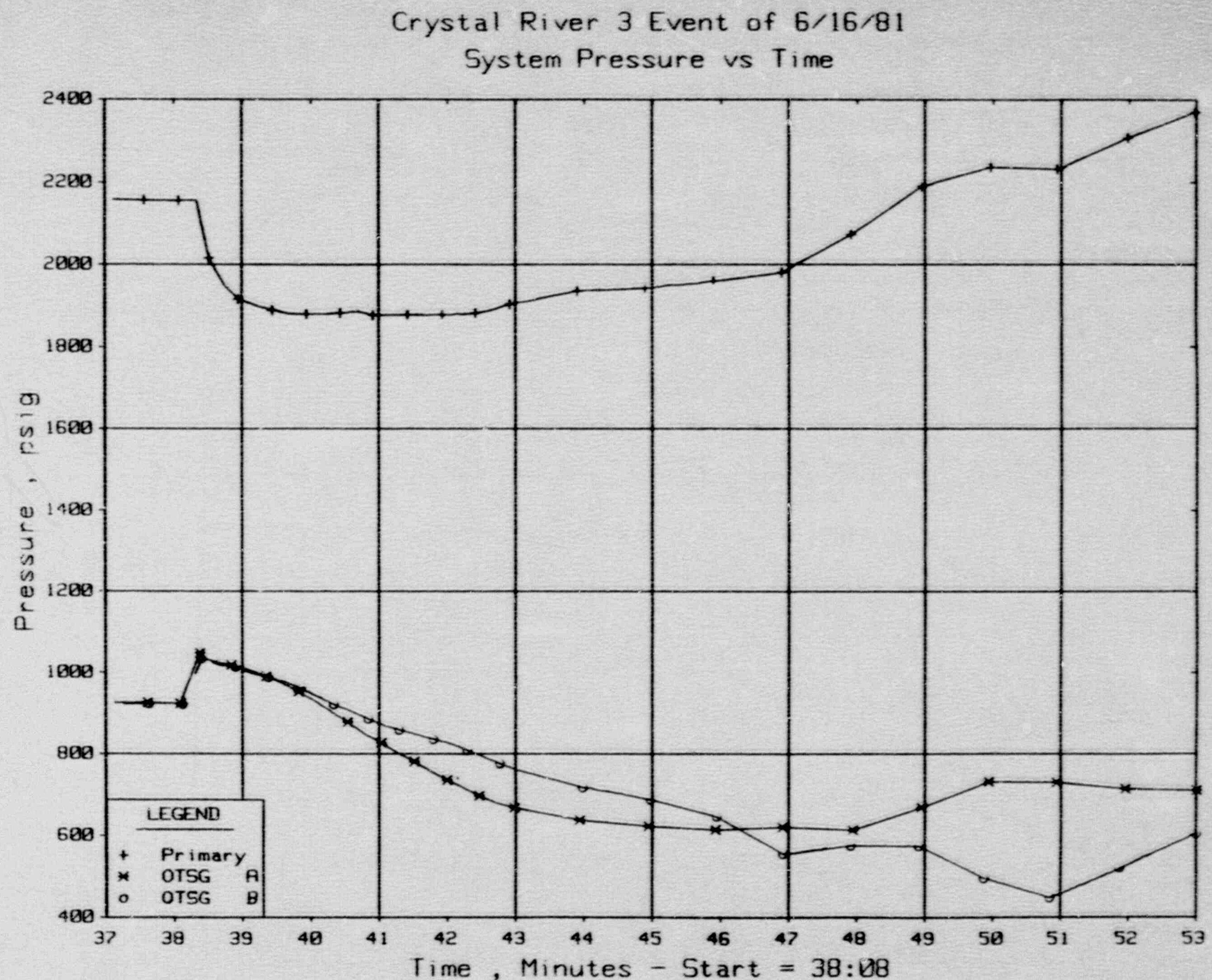



Figure 3.4 System Pressure Vs Time

Tue Feb 16 09:17:33 1988

pres.plot

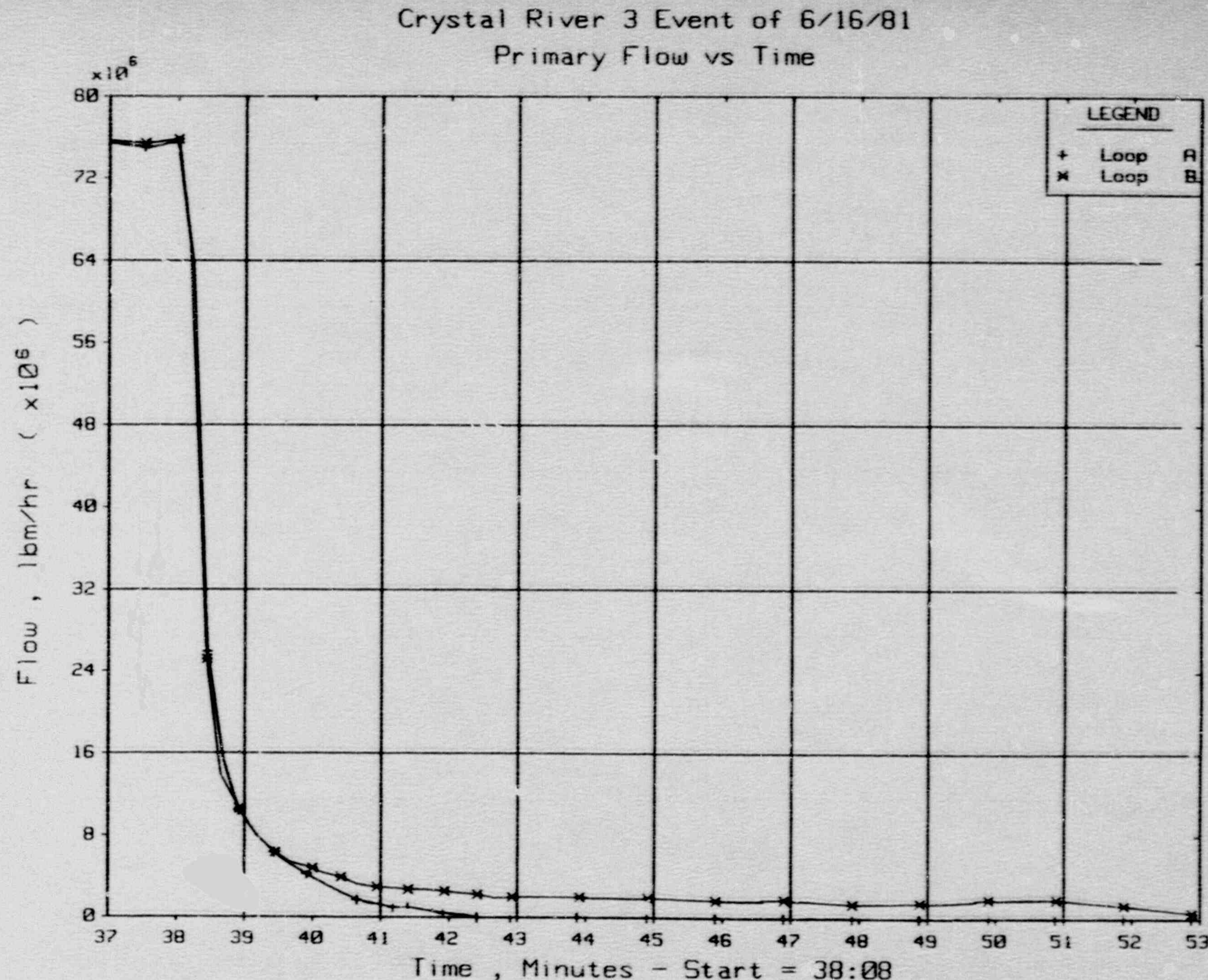



Figure 3.5 Primary Flow Vs Time

Tue Feb 15 09:31:01 1988

prit.plot

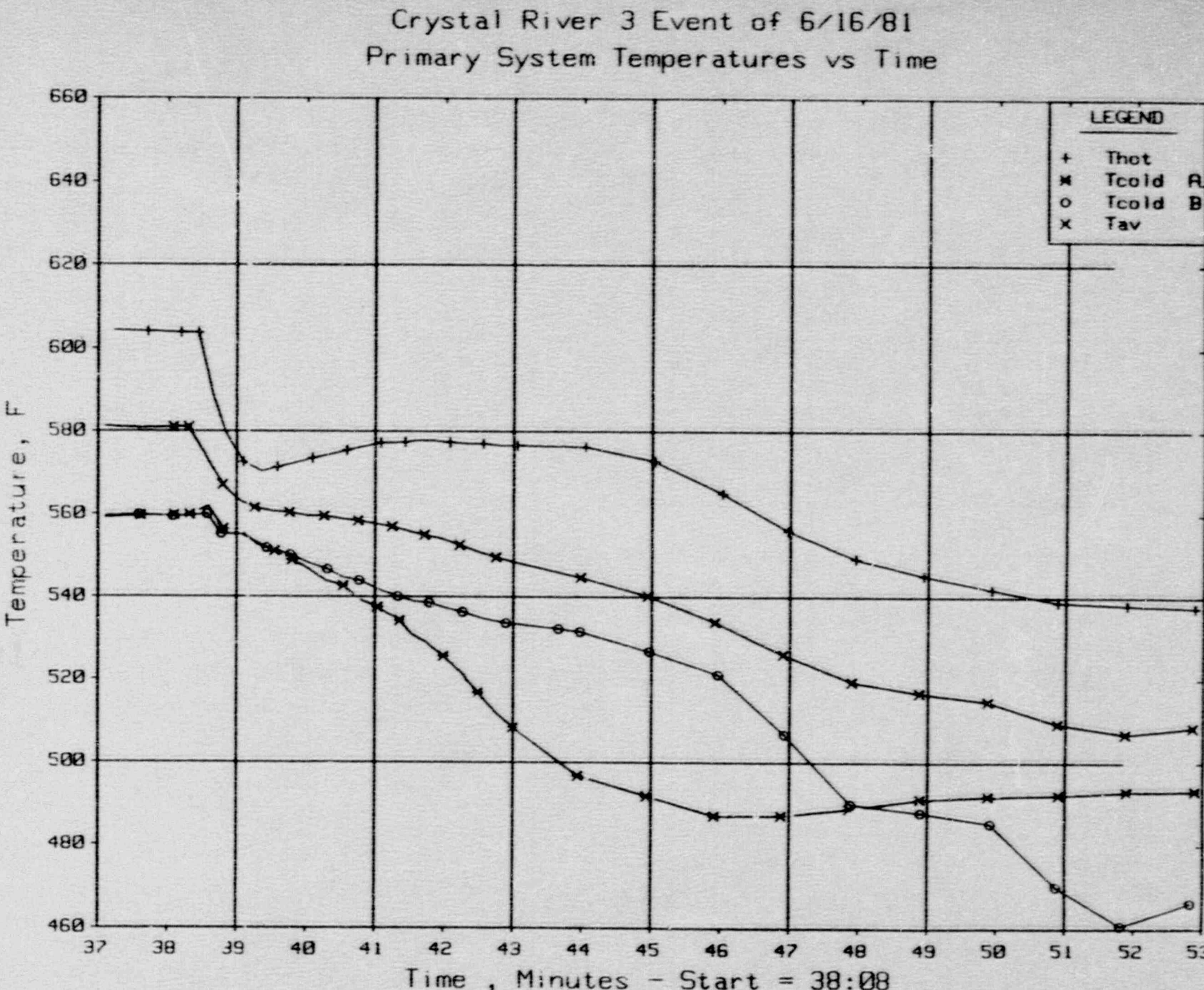



Figure 3.6 Primary System Temperature Vs Time

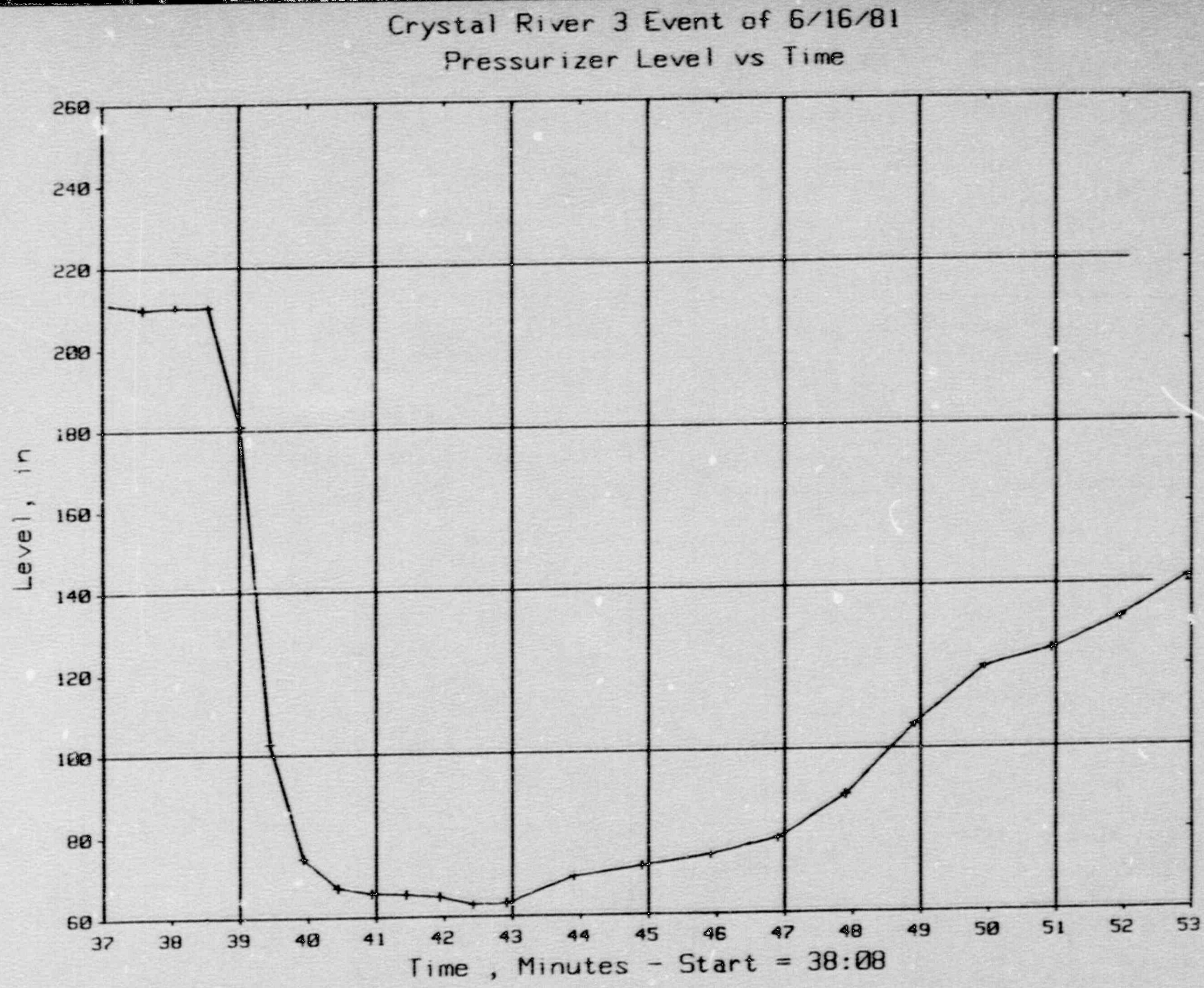



Figure 3.7 Pressurizer Level Vs Time

przl.plot

Tue Feb 16 09:27:31 1988

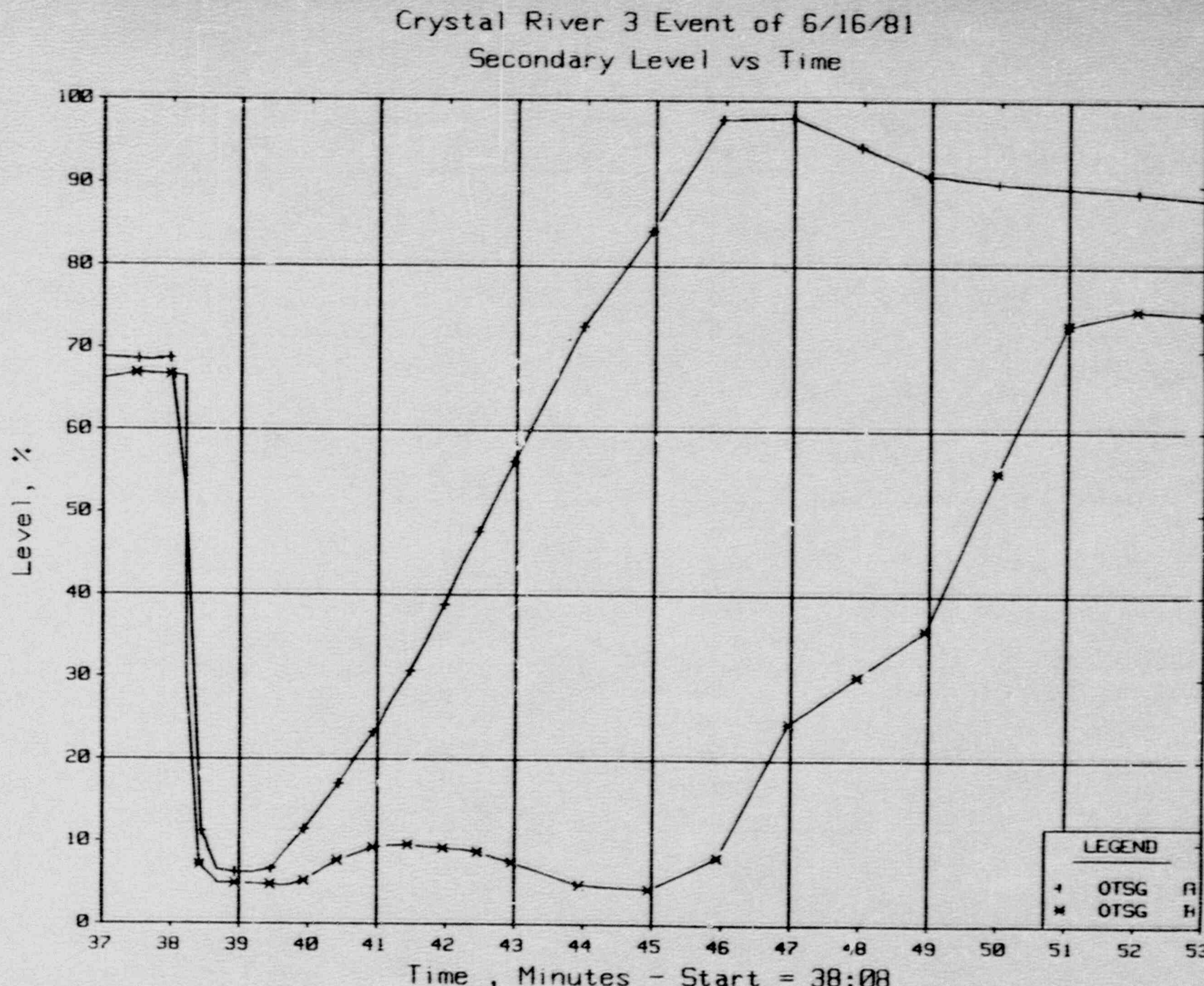



Figure 3.8 Secondary Level Vs Time

Tue Feb 16 09:22:19 1988

secl.plot

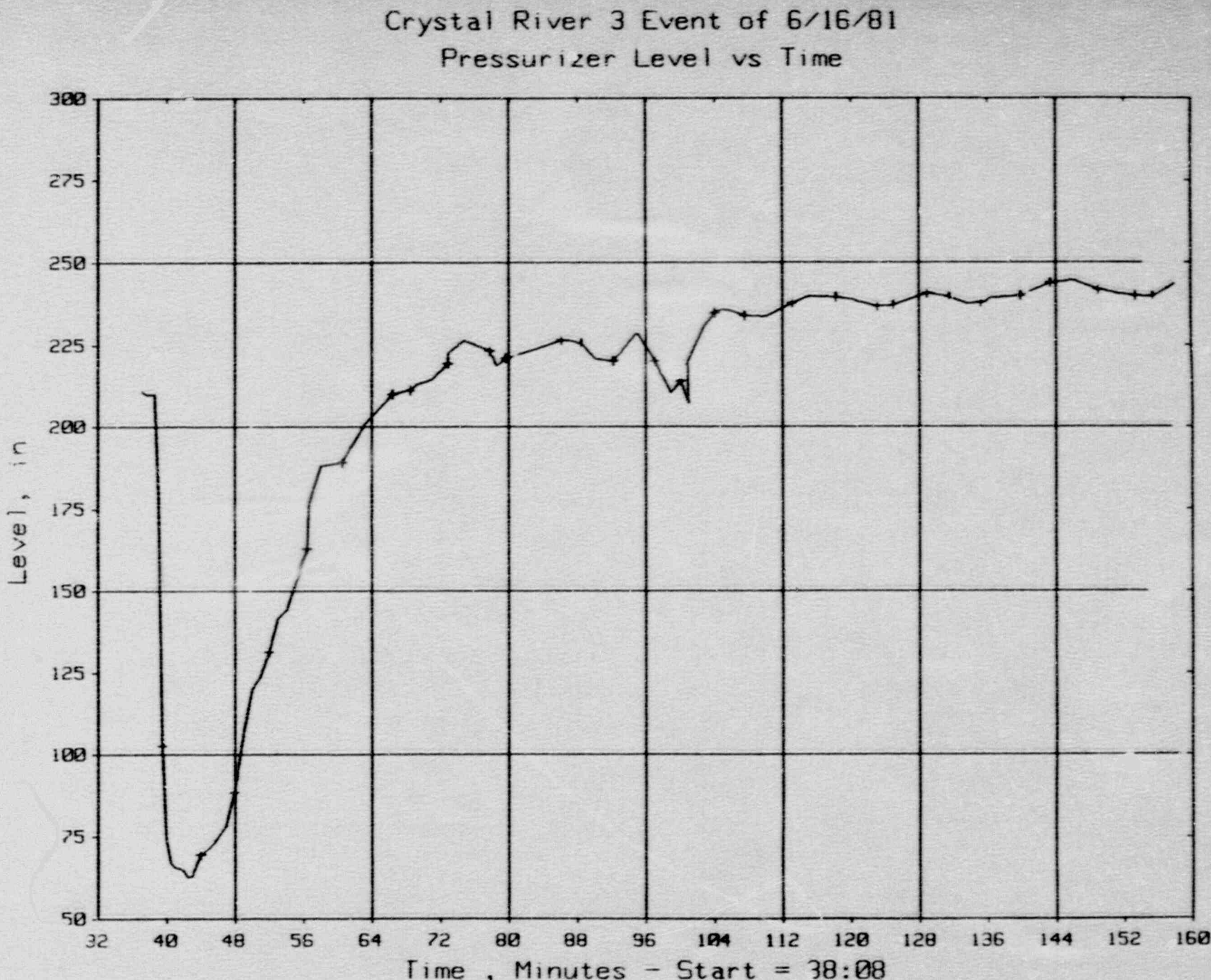



Figure 3.9 Pressurizer Level Vs Time

Tue Feb 16 09:52:36 1988

przl.pit

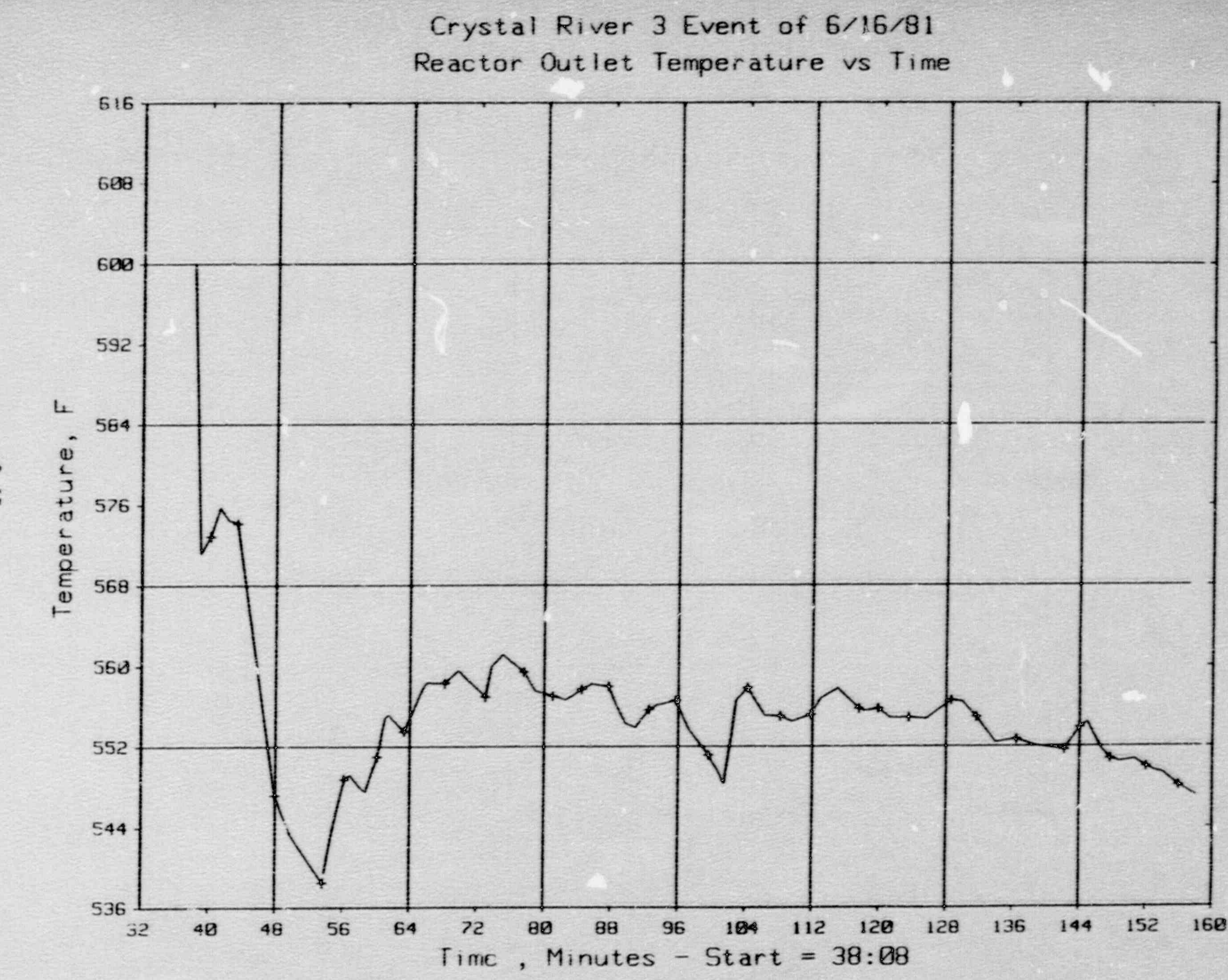



Figure 3.10 Reactor Outlet Temperature Vs Time

prit.plt

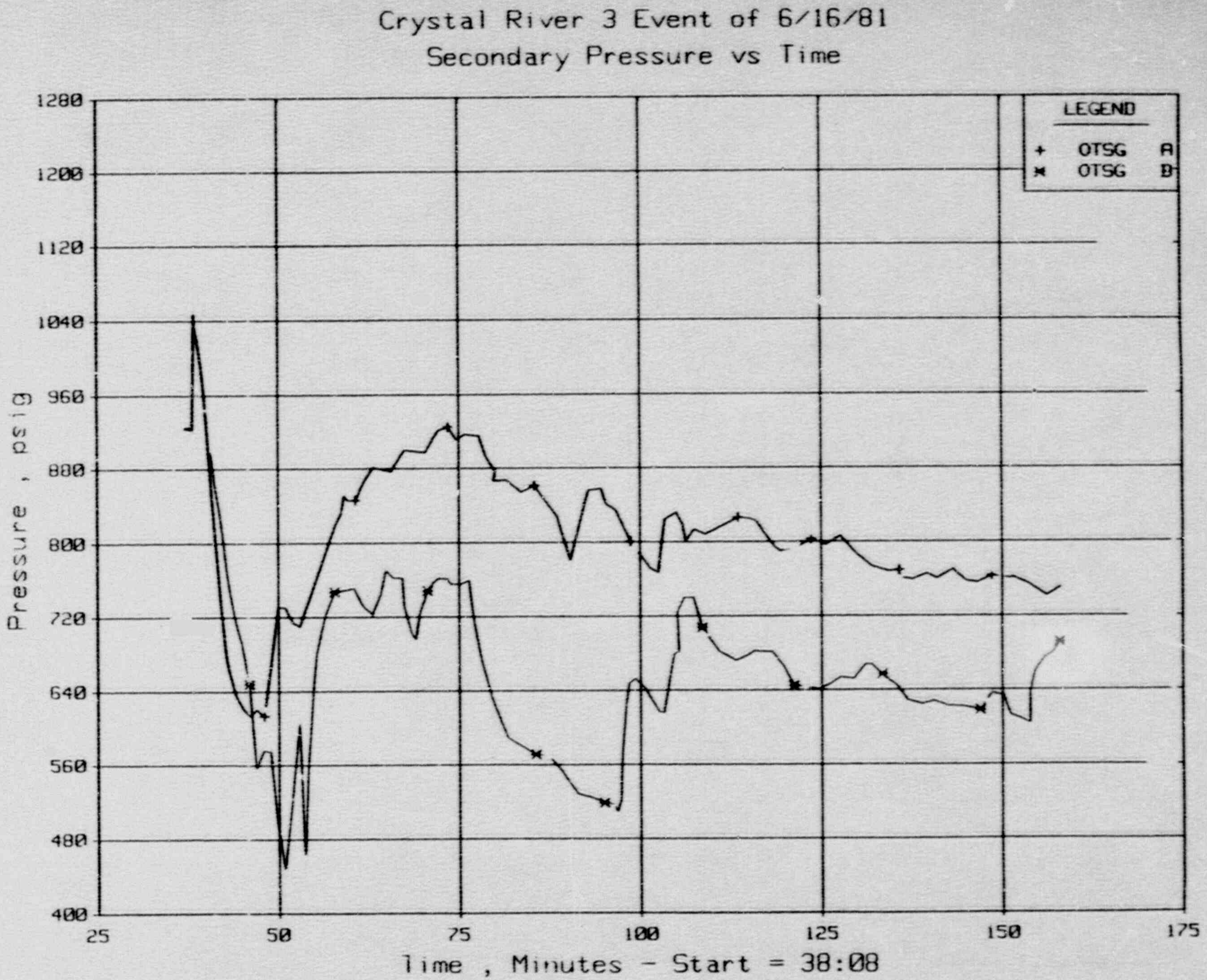



Figure 3.11 Secondary Pressure Vs Time

Tue Feb 16 09:47:35 1988

secp.pit

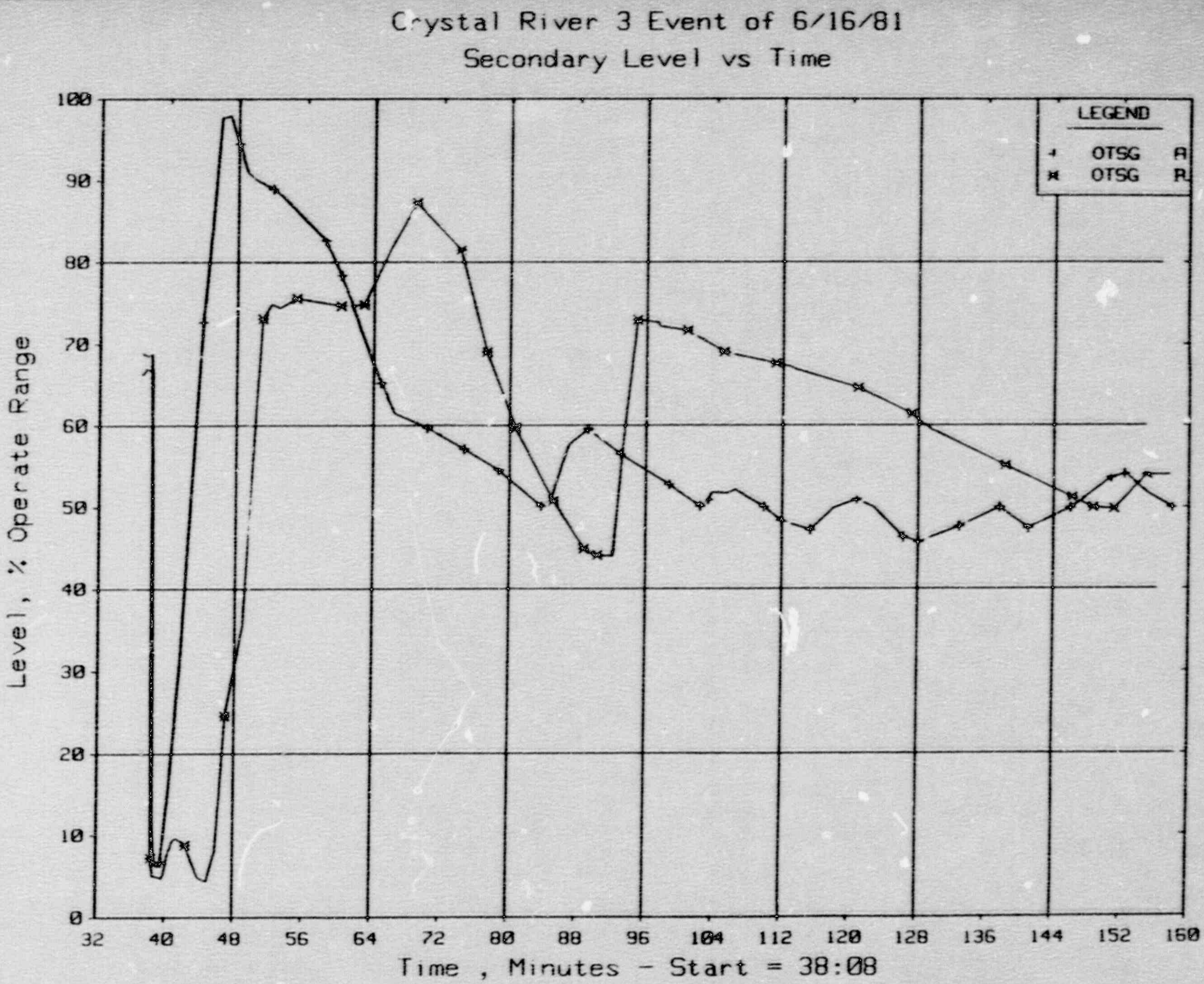



Figure 3.12 Secondary Level Vs Time

Tue Feb 16 09:49:25 1988

secl.plt

The initial conditions for this steady-state period are listed in Table 3.13. These conditions coincide with the plant parameters 90 seconds after the reactor trip when decay heat power is within the MIST facility limit and natural circulation flow has been established. The primary is to be in subcooled natural circulation at 3.5% of full power plus 0.57% to offset the losses to ambient (see Table 3.14 for conversion factors). This augmentation is greater than that used in the Phase III Nominal Test (0.4%) and will result in slightly different initial conditions. The secondary pressures are to be 980 psia. The pressurizer is controlled to obtain approximately 1905 psia primary pressure with a 3.3-ft level within the pressurizer (21.3 ft relative to SFLTS). The pressurizer spray control valve is manually closed. The PORV is in the automatic overpressure control mode as described in Appendix E of reference 6, except the open and reclose setpoints are 2400 and 2350 psig, respectively. The PORV flow orifice size is 6.75 $cm^2$ (scaled 1-5/32 in. diameter). The primary flow rate will be approximately 4% of full primary flow with cold leg temperatures of approximately 549F. The primary boundary systems are inactive. The RVVVs are manually closed. The core flood tank is isolated. The steam generator secondaries are initialized with auxiliary feedwater. The secondary levels are maintained at 10 ft using the high-elevation minimum-wetting feedwater nozzles. The feedwater temperature is approximately 110F. The primary power-to-flow ratio will be approximately unity, obtaining a hot leg fluid temperature of about 585F. The initial primary subcooling is then the saturation temperature at 1905 psia (629F) less the hot leg temperature, or 44F. The surge line fluid temperature is to be within 5F of the hot leg temperature. As an indication of steady state, all fluid and metal temperatures are to be varying less than 3 and 10F/h, respectively.

3.7.4. Initiation

The test is started after recording at least 10 minutes of steady-state data. The initiating event is the initiation of the core power decay ramp. The next steps should be performed as simultaneously as possible i.e., within an elapsed time of approximately 20 seconds.

1. Activate the auxiliary feedwater head-versus-flow simulation.

Table 3.13. Test 4CR3T2, Initial Conditions

| Quantity | Specification | Tolerance [+/-] | Derived* |
|---|---|---|---|
| Core power** | 3.5% | 0.05 | |
| Primary flow | | | 4% |
| Primary pressure | 1905 psia | 10 | |
| Hot leg inlet temperature | | | 585F |
| Cold leg exit temperature | | | 545F |
| Core exit subcooling | | | 44F |
| Pressurizer level*** | 21.3 ft | 0.2 | |
| Surge line temperature | Hot leg temp., F | 5 | |
| Secondary flow | | | 2% |
| Secondary pressure | 980 psia | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary levels | 10 ft | 1 | |
| Fluid temperature gradients | 0F/h | 3 | |
| Metal temperature gradients | 0F/h | 10 | |

*Derived quantities are for information only and should not be interpreted as control specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

Table 3.14. Test 4CR3T2, Conversion Factors

| | | | |
|---|---|---|---|
| Core power | 31.138 | kW | = 1% of MIST scaled full power |
| Primary flow | 1607.1 | lbm/h | = 1% of MIST scaled full flow |
| Secondary flow | 134.64 | lbm/h | = 1% of MIST scaled full flow |

These conversion factors are specific to Crystal River and differ slightly from those used for MIST Phase III tests (reference 9).

2. Switch control of the rector vessel vent valves from manual to automatic "independent" control (open/close setpoints of 0.125/0.04 psi).

3. De-energize the pressurizer heaters.

4. Actuate/open the low secondary pressure circuit.

The AFW and HPI simulations are specific to this test and are different from those used in the MIST Phase III tests (see Figures 3.13 and 3.14 and Tables 3.15 and 3.16). The secondary pressure control should simulate the Crystal River ADV/TBV systems at 50% of their rated capacity (one-half capacity of CR-3 capacity is 1537 lbm/h @ 1025 psia). The post-trip power function (Figure 3.15 and Table 3.17) is the same as used in the MIST Nominal Test but distorted in time by a factor of 1.36. This multiplier is the ratio of the MIST facility primary system volume to the ideally scaled Crystal River primary volume. The conversion factors for core power and primary and secondary flows to the percentage of full are listed in Table 3.14.

3.7.5. Control During Testing

Following test initiation, a series of actions must be performed to reproduce those taken by the plant operator. The test simulation requires a complex schedule of operator actions to adjust the performance of the high-pressure injection and auxiliary feedwater systems. A complete list of these actions is provided in Table 3.18. For most of the actions listed in Table 3.18, a time and a primary pressure are listed. The test operator should take the prescribed action when the specified pressure is reached. If the pressure for the action is not reached in the time specified in Table 3.18, the operator should delay performing the action as long as the specified pressure is being approached. Once beyond the specified time for the control action, the action may be taken when the pressure is within ± 1% of the specified pressure. If the system pressure stops approaching the specified pressure for a control action, then the operator should take that control action and proceed to the next step. The operator actions listed in Table 3.18 must be performed in the sequence specified. The times listed on Table 3.18 are delayed or distorted from the corresponding event listed on Table 3.12 by a factor of 1.36 i.e., MIST time = 1.36 x Crystal River time. The majority of operations involve the HPI and AFW flow rates. Action should be taken to

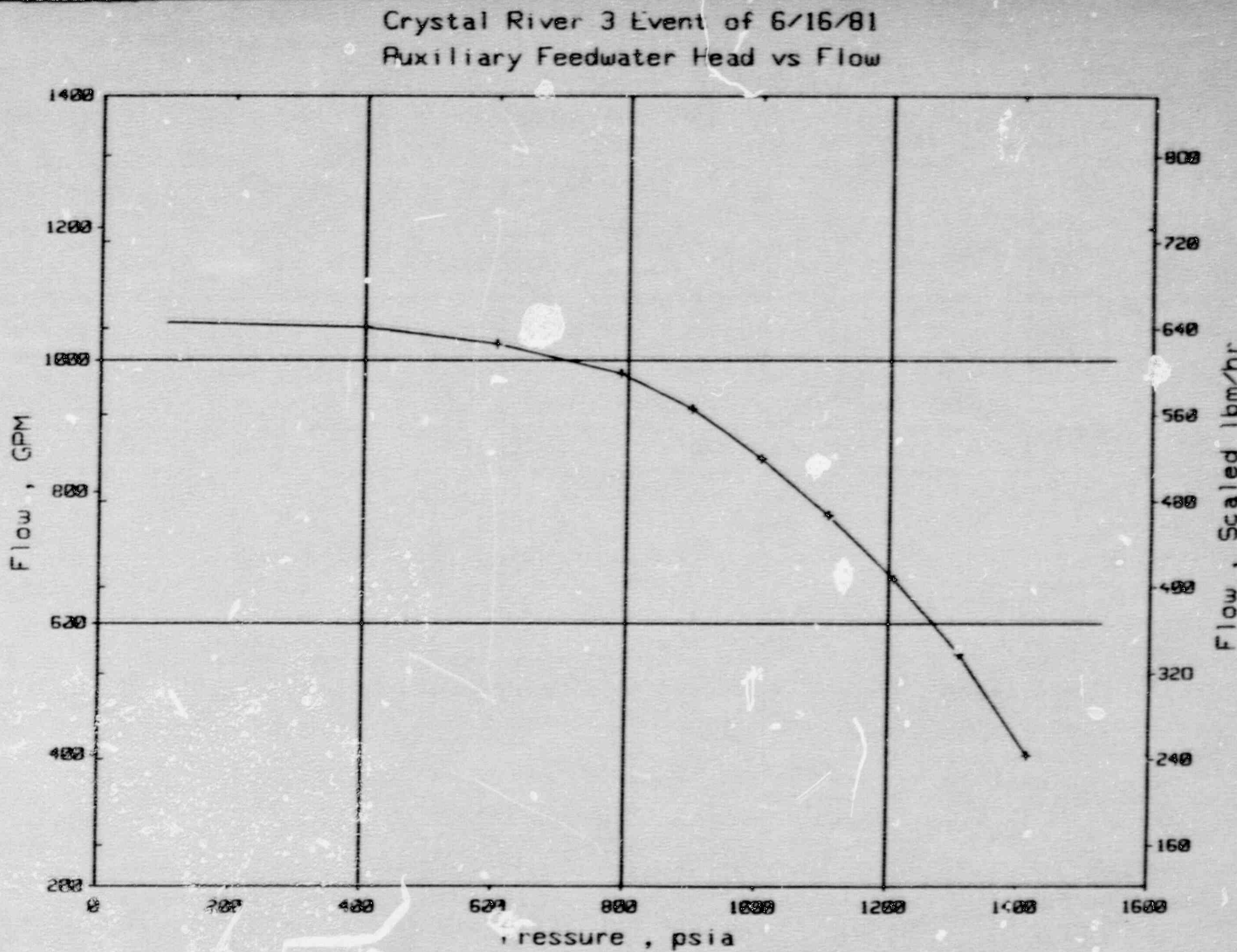



Figure 3.13 Auxiliary Feedwater Head Vs Flow

Tue Feb 16 09:10:53 1988

afw.plot

3-51

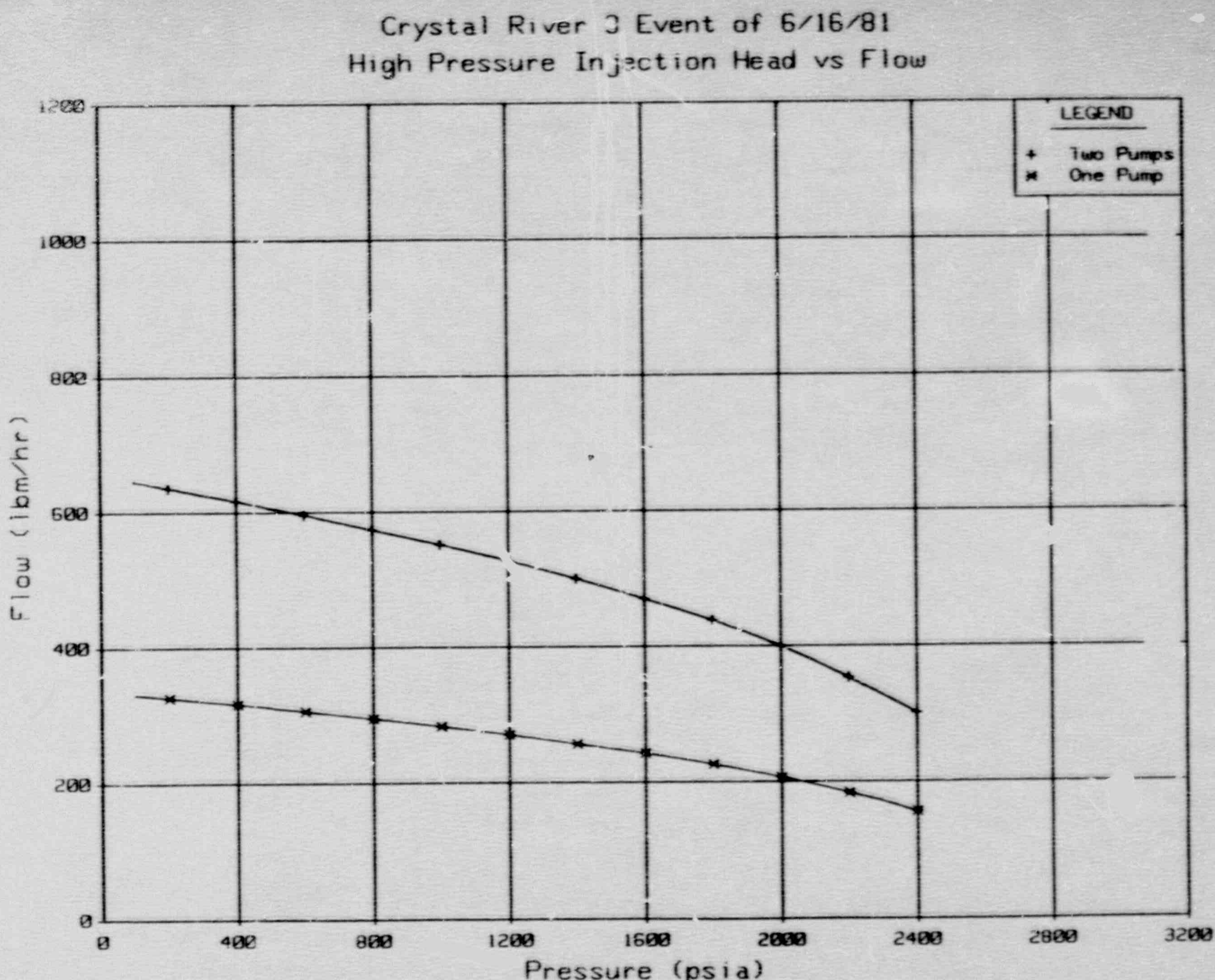



Figure 3.14 High-Pressure Injection Head Vs Flow

Tue Feb 16 09:32:43 1986

Table 3.15. Test 4CR3T2, Auxiliary Feedwater Characteristics*

| Secondary Pressure (psia) | CR-3 Flow (gpm)** | MIST Flow (lbm/h)*** |
|---|---|---|
| 100 | 1057 | 646 |
| 400 | 1050 | 641 |
| 600 | 1025 | 626 |
| 789 | 981 | 599 |
| 897 | 926 | 566 |
| 954 | 887 | 542 |
| 1003 | 850 | 519 |
| 1068 | 797 | 487 |
| 1106 | 766 | 468 |
| 1207 | 667 | 408 |
| 1269 | 599 | 366 |
| 1308 | 554 | 338 |
| 1413 | 399 | 244 |

*Data are from reference 10.

**Flow is per steam generator.

***MIST flow is scaled by a factor of 817.

Table 3.16. Test 4CR3T2, High-Pressure Injection Characteristics

| RCS Pressure (psia) | Two-Pump Flow* (lbm/h) | One-Pump Flow* (lbm/h) |
|---|---|---|
| 100 | 645 | 331 |
| 200 | 636 | 326 |
| 300 | 626 | 321 |
| 400 | 617 | 317 |
| 500 | 607 | 312 |
| 600 | 596 | 306 |
| 700 | 585 | 301 |
| 800 | 574 | 295 |
| 900 | 563 | 289 |
| 1000 | 552 | 283 |
| 1100 | 540 | 277 |
| 1200 | 527 | 270 |
| 1300 | 514 | 264 |
| 1400 | 500 | 256 |
| 1500 | 485 | 250 |
| 1600 | 470 | 242 |
| 1700 | 455 | 234 |
| 1800 | 438 | 226 |
| 1900 | 420 | 216 |
| 2000 | 400 | 206 |
| 2100 | 378 | 195 |
| 2200 | 354 | 183 |
| 2300 | 329 | 171 |
| 2400 | 302 | 157 |

*Flow is the total to the RCS.

**Data are from reference 11.

Crystal River 3 Event of 6/16/81
Post-Trip Power vs Time

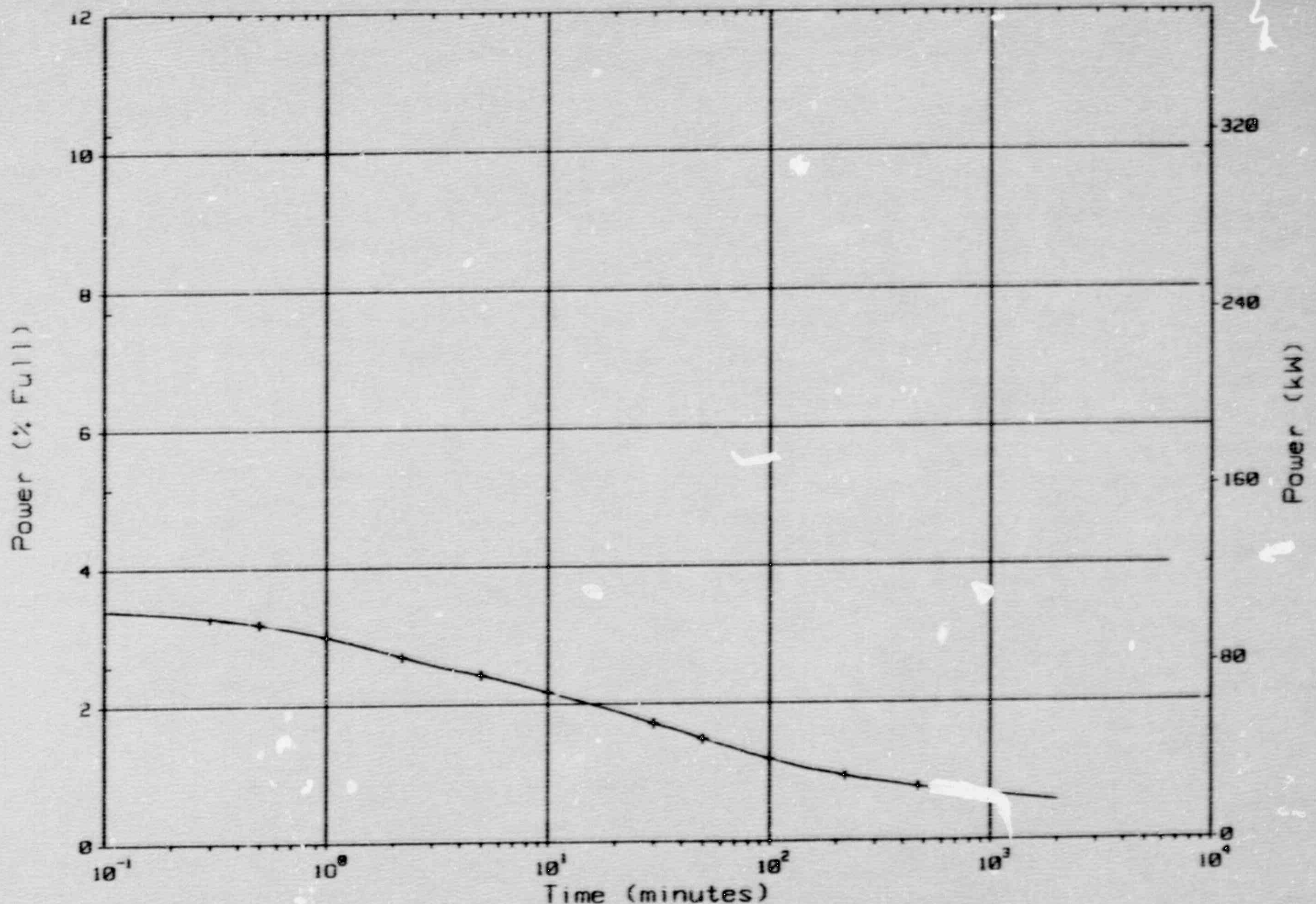



Figure 3.15 Post-Trip Power Vs Time

Tue Feb 16 08:32:25 1988

dh.plot

Table 3.17. Test 4CR3T2, Post-Trip Power

| Time (min)* | Power (%)** |
|---|---|
| 0.1 | 3.3912 |
| 0.2 | 3.3314 |
| 0.3 | 3.2764 |
| 0.4 | 3.2256 |
| 0.5 | 3.1784 |
| 0.6 | 3.1345 |
| 0.7 | 3.0937 |
| 0.8 | 3.0555 |
| 0.9 | 3.0197 |
| 1.0 | 2.9860 |
| 1.1 | 2.9541 |
| 1.2 | 2.9237 |
| 1.4 | 2.8675 |
| 1.6 | 2.8167 |
| 1.8 | 2.7708 |
| 2.0 | 2.7293 |
| 2.5 | 2.6422 |
| 3.0 | 2.5745 |
| 3.5 | 2.5224 |
| 4.0 | 2.4833 |
| 5.0 | 2.4207 |
| 6.0 | 2.3600 |
| 7.0 | 2.3038 |
| 8.0 | 2.2529 |

Table 3.17. Test 4CR3T2, Post-Trip Power (Cont'd)

| Time (min)* | Power (%)** |
|---|---|
| 9.0 | 2.2073 |
| 10.0 | 2.1668 |
| 20.0 | 1.8987 |
| 40.0 | 1.5992 |
| 60.0 | 1.4048 |
| 80.0 | 1.2765 |
| 100.0 | 1.1889 |
| 200.0 | 0.96650 |
| 300.0 | 0.86807 |
| 400.0 | 0.81325 |
| 500.0 | 0.76751 |
| 600.0 | 0.74000 |
| 700.0 | 0.71836 |
| 800.0 | 0.69778 |
| 900.0 | 0.67922 |
| 1000.0 | 0.66376 |

*Time zero is the actual decay power at 1 minute 40 seconds.

**Power is calculated by the relationship

$$P = P\,[(\text{Time}/1.36 + 1.667)].$$

Table 3.18. Test 4CR3T2, Operator Actions

| Event | Time* Min. | Time* Sec. | RCS P psia |
|---|---|---|---|
| Initiate post-trip power function.<br>Set steam generator A level to 32 ft.<br>Open low steam flow circuit. | | 0 | |
| Set steam generator B level to 11 ft. | | 41 | 1895 |
| Initiate HPI (1-pump simulation). | 2 | 31 | 1892 |
| Set steam generator B level to 9.5 ft. | 2 | 43 | 1891 |
| Increase HPI flow (2-pump simulation). | 4 | 1 | 1903 |
| Set steam generator B level to 30 ft. | 7 | 29 | 1963 |
| Set steam generator A level control to 20.7 ft. | 8 | 50 | 1981 |
| HPI pump C terminated (1-pump simulation). | 13 | 35 | 2237 |
| Set steam generator B level control to 20.7 ft. | 15 | 38 | 2262 |

*Times are relative to the initiating event i.e., loss-of-offsite power plus 1 minute 30 seconds. A "time distortion factor" of 1.36 has been applied to the corresponding events from Table 3.12. The test time is computed using the relationship

$$\text{Test Time} = 1.36 \times [\text{CR3 time} - 1.667].$$

prevent the secondary pressure in either steam generator from decreasing below 600 psia at any time during the transient. Control steam pressure at a constant 600 psi until loop conditions tend to raise pressure above this setpoint, then return to the simulated 50% ADV/TBV capacity.

### 3.7.6. Termination

The test should be terminated based on the establishment of the stable natural circulation cooldown conditions, although termination may be delayed at the discretion of the Test Engineer. These conditions are secondary pressure equal to 700 psia, and the secondary levels controlled to 50% on the operating level (20.7 ft SFLTS). Other approximate conditions are listed in Table 3.19. The Crystal River transient lasts approximately 1 hour. Data should be saved for approximately 1 hour after achieving the terminating conditions. The test may also be terminated if the plant terminal conditions cannot be achieved in the MIST facility within 5 hours following test initiation.

### 3.7.7. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.
2. Test initiation is performed as specified.
3. The specified boundary system control settings are maintained throughout the test. Because of the complexity and number of operator actions, the test is acceptable provided that the general control specifications are adhered to, and the actions performed are sufficiently annotated to permit code modeling.
4. Test termination is performed as specified.
5. All critical instrument data as specified in Appendix F reference 6 is recorded at intervals of 10 seconds or less throughout the test. Since the Crystal River 3 event did not lead to two-phase conditions in the cold legs, no changes to Category C instrument classifications are necessary, with exception to those instruments previously addressed by the Program Management Group.

Table 3.19. Test 4CR3T2, Final Conditions*

| Quantity | Approximate Values |
|---|---|
| Core power** | 1% |
| Primary flow | 1% |
| Primary pressure | 2200 psia |
| Hot leg inlet temperature | 540F |
| RC pump inlet temperature | 500F |
| Pressurizer level*** | 27.1 ft |
| Secondary flow | 1% |
| Secondary pressure | 700 psia |
| Secondary level | 20.7 ft |

*This table is provided for information only and not as a specification of the actual final conditions during the test.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

## 3.8. Test 4SEC02 -- Rancho Seco Scaling Transient

Test 4SEC02 is the second of two Phase IV tests that attempt to simulate actual plant transients. These tests are the Rancho Seco Loss-of-ICS Power Event of December 26, 1985 and the Crystal River Unit 3 Loss-of-Offsite Power Event of June 16, 1981. These transients have been selected for two reasons: First, because they are well documented (references 7 and 8) and second, because they can be simulated without the addition of hardware and control systems to the present facility. The second scaling test, the Rancho Seco Event, will be simulated in this test specification.

### 3.8.1. Purpose

The purpose of this test is to simulate, as closely as possible, a plant transient on the scaled MIST facility. The results of the test will be useful in providing benchmarking data for the code analysts and will provide insight into the scaling compromises that are known to exist in the facility. In particular, the pipe and steam generator metal masses, total primary system volume, and AFW wetting atypicalities are believed to have the greatest likelihood of influencing the results of this test. In order to compensate for the excess primary system volume of the MIST facility, a time "distortion" will be applied to the post-trip power function and the operator control actions.

### 3.8.2. Background

The Rancho Seco event occurred with the reactor at 75% full power and the ICS in the automatic mode of operation. A loss of ICS power caused the startup and main feedwater (MFW) block valves to close, thus terminating MFW flow to both steam generators. The loss of feedwater flow led to a reactor trip on high RCS pressure. The ICS failure caused the ADVs, TBVs, and AFW control valves to fail open to 50% demand. The AFW system and the secondary system safety valves quickly reduced secondary pressure. An excessive amount of AFW flow to both generators overcooled the primary system. The SFAS was actuated on low RCS pressure which started the HPI system. Copious amounts of AFW were injected until steam generator A completely filled. During the transient two to four reactor coolant pumps were constantly running. The overcooling and contraction of the RCS resulted in the formation of a saturated fluid volume within the reactor vessel head region. Large amounts of HPI flow in combination with low RCS pressure resulted in the PTS envelope being violated. Ultimately, the AFW flow was terminated and the HPI flow was throttled, resulting in the repressurization and stabilization of the plant. The thermal-hydraulic transient lasted approximately 90 minutes, although the official event lasted much longer. Table 3.20 contains a partial list of the key events and milestones of the transient. Plots of the available data are presented on Figures 3.16 through 3.36.

Table 3.20. Test 4SEC02, Key Events and Actions

| Event* | Time** Min. | Sec. |
|---|---|---|
| Loss of ICS power.<br>Startup and MFW control valves close to 50%.<br>AFW control valves, TBVs and ADVs open to 50%.<br>MFW block valves close.<br>MFW flow decreased to zero. | | 0 |
| Pressurizer spray started. | | 8 |
| AFW pump B starts. | | 14 |
| Reactor, turbine, and generator trip.<br>Pressurizer spray stopped.<br>Primary pressure reaches peak (2330 psia). | | 16 |
| AFW pump A started.<br>Hot leg temperature peaks at 606.5F. | | 19 |
| Letdown flow reduced. | | 20 |
| Secondary code reliefs lift. | | 25 |
| HPI valve A opened (full).*** | | 38 |
| Secondary code reliefs close. | | 39 |
| HPI pump B started. | 1 | 17 |
| MFW pumps tripped. | 2 | 15 |
| SFAS initiated on low RCS pressure (1600 psia).<br>Pressurizer level 15 inches.<br>HPI valve A, B, C, and D throttled.***, ****<br>AFW SFAS valves opened (full).<br>AFW pumps B stopped and re-started (half of current flow). | 3 | 10 |
| HPI pump A starts. | 3 | 12 |
| Pressurizer level goes offscale low.<br>Subcooling margin is 75F and increasing. | 3 | 13 |
| AFW SFAS valves closed. | 3 | 23 |
| AFW pumps A and B bus changed (full flow resumed). | 3 | 40 |
| Surge line empties.<br>Reactor vessel head reached saturation. | 5 | 13 |

Table 3.20. Test 4SEC02, Key Events and Actions (Cont'd)

| Event* | Time** Min. | Sec. |
|---|---|---|
| MFW flow starts (via condensate pumps). | 6 | 33 |
| HPI valve A throttled.*** | 7 | 0 |
| RCS pressure reaches minimum (1079 psia). | 7 | 38 |
| Surge line begins to fill.<br>RCS pressure starts to increase. | 7 | 43 |
| Secondary ADVs and TBVs closed. | 9 | 0 |
| Startup and MFW control valves close.<br>MFW flow stops. | 9 | 3 |
| AFW valve B partially closed. | 9 | 23 |
| HPI pump recirculation opened. | 11 | 43 |
| AFW valve A closed (full). | 12 | 35 |
| HPI valves A, B, C, and D throttled.*** | 13 | 0 |
| RC pump C stopped.<br>RCS temperature at 410F. | 14 | 13 |
| Letdown flow re-established. | 14 | 56 |
| HPI pump A stopped. | 15 | 12 |
| AFW valve A opened (full). | 15 | 53 |
| HPI valves C and D closed (full).*** | 15 | 58 |
| Makeup pump stopped. | 16 | 0 |
| Pressurizer spray started. | 19 | 13 |
| AFW valve B closed (full). | 19 | 33 |
| Steam generator secondary A overfills. | 19 | 53 |
| RCS reaches 390F, 1445 psia. | 25 | 13 |
| AFW valve A closed (full). | 26 | 13 |
| Minimum steam generator secondary pressure reached.<br>Steam generator A: 236 psia, steam generator B: 217 psia. | 26 | 23 |

Table 3.20. Test 4SEC02, Key Events and Actions (Cont'd)

| Event* | Time** Min. | Sec. |
|---|---|---|
| HPI pump B stopped. | 28 | 55 |
| HPI valves A and B closed (full).*** | 29 | 9 |
| HPI pump B started. | 30 | 7 |
| HPI pump B stopped. | 36 | 32 |
| HPI pump B started. | 36 | 43 |
| Secondary blowdown started. | 43 | 0 |
| AFW pumps A and B stopped. | 54 | 0 |
| RC pump A stopped. | 75 | 17 |
| HPI pump A started. | 181 | 0 |
| HPI pump B stopped. | 181 | 0 |

*Events were extracted from "Trip Report #75, Reactor Trip on December 26, 1975, Loss of ICS Power," prepared by Grant Simmons.

**Times are relative to the initiating event i.e., loss of ICS on December 26, 1985 at 4:13:47.

***HPI lines A, B, C, and D correspond to MIST lines A1, A2, B1, and B2.

****The HPI control valves are pre-throttled for SFAS conditions.

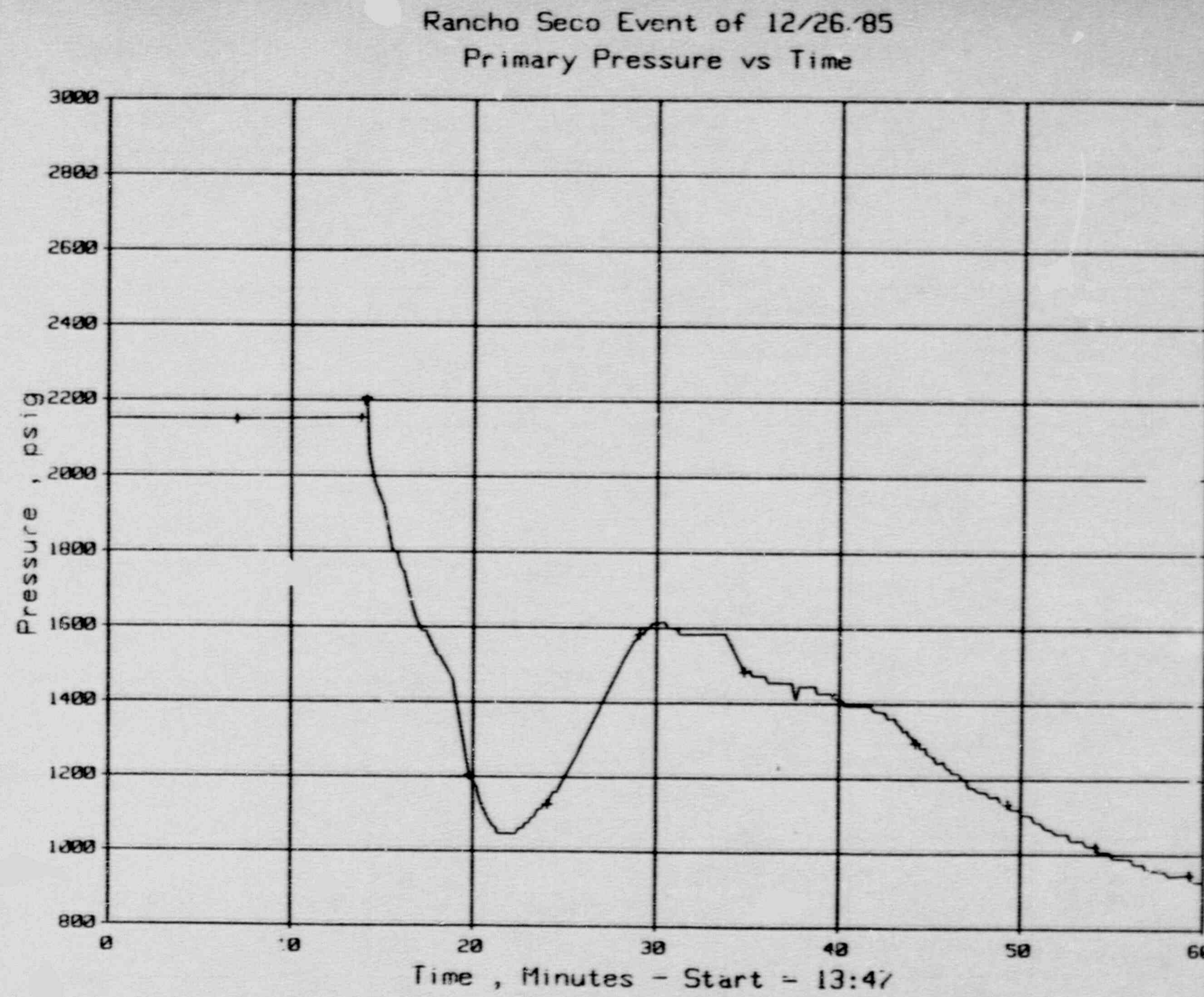



Figure 3.16 Primary Pressure Vs Time

Fri Feb 12 07:17:30 1988

rcsp.plot

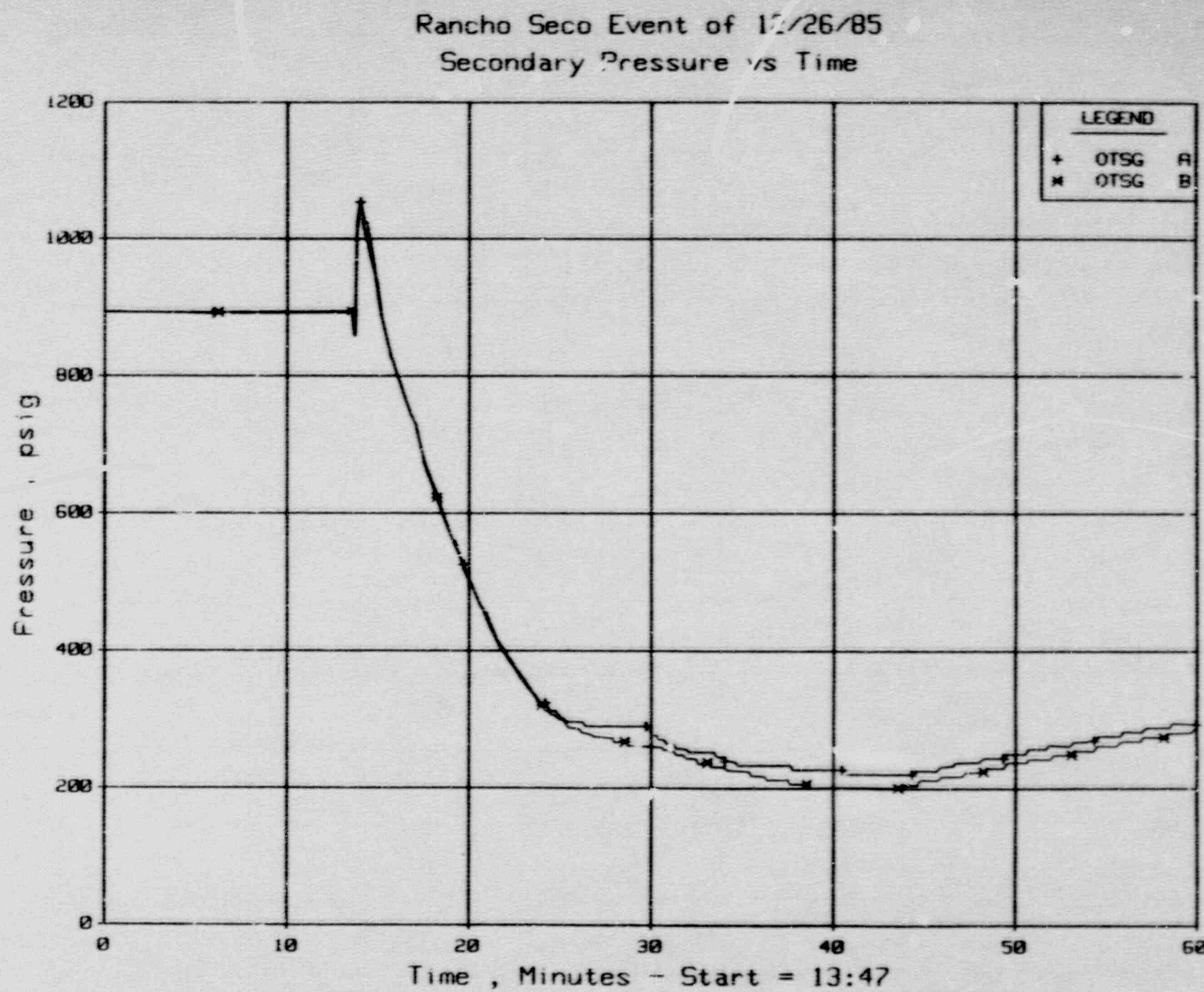



Figure 3.17 Secondary Pressure Vs Time

Fri Feb 12 07:13:36 1988

secp.plot

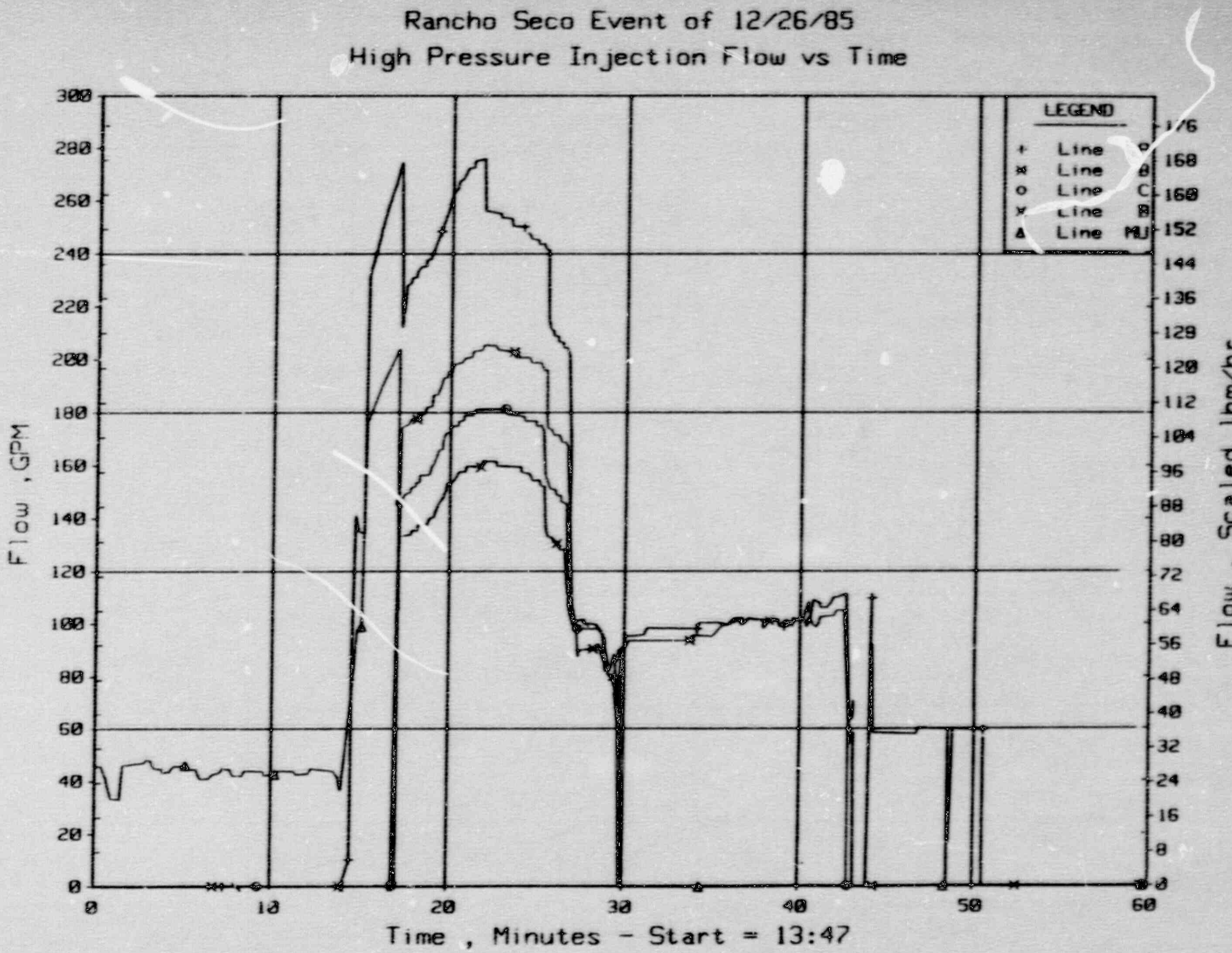



Figure 3.18 High-Pressure Injection Flow Vs Time

Fri Feb 12 07:24:53 1988

hpi.plot

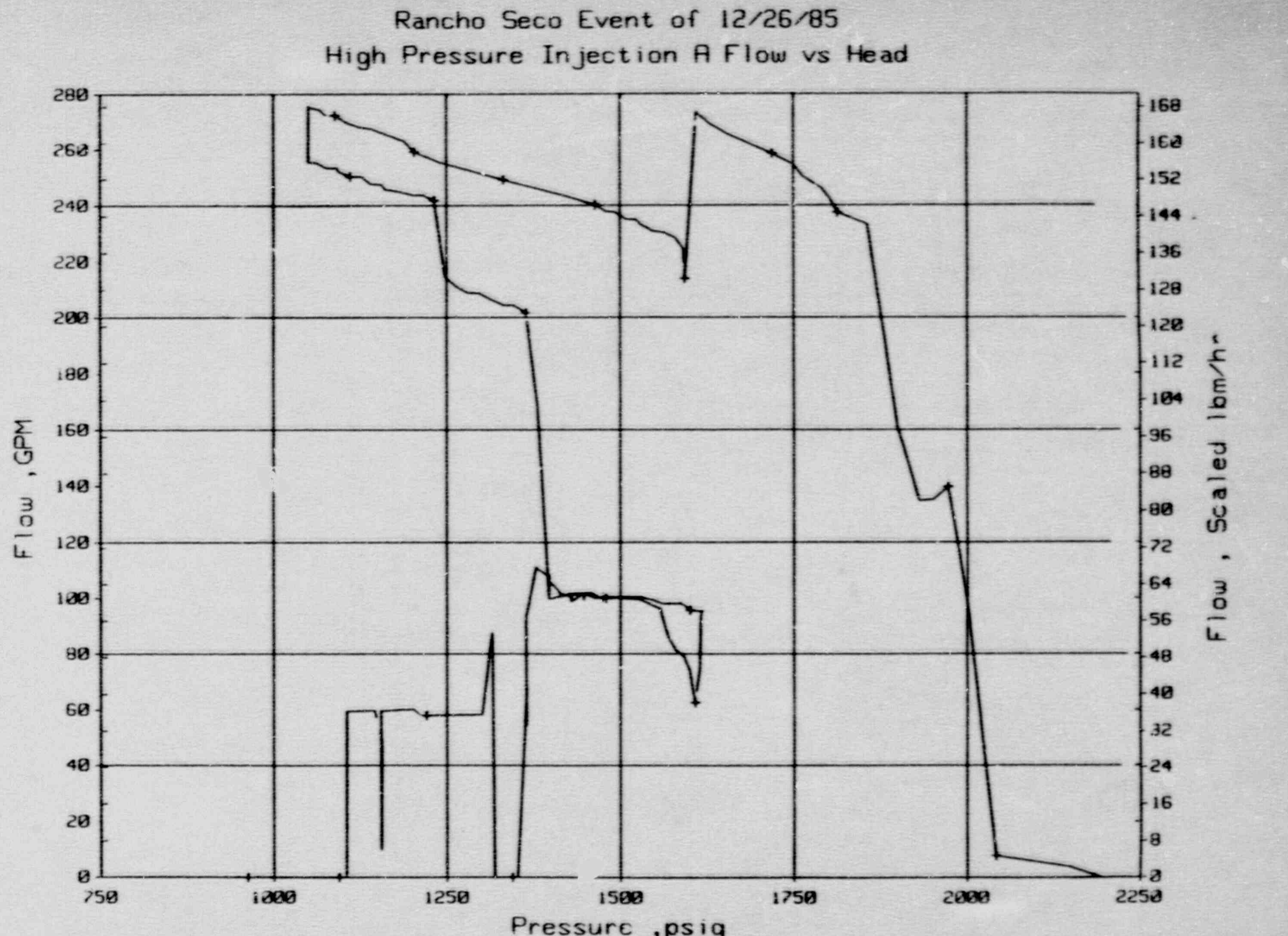



Figure 3.19 High-Pressure Injection A Flow Vs Head

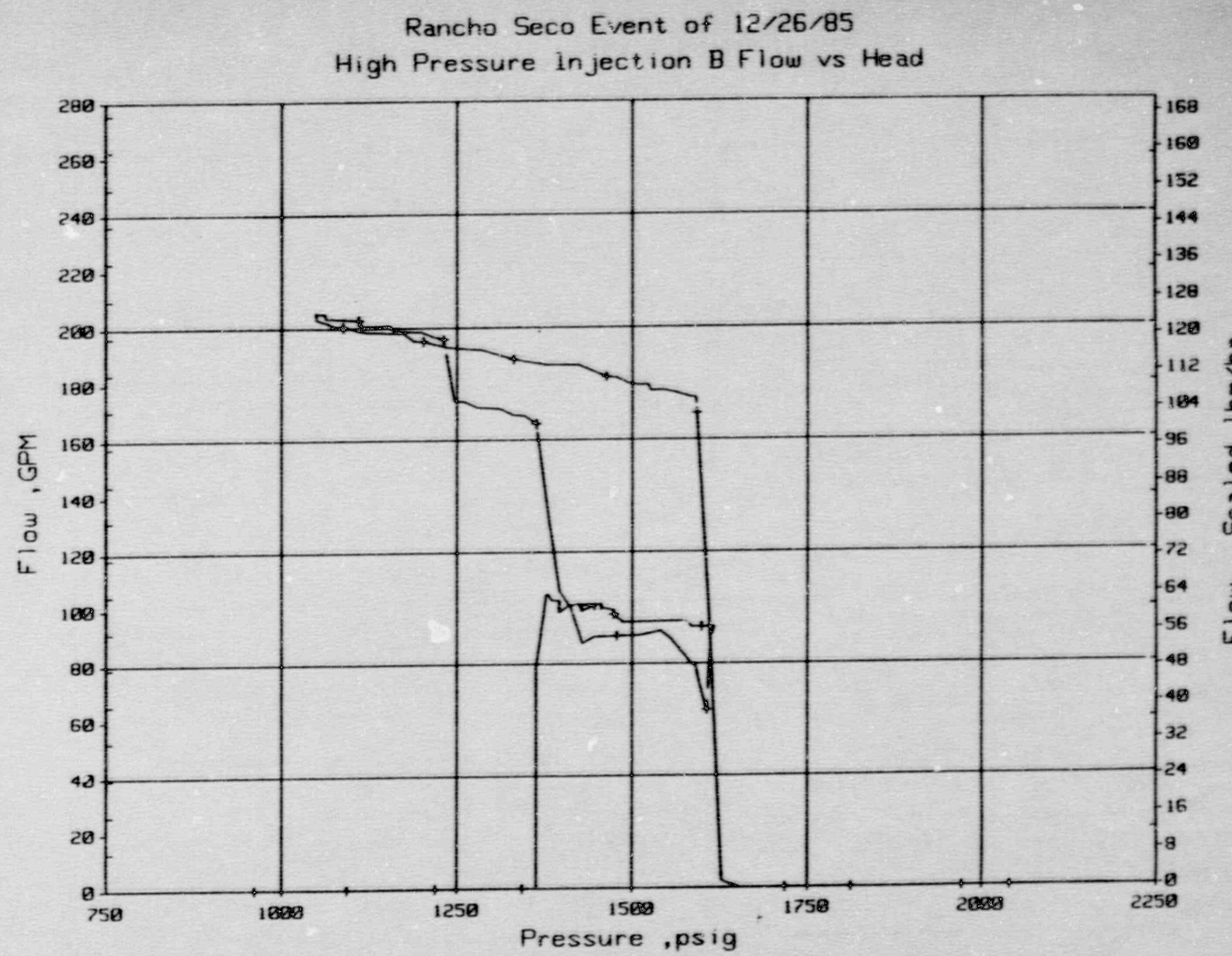



Figure 3.20 High-Pressure Injection B Flow Vs Head

Tue Feb 16 04:21:59 1988

hpibhf.plot

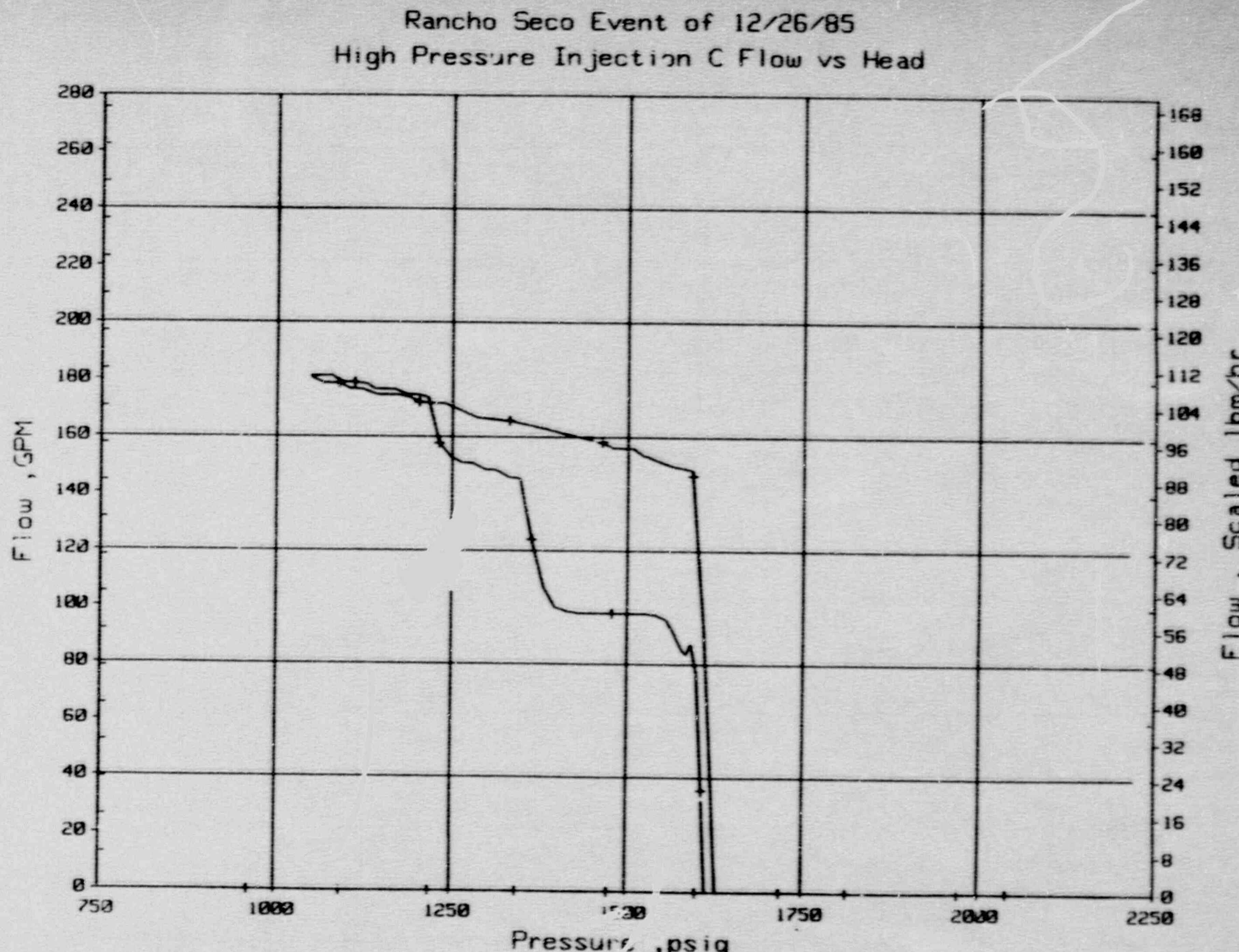



Figure 3.21 High-Pressure Injection C Flow Vs Head

Tue Feb 16 08:23:41 1988

hpichf.plot

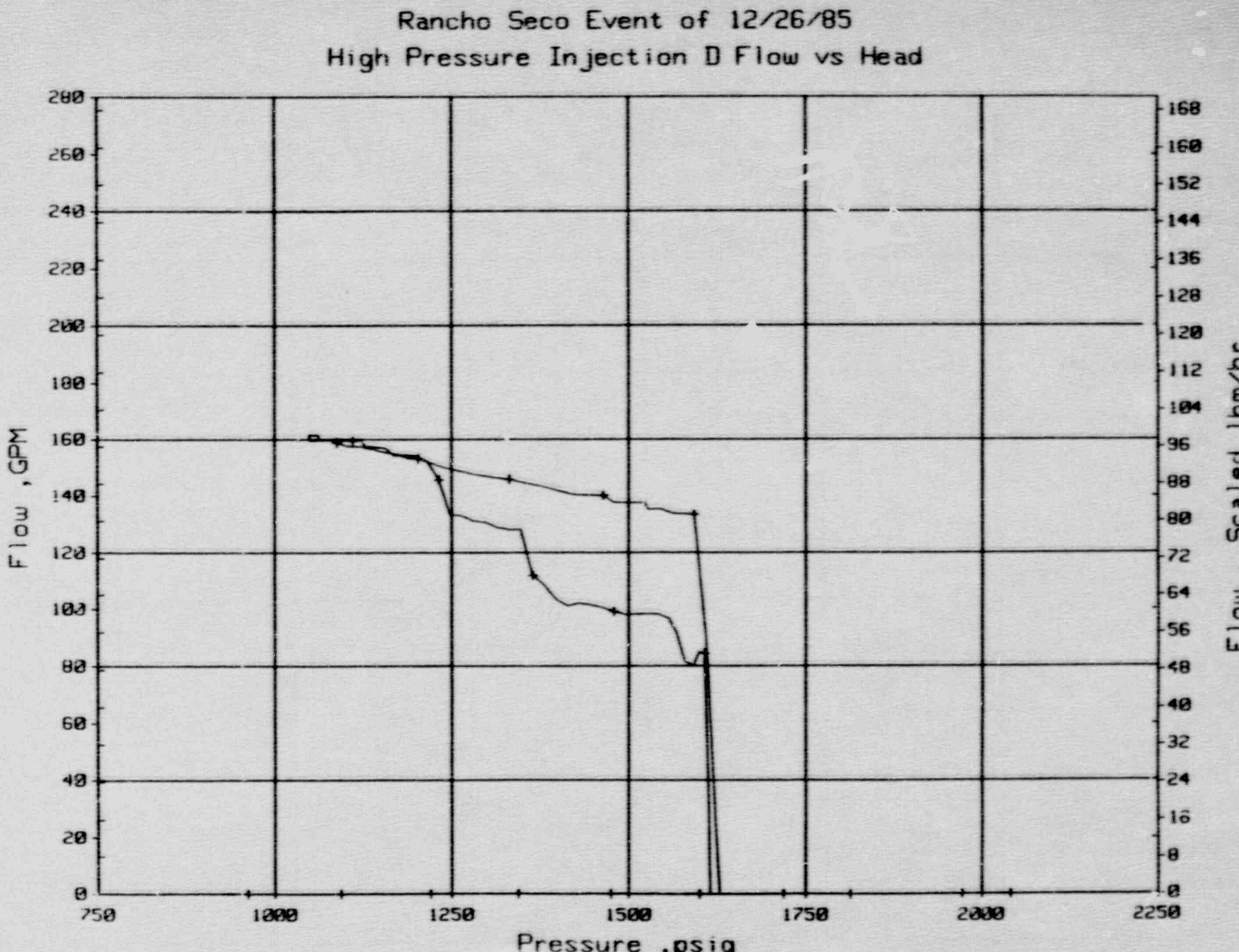



Figure 3.22 High-Pressure Injection D Flow Vs Head

Fri Feb 12 ... 1988

hp:ohf.plot

Rancho Seco Event of 12/26/85
Makeup Pump Flow vs Head

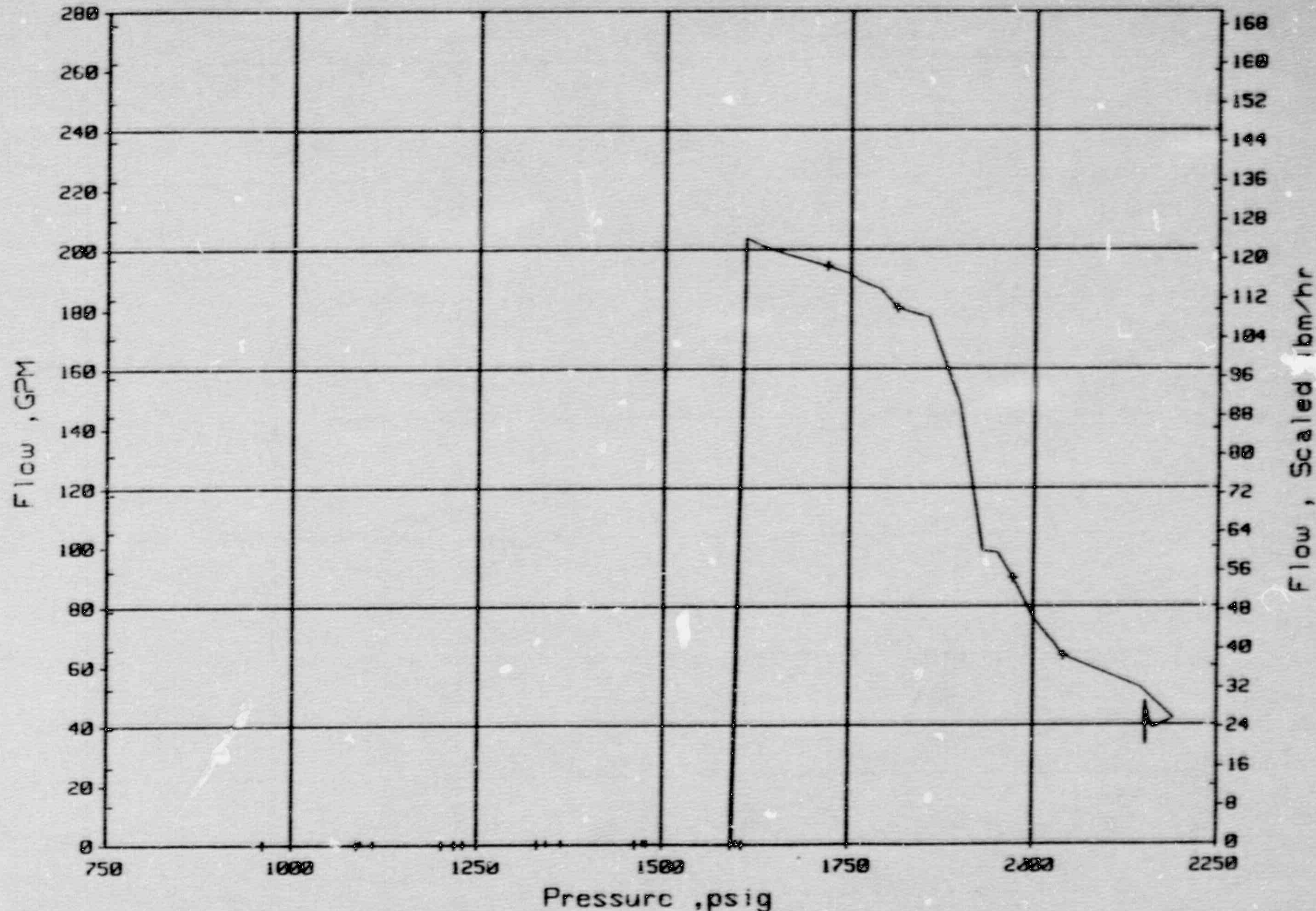



Figure 3.23 Makeup Pump Flow Vs Head

Fri Feb 12 07:34:31 1988

muhf.plot

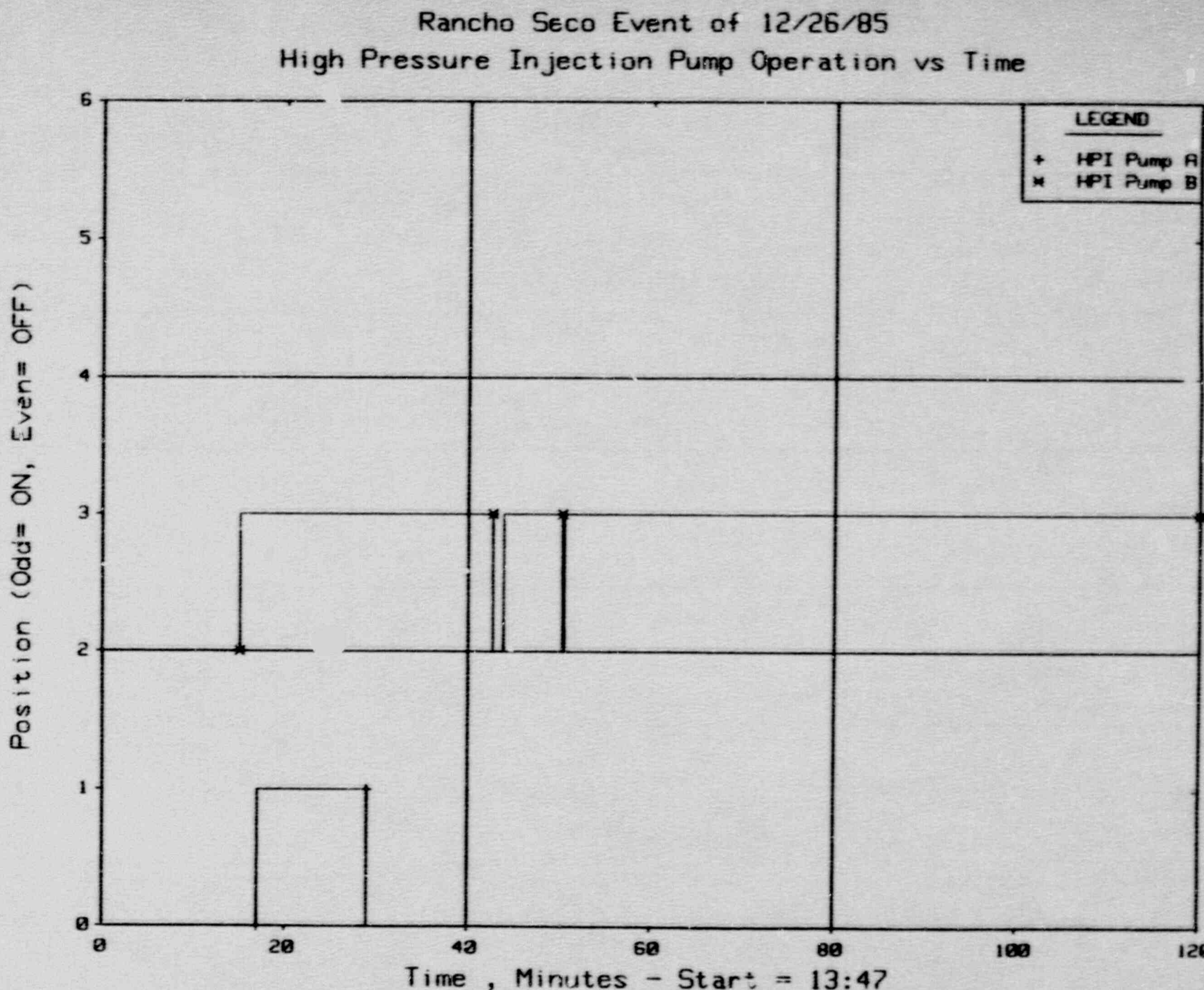



Figure 3.24 High-Pressure Injection Pump Operation Vs Time

Fri Feb 12 07:15:04 1988

hpis.plot

Rancho Seco Event of 12/26/85

High Pressure Injection Valve Positions vs Time



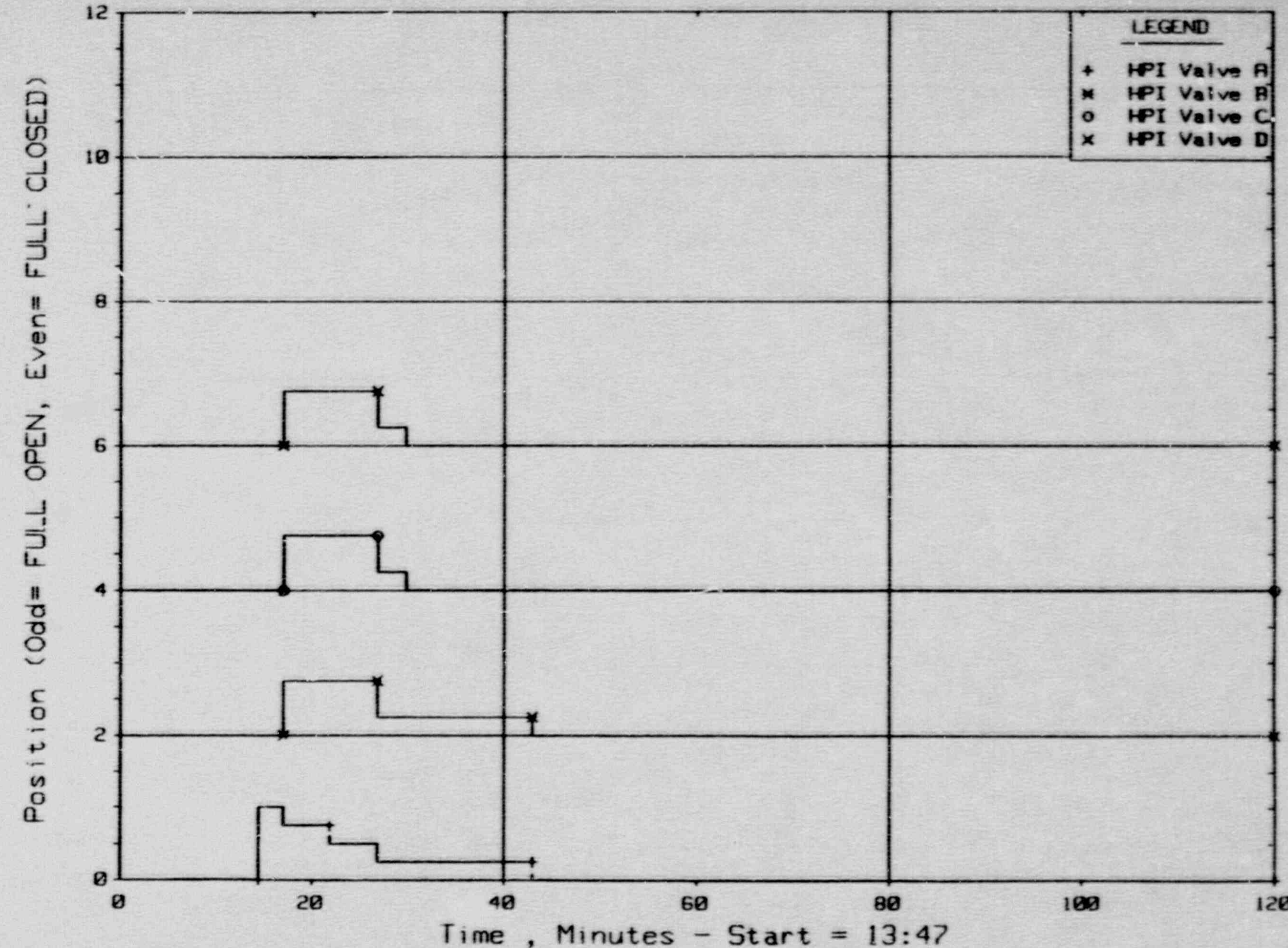



Figure 3.25 High-Pressure Injection Valve Positions Vs Time

Tue Feb 16 10:25:33 1988

hpivs.plot

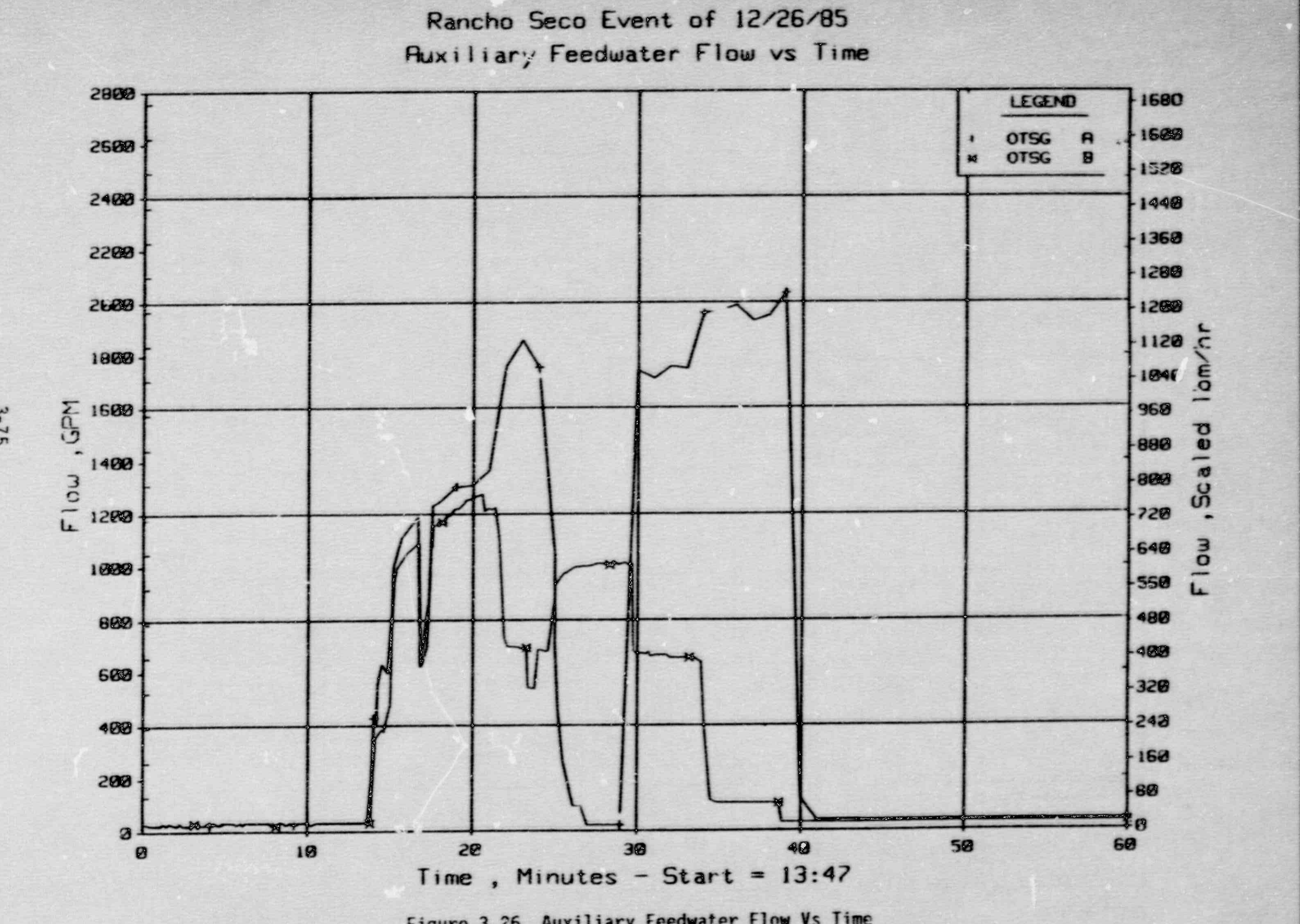



Figure 3.26 Auxiliary Feedwater Flow Vs Time

Fri Feb 12 06:57:15 1988

afw.plot

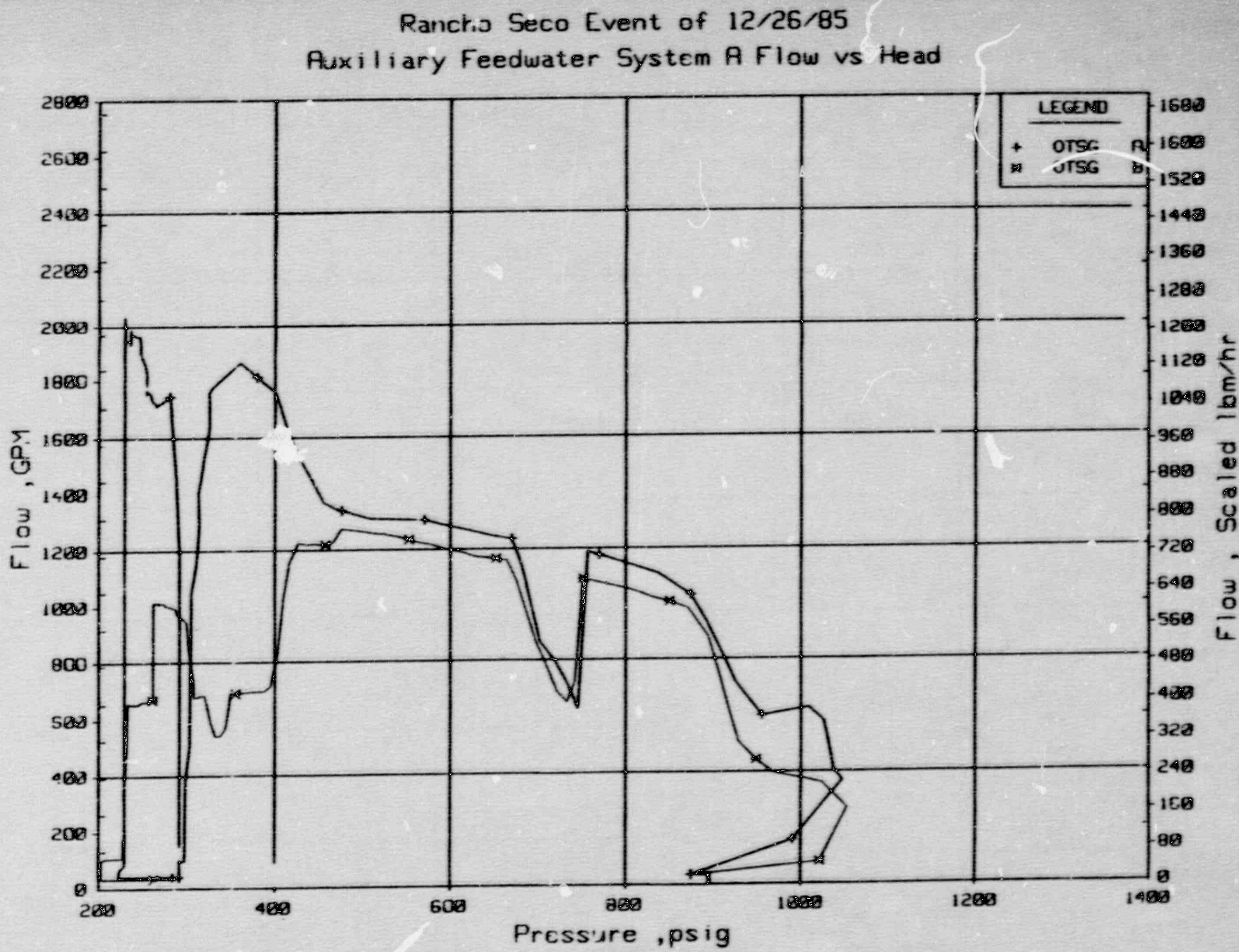



Figure 3.27 Auxiliary Feedwater System A Flow Vs Head

afwahf.plot

Fri Feb 12 07:02:51 1988

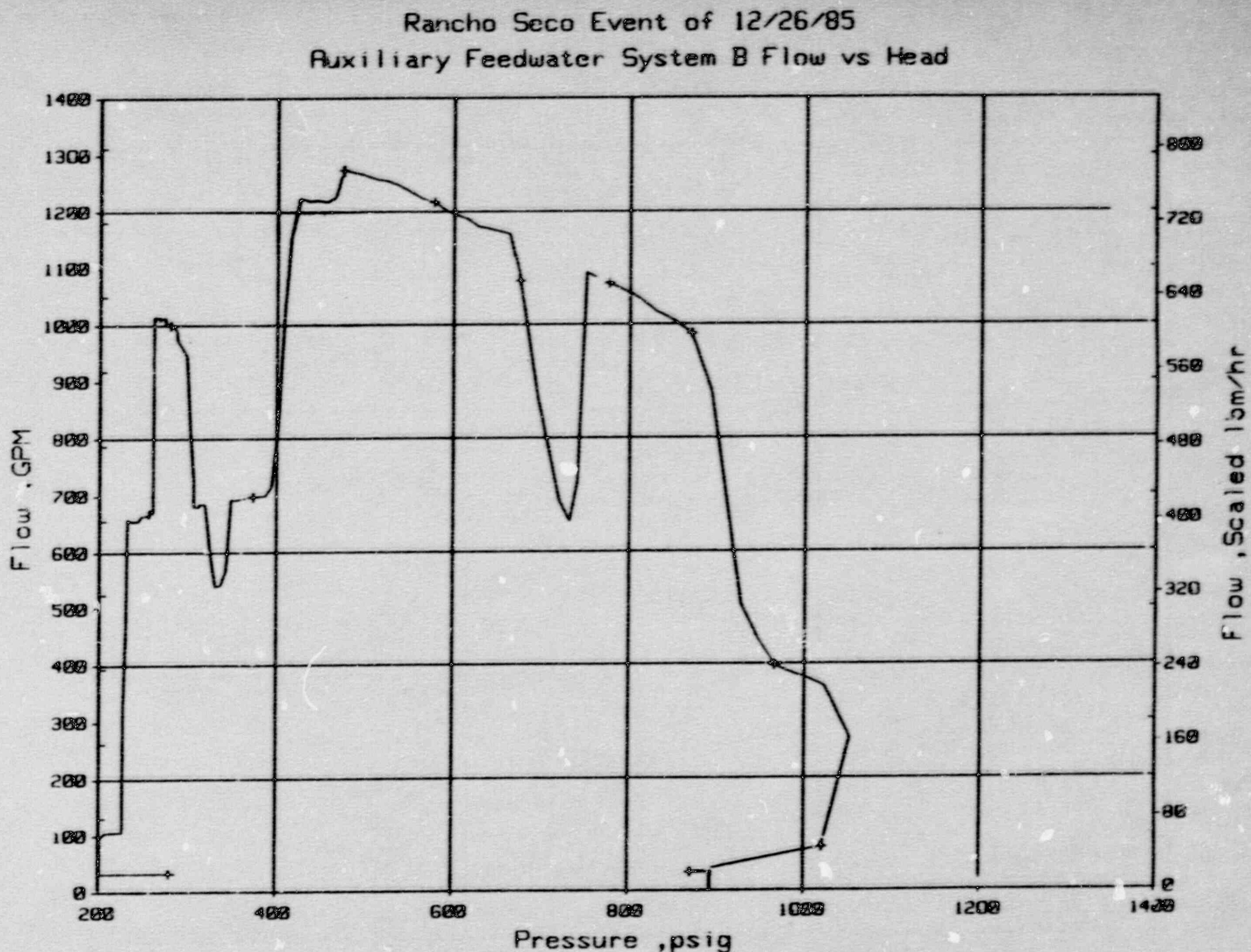



Figure 3.28 Auxiliary Feedwater System B Flow Vs Head

Fri Feb 12 07:08:42 1988

afwbhf.plot

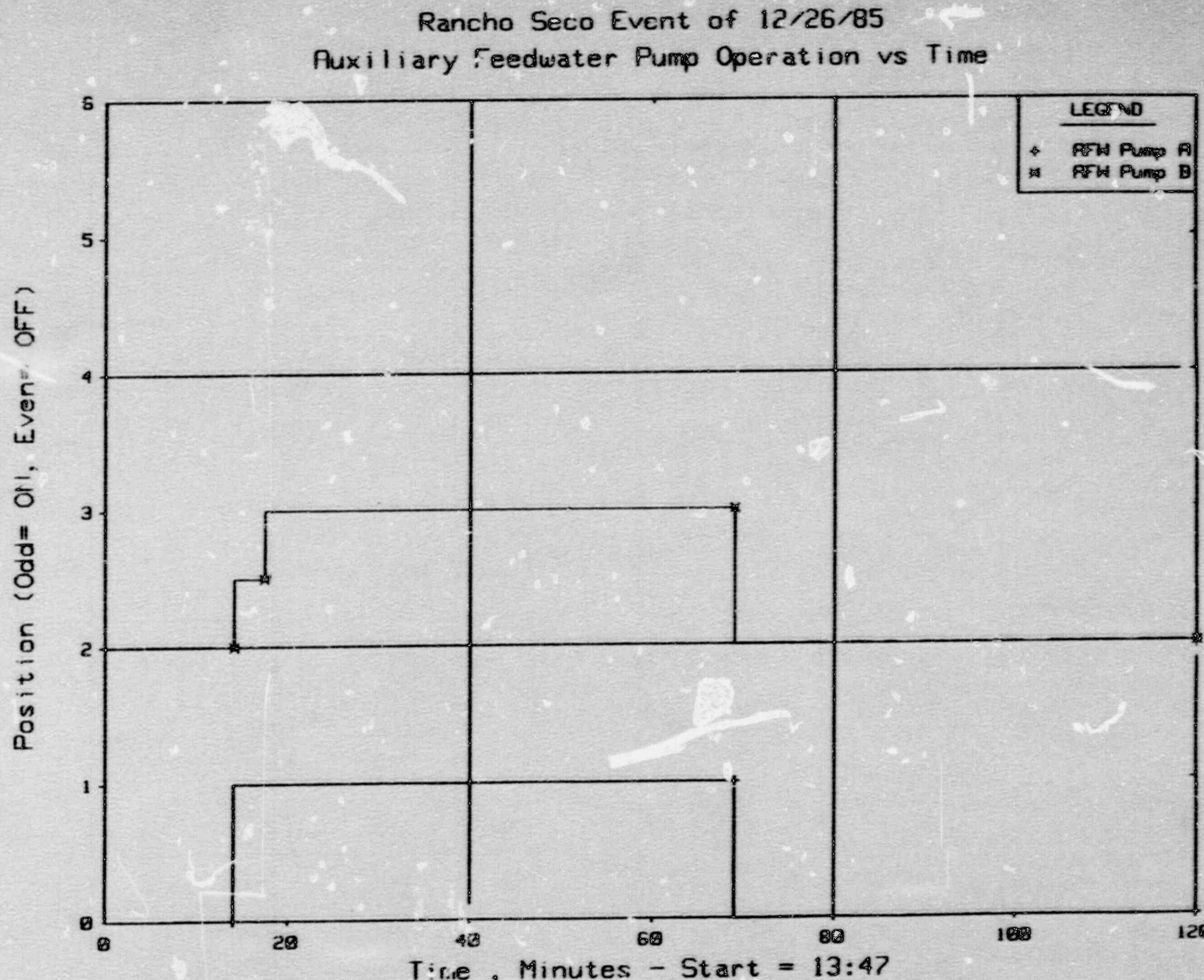



Figure 3.29 Auxiliary Feedwater Pump Operation Vs Time

Fri Feb 12 06:59:43 1988

afws.plot

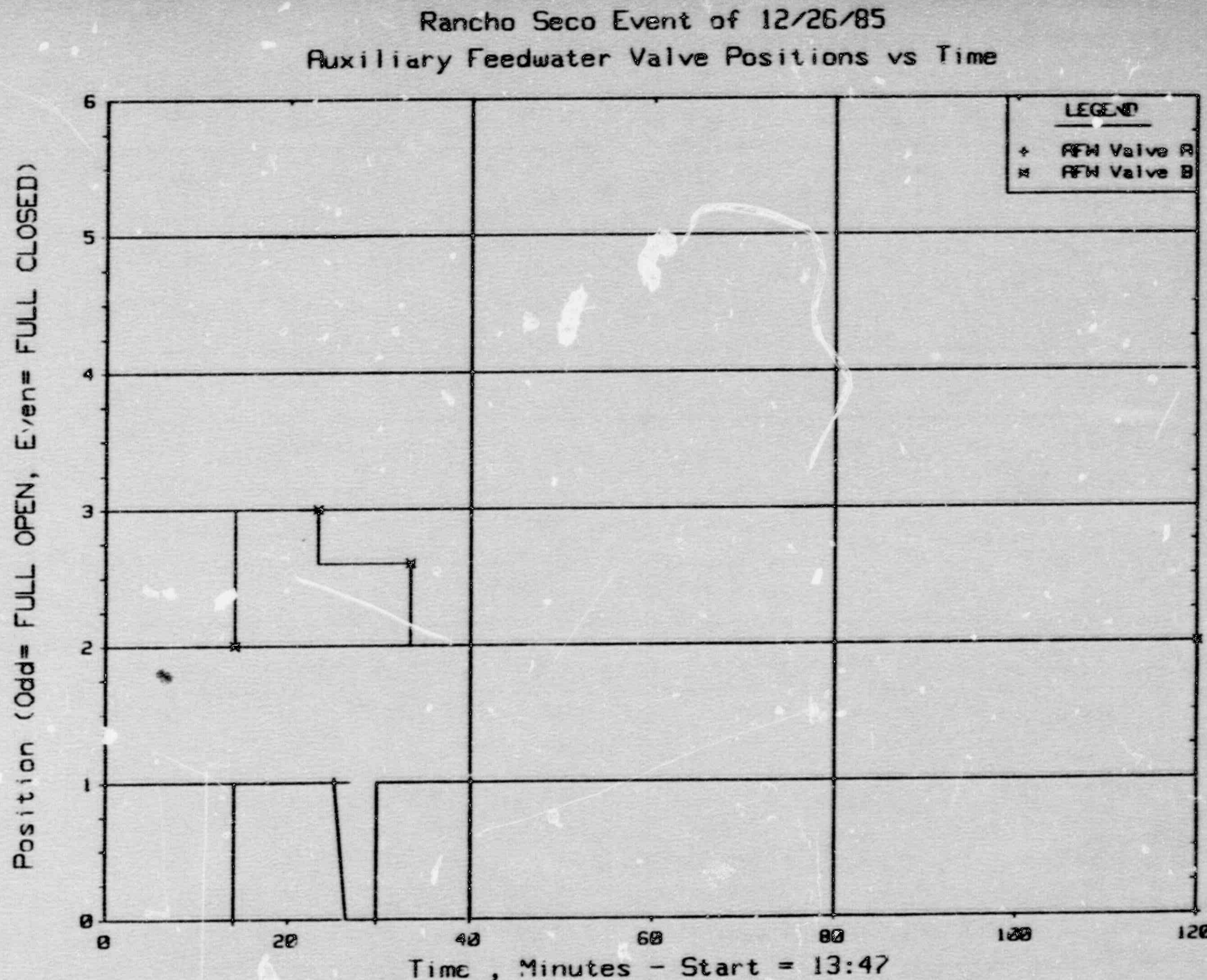



Figure 3.30 Auxiliary Feedwater Valve Positions Vs Time

Fri Feb 12 07:01:07 1988

afwvs.plot

Rancho Seco Event of 12/26/85

Reactor Coolant Pump Operation vs Time

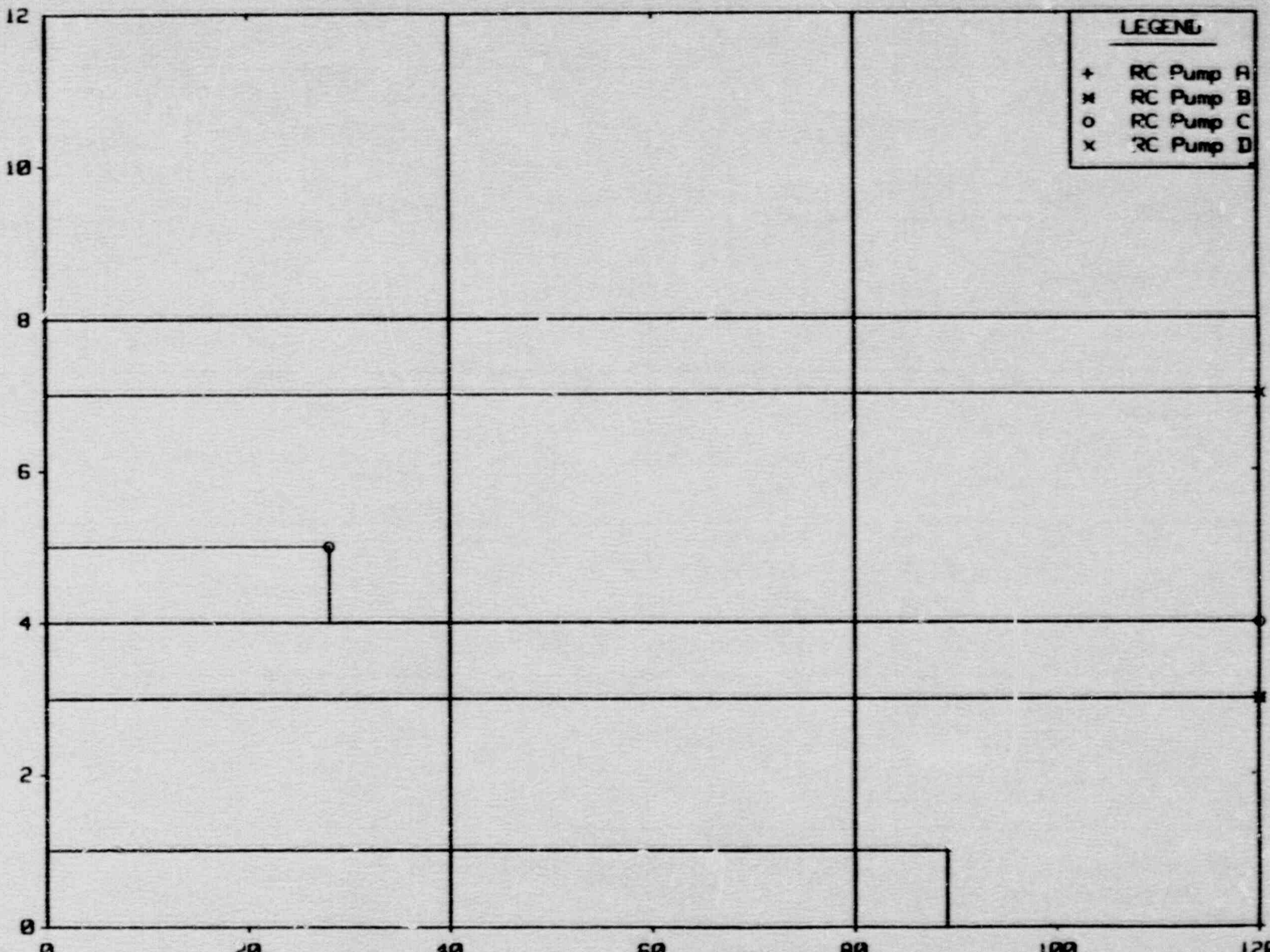



Figure 3.31 Reactor Coolant Pump Operation Vs Time

Fri Feb 12 07:15:37 1988

rcps.plot

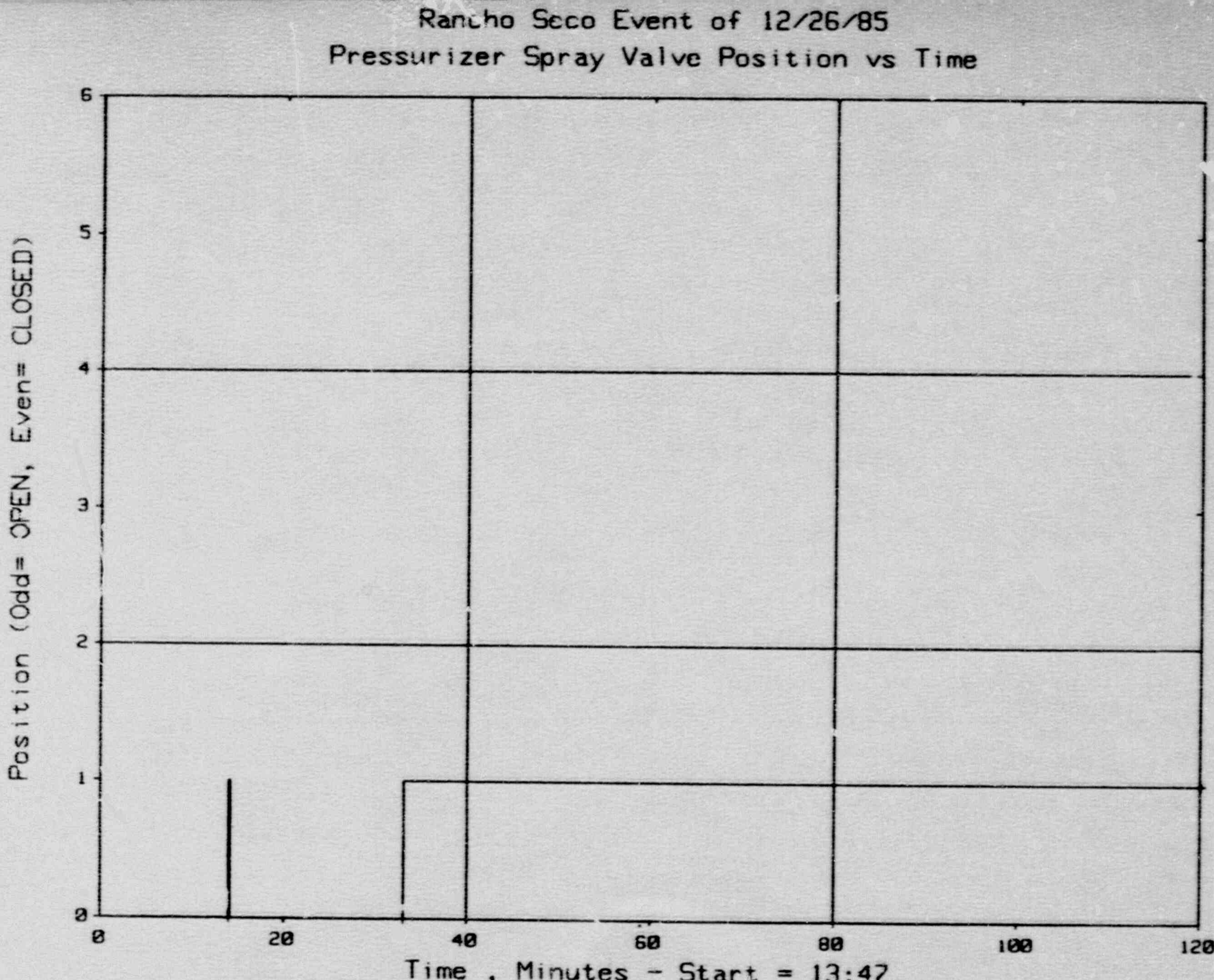



Figure 3.32 Pressurizer Spray Valve Position Vs Time

Fri Feb 12 07:29:22 1988

przs.plot

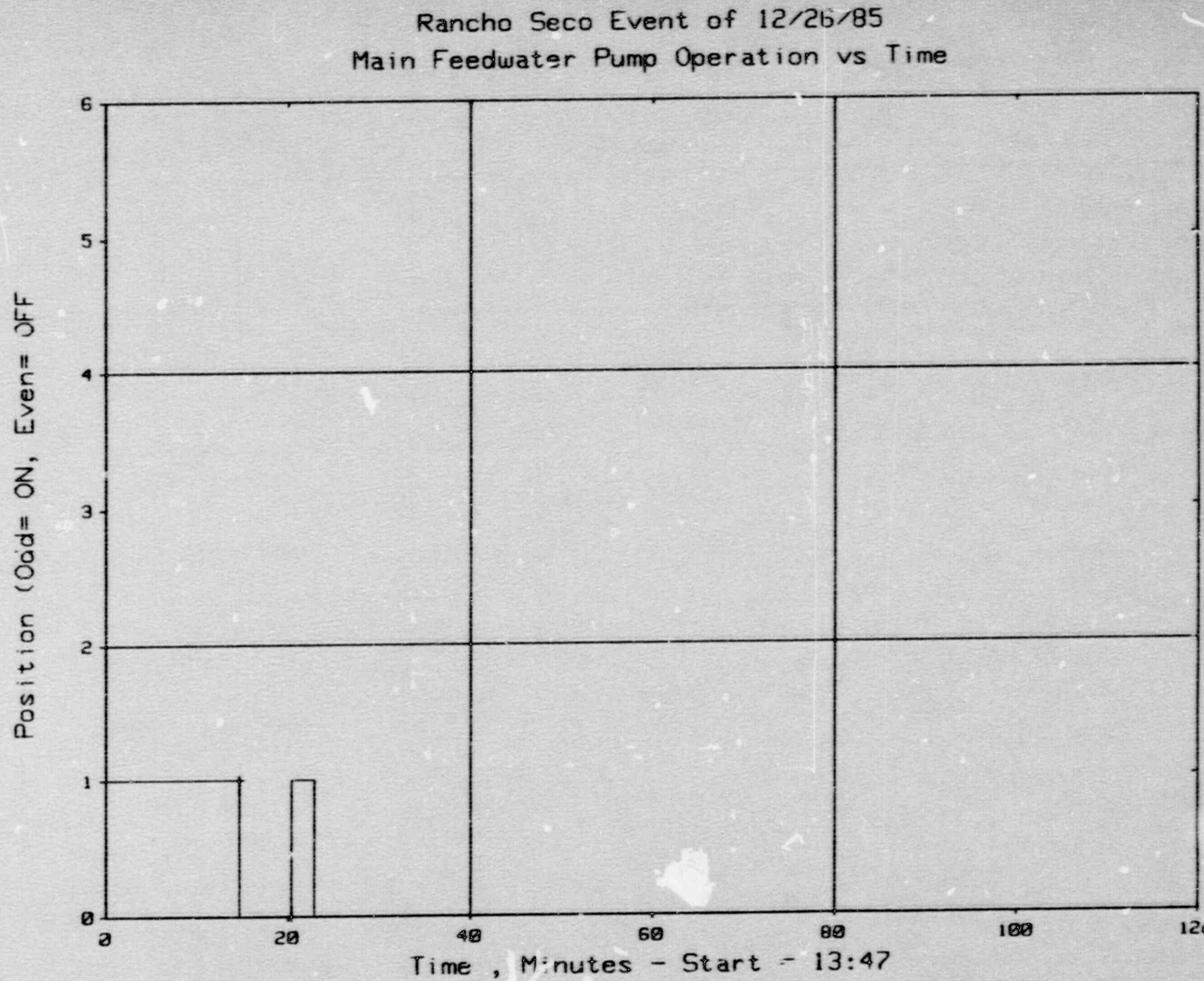



Figure 3.33 Main Feedwater Pump Operation Vs Time

Fri Feb 12 07:32:55 1988

mfw.plot

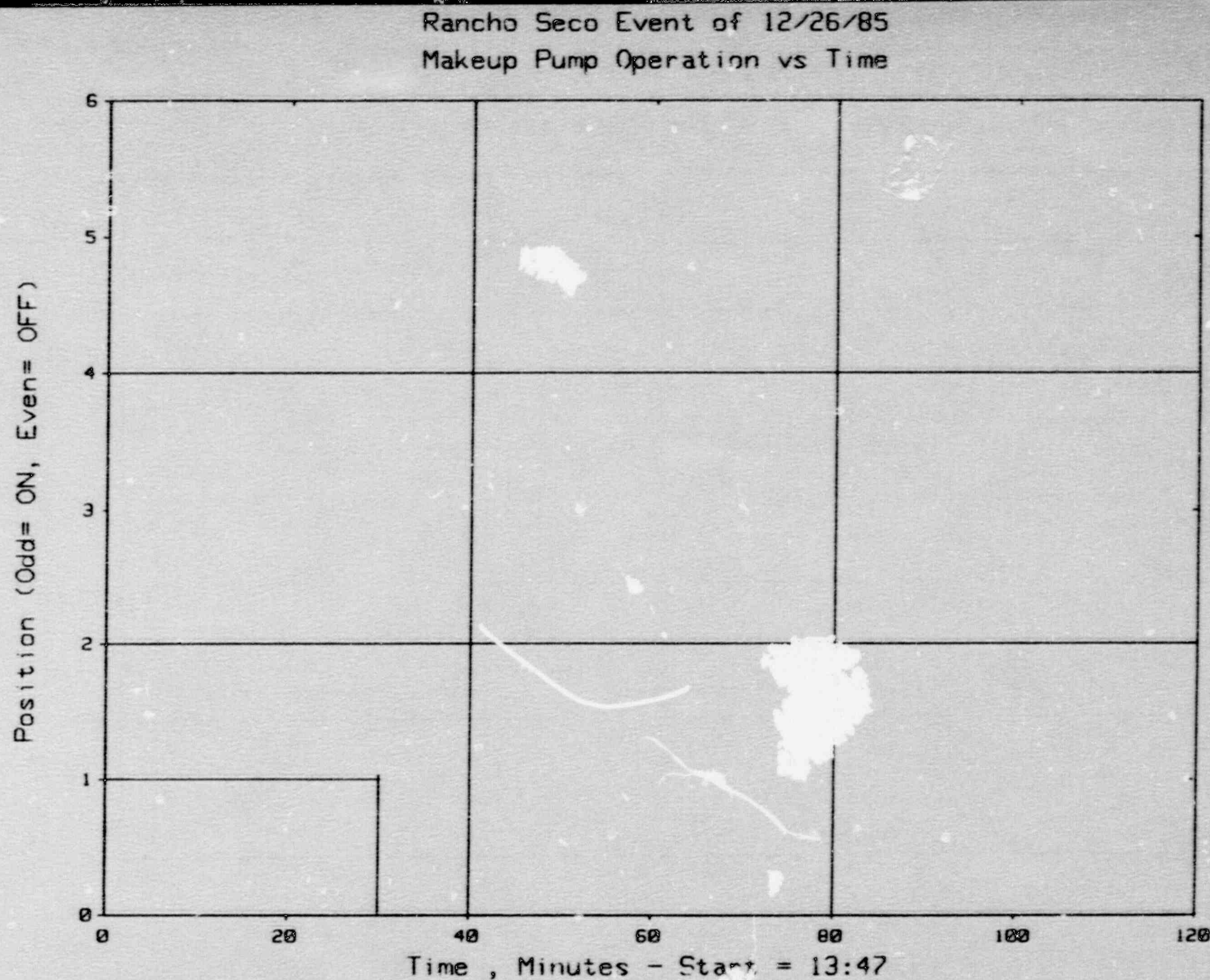



Figure 3.34 Makeup Pump Operation Vs Time

Fri Feb 12 07:36:25 1988

mus.plot

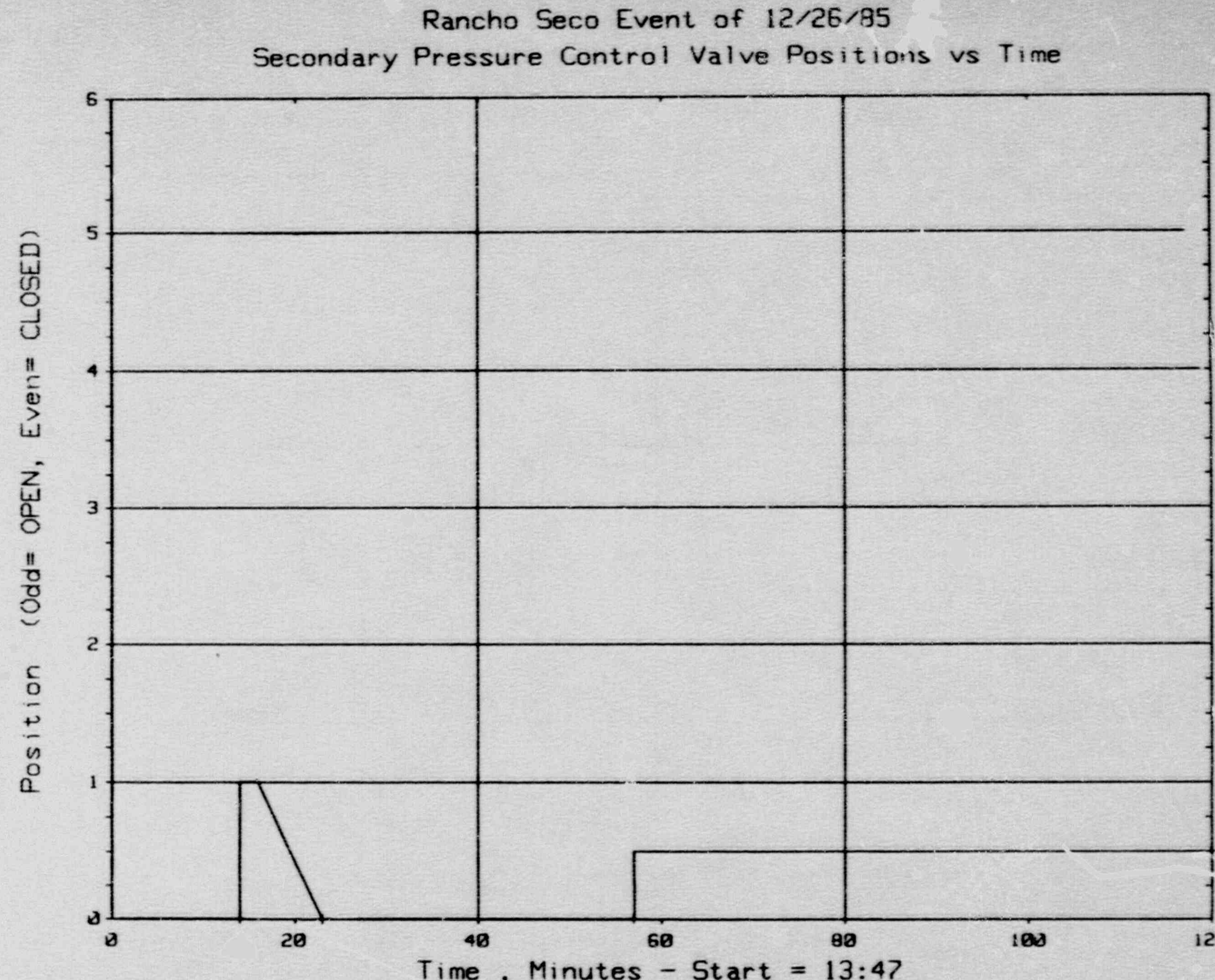



Figure 3.35 Secondary Pressure Control Valve Positions Vs Time

Fri Feb 12 07:36:21 1988

secvs.plot

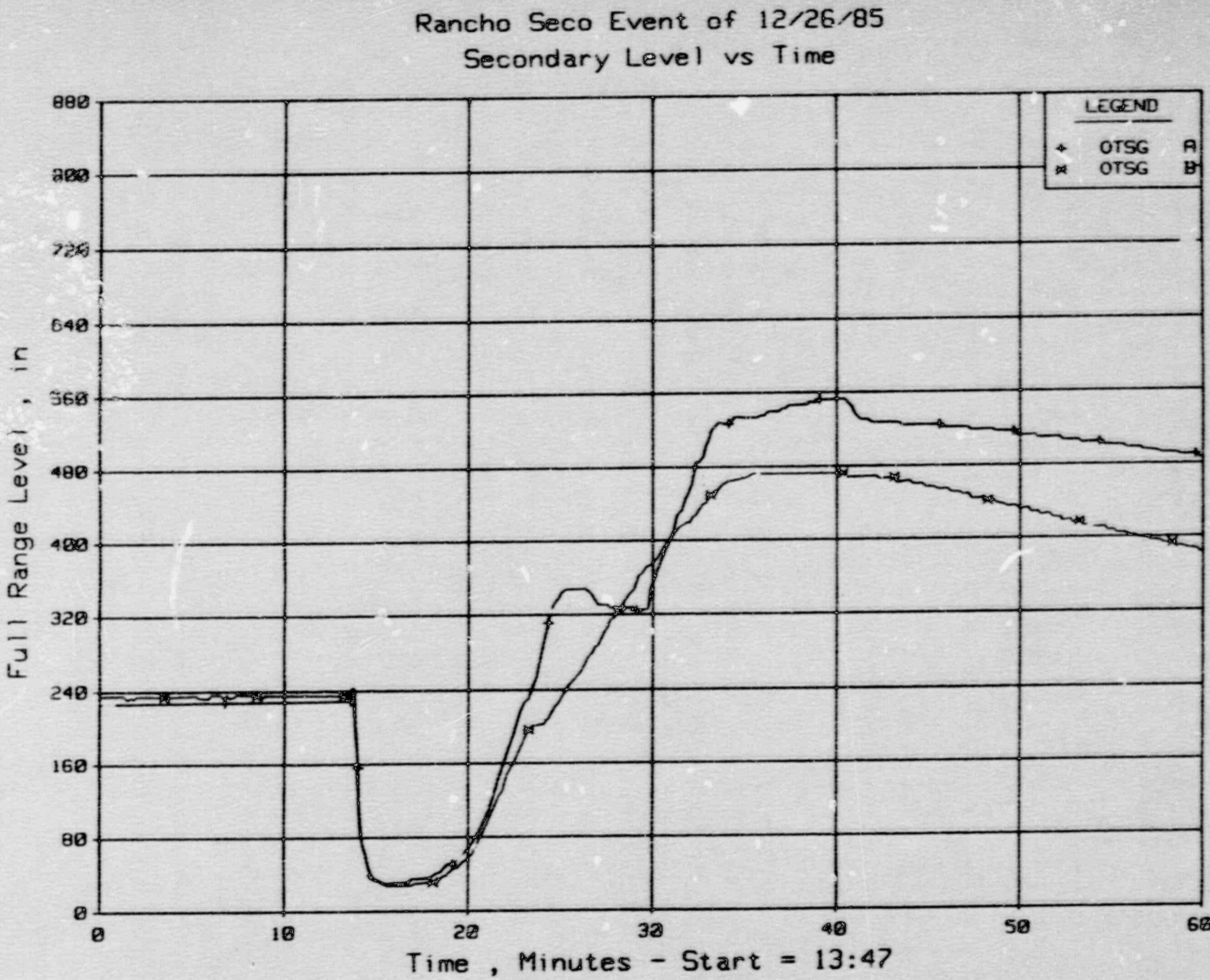



Figure 3.36 Secondary Level Vs Time

Fri Feb 12 07:15:42 1988

secl.plot

### 3.8.3. Steady-State Pretest Conditions

The loop is to be held in steady state for 10 minutes or more prior to test initiation. The initial conditions for this steady-state period are listed in Table 3.21. The primary is to be initialized with all four reactor coolant pumps running. The test will simulate the transient 25 seconds (25 seconds R-S time is 34 seconds MIST time) after main feedwater trip and 9 seconds after turbine, generator, and reactor trip (see Table 3.20). Twenty-five seconds into the transient corresponds to the lift of the main steam safety valves (MSSVs). Primary flow is 10% of full flow and core power is 7.5% of full power (see Table 3.22 for conversion factors). This power-to-flow ratio provides a lower than typical temperature difference across the core of approximately 42F. To compensate for the decreased core outlet and reactor vessel upper head temperatures, the upper head guard heater power is to be increased to provide a typical head temperature of approximately 610F. The core power is to be augmented by 0.57% to offset losses to ambient that are not compensated for by the MIST guard heating system. The pressurizer level is controlled to obtain a primary pressure of approximately 2215 psia with a 7.9-ft level (25.92 ft SFLTS), which represents a plant level of 220 inches. The pressurizer spray control valve is manually closed. The PORV is in the automatic overpressure control mode. The primary boundary systems are inactive. The RVVVs are manually closed. The core flood tank is isolated. The steam generator secondaries are initialized with main feedwater flow of 7.5% (see Table 3.22 for conversion factors) using the aspirator flow circuit to preheat the feedwater to near saturated conditions. The secondary pressures are 1075 psia. The feedwater temperature is approximately 460F. The secondary levels are initialized with 36% more inventory than at the plant in order to compensate for the excess primary system volume. The initial secondary levels are 29.1 ft and 30.7 ft for steam generators A and B, respectively. The initial conditions will result in a cold leg suction temperature of 561F, a hot leg inlet temperature of 603F, and an average primary temperature of 582F (47F subcooled). The reactor vessel vent valves, core flood, LPI, and leak measuring systems are not required to simulate this transient. The HPI and AFW head-versus-flow characteristics (Figures 3.37 and 3.38) as well as the core power function are Rancho Seco-specific and different from those used in the MIST Phase III tests (see Tables 3.23,

Table 3.21. Test 4SEC02, Initial Conditions

| Quantity | Specification | Tolerance | Derived* |
|---|---|---|---|
| Core power** | 7.5% | 0.05 | |
| Primary flow | 10.0% | 0.5 | |
| Primary pressure | 2215 psia | 25 | |
| Primary average temperature | 582F | ? | |
| Hot leg inlet temperature | | | 603F |
| RC pump inlet temperature | | | 561F |
| Pressurizer level*** | 25.9 ft | 0.2 | |
| Secondary flow | | | 7.5% |
| Secondary pressure**** | | | 1075 psia |
| Main feedwater temperature | 460F | 10 | |
| Auxiliary feedwater temperature | 110F | 20 | |
| Secondary level A | 29.1 ft | 0.5 | |
| Secondary level B | 30.7 ft | 0.5 | |

*Derived quantities are provided for information only and are redundant of other system specifications.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

****Adjust secondary pressure to obtain 582F primary average temperature.

Table 3.22. Test 4SEC02, Conversion Factors

| | | | |
|---|---|---|---|
| Core power | 33.929 | kW | = 1% of MIST scaled full power |
| Primary flow | 1689.1 | lbm/h | = 1% of MIST scaled full flow |
| Secondary flow | 143.94 | lbm/h | = 1% of MIST scaled full flow |

These conversion factors are specific to Rancho Seco and differ slightly from those used for MIST Phase III tests (reference 9).

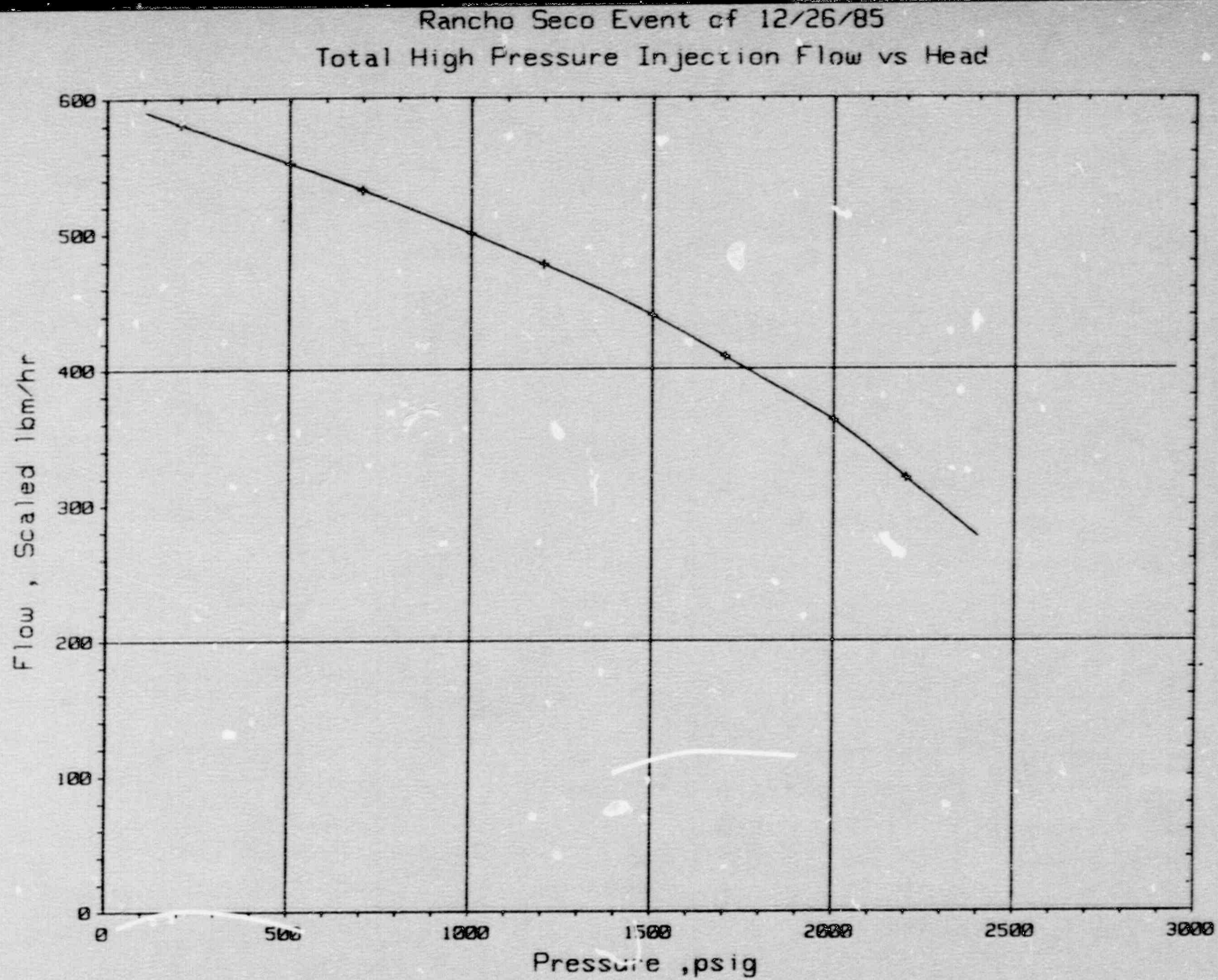



Figure 3.37 Total High-Pressure Injection Flow Vs Head

Tue Feb 16 10:47:55 1988

hpihf.plot

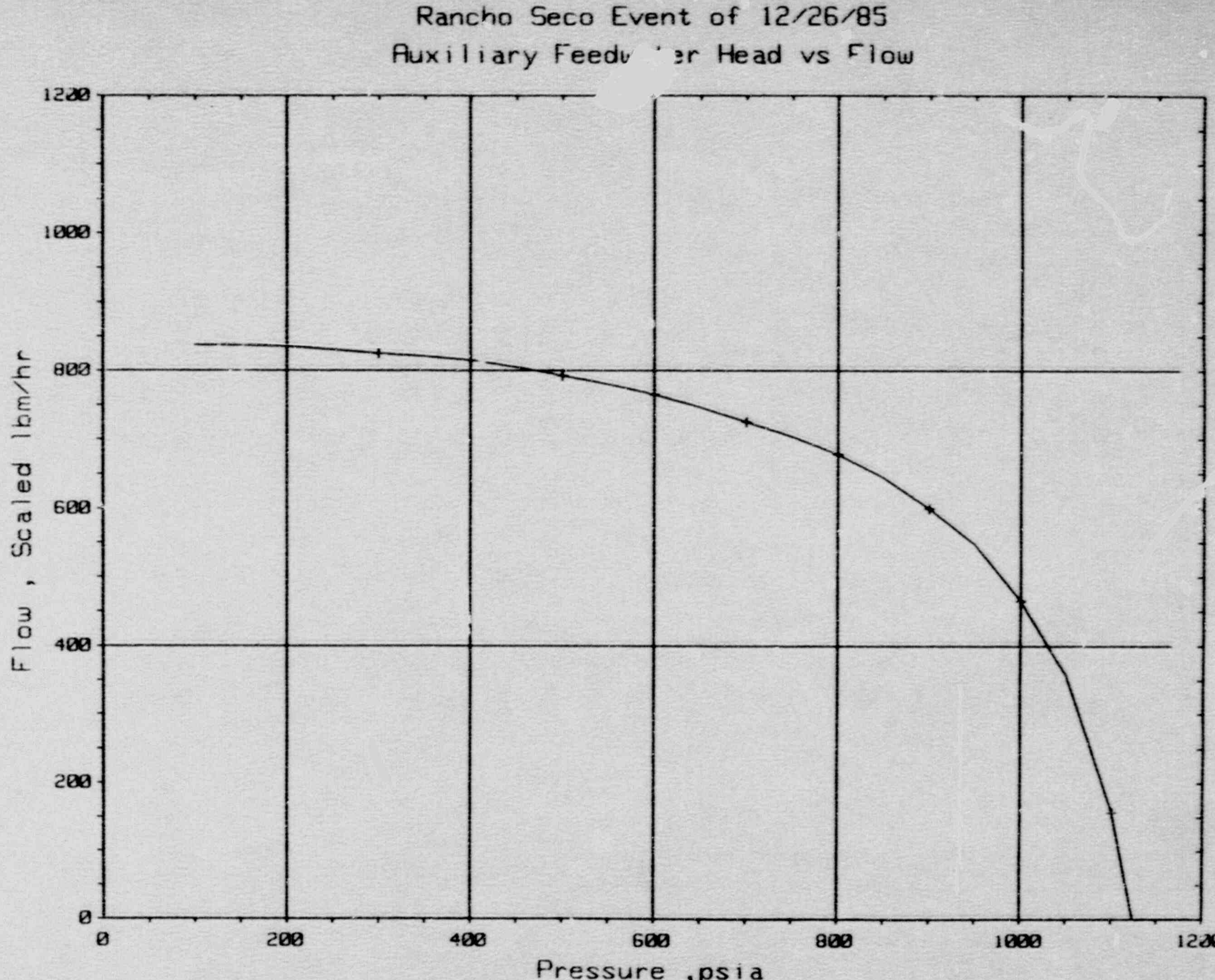



Figure 3.38 Auxiliary Feedwater Head Vs Flow



Tue Feb 16 10:49:08 1988

afwhf.plot

Table 3.23. Test 4SEC02, High-Pressure Injection Characteristics

| RCS Pressure (psig) | Total HPI Flow (lbm/h) |
|---|---|
| 100.0 | 590.3967895 |
| 200.0 | 580.8267822 |
| 300.0 | 571.2567749 |
| 400.0 | 561.6867675 |
| 500.0 | 552.2075195 |
| 600.0 | 542.6016845 |
| 700.0 | 532.4020996 |
| 800.0 | 521.8264770 |
| 900.0 | 511.0899963 |
| 1000.0 | 500.1382751 |
| 1100.0 | 489.0143432 |
| 1200.0 | 477.6096191 |
| 1300.0 | 465.8493652 |
| 1400.0 | 453.4620056 |
| 1500.0 | 439.7718200 |
| 1600.0 | 425.0508422 |
| 1700.0 | 409.2896423 |
| 1800.0 | 392.9772033 |
| 1900.0 | 377.8009338 |
| 2000.0 | 361.9666137 |
| 2100.0 | 342.0123291 |
| 2200.0 | 319.8964843 |
| 2300.0 | 298.3320312 |
| 2400.0 | 275.8500061 |

3.24, and 3.25). The conversion factors for core power and primary and secondary flows to the percentage of full are listed in Table 3.22.

### 3.8.4. Initiation

The test is started after recording at least 10 minutes of steady-state data. Although the initiating event is the opening of the high steam flow circuit valves simulating the main steam safety valves, this will be preceded by the initiation of the ramp up of RC pump flow and ramp down of core power by 1 second. Since the MIST pumps reach full speed in approximately 1 second, the core power ramp down function shown in Figures 3.39 and 3.40 is specified such that upon completion of this rapid pump ramp, the power-to-flow ratio matches that of the Rancho Seco plant at the time the main steam safety valves opened.

The Rancho Seco main steam safety valves have a capacity of 3924 lbm/s at 1100 psia, which scales to approximately 17,300 lbm/h total capacity for MIST. The MIST high steam flow circuit is reported to have a total capacity of 19,900 lbm/h at the same pressure. To simulate the plant's safety valve operation, the high steam flow circuit is to be fully opened at 1075 psia secondary pressure and closed at 1040 psia.

As discussed in Section 3.8.1, a time distortion is to be applied to the post-trip core power ramp down function to compensate for the MIST facility excess primary system volume. Table 3.26 shows the relationship between Rancho Seco core power and time, and the corresponding distorted timescale that results from the volume compensation. The core ramp down function is to be started at the point corresponding to 0.55 minutes (33 seconds) on the distorted (MIST) timescale. Therefore, the core power function to be provided in MIST is specified in Table 3.25.

The test is to be initiated by starting the core power ramp down function and simultaneously starting the ramp up for the four reactor coolant pumps to full speed. Approximately 1 second later, in rapid sequence the remainder of the initiation actions listed in Table 3.27 are to be performed. This consists of fully opening the high steam flow circuit control valves, terminating main feedwater flow, initiating auxiliary feedwater flow, and opening the low steam flow circuit control valves.

Table 3.24. Test 4SEC02, Auxiliary Feedwater Characteristics

| Secondary Pressure (psia) | AFW Flow (lbm/h) |
|---|---|
| 100.0 | 837.5 |
| 150.0 | 837.0 |
| 200.0 | 835.0 |
| 250.0 | 830.5 |
| 300.0 | 825.0 |
| 350.0 | 820.0 |
| 400.0 | 815.0 |
| 450.0 | 804.8 |
| 500.0 | 792.5 |
| 550.0 | 779.8 |
| 600.0 | 765.0 |
| 650.0 | 746.3 |
| 700.0 | 725.0 |
| 750.0 | 703.6 |
| 800.0 | 677.5 |
| 850.0 | 644.2 |
| 900.0 | 600.0 |
| 950.0 | 546.9 |
| 1000.0 | 465.0 |
| 1050.0 | 357.2 |
| 1100.0 | 157.5 |
| 1124.0 | 0.0 |

Table 3.25. Test 4SEC02, Post-Trip Power

| Time (min) | Power (%) |
|---|---|
| 0.0 | 7.5000 |
| 0.55 | 7.5000 |
| 0.60 | 7.0244 |
| 0.70 | 5.9728 |
| 0.80 | 5.3557 |
| 0.90 | 4.9264 |
| 1.00 | 4.5685 |
| 1.20 | 4.0277 |
| 1.40 | 3.6022 |
| 1.60 | 3.2934 |
| 1.80 | 3.0520 |
| 2.00 | 2.8386 |
| 3.00 | 2.3885 |
| 4.00 | 2.1264 |
| 5.00 | 1.9936 |
| 6.00 | 1.9116 |
| 8.00 | 1.7570 |
| 10.00 | 1.6735 |
| 20.00 | 1.5031 |
| 30.00 | 1.3868 |
| 40.00 | 1.2947 |
| 50.00 | 1.2210 |
| 60.00 | 1.1617 |
| 80.00 | 1.0746 |
| 100.00 | 1.0164 |
| 200.00 | 0.9057 |
| 300.00 | 0.8918 |
| 400.00 | 0.8726 |
| 500.00 | 0.8576 |
| 600.00 | 0.8439 |
| 800.00 | 0.8177 |
| 1000.00 | 0.7939 |

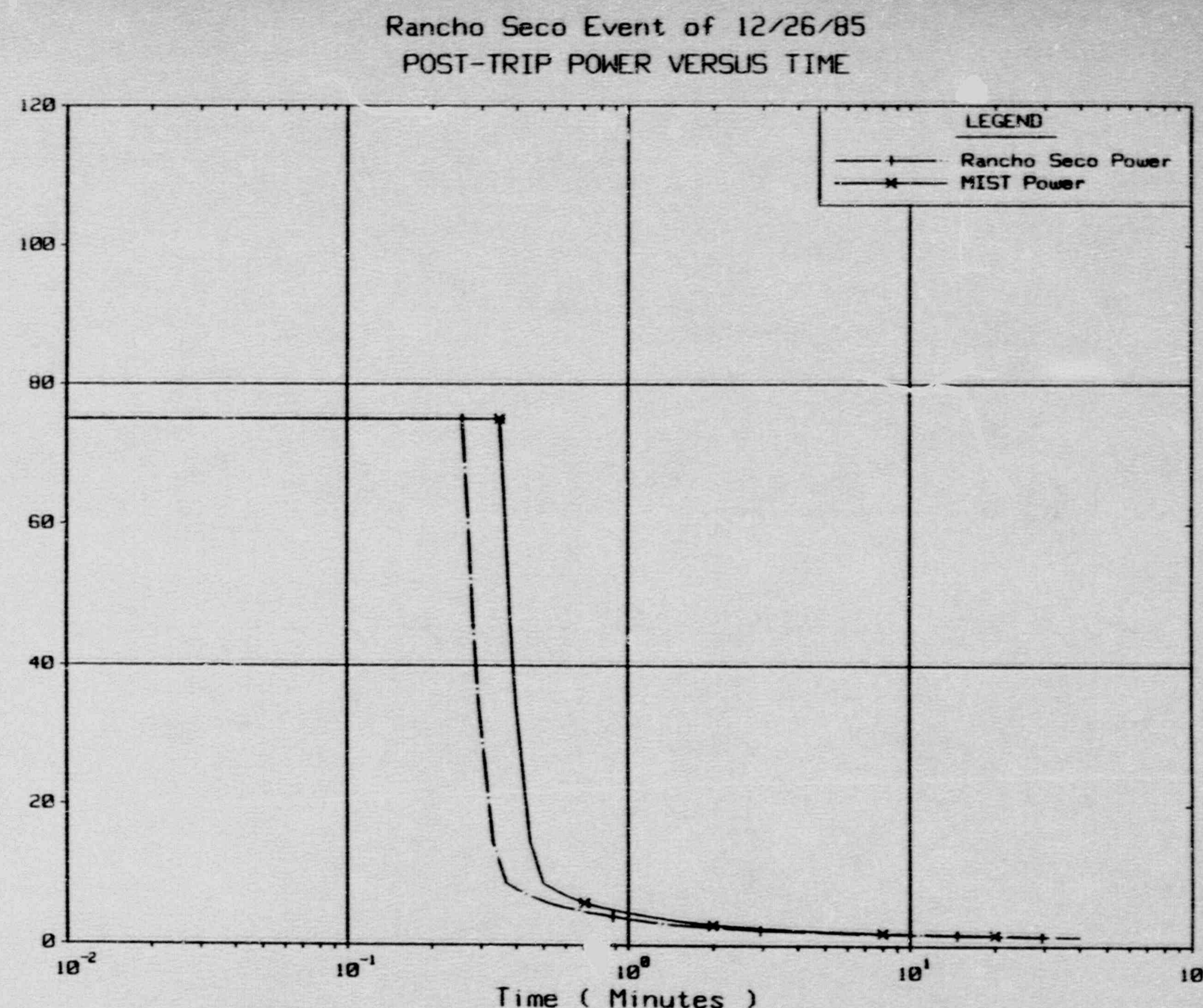



Figure 3.39 Post-Trip Power Vs Time

Tue Jul 26 09:22:55 1988

dhl.plot

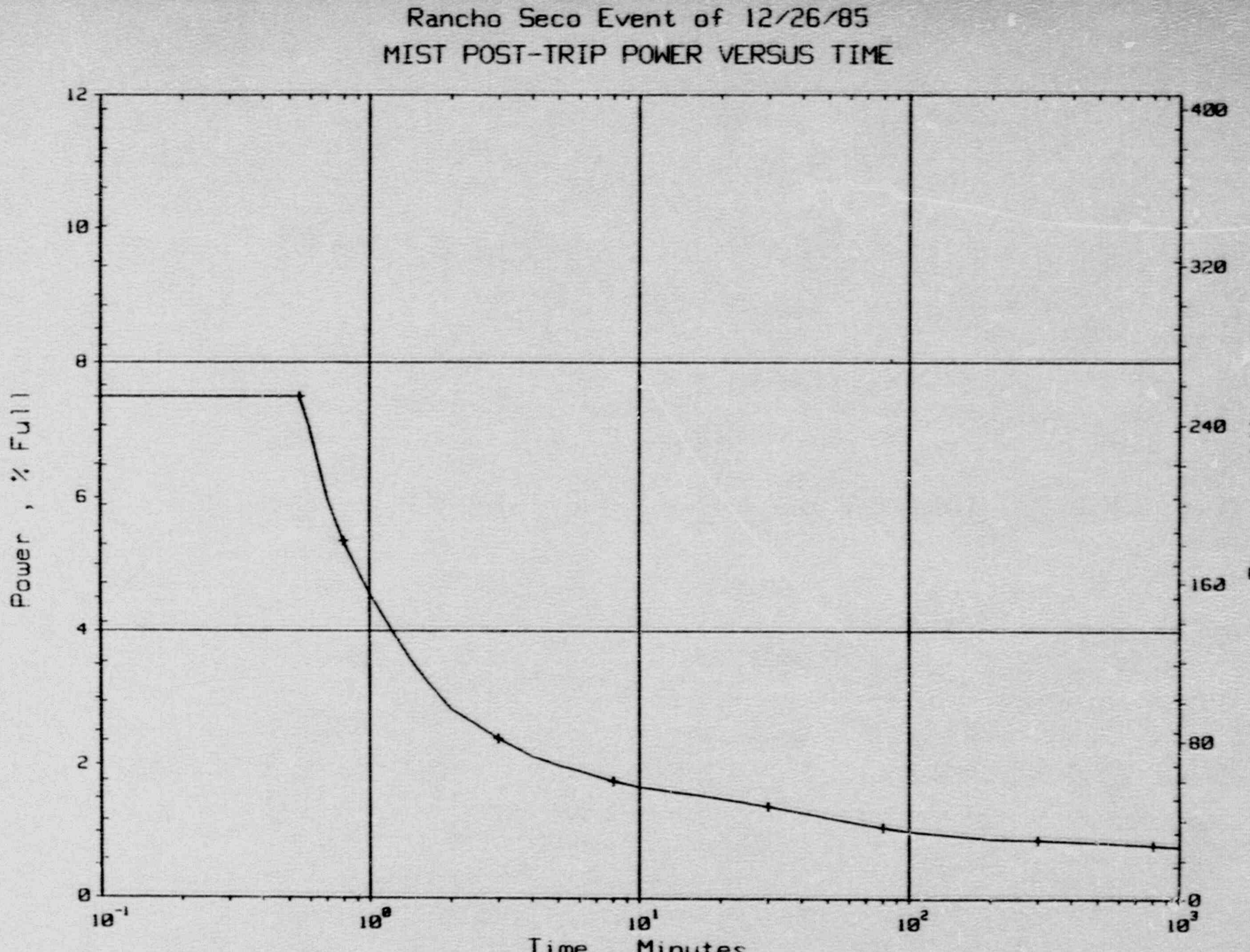



Figure 3.40 MIST Post-Trip Power Vs Time

Tue Jul 26 09:24:45 1988

dh2.plot

Table 3.26. Test 4SEC01, Core Power Vs Time for MIST and Rancho Seco

| Rancho Seco Time (min) | MIST Time (min) | Rancho Seco Q (%) |
|---|---|---|
| 0.0 | 0.000 | 75.000 |
| 0.257 | 0.350 | 75.000 |
| 0.270 | 0.367 | 60.846 |
| 0.282 | 0.383 | 46.639 |
| 0.294 | 0.400 | 34.951 |
| 0.331 | 0.450 | 14.581 |
| 0.368 | 0.500 | 8.7425 |
| 0.404 | 0.550 | 7.7891 |
| 0.441 | 0.600 | 7.0244 |
| 0.515 | 0.700 | 5.9728 |
| 0.588 | 0.800 | 5.3557 |
| 0.662 | 0.900 | 4.9264 |
| 0.735 | 1.000 | 4.5685 |
| 0.882 | 1.200 | 4.0277 |
| 1.029 | 1.400 | 3.6202 |
| 1.176 | 1.600 | 3.2934 |
| 1.324 | 1.800 | 3.0520 |
| 1.471 | 2.000 | 2.8386 |
| 2.206 | 3.000 | 2.3885 |
| 2.941 | 4.000 | 2.1264 |
| 3.676 | 5.000 | 1.9936 |
| 4.412 | 6.000 | 1.9116 |
| 5.882 | 8.000 | 1.7578 |
| 7.353 | 10.000 | 1.6735 |
| 14.706 | 20.000 | 1.5031 |
| 22.059 | 30.000 | 1.3868 |
| 29.412 | 40.000 | 1.2947 |

Table 3.27. Test 4SEC02, Operator Actions

| Event | Time* Min. | Time* Sec. | RCS P psia | Sec. P psia |
|---|---|---|---|---|
| Open high steam flow circuit control valves. | | 33 | | 1075 |
| Start post-trip power function. | | 33 | | |
| Start RC pump ramp to simulate reactor trip. | | 34 | | |
| Trip MFW flow. Open low steam flow circuit control valves. | | 34 | | |
| Start AFW flow (100% H versus Q). | | 34 | | 865 |
| Start HPI flow (38% H versus Q).** | | 52 | 2036 | |
| Close high steam flow circuit control valves. | 1 | 1 | | 1040 |
| Increase HPI flow (68% H versus Q). | 1 | 45 | 1936 | |
| Increase HPI flow (100% H versus Q). | 4 | 18 | 1600 | |
| Decrease AFW A and B flow 50% of current value. | 4 | 18 | 1600 | |
| Increase AFW A and B flow 100% of current value. | Step 10 → 20 secs. | | | |
| Start MFW (full). | 8 | 54 | | 865 |
| Close low steam flow circuit control valves. | 12 | 14 | 1089 | |
| Stop MFW. | Steam generator A level = 4.? ft, steam generator B level = 7 ft | | | |
| Decrease AFW B flow 50% of current value. | 12 | 46 | 1106 | |
| Decrease HPI flow (86% H versus Q). | 15 | 56 | 1263 | |
| Close AFW valve A (full). | 17 | 7 | 1348 | |
| Decrease HPI flow (53% H versus Q). | 17 | 41 | 1391 | |
| Stop RC pump C (MIST C2). | 19 | 20 | 1510 | |
| Decrease HPI flow (27% H versus Q).*** | 20 | 40 | 1592 | |
| Open AFW valve A full (100% H versus Q). | 21 | 36 | 1622 | |
| Start pressurizer spray. | 26 | 8 | 1601 | |

Table 3.27. Test 4SEC02, Operator Actions (Cont'd)

| Event | Time* Min. | Sec. | RCS P psia | Sec. P psia |
|---|---|---|---|---|
| Close AFW valve B (full). | 26 | 35 | 1601 | |
| Close AFW valve A (full). | 35 | 39 | 1445 | |
| Stop all HPI flow. | 39 | 20 | 1378 | |
| Start secondary blowdown.**** | 58 | 29 | 981 | |
| Stop RC pump A (MIST C1). | 102 | 23 | 785 | |

*Times are relative to the initiating event i.e., loss of ICS/MFW. A "time distortion factor" of 1.36 has been applied to the corresponding events from Table 3.20.

**The HPI control valves are pre-throttled for SFAS conditions.

***Additional throttling may be required for pressurizer level control.

****Control secondary pressure to 350 psia. If pressure greater than 350 psia then blowdown at 100F h rate. If less than or equal to 350 psia set to constant pressure control of 350 psia.

The Rancho Seco ADV and TBV capacity is 28%. During the event, the ADV and TBV demand was 50% for about 9 minutes; that is, their capacity was 14%. This capacity is approximately 2100 scaled lbm/h at 1060 psia. The MIST low steam flow circuit has a capacity of approximately 1000 lbm/h at 1100 psia (choked flow limited). As a result, the ADV and TBVs can be simulated by positioning the low steam flow circuit to fully open. The HPI system is activated at 52 seconds at 38% of the full head flow curve.

3.8.5. Control During Testing

Following test initiation, a series of actions must be performed to reproduce those taken by the plant operator. The test simulation requires a complex schedule of operator actions to adjust the performance of the high-pressure injection and auxiliary feedwater systems. A complete list of these actions is provided in Table 3.27. For most of the actions listed in Table 3.27, a time and a pressure (either primary or secondary) are listed. The test operator should take the prescribed action when the specified pressure is reached. If the pressure for the action is not reached in the time specified in Table 3.27, the operator should delay performing the action as long as the specified pressure is being approached. Once beyond the specified time for the control action, the action may be taken when the pressure is within ± 1% of the specified pressure. If the system pressure stops approaching the specified pressure for a control action, then the operator actions listed in Table 3.27 must be performed in the sequence specified. The times listed on Table 3.27 are delayed or distorted from the corresponding event listed on Table 3.20 by a factor of 1.36 i.e., MIST time = 1.36 x Rancho Seco time. This multiplier is the ratio of the MIST facility primary system volume to the ideally scaled Rancho Seco primary volume. The majority of operations involves the HPI and AFW flow rates. Table 3.27 and Figure 3.41 indicate the target flow rate when controlling HPI flow. Figure 3.42 indicates the desired flow for the AFW adjustments. At a secondary pressure of 865 psia, MFW flow is to be re-initiated. In the Rancho Seco transient, MFW flow reached a maximum of 8.8% of full flow over 2-1/2 minutes before it was terminated. The main feedwater flow resulted in an increase in secondary level of 4.2 and 7 ft in steam generators A and B, respectively. Therefore, the MIST secondary level is raised similarly at this time. At 14 minutes 56

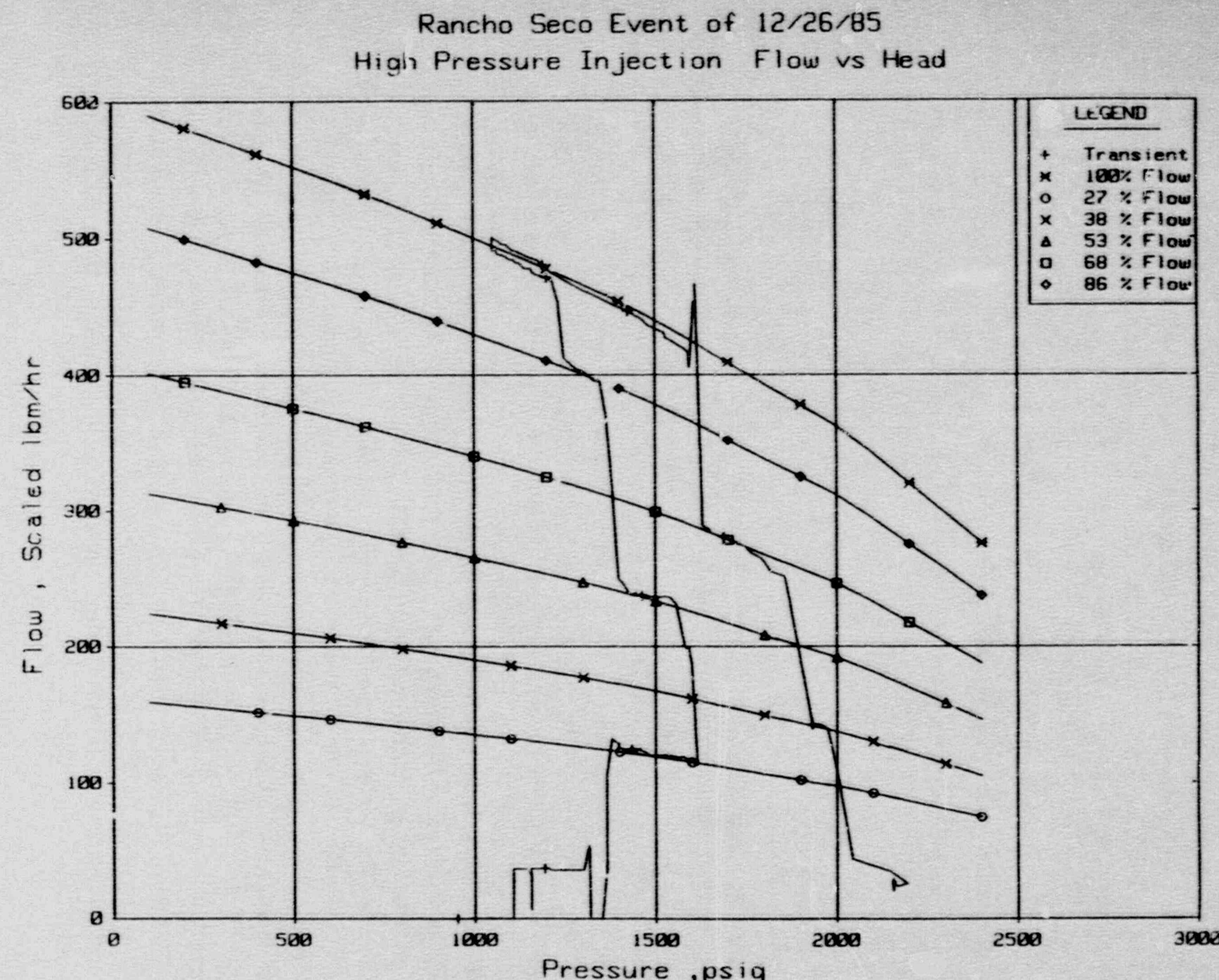



Figure 3.41 High-Pressure Injection Flow Vs Head

Tue Feb 16 08:26:11 1988

hpithf.plot

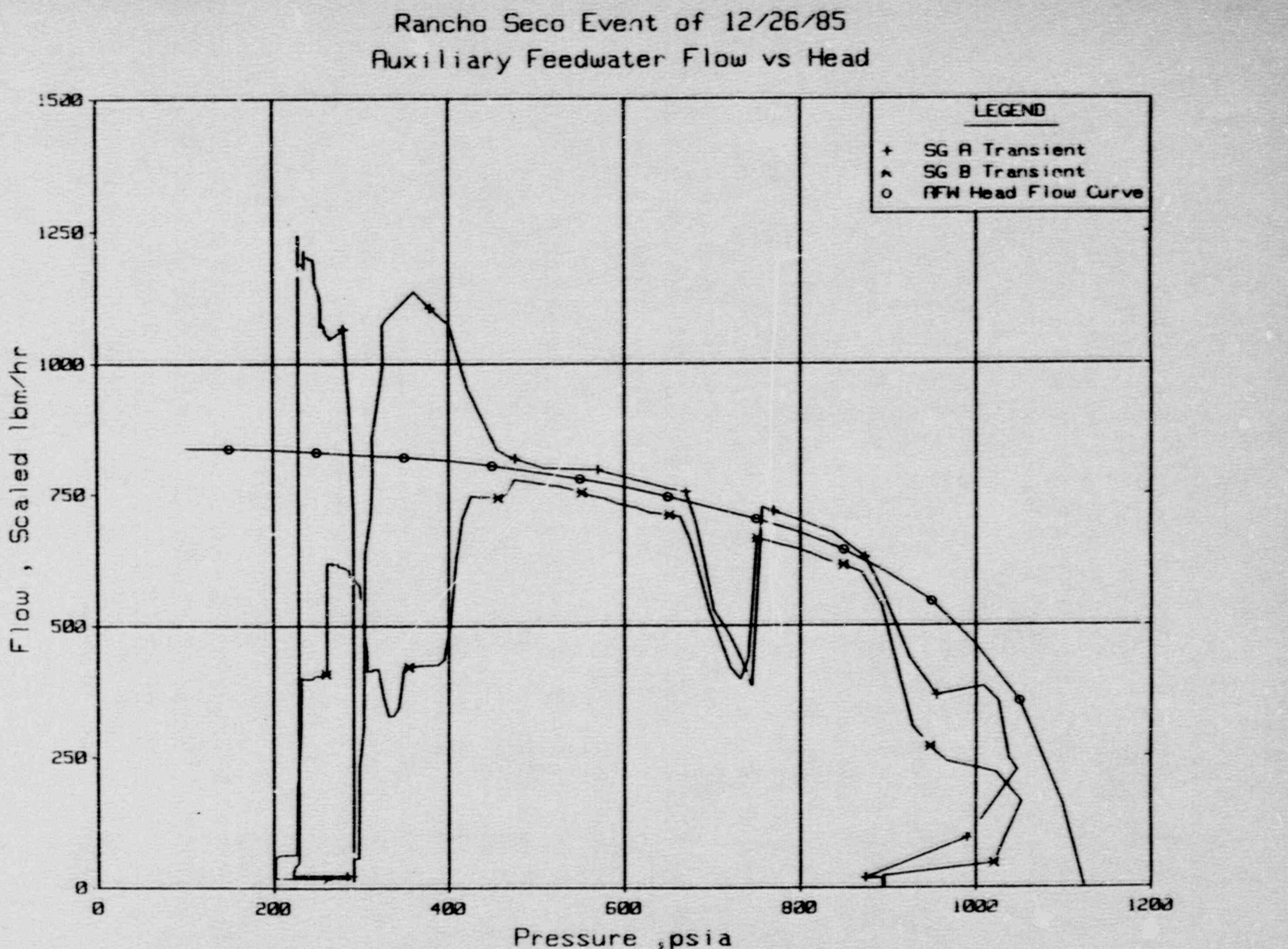



Figure 3.42 Auxiliary Feedwater Flow Vs Head



Fri Feb 12 07:10:37 1988

afwthf.plot

seconds, the Rancho Seco operators re-established letdown flow in order to control the increasing pressurizer level. Since the MIST facility does not have letdown flow capability, additional throttling of HPI may be required to control the pressurizer level to prevent its complete filling. The pressurizer level should be limited to a maximum of 26.5 ft to allow an adequate margin. The pressurizer spray is activated at an RCS pressure of 1601 psia. At a primary pressure of 981 psia, blowdown of the steam generators begins at a rate of 100F/h to approximately 350 psia secondary pressure.

3.8.6. Termination

The test should be terminated based on the establishment of the "soak" conditions established at Rancho Seco, although termination may be delayed at the discretion of the Test Engineer. These conditions are primary pressure of 785 psia, primary flow of approximately 50% (2 RCPs running), secondary pressure of 350 psia, and no secondary flow. Other approximate conditions are listed in Table 3.28. The Rancho Seco transient lasts approximately 100 minutes after the initial loss of main feedwater. Data should be saved for approximately 1 hour after achieving the terminating conditions.

3.8.7. Acceptance Criteria

1. At least 10 minutes of steady-state data are recorded at the specified initial conditions.

2. Test initiation is performed as specified.

3. The specified boundary system control settings are maintained throughout the test. Because of the complexity and number of operator actions, the test is acceptable provided that the general control specifications are adhered to, and the actions performed are sufficiently annotated to permit code modeling.

4. Test termination is performed as specified.

5. All critical instrument data as specified in Appendix F of reference 6 is recorded at intervals of 10 seconds or less throughout the test. Since the Rancho Seco event did not lead to two-phase conditions in the cold legs, the Category B instruments should include those necessary to monitor RC pump operation but exclude the gamma densitometers. No

changes to Category C instrument classifications are necessary, with the exception of those instruments previously addressed by the Program Management Group.

Table 3.28. Test 4SEC02, Final Conditions*

| Quantity | Approximate Values |
|---|---|
| Core power** | 1% |
| Primary flow | 50% |
| Primary pressure | 785 psia |
| Hot leg inlet temperature | 436F |
| RC pump inlet temperature | 435F |
| Pressurizer level*** | 21.3 ft |
| Secondary flow | 0% |
| Secondary pressure | 350 psia |
| Secondary level A | decreasing |
| Secondary level B | decreasing |

*This table is provided for information only and not as a specification of the actual final conditions during the test.

**Augment core power by 0.57% to compensate for heat losses to ambient.

***All levels are relative to the secondary face of the lower steam generator tubesheet.

# 4. PERFORMANCE

The acceptability of each test was determined by examining both the conduct of the test and the performance of the measurement systems. The acceptance criteria for each test were defined in the corresponding test procedure, which was based on the MIST Test Specifications.[5] Any condition, action, or measurement that did not meet the acceptance criteria was evaluated for its impact on test acceptability. The tests reported herein are only those that were determined to be acceptable. Any specific deviations of these tests from the acceptance criteria are described in this section.

The review of test conduct included the following checks for each test:

- System conditions and stability just prior to test initiation
- Sequence and timing of the test initiation actions
- Performance of the manual and automatic control functions
- Test termination criteria and the sequence of actions

The impact of out-of-specification conditions or actions was assessed. The deviations of those tests that were determined to be acceptable are described in section 4.1.

The following pretest and post-test data qualification checks were performed for each test:

- The acquisition of the critical measurements
- The operation of the measurement systems within their calibrated range
- The acquisition of instrument readings within their expected range of operation
- Self-consistent measurements, considering both comparable measurements and derived quantities

The appropriate measurement uncertainties were used to assess the individual measurements. The impact of the individual out-of-specification conditions was assessed. The deviations of the critical measurements of those tests that were determined to be acceptable are noted in section 4.2.

### 4.1. Conduct

The tests specified were performed according to the following test procedures:

| Test | Procedure |
|---|---|
| 410AT3 | ARC-TP-770 |
| 4NOML3 | ARC-TP-777 |
| 410BD1 | ARC-TP-771 |
| 4100B2 | ARC-TP-766 |
| 4SB011 | ARC-TP-776 |
| 4CR3T2 | ARC-TP-781 |
| 4SEC02 | ARC-TP-769 |
| 4SGPF2 | ARC-TP-767 |

All of the tests above were acceptable as performed. Initial conditions were all acceptable. The performance of all controls through the tests was acceptable, and excursions are detailed in Section 4.1.3. Test initiations and terminations were acceptable for all tests. Test 410AT3 was terminated according to procedure, but 4 hours earlier than was specified in the test specifications. The impact of the early termination was discussed with the PMG, and it did not warrant repeating the test. Test 410BD1 was extended by 4 hours to examine several phenomena that may have occurred in the latter part of Test 410AT3.

#### 4.1.1. Initial Conditions

Initial conditions for MIST Phase IV tests were defined by the governing test procedures listed above and are repeated in Table 4.1 along with the actual values from each test. All initial conditions were met.

#### 4.1.2. Test Initiation

The test initiation actions were performed acceptably for all the tests in this group. In this text, each test is referenced to the test zero time, which is defined as the last steady-state scan before leak opening (410AT3, 410BD1, 4NOML3, 4100B2, and 4SB011), or before the start of the core power ramp (4CR3T2), or before the high steam circuit control valves were fully open (4SECO2). The zero time for Test 4SGPF2 is the starting time of the data save.

Tests 410AT3 and 410BD1 were initiated by opening the 10-cm$^2$ cold leg discharge (CLD) leak. When the pressurizer drained to approximately 18.9 ft, the test initiation actions started with the AFW secondary fill, activation of the core power decay ramp, transfer of the reactor vessel vent valve (RVVV) control to automatic, and activation of steam generator ATOG pressure control. All initiation actions were performed within the specified 20-second window.

Tests 4NOML3 and 4100B2 were initiated by opening the 10-cm$^2$ (4NOML3) and 100-cm2 (4100B2) cold leg discharge leaks. When the pressurizer drained to approximately 18.9 ft, the test initiation actions started with the secondary fill, activation of the high-pressure injection (HPI) and core power decay, transfer of the RVVV control to automatic, and activation of steam generator abnormal transient operating guideline (ATOG) pressure control. All initiation actions were performed within the 20-second window.

Test 4SB011 was initiated by opening the reactor coolant pump seal leaks in cold legs B1 and A2, manually tripping the pressurizer heaters, beginning refill for both steam generators, initiating the core power decay ramp, and transferring the reactor vessel vent valve control to automatic. All initiation actions were performed within the specified 20-second time interval; however, at 7.05 minutes a flow blockage at both leak sites was noted and alternate leak sites were actuated. This leak flow blockage did not impact test initiation acceptability, since test initiation actions were not keyed on pressurizer level as normally was the case for MIST transient tests. An estimated 10 lbm of fluid would have drained through the leak site between test initiation and 7.05 minutes, which would result in a 0.4-ft decrease in pressurizer level. This pressurizer level difference would not significantly impact the transient.

Test 4CR3T2 was initiated by starting the refill of steam generator A, transferring reactor vessel vent valve control to automatic, manually tripping the pressurizer heaters, and opening the low steam flow circuit control valves to predetermined positions. All initiation actions were performed within the 20-second time interval, as required.

Test 4SEC02 was initiated by fully opening both high steam flow circuits, simultaneously bringing all reactor coolant pumps to 100% speed, beginning core power ramp, initiating full auxiliary feedwater flow to both steam generators, terminating main feedwater to both generators, and opening the low steam circuit control valves to predetermined positions. All initiation actions were performed as expected.

Test 4SGPF2 was started by establishing steady-state conditions at the minimum achievable steam generator level for at least 30 minutes. The minimum steam generator level, which was about 19 ft, was obtained by adjusting the main feedwater flow in order to establish a 22 ± 2F subcooling in the primary loop.

### 4.1.3. Control During Testing

The performance of the automatic control systems and manual interactions during the test transients is described in this section. The controls for HPI, low-pressure injection (LPI), core flood tank (CFT), pressurizer main heaters, auxiliary feedwater (AFW) and main feedwater (MFW) for steam generators A and B, core power, power-operated relief valve (PORV), steam pressure, reactor coolant pump, leak and vent, and level control for steam generators A and B performed acceptably for all the tests in this group except as noted in the following text.

#### Steam Generator Secondary Level Control

Steam generator constant level control was used in Tests 410AT3, 410BD1, 4NOML3, and 4100B2 to maintain the levels at 31.6 ± 1 ft. Steam generator constant level control was activated shortly after test initiation, when the generators were refilled to 31.6 ft. In these tests, steam generator A and B constant level controls performed acceptably. There were isolated deviations above and below the desired control tolerance. These deviations were short in duration, small in magnitude, and were observed during the loop transients. However, in Tests 410BD1 and 4100B2, notable deviations were observed during the 50-psi/minute steam generator blowdown period. In Test 4100B2, the secondary level in both generators varied between 27 and 34 ft for about

16 minutes, whereas in Test 410BD1 the secondary levels varied between 26.5 and 34.5 ft for about 75 minutes.

In Test 4SB011, the levels of steam generators A and B were controlled to 20.7 ± 1 ft from the initial fill through 36 minutes, except for a brief undershoot in both generators (minimum of 19.1 ft in steam generator A and 19.3 feet in steam generator B). At 36 minutes, the primary subcooling (RVRF21) decreased to 20F and levels were increased to 31.6 ft, as desired. Both steam generator secondary levels were controlled within the desired 31.6 ± 1 ft until the level control was deactivated according to the test procedure on the loss of natural circulation flow (147 minutes for steam generator A and 166 minutes for steam generator B).

In Test 4CR3T2, the steam generator A constant level control was invoked at 12.4 minutes as the primary pressure reached 1981 psia. The steam generator steamed down from 24.6 ft to the desired level of 20.7 ft in about 18.1 minutes. The generator A secondary level was controlled within the desired range of 20.7 ± 1 ft for the duration of the test. The steam generator B secondary (B-SG) level was held at 10.0 ft prior to the test initiation. Then, after the test was initiated, the B-SG level setpoint was adjusted to 11, 9.5, 30, and 20.7 ft at 25 seconds, 30 seconds, 11.5 minutes, and 15.9 minutes, as expected. Between 25 seconds and 30 seconds, the steam generator level was increasing, as desired. Between 30 seconds and 11.5 minutes, the secondary level was maintained within ± 2 ft of the desired value. This amount was larger than specified ± 1 ft due to the relatively large AFW and steam flow rates and low water levels during this time interval. Between 11.5 minutes and 15.9 minutes, the B-SG secondary level was increasing as expected. After 15.9 minutes, the B-SG secondary was maintained at the desired setpoint of 20.7 ± 1 ft.

In Test 4SGPF2, the steam generator level control was acceptable. Steam generator A and B fluid levels were held within 1 ft of the required elevations for at least 30 minutes as indicated below:

| Periods, Minutes | Feedwater System | Steam Generator A, ft | Steam Generator B, ft |
|---|---|---|---|
| 0-30 | Main | 19.3 | 19.2 |
| 328-358 | Main | 26.1 | 26.1 |
| 519-549 | Main | 33.3 | 33.2 |
| 767-798 | Main | 40.0 | 39.9 |
| 917-950 | AFW | 40.0 | 39.9 |
| 1091-1123 | AFW | 33.2 | 33.0 |
| 1291-1320 | AFW | 26.2 | 26.5 |
| 1478-1508 | AFW | 19.5 | 19.2 |

Constant steam generator level control was not required for Test 4SEL02.

Steam Pressure Control

The ATOG steam pressure control was used in Tests 410AT3, 4NOML3, 4100B2, and 410BD1 (only for the first 30 minutes) for the entire test duration. Performance of the ATOG steam pressure control was examined using the temperature difference between the core outlet and the maximum of the two steam generator secondary saturation temperatures. According to the temperature difference (DT), the following control was required during the four tests mentioned above:

1. If the DT was greater than or equal to 50F, secondary steam pressure control was maintained constant.

2. If the DT was less than 50 but greater than 0F, a secondary cooldown rate of 100F/h was activated (74F/h for Test 4NOML3) and maintained until the DT increased to 50F, at which time constant pressure control was invoked.

3. If the DT was less than 0F, a secondary blowdown rate of 50 psi/min (37 psi/min for Test 4NOML3) was activated and maintained until the DT increased to 50F, at which time constant pressure was invoked.

The control system performed as intended in these four tests. In Test 410AT3, control modes 1 and 2 were called for and no anomalies were noted. For the first 90 minutes of the test, while control mode 1 was invoked, steam generators A and B depressurized about 700 psia due to AFW overcooling, as is normally observed.

During the first 30 minutes of Test 410BD1, control mode 1 was active and AFW overcooling masked ATOG steam pressure control. The 50-psi/minute blowdown was activated for both steam generators from the current ATOG setpoint at 30 minutes, as required. Blowdown rates for both generators were 50.0 ± 2.5

psi/minute until 42 minutes when the generator A and B steam valves were fully open. Both steam valves remained fully open until after test termination.

At the initiation of Test 4100B2, DT was less than 50F. Test operators noted that both steam pressure setpoints began ramping immediately after the transfer to ATOG control. As is normally the case, AFW overcooling masked ATOG steam pressure. Control mode 3 was invoked at 16.5 minutes when DT decreased below 0F. Both steam valves were fully open within 6 minutes and before the specified blowdown rate was achieved. Blowdown rates reached 45 psi/minute and had averaged 37 psi/minute for both steam generators by the time the steam valves were fully open. The deviation from the desired 50-psi/minute blowdown rate for both steam generators occurred in part because the blowdown started at a relatively low secondary pressure. The observed blowdown rate is explainable and can be modelled, therefore test impact is minimal.

In Test 4NOML3, control modes 1, 2, and 3 were activated several times. The longest period during which control mode 1 was active was between 130 and 495 minutes. During this time, the pressure in steam generators A and B dropped by about 95 psia due to heat losses in the steam generators. Control mode 2 was activated at test initiation for about 2 minutes, then at 35 minutes it was triggered again for about one hour. During this period, both generators depressurized at a rate of 76 F/h, as expected. Control mode 3 was activated first at 495 minutes and again at 560 minutes. During both periods, the pressures of steam generators A and B were below 225 psia and the 37-psi/min blowdown rate was not established in either steam generator by the time the steam valves were fully open. The deviation from the desired 37-psi/minute blowdown rate for both steam generators occurred in part because the blowdown started at a relatively low secondary pressure. The observed blowdown rate is explainable and can be modelled, therefore test impact is minimal.

In Test 4SB011, steam pressure for both generators was maintained at the specified 1010 psia from test initiation through primary flow interruption at 147 minutes, except for the expected brief auxiliary feedwater overcooling during refill. At 147 minutes, loop A interrupted, calling for the reduction of steam generator B pressure to 910 psia, and adjustment of the generator A steam valve to the last sustained valve position prior to loop interruption. Both tasks were accomplished at 150 minutes, and the noted generator A steam valve position was 95.5% closed. At 166 minutes, both loops were interrupted and the generator B steam valve was set to 80% closed (which was the last sustained valve position prior to loop interruption). Due to the two-phase conditions at the steam orifice, the steam flow rate measurements of steam generators A and B were not reliable after 150 minutes and 166 minutes, respectively.

At initiation of Test 4CR3T2, the steam valves of steam generators A and B were opened to the pre-determined position and resulted in the desired total steam flow of approximately 1400 lbm/h at 950 psia. At 6.8 minutes, steam pressure in both generators decreased to approximately 600 psia. At that point, the steam pressure was to be controlled at approximately 600 psia until test termination to avoid the facility limit on primary-to-secondary pressure differential. The procedure called for the steam valves to be manually closed, then switched to automatic constant pressure control at 600 psia. Instead, the steam pressure control was switched to constant pressure at 600 psia, which resulted in a gradual reduction in steam flow rather than the intended abrupt decrease. This deviation had little impact on steam generator B (on constant level control at 9.5 ft) and steam generator A (filling from 9.5 toward 32.0 ft).

In Test 4SEC02, the high steam circuits were closed at 1.32 minutes, as expected; however, the generator A limit switch (SSLS03) indication was incorrect (indicator showed that the switch did not close until 13.9 minutes). At 13.9 minutes, a rapid achievement of 25 lbm/h steam flow rate in both generator was called for. However, due to steam valve control limitation, steam flow of about 26.0 $\pm$ 3.0 lbm/h was established in generator A at about 16 minutes, and a steam flow of 27.0 $\pm$ 2.0 lbm/h was established in generator B at about 15.9 minutes. A steam generator secondary cooldown rate of 104F/h (desired 100F/h) was initiated between 58.9 and 59.8 minutes based on time because the primary pressure never attained the specified setpoint of 981 psia.

In Test 4SGPF2, steam generator A and B pressures were within the allowable control band (1010 $\pm$ 10 psia) during all steady-state periods, as desired.

Steam Generator Main Feedwater Control

The main feedwater was only used in Tests 4SEC02 and 4SGPF2. In these two tests, the MFW control performance was acceptable. In Test 4SEC02, the main feedwater was used to establish steady-state conditions. During the transient, the main feedwater to steam generator B was restarted at 13.9 minutes based on time criteria and was stopped a minute later. This action was taken because the desired trigger conditions, secondary levels between 6.5 and 7.5 ft, were not reached. The value of the steam generator B secondary level was 19.4 ft and increasing. The main feedwater to generator A was restarted and stopped as was expected.

In Test 4SGPF2, the main feedwater valve was used to establish steady-state conditions at 19, 26, 33, and 40 ft, as required. Note that the 19-ft elevation is the minimum steam generator level achieved in order to establish a 2[illegible] ± 2F subcooling in the primary loop.

Steam Generator Auxiliary Feedwater Control

The performance of the AFW control for all tests in this group was acceptable.

In Tests 410AT3, 410BD1, 4NOML3, and 410OB2, the AFW control was used to maintain the feedwater flow rate at the full head/flow characteristic during the secondary fill transient. In these four tests, the AFW to generators A and B achieved the required flow rate during all the tests remaining within ± 10 to ± 15 lbm/h (± 1.3 to ± 1.9%) of the required head/flow characteristic during the steam generator refill. However, for one scan (5 seconds) following the transfer to head/flow AFW control, delivered feedwater exceeded the required flow rate by 25.9 to 163 lbm/h.

In Test 4SBO11, the AFW was used to fill the generators at half head/flow capacity at test initiation, and later at 36 minutes when primary subcooling decreased to 20F. During both steam generator refill periods, the measured flow rate was within ± 8 lbm/h (± 2%) of the intended head/flow characteristics, except for a few isolated spikes when delivered flow exceeded required feedwater by 190 to 265 lbm/h for less than 3 scans (<15 seconds). At 147 minutes, when single-loop cooldown was initiated, the AFW control valve was manually adjusted to establish a 76-lbm/h flow into generator A, as intended. At 168.3 minutes, the AFW of generator B was also adjusted to establish 76 lbm/h flow into the generator, as desired. This action followed the loop A and B interruptions at 166 minutes.

In Test 4CR3T2, the full-capacity AFW flow into generator A was started at test initiation until 12.3 minutes (start of generator A boildown), as intended. The full-capacity AFW of generator B was activated at 0.5 minutes for 40 seconds and again from 11.6 minutes to 16 minutes, as required. The AFW activation actions of generator B were taken as the primary pressure increased to 1895 psia (at 0.5 minutes) and 1963 psia (at 11.6 minutes). During the AFW injection periods, the measured AFW flow rate was between ± 5 and ± 20 lbm/h (± 1% and ± 3%) of the required head/flow characteristics. Following AFW initiation, delivered feedwater exceeded required feedwater by as much as 180 to 190 lbm/h (29% to 36%). These excursions lasted between 5 to 25 seconds.

In Test 4SEC02, the steam generator auxiliary control for steam generator B was acceptable during the test. Steam generator A auxiliary feedwater control did not perform as desired in that it supplied only 57.7% of the desired flow due to erroneous evaluation of the controller setpoints. However, all actions to adjust the generator B AFW flow were taken, as required. Most of these actions were taken based on time. The performance of the generator A AFW control was acceptable since the feedwater flow was known and can be modelled.

In Test 4SGPF2, the AFW valve was manually adjusted to establish the desired steam generator secondary level.

Power-Operated Relief Valve

The PORV control for all tests was acceptable. In Tests 410AT3, 410BD1, 4NOML3, 4100B2, and 4SB011, primary pressure remained below the 2350-psia actuation pressure, and the PORV did not automatically actuate. However, in Test 410BD1, the PORV was manually opened to lower the primary pressure, as called for in the test procedure. In Test 4SGPF2, the PORV was manually closed as expected. In Test 4CR3T2, the PORV actuated a total of 754 times, controlling the primary pressure between 2330 and 2400 psia. The first actuation was performed manually to keep the primary-to-secondary pressure difference below 1800 psia. In Test 4SEC02, the PORV actuated automatically as the primary pressure increased to 2350 psia. In addition, the PORV was activated manually to keep the primary-to-secondary pressure difference below 1800 psia.

High-Pressure Injection

The performance of the HPI control for all tests was acceptable. HPI was not required for Tests 410AT3, 410BD1, 4SB011, and 4SGPF2. In Tests 4NOML3 and 410GB2, HPI was manually and automatically controlled according to the following:

1. Maintenance of the full head/flow characteristic for all times when subcooling was less than 70F.

2. Automatic HPI throttling to control subcooling between 70 and 80F.

3. Manual interruption when core exit subcooling (RVRF21) exceeded 100F.

During activation of control mode 1 in both tests, the maximum deviation of the HPI flow rate from the head/flow characteristic was about 5 lbm/h (0.75%). Control modes 2 and 3 were also active in both tests, as expected.

In Test 4CR3T2, HPI was first activated at 0.42 minutes as the primary pressure decreased to 1892 psia. HPI was delivered at 0.92 minutes, and flow rate was controlled at 225 lbm/h (50% head/flow characteristic) until 4.1 minutes. In this period, HPI occasionally deviated from the desired flow rate, but the variation in flow rate was acceptable. Between 4.1 and 15.7 minutes, HPI was maintained at 450 ± 10 lbm/h (100% head/flow characteristics), as required. After 15.7 minutes and until test termination, HPI was maintained between 120 and 190 lbm/h (desired was approximately 155 lbm/h, 50% of the head/flow characteristics).

In Test 4SEC02, the HPI flow was adjusted based on primary loop pressure or time criterion. Based on pressure criteria, HPI flow was started at 38% of the head/flow limit at 1.08 minutes and a loop pressure of 2037 psia. Then, at 3.7 minutes, and loop pressure of 1917 psia, HPI was increased to 68% of head/flow. HPI was further increased to 100% of the head/flow limit at about 12.8 minutes when the primary was about 1779 psia. Based on time criteria, HPI was reduced to 86%, 53%, and 27% of head/flow limit at 15.5, 17.3, and 20.2 minutes, respectively. HPI was terminated based on time, at approximately 38.4 minutes when the primary pressure recorded just above 1900 psia. Following the HPI flow rate setpoint adjustment, peak-to-peak oscillations of 310, 300, and 200 lbm/h were noted at approximately 2.33, 3.7, and 15.37 minutes. Other deviations between desired and delivered HPI flow rates were also noted, but they were all acceptable.

Low-Pressure Injection Control

The low pressure injection system was manually isolated for Tests 4SEC02, 4CR3T2, 4SGPF2, and 4SB011. As for Tests 410BD1, 410AT3, 4100B2, and 4NOML3, the LPI system was active and the control performance was acceptable despite a few minor excursions. The introduction of LPI to the primary started as the loop pressure decreased to about 203 psia. Initially, the presence of LPI increased the primary loop depressurization rate, rapidly increasing the required injection rate. During periods when the required LPI setpoint was rapidly changing with primary pressure, delivered LPI flow lagged behind the desired setpoint by approximately 15 seconds, causing a deviation between desired and actual LPI flow rate of about 400 lbm/h (8.9% of full capacity). During periods when primary pressure was nearly stable, the LPI flow rate was controlled within 150 to 180 lbm/h of setpoint (3.75-4.00% of head-flow LPI at runout). An offset of this magnitude results from the combined impact of using an existing transmitter (RVGP01) ranged from 0 to 2500 psia for control measurements in the range of 120 to 205 psi and the steep slope of the required LPI head-flow curve in this range.

Reactor Vessel Vent Valve Control

The reactor vessel vent valves (RVVVs) were in independent automatic control mode for all tests in this group, except for Tests 4SEC02 and 4SGPF2. In these two tests, the RVVVs were manually closed during the entire tests.

The RVVV actuation differential pressures were evaluated at the beginning and at the end of the MIST Phase IV Test Program, and the vent valve performance was acceptable. The RVVV opening and closing differential pressures (desired open/close = 0.125/0.04 psid) recorded in the data base for this test program were acceptable.

Core Flood Tank

The core flood tank (CFT) control was satisfactory for all tests. For Tests 4CR3T2, 4SEC02, and 4SGPF2, the core flood tank was manually isolated, as expected. The CFT water inventory was discharged into the loop during Tests 410AT3, 410BD1, 4NOML3, and 4100B2. The CFT isolation valves opened when primary pressure was between 635 and 650 psia. In Test 4SB011, the CFT remained isolated since the primary pressure remained above the actuation pressure.

In Test 410AT3, the CFT control was left on auto until test termination. In Test 4NOML3, the CFT was manually isolated when the core exit subcooling exceeded 50F and the primary pressure was less than 715 psia. In Tests 410BD1 and 4100B2, the CFT was automatically isolated on low level.

Pressurizer Main Heaters

The pressurizer main heaters were tripped off on low pressurizer level at test initiation for Tests 410AT3, 410BD1, 4NOML3, 4100B2, and 4SEC02. In Tests 4CR3T2 and 4SB011, the pressurizer main heaters were manually tripped at test initiation. In Test 4SGPF2, the pressurizer heaters remained energized during the entire test, as desired.

Core Power

The core power decay ramp was activated at test initiation in all tests in this group except 4SGPF2.

The core power control performed satisfactorily during each test. Core power was maintained within 1.5 kW of the intended core power decay curve throughout the tests. In Test 4SEC02, the core power briefly deviated from the specified curve by as much as -9.3 kW (-9%) to about +2.5 kW (2.3%) during the start of the ramp. In Test 4SGPF2, core power control was maintained constant at 258.8 $\pm$ 1.5 kW, as required, until test termination.

Leak and Vent System Control

For all tests in this group, all leaks and vents were actuated in accordance to the test procedures. The single-phase leak system was inactive for Tests 4SEC02, 4CR3T2, and 4SGPF2. The active leak for Tests 410AT3, 410BD1, and 4NOML3 was the 10-$cm^2$ cold leg discharge leak. The active leak for Test

4100B2 was the 100-$cm^2$ cold leg discharge leak. Test 4SB011 was initiated using the A2 and B1 cold leg reactor coolant pump seal leak sites. However, these two leak sites were plugged, and at 7.05 minutes the A1 and B2 leak sites were activated. The 7 minutes without leak flow did not impact the acceptability of the test as discussed earlier in Section 4.1.2. Listed below are the measured throat diameter of the leaks used in the MIST Phase IV tests:

| Test | Nominal Leak Size | Location | Measured Leak Size Throat ID - Inches |
|---|---|---|---|
| 410AT3 | scaled 10 $cm^2$ | B1 CLD | 0.0475 |
| 410BD1 | scaled 10 $cm^2$ | B1 CLD | 0.0475 |
| 4NOML3 | scaled 10 $cm^2$ | B1 CLD | 0.0475 |
| 4100B2 | scaled 100 $cm^2$ | B1 CLD | 0.1558 |
| 4SB011 | scaled 0.25 $cm^2$ | A2 RCP | 0.0080, and |
| | | B1 RCP | 0.0080 |
| 4SB011 | scaled 0.25 $cm^2$ | A1 RCP | 0.0093, and |
| | | B2 RCP | 0.0097 |

In all tests except 4SEC02, 4CR3T2, and 4SGPF2, the hot leg high-point vents and the reactor vessel upper head vent were used after test termination, as indicated by V2MM03 and V2MM02.

In Test 4100B2, the leak flow saturated 95 seconds after opening and remained saturated until 35 minutes when LPI fluid filled the cold leg discharge piping past the leak elevation. As leak subcooling was restored and began increasing, leak flow rapidly increased. Shortly after 35 minutes, leak flow was subcritical, limited by Euler pressure loss through the single-phase leak system. Ideal modeling of the 100-$cm^2$ leak required critical flow to be maintained until 43 minutes when leak temperature decreased below 212F. After this time, the orifice Euler number governed leak flow. Test acceptability was not impacted since an accurate measurement of leak flow was available for the entire test, permitting code modelling.

<u>Reactor Coolant Pump Control</u>

The reactor coolant pumps (RCPs) were only active for Tests 410BD1 and 4SEC02. In these two tests, the reactor coolant pump control was acceptable.

In Test 4SEC02, the pumps operated at less than 10% speed prior to test initiation, as specified. Then, all four pumps were brought up simultaneously to 100% speed in less than 10 seconds. The pump coastdown occurred, as required, at 101.83 minutes for the A1 reactor coolant pump (RVGP01 was 1955.5 psia), and at 18.3 minutes for the B1 pump, when the primary pressure registered a value of 2009.1 psia. Both these actions were executed properly based on time due to the approach to the primary pressure value. The reactor coolant pump for A2 cold leg tripped off unscheduled at approximately 87 minutes due to voltage surge in the input power line, and was off for about 15 minutes. This event did not impact test acceptability.

In Test 410BD1, the B1 reactor coolant pump was bumped as specified at 945 minutes, and the A1 reactor coolant pump was bumped at 960 minutes, as required. The pump bump was needed to induce LPI and refill the primary. When the pumps were bumped, the rampur to 100% speed was completed in 16 seconds, as expected. The pump coastdown for the B1 and A1 pumps was initiated at 7 seconds and 3 seconds, respectively, after each pump had reached 100% speed during rampup. The coastdown of both pumps was successful.

4.1.4. Termination

Test termination activities were acceptable for all the tests in this group.

Test 410BD1 was terminated after completing the second reactor coolant pump bump. Test 410AT3 was terminated according to procedure, but 4 hours earlier than was indicated in the test specifications. This early termination did not warrant repeating the test since a similar test (410BD1) was performed. Test 410BD1 demonstrated the same primary pressure trend with nearly identical loop conditions. Primary repressurization and boiler-condenser-mode cooldown, which would have occurred after terminating Test 410AT3, were observed in Test 410BD1.

Test 4NOML3 was terminated due to maximum time duration (11 hours). Test 4100B2 was terminated 2 hours after primary pressure dropped below 200 psia. Tests 4SEC02 and 4SGPF2 were terminated after completing all scheduled operator actions.

Test 4CR3T2 was terminated at 225 minutes, approximately 75 minutes earlier than specified. The early termination was authorized by the B&W IST Program Manager. At 225 minutes, the primary system had been filled with water, with the PORV actuating at 15- to 20-second intervals, and the primary fluid cooldown rate was less than 1F/h. No change in these conditions was expected, so the test was terminated to limit stress on the facility.

Test 4SB011 was terminated at 226 minutes when the steam generator A steam valve was manually opened in anticipation of exceeding the secondary pressure facility limit. This early termination did not impact the acceptability of the test for the purposes of examining the effect of mitigating actions during the station blackout transient.

In all tests, the loop was refilled and the reactor vessel upper head void was removed prior to the termination of acquiring data.

## 4.2. Instruments

Each of the eight tests in the MIST Phase IV test group series used a common set of instrumentation. The critical instruments in this set are defined in Table 4.2. The measurements obtained from the instrumentation were checked to assure acceptable operation during the tests. Checks on instrument measurements were performed by computer-automated data qualification activities and manual examination of the analysis plots. Data qualification activities for each test in this group were performed at steady-state, pretest initial conditions, during the test transient, and after test termination as summarized below:

| | | Time of Performance | | |
|---|---|---|---|---|
| Check | Purpose | Before Test | During Test | After Test |
| NOREAD | Definition of instruments not acquiring data | x | x | x |
| ANDCHK | Calibration check of the Analogic data acquisition system | x | | x |
| ZEROS | Zero check of instrument transmitters | x | | x |
| RANGE | Validity of instrument measurement as compared to expected range | x | x | x |
| CONSIS | Instrument and derived quantity consistency check | x | x | |

As a result of these manual and automatic data qualification checks applied to the measurements and derived quantities in the test data base, the critical instruments identified in Table 4.3 were determined to be invalid during all or part of the test. In most instances, there was sufficient redundancy in the group of critical instruments so that the individual failure did not violate the requirements of the Critical Instrument List. In the other cases, the existence of the failed critical instrument did not warrant repeating the test.

Prior to and after completion of the test, a "zero" reading was obtained for all differential pressure and pressure transmitters, mass flow meters, weigh tank load cells, and reactor core voltage and current measurements. For those critical instruments that failed the zero check (defined in the Immediate Report for each test), the magnitude of the failure was small enough that measurement performance was not degraded to a condition that warranted repeating the test. The instrumentation performance during these tests was fully acceptable based upon this check.

## Table 4.1. Test Initial Conditions for MIST Phase IV Test Series

| System | Parameter | VTAB | Units | Desired | Tolerance | Actual Values | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 410AT3 | 4NOML3 | 410BD1 | 4100B2 | 4SB011 | 4CR3T2 | 4SEC02 | 4SGPF2 |
| Primary | | | | | | | | | | | | | |
| | Pressure | RVGP01 | psia | (a) | (a) | 1730 | 1735 | | | | | | |
| | | | | 1750 | (a) | | | 1743 | 1743 | | | | |
| | | | | 2000 | ±10 | | | | | 2004 | | | |
| | | | | 1905 | +10/-0 | | | | | | 1908 | | |
| | | | | 2215 | ±25 | | | | | | | 2217.7 | |
| | | | | 2200 | ±50 | | | | | | | | 2206.6 |
| | Hot leg subcooling | (b) | deg F | 22.0 | ±2 | 21.2 | 21.8 | 22.7 | 22.4 | (c) | (c) | (c) | 23.5 |
| | Core power | RVWM20 | kW | 134.31 | ±1.65 | 133.6 | | 134.61 | 134.47 | 134.75 | | | |
| | | | | 128.70 | ±1.65 | | 129.23 | | | | | | |
| | | | | 127.8 | ±1.65 | | | | | | 128.1 | | |
| | | | | 273.3 | ±1.65 | | | | | | | 273.2 | |
| | | | | 258.80 | ±1.65 | | | | | | | | 259.11 |
| | Pressurizer level | PZLV20 | ft | 23.0 | (d) | 23.0 | | 22.9 | 22.9 | 23.0 | | | |
| | | | | 22.6 | (d) | | 22.5 | | | | | | |
| | | | | 21.3 | (d) | | | | | | 21.4 | | |
| | | | | 25.1 | (d) | | | | | | | 24.9 | |
| | | | | 23.0 | (d) | | | | | | | | 24.3 |
| | | | | | | Level variation met specification for all tests. | | | | | | | |
| | Pressurizer surge line fluid temperature | PZTC01 | deg F | Match HITC11 | ±5<br>±10 for 4SEC02 | HITC11 -4.5 | HITC11 -0.8 | HITC11 +1.4 | HITC11 -2.7 | HITC11 -2.9 | HITC11 -1.2 | HITC11 +0.98 | (c) |
| | RV upper head temperature | RVTC23 | deg F | 601 | +3/-10 | (c) | (c) | (c) | (c) | (c) | (c) | 598.44 | (c) |

## Table 4.1. Test Initial Conditions for MIST Phase IV Test Series (Cont'd)

| System | Parameter | VTAB | Units | Desired | Tolerance | Actual Values 4IOAT3 | 4NOML3 | 4IOBD1 | 4IOOB2 | 4SBO11 | [illegible] | 4SEC02 | 4SGPF2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fluid/metal temperatures | (e) | deg F | Varying less than 3F/h for fluid and 10F/h for metal during a 30-minute interval. | | For all tests, fluid and metal temperature variat[illegible] specification. | | | | | | | |
| | Pump speed | C1TA20 | rpm | 352.0 | Adjust to get desired down-comer flow rate. | (c) | (c) | (c) | (c) | (c) | (c) | 291.3 | (c) |
| | | C2TA20 | | 349.0 | | | | | | | | 300.4 | |
| | | C3TA20 | | 353.0 | | | | | | | | 291.3 | |
| | | C4TA20 | | 350.0 | | | | | | | | 289.8 | |
| S condary | | | | | | | | | | | | | |
| | Pressure | S1GP01 | psia | 1010 | ±10 | 1013 | 1014 | 1013 | 1013 | 1013 | | | 1016 |
| | | S2GP01 | | | | 1013 | 1015 | 1013 | 1013 | 1012 | | | 1009 |
| | | S1GP01 | | 980 | ±10 | | | | | | 986 | | |
| | | S2GP01 | | | | | | | | | 985 | | |
| | | S1GP01 | | 1075 | ±25 | | | | | | | 1070 | |
| | | S2GP01 | | | | | | | | | | 1075 | |
| | Level | S1LV20 | ft | 5.0 | ±1.0 | 4.0 | | 5.4 | 4.6 | 5.1 | | | |
| | | S2LV20 | | | | 4.2 | | 5.2 | 4.7 | 5.3 | | | |
| | | S1LV20 | | 3.5 | ±1.0 | | 3.5 | | | | | | |
| | | S2LV20 | | 3.4 | ±1.0 | | 3.5 | | | | | | |
| | | S1LV20 | | 10.0 | ±1.0 | | | | | | 9.9 | | |
| | | S2LV20 | | | | | | | | | 10.0 | | |
| | | S1LV20 | | 27.9 | ±0.5 | | | | | | | 27.7 | |
| | | S2LV20 | | 29.6 | ±0.5 | | | | | | | 29.6 | |
| | | S1LV20 | | (f) | | | | | | | | | 19.3 |
| | | S2LV20 | | (f) | | | | | | | | | 19.2 |

## Table 4.1. Test Initial Conditions for MIST Phase IV Test Series (Cont'd)

| System | Parameter | VIAB | Units | Desired | Tolerance | Actual Values | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 4I0AI3 | 4NOML3 | 4I0BD1 | 4I00B2 | 4SB011 | 4CR3T2 | 4SEC02 | 4SGPF2 |
| | Auxiliary feedwater temperature | SFRT01 | deg F | 110 | ±20 | 119.0 | 121.5 | 119.6 | 122.9 | 112.7 | 120.0 | (c) | (c) |
| | | SFRT02 | | | | 121.0 | 122.9 | 120.8 | 123.9 | 113.2 | 121.1 | (c) | (c) |
| | Main feed temperature | SFRT03 | deg F | 460 | ±10 | (c) | (c) | (c) | (c) | (c) | (c) | 459.3 | |
| | | SFRT04 | | | | (c) | (c) | (c) | (c) | (c) | (c) | 458.6 | |
| | | SFRT03 | | (g) | | | | | | | | | 452.0 |
| | | SFRT04 | | | | | | | | | | | 451.5 |
| | Main feed flow | SFOR07 | lbm/h | 540 | ±36 | (c) | (c) | (c) | (c) | (c) | (c) | 528.9 | (c) |
| | | SFOR08 | | | | (c) | (c) | (c) | (c) | (c) | (c) | 536.9 | (c) |
| Core Flood Tank | | | | | | | | | | | | | |
| | Pressure | CFGP01 | psia | 600 | ±10 | 601.0 | 595.5 | 599.9 | 600.9 | 604.0 | (c) | (c) | (c) |
| | Level | CFLV20 | ft | 42.8 | ±0.3 | 43.0 | 43.0 | 42.9 | 43.0 | 43.0 | (c) | (c) | (c) |

(a) Pressure must be adjusted to give a hot leg subcooling of 22 ± 2F as given by the difference between H1TC11 and RVRF20 (which is the saturation temperature based on RVGP01).

(b) Hot leg subcooling was defined by the difference between H1TC11 and RVRF20 (the saturation temperature based on RVGP01).

(c) Not applicable for this this test.

(d) The tolerance of the pressurizer level is:

- level should be within ± 0.2 ft for all tests, except for test 4SGPF2 (tolerance is ± 1.5 ft).
- level variation must be less than ±0.6 ft/h

(e) The following fluid and metal temperature measurements were used to define steady-state (minimum time interval of 30 minutes without test operator manual control adjustments):

Fluid: H1RT01, H2RT01, P1RT02, P2RT02.
Metal: P2MT01, C1MT04, C2MT04, C3MT04, C4MT04, RVMT24, RVMT25.

(f) Steam generator secondary levels must be adjusted to give a hot leg subcooling of 22 ± 2F as given by the difference between H1TC11 and RVRF20 (which is the saturation temperature based on RVGP01).

(g) The main feedwater temperature required for Test 4SGPF2 is the maximum achievable by the MIST main feedwater heater control system.

## Table 4.2. Critical Instruments for the MIST Phase IV Test Series

| Component | Instrument Type | Critical Instruments: Test 410BD1, 410AT3 | Additional Instruments to those of Tests 410BD1 or 410AT3: 4NOML3 | 4100B2 | 4SB011 | 4CR3T2 | 4SEC02 | 4SGPF2 |
|---|---|---|---|---|---|---|---|---|
| Reactor Vessel | Ammeter | RVAM01 | - | - | - | - | - | - |
| | Conductivity Probe | RVCP01-04 | - | - | - | - | - | NR |
| | Differential Pressure | RVDP01,03-09 | RVDP02 | - | RVDP02 | - | RVDP01-05 (Only) | RVDP01 ONLY |
| | Differential Temperature | RVDT01-04,23 | - | - | - | - | - | - |
| | Pressure Transmitter | RVGP01 | - | - | - | - | - | - |
| | Limit Switch | RVLS01-04 | - | - | - | RVLS09 | - | NR |
| | Metal Thermocouple | RVMT01-04,23 | RVMT24,25 | - | RVMT24,25 | RVMT24,25 | RVMT24,25 | - |
| | | RVMT05-22 (12 of 18) | - | - | - | - | - | - |
| | Fluid Thermocouple | RVTC01,02 (1 of 2) | - | - | - | - | - | - |
| | | RVTC16-20 | - | - | - | - | - | - |
| | | RVTC03-15 (9 of 13) | - | - | - | - | - | - |
| | | RVTC21-23 (2 of 3) | - | - | - | - | - | - |
| | Voltmeter | RVVM01 | - | - | - | - | - | - |
| | Power Controller | - | - | - | - | - | RVWM01-04,23 | - |
| Hot Legs | Conductivity Probe | H1CP01-10 (5 of 10) | - | - | - | - | - | NR |
| | | H2CP01-10 (5 of 10) | - | - | - | - | - | NR |
| | Differential Pressure | H1DP01-04,09-12,14 | - | - | (1) | H1DP05-08,13,15 | H1DP05-08,13,15 | H1DP01,14 ONLY |
| | | H2DP01-04,09-12,14,16 | - | - | (1) | H2DP05-08,13,15 | H2DP05-08,13,15 | H2DP01,02,14,16 ONLY |
| | Differential Temperature | H1DT01-04 | - | - | - | - | - | - |
| | | H2DT01-04 | - | - | - | - | - | - |
| | Limit Switch | H1LS01,H2LS01 | - | - | - | - | - | NR |
| | Metal Thermocouple | H1MT01-04 | - | - | - | - | - | - |
| | | H2MT01-04 | - | - | - | - | - | - |
| | Resistance Temp. Detector | H1RT01 or H1TC01, | - | - | - | - | - | - |
| | | H2RT01 or H2TC01 | - | - | - | - | - | - |
| | Fluid Thermocouple | H1TC02-09 (5 of 8) | - | - | - | - | - | - |
| | | H2TC02-09 (5 of 8) | - | - | - | - | - | - |
| | | H1TC10-12 (1 of 3) | - | - | - | - | - | - |
| | | H2TC10-12 (1 of 3) | - | - | - | - | - | - |
| | | H1TC13-19 (5 of 7) | - | - | - | - | - | - |
| | | H2TC13-19 (5 of 7) | - | - | - | - | - | - |
| | Power Controller | - | - | - | - | - | H1WM01-04, | NR |
| | | - | - | - | - | - | H2WM01-04 | NR |

## Table 4.2. Critical Instruments for the MIST Phase IV Test Series (Cont'd)

| Component | Instrument Type | Critical Instruments: Test 410BD1, 410AT3 | Additional instruments to those of Tests 410BD1 or 410AT3: 4NOML3 | 410OB2 | 4SB011 | 4CR3T2 | 4SEC02 | 4SGPF2 |
|---|---|---|---|---|---|---|---|---|
| Steam Generator A | Differential Pressure | P1DP04,S1DP01,03 | - | - | - | - | S1DP02 | - |
| | Differential Temperature | S1DT01-05 | - | - | - | - | - | - |
| | Pressure Transmitter | P1GP01,S1GP01 | - | - | - | - | - | - |
| | Metal Thermocouple | S1MT01-05 | - | - | P1MT01 | P1MT01 | P1MT01 | NR |
| | Resistance Temp. Detector | P1RT01,02 | - | - | - | - | - | - |
| | Fluid Thermocouple | P1TC01-03,13-16,23-26,& | - | - | - | - | - | - |
| | | P1TC33-36 (10 of 15) | - | - | - | - | - | - |
| | | P1TC18,27,28,37,38 (3 of 5) | - | P1TC17 | - | - | - | - |
| | | P1TC09-12,19-22,29-32 (8 of 12) | - | - | - | - | - | - |
| | | S1TC01,02,26 (2 of 3) | - | - | - | - | - | - |
| | | S1TC03-12 (7 of 10) | - | - | - | - | - | - |
| | | S1TC13-23,25 (8 of 12) | - | - | - | - | - | - |
| | | S1TC24 | - | - | - | - | - | - |
| | Power Controller | - | - | - | - | - | S1WM01-05 | NR |
| | Limit Switches | - | S1LS02 | - | S1LS02 | S1LS02,03 | S1LS02,03 | - |
| Steam Generator B | Conductivity Probe | S2CP01-12 (6 of 12) | - | - | - | - | - | NR |
| | Differential Pressure | P2DP06,S2DP01,S2DP12 | - | - | - | - | - | - |
| | | S2DP02-11 (5 of 10) | - | - | - | - | - | - |
| | Differential Temperature | S2DT01-05 | - | - | - | - | - | - |
| | Pressure Transmitter | P2GP01,S2GP01 | - | - | - | - | - | - |
| | Metal Thermocouple | S2MT01-05 | - | - | P2MT01 | P2MT01 | P2MT01 | - |
| | Resistance Temp. Detector | P2RT01,02 | - | - | - | - | - | - |
| | Fluid Thermocouple | P2TC01-13 (9 of 13) | - | - | - | - | - | - |
| | | P2TC14-28 (10 of 15) | - | - | - | - | - | - |
| | | P2TC29-43 (10 of 15) | - | - | - | - | - | - |
| | | P2TC44-53 (7 of 10) | - | - | - | - | - | - |
| | | S2TC01-08,55 (6 of 9) | - | - | - | - | - | - |
| | | S2TC09-19 (7 of 11) | - | - | - | - | - | - |
| | | S2TC20-33,54 (10 of 15) | - | - | - | - | - | - |
| | | S2TC34-53 ([illegible] of 20) | - | - | - | - | - | - |
| | Power Controller | - | - | - | - | - | S2WM01-05 | NR |
| | Limit Switch | - | S2LS02 | - | S2LS02 | S2LS02,05 | S2LS02-05 | NR |

## Table 4.2. Critical Instruments for the MIST Phase IV Test Series (Cont'd)

| | | Critical Instruments | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Additional Instruments to those of Tests 410BO1 or 410AT3 | | | | | |
| Component | Instrument Type | Test 410BO1, 410AT3 | 4NOML3 | 410OB2 | 4SB011 | 4CR3T2 | 4SEC02 | 4SGPF2 |
| Cold Legs (n=1,2,3,4) | Differential Pressure | C1DP01-04,06-08 | - | - | - | C1DP05 | C1DP01,02,07,08* | - |
| | | C2DP01-04,06-09 | - | | - | C2DP05 | C2DP01,02,07-09* | (4) |
| | | C3DP02-04,06-08 | - | | - | C3DP05 | C3DP01,02,07,08* | - |
| | | C4DP02-04,06-08 | - | | - | C4DP05 | C4DP01,02,07,08* | - |
| | Differential Temperature | CnDT01-03 | - | | - | - | - | - |
| | Metal Thermocouple | CnMT01-03 | - | - | CnMT04 | CnMT04 | CnMT04 | - |
| | Resistance Temperature | CnRT01,02 | - | - | - | - | - | - |
| | Fluid Thermocouple | CnTC02 | - | | - | - | - | - |
| | | CnTC03-06 (3 of 4) | - | - | - | - | - | - |
| | | CnTC07-10 (3 of 4) | - | - | - | - | - | - |
| | | CnTC11-14 (3 of 4) | - | - | - | - | - | - |
| | Turbine meter | - | - | - | - | - | CnTM01 | NR |
| | Wattmeters | - | - | - | C1,C2WM04 | - | CnWM01-04 | NR |
| | Ammeters | - | - | - | C1,C2AM01 | - | CnAM01 | NR |
| | Tachometers | - | - | - | C1,C2TA01 | - | CnTA01-03 | NR |
| | | | | | C1,C2TA02 | | | |
| | | | | | C1,C2TA03 | | | |
| | | | | | C1,C2TA20 | | | |
| | Limit Switch | - | CnLS03 | - | CnLS03 | - | - | NR |
| | | | CnLS04 | - | CnLS04 | | | |
| | | | CnLS06 | - | CnLS06 | | | |
| Reactor Vessel Downcomer | Differential Pressure | DCDP01,02,05-08 | DCDP04 | - | DCDP04 | DCDP04 | DCDP04 | - |
| | Differential Temperature | DCDT01-03 | - | - | - | - | - | - |
| | Metal Thermocouple | DCMT01-03 | - | - | DCMT04 | DCMT04 | DCMT04 | - |
| | Resistance Temp. Detector | DCRT01 | - | - | - | - | - | - |
| | Fluid Thermocouple | DCTC01-04 | - | - | - | - | - | - |
| | | DCTC05-12 (5 of 8) | - | - | - | - | - | - |
| | | DCTC13-40 (19 of 28) | - | - | - | - | - | - |
| | | DCTC41-46 (4 of 6) | - | - | - | - | - | - |
| | Power Controller | | - | - | - | - | DCWM01-03 | NR |
| Pressurizer | Differential Pressure | PZDP01,02 | - | - | - | - | - | - |
| | Differential Temperature | PZDT01,02 | - | - | - | PZDT03 | PZDT03 | - |
| | Pressure Transmitter | PZGP01 | - | - | - | - | - | - |

## Table 4.2. Critical Instruments for the MIST Phase IV Test Series (Cont'd)

| Component | Instrument Type | Critical Instruments: Test 410BD1, 410AT3 | Additional Instruments to those of Tests 410BD1 or 410AT3: 4NOML3 | 4100B2 | 4SB011 | 4CR3T2 | 4SE'02 | 4SGPF2 |
|---|---|---|---|---|---|---|---|---|
| Pressurizer | Metal Thermocouple | PZMT01,02 | - | - | PZMT03 | PZMT03 | PZMT03 | - |
| | Resistance Temp. Detector | PZRT01 or PZTC09 | - | - | - | - | - | - |
| | Fluid Thermocouple | PZTC01,02 | PZTC09 | - | PZTC09 | PZTC09-10 | PZTC09-10 | - |
| | | PZTC04-08 (4 of 5) | - | - | - | - | - | - |
| | Power Controller | PZWM04 | - | - | - | - | PZWM01-03 | - |
| HPI | Differential Pressure | HPDP01 | - | - | - | - | - | NR |
| | Flowmeter | HPMM01-05 | - | - | - | - | - | NR |
| | Fluid Thermocouple | HPTC01 | - | - | - | - | - | NR |
| LPI | Limit Switch | LPLS01 | - | NR | - | NR | NR | NR |
| | Flowmeter | LPMM01 | - | - | - | NR | NR | NR |
| | Fluid Thermocouple | LPTC01 | - | - | - | NR | NR | NR |
| Single-Phase Vent System | Load Cell | V1LC01,02 | - | - | - | NR | NR | NR |
| | Limit Switch | V1LS01,02,07 | - | V1LS06 | V1LS11-14 | NR | NR | NR |
| | Fluid Thermocouple | V1TC02 | - | HPTC01 | V1TC11-14 | NR | NR | NR |
| | Flowmeter | V1MM01 | - | (2) | (3) | NR | NR | NR |
| Leak Quality System | Pressure Transmitter | LQGP01 | - | - | - | NR | NR | NR |
| | Flowmeter | LQMM01 | - | - | - | NR | NR | NR |
| | Fluid Thermocouple | LQTC01-05 | - | - | - | NR | NR | NR |
| Two-Phase Vent System | Load Cell | V2LC01-04 | - | - | - | - | - | NR |
| | Limit Switch | V2LS0[illegible]-06 | - | - | - | - | - | NR |
| | Flowmeter | V2MM01-03 | - | - | - | - | - | NR |
| | Fluid thermocouple | V2TC01-04 | - | - | - | - | - | NR |
| Core Flood Tank | Differential Pressure | CFDP01 | - | - | - | NR | NR | NR |
| | Pressure Transmitter | CFGP01 | - | - | - | NR | NR | NR |
| | Limit Switch | CFLS01,02 (1 of 2) | - | - | - | NR | NR | NR |
| | Fluid Thermocouple | CFTC01 | - | - | - | NR | NR | NR |
| | | CFTC02,03 (1 of 2) | NR | - | NR | NR | NR | NR |

## Table 4.2. Critical Instruments for the MIST Phase IV Test Series (Cont'd)

| Component | Instrument Type | Critical Instruments: Test 410BD1, 410AT3 | Additional Instruments to those of Tests 410BD1 or 410AT3: 4NOML3 | 410OB2 | 4SBO11 | 4CR3T2 | 4SEC02 | 4SGPF2 |
|---|---|---|---|---|---|---|---|---|
| Gas Addition | Fluid Thermocouple | GATC02-04 | - | - | - | - | - | - |
| Auxiliary Feedwater Circuit | Differential Pressure | SFDP01-06 | - | - | - | - | - | - |
| | Resistance Temp. Detector | SFRT01,02 | - | - | - | - | - | - |
| | Limit Switch | - | - | - | - | - | - | S1,S2LS02 |
| Main Feedwater Circuit | DP transmitter | - | - | - | - | - | SFDP07,08 | SFDP07,08 |
| | RTD | - | - | - | - | - | SFRT03,04 | SFRT03,04 |
| | Fluid Thermocouple | - | - | - | - | - | SFTC03,04 | S1LS03,S2LS05 |
| | Limit Switch | - | - | - | - | - | - | - |
| Steam Circuit | Differential Pressure | SSDP01-06 | - | - | - | - | SSDP07,08 | - |
| | Resistance Temp. Detector | SSRT01,02 | - | | - | - | - | - |
| | Fluid Temperature | SSTC01-03 (1 of 2) | - | - | - | - | - | - |
| | | SSTC02,04 (1 of 2) | - | - | - | - | - | - |
| Miscel-laneous | Resistance Temperature Detector Shunt | MSRF01 | - | - | - | - | - | - |
| | Reference Oven Temperature | | MSTC01-07 | - | - | - | - | - |

Symbols:

NR: means instrument not required
*: means that is the only required instrument

(1) These instruments, H1 & H2DP02, 03, are not required for Test 4SBO11.

(2) These instruments, V1LS07 and V1TC02, are not required for Test 410OB2.

(3) This instrument, V1TC02, is not required for Test 4SBO11.

(4) This instrument, C2DP09, is not required for Test 4SGPF2.

## Table 4.3. Critical Instruments Not Available for the MIST IV Test Series

| Instrument | Description | 410AT3 | 4NOML3 | 410BD1 | 410OB2 | 4SB011 | 4CR312 | 4SEC02 | 4SGPF2 | Backup Available |
|---|---|---|---|---|---|---|---|---|---|---|
| C1DT01 | Guard heater zone 1 loop A1 control at 2.60 ft | * | * | * | * | * | * | * | * | ** |
| C1DT02 | Guard heater zone 2 loop A1 control at 17.30 ft | | | * | | | * | | | ** |
| C3DT03 | Guard heater zone 3 loop A2 control at 23.48 ft | * | * | * | * | * | * | * | * | *** |
| C4DT01 | Guard heater zone 1 loop B2 control at 2.59 ft | * | * | * | * | * | * | * | * | ** |
| C4DT03 | Guard heater zone 3 loop B2 control at 23.47 ft | * | * | * | * | * | * | * | * | ** |
| C2TC04 | Pump suction fluid temperature at 2.36 ft | | | | | | | x | | yes |
| H1DT01 | Guard heater zone 14 control at 29.63 ft | | | | * | | * | | | ** |
| H1CP02 | Hot leg fluid conductivity probe at 28.54 ft | x | x | x | x | x | | x | | yes |
| H1CP04 | Hot leg fluid conductivity probe at 43.45 ft | x | x | x | | x | | | | yes |
| H1CP05 | Hot leg fluid conductivity probe at 50.71 ft | | | | x | | | | | yes |
| H1CP06 | Hot leg fluid conductivity probe at 59.72 ft | x | x | x | x | x | | x | | yes |
| H1CP07 | Hot leg fluid conductivity probe at 63.56 ft | x | x | x | x | x | x | | | yes |
| H1CP09 | Hot leg fluid conductivity probe at 66.65 ft | | | | | | x | | | yes |
| H2CP01 | Hot leg fluid conductivity probe at 23.14 ft | | | x | | | x | | | yes |
| H2CP02 | Hot leg fluid conductivity probe at 28.52 ft | x | x | x | x | x | x | x | | yes |
| H2CP03 | Hot leg fluid conductivity probe at 36.13 ft | | | | x | | | | | yes |
| H2CP04 | Hot leg fluid conductivity probe at 43.41 ft | x | x | x | x | x | | x | | yes |
| H2CP05 | Hot leg fluid conductivity probe at 50.68 ft | x | x | x | x | x | | x | | yes |
| H2CP06 | Hot leg fluid conductivity probe at 59.69 ft | x | x | x | x | x | | x | | yes |
| H2CP07 | Hot leg fluid conductivity probe at 63.56 ft | x | x | x | x | x | | x | | **** |
| H2CP08 | Hot leg fluid conductivity probe at 65.65 ft | x | x | x | x | x | x | x | | **** |
| H2CP10 | Hot leg fluid conductivity probe at 65.65 ft | x | x | x | x | x | | x | | **** |
| P1TC09 | Generator A primary fluid temperature at 51.06 ft | | x | x | x | x | x | | x | yes |
| P1TC10 | Generator A primary fluid temperature at 50.56 ft | | x | x | x | x | x | | x | yes |
| P1TC11 | Generator A primary fluid temperature at 50.06 ft | | x | x | x | x | x | | x | yes |
| P1TC12 | Generator A primary fluid temperature at 49.06 ft | | | | | | x | | | yes |
| P1TC14 | Generator A primary fluid temperature at 43.06 ft | | x | x | x | x | x | | x | yes |
| P1TC15 | Generator A primary fluid temperature at 39.06 ft | | x | x | x | x | x | | x | yes |
| P1TC16 | Generator A primary fluid temperature at 35.06 ft | | | x | | | x | | | yes |
| P1TC18 | Generator A primary fluid temperature at 23.06 ft | | | x | | | x | | | yes |
| P1TC30 | Generator A primary fluid temperature at 50.58 ft | x | x | x | x | x | x | x | x | yes |
| P1TC35 | Generator A primary fluid temperature at 39.08 ft | x | x | x | x | x | x | x | x | yes |
| P2TC01 | Generator B primary fluid temperature at 50.50 ft | x | x | x | x | x | x | x | x | yes |
| P2TC12 | Generator B primary fluid temperature at 49.50 ft | x | x | x | x | x | x | x | x | yes |
| P2TC29 | Generator B primary fluid temperature at 29.25 ft | | | | x | | x | | | yes |
| P2TC30 | Generator B primary fluid temperature at 29.25 ft | x | x | x | x | x | x | x | x | yes |
| P2TC32 | Generator B primary fluid temperature at 26.25 ft | x | x | x | x | x | x | | x | yes |
| P2TC40 | Generator B primary fluid temperature at 14.25 ft | x | x | x | x | x | x | x | x | yes |
| RVDT01 | Core inlet guard heater control DT at 1.88 | * | * | * | * | * | * | * | * | *** |
| RVTC09 | Core fluid temperature (mid-bundle) at 15.23 ft | x | x | x | x | x | x | | x | yes |
| RVCP01 | Conductivity probe below hot leg nozzle at 21.12 ft | | | | x | | x | | | *** |
| RVCP02 | Conductivity probe above hot leg nozzle at 21.32 ft | | | x | x | x | | | | *** |
| RVCP04 | Conductivity probe above RVVV line at 24.22 ft | | | | x | | x | | | *** |
| S1TC04 | Generator A secondary fluid temperature at 11.07 ft | | | | | | | x | | yes |
| S1TC16 | Generator A secondary fluid temperature at 38.19 ft | | | | | | | x | | yes |
| S2CP04 | Generator B secondary fluid temperature at 30.04 ft | x | x | x | x | x | x | x | | yes |
| S2CP10 | Generator B secondary fluid temperature at 33.03 ft | | | | | | x | | | yes |

x Instrument was not available.
* Metal temperature used for guard heater control in place of the differential temperature.
** Approval for test performance without this instrument received per PMG Transmittal Nos. 566 and 606.
*** Approval for test performance without this instrument received per PMG Transmittal No. 716.
**** Approval for test performance without this instrument received per PMG Transmittal No. 689.

# 5. OBSERVATIONS

## 5.1. Observations of Test 4NOML3

Test 4NOML3 was an SBLOCA test that had a scaled 10-$cm^2$ leak in the cold leg B1 discharge, used time distorted core power, and employed the simulated high-pressure injection and low-pressure injection emergency core cooling systems.

The primary system depressurized rapidly upon opening the leak (See 1, Figure 5.1). When the core exit saturated, the primary system pressure stabilized (See 2, Figure 5.1). This stabilization occurred at a higher pressure for Test 4NOML3 than was observed in the Phase III Nominal Tests and was apparently a direct result of a higher core power due to the time distortion applied to the decay heat function.

The steam generator secondary pressure response for both steam generators was very similar during this time. Refill of the secondary side of the steam generators to 31.6 ft (See 1, Figure 5.2) resulted in a decrease of the secondary side pressure to approximately 630 psia in steam generator A (See 3, Figure 5.1) and 730 psia in steam generator B (See 4, Figure 5.1). Subsequent to the refill of both steam generator secondary sides, primary flow existed in both loops (See 1, Figures 5.3 and 5.4) and primary-to-secondary heat transfer resulted in an increase in the secondary side pressure of both steam generators. Both steam generators then stabilized at approximately 800 psia (See 5, Figure 5.1). These secondary side pressure responses are significantly different from those observed in the Phase III Nominal Tests where asymmetric steam generator responses were observed.

The primary system continued to lose inventory (See 1, Figure 5.5), established intra-cold leg flow in both loops (See 2, Figure 5.3 and 5.4), and depressurized (See 6, Figure 5.1) as a result of leak-HPI cooling. The decreasing core exit temperature, which was a result of the depressurization as the core exit temperature remained saturated, eventually initiated the steam generator ATOG control function and established a cooldown rate of approximately 75F/h (See 1, Figure 5.6).

As the primary pressure decreased, HPI flow eventually exceeded the leak flow (See 1, Figure 5.7) and some fluid from the CFT was discharged into the primary system (See 1, Figure 5.8). Primary system refill had therefore begun as observed by the increasing primary system total fluid mass (See 1, Figure 5.9).

The rate of primary system depressurization decreased (See 2, Figure 5.6) as the reactor vessel level began increasing (See 1, Figure 5.10). As the reactor vessel level approached and exceeded the hot leg nozzle elevation, the discharge of steam into the hot legs ceased (thus decreasing the primary loop driving head) and the primary system repressurized (See 3, Figure 5.6). This repressurization peaked at approximately 610 psia as the leak and HPI flows equalized (See 2, Figure 5.7).

The primary system pressure then remained relatively stable (approximately 275 psi higher than the secondary pressure) for the next six hours of the test (See 4, Figure 5.6). A gradual decrease in the primary system pressure occurred over this time and appears to be a result of the core power decay. Also during this time, the primary system refilled as indicated by the increase in primary system mass (See 2, Figure 5.9). The refill of the primary loop occurred in an asymmetrical manner, with the loop A hot leg riser and stub levels increasing at a greater rate than those in loop B (See 1, Figure 5.11). Preliminary indications are that the refill of the hot leg riser and stub is governed by the quenching of the piping in these regions. The refill rate also appears to increase when the collapsed liquid level attains the elevation of the guard heater control thermocouple, thus quenching the pipe, reducing the thermocouple temperature, and decreasing the guard heater power. The hot leg stub region appears to govern the refill process as it is the last region of the hot leg to refill. The asymmetric refill of the two hot legs, however, may be strictly due to the leak being located in loop B.

Eventually, the hot leg A riser level approached the U-bend spillover elevation (See 2, Figure 5.11) and when the loop A driving head increased sufficiently, a significant increase in the loop A flow occurred. This abrupt increase in flow caused highly subcooled fluid, which resided in the downcomer (See 1, Figure 5.12), to enter and subcool the core (See 2, Figure 5.12). When the core exit temperature subcooled, the steam generator pressure control automatically initiated a blowdown (See 5, Figure 5.6) and HPI was throttled (terminated) by the loop operators (See 3, Figure 5.7). Therefore, the primary system inventory decreased as a result of the leak flow exceeding the HPI flow (See 3, Figure 5.9).

The subcooling of the core region and the hot leg resulted in the loss of driving head and flow interrupted. The core region began to heat up and when the core exit temperature attained 50F subcooling, HPI was actuated (See 4, Figure 5.7). This sequence of events repeated three more times (See 6, Figure 5.6).

The HPI was not terminated on the last aforementioned occurrence but was throttled (automatically) to approximately one-third of its initial value (See 5, Figure 5.7). Loop A flow was maintained at this time, as indicated by forward flow in both the A1 and A2 cold legs (See 1, Figure 5.13), and the primary system depressurized (See 7, Figure 5.6) as primary-to-secondary heat transfer was established in loop A.

This depressurization apparently resulted in the flashing of liquid in the hot leg B riser and steam generator primary as indicated by the decreasing levels (See 3, Figure 5.11). The primary pressure decreased below 200 psia (See 8, Figure 5.6) and LPI actuated (See 6, Figure 5.7). The LPI actuation resulted in the refill of the downcomer (See 2, Figure 5.10) and the refill of the reactor vessel to an elevation above the reactor vessel vent valves (See 3, Figure 5.10). The hot leg B riser and stub level stabilized at approximately the steam generator upper tubesheet elevation (See 4, Figure 5.11). Flow in loop A was maintained and intra-cold leg flow was established in the B cold legs (See 2, Figure 5.13). The test was then terminated based upon the maximum test duration criteria (the test was actually extended beyond the maximum test duration criteria in anticipation of LPI actuation).

## 5.2. Observations of Test 410AT3

Test 410AT3 was an SBLOCA test without the benefit of the high-pressure injection system that had a scaled 10-$cm^2$ leak in the cold leg B1 discharge, utilized the standard abnormal transient operating guideline (ATOG) control schemes and employed the simulated low-pressure injection system.

The primary system depressurized rapidly upon opening the leak (See 1, Figure 5.14). The initial effect of no HPI was a more rapid depletion of primary system inventory than observed in the Phase III Nominal Test. The depletion was followed by the complete voiding of all four cold leg discharge pipes (See 1, Figure 5.15) and primary loop flow interruption (See 1, Figure 5.16). The voiding of the cold legs resulted in voided conditions at the leak site and a decreased leak flow rate (See 1, Figure 5.17). Both steam generator secondary pressures responded in a symmetrical manner (decreasing to approximately 750 psia, See 2, Figure 5.14) as the secondary levels were filled by AFW to 31.6 ft (See 1, Figure 5.18).

When the flow interrupted, the difference between the core exit temperature and the steam generator secondary saturation temperature was greater than 50F. Therefore, the control function for the ATOG cooldown did not actuate early (remained set at 1010 psia) in Test 410AT3, whereas in the Phase III Nominal Test, the control function for the ATOG cooldown became active in steam generator B. This activity apparently permitted periods of steam generator heat transfer which, along with HPI, aided primary depressurization in the Phase III Nominal Test. Thus, a significantly different primary system pressure response occurred early in the transient. Test 410AT3 repressurized at this time (See 3, Figure 5.14) as a result of no HPI and no steam generator heat transfer. The repressurization and the phenomena that occurred during the repressurization were similar to those observed during the Phase III Mapping Tests.

The primary system continued to repressurize, while losing inventory, until the primary level in steam generator A descended to the secondary pool elevation (See 2, Figure 5.18). Steam generator heat transfer was established and resulted in a depressurization of the primary system (See 4, Figure 5.14). The steam generator B primary level continued to decrease (See

3, Figure 5.18) and subsequently heat transfer was also established in steam generator B.

The establishment of steam generator heat transfer resulted in an increase in the secondary pressure (See 5, Figure 5.14) (therefore increasing the steam generator secondary saturation temperature) and a decrease in the primary pressure (therefore decreasing the core exit temperature that was saturated). Eventually, the difference between the core exit and the steam generator secondary saturation temperature reached 50F and the ATOG cooldown commenced (See 6, Figure 5.14).

The cooldown resulted in a depressurization of the primary system (See 1, Figure 5.19), which eventually led to CFT and LPI actuation. During this depressurization, all four cold leg discharge pipes remained voided (See 2, Figure 5.15), the cold leg suction pipes began voiding (See 1, Figure 5.20), and little, if any, forward primary loop flow was observed -- in fact, preliminary indications are that backflow may have existed in each cold leg (See 1, Figure 5.21).

When LPI actuated (See 1, Figure 5.22), a rapid increase of the primary system inventory occurred. All four cold leg discharge and suction pipes refilled completely (See 3, Figure 5.15 and See 2, Figure 5.20), the downcomer and the reactor vessel levels increased to near the reactor vessel vent valve elevation (See 1, Figure 5.23), the pressurizer surge line filled (See 1, Figure 5.24), and the hot leg riser and steam generator primary levels also increased but did not refill completely (See 1, Figure 5.25).

The LPI actuation subcooled the core exit temperature (See 1, Figure 5.26) and decreased the primary system pressure approximately 25 psi (See 2, Figure 5.19). The primary system, however, began to repressur[illegible] (See 3, Figure 5.19), apparently due to the stored energy in the system, the decrease in the leak energy as a result of subcooling the leak site, and the decreased steam generator heat transfer. LPI subsequently terminated due to the increasing primary system pressure (See 2, Figure 5.22). Apparently, circulation was not established because of the lack of a sufficient driving head to initiate forward loop flow.

The core region then began a heatup (See 2, Figure 5.26) that resulted in a similar system response to the repressurization that occurred early in the transient. The characteristic response and phenomena observed in the Phase III Mapping Tests were also observed during the repressurization phases of Test 410AT3, i.e., lower region voiding, hot leg heatup, establishment of sufficient driving head to obtain forward loop flow, lower region void collapse, loss of driving head and therefore forward loop flow interruption, a core heatup, and then the phenomena above repeat a number of times.

The primary system pressure attained approximately 725 psia during this repressurization phase of the transient (See 4, Figure 5.19). The primary system continued to lose inventory during the repressurization phase. The steam generator primary levels eventually descended to the secondary pool elevation (See 1, Figure 5.27), steam generator heat transfer was established, and a slight depressurization was observed (See 5, Figure 5.19). The test was terminated at this time.

## 5.3. Observations of Test 410BD1

Test 410BD1 was an SBLOCA transient that was also performed without the high-pressure injection system. The test used a scaled 10-cm$^2$ cold leg B1 discharge leak, low-pressure injection and a 50-psi/min blowdown of the secondary system. A PORV actuation and reactor coolant pump bumps were also performed during the test conduct.

The primary system depressurized rapidly upon opening the leak (See 1, Figure 5.28). The initial effect of no HPI resulted in a rapid depletion of primary system inventory. Voiding of all four cold leg discharge pipes occurred (See 1, Figure 5.29), partial voiding of the suction pipe in cold legs A1 and B1 also occurred (See 1, Figure 5.30), and primary loop flow interrupted (See 1, Figure 5.31). The steam generator secondary pressures initially responded in a symmetrical manner, however, a slight amount of heat transfer occurred in steam generator B that caused the pressures to diverge slightly (See 2, Figure 5.28) as the secondary levels were filled by AFW to 31.6 ft (See 1, Figure 5.32).

Upon flow interruption, the primary system repressurized (See 3, Figure 5.28), hot leg heatup commenced (See 1, Figure 5.33) that eventually established a sufficient amount of driving head, and a ow pulse resulted (See 2, Figure 5.31). The flow pulses that resulted from the hot leg heatups alternated between loops, i.e., the first flow pulse occurred in loop A, the second in loop B, and the third in loop A (See 3, Figure 5.31). The repressurization and the phenomena that occurred d ring the repressurization were similar to those observed during the Mapping Tests and Test 410AT3. In fact, the primary system pressure responses for the first 37 minutes of Tests 410AT3 and 410BD1 are almost identical (See 1, Figure 5.34).

At 30 minutes, the loop operator actuated the 50-psi/min steam generator blowdown control. The control function for the blowdown control began to decay from its initial setpoint (1010 psia); however, both steam generators were at a lower pressure than 1010 psia at this time (See 4, Figure 5.28). Therefore, delays of approximately 3 minutes for steam generator B and 5 minutes for steam generator A were observed prior to the opening of the steam valves and the initiation of the steam generator depressurizations (See 5, Figure 5.28).

A hot leg heatup was in progress when the steam generator blowdown began (See 6, Figure 5.28). The predominant flow path for this heatup was loop A. The blowdown of steam generator B was initiated first and apparently had no effect on the primary system pressure response. The hot leg heatup continued and a flow pulse in loop A caused primary-to-secondary heat transfer (See 7, Figure 5.[illegible] Primary system flow, however, interrupted again (See 4, Figure 5.31), the primary system repressurized (See 8, Figure 5.28), and hot leg heatup commenced (See 2, Figure 5.33).

During the hot leg heatup, both steam generators continued to blow down and no impact was observed on the primary system pressure response (See 8, Figure 5.28). The steam generator secondary side levels decreased during this time (See 2, Figure 5.32) as apparently more secondary side liquid flashed to steam than was being replenished by AFW flow.

The hot leg heatup eventually resulted in the establishment of sufficient driving head to cause primary system flow (See 5, Figure 5.31). At this time, the AFW flow rate exceeded the steam flow rate in both steam generators (See 1, Figures 5.35 and 5.36) and when prim[illegible] loop flow began, primary-to-secondary heat transfer occurred (See 9, Figure 5.28) that resulted in a rapid depressurization of the primary system (See 10, Figure 5.28). The MIST steam valves fully opened; however, the steam generation rates were greater than the flow capacity of the steam lines. Thus, the secondary side pressures increased (See 9, Figure 5.28) and the 50-psi/min blowdown control could not be achieved (See 11, Figure 5.28).

When primary-to-secondary heat transfer was established, the AFW flow rate exceeded the head/flow capacity as the control system attempted to maintain a constant level (the MIST facility was designed to perform in this manner). Therefore, had the AFW head/flow characteristics been adhered to, a reduction in secondary side inventory would have occurred (the extent of the inventory loss cannot be determined as both the steam and AFW flow rates exceeded the range of the instrumentation). The primary system pressure response may be affected by this method of control because if an inventory reduction had occurred, AFW flow would have to be maintained over an extended period, thus increasing the potential for heat transfer and depressurization of the primary system.

Subsequent to the rapid depressurization of the primary system, an oscillatory decreasing pressure response occurred (See 11, Figure 5.28). The oscillatory response resulted from brief periods of heat transfer in steam generator A. During the rapid depressurization and the subsequent depressurizations that occurred in an oscillatory manner, superheated conditions were observed in the downcomer (See 1, Figure 5.37) and cold legs (See 1, Figure 5.38). The rapid depressurization quickly decreases the saturation temperature of the primary system. However, the downcomer metal cannot dissipate its stored energy as rapidly, therefore saturated steam discharged through the reactor vessel vent valves becomes superheated in the downcomer. The superheated steam flows backward in the cold leg, impedes, and eventually interrupts flow. The leak discharge also indicated periods of superheated conditions (See 1, Figure 5.39) and resulted in reduced leak flow rates (See 1, Figure 5.40). The varying leak fluid conditions appear to have caused the oscillatory primary system pressure response.

When a rapid depressurization occurs, the fluid in the primary system is highly susceptible to flashing. During the rapid primary system depressurization and the subsequent minor depressurizations that occurred in an oscillatory manner, the core region fluid flashed as observed by the decrease in the core region collapsed liquid level (See 1, Figure 5.41). Although core uncovery was indicated by the collapsed liquid level, core cooling was maintained as indicated by the core exit temperature, which did not superheat but remained saturated (See 1, Figure 5.42). Flashing was also observed in both loop B cold leg suctions pipes during these depressurizations (e.g., See 1, Figure 5.43).

The primary system pressure decreased to approximately 290 psia (See 1, Figure 5.44), all four cold leg discharge pipes had completely voided (See 1, Figures 5.45 and 5.46), and when the loop B cold leg suction pipes began to void (See 1, Figure 5.47), the primary system repressurized (See 2, Figure 5.44). Since the primary pressure did not decrease to the LPI setpoint, LPI did not actuate during the initial blowdown of Test 410BD1.

During the repressurization, the voiding of the cold leg suction pipes resulted in an increased steam generator primary level as the increased pressure apparently displaced the column of liquid. The hot leg riser level also increased (apparently a manometric balance in a loop). The cold leg suction voiding alternated between loops and caused the hot leg riser and steam generator primary levels to (1) increase in the loop whose cold leg suction voided and (2) decrease in the loop whose cold leg suction did not void (See 1, Figure 5.48). This response continued until the steam generator A primary level descended to the secondary pool elevation (See 2, Figure 5.48). When this descent occurred, the loop A levels stabilized at the secondary pool elevation and the loop B hot leg riser and steam generator primary levels began a continuous descent (See 3, Figure 5.48). During the entire repressurization, steam and AFW flow existed in both steam generators (Figures 5.49 and 5.50) and a condensing surface was available (Figure 5.48), thus indicating that core-generated steam did not flow up the hot legs to the steam generators.

When the levels in loop A descended to the secondary pool elevation, no increase in primary-to-secondary heat transfer was observed. However, when the levels in loop B descended to the secondary pool elevation, primary-to-secondary heat transfer occurred in both loops, as indicated by the increase in AFW and steam flow in both steam generators (See 1, Figures 5.51 and

5.52). The primary system then depressurized (See 3, Figure 5.44), and when the pressure descended to the LPI setpoint (See 4, Figure 5.44), LPI flow was initiated (See 1, Figure 5.53). The rapid depressurization associated with LPI flow also results in the flashing of primary fluid. For Test 410BD1, the core region flashed but the cold leg suction did not flash. This flashing differs from Test 410AT3, where the cold leg suction flashed and was dependent on the secondary side conditions when LPI actuated, i.e., lower secondary side pressure results in colder fluid temperatures in the cold leg suction, therefore, the fluid is more subcooled and less likely to flash.

Subsequent to the LPI actuation, the primary system repressurized in a manner similar to that observed in Test 410AT3. The maximum pressure attained was approximately 625 psia (See 5, Figure 5.44).

The hot leg riser and steam generator primary level response was similar to that observed during the first repressurization, i.e., the loop A levels descended to the secondary pool elevation before the loop B levels (See 1, Figure 5.54). When the loop B levels descended to the secondary pool elevation, primary-to-secondary heat transfer was established and the primary system depressurized (See 6, Figure 5.44).

When the loop operator felt that the primary system pressure was stabilizing, the PORV was actuated (See 7, Figure 5.44) and remained open approximately 14 minutes. The primary system depressurized as a result of the open PORV and LPI actuated (See 8, Figure 5.44). The operator then closed the PORV and the primary system responded in a manner similar to that observed after the first LPI actuation.

The primary system repressurized to approximately 530 psia (See 9, Figure 5.44) and then depressurized when, as observed in the previous similar depressurizations, the level in the loop B steam generator primary descended to the pool elevation (See 2, Figure 5.54). When the loop operator felt that the primary system pressure was stabilizing, the reactor coolant pump in cold leg B1 was bumped (See 10, Figure 5.44). The primary system pressure decreased and LPI actuated for the third time during this transient. The primary system pressure response subsequent to the LPI actuation was similar to the previous occurrences. A second reactor coolant pump bump (A1) was performed (See 11, Figure 5.44); however, little, if any, effect was observed since the test was terminated approximately 2 minutes later.

The duration of Test 410BD1 was 961 minutes. Core power augmentation may have a significant effect on the repressurizations observed during the transient and the test duration. At test termination, the core power augmentation was approximately 50% of the total core power. Through reductions in the core power augmentation, the magnitude of the repressurizations may be reduced and the potential for establishing natural circulation cooldown may be enhanced. See section 6.1 for additional discussion on this subject.

## 5.1. Observations of Test 4100B2

Test 4100B2 had a scaled 100-cm$^2$ leak in the cold leg B1 discharge and employed the simulated high-pressure injection and low-pressure injection emergency core cooling systems.

The primary system depressurized rapidly upon opening the large (100-cm$^2$ scaled) leak (See 1, Figure 5.55). HPI actuated (See 1, Figure 5.56) and AFW actuated, increasing the steam generator secondary side levels to 31.6 ft (See 1, Figure 5.57).

As a result of the rapid depressurization, the core exit fluid quickly attained saturated conditions (See 1, Figure 5.58), the reactor vessel and the downcomer voided with the downcomer level descending to the nozzle elevation (See 1, Figure 5.59), and core-generated steam was discharged into the cold leg discharge pipes, thus voiding the cold legs (See 1, Figures 5.60 and 5.61) and interrupting primary loop flow (See 1, Figure 5.62).

The leak flow rate was approximately 8000 lb/h shortly after the leak was opened (See 2, Figure 5.56). The leak flow rate decreased rapidly (See 3, Figure 5.56) as the primary system depressurized and decreased further when the leak site fluid conditions saturated and then voided (See 4, Figure 5.56).

The steam generator secondary side pressures decreased as the secondary side was filled to 31.6 ft (See 2, Figure 5.55). Upon completion of the secondary side fill, the steam generator pressures stabilized at approximately 650 psia (See 3, Figure 5.55). The primary pressure, however, continued decreasing

(See 4, Figure 5.55) as the leak flow exceeded the HPI flow (See 5, Figure 5.56). The primary system depressurization resulted in the flashing of liquid to steam in the hot leg risers and steam generator primary. The flashing of the liquid resulted in the complete voiding of the hot leg risers (See 1, Figure 5.63) and a collapsed liquid level of approximately 14 ft in the steam generator primary. The voiding of the hot leg risers in conjunction with the pipe metal heat and, potentially, the guard heaters, resulted in superheated conditions over the entire length of the hot legs (See 1, Figures 5.64, 5.65, and 5.66).

The rapid primary side depressurization prevented the ATOG cooldown (100F/h) of the steam generators from becoming effective, i.e., the steam generator control pressure remained above the actual steam generator pressure, therefore the steam valves remained closed. The primary pressure decreased to a value less than the secondary side pressure (See 5, Figure 5.55). At this time, the ATOG steam generator control was placed in the blowdown mode (50 psi/min). However, the ATOG control pressure was still greater than the actual steam generator pressure and a delay of approximately 5 minutes was observed prior to the opening of the steam valves that initiated the blowdown of the secondary sides (See 6, Figure 5.55). This delay resulted in a period of approximately 7 minutes wherein reverse heat transfer, secondary-to-primary, existed (See 7, Figure 5.55).

As the steam generator blowdown commenced, the primary system depressurized at essentially the same rate as the secondary side (See 8, Figure 5.55). This rapid depressurization resulted in the flashing of liquid to steam in the cold leg suction pipes (See 2, Figures 5.60 and 5.61) and in the reactor vessel (See 2, Figure 5.59). Metal heat, apparently from the reactor coolant pumps, resulted in the superheating of fluid in the cold legs (See 1, Figures 5.67 and 5.68). Superheated fluid conditions were also observed in the upper downcomer, but only in quadrant A2 (See 1, Figure 5.69).

The voiding of the lower regions apparently resulted in the displacement of liquid into the hot leg risers and the steam generator primary as indicated by the increase in their levels (See 2, Figure 5.63).

As the primary system pressure decreased, the core flood tank discharged fluid into the primary system (See 1, Figure 5.70), HPI flow eventually exceeded the leak flow (See 6, Figure 5.56), and LPI actuated (See 7, Figure 5.56). These actions resulted in an increase in the primary system inventory (See 1, Figure 5.71).

When LPI actuated, the fluid conditions at the leak site became subcooled and the leak flow rate increased (See 8, Figure 5.56). The summation of the LPI and HPI flow remained greater than the leak flow (See 9, Figure 5.56), and primary system inventory continued to increase (See 2, Figure 5.71). The cold leg suction pipes in both loops remained voided (See 3, Figures 5.60 and 5.61) and did not refill until an intra-cold leg flow pulse occurred. The intra-cold leg flow occurred first in loop A (See 2, Figure 5.62) and occurred approximately 30 minutes later in loop B (See 3, Figure 5.62). The hot leg risers apparently refilled to the U bend spillover elevation (See 3, Figure 5.63), however, sustained natural circulation was not established. The inability of the primary system to establish sustained natural circulation appears to be related to the collapse of the cold leg suction voids (that caused the hot leg levels to descend below the U-bend spillover elevation, See 4, Figure 5.63) and the diminished natural circulation driving head resulting from the termination of core steam production as the core region fluid subcooled (See 2, Figure 5.58).

The subcooling of the core region fluid was a result of the LPI flow rate. The loop operating procedures required throttling HPI (See 10, Figure 5.56) when the core outlet subcooling attained 75F and terminating HPI (See 11, Figure 5.56) when 100F subcooling was attained. The reductions in HPI flow occurred in coincidence with the primary system attaining leak/HPI-LPI equilibrium, and the primary system rate of inventory increase was markedly reduced (See 3, Figure 5.71).

The primary system pressure decreased to approximately 125 psia (See 9, Figure 5.55) and then repressurized to approximately 160 psia (See 10, Figure 5.55) as leak/HPI and/or LPI equilibrium was established. The primary system pressure then remained essentially constant until test termination (See 1, Figure 5.72). The fluid temperature in the hot legs apparently governed the primary system pressure as these temperatures continued near saturation while the remainder of the primary system was generally experiencing a cooling trend.

When the test was terminated (based upon the criteria of the pressure being less than 200 psia for 2 hours), the hot leg A riser and stub was filling while the B levels were essentially constant and lower than those in loop A (See 1, Figure 5.73). Primary loop flow had not been established when the test was terminated.

## 5.5. Observations of Test 4SB011

Test 4SB011 was an SBLOCA accompanied by the loss of all AC power (station blackout). The test simulated reactor coolant pump seal leakage by incorporating a scaled 0.25 $cm^2$ leak in each of the A1 and B2 reactor coolant pumps. High- and low-pressure injection was unavailable and the auxiliary feedwater system capacity was reduced by one-half.

Upon initiation of the transient, the primary system pressure decreased (See 1, Figure 5.74). The loop operator, however, observed that leak flow had not been established (apparently, the leak orifices in reactor coolant pump locations A2 and B1 had plugged). The loop operator closed the valves for leak sites in A2 and B1 and opened the valves for the alternate leak sites in reactor coolant pumps A1 and B2. Leak flow was then observed. Therefore, leak actuation for this test was delayed approximately 7 minutes from test initiation (See 1, Figure 5.75). The delayed leak actuation did not impact the typical phenomena observed during SBLOCA tests.

The steam generator secondary side levels were initially raised to 20.7 ft (See 1, Figure 5.76) according to the procedure using one-half AFW flow capacity. Although the steam flow decreased and eventually ceased (See 1, Figure 5.77), a sufficient amount of primary-to-secondary heat transfer occurred during the refill to maintain the steam generator secondary pressures near the control setpoint of 1010 psia (See 2, Figure 5.74). The refill of the secondary side also increased the loop driving head and a slight increase in the cold leg flow rates over the initial steady-state values was observed (See 1, Figure 5.78). The primary loop flow rates then remained nearly constant during the refill to 20.7 ft (See 2, Figure 5.78). When the level attained 20.7 ft (See 2, Figure 5.76), AFW was terminated (See 2, Figure 5.77). Primary-to-secondary heat transfer continued, steam and AFW flow were re-established (See 3, Figure 5.77), and the primary loop flow rate essentially stabilized at a steady-state value that was less than the initial steady-state flow rate (See 3, Figure 5.78). The decreased primary loop flow rate was a direct result of the decaying core power as a function of time, i.e., lower core power resulted in lower natural circulation flow rates.

The primary system continued to lose inventory and depressurized (See 3, Figure 5.74). The depressurization resulted in a decrease in the saturation temperature and when the core exit temperature attained 20F subcooled, the loop operator (as per the procedures) increased the secondary side level of the steam generators to 31.6 ft (See 3, Figure 5.76). The primary system flow rate responded in a manner identical to the increased AFW flow (See 4, Figure 5.78) as was observed during the level increase to 20.7 ft. The primary system flow rate response highlighted the significance of the AFW for establishing natural circulation driving head, whereas the difference in the secondary pool level had little, if any, effect on the natural circulation driving head.

The continued loss of inventory resulted in the voiding of the reactor vessel upper head region (See 1, Figure 5.79) and a continued depressurization until the fluid temperature at the core exit saturated (See 4, Figure 5.74). A gradual repressurization then commenced (See 5, Figure 5.74).

During this repressurization, the primary system continued to lose inventory (See 1, Figure 5.80), the reactor vessel and the downcomer levels continued to void (See 2, Figure 5.79), and the characteristic reactor vessel vent valve cycling occurred as the pressure equalized between the reactor vessel and the downcomer (See 1, Figure 5.81). The cyclical behavior of the reactor vessel vent valve was similar to that observed during the MIST Phase III Mapping Tests.

As the downcomer voided, the increased back pressure at the cold leg nozzle affected the primary loop flow rate as observed by the gradual decrease in the cold leg flow rates (See 5, Figure 5.78). As the level in the downcomer approached the cold leg nozzle elevation, backflow began to occur in the cold leg discharge pipe. When the level in the downcomer descended to the cold leg nozzle elevation, steam was discharged into the cold leg discharge pipes and intra-cold leg flow was established (See 6, Figure 5.78). Cold legs A1 and B1 flowed backward while cold legs A2 and B2 flowed forward.

Subsequently, flow interrupted in each cold leg in a sequential manner (B1, A1, then A2 and B2 interrupted simultaneously). The response observed during the voiding of the downcomer is also similar to the response observed during the Phase III Mapping Tests.

During the voiding of the downcomer (discussed above) and prior to complete flow interruption, the primary loop flow goes through periods of intermittent flow, alternating from one loop and then the other loop (See 7, Figure 5.78). The loop operator, according to the test procedure, was to establish a scaled 125-gpm AFW flow rate and set the steam valve position upon loop flow interruption. The loop operator had difficulty determining loop flow interruption during this period of intermittent alternating loop flow. When the loop operator determined that the flow interruption criteria had been met in loop A, he performed the necessary actions for steam generator A. At this time, the steam flow was less than the specified AFW flow rate and steam generator A secondary side level began to increase (See 4, Figure 5.76). Approximately 20 minutes later, the loop operator determined that flow interruption also occurred in loop B. He performed the prescribed actions and steam generator B secondary side level began to increase (See 5, Figure 5.76).

Subsequent to performing the prescribed actions on steam generator A and prior to the operator performing them on steam generator B, the primary system repressurized (See 6, Figure 5.74) and a hot leg heatup commenced. The steam generator secondary sides depressurized (See 7, Figure 5.74) as a combined result of the lack of primary-to-secondary heat transfer and the AFW flow rate exceeding the steam flow rate.

The hot leg heatup eventually resulted in sufficient driving head and a flow pulse occurred in both loops (See 8, Figure 5.78). In response to the flow pulse, the primary system depressurized rapidly (See 8, Figure 5.74), the voids in the cold leg discharge pipes collapsed (See 1, Figure 5.82), the reactor vessel and downcomer levels increased (See 3, Figure 5.79), and primary-to-secondary heat transfer was established in both steam generators (See 9, Figure 5.74).

The flow pulse resulted in a different fluid density distribution around the loops that was unable to provide a sufficient amount of driving head and flow interrupted (See 9, Figure 5.78). Lower region voiding and hot leg heatup then commenced. Three more occurrences of the phenomena associated with flow pulses were observed (See 10, Figure 5.78) that resulted in loop flow in loop B for the first flow pulse, loop A for the second, and both loops for the third.

During this time, both steam generator secondary side levels continued increasing (See 6, Figure 5.76) as a result of the integrated AFW flow rate exceeding the integrated steam flow rate. Since the steam valve position was fixed, according to procedure, the maximum steam flow rate was limited. When the secondary side level became relatively full (See 7, Figure 5.76) and a flow pulse occurred in loop A (See 11, Figure 5.78), primary-to-secondary heat transfer was established. The fixed steam valve position did not permit a sufficient amount of flow to be discharged from the steam generator and a steam generator A secondary side pressure excursion occurred (See 10, Figure 5.74). The pressure excursion was of sufficient magnitude that the facility design limit for the steam generator was exceeded.

The loop operator then anticipated the next flow pulse, and when it occurred, he manually opened (fully open) steam valve A. The pressure excursion in steam generator A again exceeded the facility design limit (as indicated by the entry in the operator's log book). Steam generator B also experienced a secondary side pressure excursion at this time (See 11, Figure 5.74). The loop operator then terminated the test before causing any physical damage to the test facility.

### 5.6. Observations for the Steady-State Tests Using Main Feedwater of Test 4SGPF2

A series of tests was performed to provide steady-state steam generator performance data using main feedwater. The tests were conducted at various steam generator secondary levels with the primary system in a subcooled natural circulation condition.

The steady-state tests that used main feedwater (MFW) were performed at steam generator secondary levels of approximately 19, 26, 33, and 40 ft. MFW at approximately 450F was supplied to the simulated steam generator downcomer. The simulated aspiration ports (at elevation 32 ft) provided fluid from the steam generator tube bundle region that mixed with the MFW, thus preheating the fluid in the steam generator downcomer. The preheated fluid in the steam generator downcomer then enters the steam generator tube bundle region approximately 0.5 ft above the lower tubesheet. For the steady-state tests that were conducted with secondary levels at 19, 26, and 33 ft, the fluid conditions in the tube bundle at the simulated aspirator port elevation were either superheated or saturated steam. The mixing of the fluid passing through the aspirator line with the MFW resulted in the preheating of the MFW to a saturated condition. Thus, the entire tube bundle length was devoted to boiling and superheating the MFW.

For the MFW tests with the secondary levels at 19, 26, and 33 ft, the lower region of the steam generator contained saturated liquid. Thus, the steam generator primary outlet temperature remained essentially constant and was equivalent to the secondary side saturation temperature.

The steady-state MFW test that was conducted with the steam generator secondary level at approximately 40 ft resulted in the aspirator port elevation being covered by either saturated liquid or by lower quality steam than occurred for the other MFW tests. The result was that the mixing of the fluid passing through the aspirator line with the main feedwater was not capable of maintaining a saturated fluid condition at the MFW injection location. The MFW temperature at the injection location was approximately 10F subcooled. Therefore, the steady-state MFW test with the steam generator level at approximately 40 ft differed from the other MFW tests in that a portion of the tube bundle length was devoted to raising the MFW temperature to saturation, thus decreasing the boiling and superheating lengths. The subcooled pool also increased the driving head on the primary side; thus, direct comparisons of this test with the other three MFW tests must account for the differences imposed on the secondary side fluid conditions when the level covers the aspiration port elevation.

The core power level and the primary and secondary pressures were maintained essentially constant for each MFW steady-state test. Thus, the variations in the secondary levels resulted in significant variations in primary loop flow rate and corresponding variations in the core outlet temperature. The variation in the primary loop flow rates and core exit temperature versus the steam generator secondary level for the steady-state tests using MFW is shown on Figure 5.83. As expected, the primary loop flow rate increased as the steam generator secondary level increased, due to the increased driving head, and the core exit temperature decreased as primary loop flow increased. An approximately 175-lb/h difference in the loop A and B flow rate was also observed, with the loop B flow always being greater.

For steam generator B, the results from the MFW steady-state tests indicate that the primary fluid axial temperature distributions between the steam generator tubes are essentially equal over the entire tube length (Figures 5.84 through 5.87). A comparison of the steam generator secondary side axial fluid temperature distribution also indicated similar temperatures independent of cell location (Figures 5.84 through 5.87). The uniformity of the primary and secondary axial temperature distributions independent of either tube or cell location (See Figure 5.88 for tube and cell locations) implies that the primary loop flow rate was essentially equally distributed among the 19 tubes within the steam generator.

The output of the pitot tubes indicated similar flow rates (Figures 5.89 through 5.92) in the five instrumented tubes (the instrumented tubes traversed the cross section of steam generator B and were located in tubes J, C, A, F, and R). However, the magnitude of the pitot tube measured flow rates appears excessively high (by a factor of 1.5), if it is assumed that the flow rate in each tube is equal, when compared to the loop flow rate obtained from the cold leg venturi meters.

The MFW steady-state tests also showed that essentially symmetrical performance was obtained in both steam generators. Although the instrumentation in steam generator A was limited, a comparison of the primary and secondary fluid axial temperature distributions indicates similar results for both steam generator A and B (Figures 5.93 through 5.96).

The following observations can also be made regarding the MFW steady-state tests:

- Secondary side axial temperature distributions are well defined with regard to subcooled, saturated, and superheated regions (Figure 5.87).
- The four steam line (two steam lines per steam generator) temperatures were essentially equal (Figure 5.97).

- The steam temperature varies with the steam generator secondary level. The lowest steam generator secondary level resulted in the highest steam temperature (Figure 5.97).

- The MFW steady-state tests performed with the steam generator secondary levels at approximately 19 and 26 ft resulted in secondary side cell and steam line temperatures that were approximately equal to the steam generator primary fluid inlet temperature (Figures 5.84 and 5.85). Both of these tests have an excess of tube length devoted to superheating the secondary fluid. Therefore, essentially no heat transfer occurs in the upper region of the steam generators.

- The MFW steady-state tests performed with the steam generator levels at approximately 33 and 40 ft resulted in secondary side cell and steam line temperatures that were lower than the steam generator primary fluid inlet temperature (Figures 5.86 and 5.87).

- The primary loop natural circulation driving head for the MFW steady-state tests was provided strictly by the steam generator secondary level. A difference of approximately 1500 lb/h in the primary loop flow was observed for the approximately 20-ft variation in the secondary level (Figure 5.83).

## 5.7. Observations for the Steady-State Tests Using Auxiliary Feedwater of Test 4SGPF2

A series of tests was performed to provide steady-state steam generator performance data using auxiliary feedwater. The tests were conducted at various steam generator secondary levels with the primary system in a subcooled natural circulation condition.

The steady-state tests that used auxiliary feedwater were performed at steam generator secondary levels of approximately 19, 26, 33, and 40 ft. AFW at approximately 120F was injected into the steam generator through the minimum wetting nozzle. The elevation of the injection location was approximately 50.8 ft (1 ft 3 in. below the upper tubesheet), and the orientation of the steam generator tube bundle to the nozzle is shown on Figure 5.88.

The core power level and the primary and secondary pressures were maintained essentially constant for each AFW steady-state test. The variations in the secondary levels resulted in slight variations in primary loop flow rate and corresponding slight variations in the core exit temperature (Figure 5.98).

The results obtained from the AFW steady-state tests indicated that the primary loop flow rates are relatively independent of the steam generator secondary level. The injection of cold auxiliary feedwater near the top of the steam generator resulted in essentially a constant driving head that yielded an almost constant primary loop flow rate and core exit temperature (the maximum difference in primary loop flow between the maximum and minimum steam generator secondary levels tested was approximately 400 lb/h and the corresponding difference in the core exit temperature was approximately 4F (Figure 5.98). As observed during the MFW tests, a difference in the loop A and B flow rates was also observed for the AFW tests. The loop B flow rate was approximately 125 lb/h greater than the loop A flow rate.

Since steam generator B was instrumented to a greater extent than steam generator A, the following discussion of the observations was based on the instrumentation in steam generator B. However, note that for tubes J and R, the axial temperature profile on the primary side was very similar for both steam generators. Therefore, both steam generators appear to have operated in a symmetrical manner.

The results from the AFW steady-state tests indicate that the primary fluid axial temperature distributions between the steam generator tubes are not equal (Figures 5.99 through 5.102) and are dependent upon their relative location with respect to the AFW nozzle (Figure 5.88). For these tests, the lowest observed primary fluid temperature occurred in the "J" tube, the tube closest to the AFW nozzle. The central tube, "A," was also affected by the AFW injection. The primary fluid temperature in tube A was greater than that observed in tube J over approximately the uppermost 8 ft of tube length. Below this elevation, the primary fluid temperatures in tubes A and J were essentially equal. The farthest tube from the AFW nozzle, tube "R," exhibited the least effect on the primary fluid temperature.

The steam generator secondary side axial fluid temperature distribution was also affected by the injection of AFW (Figures 5.99 through 5.102). The fluid temperature in cell A-B-C, near the center tube (A), consistently exhibited the greatest amount of subcooling. A possible expectation could be that the fluid temperature in cell B-J-H, near the AFW nozzle, should indicate the greatest amount of subcooling. However, the velocity of the AFW as it entered the tube bundle resulted in a greater penetration depth of the AFW. The greater penetration depth in conjunction with the relative difference in the elevation of the AFW nozzle and the thermocouples resulted in a higher indicated subcooling in the cell near the center tube, cell A-B-G. It is believed that if the thermocouples were located at a higher elevation so that all the cell thermocouples were in the AFW flow stream, the maximum subcooling would occur in the cell nearest the AFW nozzle, and the subcooling would decrease as the AFW traversed the tube bundle. Similarly, reduced AFW flow rates would decrease the penetration depth and the indicated subcooling in the cells at the instrumented elevation would also exhibit a similar response, i.e., maximum subcooling occurs in the cell nearest the AFW nozzle and decreases as the tube bundle is traversed. This response can be observed by examining the cell temperature responses during the transition period between the MFW and the AFW steady-state tests with the steam generator level at approximately 40 ft. During this time, AFW was initiated and gradually increased, Figure 5.103. The observed cell temperature responses (Figures 5.104 and 5.105) are representative of the previously discussed explanation regarding the indicated subcooling in the cells.

The response of the thermocouple S2TC47 in the A-B-G cell at 50.5 ft indicates that a relatively localized subcooled region exists and that this region is rather unstable; subcooling varies from approximately 35 to 89F (See 1, Figure 5.105). At an elevation of 50 ft, the fluid temperature in the A-B-G cell (S2TC44) stabilized but the subcooling decreased to approximately 5F (See 2, Figure 5.105).

The variations observed in the primary fluid temperature between tubes implies that the flow rate through the tubes was not uniform. The tubes that experienced the least effect of the AFW, tubes farthest removed from the AFW nozzle, would also have the least flow. The tubes that experienced the greatest effect of the AFW, those nearest the AFW nozzle, would have the greatest flow. The results obtained from the pitot tubes confirm that variations in tube flow rates existed, Figures 5.106 through 5.109. The tube farthest from the AFW nozzle (R) consistently exhibited the lowest indicated flow rate, while the tube closest to the AFW nozzle (J) consistently exhibited the highest indicated flow rate. The indicated flow rates in tubes J, C, and A showed that essentially the same flow rate existed in these tubes. The magnitude of the pitot tube indicated flow rate appears high (as observed in the MFW steady-state tests where the results showed that the indicated flow ra[illegible]gh by a factor of 1.5). If it is assumed that the indicated pitot tube flow rates are high by 50%, a flow distribution between the tubes can be determined that yields very good agreement with the measured venturi flow rates for each AFW steady-state test. The tube flow distribution that resulted in the best agreement was

Six tubes have a flow rate equal to the flow rate of tube J.

Eight tubes have a flow rate equal to the flow rate of tube F.

Five tubes have a flow rate equal to the flow rate of tube R.

This proposed flow distribution is shown on Figure 5.110. Steam generator A had thermocouples in tube N. The axial temperature profile on the primary side for tube N was similar to that for tube R. Therefore, the flow rate in tubes N and R should be similar, thus providing additional justification for the proposed flow distribution.

The pitot tube results also indicated that the flow rate in the tubes farthest from the AFW nozzle (tubes F and R) were affected by the steam generator secondary level. As the steam generator secondary level increased, the flow in these tubes increased (Figure 5.111), thus indicating that the driving head for these tubes was directly related to the steam generator secondary level. The flow rate in the tubes nearest the AFW nozzle (tubes J, C, and A), however, responded inversely to the steam generator secondary level, i.e., as the level increased, the flow rate in these tubes decreased (Figure 5.111).

The following observations can also be made regarding the AFW steady-state tests:

- Axial temperature profiles in the steam generator A tubes were similar to those observed in the steam generator B tubes (Figures 5.112 through 5.115), therefore exhibiting symmetric steam generator performance.

- For the test conditions investigated, the effect of AFW was observed on the center tube (tube A). Therefore, the AFW penetrated at least three rows into the tube bundle.

- The primary fluid temperature versus elevation in both tubes J and A was essentially independent of the steam generator secondary level (Figures 5.99 through 5.102).

- The secondary fluid temperatures in the cell near tube J (cell B-J-H) were either subcooled (near the AFW nozzle elevation) or saturated over the entire tube length for the AFW steady-state tests that had a steam generator secondary side level equal to or greater than approximately 26 ft (Figures 5.99 through 5.101). For the test performed at a steam generator secondary level of approximately 19 ft, an unstable thermocouple reading was observed at 29.3 ft (Figure 5.116), with the temperature varying from saturation to approximately 5F superheat.

- Based upon the available steam generator secondary side thermocouples, the fluid temperatures in the cell near tube A (cell A-B-G) were either subcooled (near the AFW nozzle elevation) or saturated over the entire tube length for the AFW steady-state test with the steam generator secondary level at 40 ft (Figure 5.99). For the test performed with the steam generator secondary level at 33 ft, an unstable thermocouple reading was observed at 38.2 ft (Figure 5.117) and for the tests performed with the steam generator secondary level at 26 and 19 ft, unstable thermocouple readings were observed at both 38.2 and 32.2 ft (Figures 5.118 through 5.121).

- The secondary fluid temperature in the cell near tube R (cell E-P-R) appears to be affected only slightly near the AFW nozzle elevation, and saturation temperature was not attained over the portion of the tube that was above the steam generator secondary level for all the AFW steady-state tests (Figures 5.99 through 5.102). No unstable thermocouple readings were observed in the E-P-R cell.

- The occurrence of the unstable thermocouple readings in the B-J-H and A-B-G cells and non-occurrence in the E-P-R cell implies that the unstable temperature was a result of the effect of AFW and not level swell of the steam generator pool. Therefore, for the core power level and the AFW flow rate tested, the effects of AFW were observed down to the 29-ft elevation in cell B-J-H and down to the 32.2-ft elevation in cell A-B-G.

- A reheat of the secondary fluid occurs above the AFW nozzle elevations as the steam line temperatures (elevation 51.6 ft) are greater than the temperature of the secondary fluid at or below the AFW nozzle (elevation 50.8 ft) (Figures 5.99 through 5.102).

- The steam temperature remained essentially constant for all steam generator secondary levels tested. However, a variation of 4F between the two steam line temperatures in the same steam generator was observed to occur in both steam generators. The steam line that was farthest away from the AFW nozzle indicated the lowest temperature (Figure 5.97).

- The injection of relatively cold AFW at a high elevation in the steam generator resulted in the establishment of a driving head that provided primary loop flow rates in excess of those obtained from the MFW steady-state tests over the entire range of steam generator secondary levels investigated (Figure 5.122).

## 5.8. Observations of Test 4CR3T2

Test 4CR3T2 was an attempt at simulating the Crystal River Unit 3 (CR-3) loss-of-offsite power event that occurred on June 16, 1981. The CR-3 plant transient was selected because no hardware or control modifications to the MIST facility were required and documentation (reference 7) existed from which test boundary conditions could be established.

Numerous MIST loop operator actions were required in attempting to simulate the plant transient. These actions resulted from the interpretation of the actions performed by the plant operators during the actual plant transient as identified in reference 7.

A direct assessment of the ability of the MIST facility to simulate a plant transient cannot be made from the results of Test 4CR3T2. The response of this test differed significantly from the response of the plant transient (figures included in Section 3.7, Test Specifications, depict the actual plant transient response and can be used for comparative purposes). The different response of this test from that of the plant transient can be attributed to differences in the boundary conditions. The major boundary condition differences that were identified were the HPI flow rate, AFW flow rate, and the steam generator secondary pressure. The observations described in this section address the test as it was performed.

MIST Test 4CR3T2 was initiated by activating the core power decay heat ramp (See 1, Figure 5.123), thus simulating a reactor trip as a result of a loss of offsite power. Full head flow AFW was initiated to steam generator A (See 1, Figure 5.124) to fill the secondary side to 32 ft, and steam generator B was set to maintain constant level control at approximately 10 ft (See 1, Figure 5.125). The steam valves for both steam generators were opened to simulate the turbine bypass system and the atmospheric dump valves. Both steam generators began steaming (See 2, Figure 5.124 and See 1, Figure 5.126) and AFW actuated in steam generator B (See 2, Figure 5.126) in either an attempt to maintain a constant level or establish an increased control setpoint (as specified based upon primary pressure). The steam flow rate exceeded the AFW flow rate in steam generator A (See 3, Figure 5.124); thus, the desired refill of steam generator A was not attained (See 2, Figure

5.125). AFW flow to steam generator B terminated (See 3, Figure 5.126) when the loop operator reduced the level control setpoint to 9.5 ft (as specified based upon primary pressure).

The primary system pressure decreased initially as a result of a decrease in core power and then as a result of primary-to-secondary heat transfer (See 1, Figure 5.127). During the initial primary system depressurization, the loop operator initiated HPI based upon a specified criteria of either absolute pressure or timing. At approximately 1 minute after test initiation, the loop operator actuated, as specified based upon primary pressure, the simulated one HPI pump (See 1, Figure 5.128). At approximately 4 minutes after test initiation, the loop operator actuated, based upon the timing criteria, two simulated HPI pumps (See 2, Figure 5.128). During this time, the primary system depressurized to approximately 1725 psia (See 2, Figure 5.127) and both steam generators depressurized (See 3, Figure 5.127).

Subsequent to the start of the simulated second HPI pump, the rate at which inventory was added to the primary system increased (See 1, Figure 5.129), the pressurizer level began to increase (See 1, Figure 5.130), and a primary system repressurization commenced (See 4, Figure 5.127). Both steam generators continued to depressurize and at approximately 7 minutes, the pressure had decreased to approximately 600 psia (See 5, Figure 5.127). As according to the test procedures, the secondary pressure was to be controlled at 600 psia for the remainder of the test to avoid the facility limit on primary-to-secondary pressure differential.

The simulated two HPI pumps inventory addition to the primary system continued until approximately 15.4 minutes (See 3, Figure 5.128), at which time the flow rate was decreased to a simulation of one HPI pump (as specified based upon primary pressure). The simulation of one HPI pump continued through the remainder of the test.

The steam generator secondary levels increased to approximately 25 ft in both generators (See 3, Figure 5.125), and the steam generator level control setpoint was reduced to 20.7 ft (as specified based upon primary pressure). Both steam generator levels eventually decreased to the control setpoint (See 4, Figure 5.125) and were maintained through the remainder of the test.

The primary system pressure continued to increase, and when the primary-to-secondary pressure difference approached the facility limit, the loop operator manually opened the PORV (See 1, Figure 5.131). The primary pressure decreased (See 6, Figure 5.127) in response to the discharge of steam through the PORV.

The continued addition of inventory to the primary system by means of the one HPI pump simulation resulted in numerous automatic PORV actuations (See 2, Figure 5.131) and the complete refill of the pressurizer (See 2, Figure 5.130). Subsequent to the complete refill of the pressurizer, the primary system stabilized in a steady-state natural circulation mode at approximately 2400 psia, with inventory addition from the one HPI pump simulation and inventory discharge through the PORV. The test was terminated at 225 minutes.

5.9. Observations of Test 4SEC02

Test 4SEC02 was an attempt at simulating the Rancho Seco loss of integrated control system (ICS) power event of December 26, 1985. The Rancho Seco plant transient was selected because no hardware or control modifications to the MIST facility were required and documentation (reference 12) existed from which test boundary conditions could be established.

Numerous MIST loop operator actions were required in attempting to simulate the plant transient. These actions resulted from the interpretation of the actions performed by the plant operators during the actual plant transient as identified in reference 12.

A direct assessment of the ability of the MIST facility to simulate a plant transient cannot be made from the results of Test 4SEC02. The response of this test differed significantly from the response of the plant transient (figures included in Section 3.8, Test Specifications, depict the actual plant transient response and can be used for comparative purposes). The different response of this test from that of the plant transient appears to have occurred immediately after test initiation and appears to be attributable to differences in the secondary side boundary conditions. The boundary conditions that appear to have affected the transient response were:

- The MIST simulation of the plant safety valves.

- Reduced AFW flow rate in steam generator A.

- The MIST simulation of the atmospheric dump valves and turbine bypass valves.

The simulation of the plant safety valves appears to have resulted in a choked flow condition downstream of the flow control valve and, as such, the steam relief capacity was less than desired. The AFW flow rate for steam generator A was approximately 57% of the desired flow during the entire test duration and was a result of an erroneous evaluation of the AFW controller setpoints. The design of the MIST steam lines resulted in an interaction between the simulated plant safety valves and the simulation of the atmospheric dump valves and turbine bypass valves. The result was a reduced flow rate through the simulated atmospheric dump valves and turbine bypass valves.

These discrepancies affected the secondary side heat removal capability, which provided less than that desired, and resulted in a primary system pressure response that was of considerably higher magnitude than observed during the plant transient.

The observations described in this section address the test as it was performed and no attempt was made to verify the specified boundary conditions during the remainder of the test.

MIST Test `FCO2 was initiated by the loop operators manually performing the following ac..ons at essentially the same time:

- Fully open the simulated plant safety valve steam lines (high flow steam lines) for both steam generators.

- Increase the speed of all four reactor coolant pumps from 10% to 100% speed.

- Ac'uate the core power decay ramp.

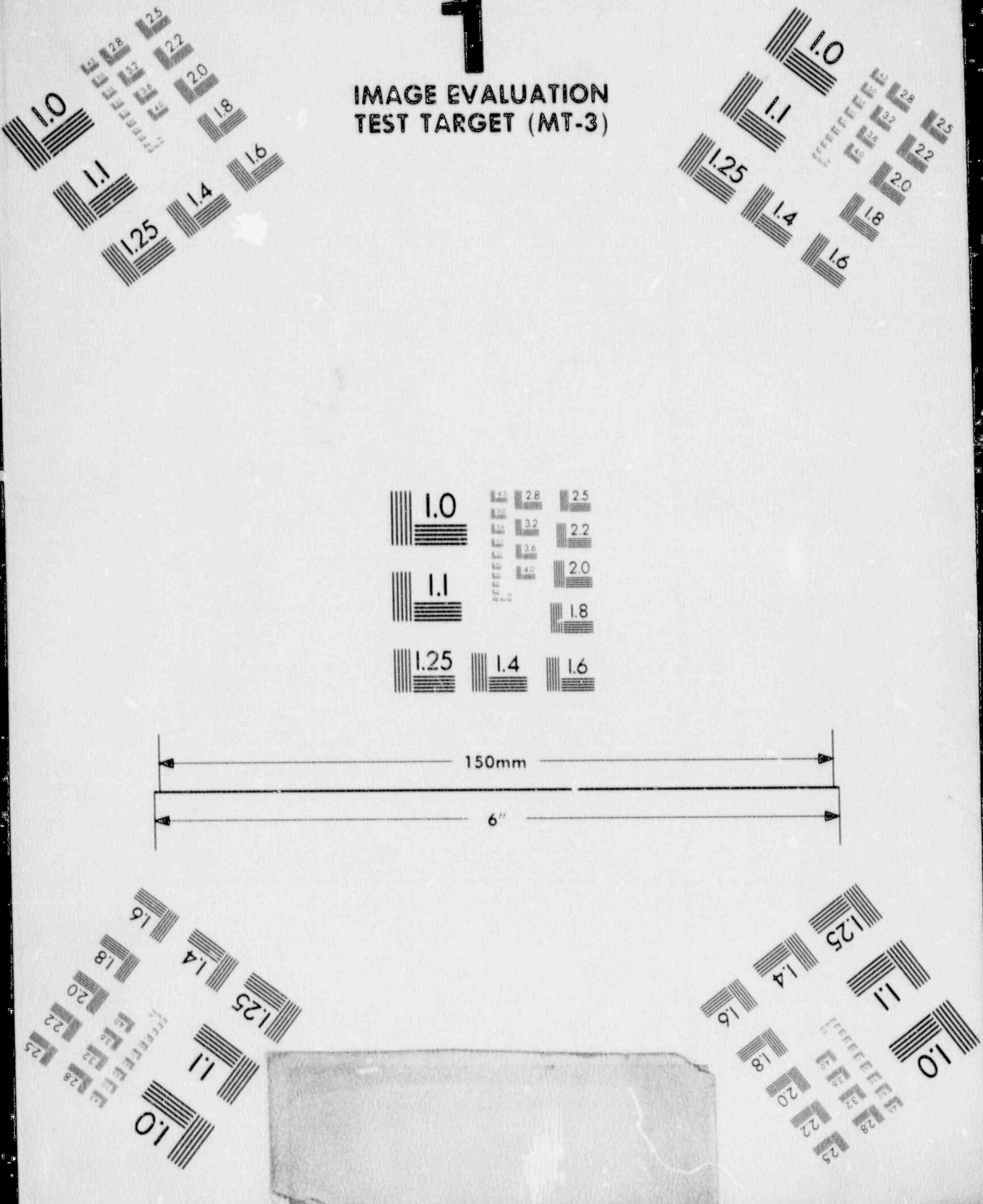
- Start AFW flow to both steam generators.

- Terminate main feedwater (MFW) flow to both steam generators.

- For each steam generator, open the control valve for the low flow steam lines to a predetermined position that simulates the flow capacity of the turbine bypass system and the atmospheric dump valves.

# 1

## IMAGE EVALUATION TEST TARGET (MT-3)



The initiating actions were performed as intended and were verified by the data plots. The limit switches for the high flow steam circuits indicated that the control valves opened upon test initiation (See 1 on Figures 5.132 and 5.133). The reactor coolant pump tachometers indicated that the speed of each pump increased from approximately 10% to 100% shortly after test initiation (See 1, Figure 5.134). The core power decay ramp began upon test initiation (See 1, Figure 5.135). AFW was actuated upon test initiation (See 1 on Figures 5.136 and 5.137) and MFW was terminated (See 2 on Figures 5.136 and 5.137) upon test initiation. Although no positive indication exists for the action relative to the increased opening of the control valves in the low flow steam circuits, the observed increased magnitude of the steam flow (See 3 on Figures 5.136 and 5.137) indicates that the control valves had been opened further prior to approximately 1.5 minutes; therefore, the numerous operator actions required to initiate Test 4SEC02 were performed satisfactorily.

In addition to the initiating operator actions discussed above, the loop operators were required to open one isolation valve in each high flow steam line. These are hand-operated valves that were required to be closed, as a result of excess leakage through the control valves, and were opened prior to performing the required initiating actions.

On test initiation, the primary system pressure decreased rapidly from 2220 to 2035 psia (See 1, Figure 5.138). The primary system then rapidly repressurized to approximately 2100 psia (See 2, Figure 5.138) before beginning a gradual depressurization that attained a minimum of approximately 1780 psia (See 3, Figure 5.138). Upon test initiation, the steam generators repressurized in an asymmetrical manner (See 4, Figure 5.138). The observed asymmetry appears to be a result of opening the control valves either at slightly different times or they may have different stroke rates. The pressure in both steam generators then converged and a gradual depressurization commenced, attaining a minimum pressure of approximately 500 psia (See 5, Figure 5.138).

The Rancho Seco transient of December 26, 1985 resulted in a depressurization of the primary system that attained a minimum pressure of approximately 1050 psig about 8 minutes after the transient occurred. During this period, the steam generator pressures had decreased to approximately 400 psig; therefore, the initial response of MIST Test 4SEC02 did not replicate the Rancho Seco transient.

Based upon a comparison of the primary and secondary system pressure response for the test and the plant transient, the design and physical arrangement of the MIST steam circuits appear to have affected the desired boundary conditions. The steam circuits appear to have limited the steam flow rate and as a result, primary-to-secondary heat transfer was limited. The limited flow capability of the MIST secondary side was first observed during the initial phase of the transient when the steam safety valves were simulated. During the time when the safety valves were open, the simulation of the turbine bypass valves (TBVs) and the atmospheric dump valves (ADVs) opening to 50% capacity was to occur. The loop operators opened the control valves to the predetermined positions on the high flow steam circuits (simulated safety valves) and the low flow steam circuits (simulated 50% capacity of ADVs and TBVs). The low flow steam circuit had been in use during the steady-state period prior to test initiation, and at test initiation, the loop operators opened the control valves further. An expected increase in the steam flow through the low flow steam circuit did not occur. Instead, the steam flow rate decreased on test initiation (See 4 on Figures 5.136 and 5.137) and then increased (See 5 on Figures 5.136 and 5.137) approximately 1.3 minutes after test initiation.

A schematic of the steam flow circuits is shown on Figure 5.139. The low flow circuit contains a flow orifice and a control valve. The high flow circuit contains only a control valve and has no flow orifice or provisions for flow measurement. The piping for the high flow and the low flow steam circuits join together downstream of the control valves. When the control valve in the high flow steam circuit was opened, the backpressure at the control valve in the low flow steam circuit increased. The backpressure on the low flow steam circuit was apparently higher than the critical pressure and therefore a reduction in the flow rate was observed (See 4 on Figures 5.136 and 5.137). When the control valve in the high flow steam circuit was closed, the backpressure at the control valve in the low flow steam circuit decreased. The decreased backpressure permitted the re-establishment of critical flow through the low flow steam circuit; thus, an increase in the flow rate was observed (See 5 on Figures 5.136 and 5.137). Therefore, even though the loop operators further opened the control valves in the low flow steam circuits, a reduction in the flow rate (approximately 20% of the intended flow rate) through this steam circuit occurred. Thus, during the initial approximately 1.3 minutes of the test, the simulation of the steam discharged through the ADVs and TBVs did not occur. The reduced flow rate through the low flow steam circuits contributed to the observed difference in the steam generator pressure between the test and the plant transient.

Although no flow measurement was available for the high flow steam circuit (simulated safety valves), the steam flow was also suspected to be limited by an unanticipated high backpressure that was provided to the steam circuit by the condensate backpressure control valve in the secondary circuit. The high backpressure may have limited the steam flow, thus preventing the desired initial steam generator blowdown from being achieved.

When the simulated safety valves closed, the steam generator pressure for Test 4SEC02 was approximately 50 psi greater than that observed during the plant transient. As the test progressed, the steam generator pressure continued to diverge from that observed during the plant transient and at approximately 8 minutes, resulted in a steam generator pressure that was approximately 280 psi greater than observed during the plant transient. Thus, the continued divergence of the steam generator pressure for the plant transient and the test implies that the secondary side boundary conditions for the MIST test, subsequent to the closure of the simulated safety valves, did not replicate those that occurred during the plant transient.

Another factor that contributed to this observed difference in the steam generator pressure was the less-than-desired AFW flow rate supplied to steam generator A. Due to an erroneous evaluation of the controller setpoints, only approximately 57% of the desired AFW flow rate was supplied to steam generator A throughout the entire test. A comparison of the AFW flow rate for both steam generators over the initial 8 minutes of the test (Figure 5.140) highlights this discrepancy in the AFW flow rates.

Potentially, a fourth factor may have limited the steam generator depressurization rate for the MIST test. This factor also relates to the design and physical arrangement of the steam circuits and concerns the combining of the steam lines from steam generator A with those of steam generator B (Figure 5.139). This arrangement has the potential for imposing a backpressure effect of one steam generator on the other and can occur throughout the entire test.

The inability of the MIST facility to simulate the plant transient secondary side response could be a result of the following factors:

- The MIST simulation of the safety valves may not have provided sufficient steam flow to simulate the actual plant steam flow.
- Interaction of the MIST high flow and low flow steam circuits.
- Interactions between the MIST steam generator A and steam generator B steam circuits.
- A steam generator A AFW flow rate that was less than desired for the MIST test.
- The MIST simulation of the ADVs and TBVs may not provide sufficient steam flow to simulate the actual plant steam flow.
- When the ICS power was lost during the plant transient, the ADVs and the TBVs are supposed to open to 50% of demand. These valves may have opened further; thus, the steam flow may have been greater than that expected when the control valves are 50% open.
- The Rancho Seco plant had three ADVs per steam generator. Each valve has the steam-relieving capability of 3-1/2% full power. Four of these valves are normally isolated to prevent a rapid cooldown should the ICS experience certain single failures. These failures would have opened all the TBVs and ADVs. If the loss of ICS power opened all six of the ADVs to the 50% demand position, the steaming capability would have been 20% steam dump capacity rather than 14% if only two ADVs opened.
- A combination of the factors listed above.

As the primary system pressure decreased to approximately 2036 psia, the loop operator actuated HPI (See 1, Figure 5.141) according to the test procedure. The HPI flow was to be equivalent to 38% of full head-flow capacity. As can be observed on the figure, the measured HPI flow rate was initially very unstable (See 2, Figure 5.141) and then stabilized at approximately 38% of full head-flow (See 3, Figure 5.141). As the primary system continued to depressurize to approximately 1936 psia, the loop operators increased the HPI flow rate, per the test procedure, to approximately 68% of full head-flow (See 4, Figure 5.141). Again, the HPI flow rate was very unstable subsequent to the change in the control setting (See 5, Figure 5.141) and then stabilized at approximately 68% of full head-flow (See 6, Figure 5.141). The unstable response in the HPI flow rate occurred throughout the entire test whenever a change (either an increase or a decrease) in the HPI flow rate was made (Figure 5.142), and in many cases, required loop operator intervention to stabilize the HPI flow rate. This unstable response in the HPI flow rate highlights the need to investigate the MIST HPI system, controls, and flow measurement instrumentation, particularly if the MIST facility is to be used to simulate plant transients that have numerous changes in the HPI flow rate.

As the test progressed, the primary system pressure decreased, but at a much lower rate than that observed during the plant transient. The reduced primary-to-secondary heat transfer, apparently as a result of the previously discussed discrepancies in the secondary system boundary conditions, resulted in a primary system pressure response that attained a minimum pressure of approximately 1780 psia about 13 minutes after test initiation (See 1, Figure 5.143). The plant transient attained a minimum primary system pressure of approximately 1036 psia about 8 minutes after the loss of ICS power occurred. During the plant transient, 100% head-flow HPI was initiated at 1600 psia about 3.6 minutes after the loss of ICS power. MIST Test 4SEC02 did not depressurize to 1600 psia and when the loop operator noted that the primary system pressure was apparently stabilizing at a pressure greater than 1600 psia, 100% head-flow HPI was initiated (See 1, Figure 5.142).

When the HPI flow rate was increased to 100% head-flow, the test procedure required the loop operators to perform a number of actions in a relatively short time. These operator actions consisted of changes in steam generator A and B AFW flow rates, initiation and termination of MFW flow to both steam generators, and the closing of the steam valves in both steam generators to a position that produced a steam flow rate of approximately 25 lb/h.

With the reactor coolant pumps operating, the loop flow rates are of large magnitude such that the primary system responded in an essentially isothermal manner, i.e., the primary loop delta-T was approximately zero. During the initial approximately 13 minutes of the test, the energy removal capability of the steam generators was of sufficient magnitude that the primary system was essentially isothermal at the steam generator saturation temperature. Therefore, as the steam generators depressurized, the primary system fluid temperature decreased. The decrease in the primary fluid temperature resulted in the contraction of the primary fluid volume, which caused the depressurization of the primary system. As the steam generator pressure decreased, the energy removal capability of the steam generators also decreased, which eventually resulted in the stabilization of the primary system pressure. When the loop operator decreased the AFW flow rate to both steam generators (See 1 on Figures 5.144 and 5.145), the energy removal capability of the steam generators decreased and an increase in the primary system pressure occurred (See 2, Figure 5.143). The loop operator then increased the AFW flow rate to both steam generators, attaining approximately the same flow rate as prior to the reduction in AFW flow (See 2 on Figures 5.144 and 5.145). The energy removal capability of the steam generators therefore increased and the primary system pressure again stabilized (See 3, Figure 5.143). The loop operators then reduced the steam flow rate to approximately 25 lb/h for each steam generator (See 3 on Figures 5.144 and 5.145). This action resulted in a significant reduction in the energy removal capability of the steam generators and a primary system repressurization commenced (See 4, Figure 5.143).

When the primary pressure increased to approximately 2100 psia, the MIST test facility design limit for the primary-to-secondary pressure difference was approached and the loop operators manually opened the PORV (See 5, Figure 5.143). Subsequently, a number of manual PORV actuations were performed (See 6, Figure 5.143) to preclude exceeding the test facility design limit.

During this initial time period of MIST Test 4SEC02, the loop operators realized that the actual response of the test was entirely different from the expected (plant transient) response. A decision was then made to perform the remaining operator actions, as specified by the test procedure, based upon the timing criteria rather than the pressure criteria.

At approximately 19 minutes, the reactor coolant pump in cold leg B1 was tripped (See 2, Figure 5.134). Prior to the pump trip, an essentially stagnant fluid region existed in the upper downcomer. When the reactor coolant pump was tripped, a pressure gradient developed at the cold leg nozzle elevation and a flow path through the upper downcomer was established. This observation was deduced from the fluid thermocouple responses in the downcomer. The downcomer fluid temperatures at the 23.8-ft elevation (approximately 2.5 ft above the cold leg nozzle elevation) were decreasing gradually and did not follow the cold leg fluid temperature response prior to the pump trip (See 1, Figure 5.146). When the pump was tripped, the fluid temperatures at the 23.8-ft elevation immediately decreased (See 2, Figure 5.146) and then tracked the cold leg fluid temperature (See 3, Figure 5.146). Although the fluid temperature in each quadrant of the downcomer decreased and attained the cold leg fluid temperature, this occurred in the sequential manner B2, B1, A2, A1 (See 1, Figure 5.147).

After the B1 reactor coolant pump was tripped, the flow in cold leg B1 reversed and the flow rate in the other three cold legs increased (See 1 on Figures 5.148 through 5.151).

During this initial phase of the test, the steam generator secondary side levels initially decreased and when the AFW flow rate exceeded the steam flow rate, the levels increased (See 1, Figure 5.152). The time difference when steam generators A and B began filling was a direct result of the reduced AFW flow rate (erroneous control setpoint) for steam generator A.

When the primary system pressure began increasing, the pressurizer level also started increasing (See 1, Figure 5.153). The rate at which the pressurizer level increased (See 2, Figure 5.153) was observed to respond to changes in the HPI flow rate. The HPI flow rate was then decreased to and maintained at approximately 100 lb/h. The pressurizer level responded with a gradually increasing trend (See 3, Figure 5.153) resulting from the HPI and the heatup of the primary system fluid. At approximately 26 minutes, the loop operator initiated pressurizer spray (See 1, Figure 5.154). The pressurizer spray continued through test termination. The spraying of cold leg fluid into the top of the pressurizer condensed steam in the pressurizer and a slight depressurization of the primary system occurred (See 7, Figure 5.143). The pressurizer spray also resulted in an increase in the rate at which the pressurizer level increased (See 4, Figure 5.153). The pressurizer eventually filled and the primary system was now water solid, HPI was on, and a heatup was in progress; thus, a rapid increase in the primary pressure occurred (See 8, Figure 5.143). The loop operator then terminated HPI (See 2, Figure 5.142). The primary system pressure, however, continued increasing as the primary system heatup continued.

AFW was terminated when the steam generators completely refilled. Steam generator B refilled at approximately 26 minutes (See 2, Figure 5.152) and steam generator A refilled at approximately 36 minutes (See 3, Figure 5.152). Subsequent to the termination of AFW, the energy removal capability of the steam generators decreased further and was limited to the energy removal capability of approximately 25 lb/h from each steam generator. The steam generators then began to repressurize (See 9, Figure 5.143).

The test facility primary-to-secondary differential pressure design limit was again approached and the loop operator manually opened the PORV four times (See 1, Figure 5.155). The continuously increasing steam generator pressure aided the test facility design limit for primary-to-secondary pressure differential, thus permitting an increasingly higher primary system pressure. Eventually, the primary system pressure increased to the PORV opening setpoint and a number of automatic PORV actuations occurred (See 2, Figure 5.155).

At approximately 58 minutes, the loop operator initiated a steam generator cooldown of 100F/h. The cooldown was accomplished by permitting the boil-off of steam generator secondary inventory. The steam generator secondary side levels indicated approximately full when the cooldown was initiated (See 1, Figure 5.156). The steam valve then opened, resulting in an increased steam flow rate from both steam generators (See 1, Figure 5.157). The increased steam flow rate resulted in a higher steam generator energy removal capability and a primary system depressurization commenced (See 3, Figure 5.155).

During the initial phase of the steam generator cooldown, asymmetric conditions were established in the steam generators. The steam flow rate for steam generator A attained a maximum value that was greater than that for steam generator B by a factor of approximately 1.6 (See 2, Figure 5.157). The observed asymmetry in the steam generator steam flow rates was apparently a result of asymmetrical primary loop flow rates that was caused by the operation of two reactor coolant pumps in loop A and only one in loop B. Thus, loop A had a higher potential for primary-to-secondary heat transfer.

The primary system pressure decreased rapidly when primary-to-secondary heat transfer was established. However, when the saturation temperature decreased and attained the reactor vessel upper head temperature (See 1, Figure 5.158), the reactor vessel head voided, thus causing a decrease in the primary system depressurization rate (See 4, Figure 5.155).

Coincident with the reactor vessel head voiding, the steam flow rates for each steam generator began decreasing (See 2, Figure 5.157). The steam flow rate for steam generator A continuously decreased in an essentially linear manner (See 3, Figure 5.157). The steam flow rate for steam generator A also decreased in a stair-step manner. The cause of this response appears to be related to the response of the control valve to the control signal as it attempted to maintain the specified cooldown rate. The steam flow rate for steam generator B was observed to decrease (See 4, Figure 5.157) and then increase (See 5, Figure 5.157). The magnitude of the steam flow rate from steam generator B then exceeded that of steam generator A. During this cooldown of the steam generators, AFW was unavailable. Therefore, the steam generator secondary levels decreased (See 2, Figure 5.156) and the steam flow rates decreased towards zero (See 6, Figure 5.157) as the secondary side inventory boiled off. Both steam generators appear to have eventually dried out as the measured liquid level indicated zero (See 3, Figure 5.156).

Essentially, the complete loss of secondary side inventory and the lack of AFW terminated the energy removal capability of the steam generators. The primary system had been depressurizing as the steam generators were being steamed and descended to a pressure of approximately 1150 psia (See 1, Figure 5.159). The inability of the steam generators to remove energy resulted in the inhibition of primary-to-secondary heat transfer and the primary system repressurized (See 2, Figure 5.159). The test facility design limit for the primary-to-secondary differential pressure was again approached and the loop operators manually actuated the PORV repeatedly (See 3, Figure 5.159) to prevent damage to the test facility.

Shortly after the primary system repressurization discussed above began, an inadvertent reactor coolant pump trip in cold leg A2 occurred (See 1, Figure

5.160). This reactor coolant pump trip was not observed by the loop operators. The A2 pump trip resulted in backflow in cold leg A2 (See 2, Figure 5.150) and an increase in the cold leg A1 flow rate (See 2, Figure 5.148). The cold leg B flow rates also responded to the A2 pump trip as a slight increase in forward loop flow was observed in cold leg B2, the reactor coolant pump was operating (See 2, Figure 5.151), a decrease in backflow was observed in cold leg B1, the reactor coolant pump was tripped (See 2, Figure 5.149). Other than the effects observed above, the inadvertent trip of the A2 reactor coolant pump did not affect the transient response.

At approximately 102 minutes, the loop operator tripped the A1 reactor coolant pump (See 2, Figure 5.160) as per the test procedure. At this time, the loop operator noticed that the A2 reactor coolant pump was off and he then restarted the A2 pump (See 3, Figure 5.160). The pump trips and restart appear to have had a negligible effect on the transient response.

As previously discussed, the test facility design limit for primary-to-secondary pressure differential required that the loop operator manually actuate the PORV. The lack of secondary side inventory resulted in decreasing steam generator pressure. Therefore, primary and secondary pressures were diverging and the decision was made to terminate the test.

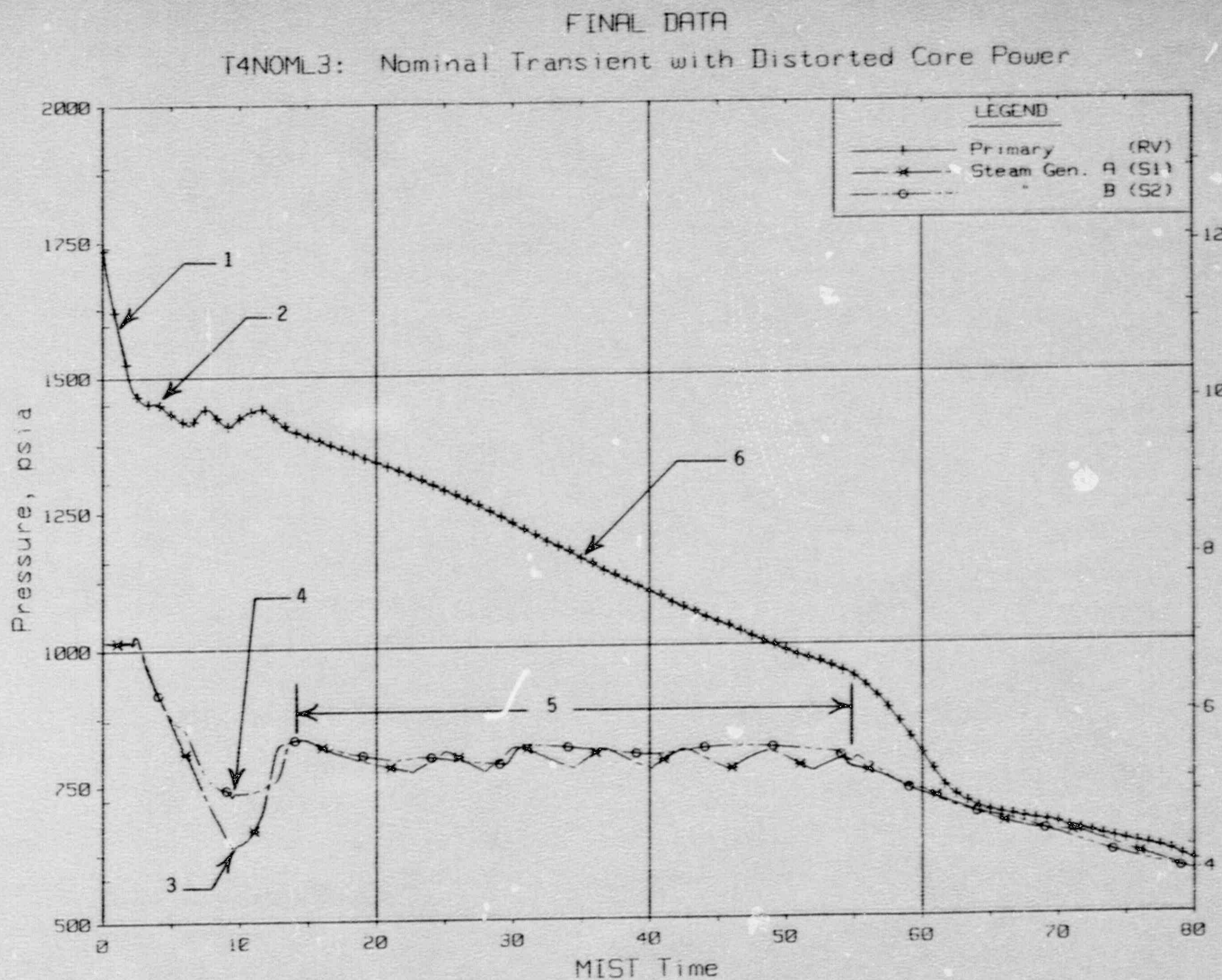



Figure 5.1 Primary and Secondary System Pressures (GP01s)

PSGP1

Thu Oct 6 12:49:25 1988

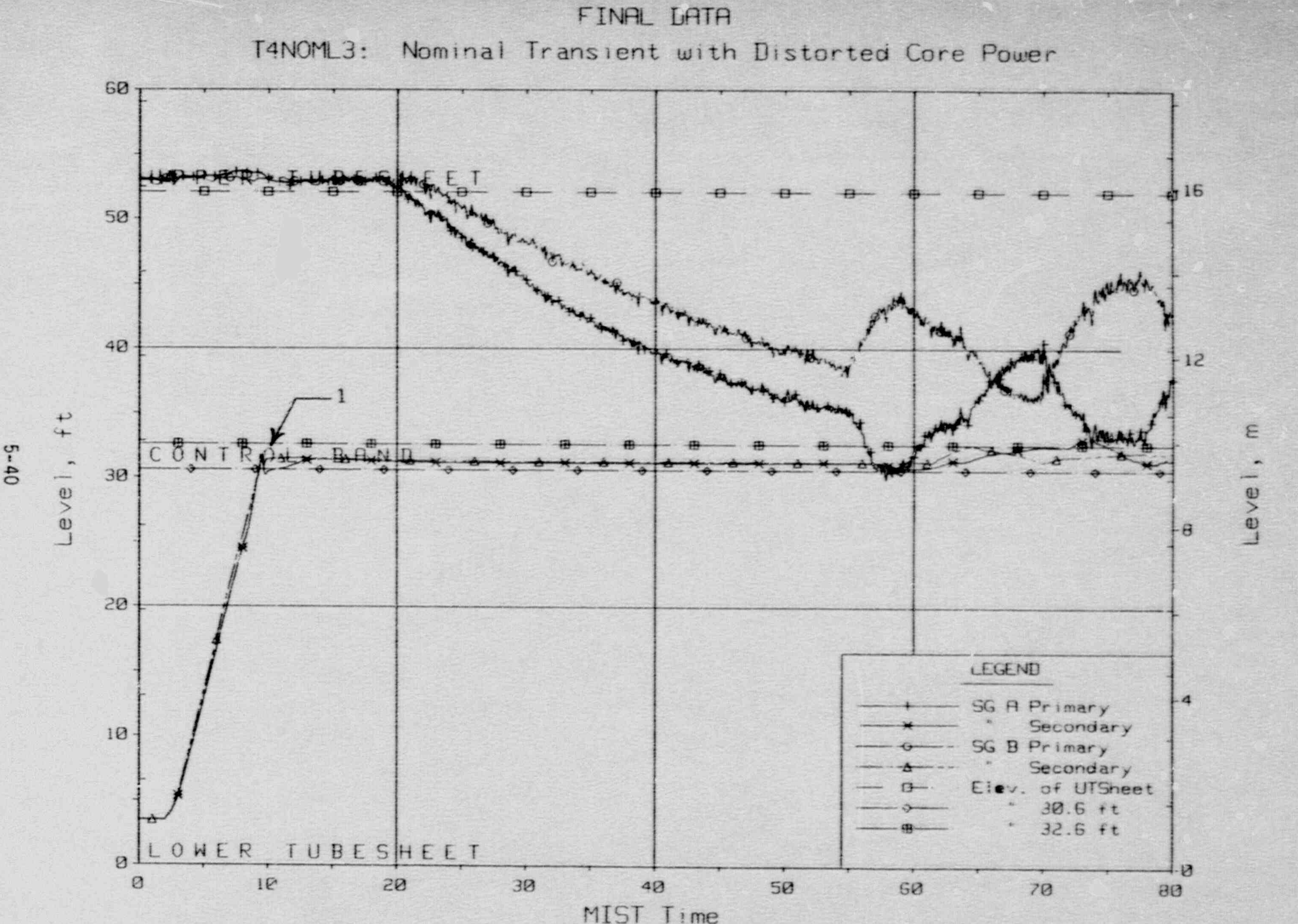



Figure 5.2 Steam Generator Collapsed Liquid Levels

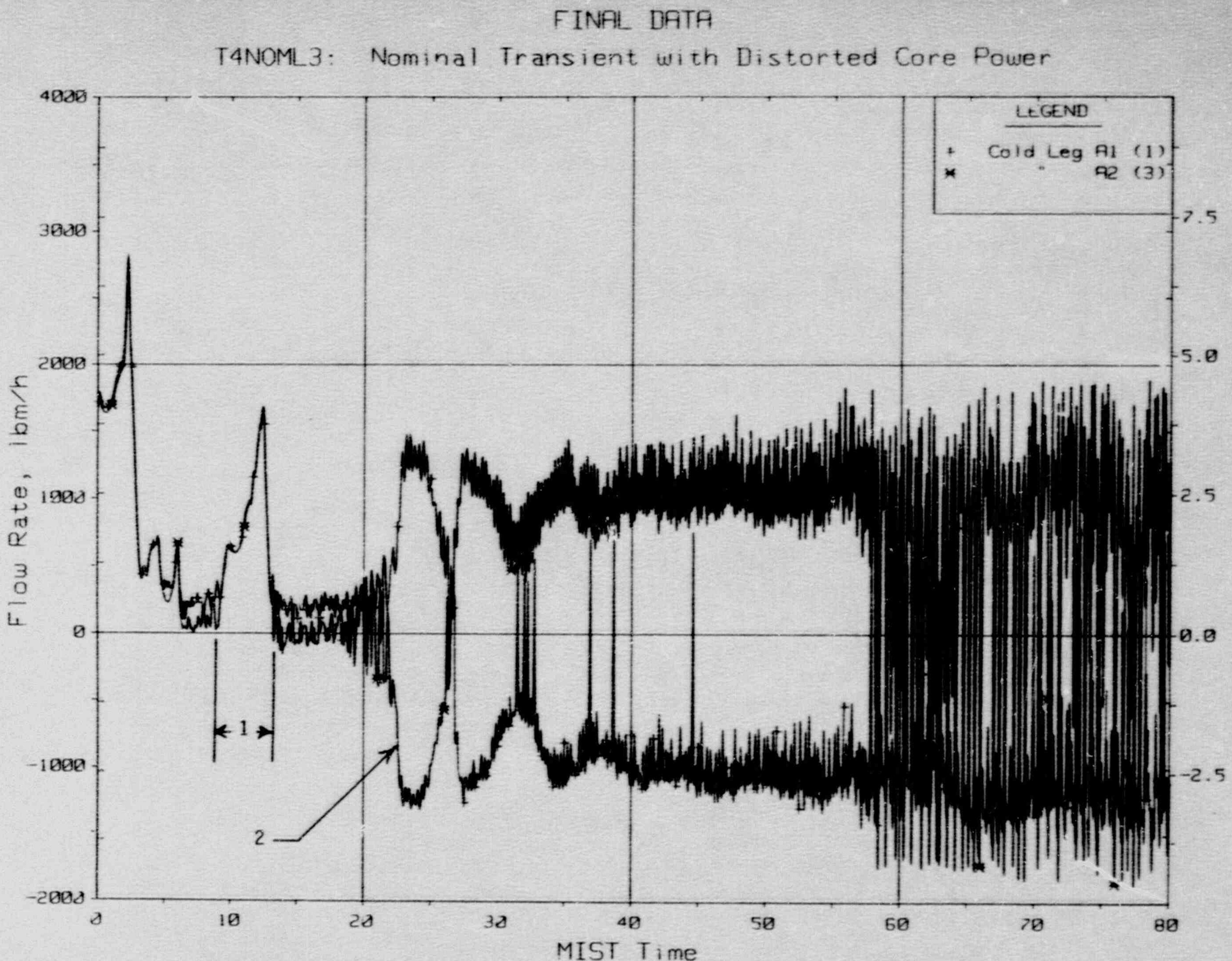



Figure 5.3 Loop A Cold Leg (Venturi) Flow Rates (CnVN20s)

Thu Nov 17 09:40:09 1988

PRFL5

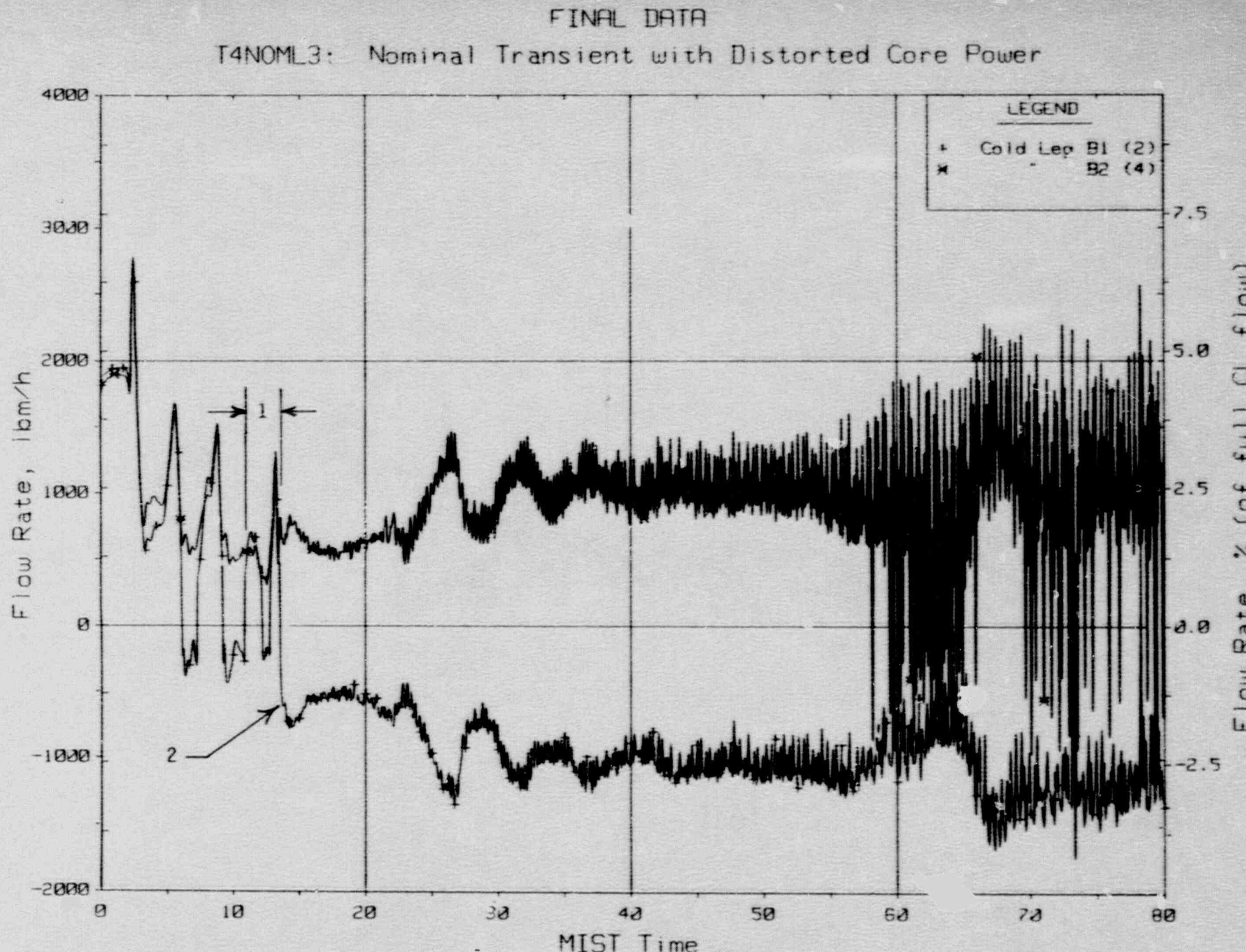



Figure 5.4 Loop B Cold Leg (Venturi) Flow Rates (CnVN20s)

Thu Nov 17 09:44:59 1988

PRFL6

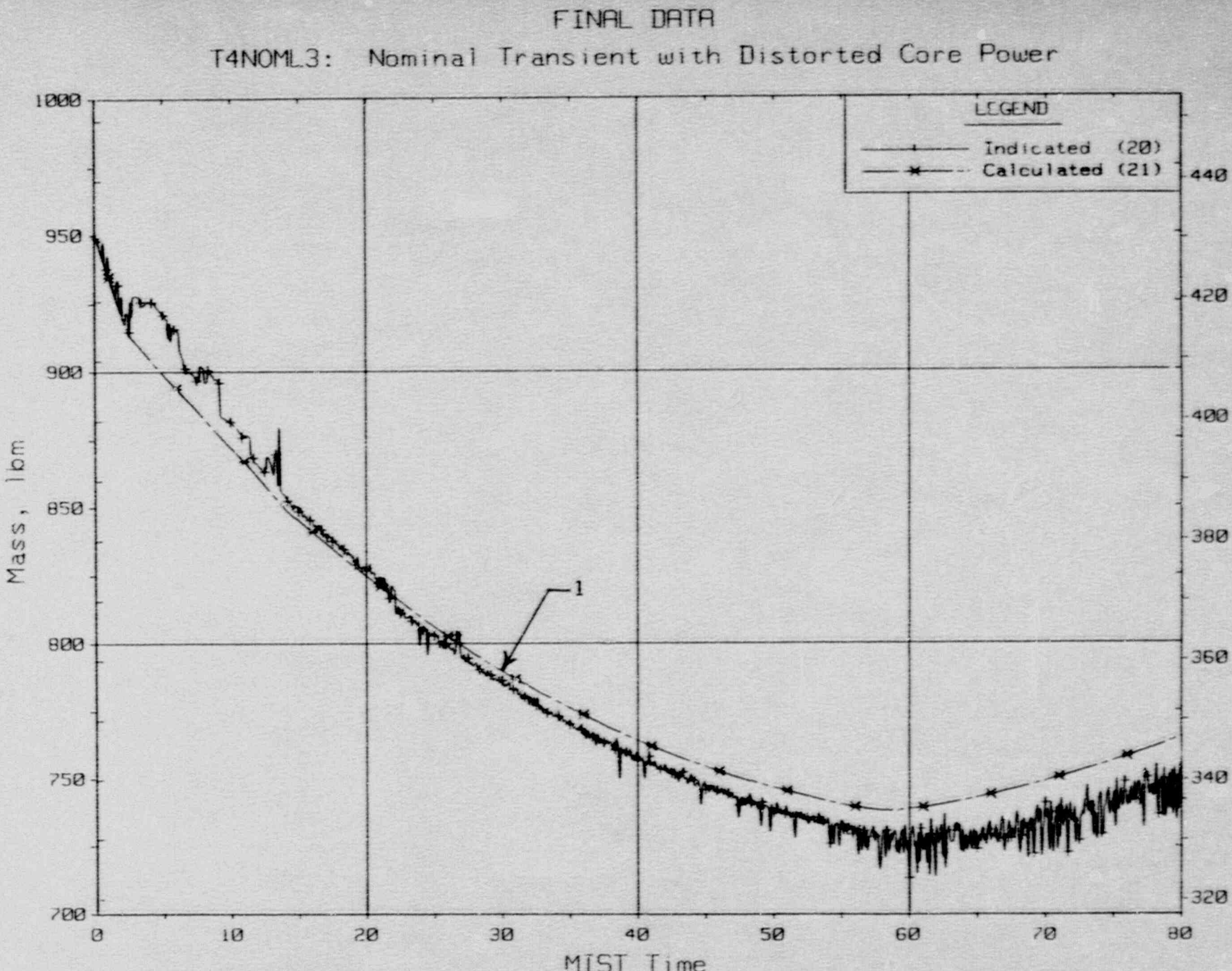



Figure 5.5 Primary System Total Fluid Mass (PLMLs)

Thu Oct 6 12:14:20 1988

PRML1

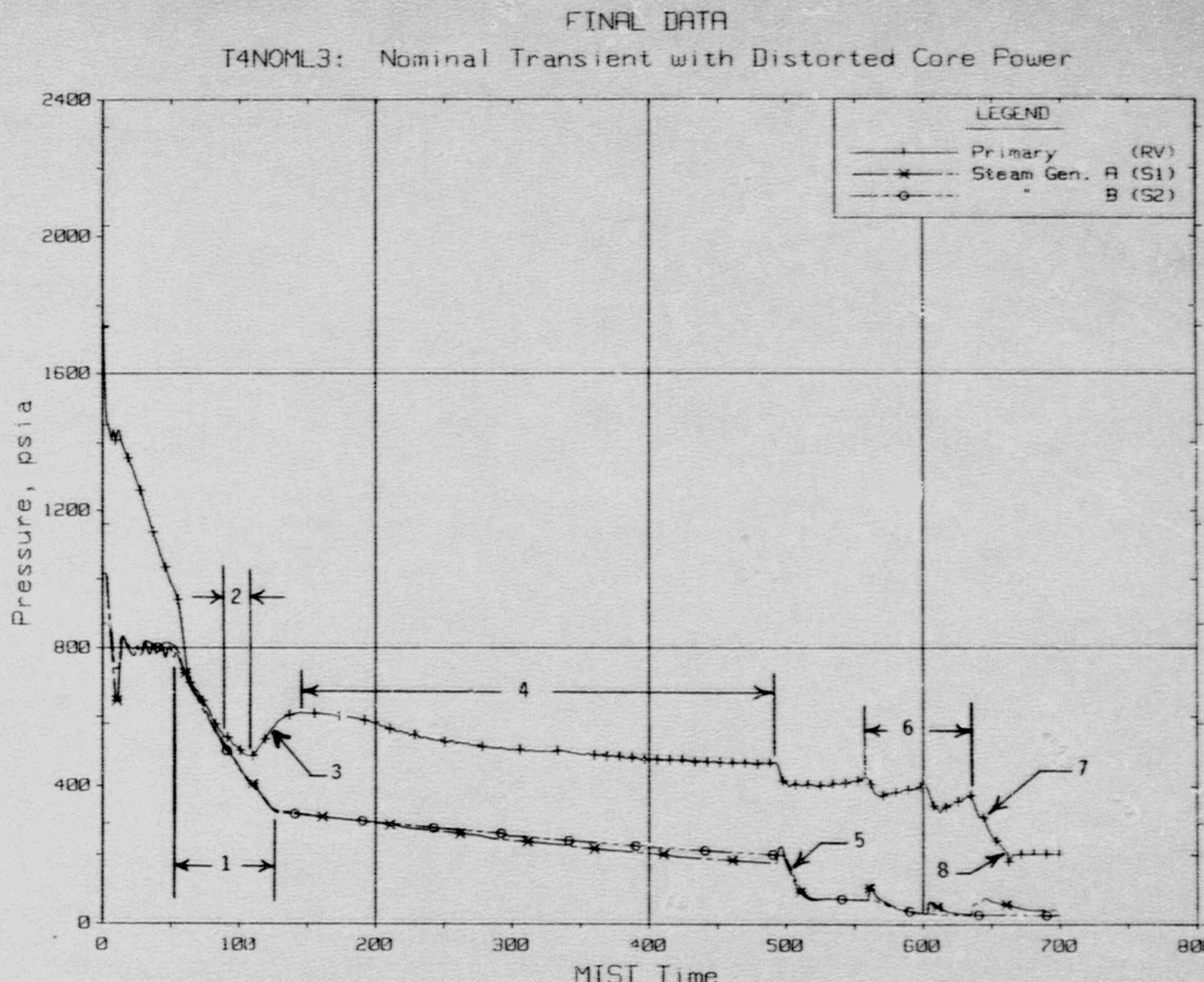



Figure 5.6 Primary and Secondary System Pressures (GPOls)



Thu Oct 6 13:40:24 1988

PSGP1

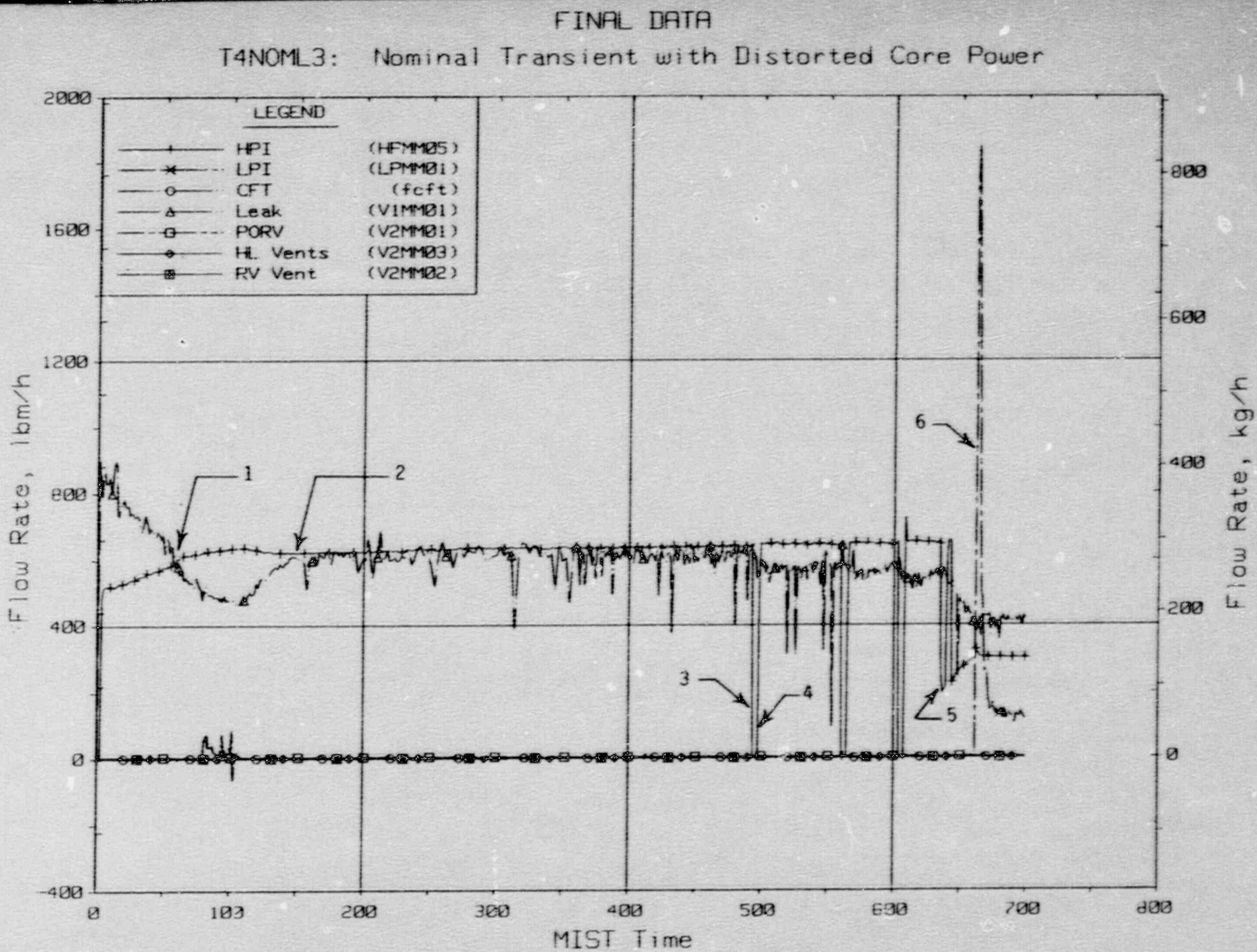



Figure 5.7 Primary System Boundary Flow Rates

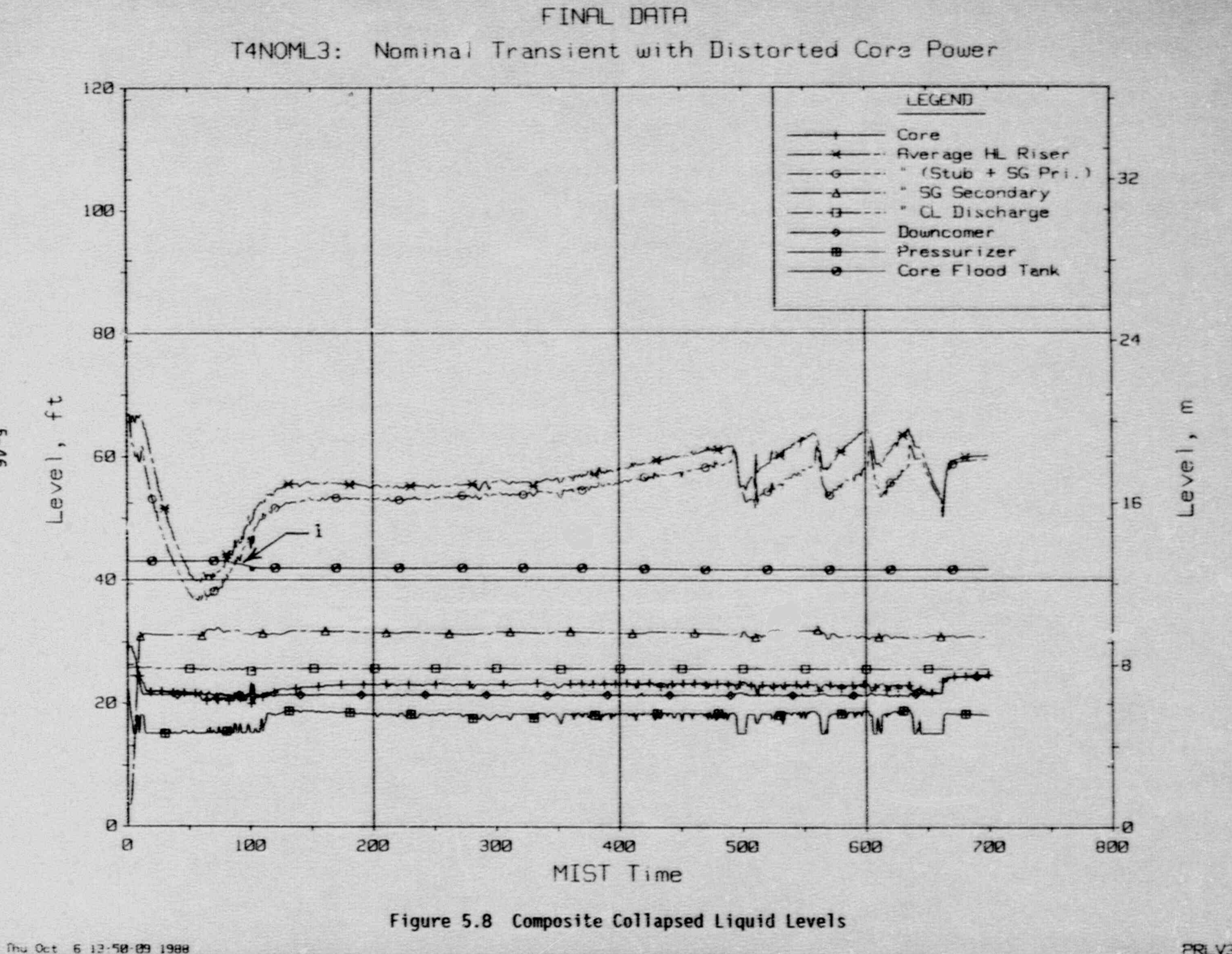



Figure 5.8 Composite Collapsed Liquid Levels

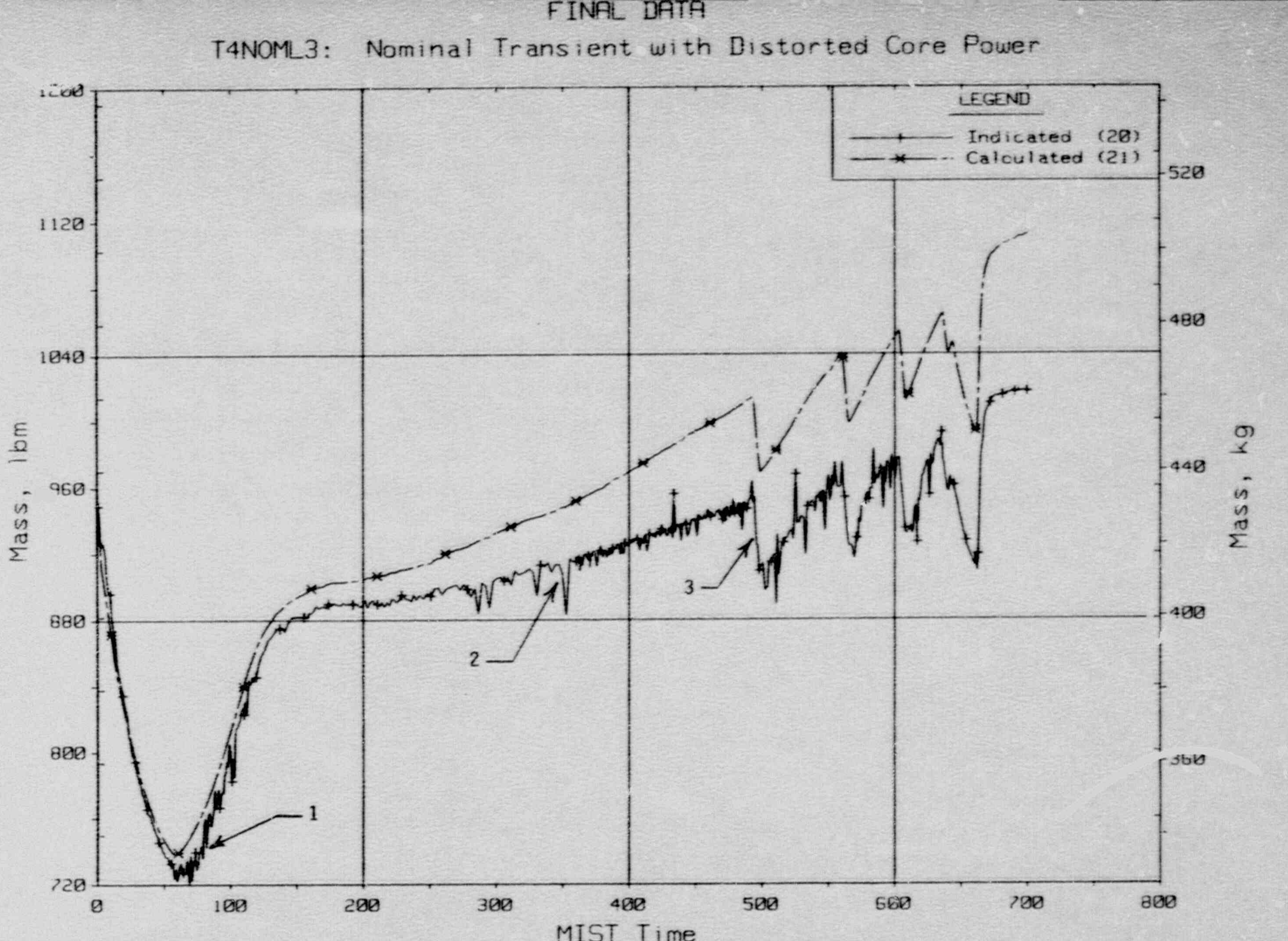



Figure 5.9 Primary System Total Fluid Mass (PLMLs)

Thu Oct 6 13:52:49 1988

PRML1

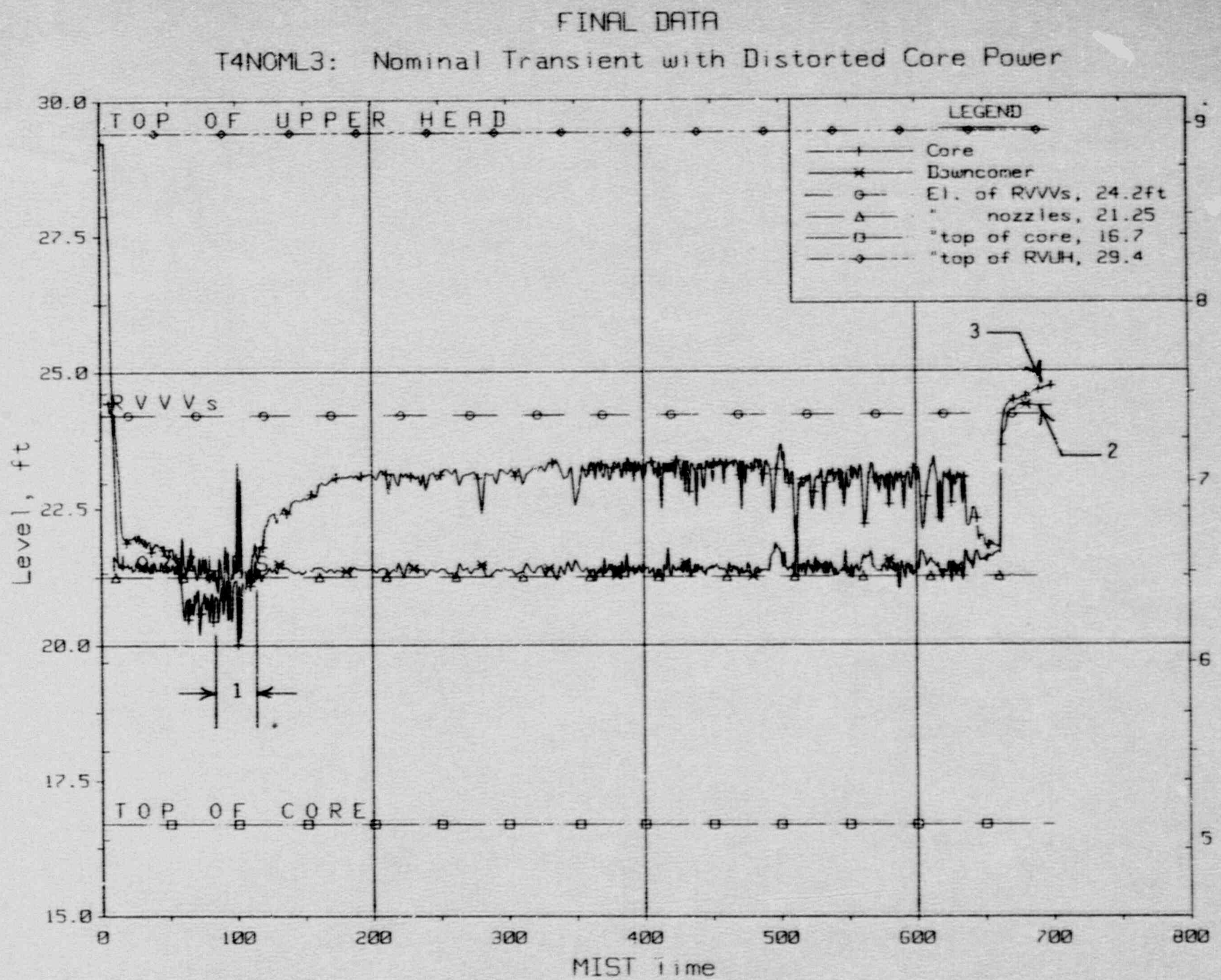



Figure 5.10 Core Region Collapsed Liquid Levels



COLV1

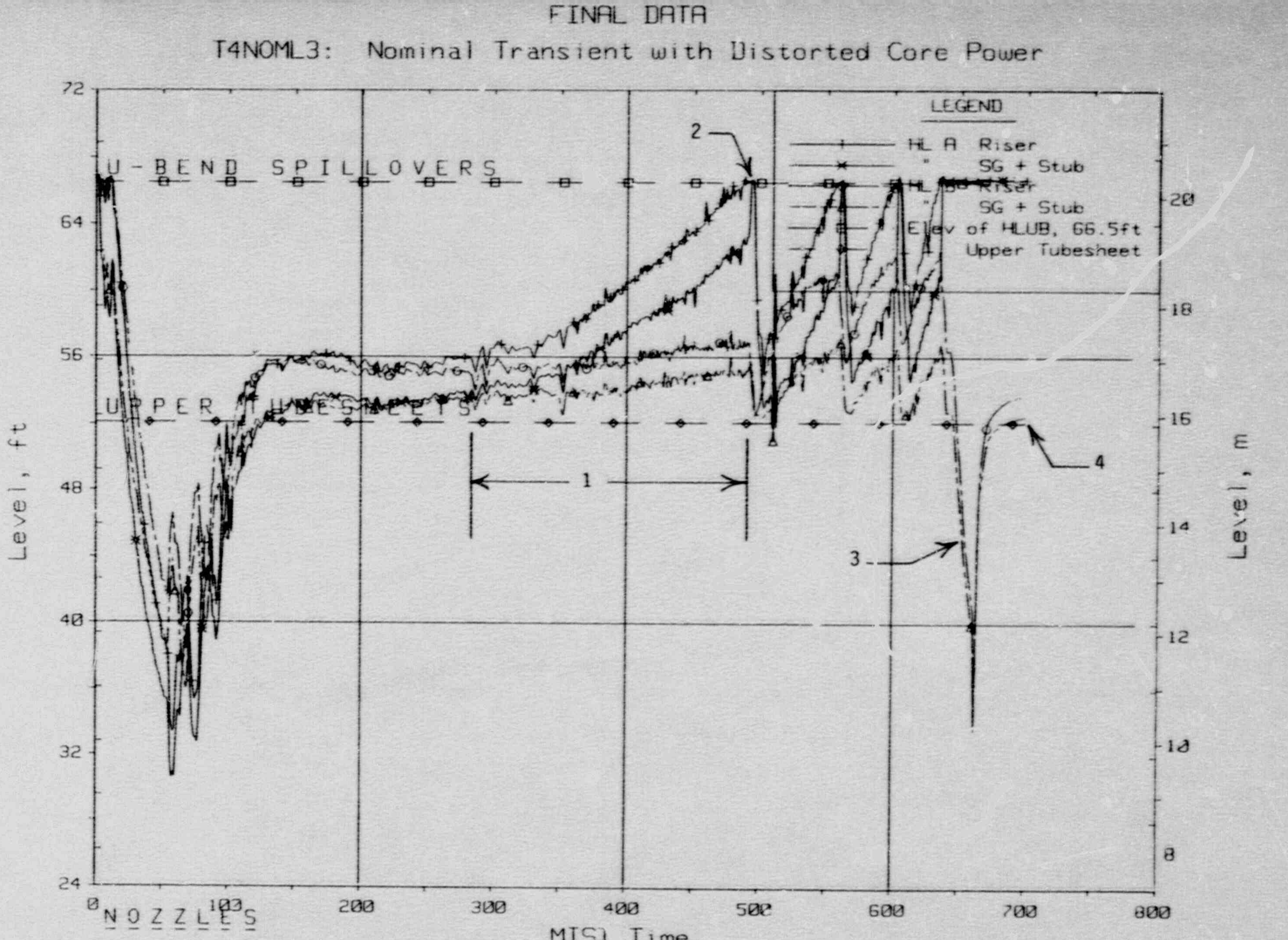
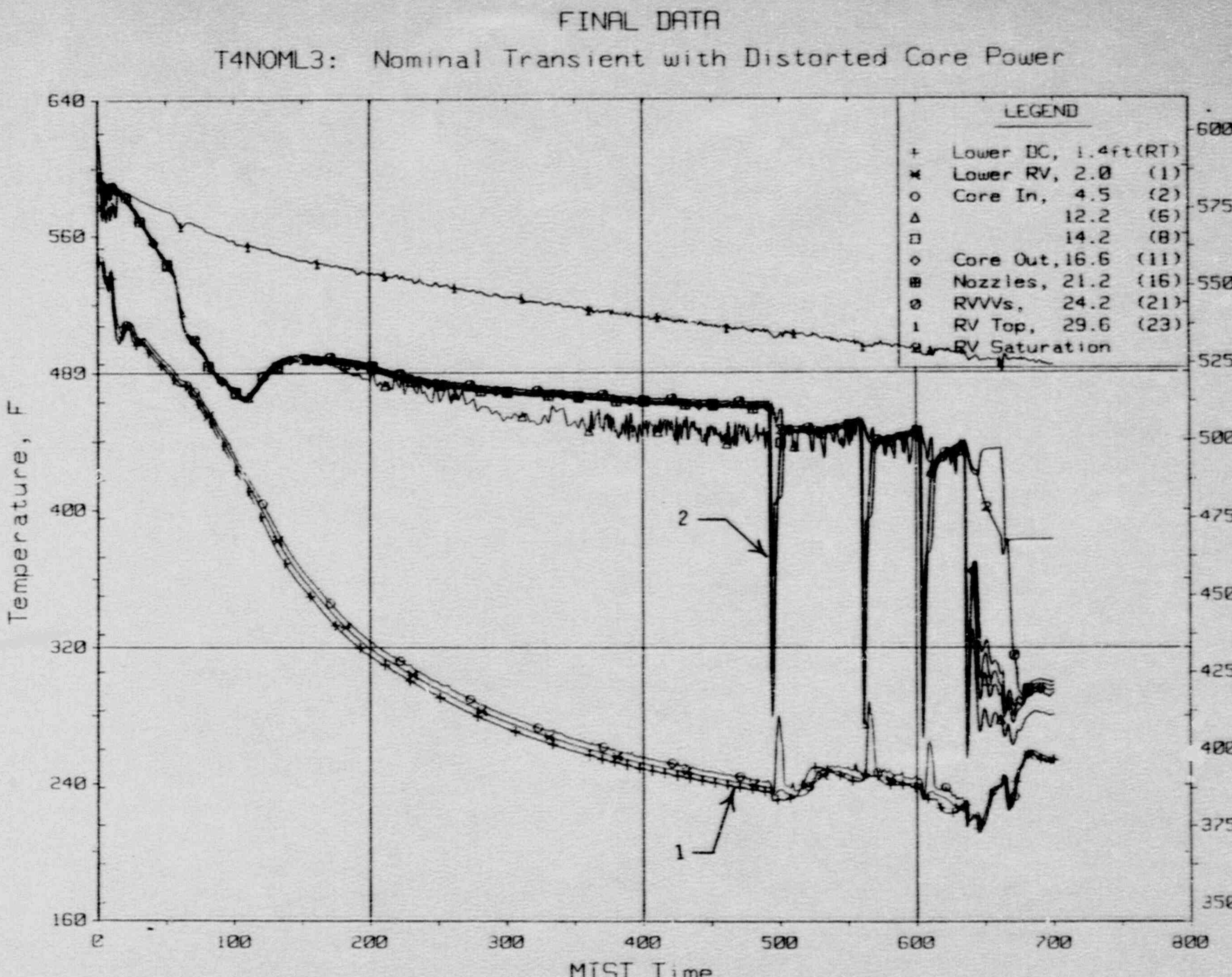



Figure 5.11 Hot Leg Riser and Stub Collapsed Liquid Levels

Thu Oct 6 14:00:45 1988

HLLV1




5-50

**Figure 5.12 Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs)**

Fri Oct 6 14:05:53 1988

RVTC0

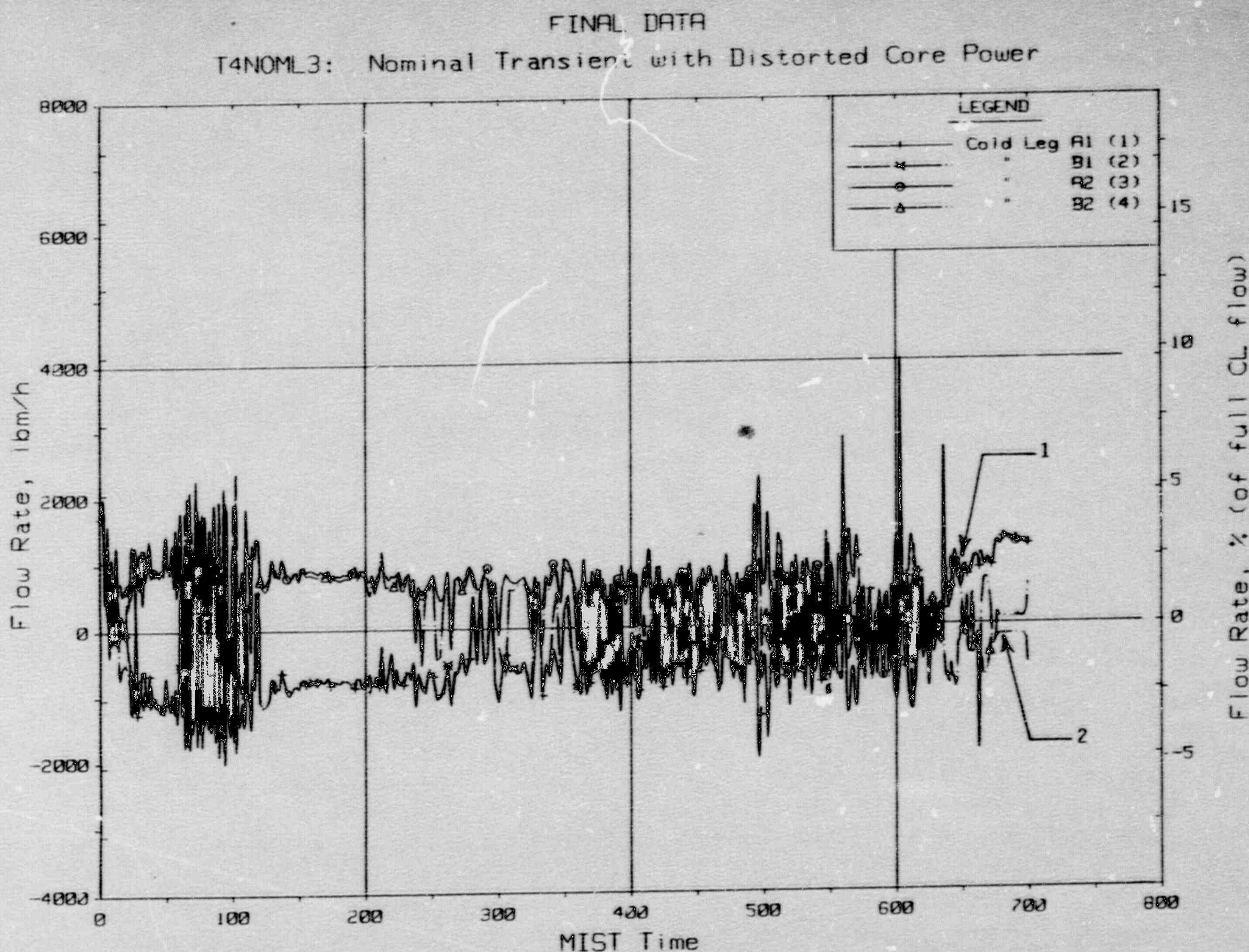



Figure 5.13 Cold Leg (Venturi) Flow Rates (CnVN20s)

CLFL0

Thu Nov 17 10:00:37 1988

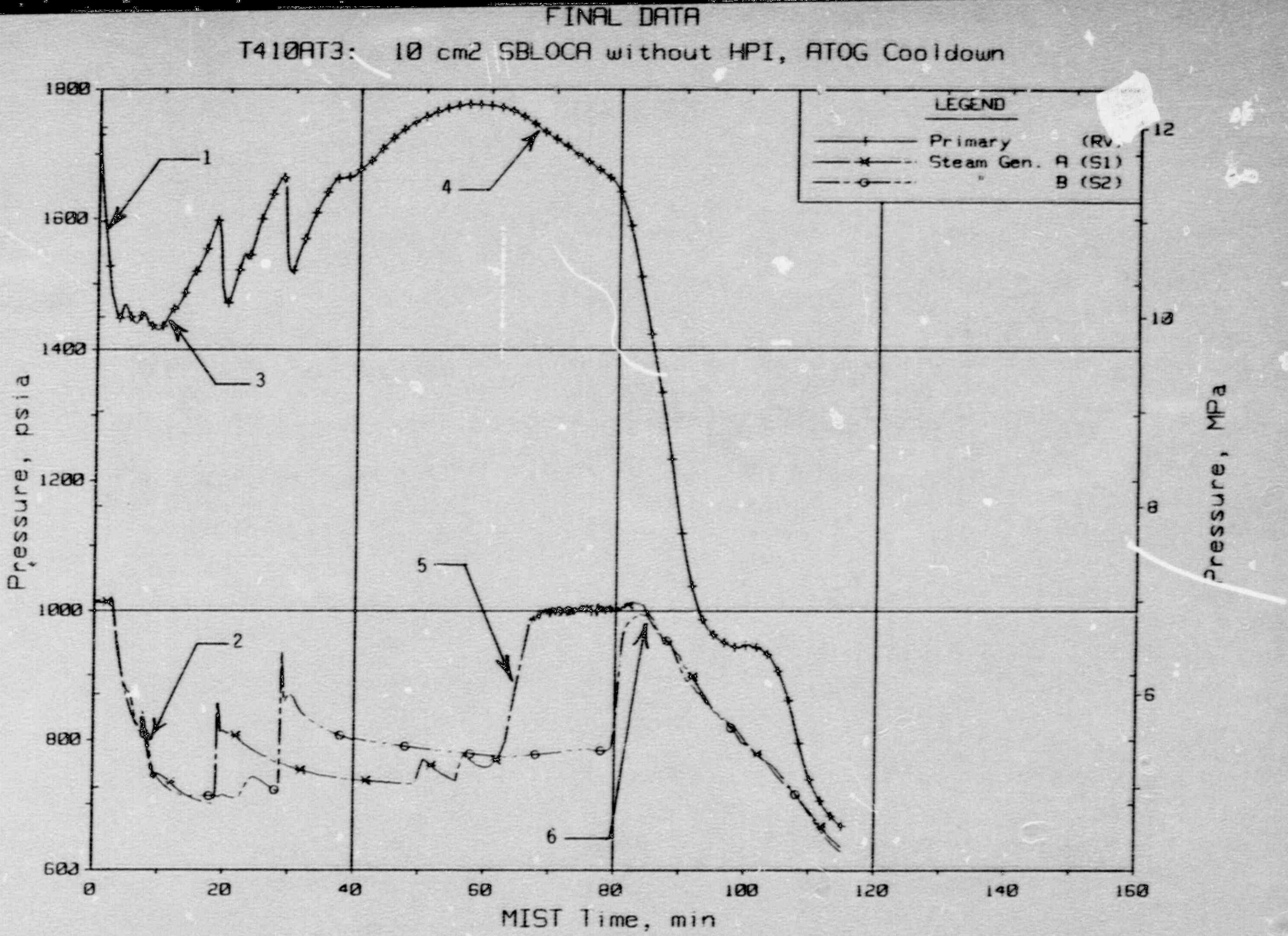



Figure 5.14 Primary and Secondary System Pressures (GP01s)

Tue Aug 23 15:48:06 1988

PSGP1

Figures for Test 410AT3

10-$cm^2$ SBLOCA Without HPI, ATOG Cooldown

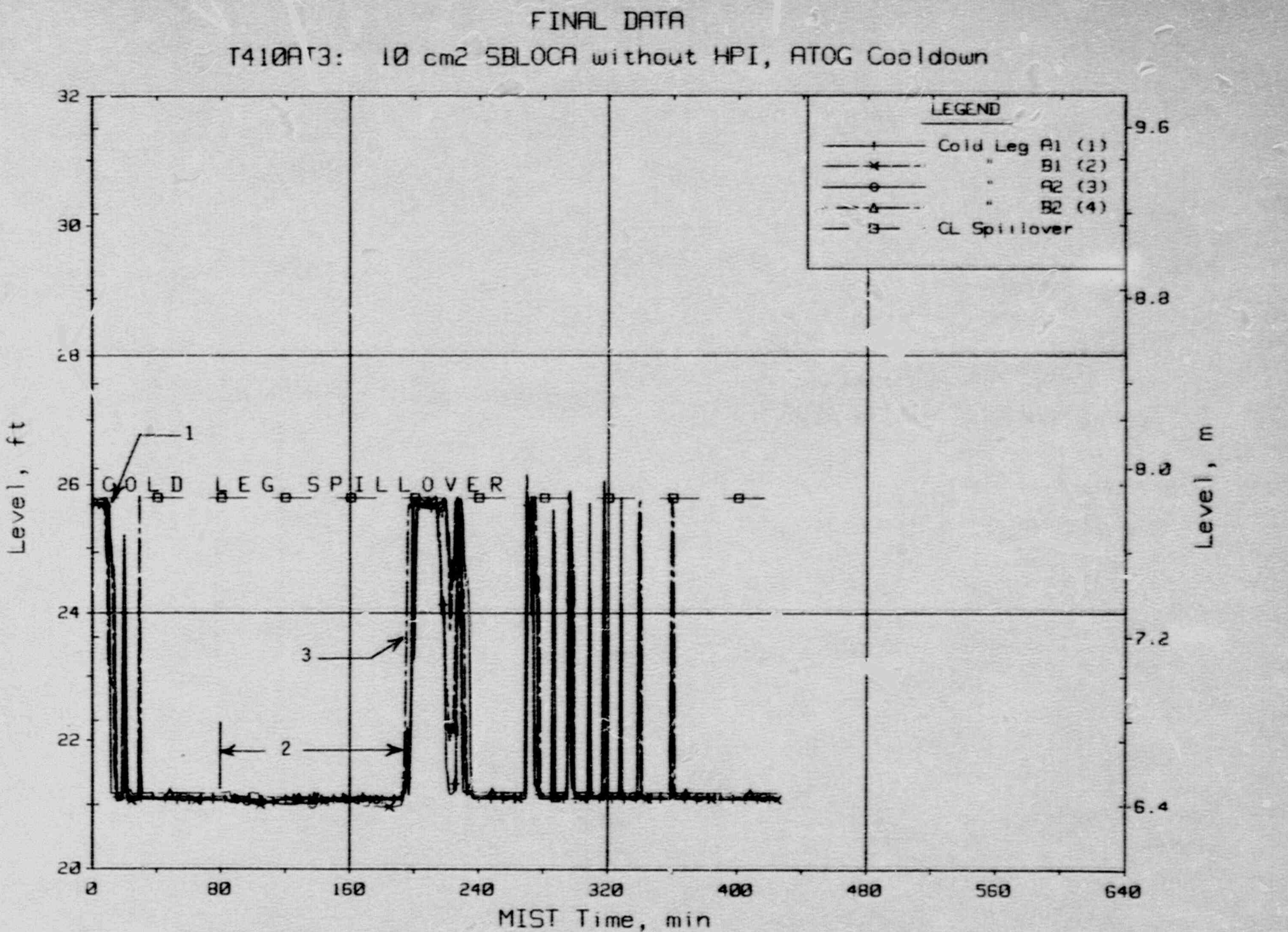



Figure 5.15 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Tue Aug 23 16:08:22 1988

CLLV5

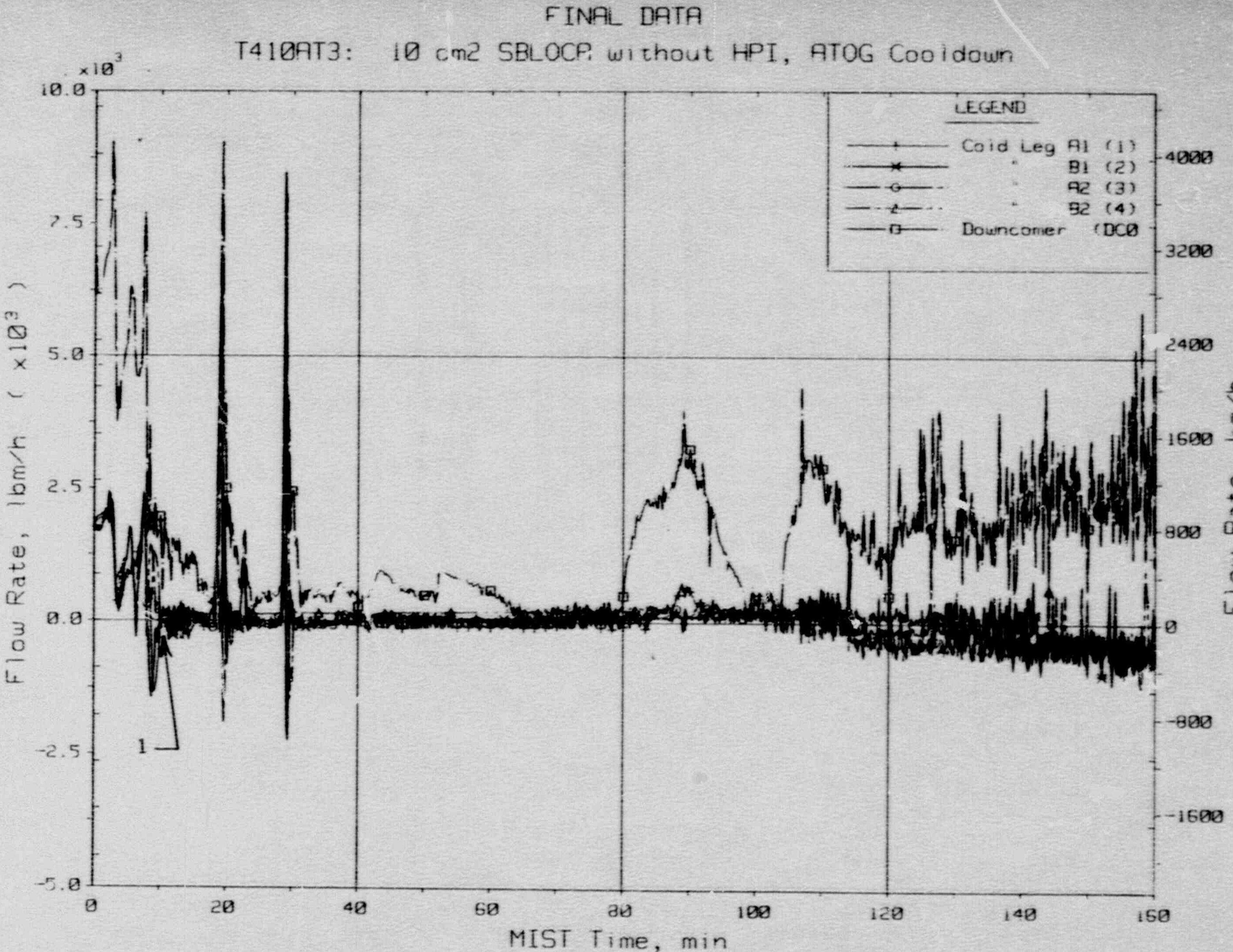



Figure 5.16 Primary System (Venturi) Flow Rates (VN20s)

Tue Nov 15 14:27:35 1988

PRFL0

FINAL DATA

T410AT3: 10 cm2 SBLOCA without HPI, ATOG Cooldown

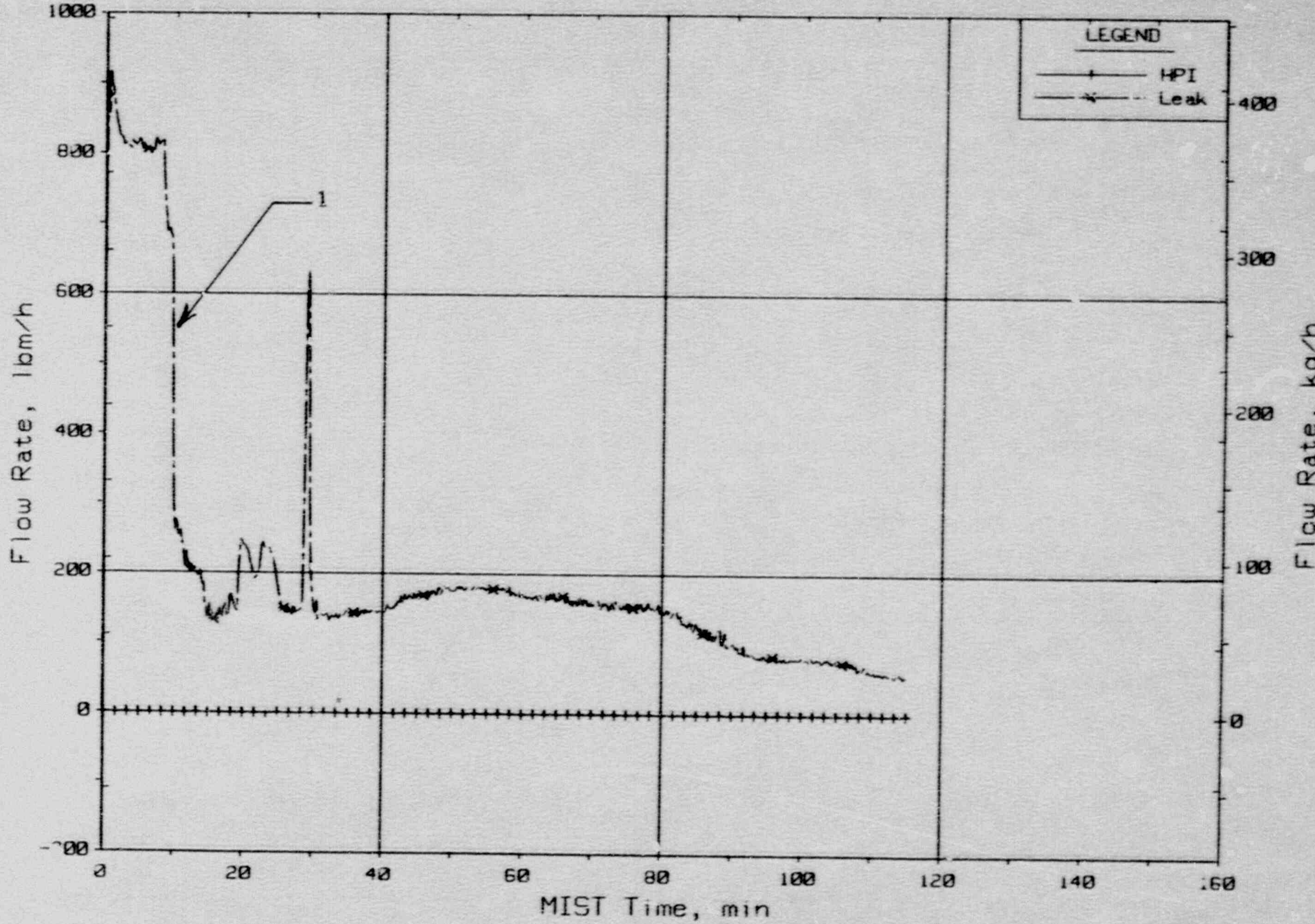



Figure 5.17 Primary System Boundary Flow Rates

5-55

Tue Aug 23 15:54:31 1988

PRFL8

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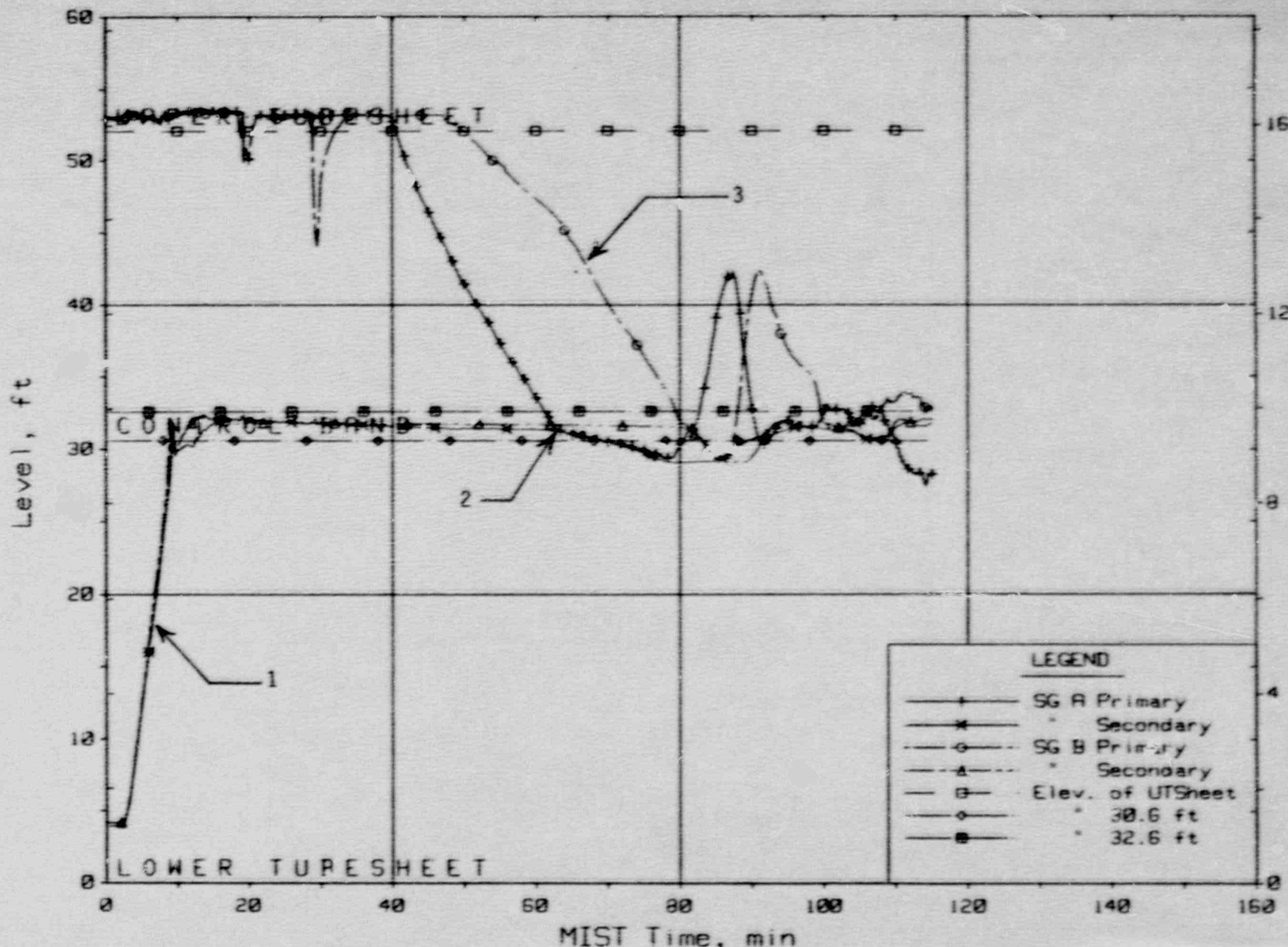



Figure 5.18 Steam Generator Collapsed Liquid Levels

Tue Aug 23 16:03:21 1988

SGLV2

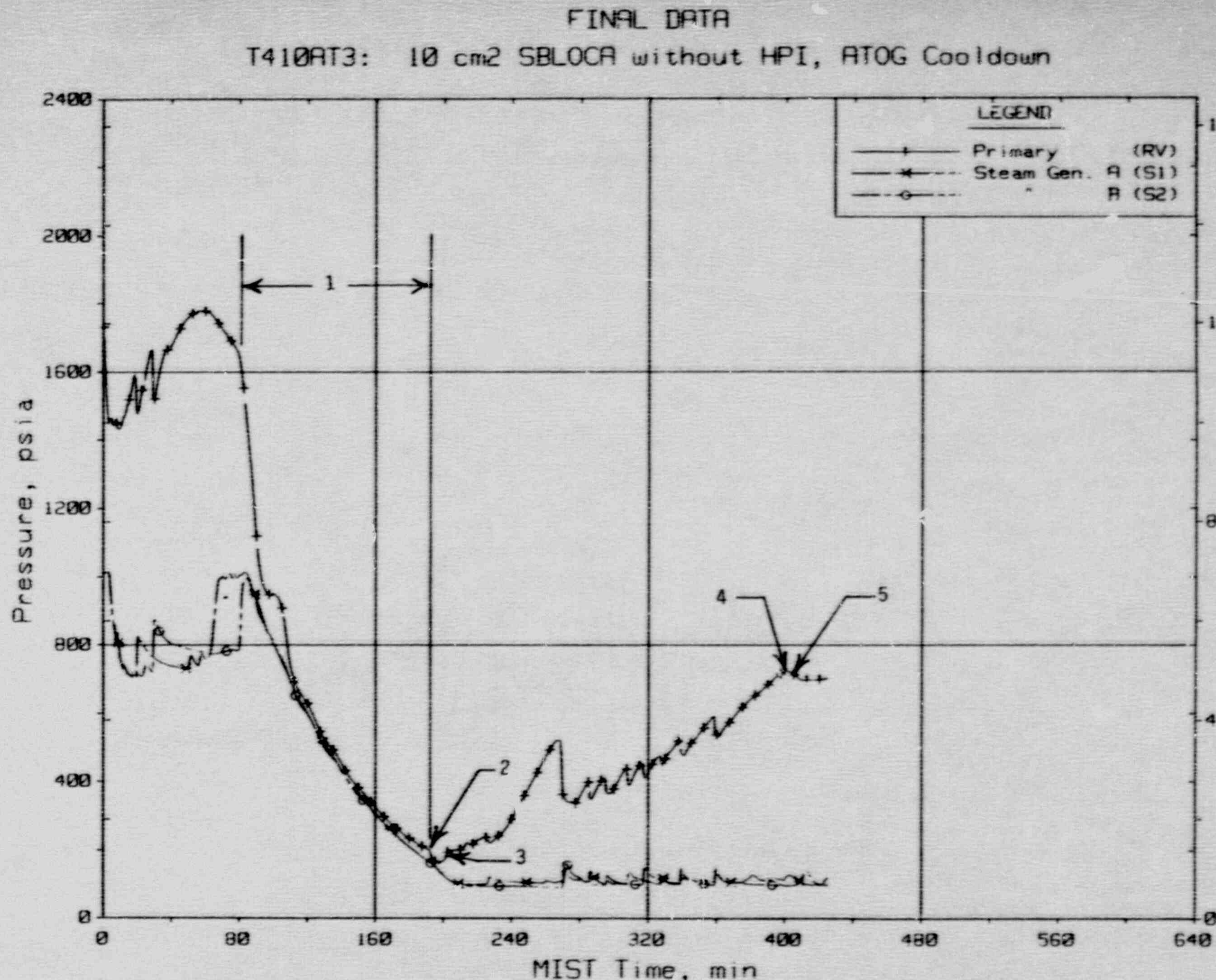



Figure 5.19 Primary and Secondary System Pressures (GP01s)

Tue Aug 22 16:11:06 1988

PSGP1

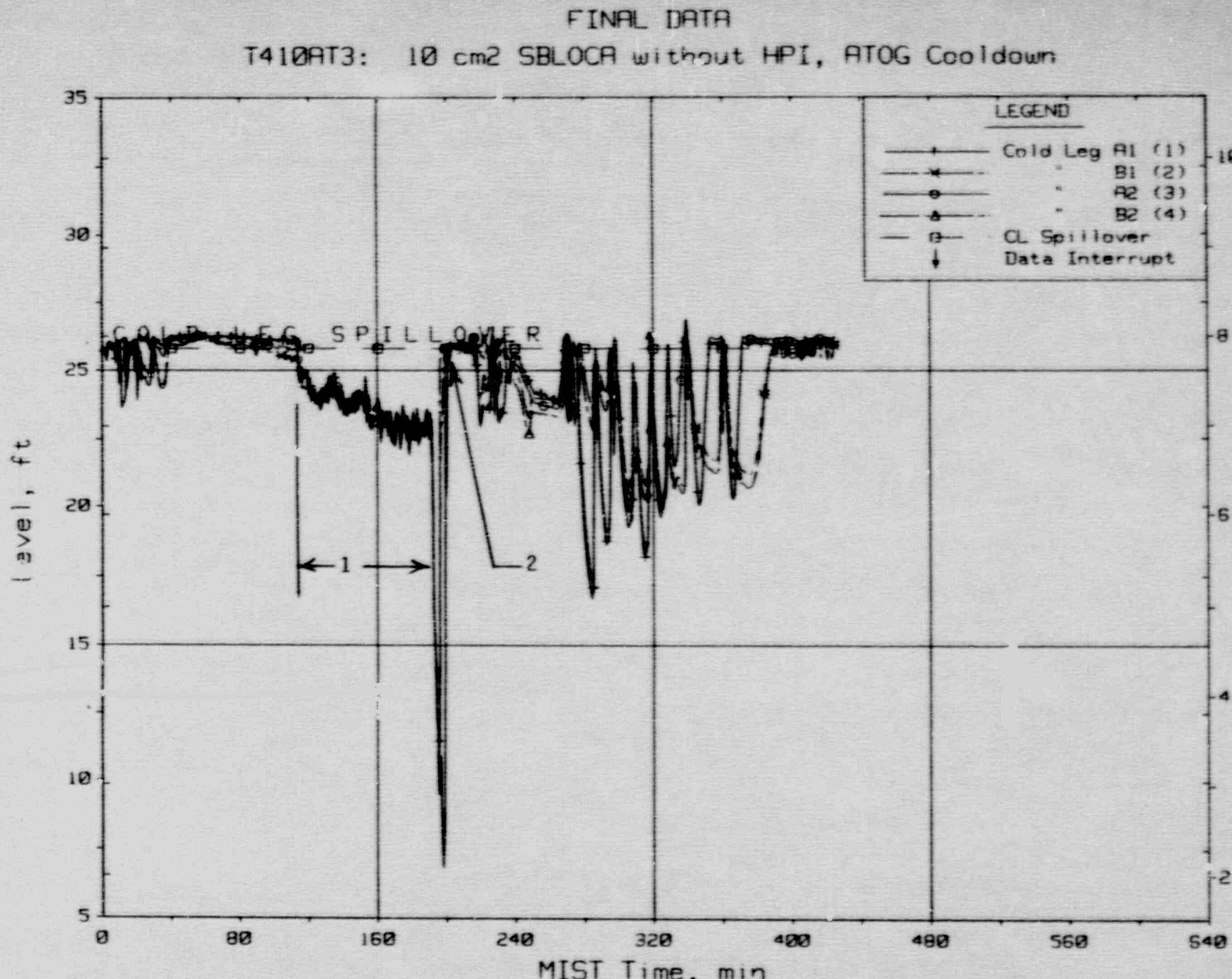



Figure 5.20 Cold Leg Suction Collapsed Liquid Levels (CnLV22s)

Tue Sep 13 14:30:02 1988

CLLV4

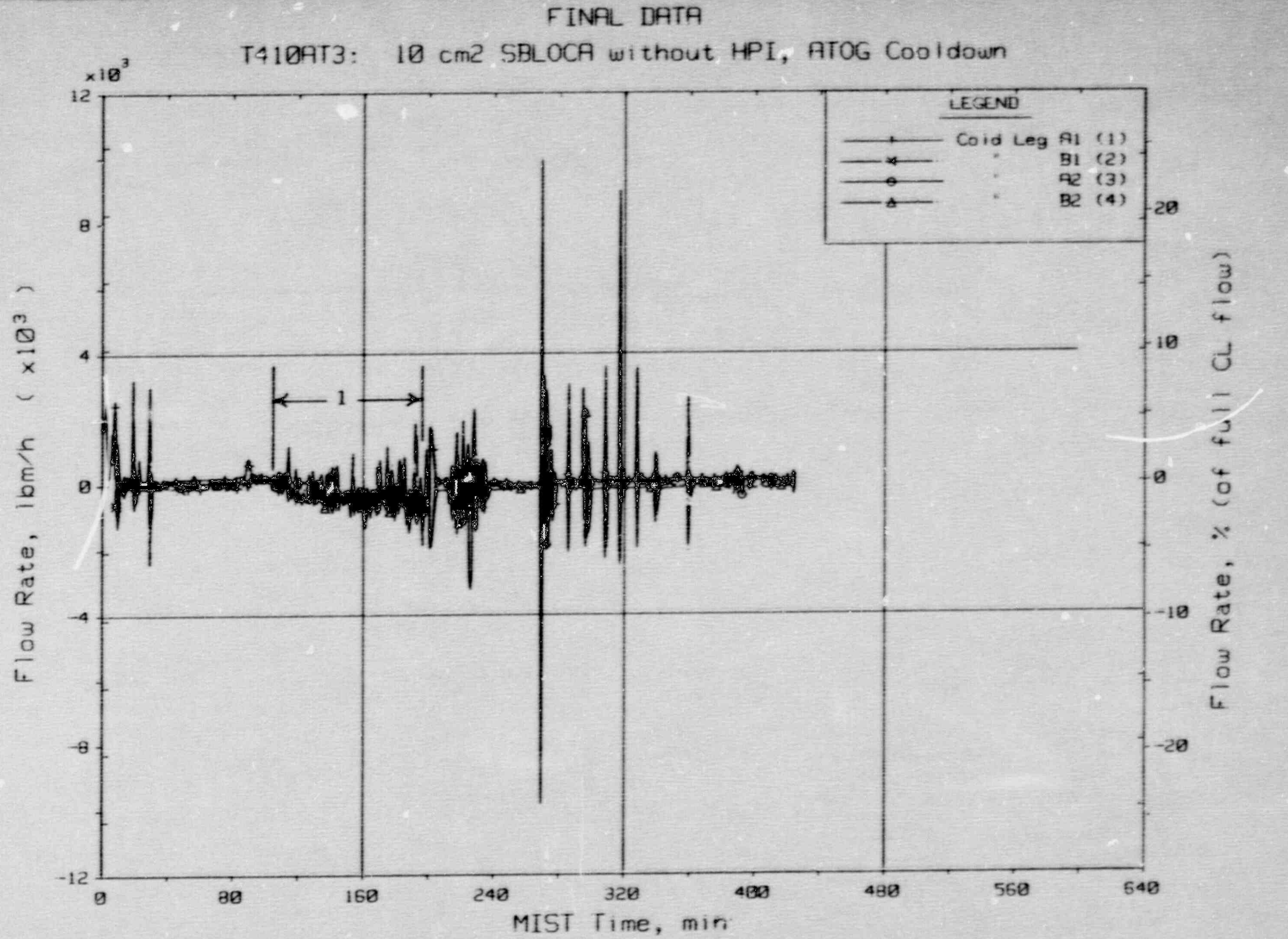



**Figure 5.21 Cold Leg (Venturi) Flow Rates (CnVN20s)**

Mon Nov 14 10:02:28 1988

CLFL0

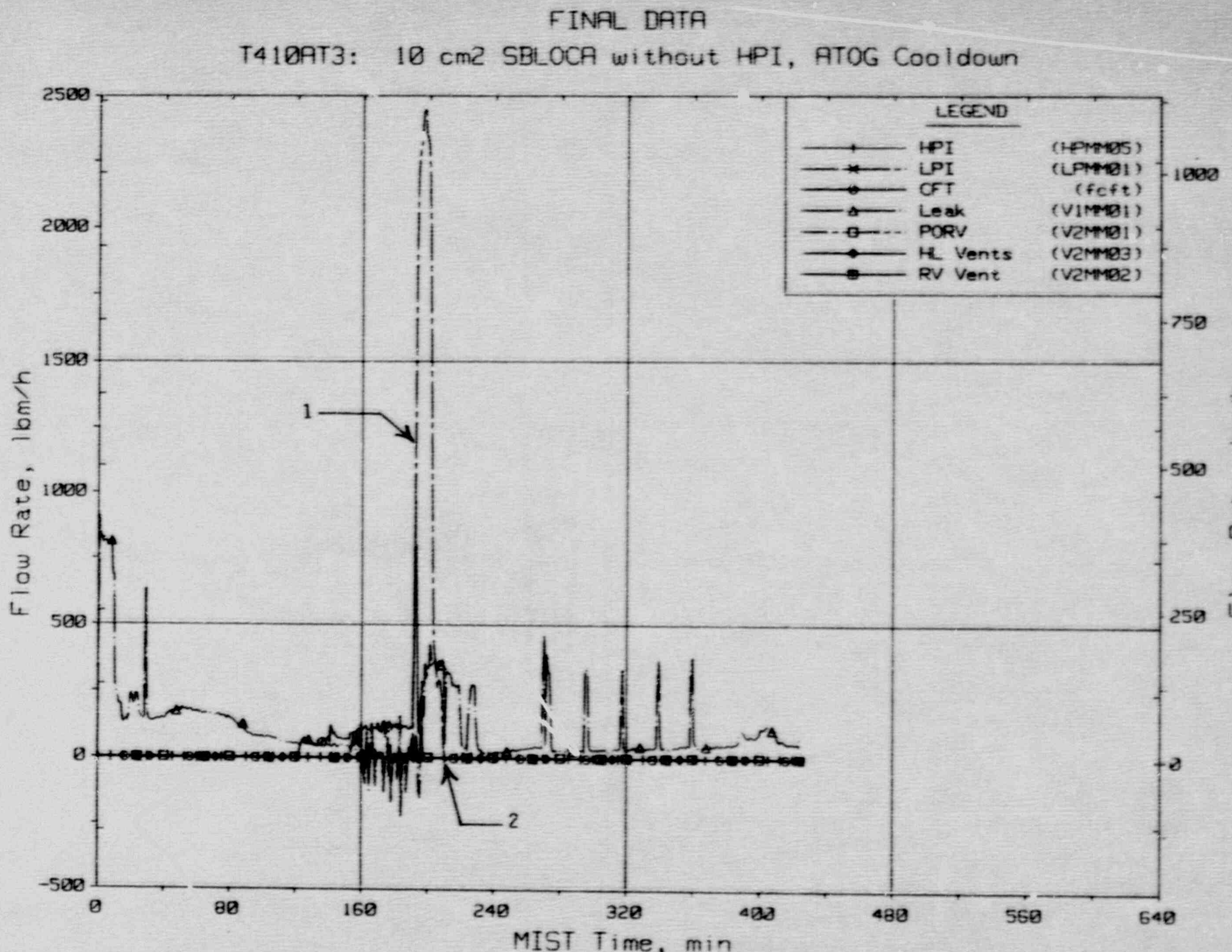



Figure 5.22 Primary System Boundary Flow Rates

Tue Nov 15 12:34:11 1988

PRFL3x

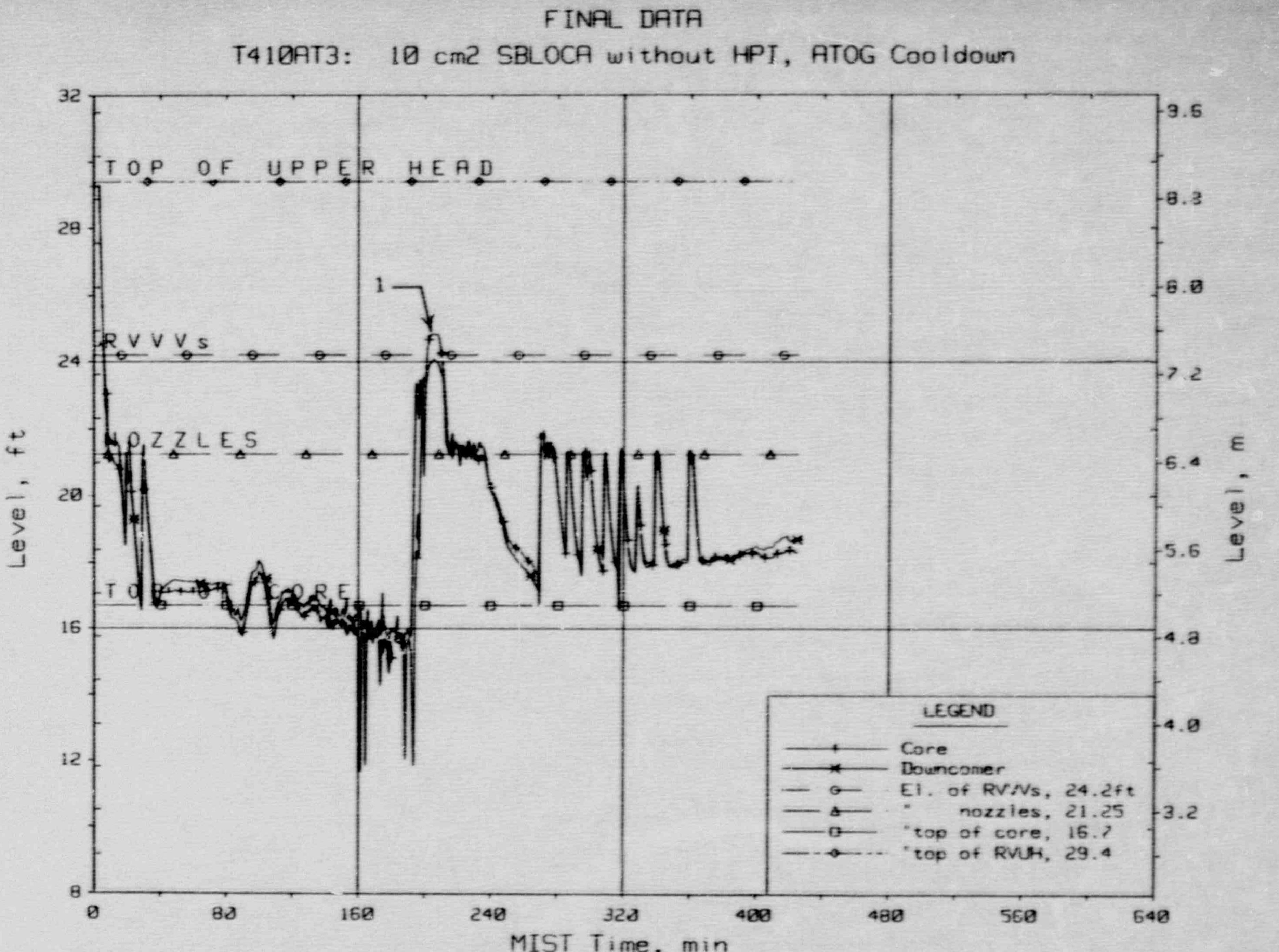



Figure 5.23 Core Region Collapsed Liquid Levels

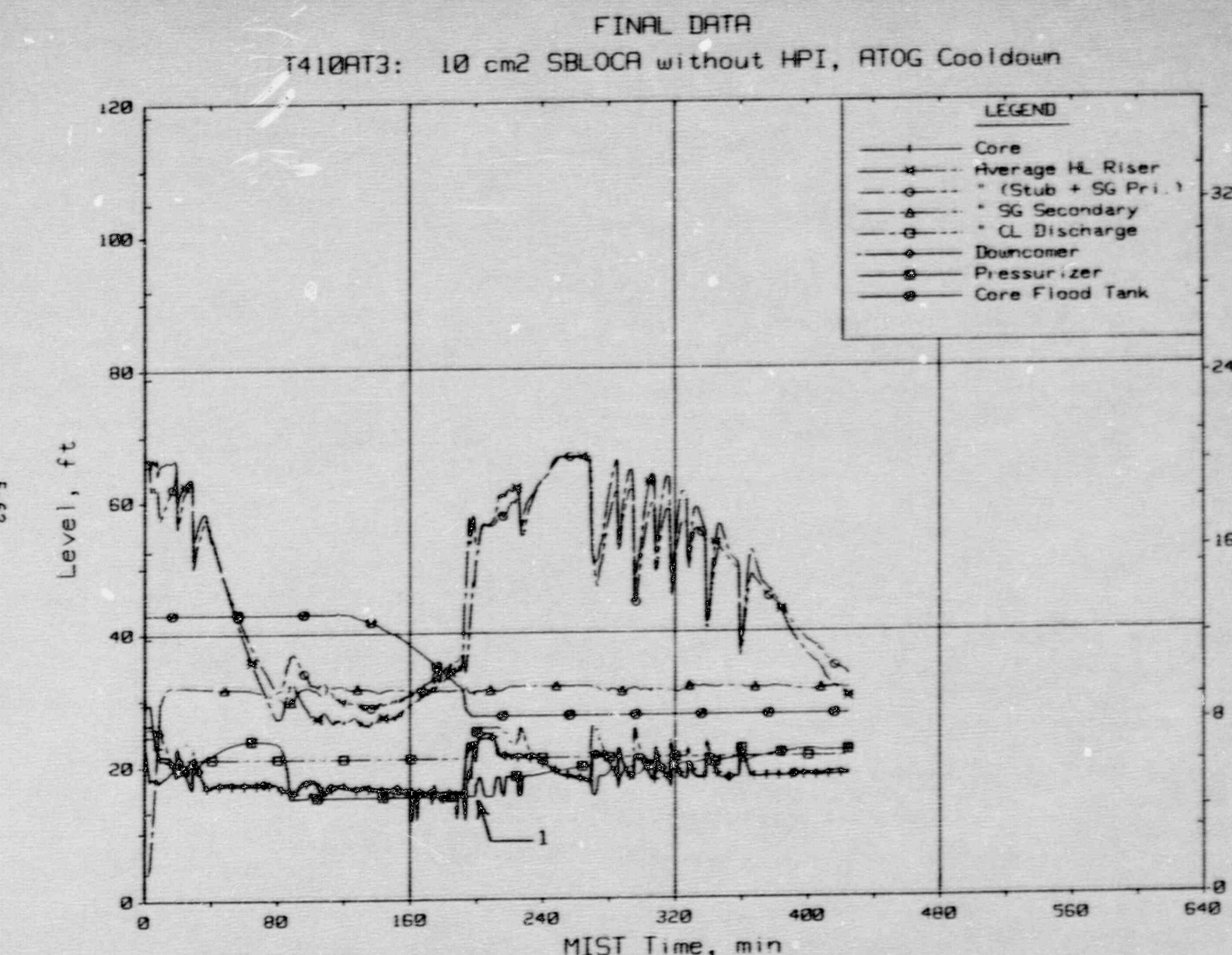



Figure 5.24 Composite Collapsed Liquid Levels

PRLV3

Tue Aug 23 16:29:14 1988

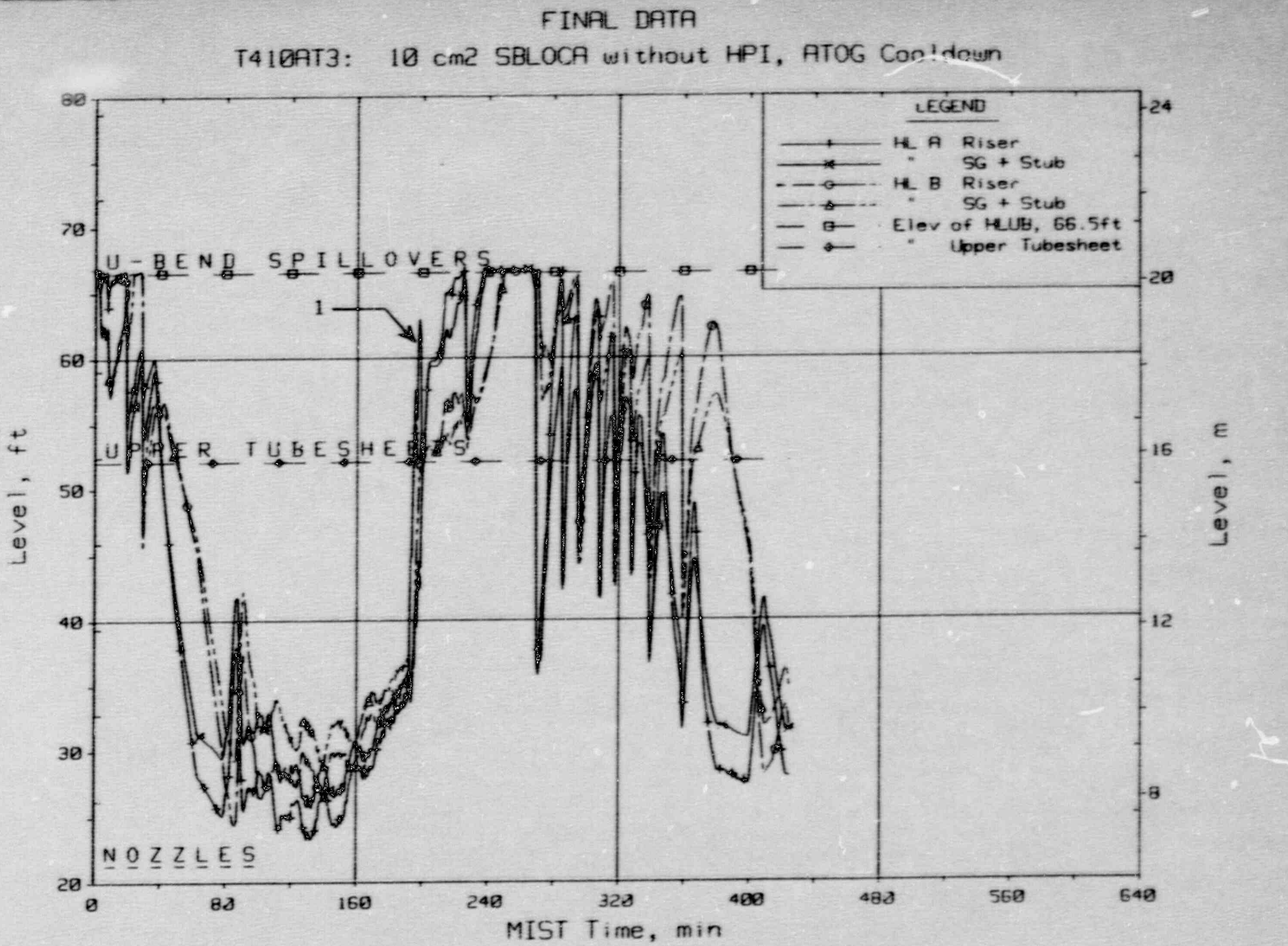



Figure 5.25 Hot Leg Riser and Stub Collapsed Liquid Levels

Tue Aug 23 16:28:14 1988

HLLV1

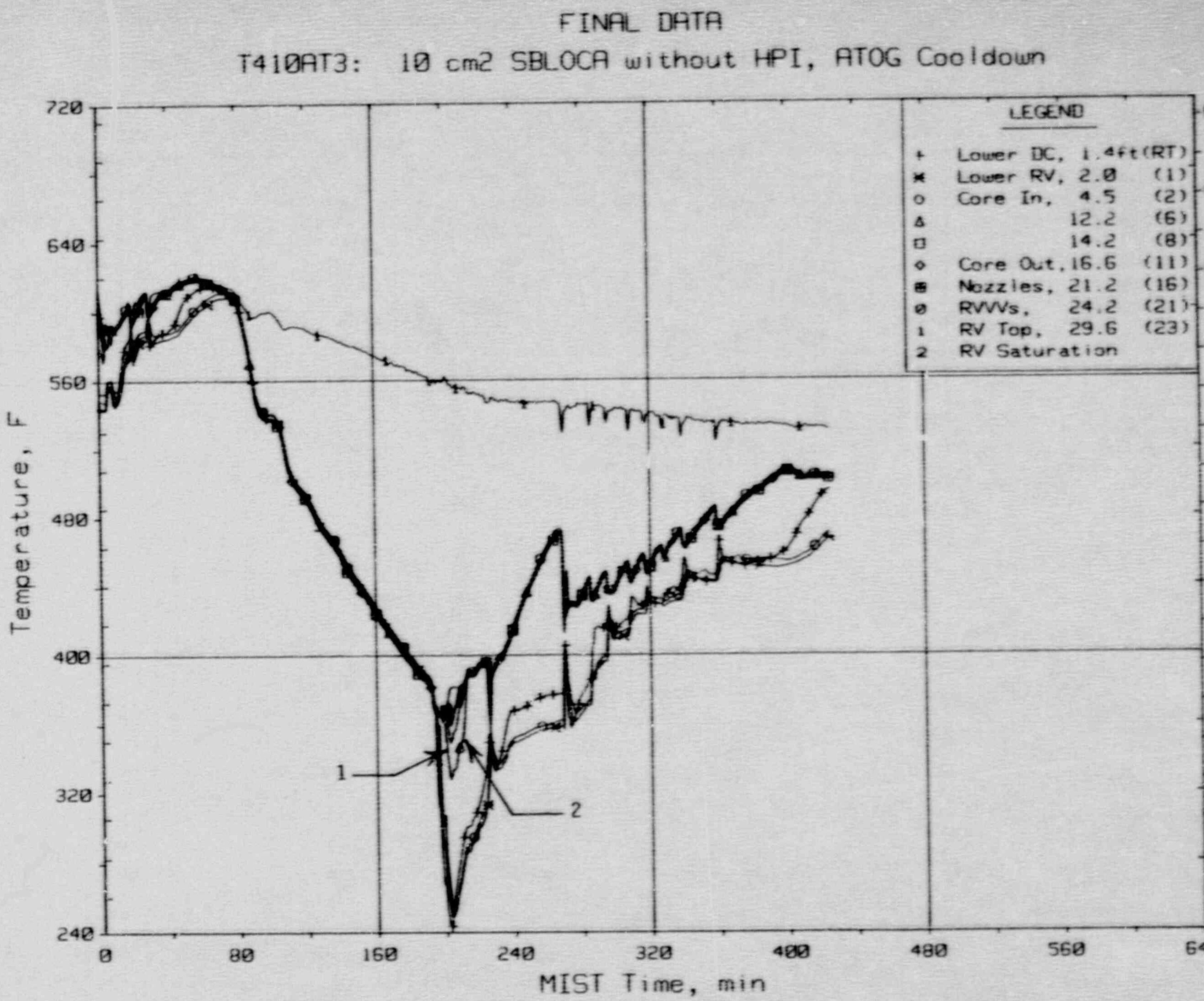



Figure 5.26 Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs)



Tue Aug 23 16:22:21 1988

RVTC0

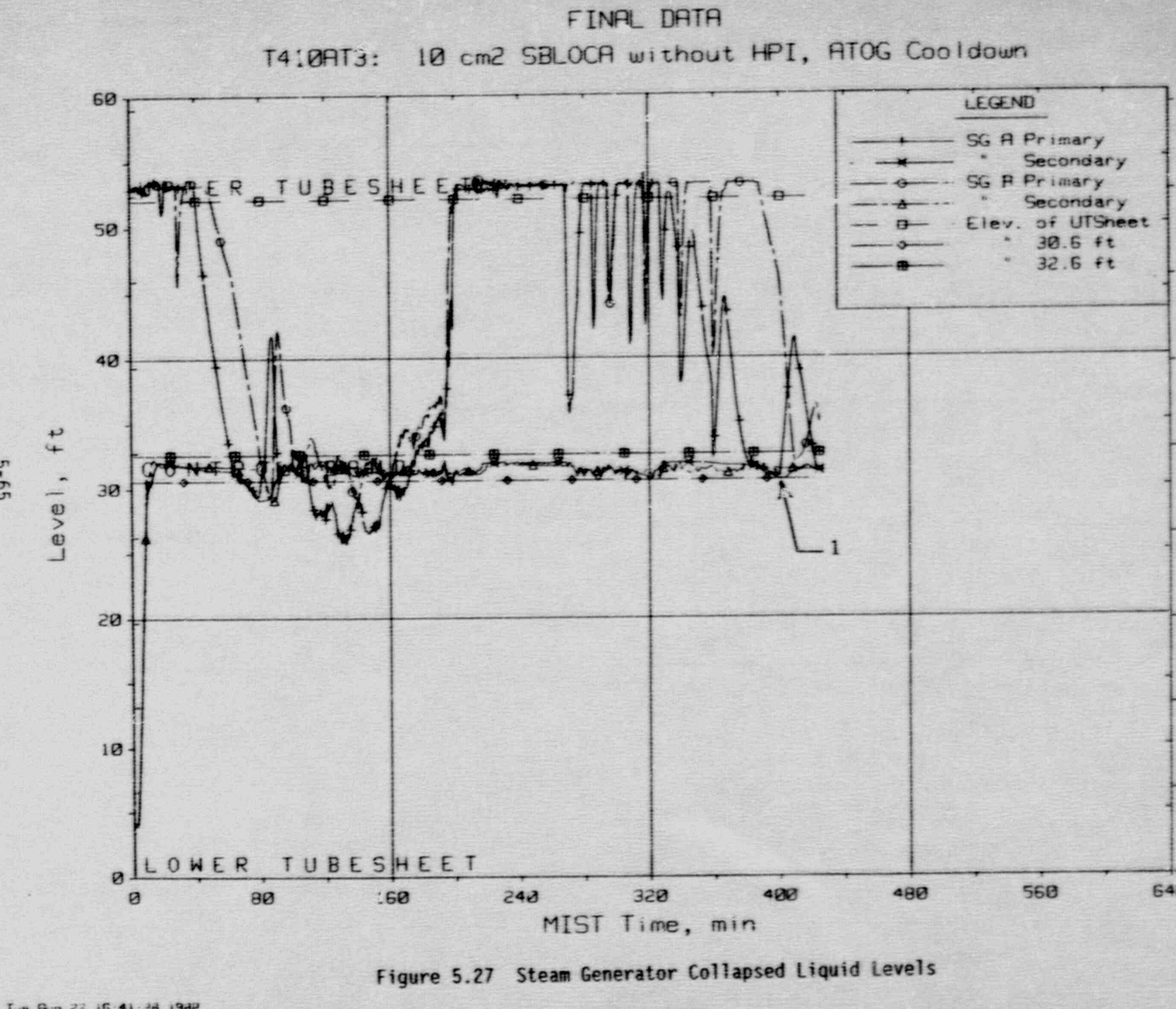



Figure 5.27 Steam Generator Collapsed Liquid Levels

SGLV2

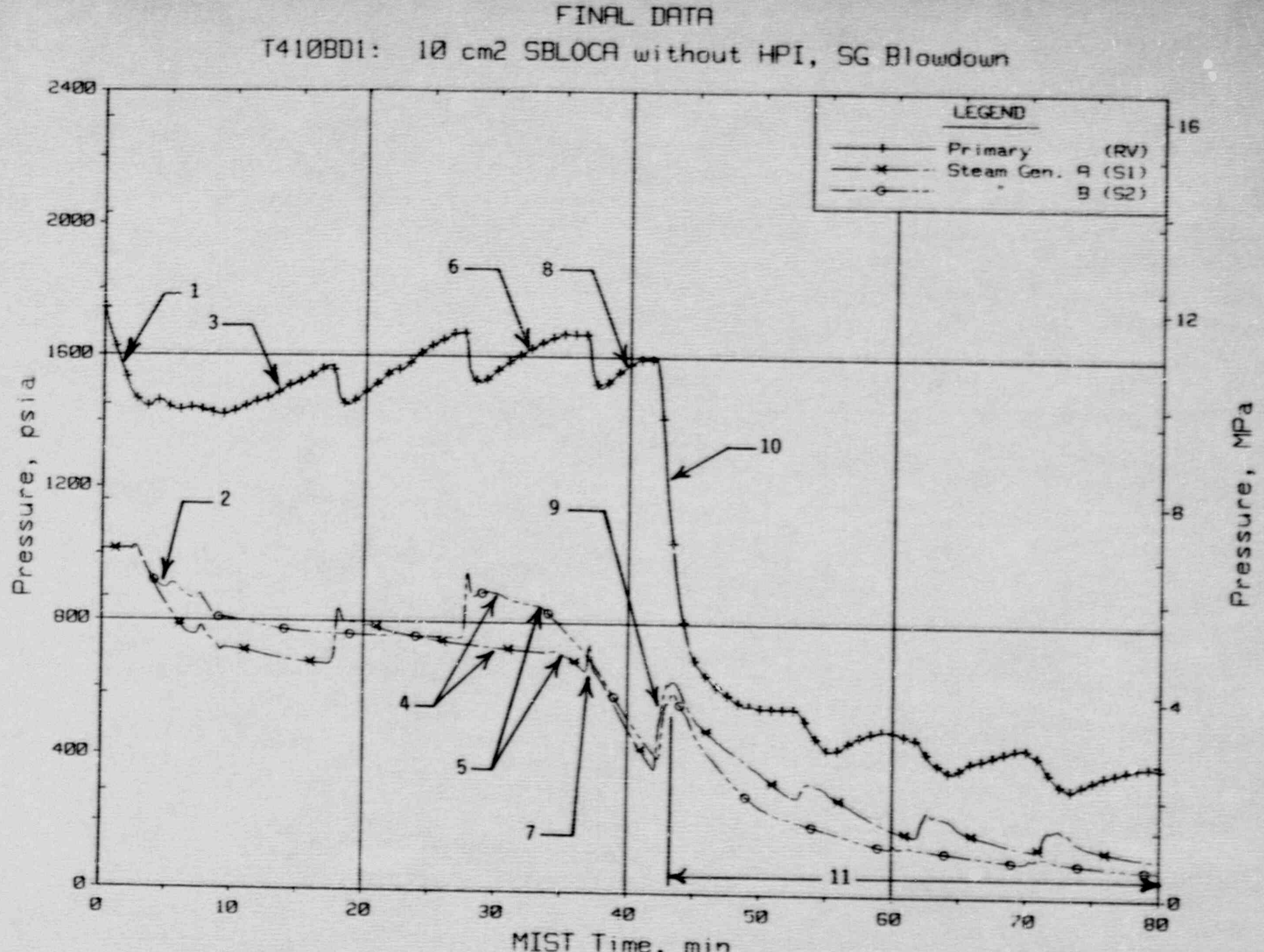



Figure 5.28 Primary and Secondary System Pressures (GPOIs)

Wed Sep 28 11:09:51 1988

PSGP1

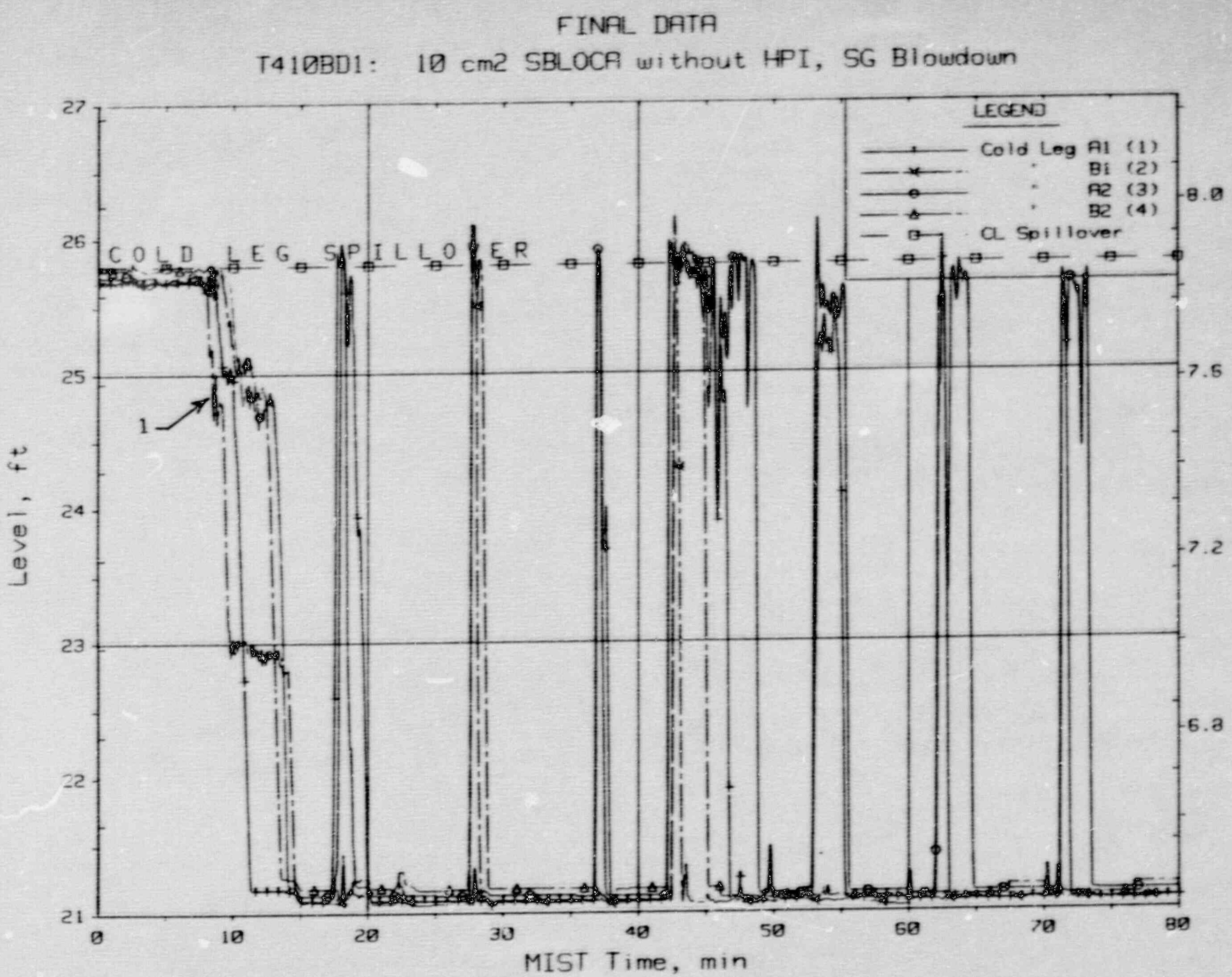



Figure 5.29 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

CLLV5

Wed Sep 28 11:04:57 1988

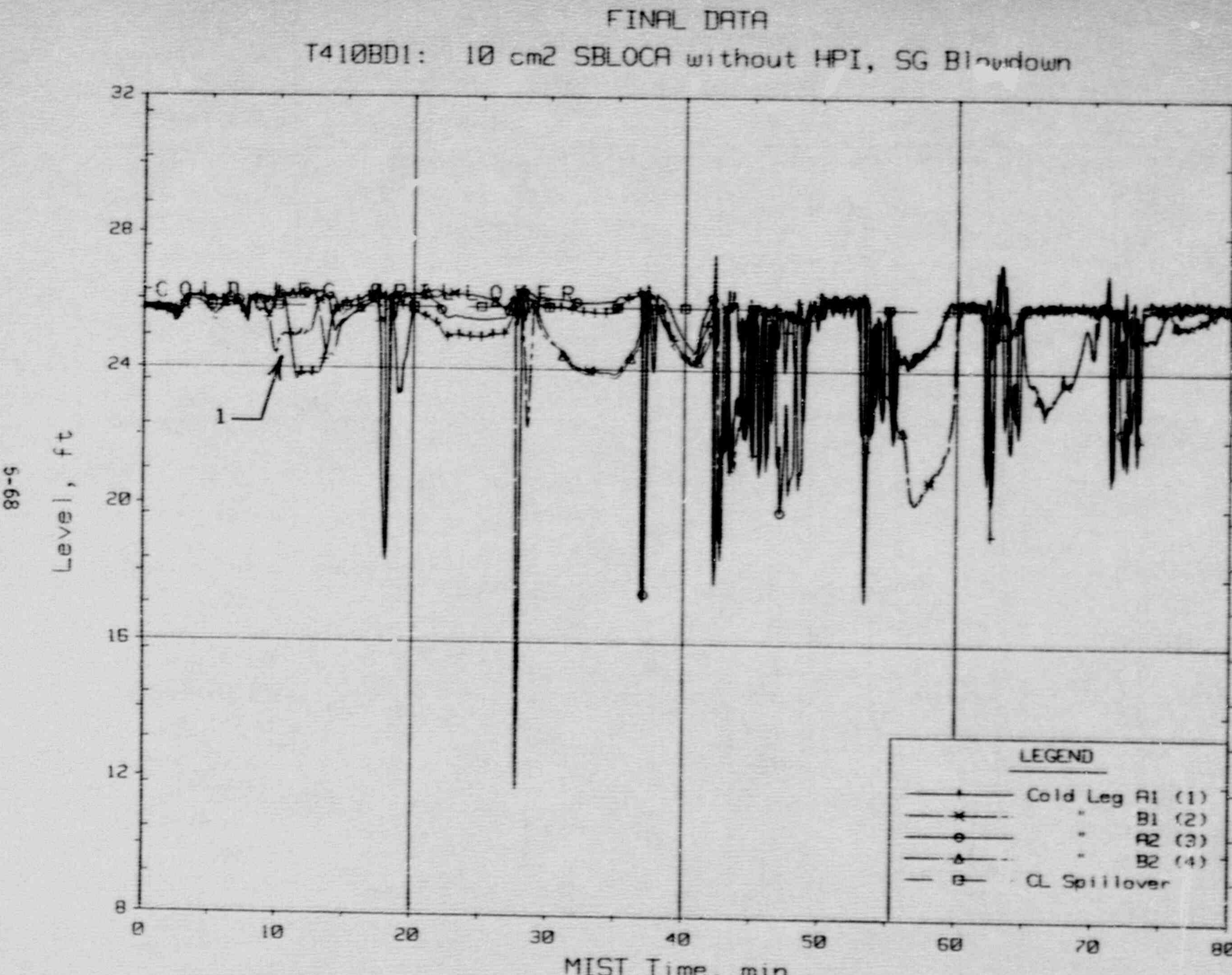



Figure 5.30 Cold Leg Suction Collapsed Liquid Levels (CnLV22s)

Wed Sep 28 11-09-04 1988

CLLV4

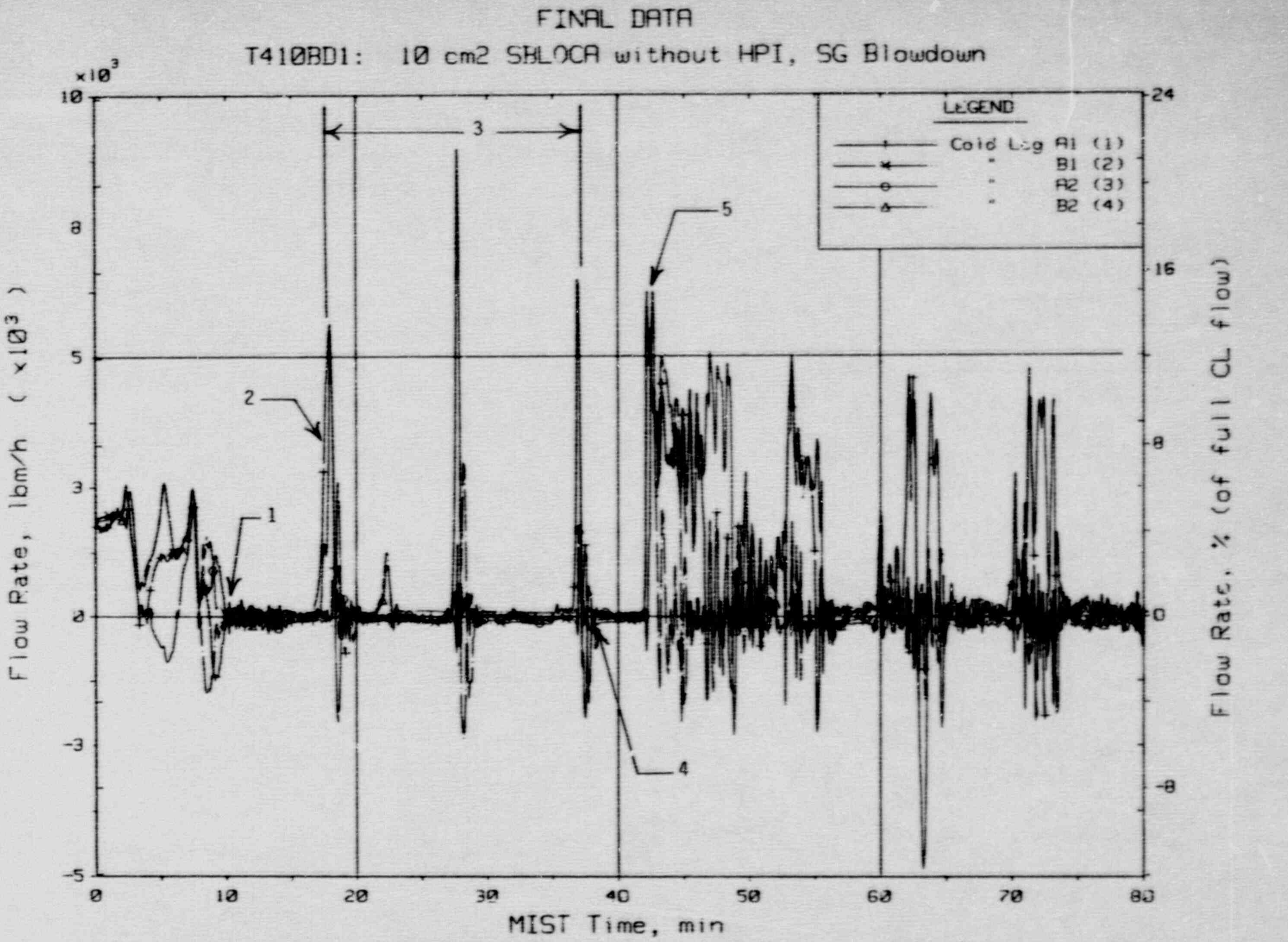



Figure 5.31 Cold Leg (Venturi) Flow Rates (CnVN20s)

Tue Nov 1 11:01:22 1988

CLFLO

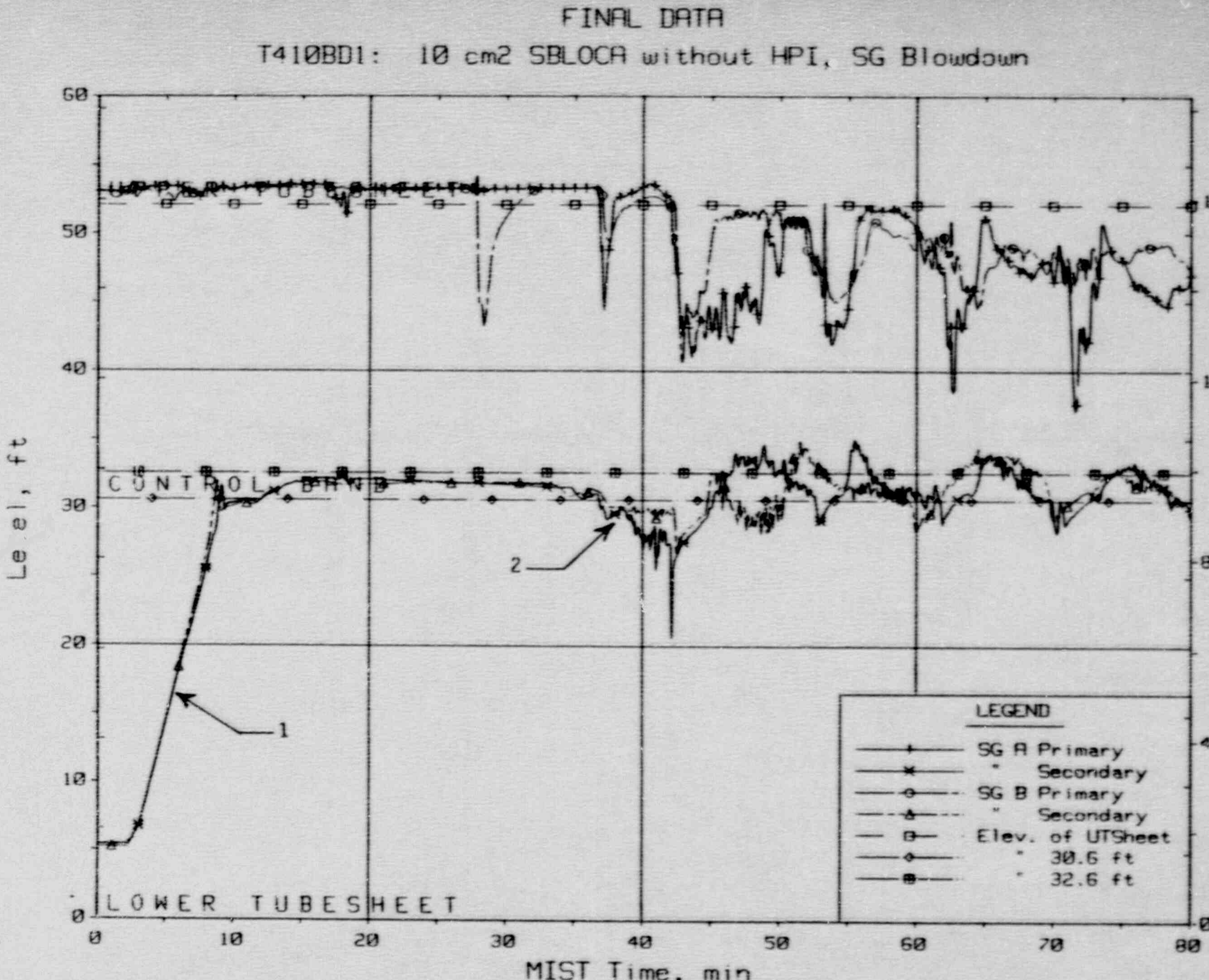



Figure 5.32 Steam Generator Collapsed Liquid Levels

Wed Sep 28 11:21:28 1988

SCLV2

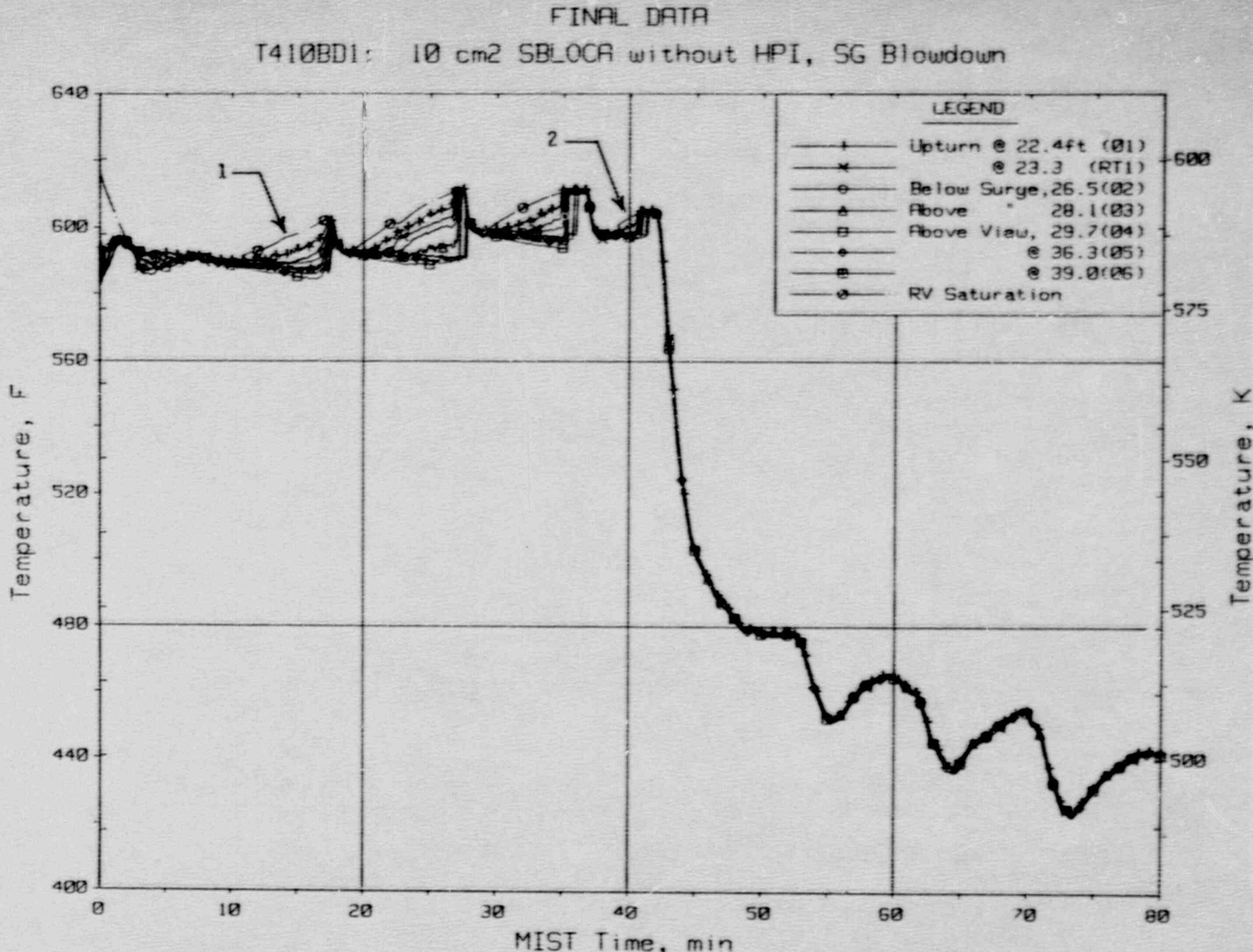



Figure 5.33 Hot Leg A Lower-Elevation Riser Fluid Temperatures (HITCs)

Wed Sep 28 11:26:52 1988

HITC1

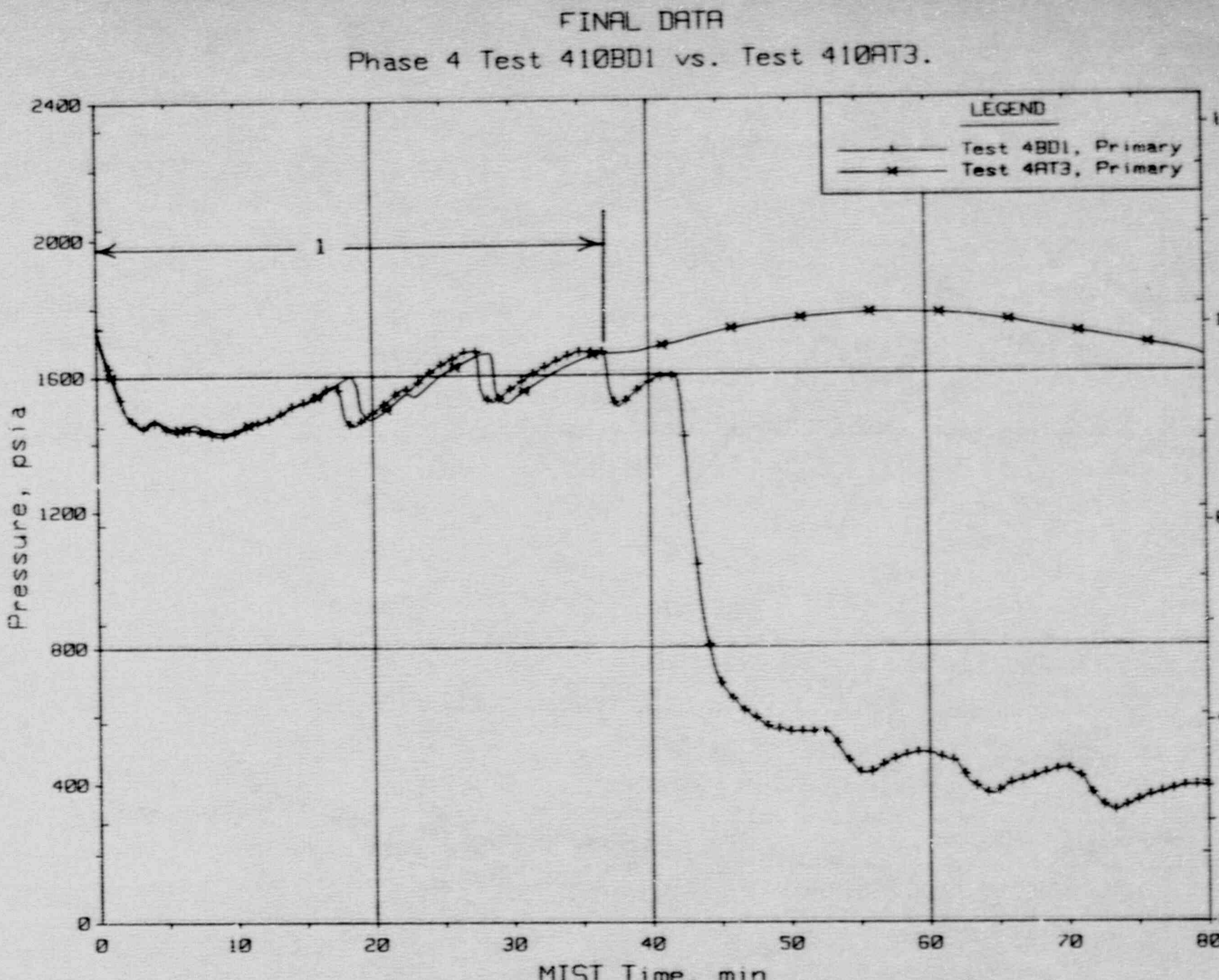



Figure 5.34 Primary System Pressures (GP01s)

Tue Oct 4 12:22:03 1988

abPSGP1

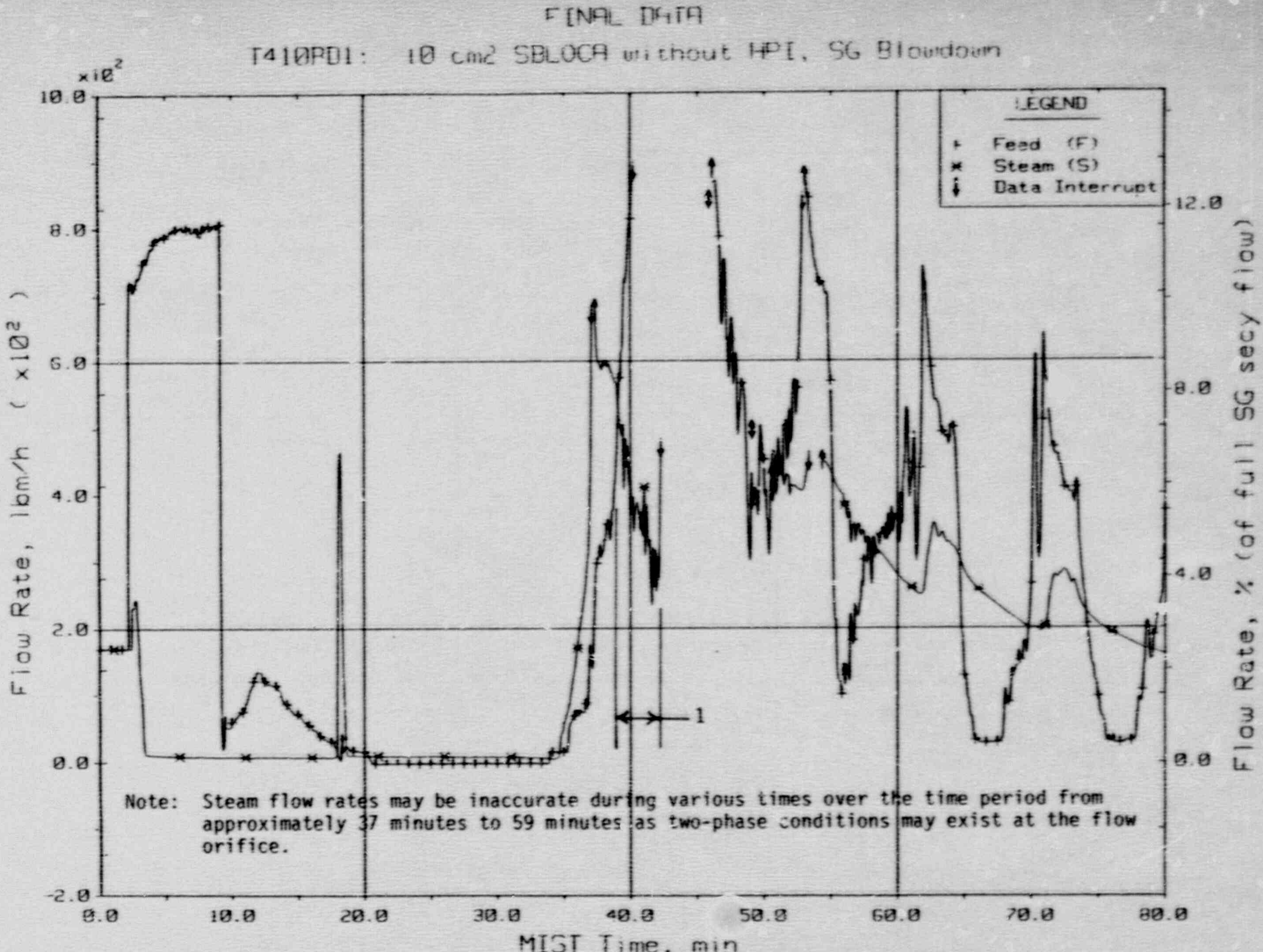



Figure 5.35 Steam Generator A Flow Rates (SaOR20s)



Wed Dec 30 12:00:01 1987

SCFL1

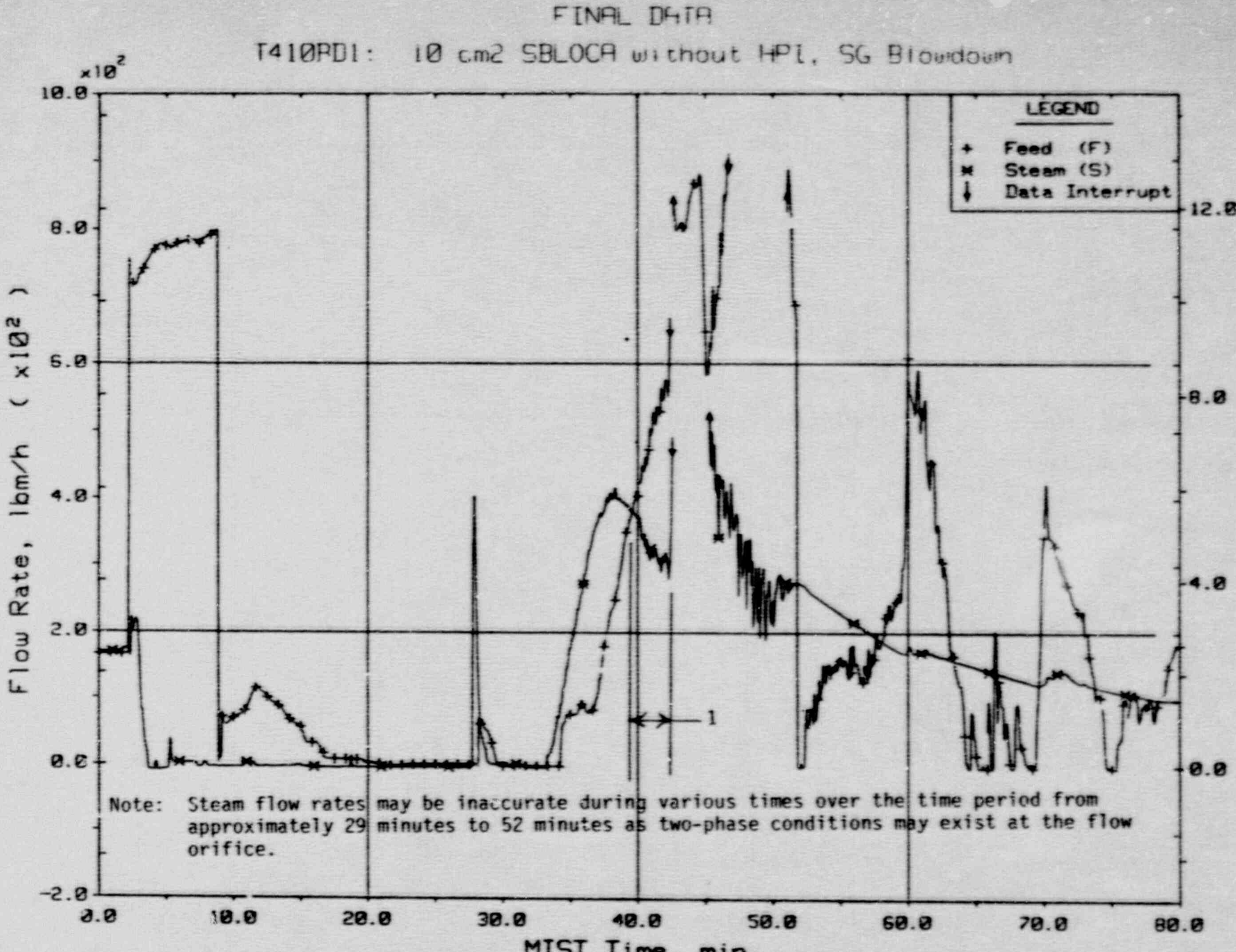



Figure 5.36 Steam Generator B Flow Rates (SaOR21s)



Wed Dec 30 11:57:20 1987

SCFL2

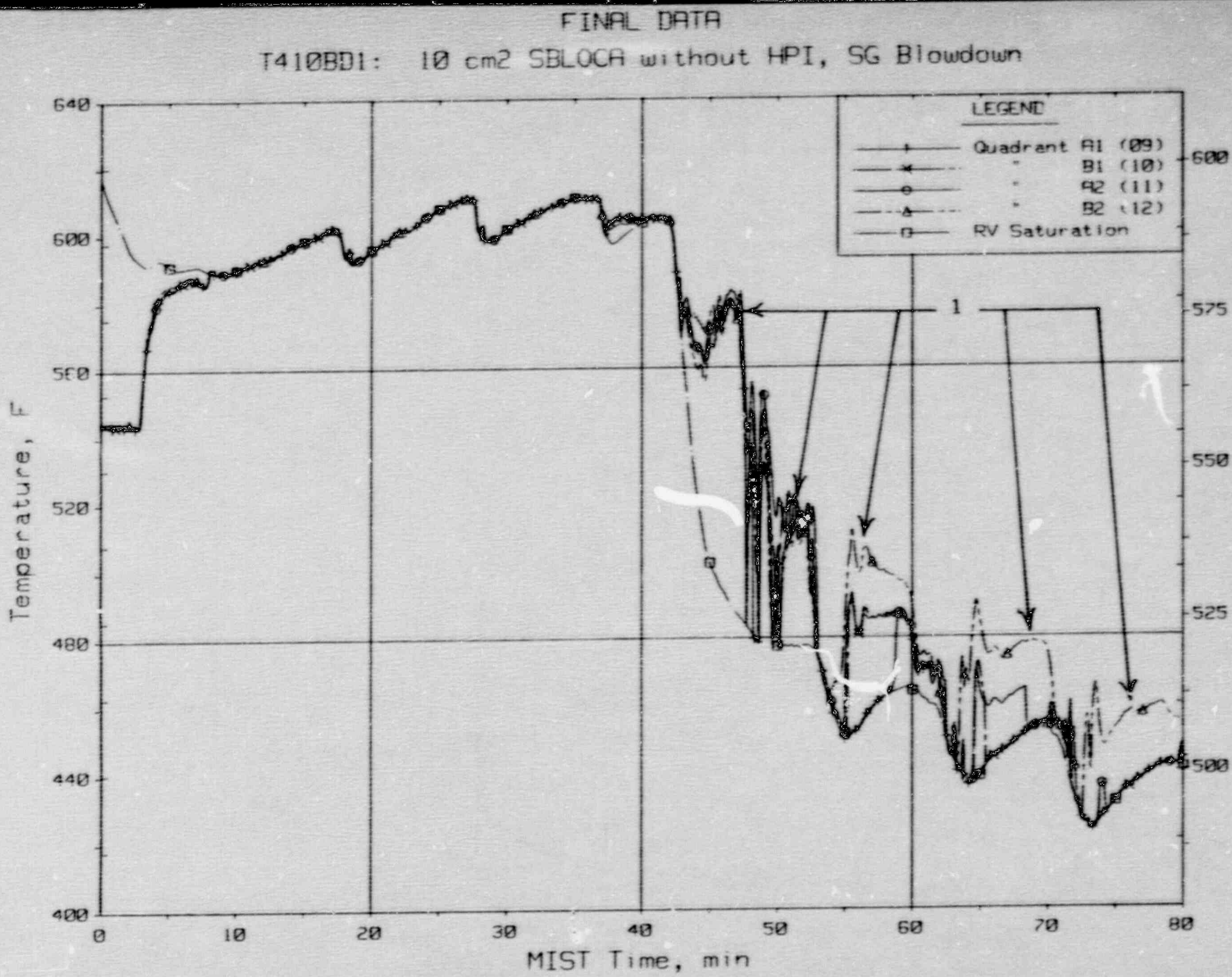



Figure 5.37 Downcomer Fluid Temperatures Above Nozzles, Elevation 21.9 ft (DCTCs)

DCTR6

Thu Sep 29 10:39:22 1988

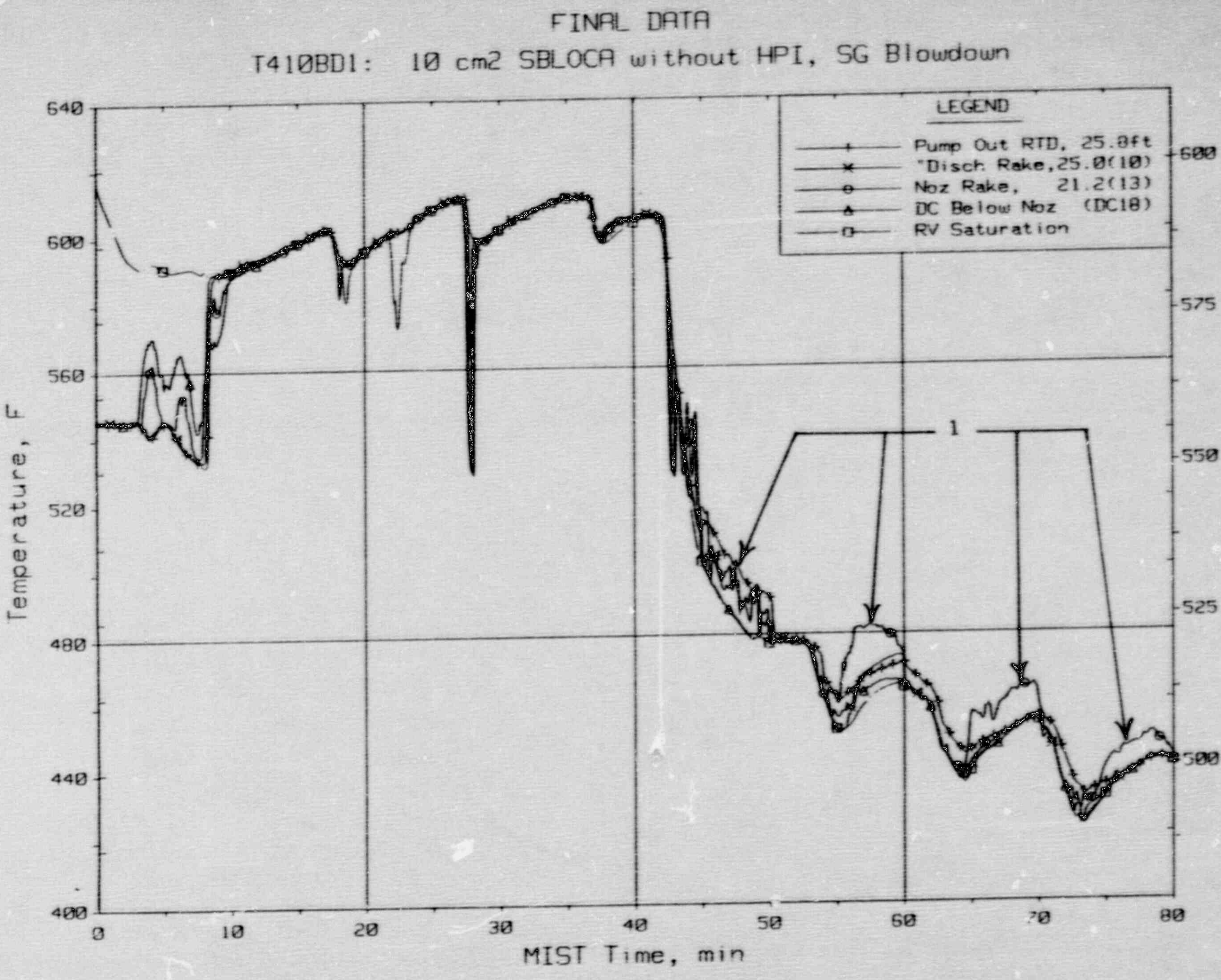



Figure 5.38 Cold Leg B1 Discharge Fluid Temperatures (C2TCs)

C2TC2

Wed Sep 28 11:26:07 1988

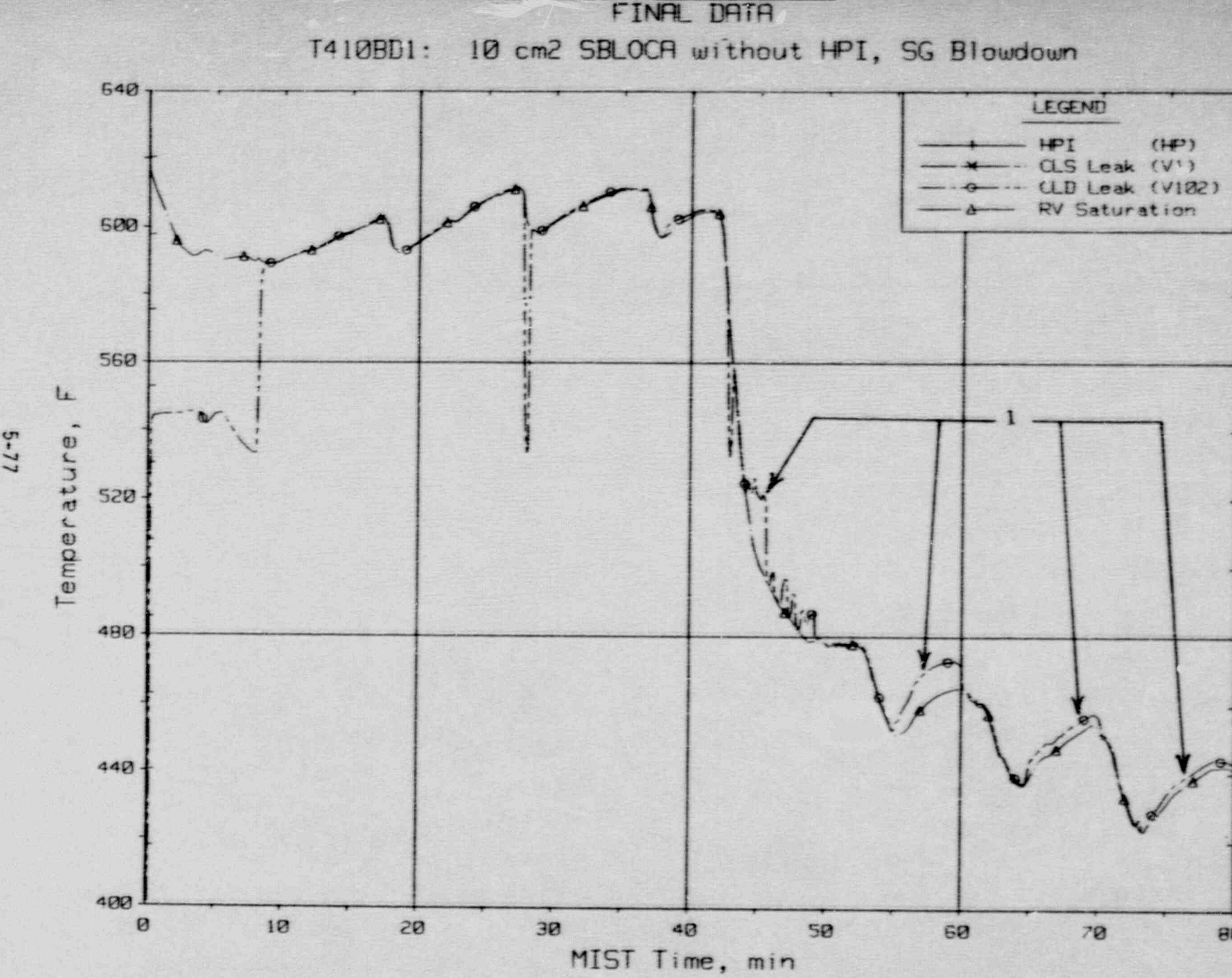



Figure 5.39 Single-Phase Discharge and HPI Fluid Temperatures (TC01s)

Thu Sep 29 10:51:47 1988

PRTC1

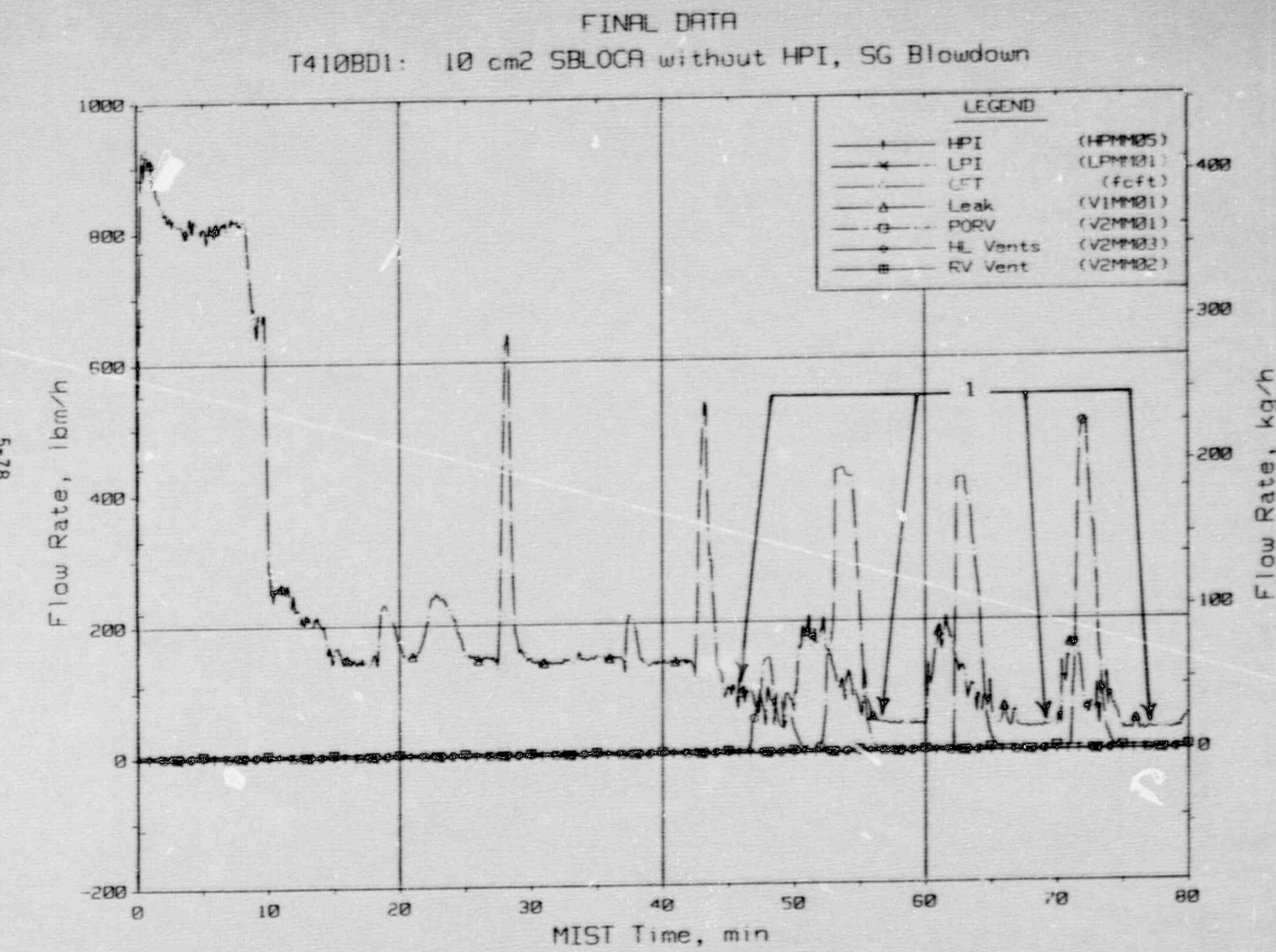



**Figure 5.40 Primary System Boundary Flow Rates**

PRFL3p

Wed Sep 28 11:50:17 1988

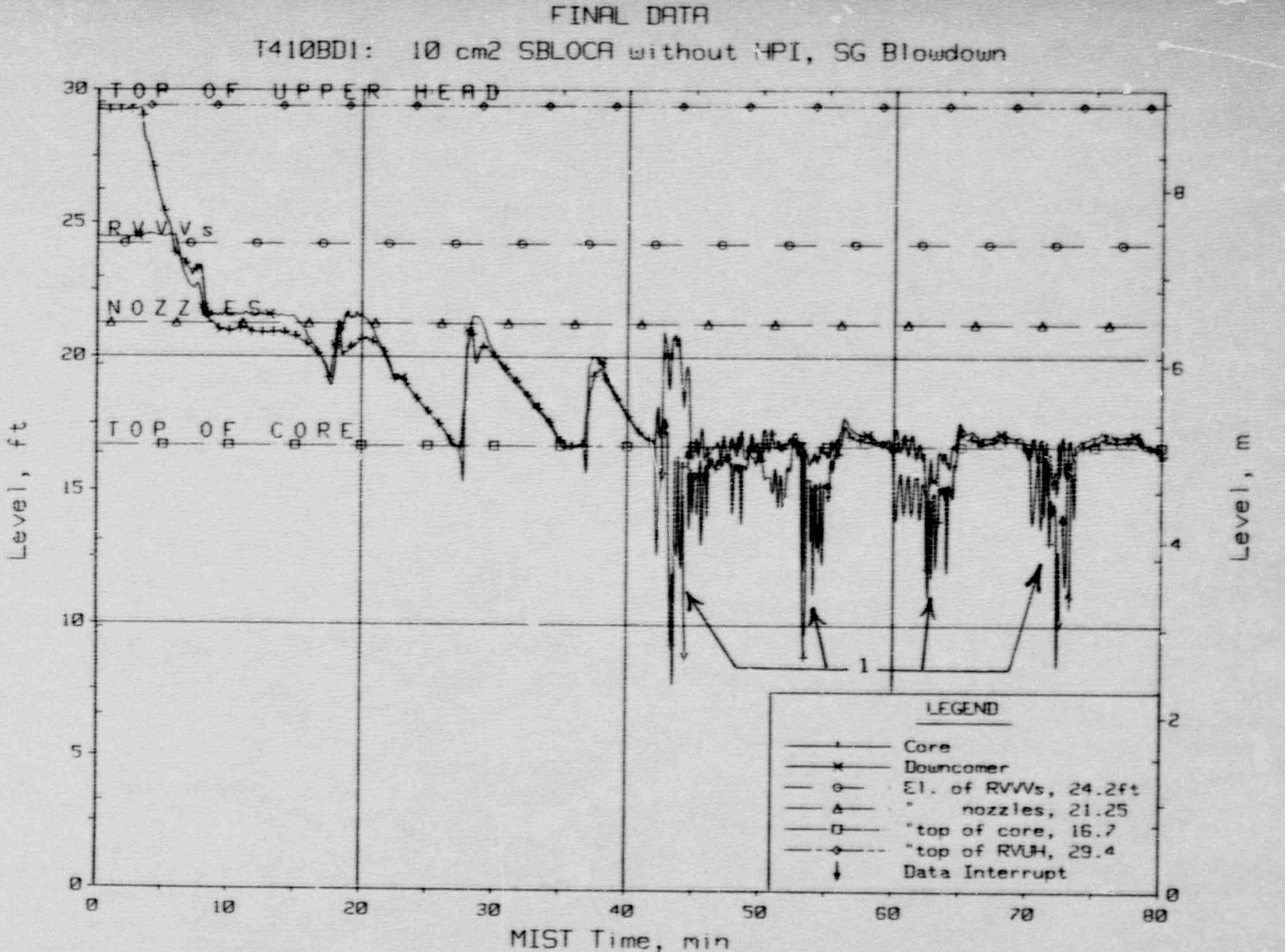
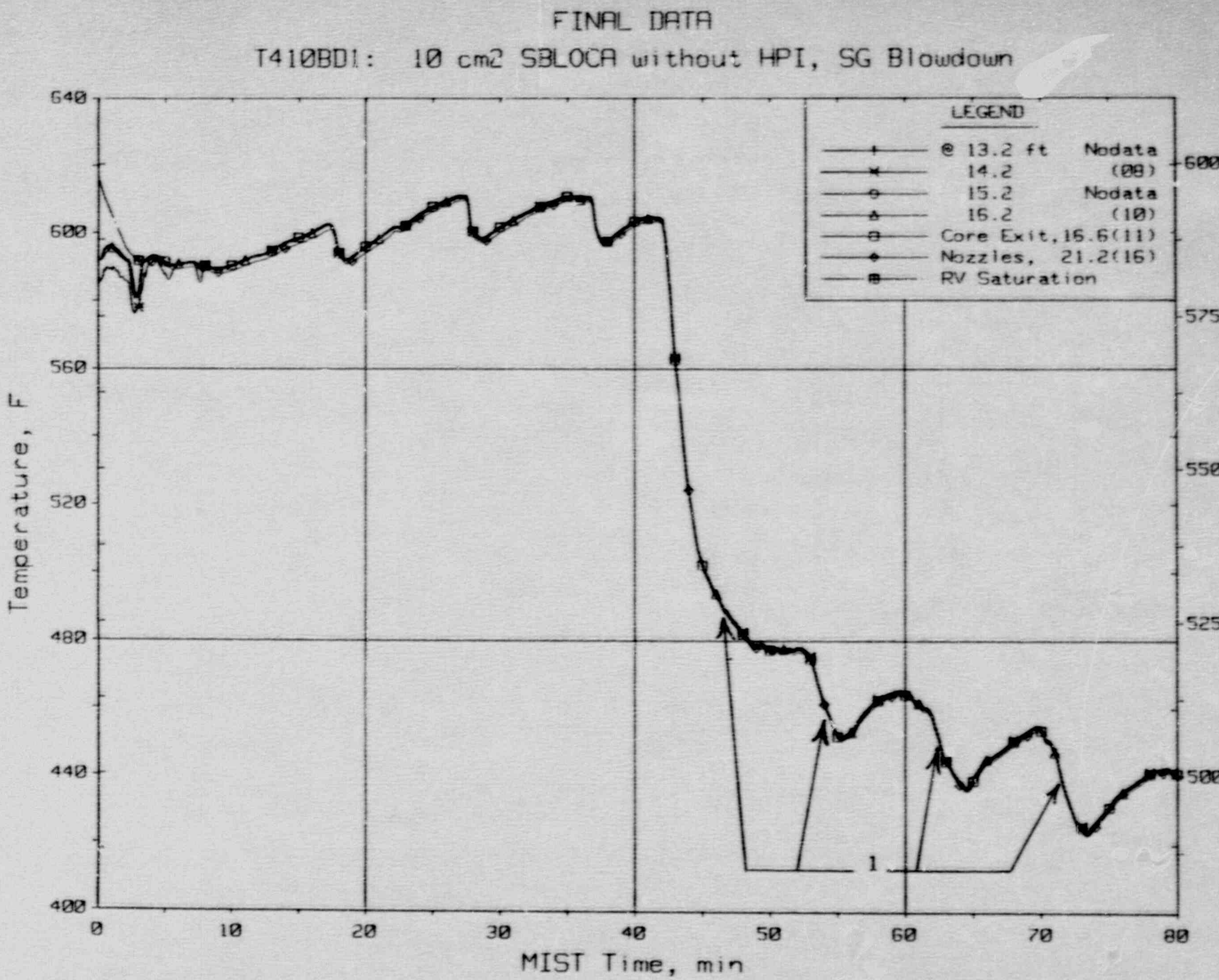



Figure 5.41 Core Region Collapsed Liquid Levels

Wed Sep 28 11:54:20 1988

COLV1




5-80

**Figure 5.42 Reactor Vessel Mid-Elevation Fluid Temperatures (RVTCs)**

Wed Sep 28 11:42:07 1988

RVTC2

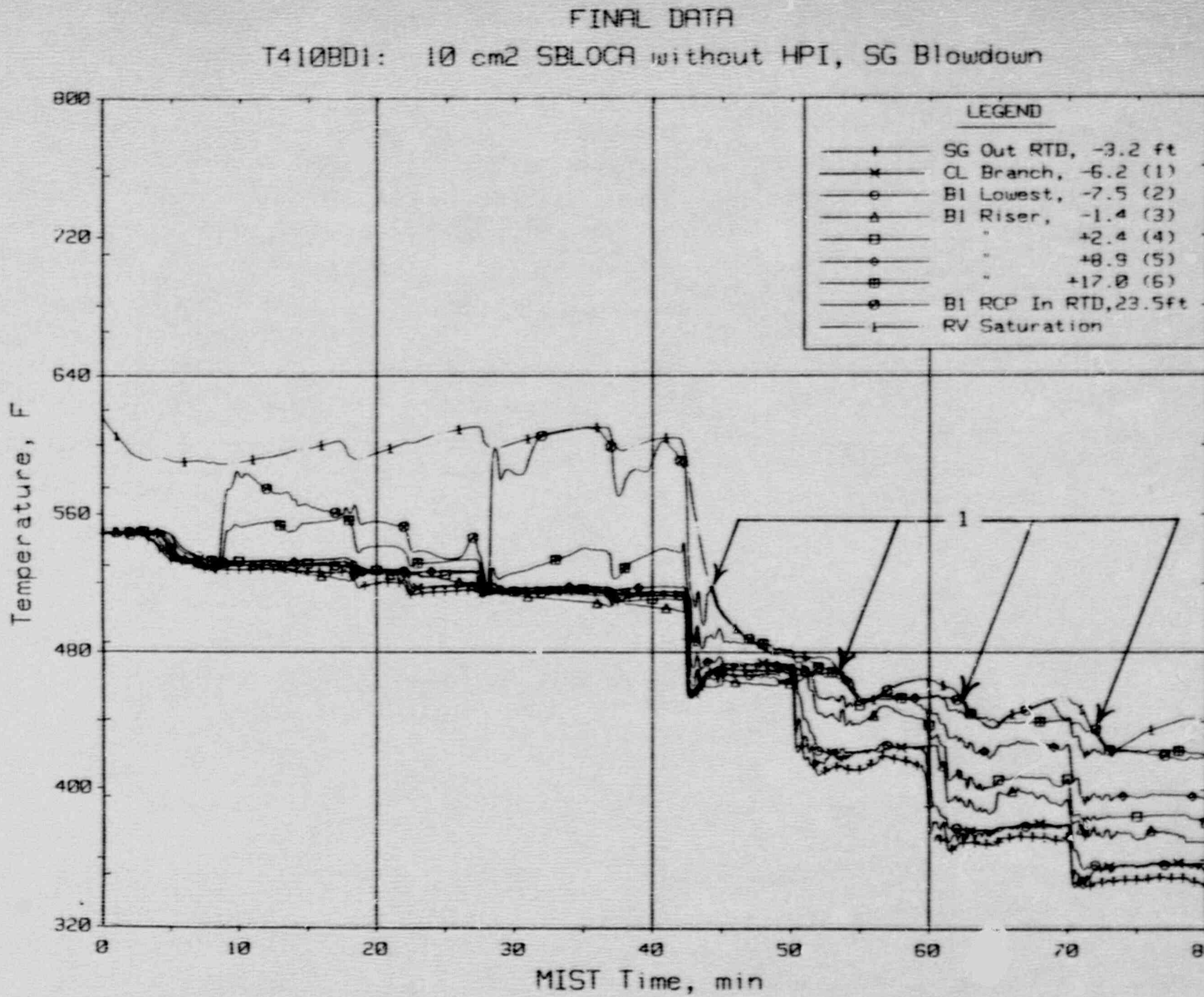



Figure 5.43 Cold Leg B1 Suction Fluid Temperatures (C2TCs)

Wed Sep 28 12:00:09 1988

C2TC1

FINAL DATA

T410BD1: 10 cm2 SBLOCA without HPI, SG Blowdown

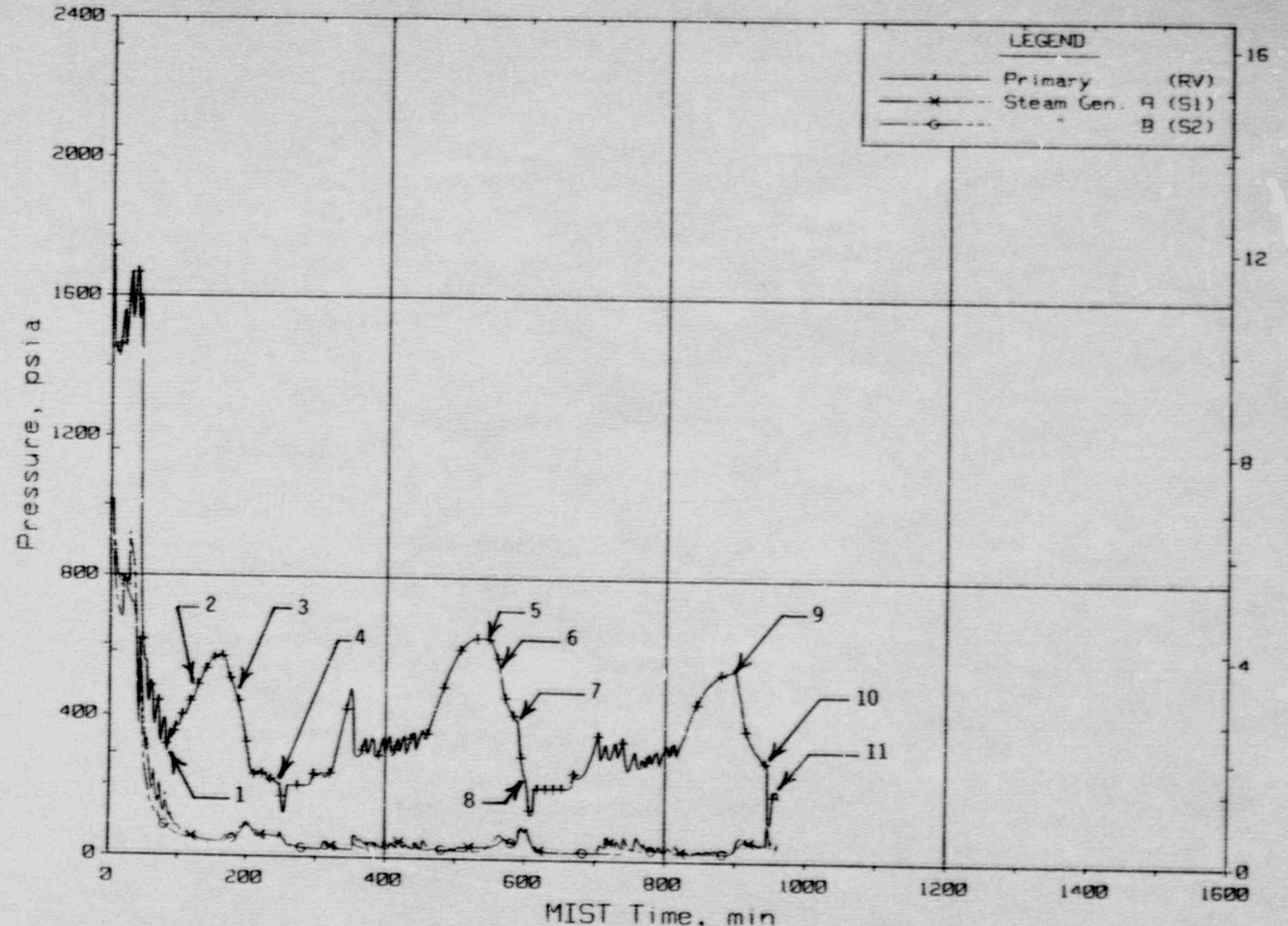



Figure 5.44 Primary and Secondary System Pressures (GPOIs)

Wed Sep 28 12:02:59 1988

PSGP1

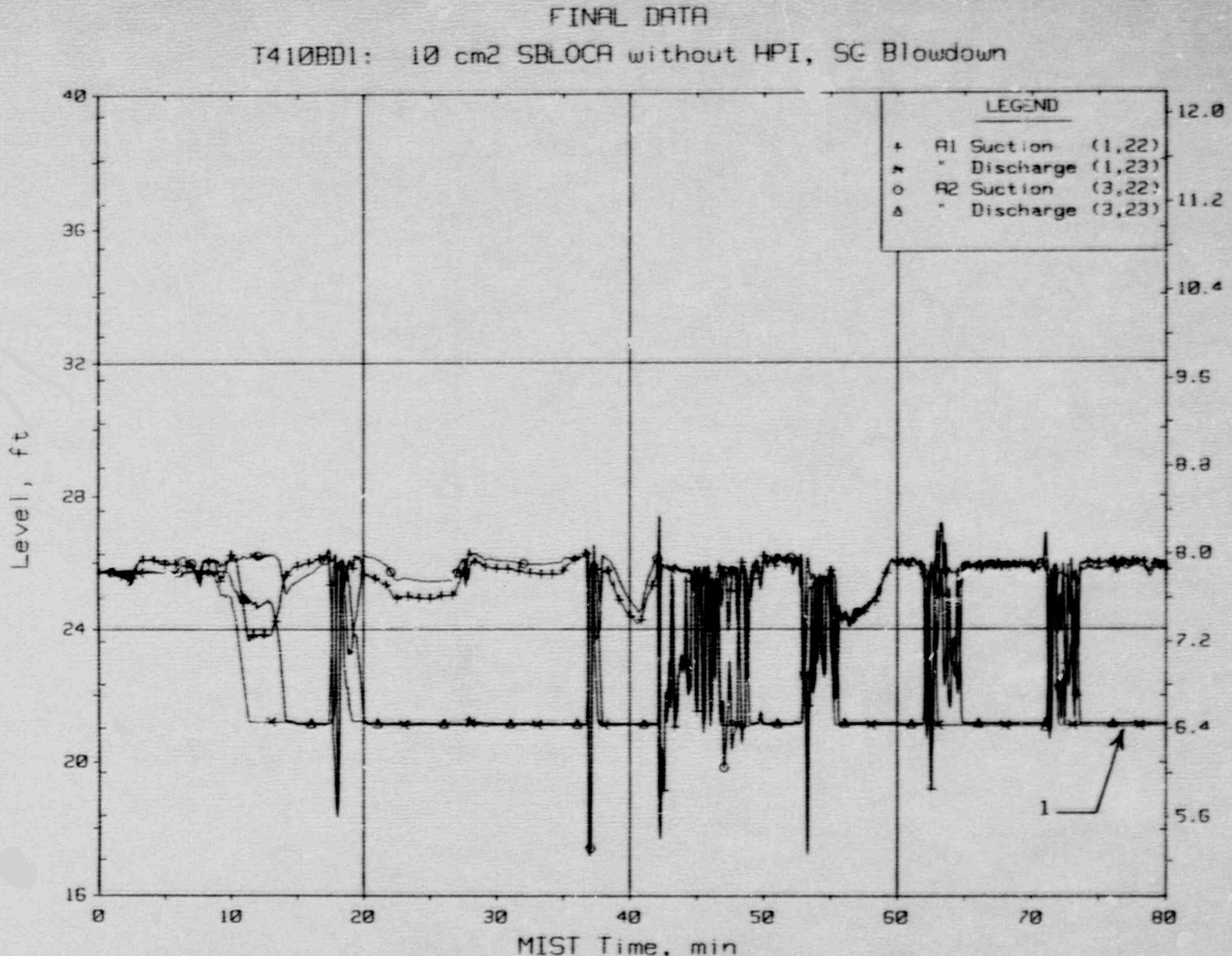



Figure 5.45 Loop A Cold Leg Collapsed Liquid Levels (LVs)

Wed Sep 28 12:06:11 1988

CLLV1

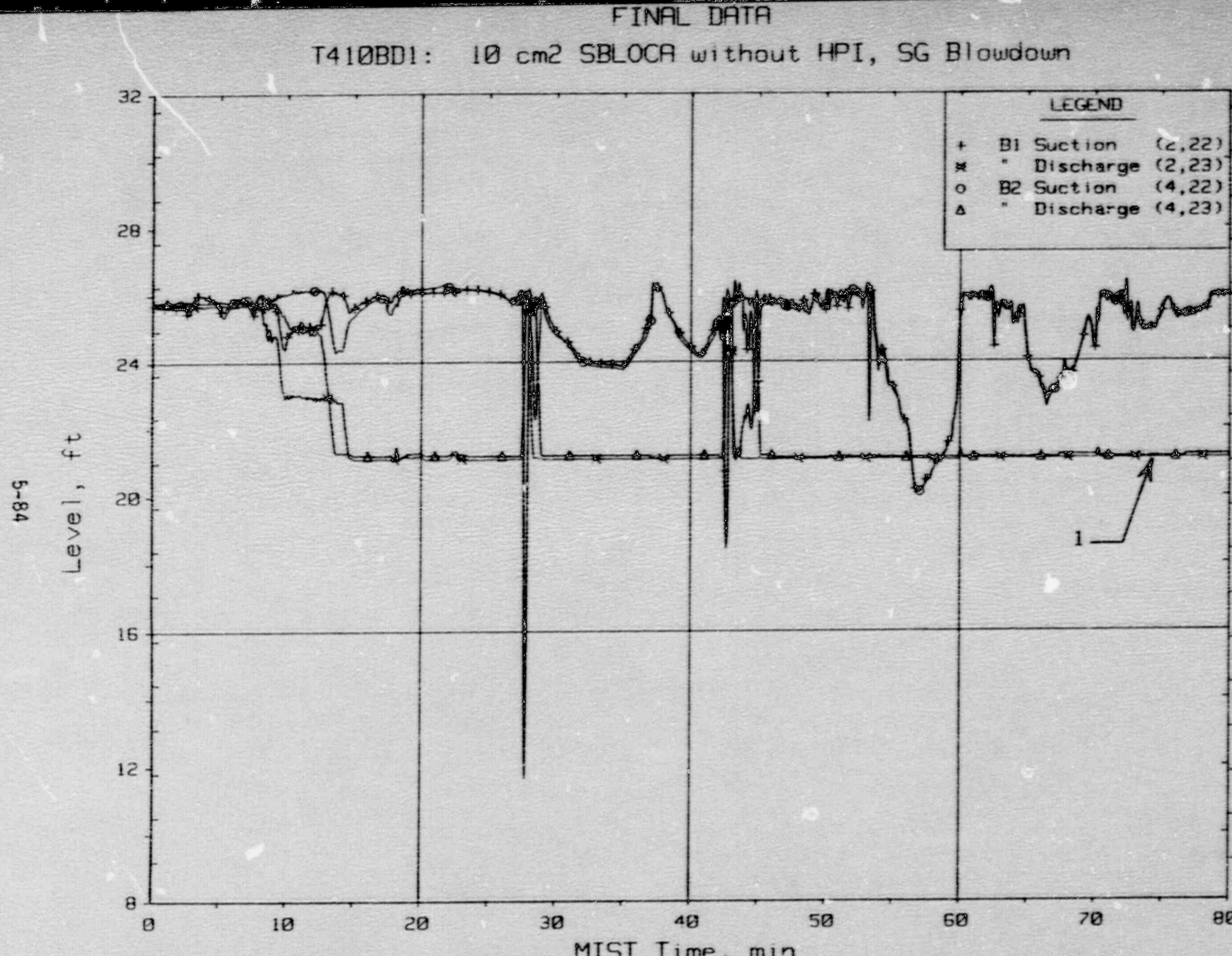



Figure 5.46 Loop B Cold Leg Collapsed Liquid Levels (LVs)

Wed Sep 28 12:09:20 1988

CLLV2

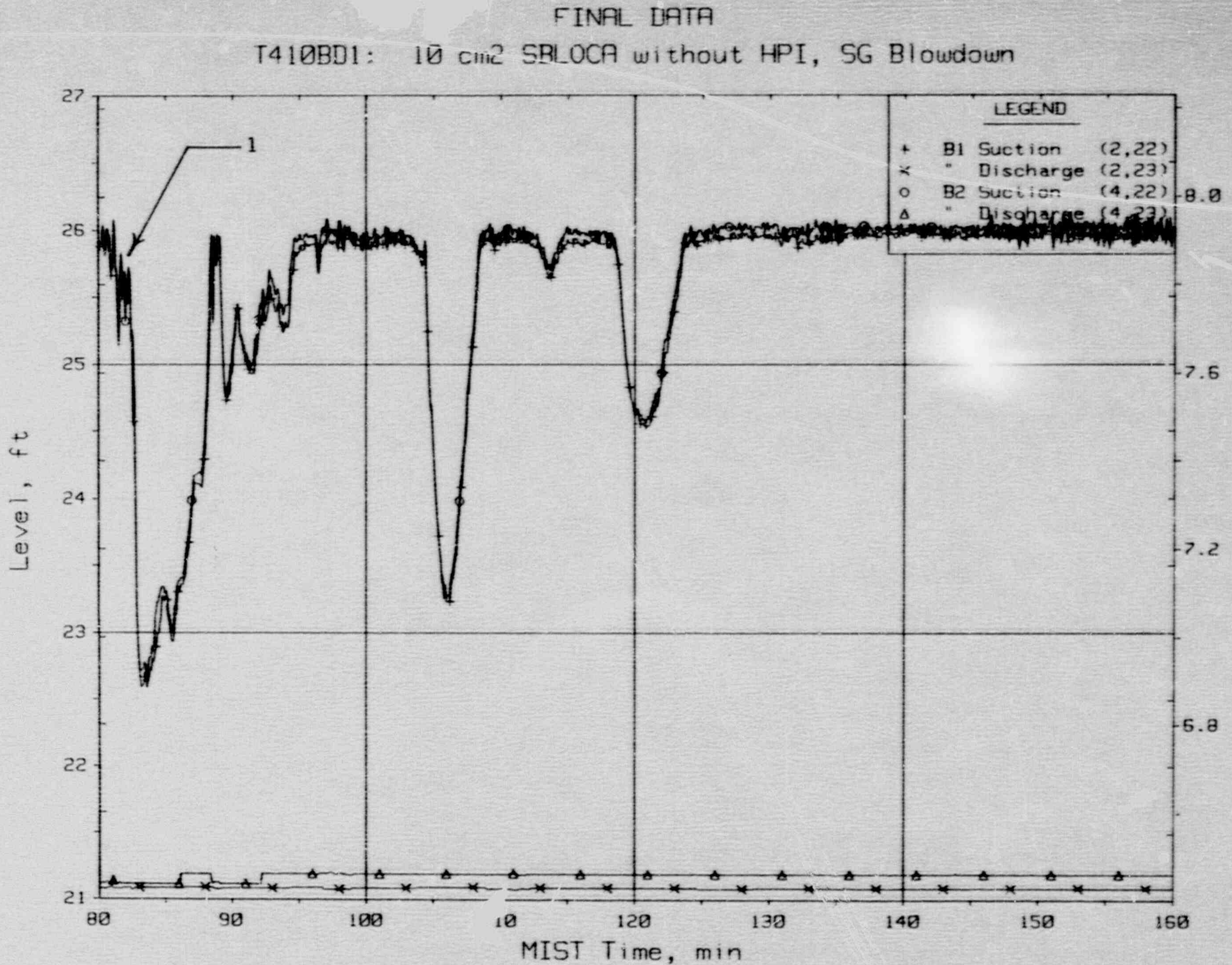



Figure 5.47 Loop B Cold Leg Collapsed Liquid Levels (LVs)

Wed Sep 28 12:12:28 1988

CLLV2

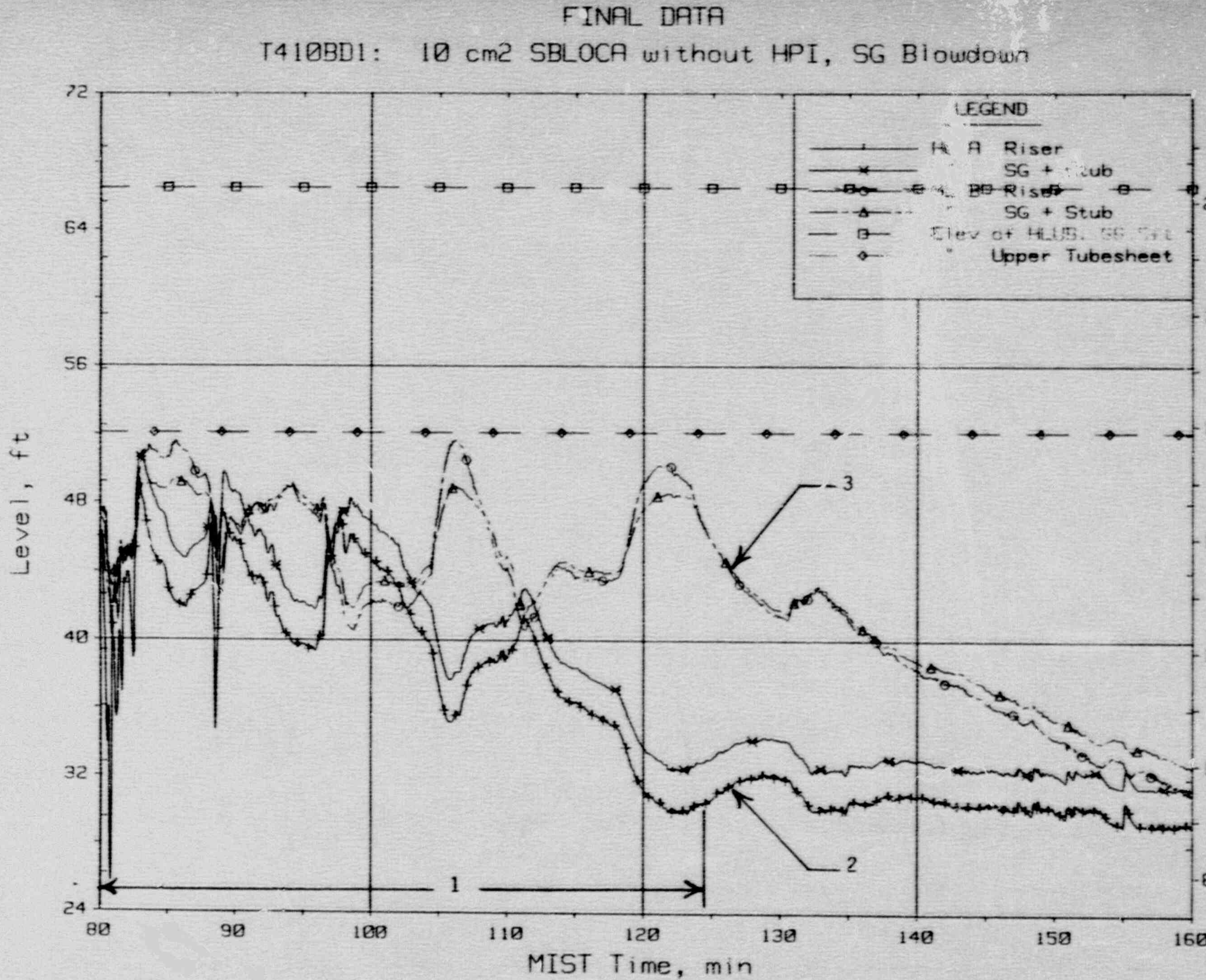



Figure 5.48 Hot Leg Riser and Stub Collapsed Liquid Levels

Wed Sep 28 12:16:43 1988

HLLV1

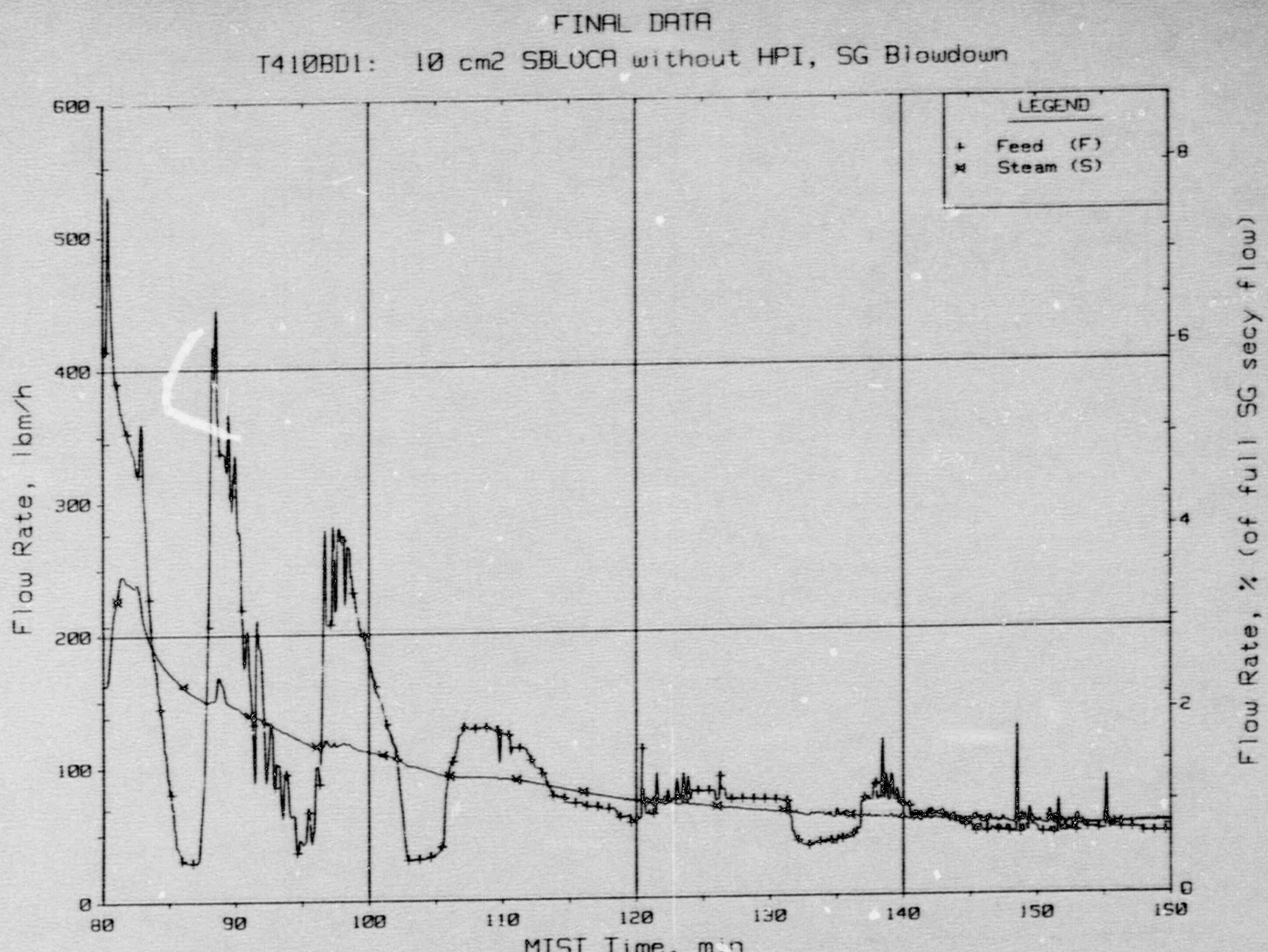



Figure 5.49 Steam Generator A Flow Rates (SaOR20s)

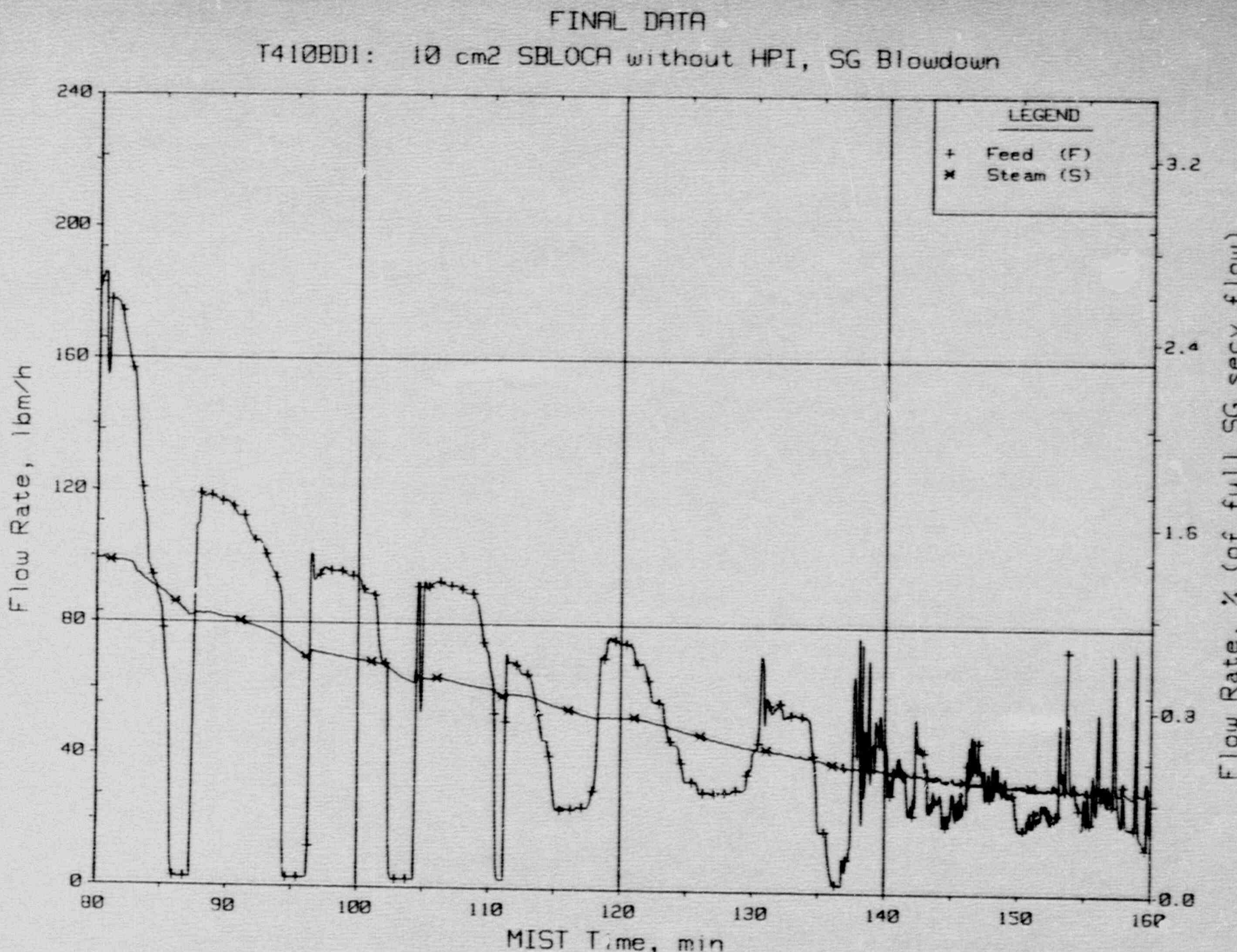



Figure 5.50 Steam Generator B Flow Rates (SaOR21s)

Wed Sep 28 12:21:56 1988

SCFL2

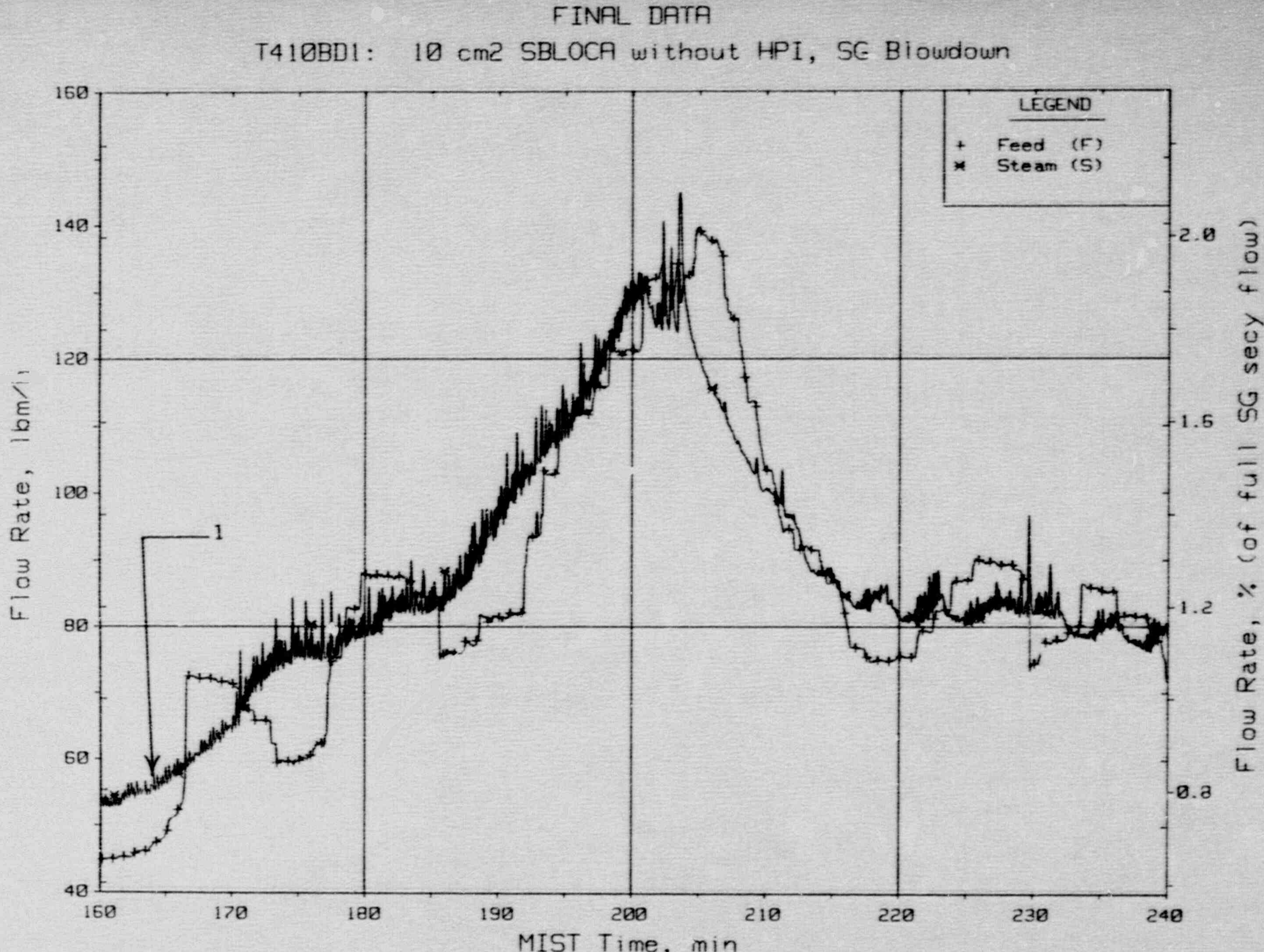



Figure 5.51 Steam Generator A Flow Rates (SaOR20s)

Wed Sep 28 12:24:28 1988

SCFL1

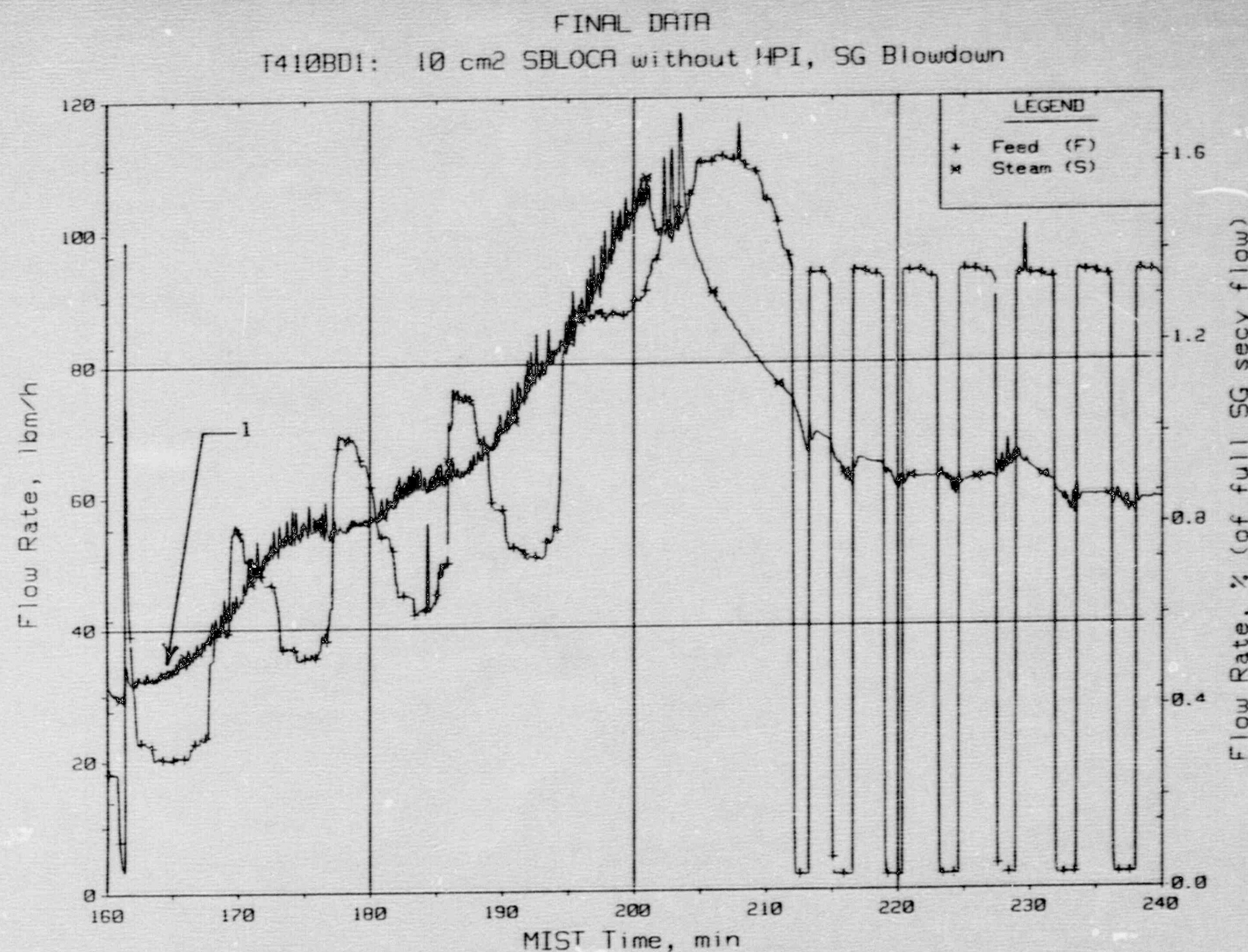



Figure 5.52 Steam Generator B Flow Rates (SaOR21s)

SCFL2

Wed Sep 28 12:27:02 1988

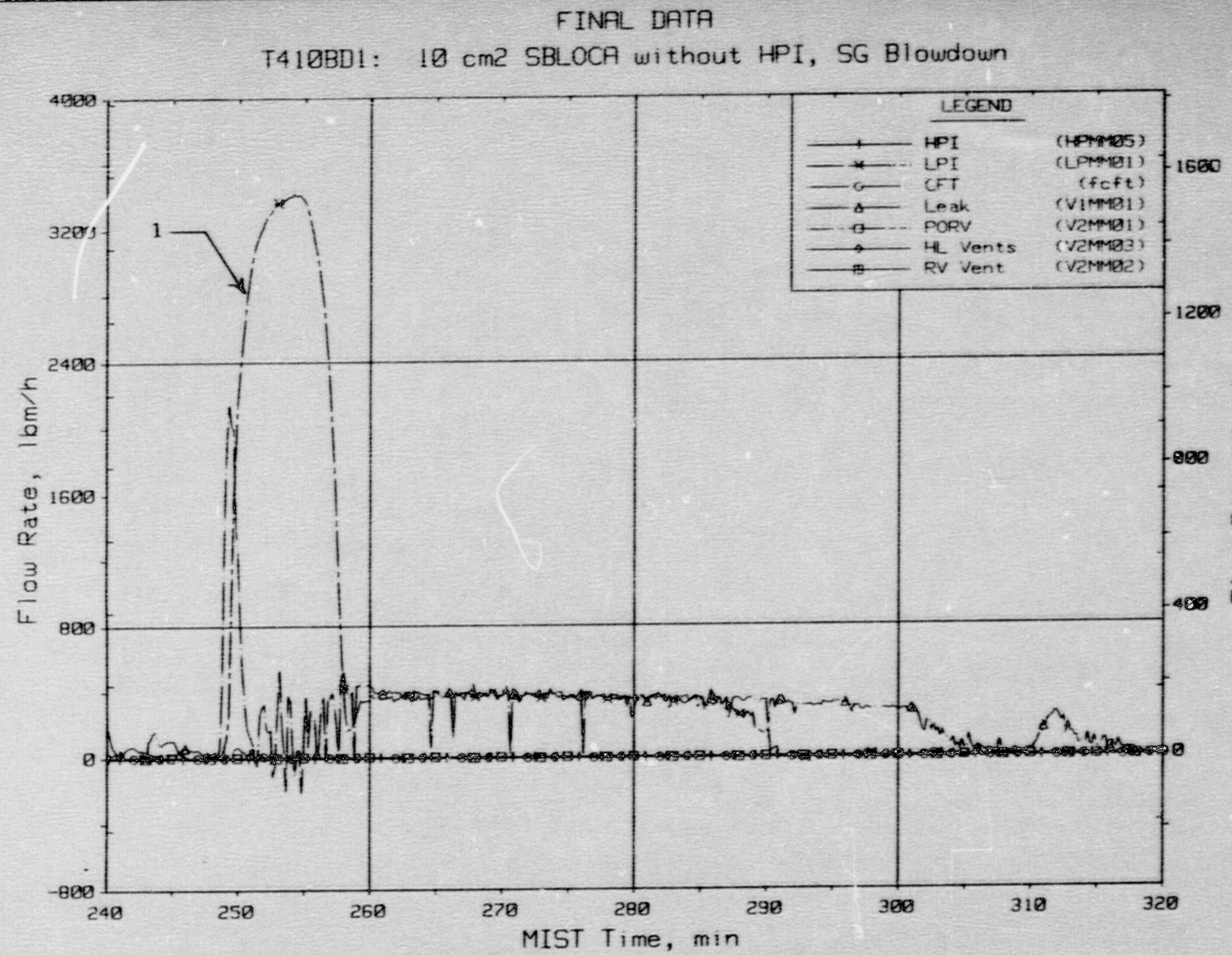



Figure 5.53 Primary System Boundary Flow Rates

Thu Sep 29 09:32:23 1988

PRFL3p

FINAL DATA

T410BD1: 10 cm2 SBLOCA without HPI, SG Blowdown

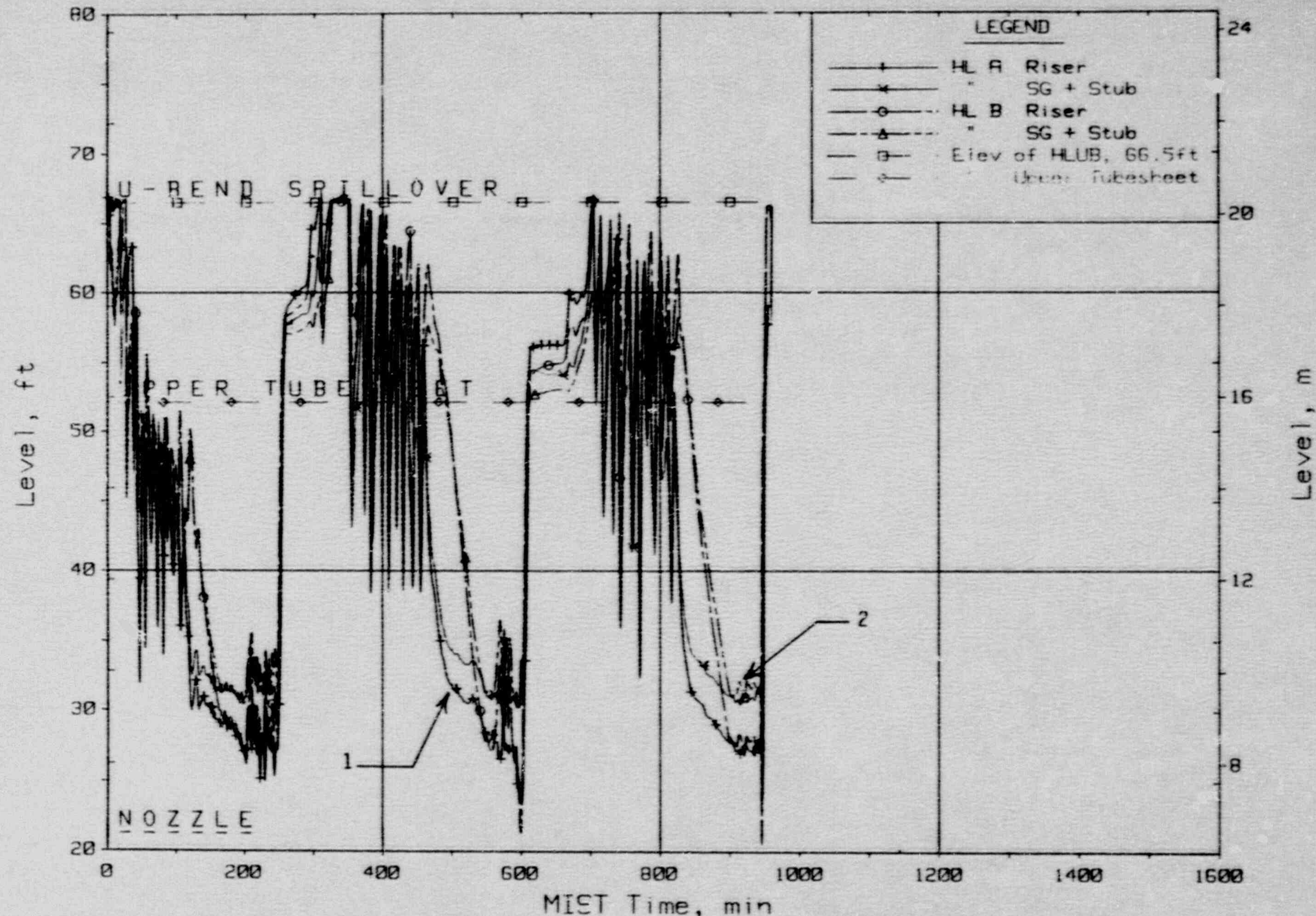



Figure 5.54 Hot Leg Riser and Stub Collapsed Liquid Levels



Thu Sep 29 09:37:01 1988

HLLV1

Figures for Test 4100B2

Larger SBLOCA, 100 $cm^2$

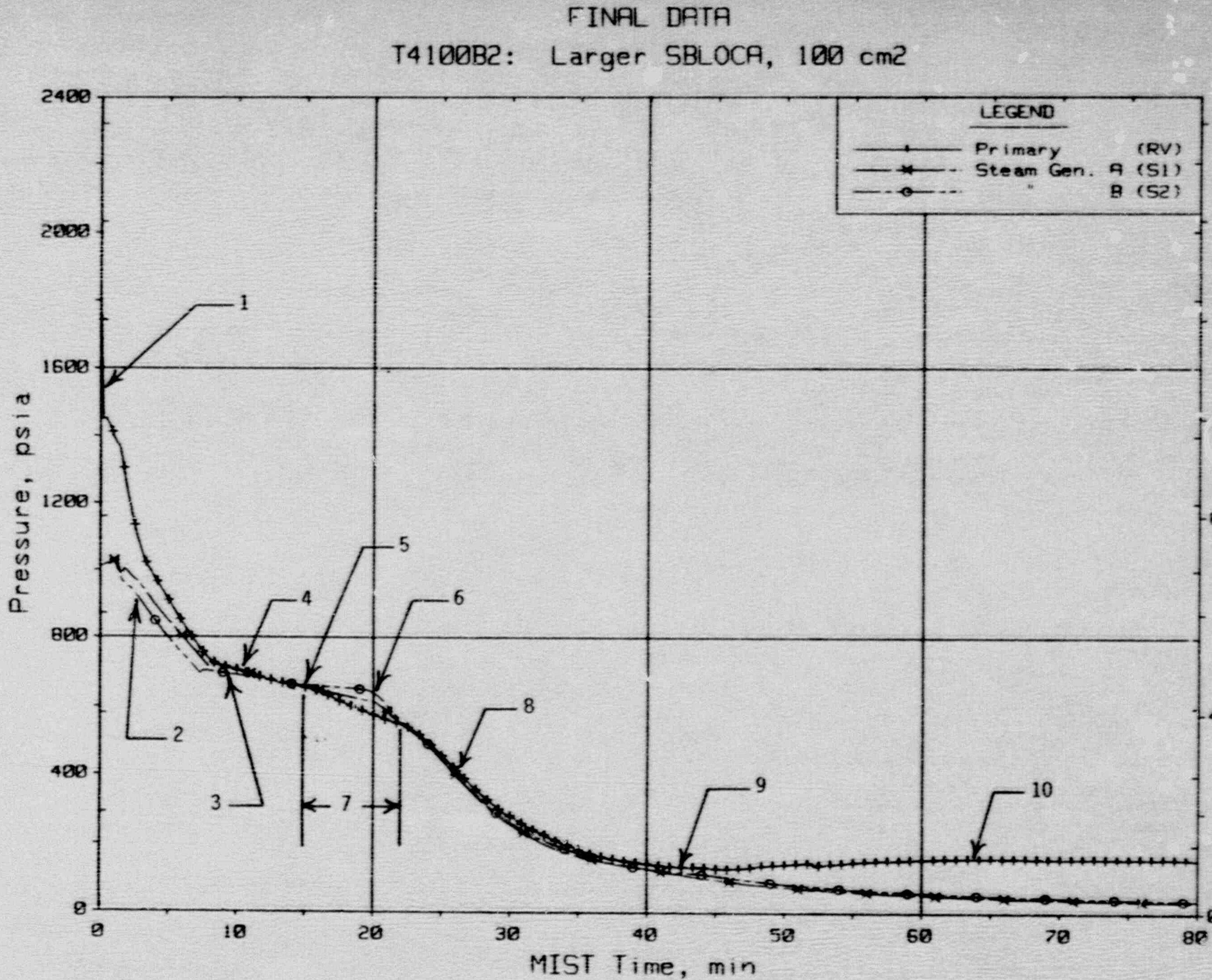



Figure 5.55 Primary and Secondary System Pressures (GP01s)



Mon Sep 19 09:48:55 1988

PSGP1

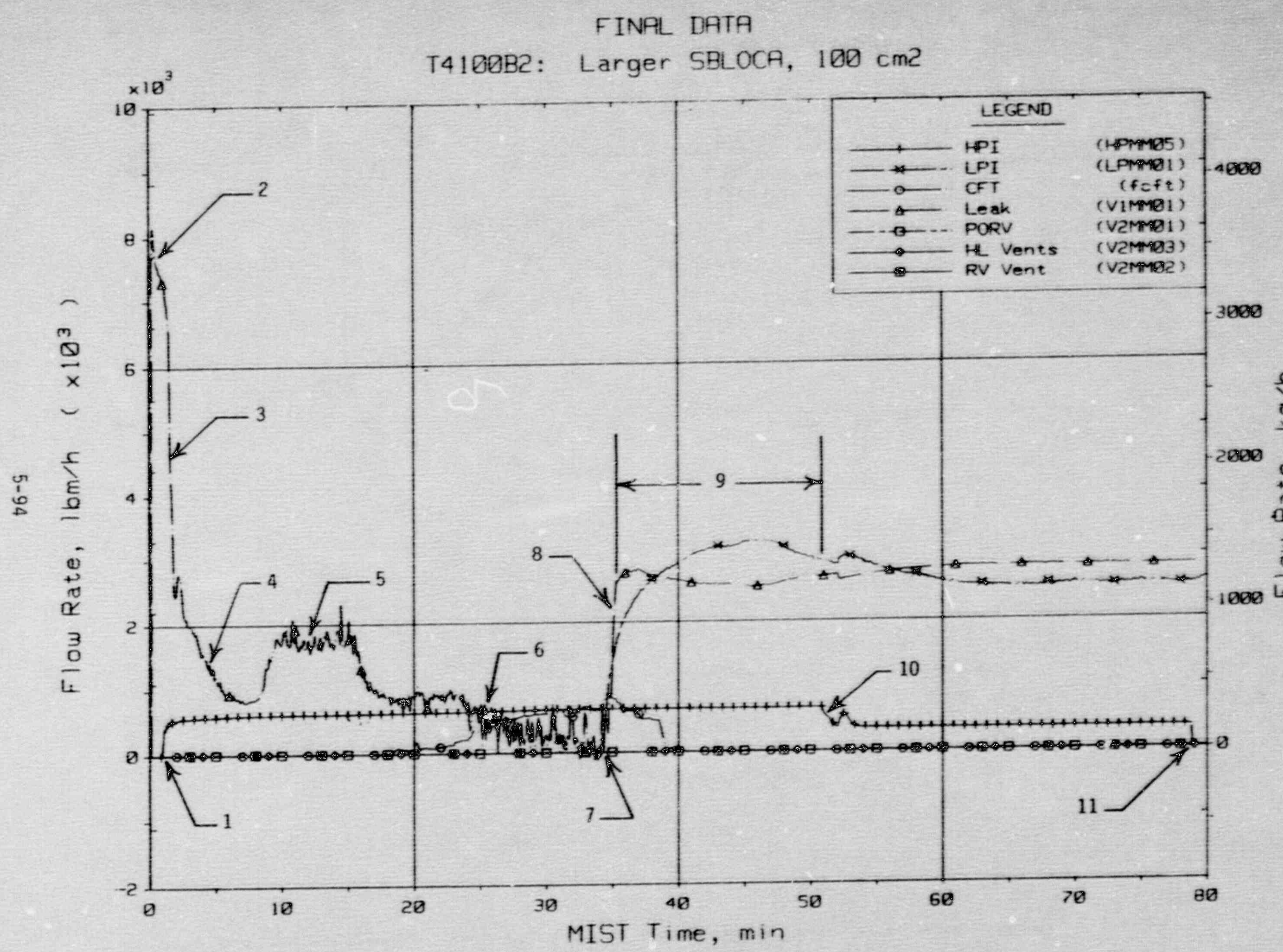



Figure 5.56 Primary System Boundary Flow Rates

PRFL3p

Mon Sep 19 09:56:11 1988

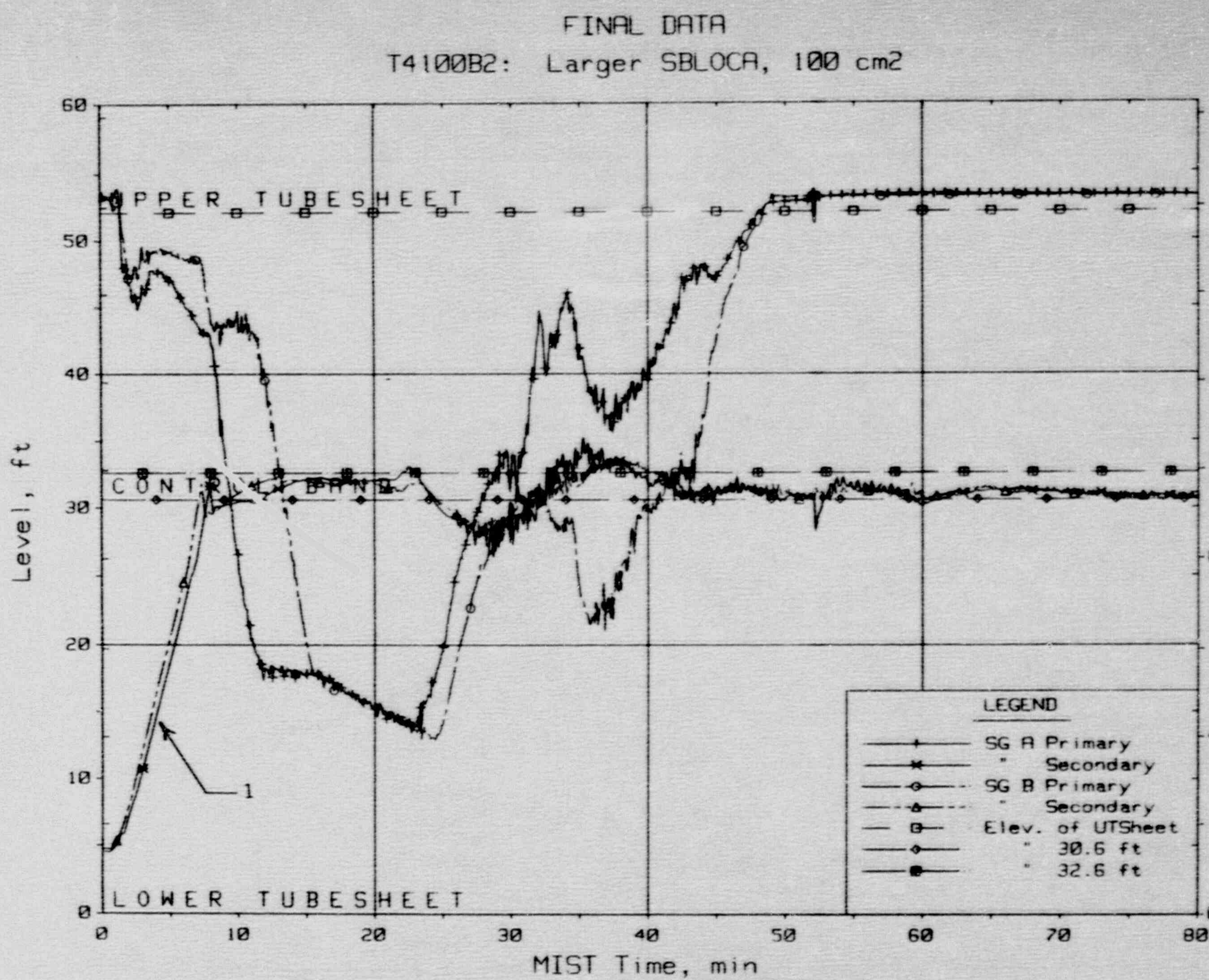
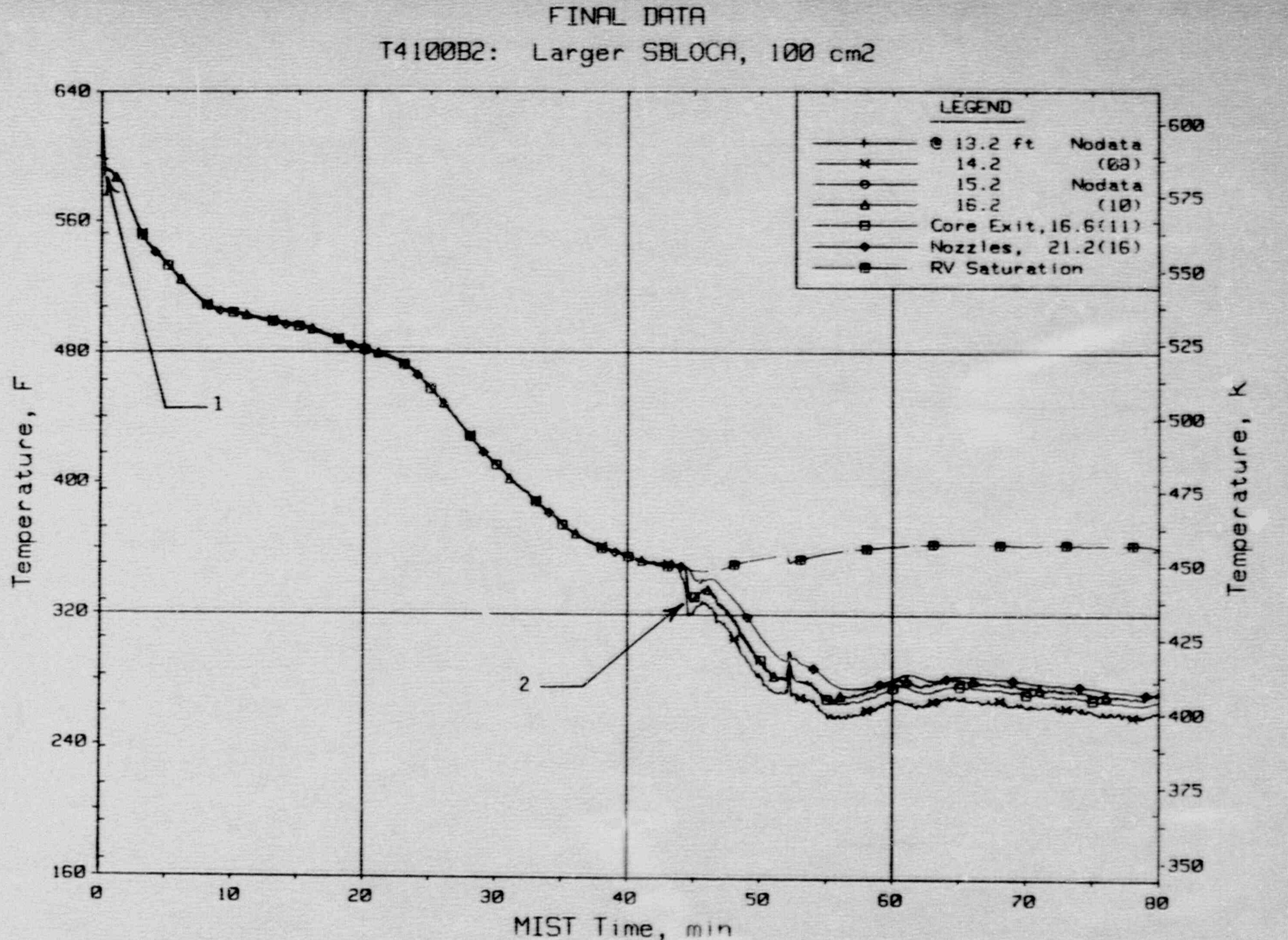



Figure 5.57 Steam Generator Collapsed Liquid Levels

Mon Sep 19 10:02:34 1988

SCLV2




5-96

Figure 5.58 Reactor Vessel Mid-Elevation Fluid Temperatures (RVTCs)

Mon Sep 19 10:10:12 1988

RVTC2

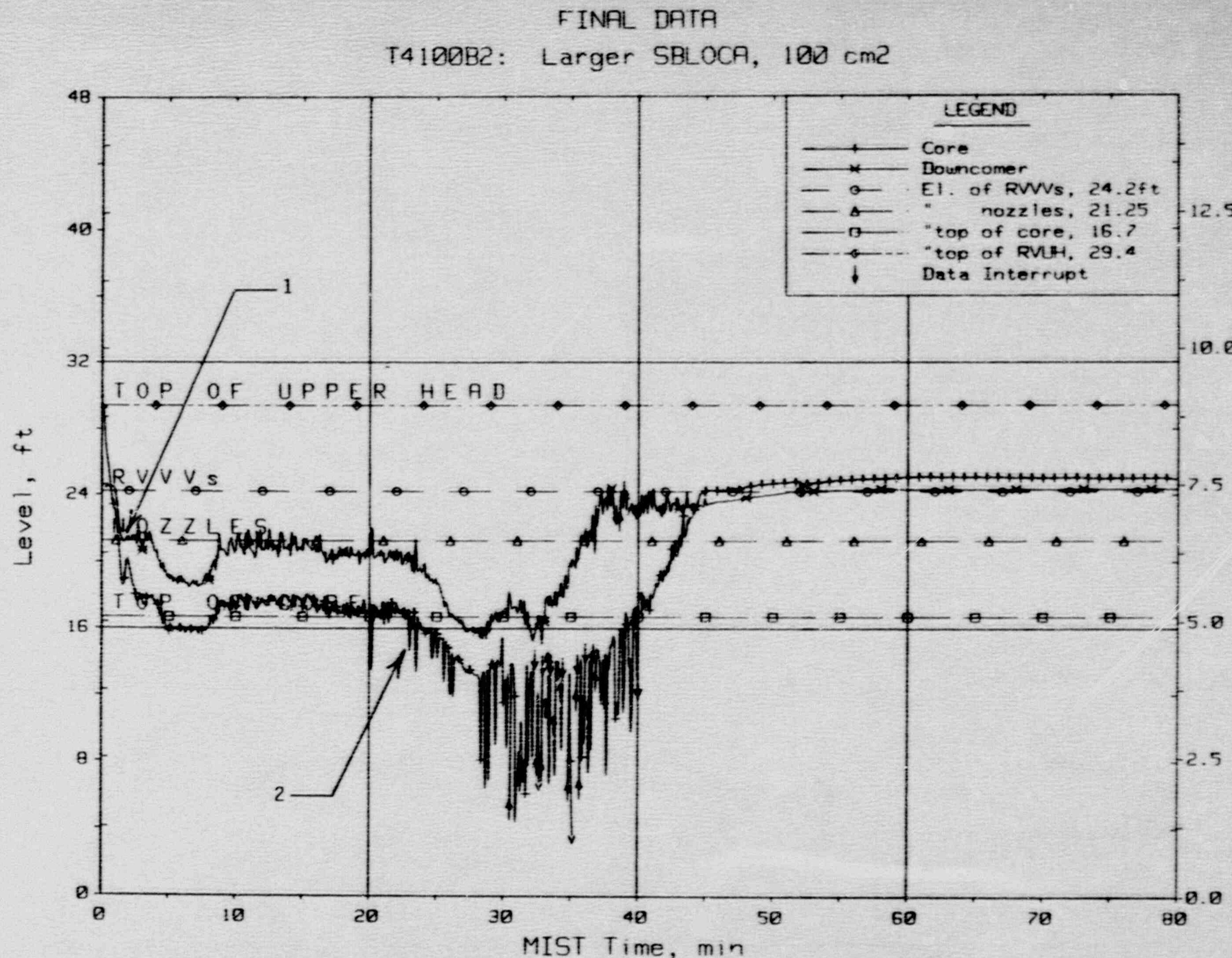



Figure 5.59 Core Region Collapsed Liquid Levels

Mon Sep 19 10:17:48 1988

COLV1

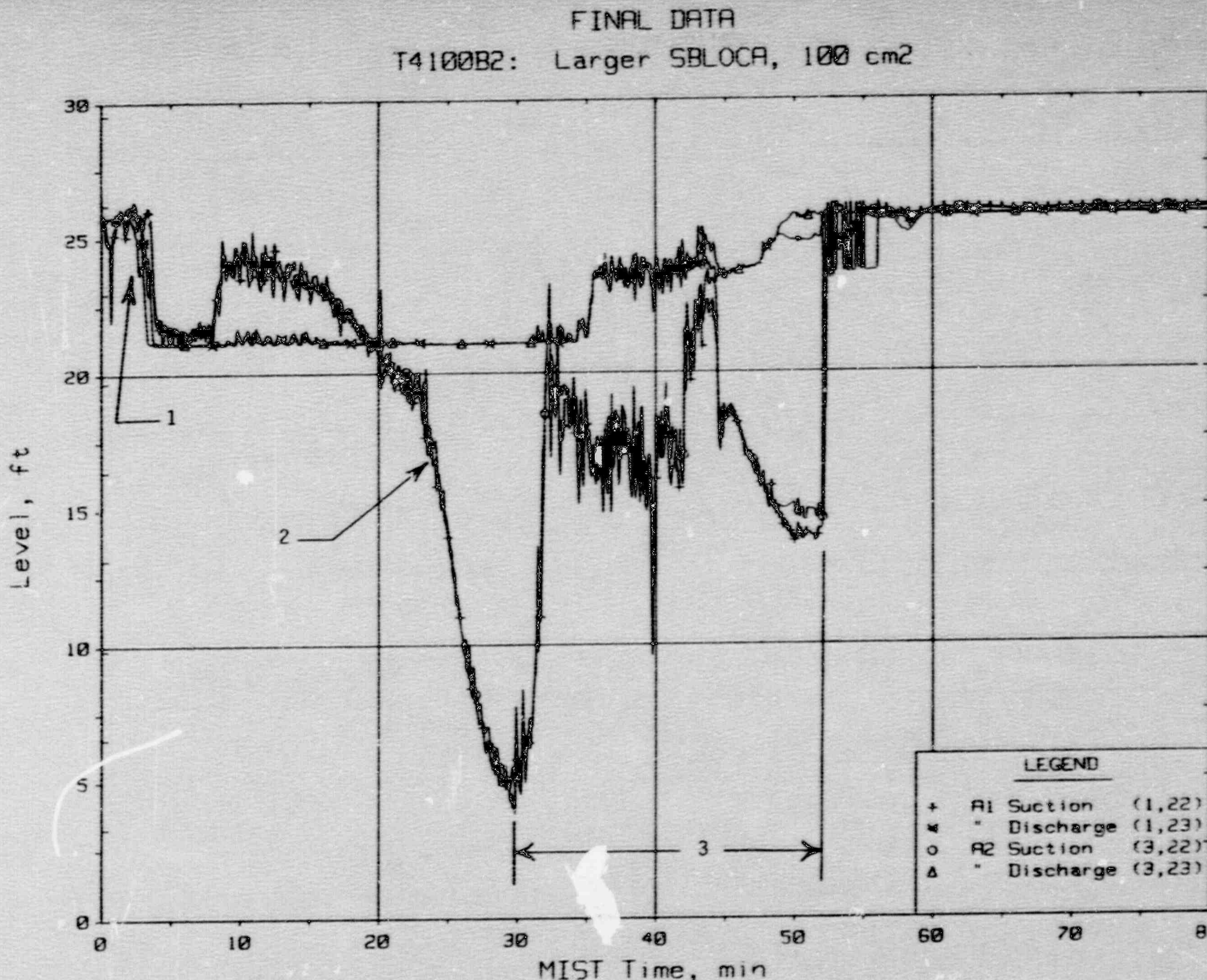



Figure 5.60 Loop A Cold Leg Collapsed Liquid Levels (LVs)

Mon Sep 19 10:20:36 1988

CLLV1

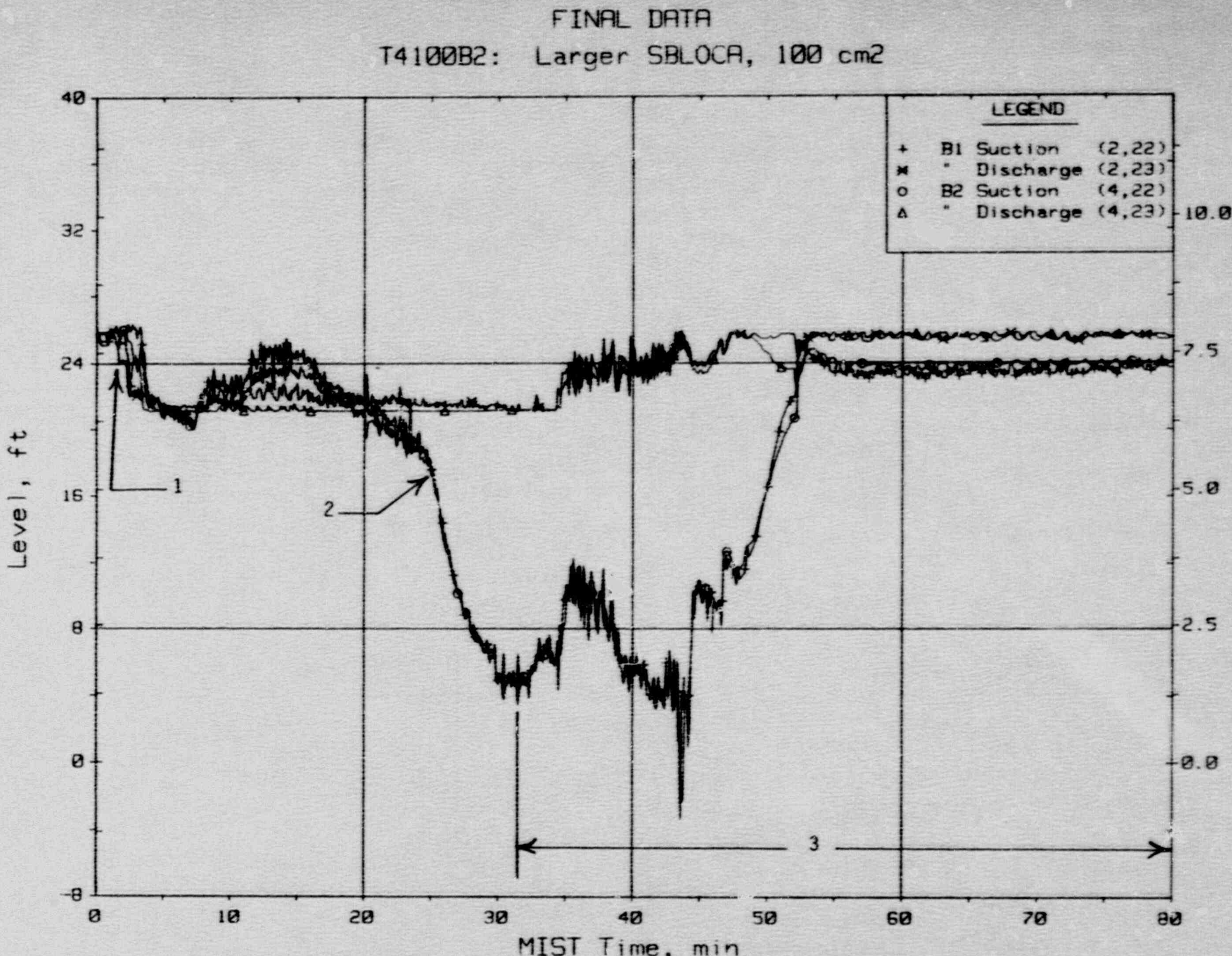


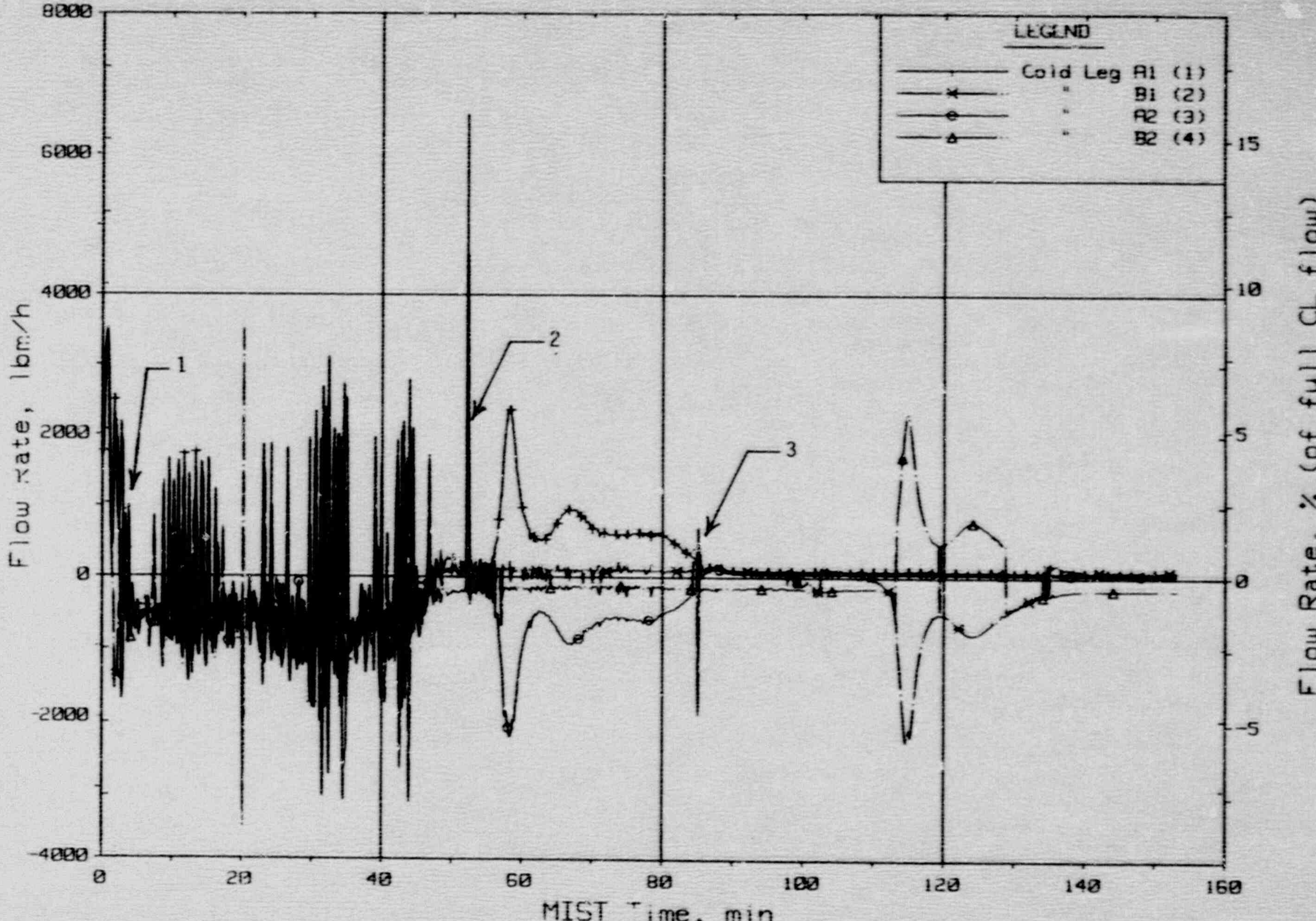

Figure 5.61 Loop B Cold Leg Collapsed Liquid Levels (LVs)

Mon Sep 19 10:33:25 1988

CLLV2

FINAL DATA

T4100B2: Larger SBLOCA, 100 cm2




5-100

Figure 5.62 Cold Leg (Venturi) Flow Rates (CnVN20s)

Thu Oct 27 13:42:43 1988

CLFL0

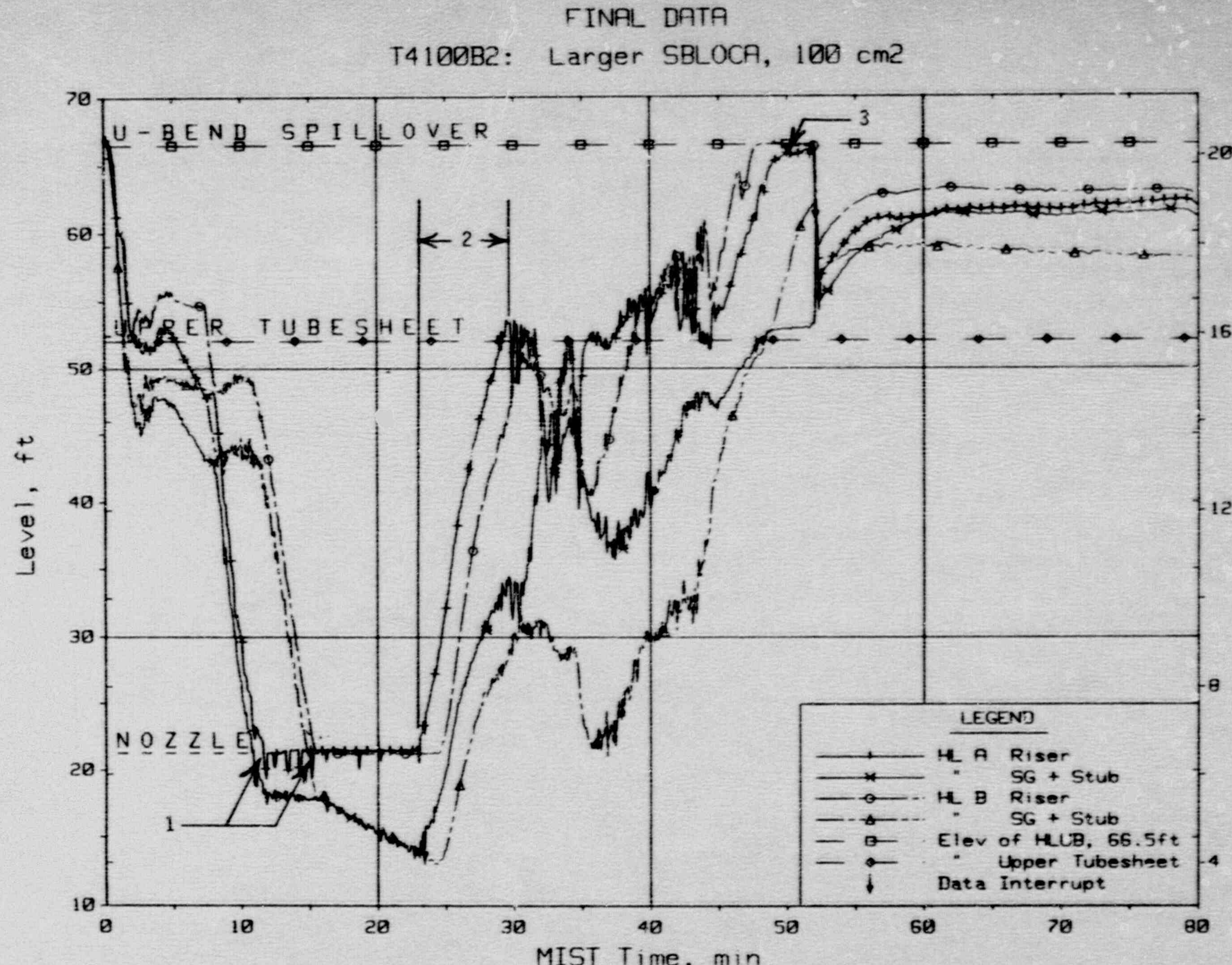



Figure 5.63 Hot Leg Riser and Stub Collapsed Liquid Levels

Mon Sep 19 10:41:11 1988

HLLV1

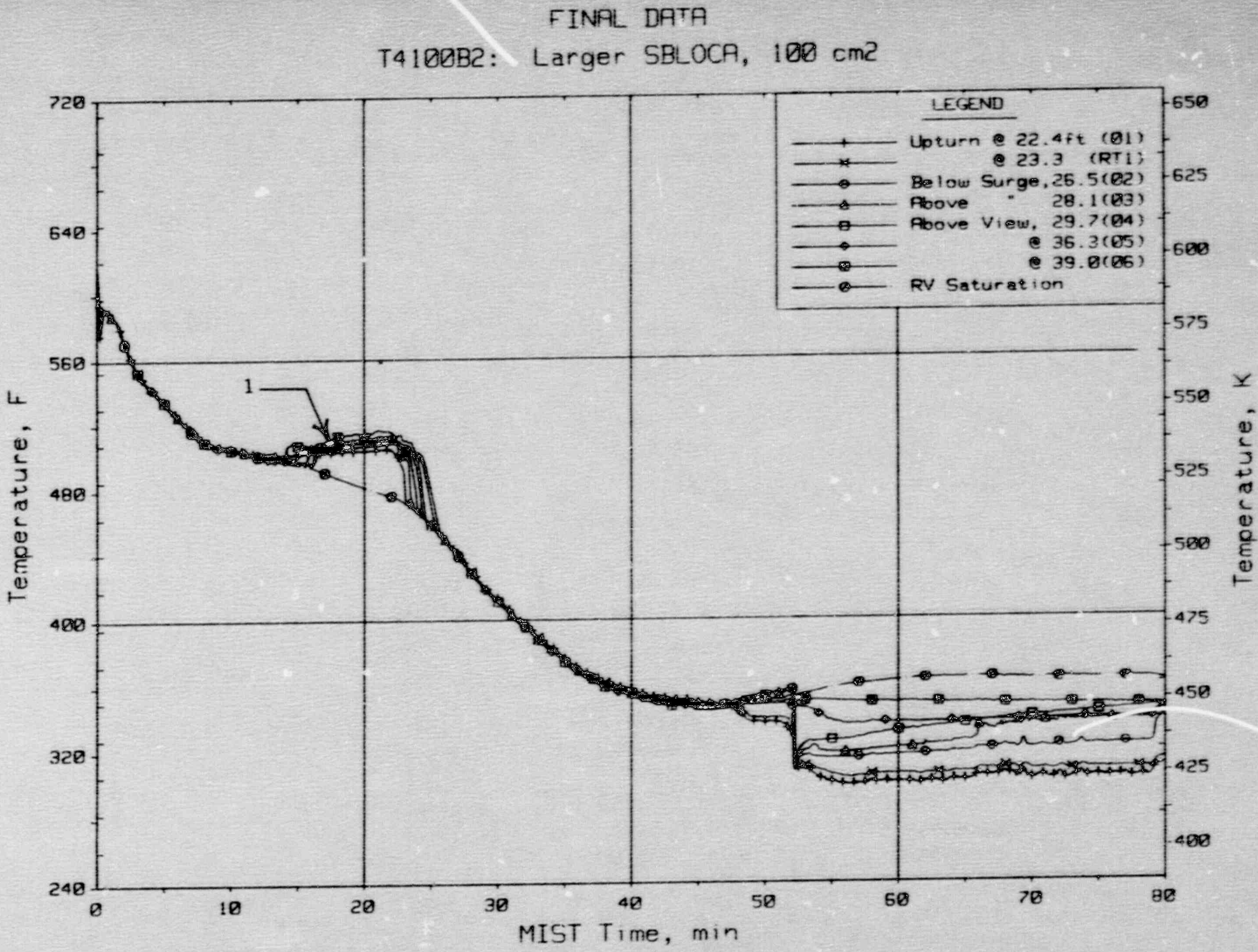



Figure 5.64 Hot Leg A Lower-Elevation Riser Fluid Temperatures (HITCs)

Mon Sep 19 10:46:45 1988

HITC1

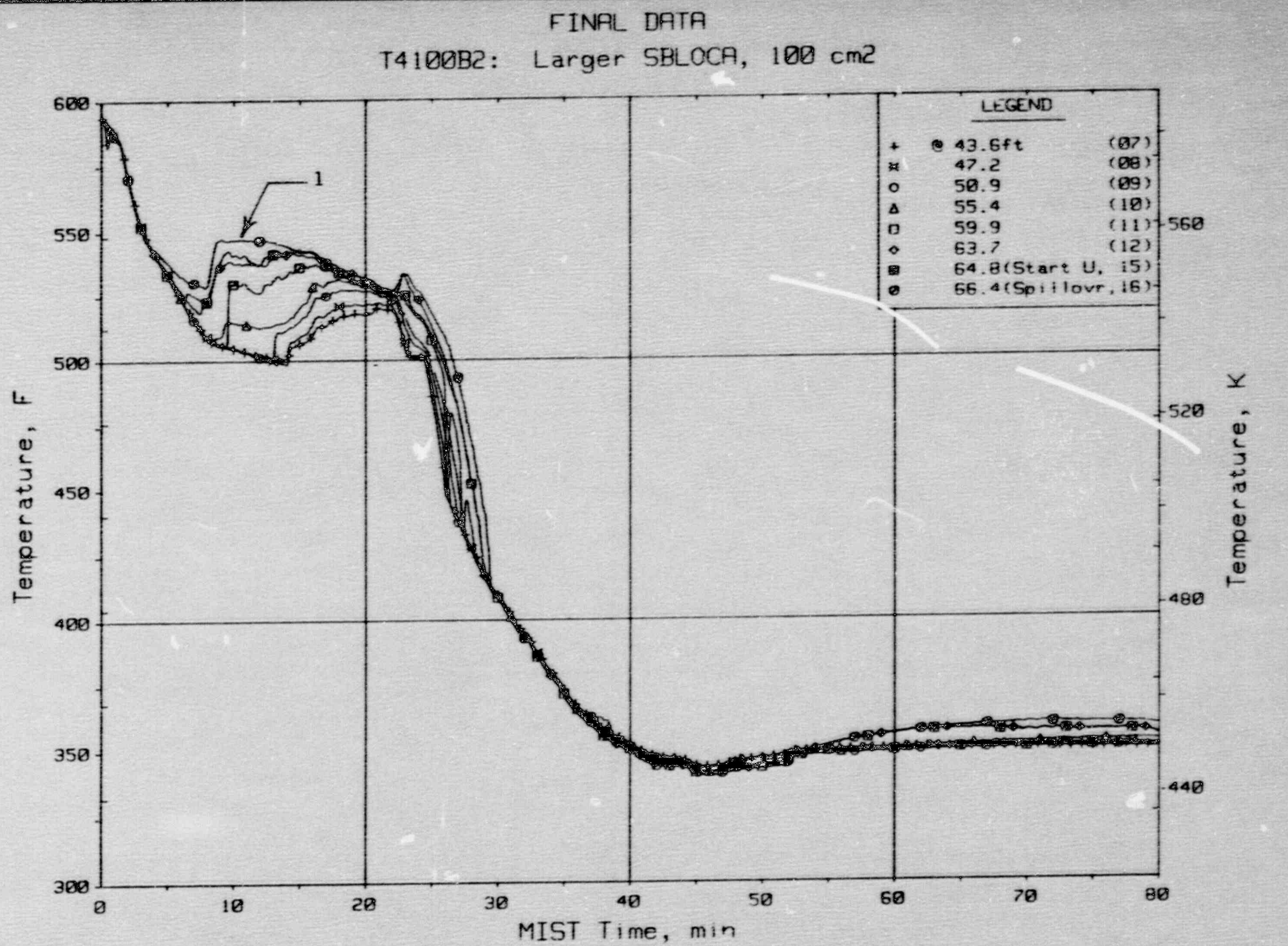



Figure 5.65 Hot Leg A Upper-Elevation Riser Fluid Temperatures (HITCs)

Mon Sep 19 11:03:41 1988

HITC2

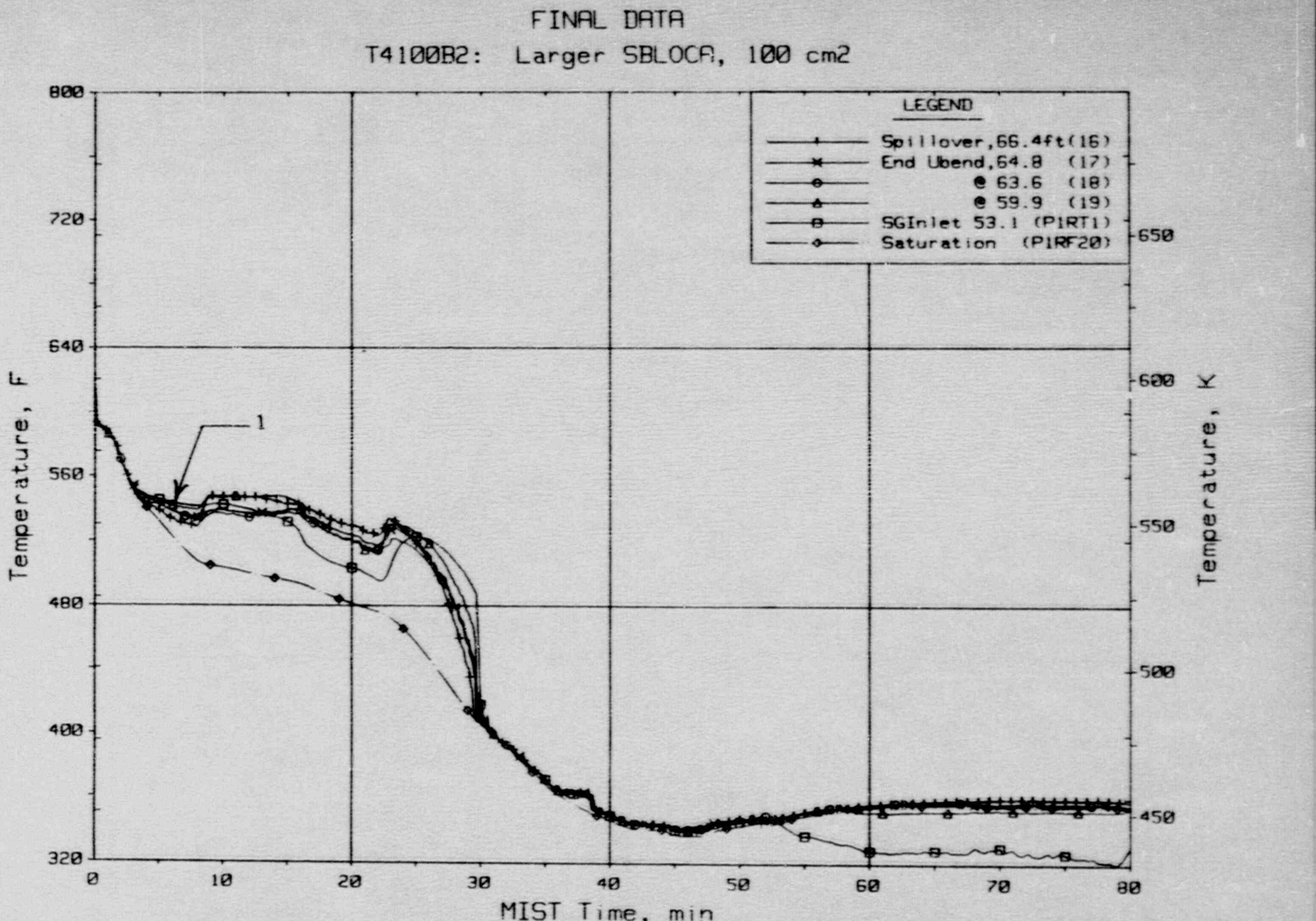



Figure 5.66 Hot Leg A Fluid Temperatures Beyond U-Bend (H1TCs)

Mon Sep 19 11:14:38 1988

H1TC3

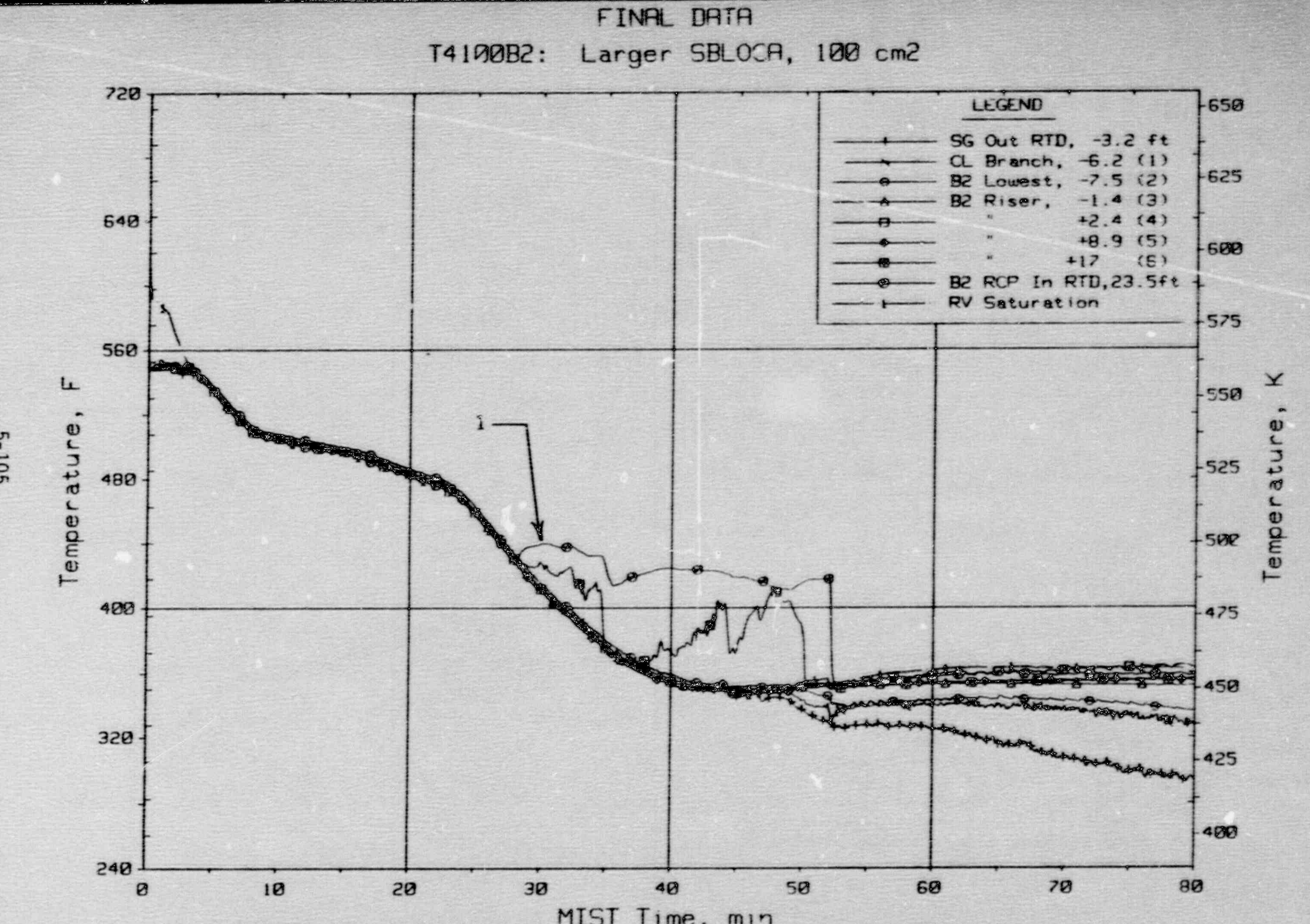



Figure 5.67 Cold Leg B2 Suction Fluid Temperatures (C4TCs)

Mon Sep 19 11:31:06 1988

C4TC1

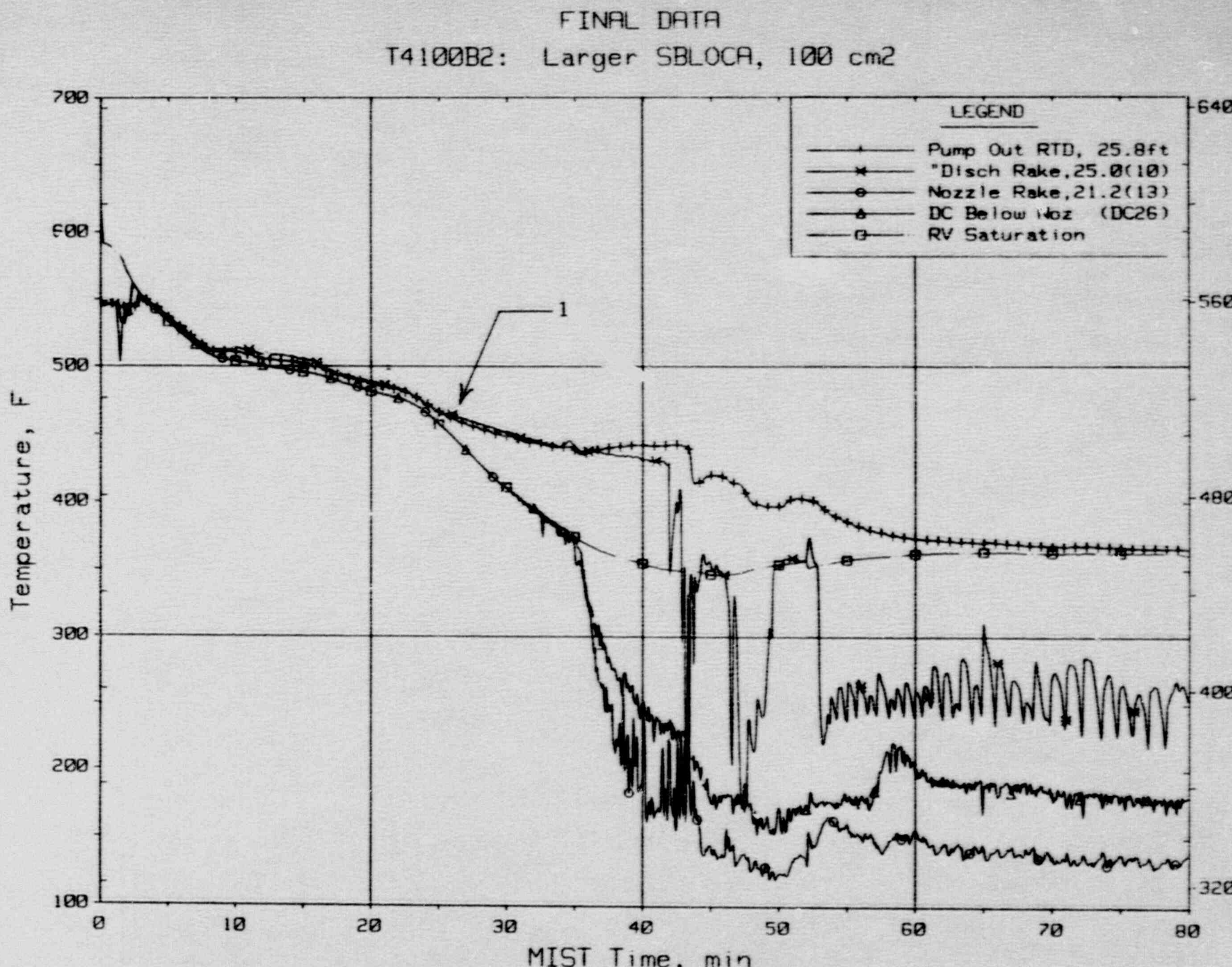



Figure 5.68 Cold Leg B2 Discharge Fluid Temperatures (C4TCs)

Mon Sep 19 11:40:07 1988

C4TC2

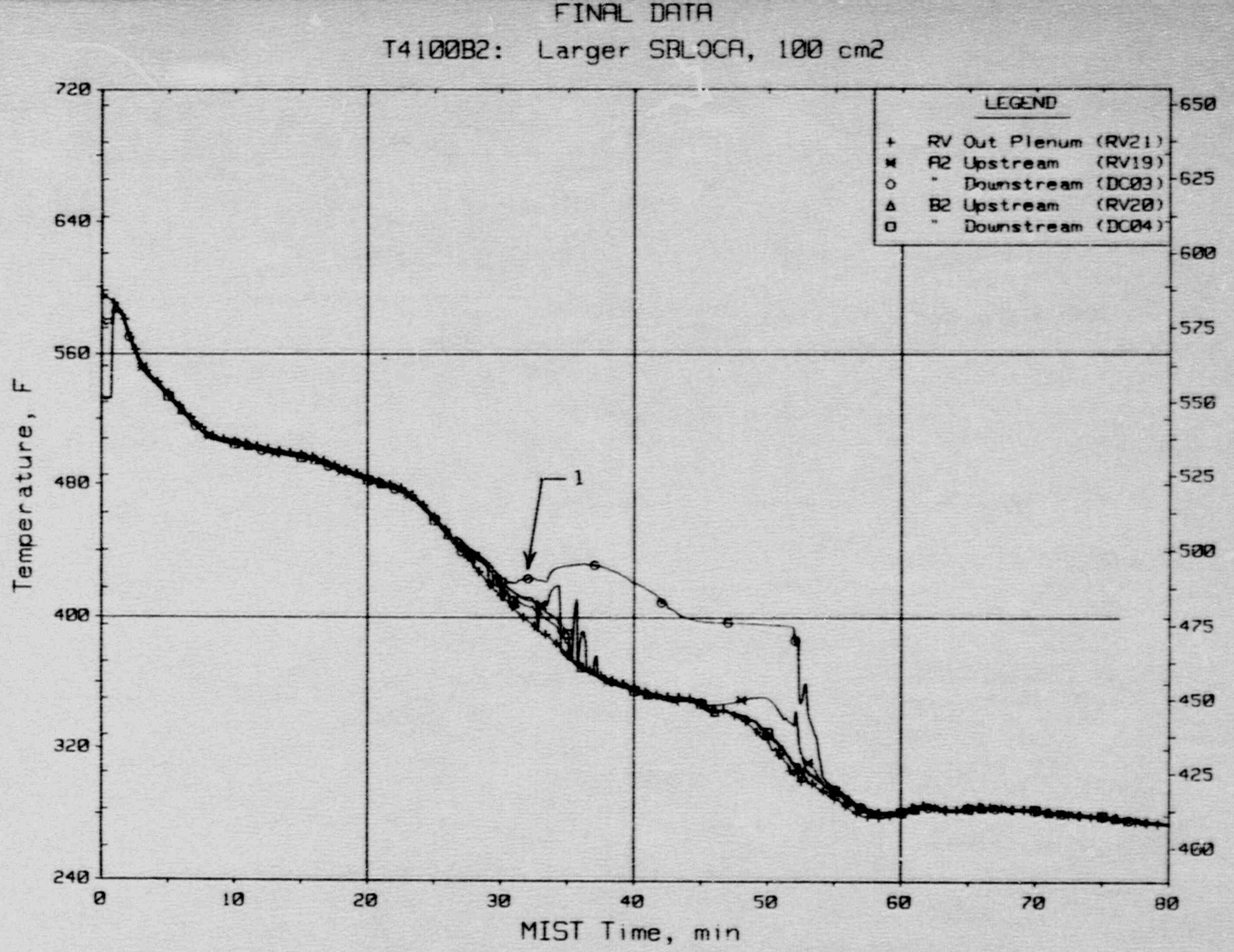



Figure 5.69 RVVVs A2 and B2 Bracketing Fluid Temperatures (TCs)

Mon Sep 19 11:49:31 1988

VVTC2

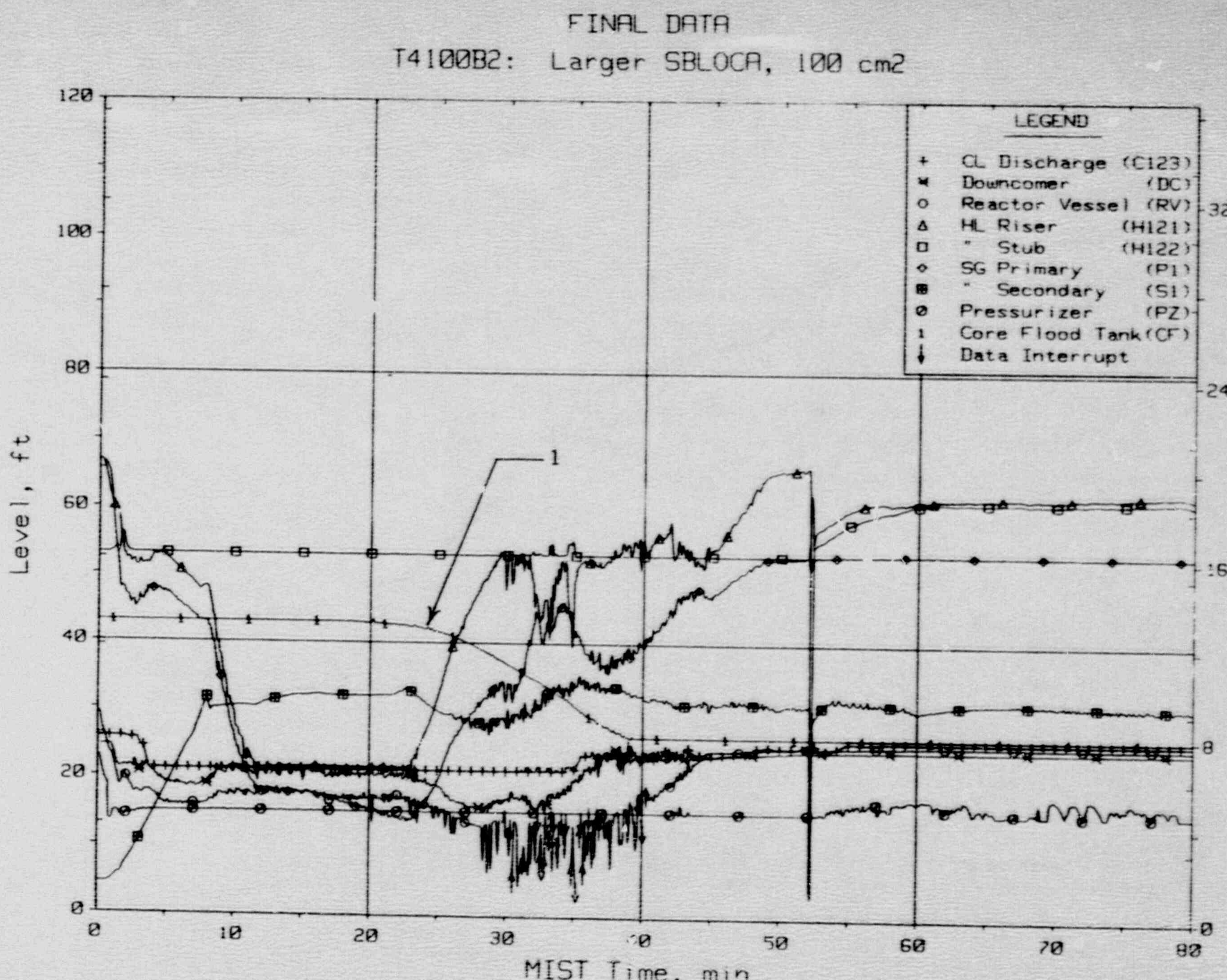



Figure 5.70 Loop A Collapsed Liquid Levels (LV20s)

Mon Sep 19 11:58:02 1988

PRLV1

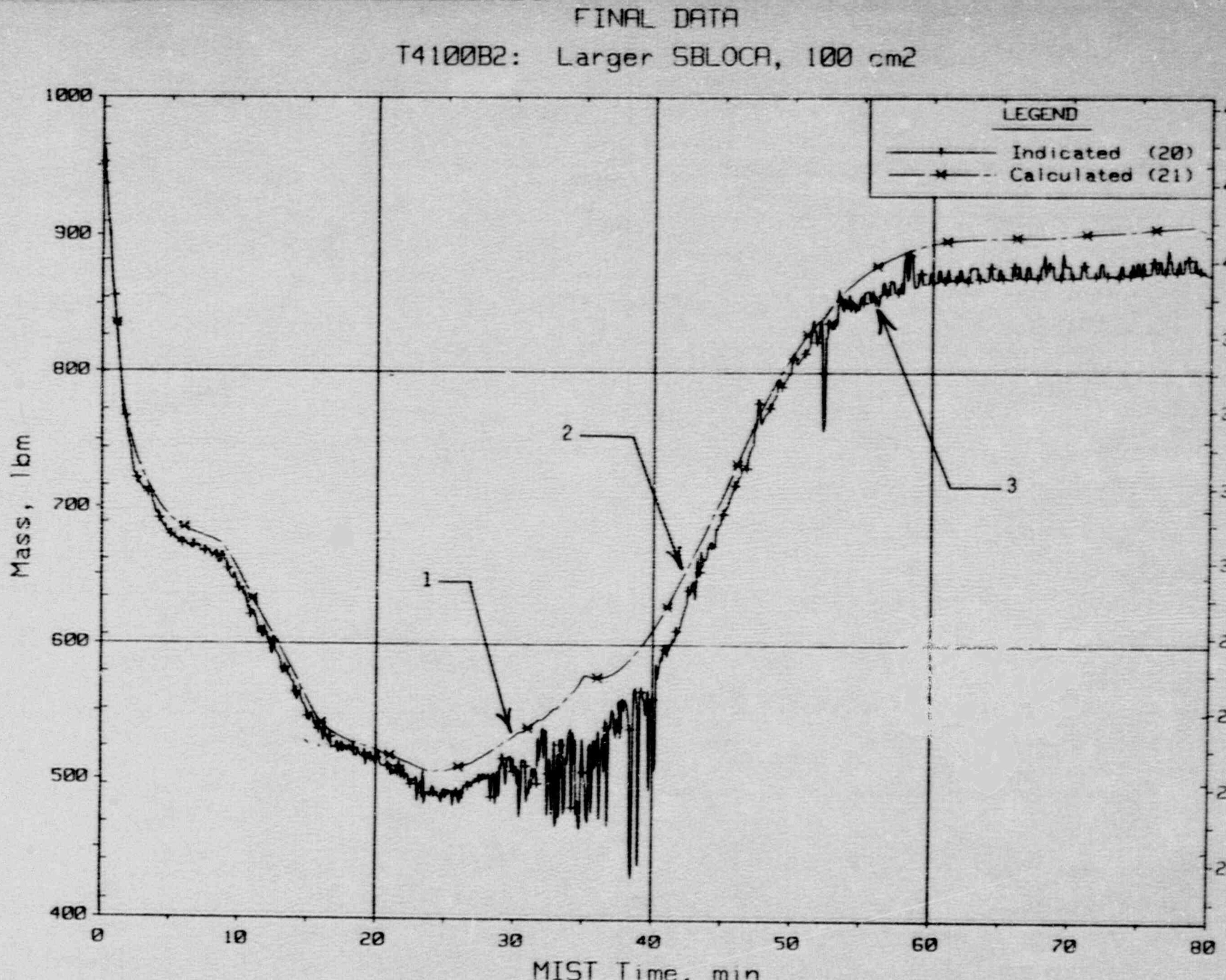



Figure 5.71 Primary System Total Fluid Mass (PLMLs)

Mon Sep 19 12:03:05 1988

PRML1

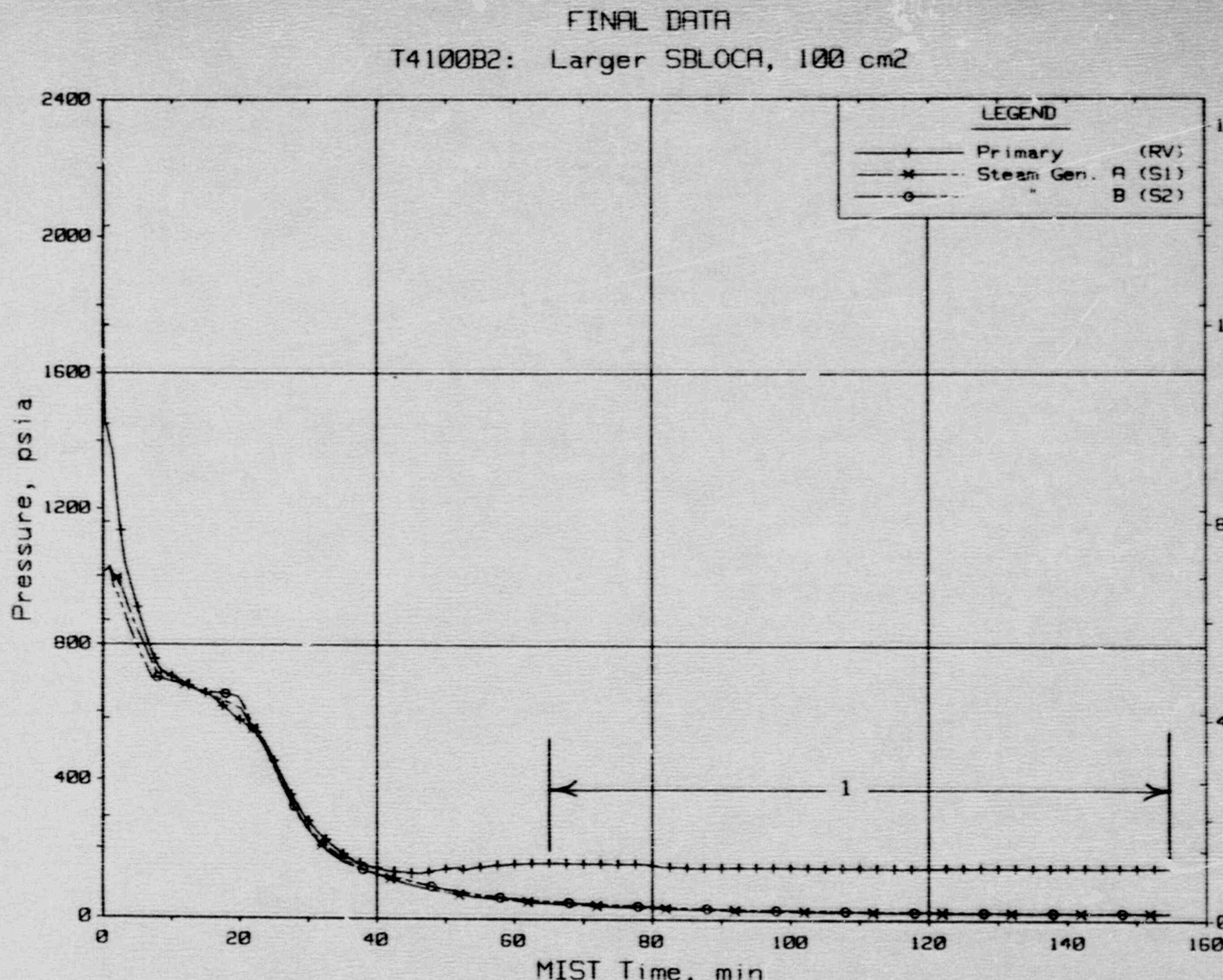





Figure 5.72 Primary and Secondary System Pressures (GPOls)

Tue Sep 20 09:59:23 1988

PSGP1

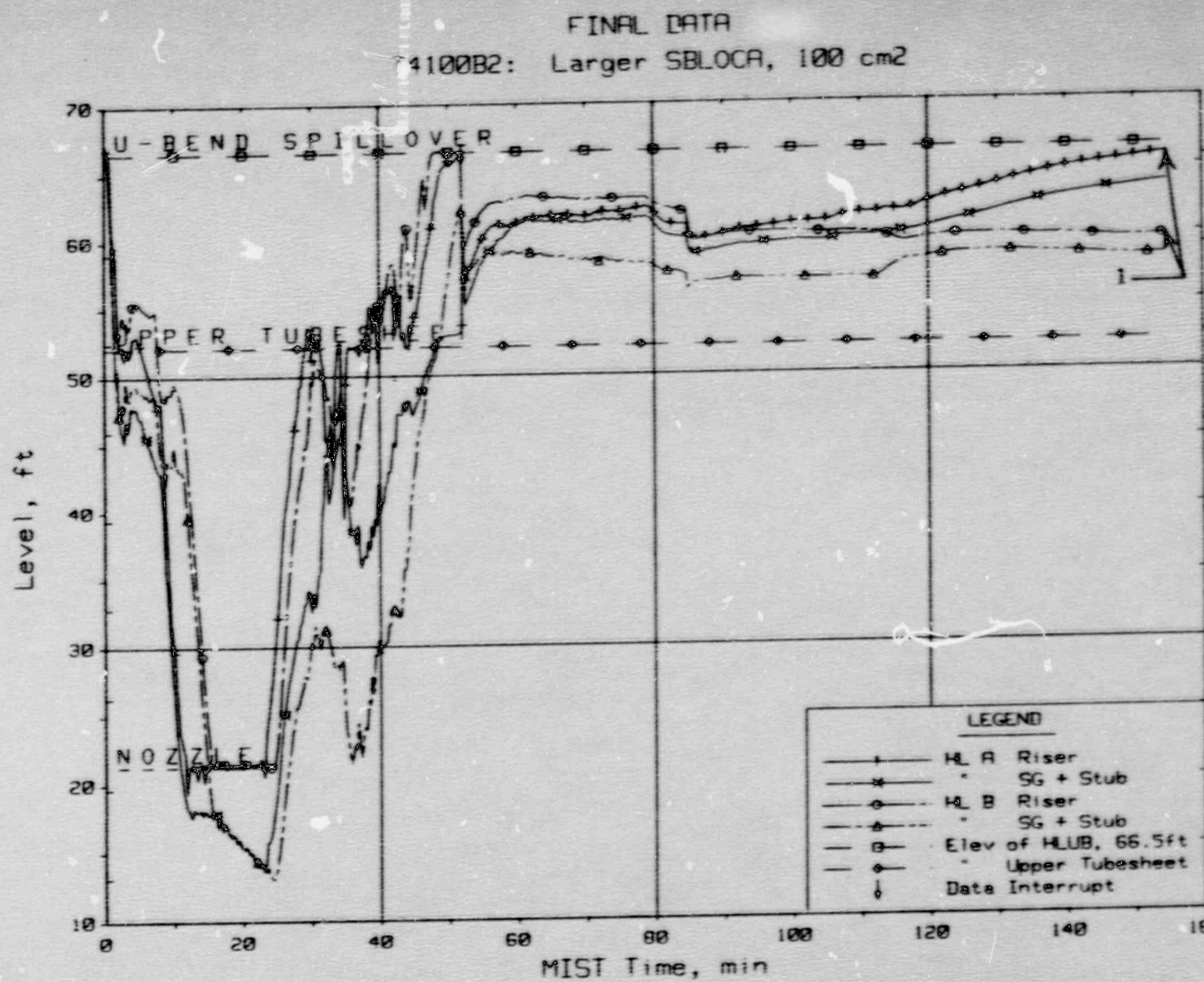



Figure 5.73 Hot Leg Riser and Stub Collapsed Liquid Levels

HLLVI

Tue Sep 20 10:05:40 1988

Figures for Test 4SB011

Station Blackout

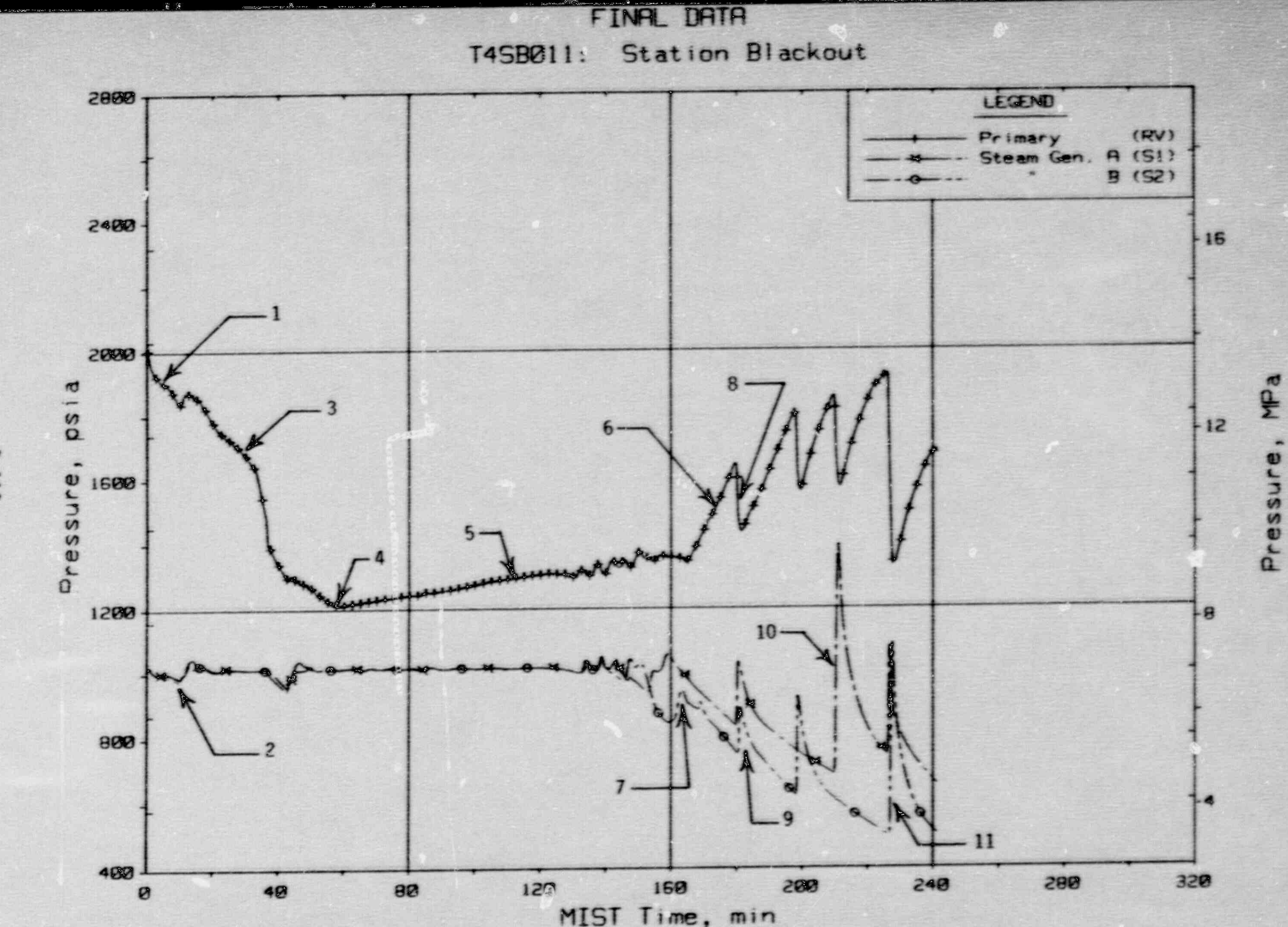



Figure 5.74 Primary and Secondary System Pressures (GP01s)

Wed Sep 14 09:48:30 1988

PSGP1

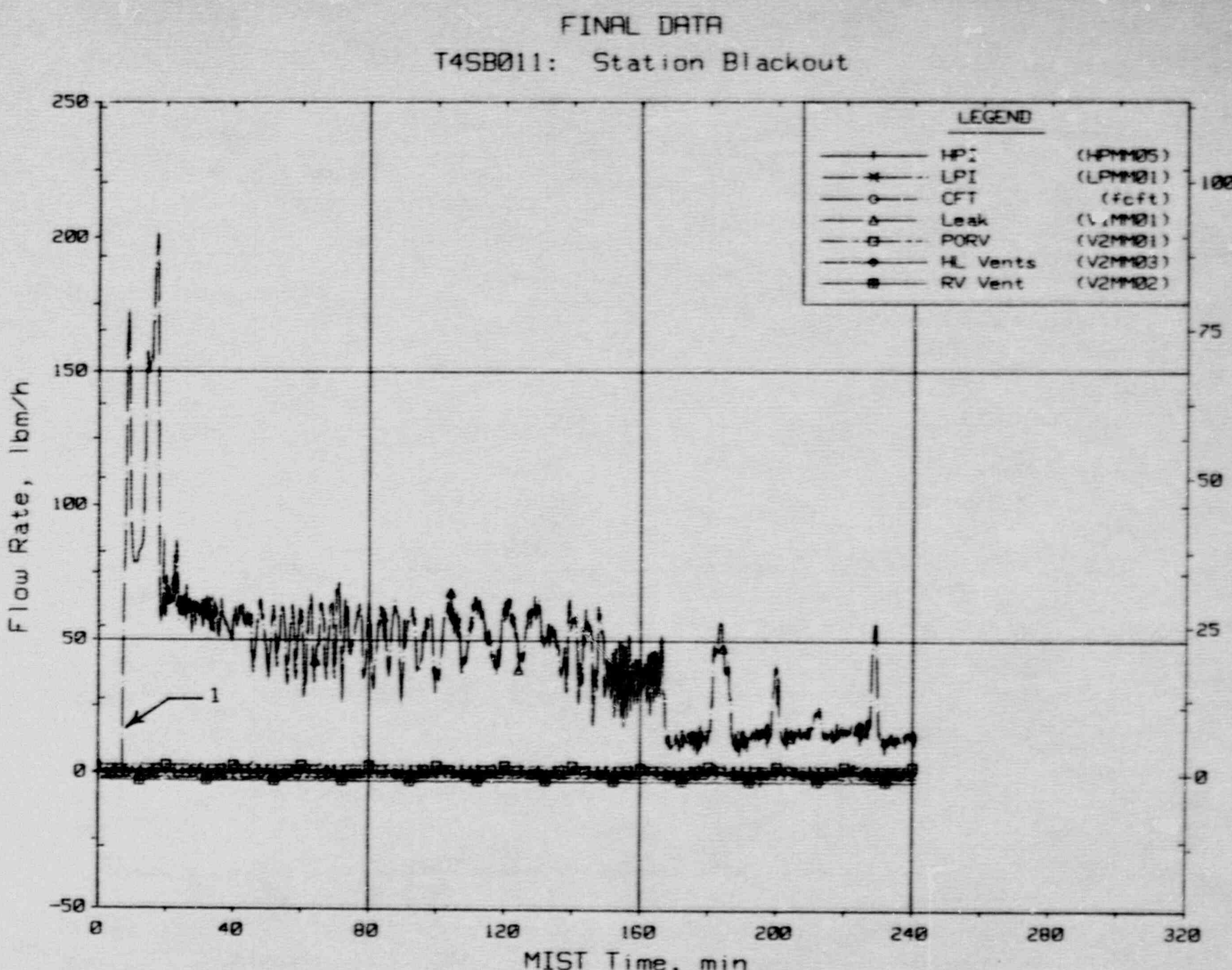



Figure 5.75 Primary System Boundary Flow Rates

Wed Sep 14 10:22:55 1988

PRFL3p

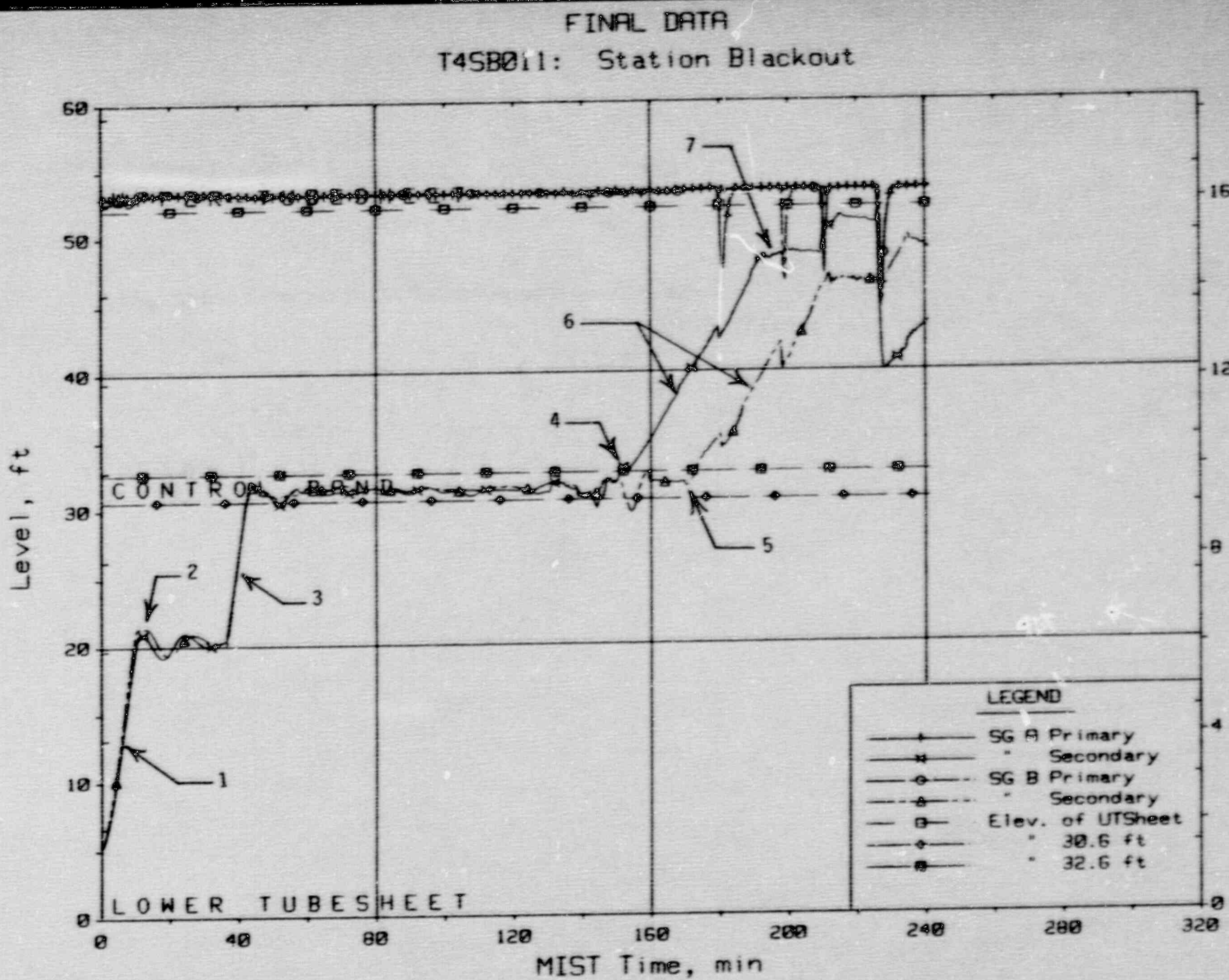



Figure 5.76 Steam Generator Collapsed Liquid Levels

SCLV2

Wed Sep 14 08:31:44 1988

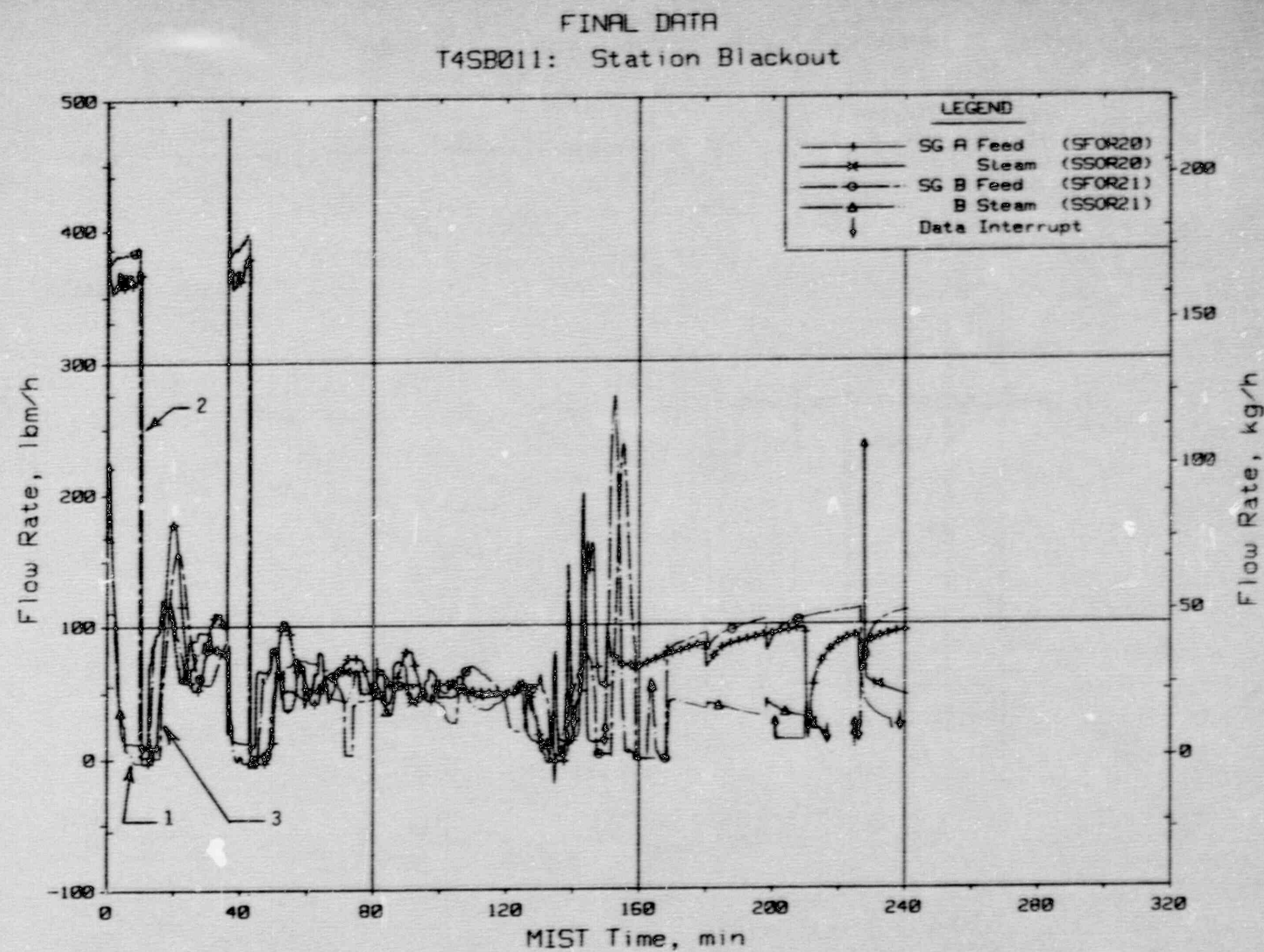



Figure 5.77 Steam Generator Secondary Flow Rates (SaOR2ns)

Wed Nov 9 14:50:27 1988

SGFL0

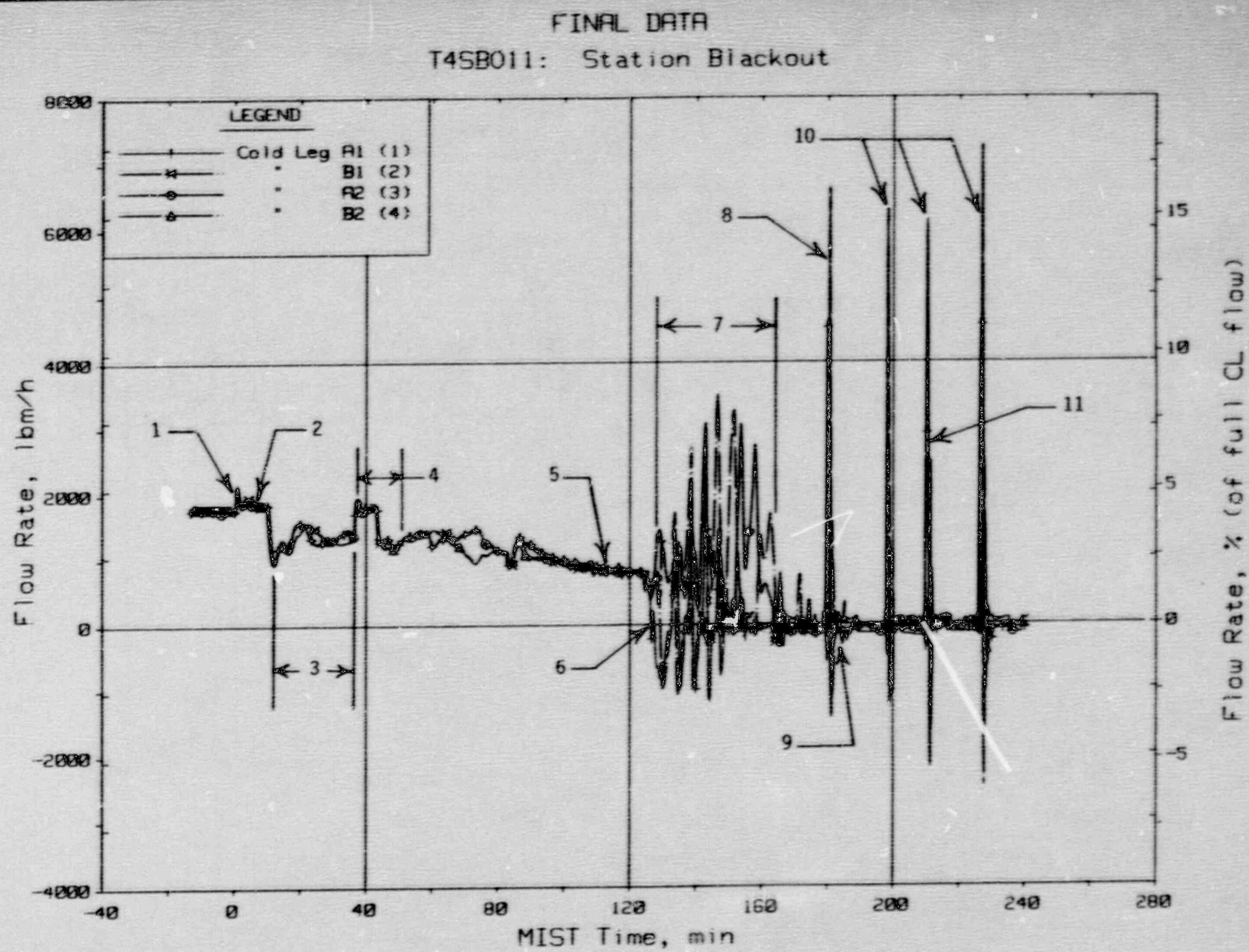



Figure 5.78 Cold Leg (Venturi) Flow Rates (CnVN20s)

CLFL0

Tue Nov 15 14:41:40 1988

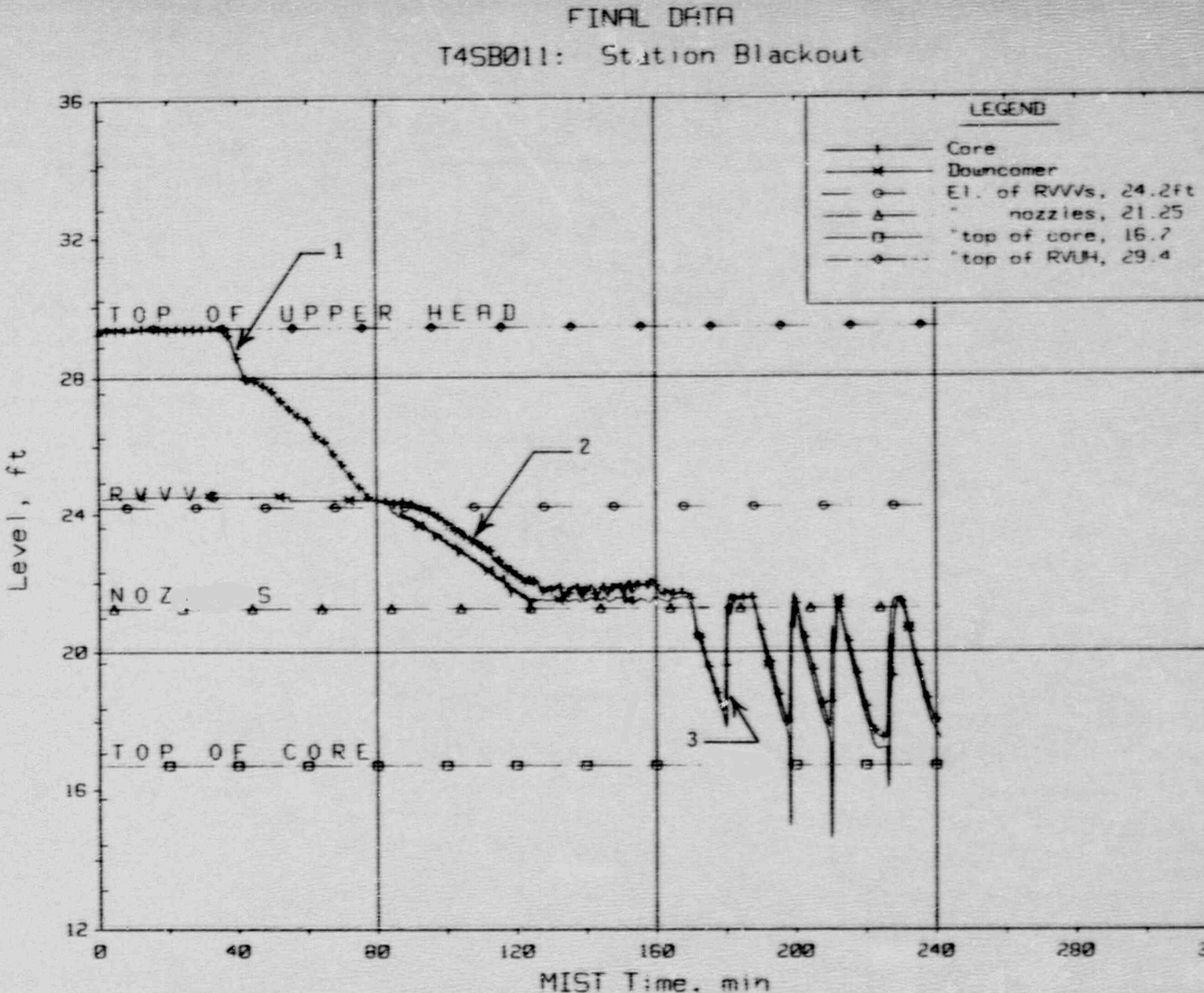



Figure 5.79 Core Region Collapsed Liquid Levels

Wed Sep 14 10:37:40 1988

COLV1

5-117

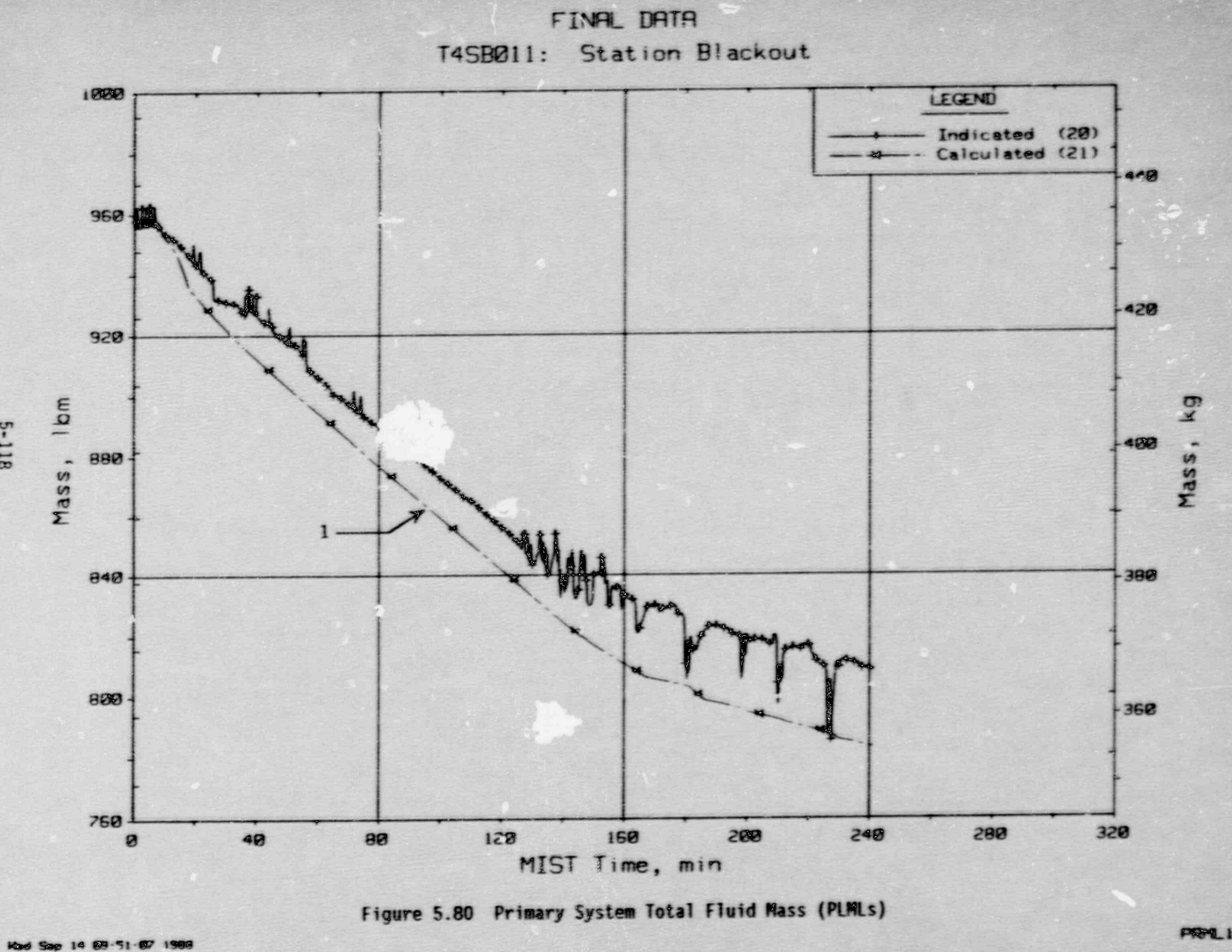



Figure 5.80 Primary System Total Fluid Mass (PLMLs)

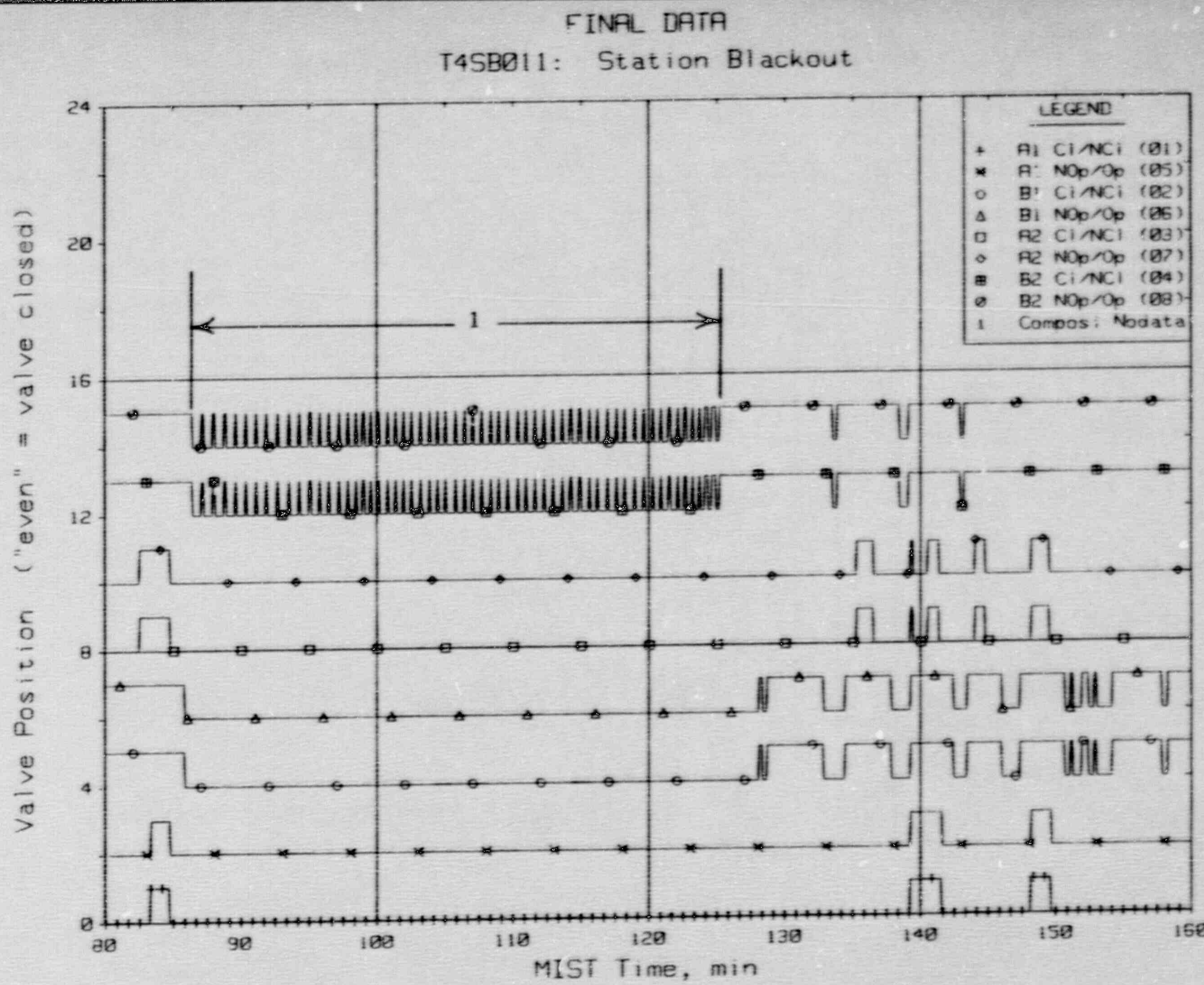



Figure 5.81 Reactor Vessel Vent Valve Limit Switch Indications (RVLSs)

VVLS2

Fr: Sep 16 10:56:24 1988

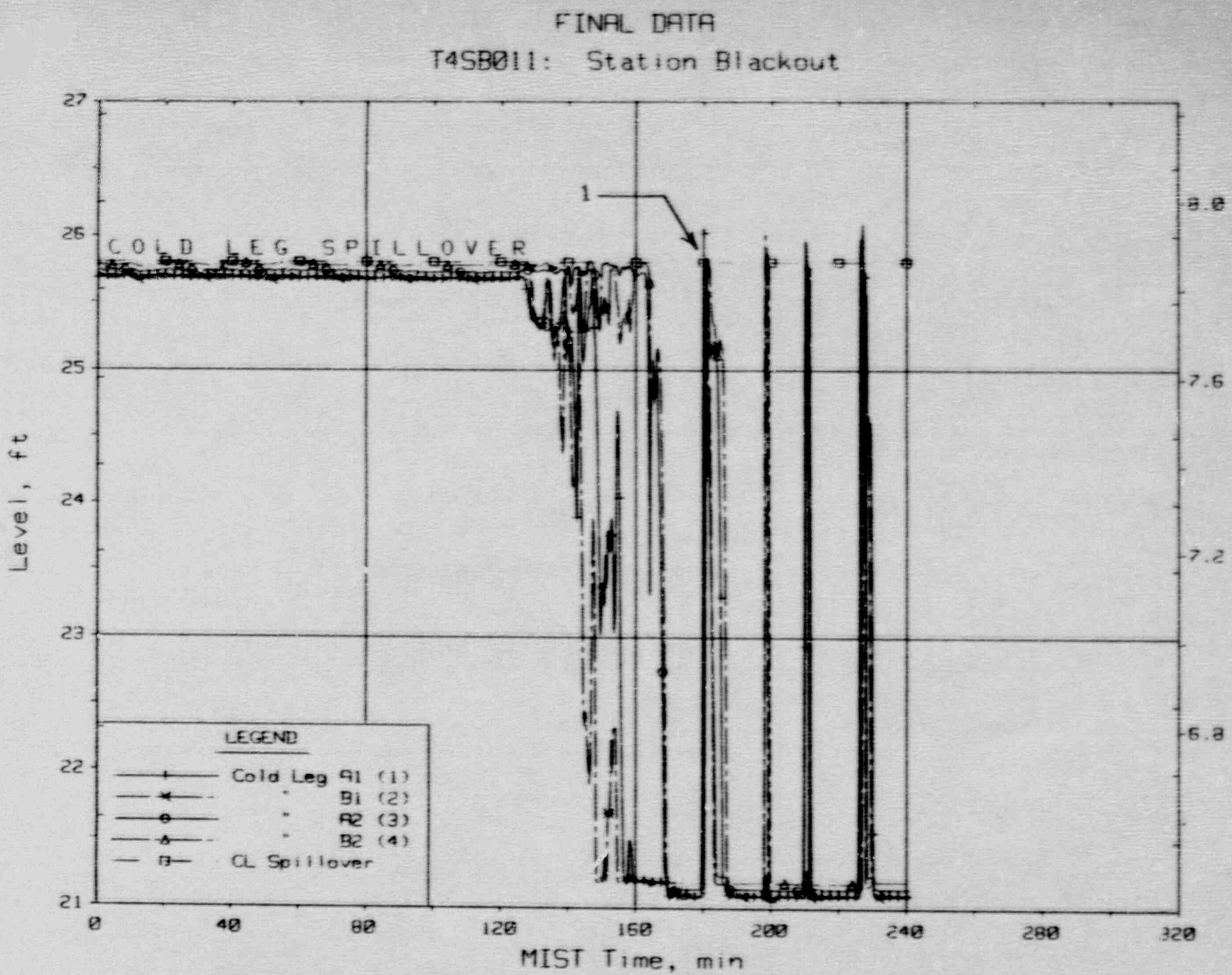



Figure 5.82 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Wed Sep 14 10:45:19 1988

CLLV5

Figures for Test 4SGPF2

Steam Generator Performance - MFW

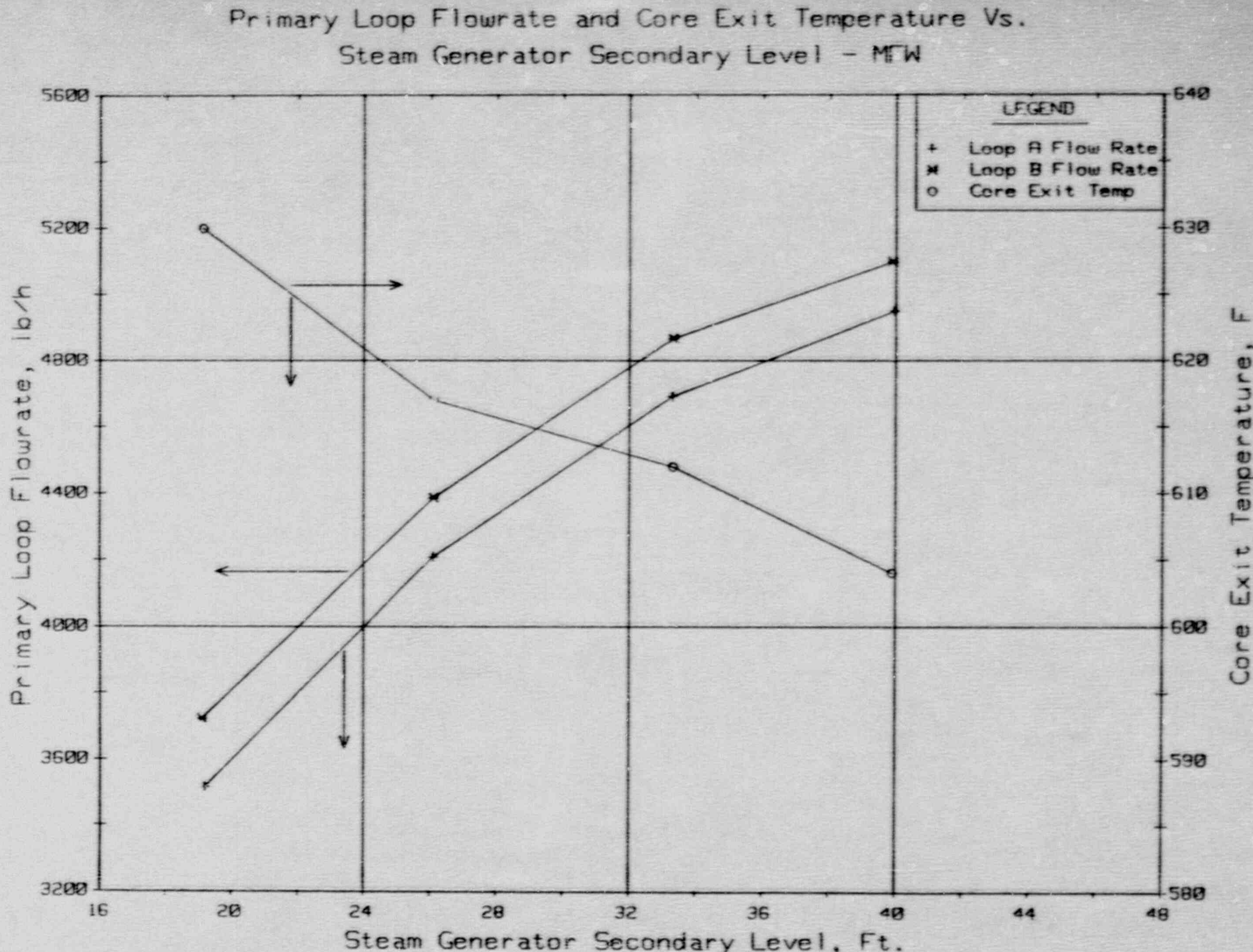



**Figure 5.83 Primary Loop Flow Rate and Core Exit Temperature Vs Steam Generator Secondary Level - MFW**

Fri Sep 30 11:33:15 1988

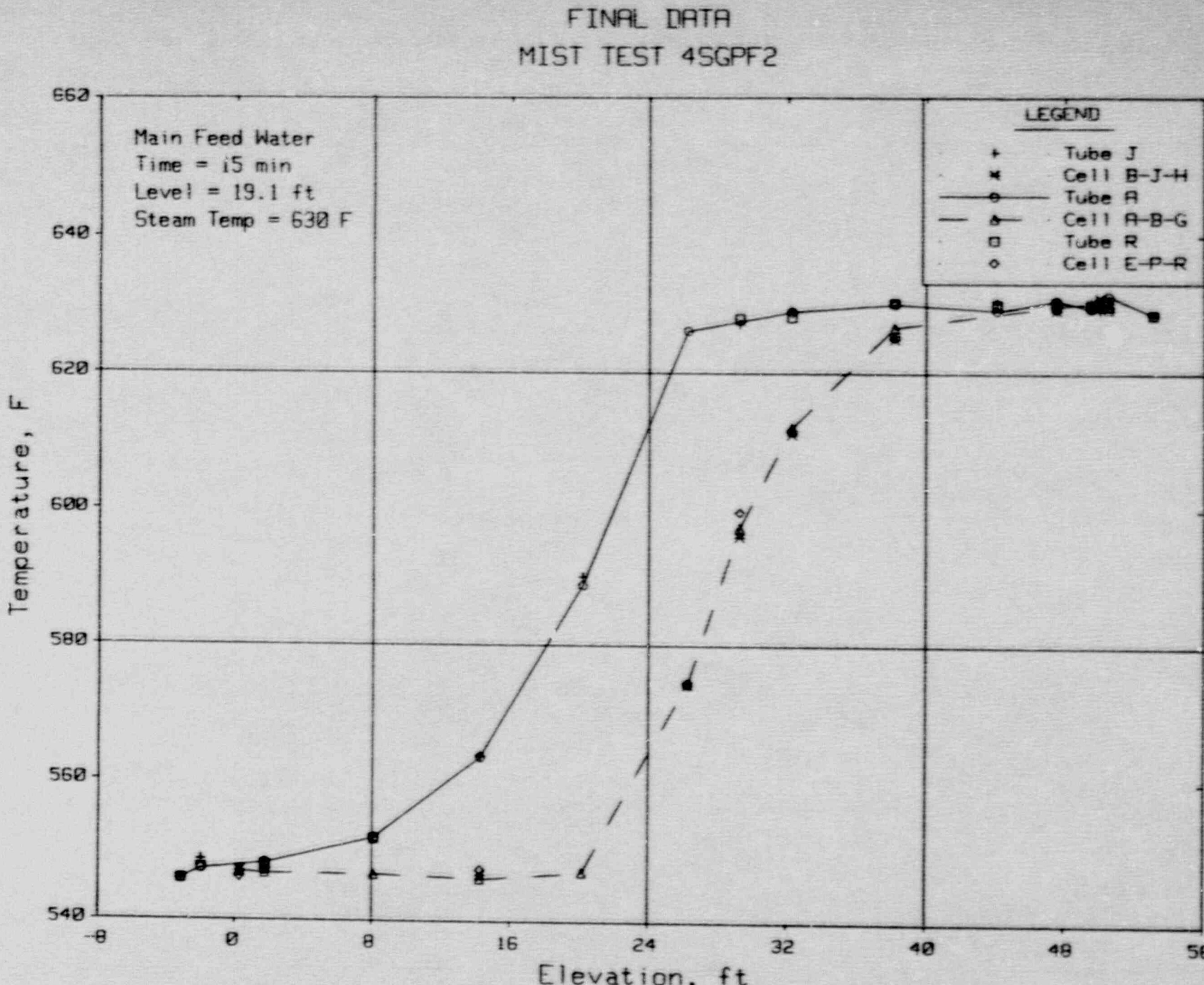



Figure 5.84 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 16:17:34 1989

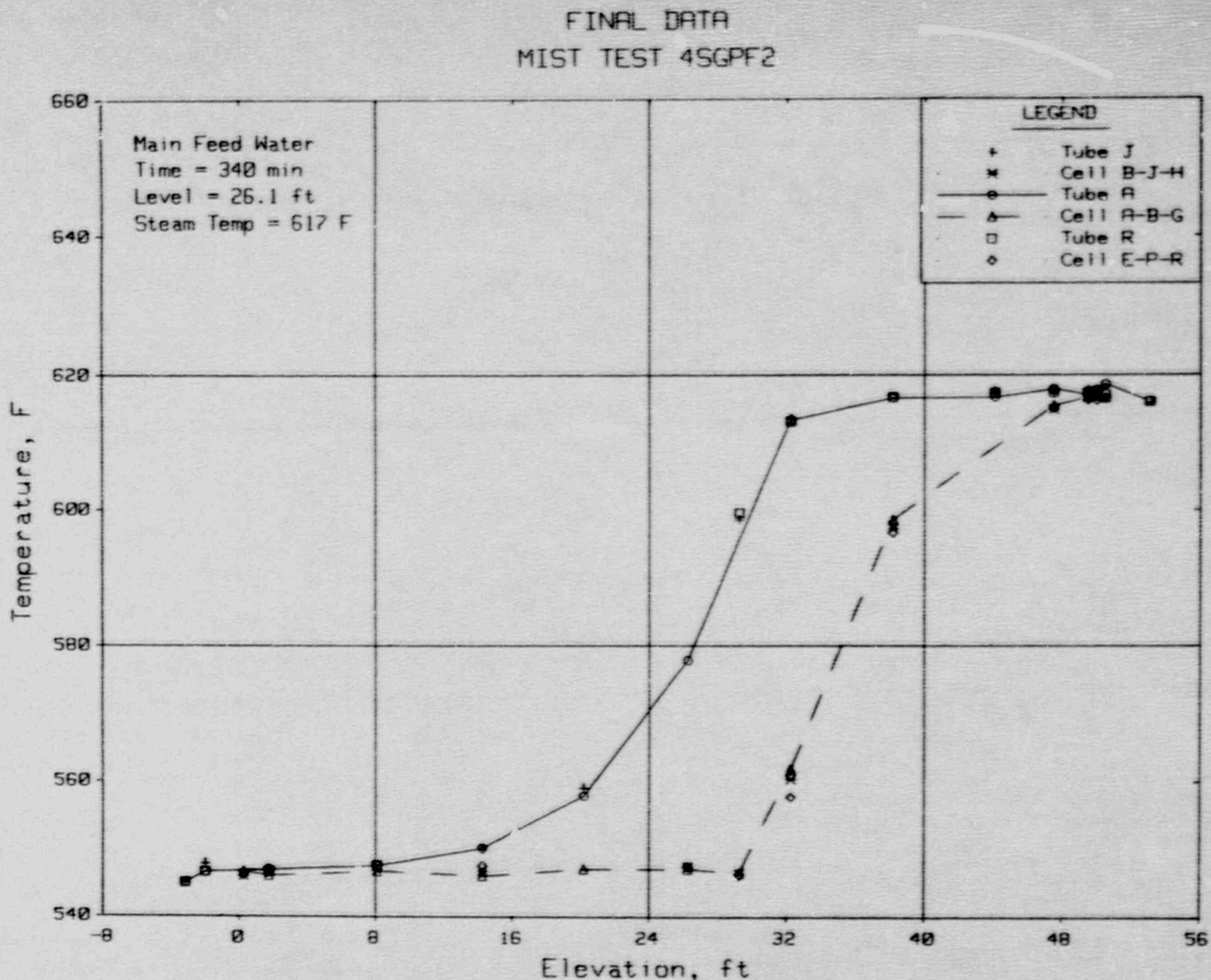



Figure 5.85 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 16:15:41 1989

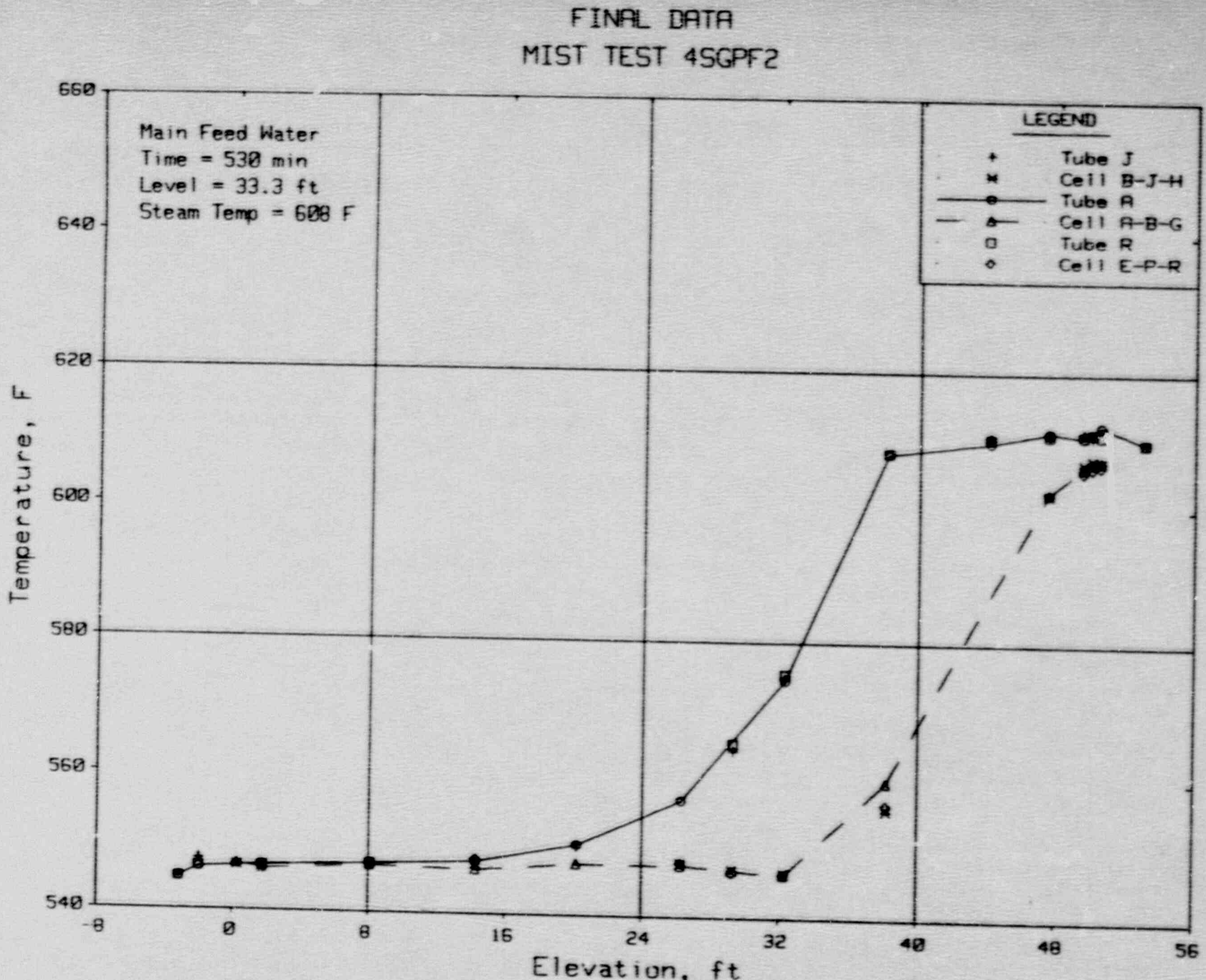



Figure 5.86 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 5 16:13:47 1988

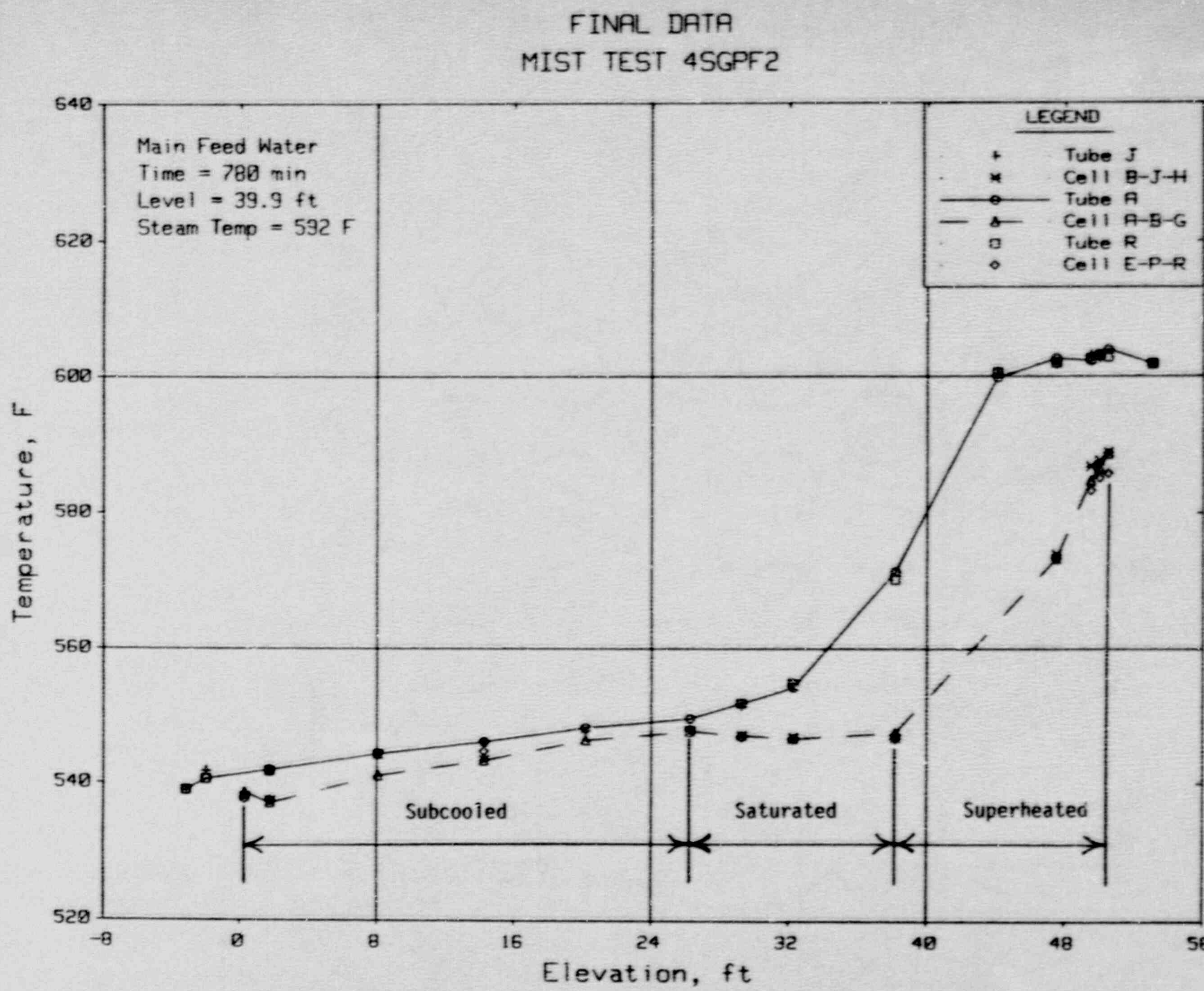



Figure 5.87 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 16:11:49 1988

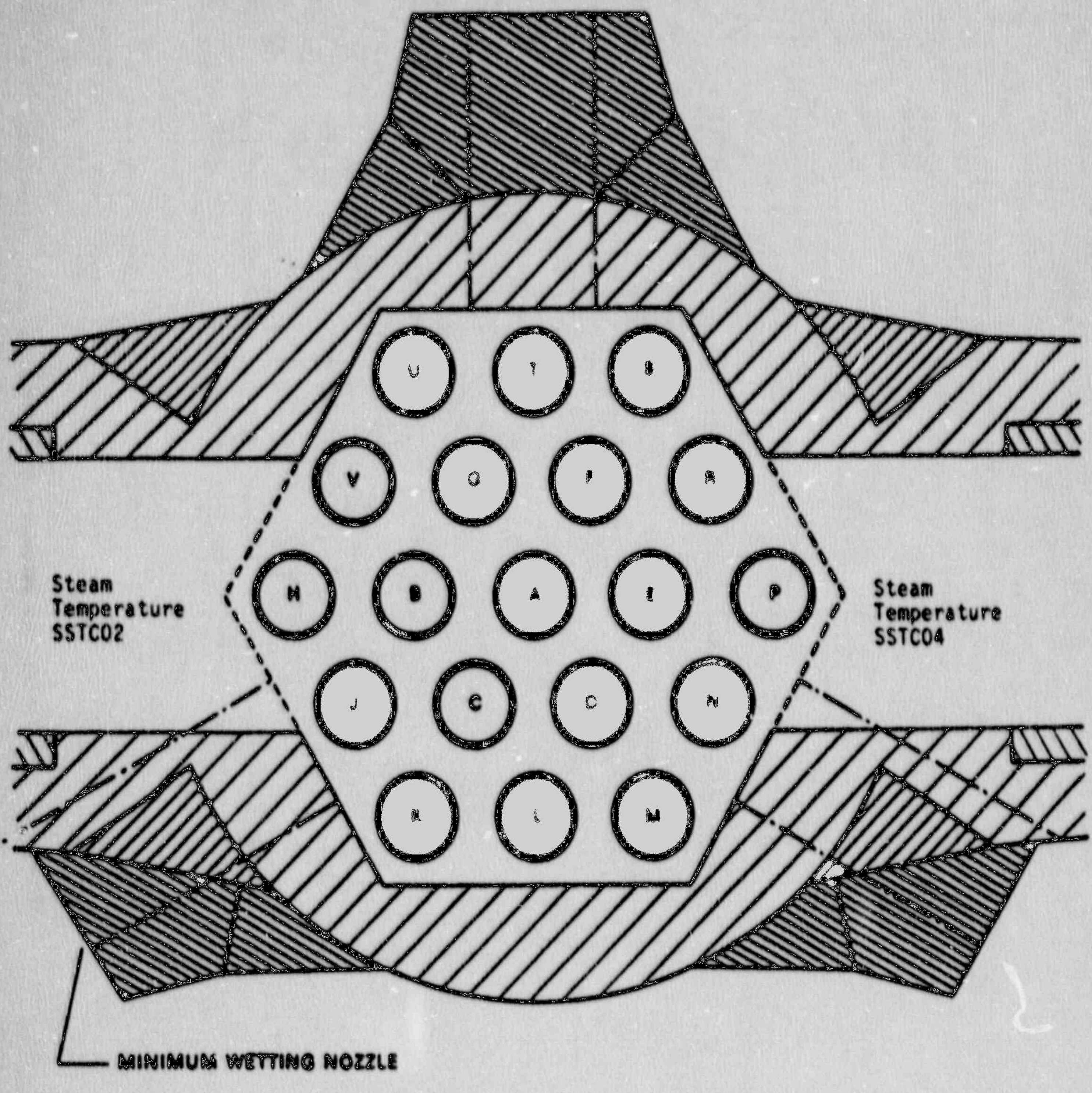



Figure 5.88 OTSG B Cross Section Showing Tube Identification

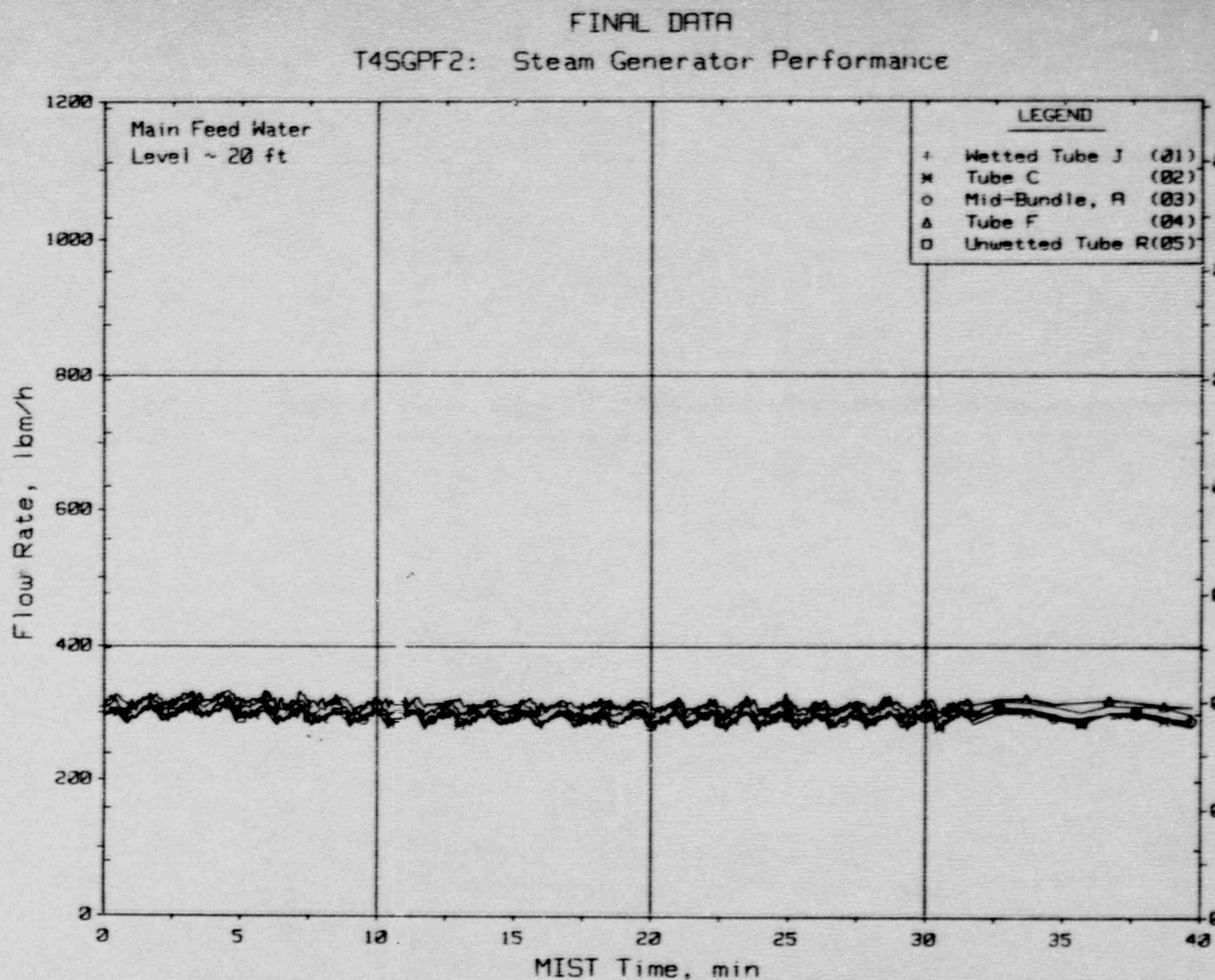


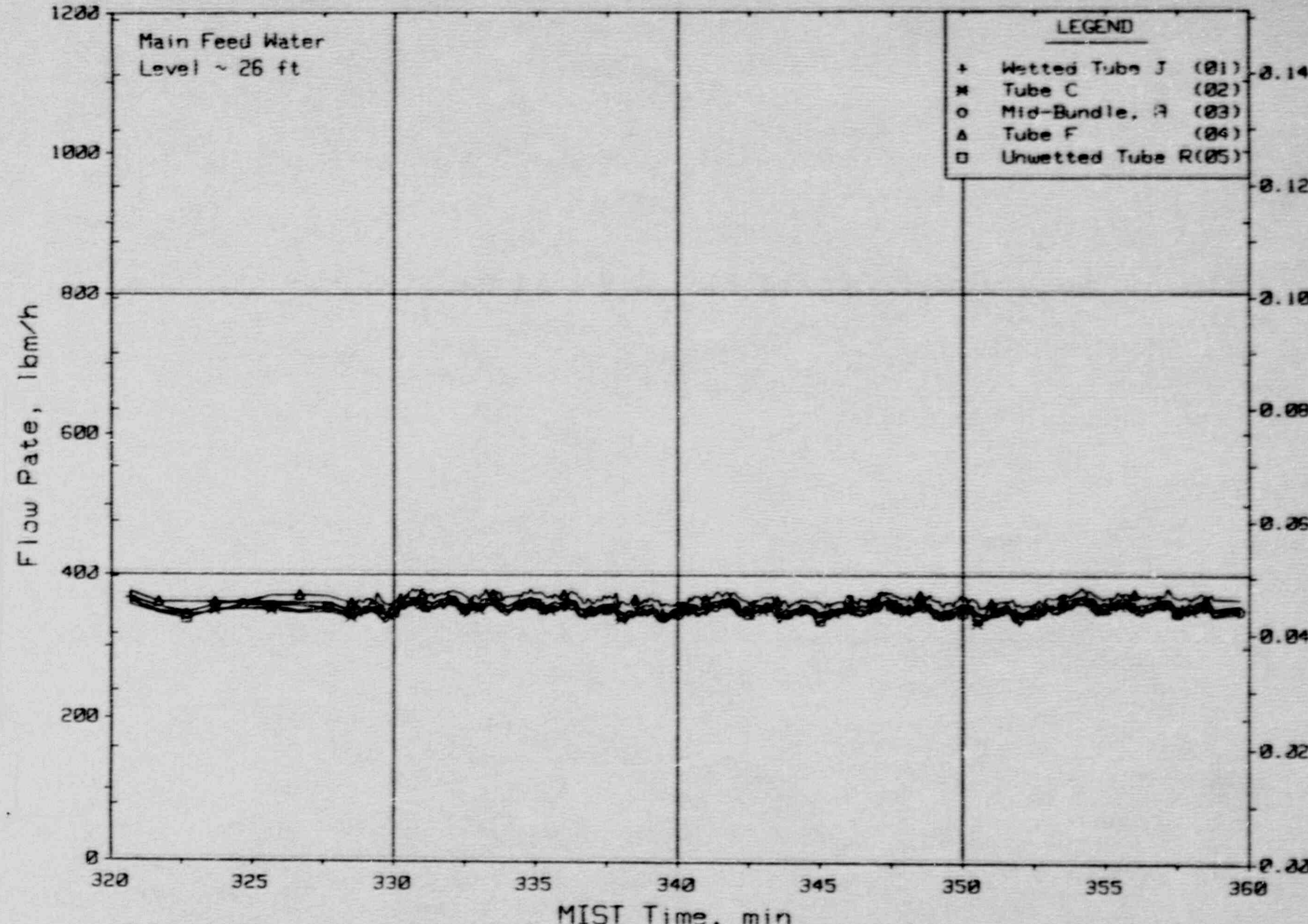

Figure 5.89 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

Fri Jun 10 13:24:28 1988

P2FL1

FINAL DATA

T4SGPF2: Steam Generator Performance




5-128

Figure 5.90 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

Fri Jun 10 13:30:34 1988

P2FL1

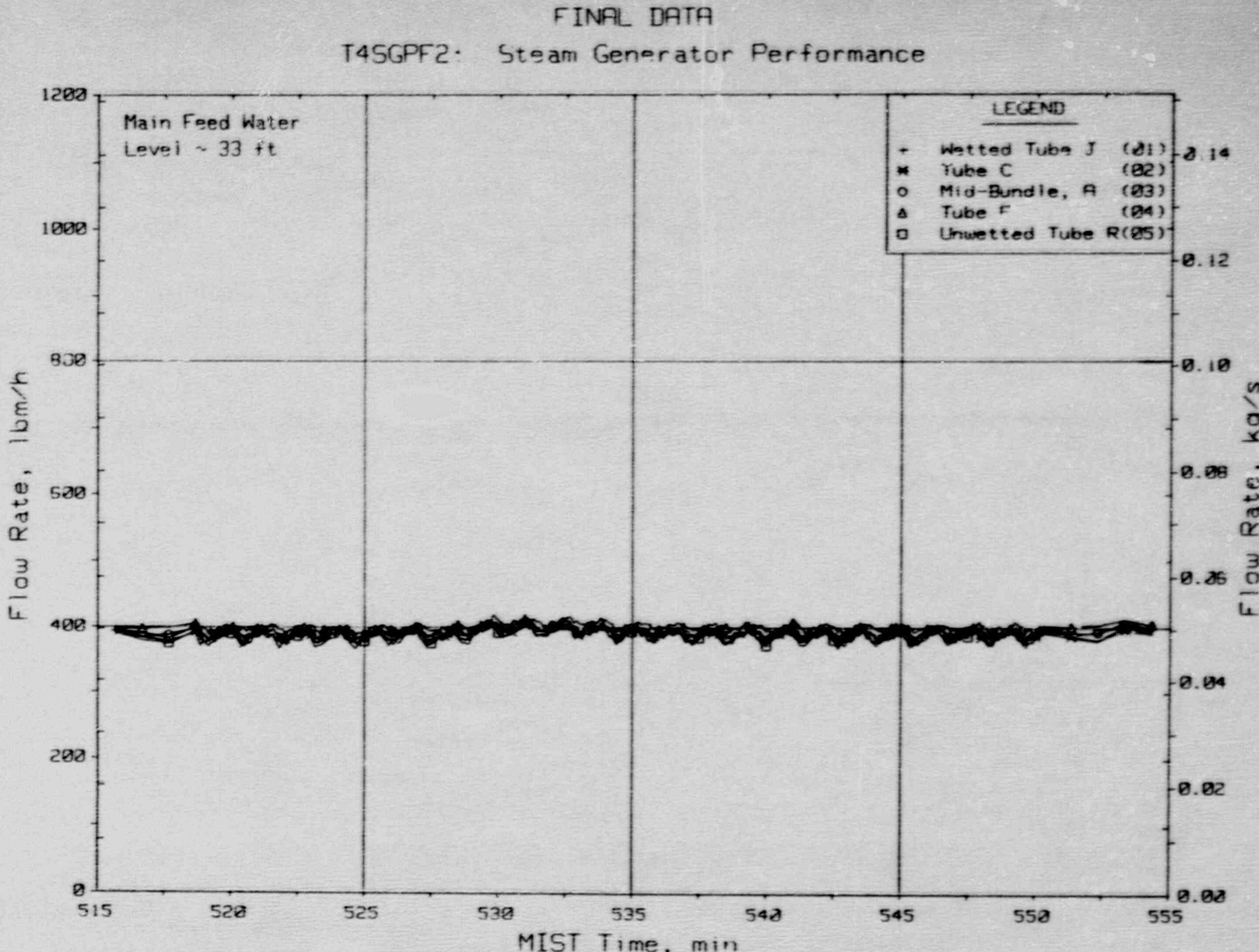





**Figure 5.91 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)**

Fri Jun 10 13:36:50 1988

P2FL1

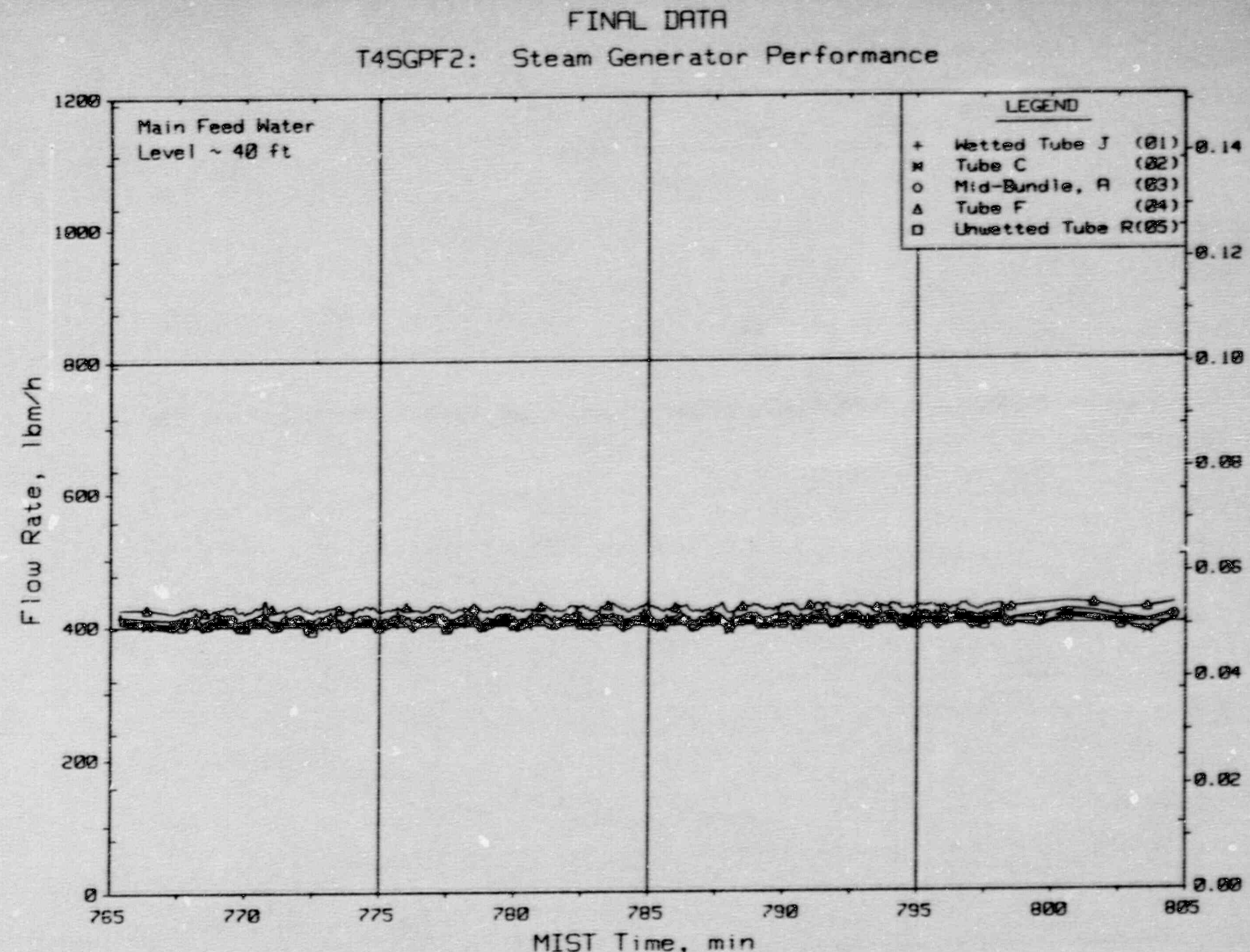



Figure 5.92 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

Fri Jun 10 13:54:12 1988

P2FL1

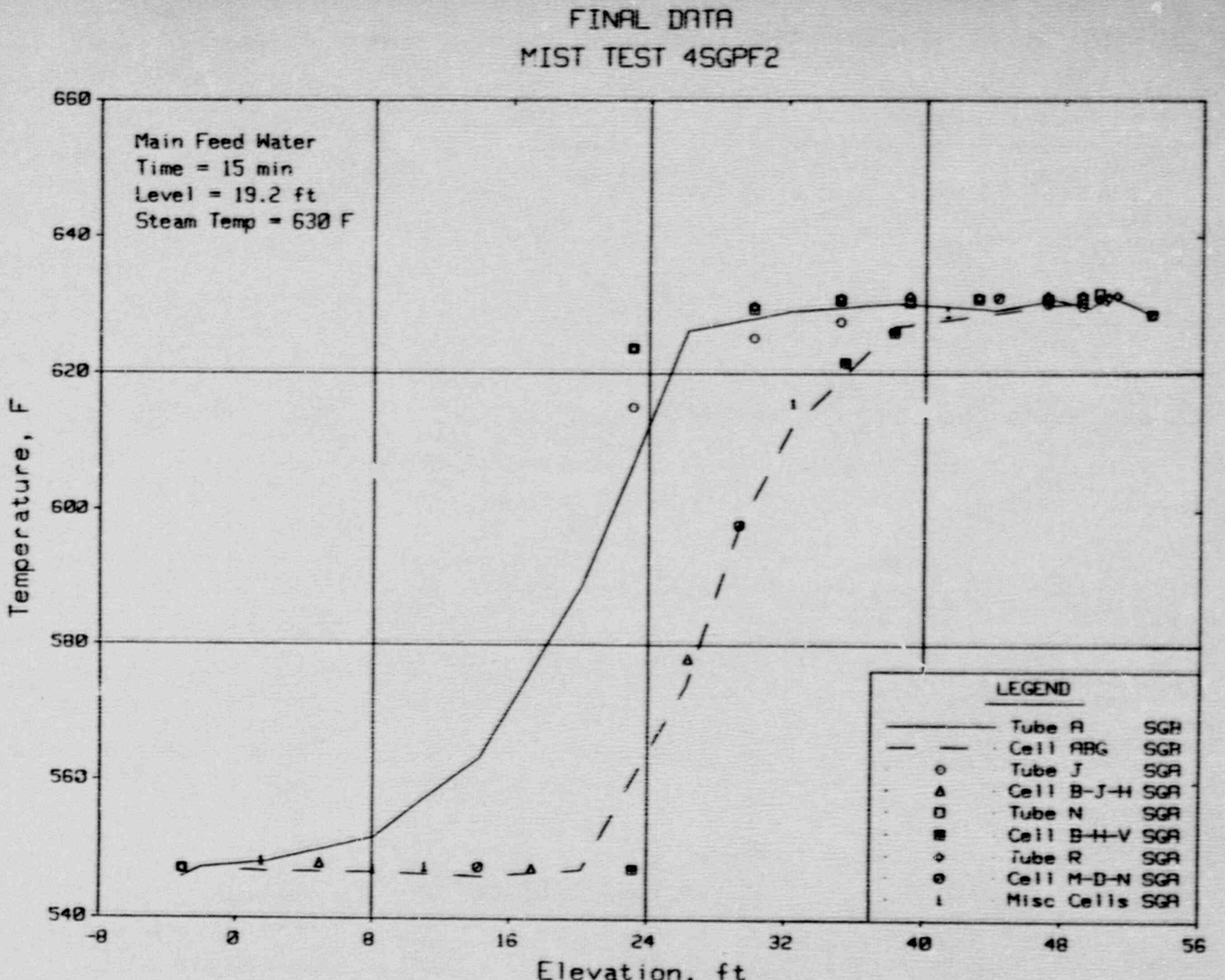



Figure 5.93 Comparison of Steam Generator A and B Primary and Secondary Axial Temperature Distribution

Fri Jun 10 10:02:30 1988

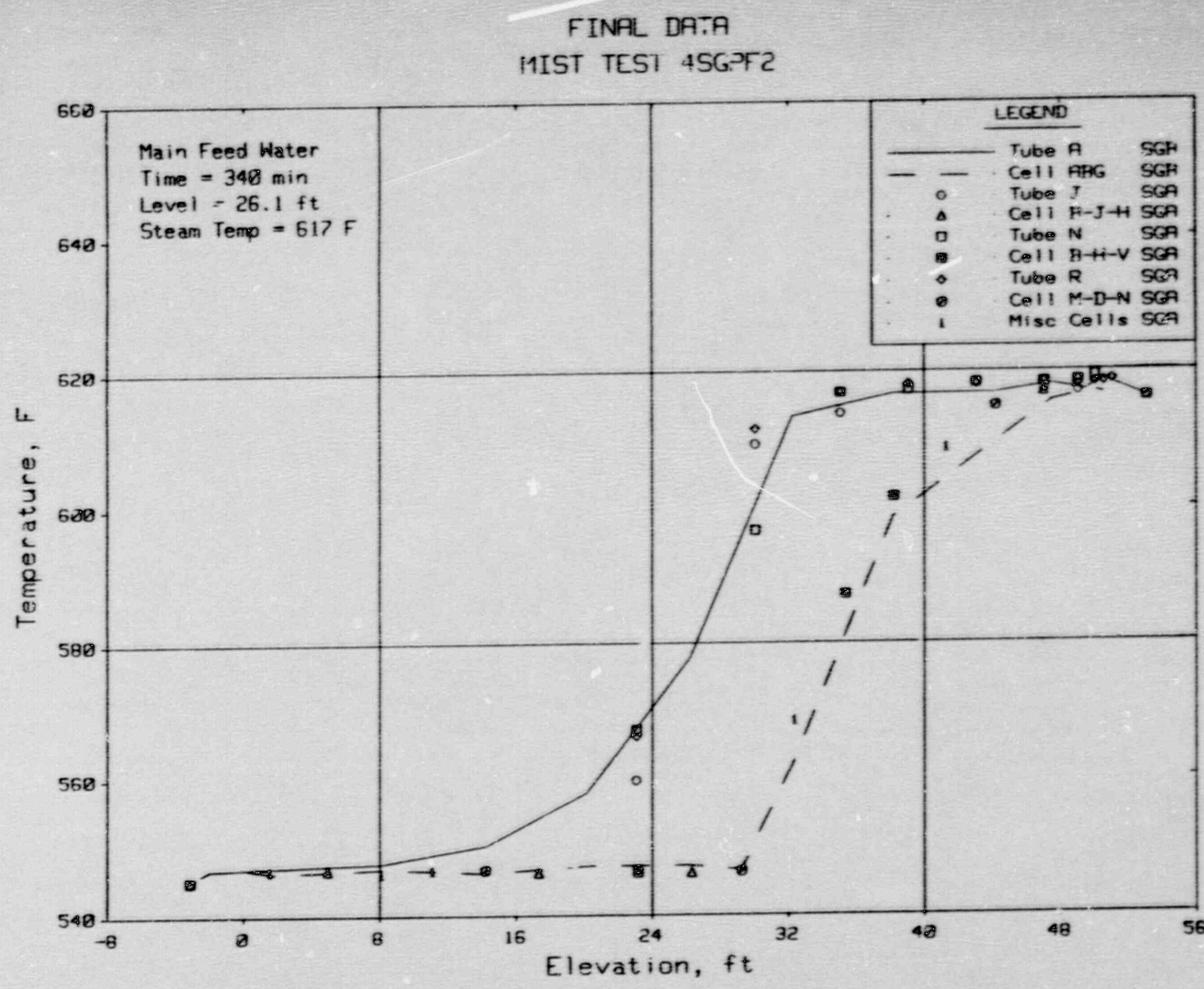



Figure 5.94 Comparison of Steam Generator A and B Primary and Secondary Axial Temperature Distribution

Fri Jun 10 10:00:14 1988

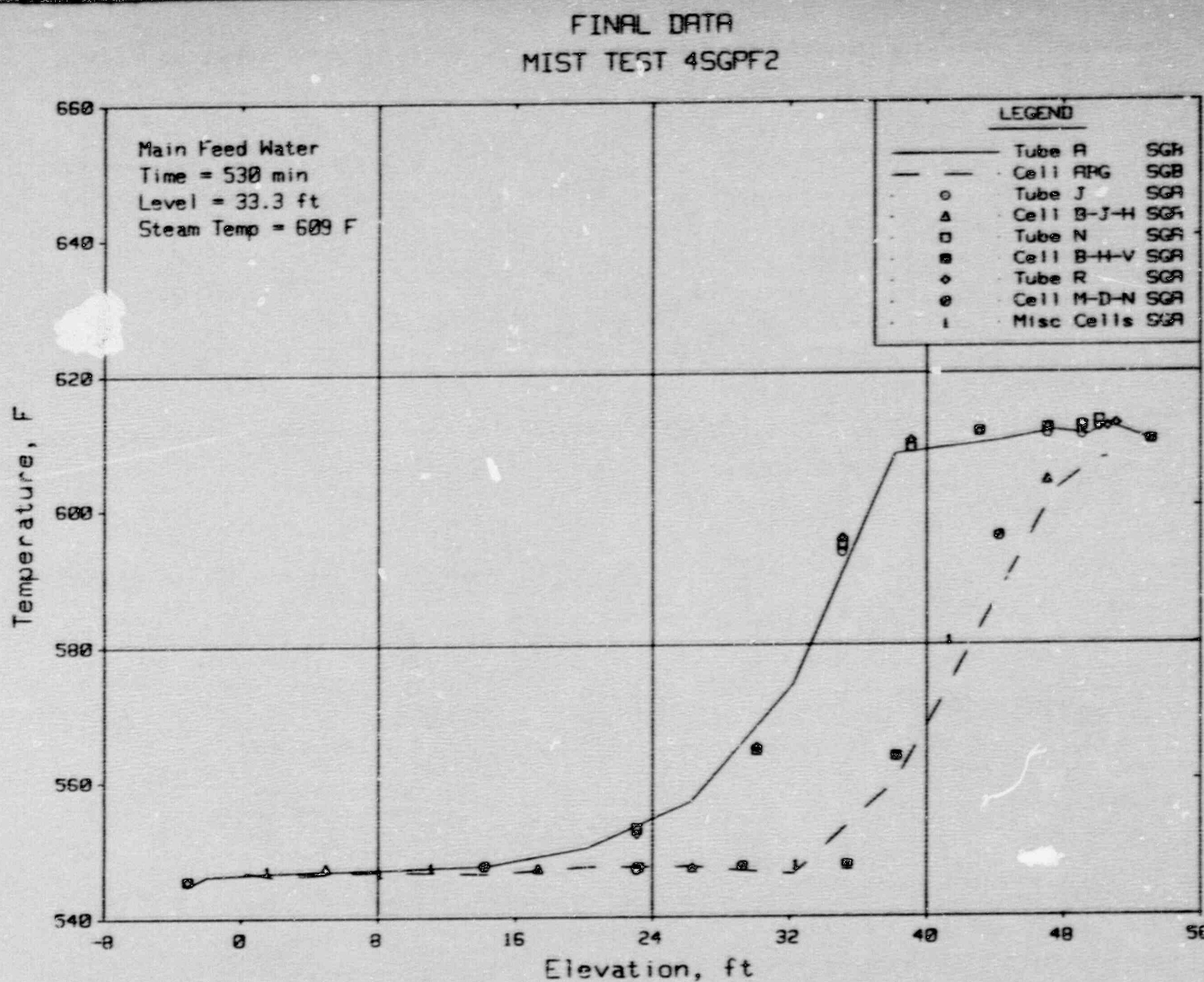



Figure 5.95 Comparison of Steam Generator A and B Primary and Secondary Axial Temperature Distribution

Fri Jun 10 09:58:10 1988

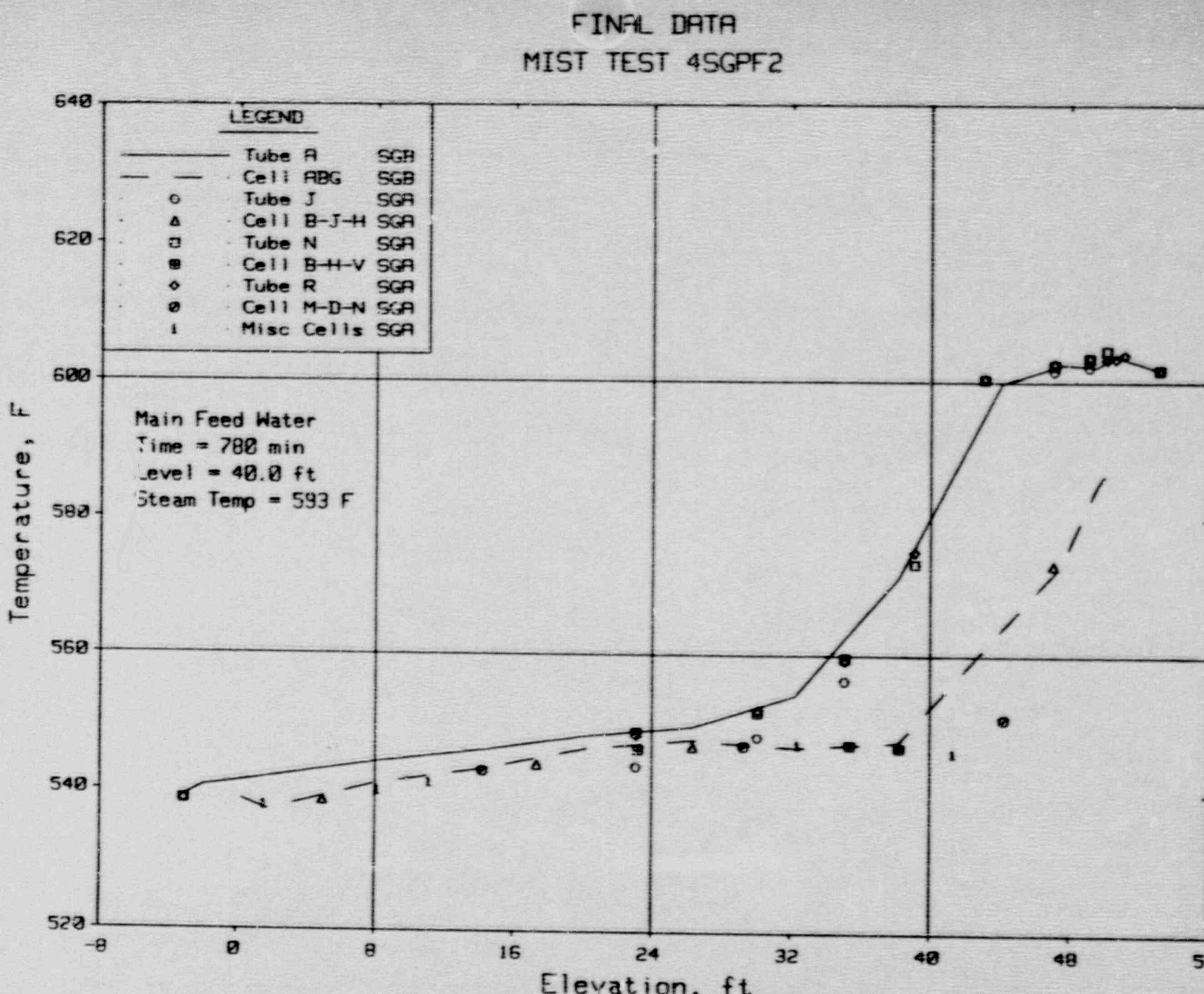



Figure 5.96 Comparison of Steam Generator A and B Primary and Secondary Axial Temperature Distribution

Fri Jun 10 09:56:05 1988

FINAL DATA

T4SGPF2: Steam Generator Performance

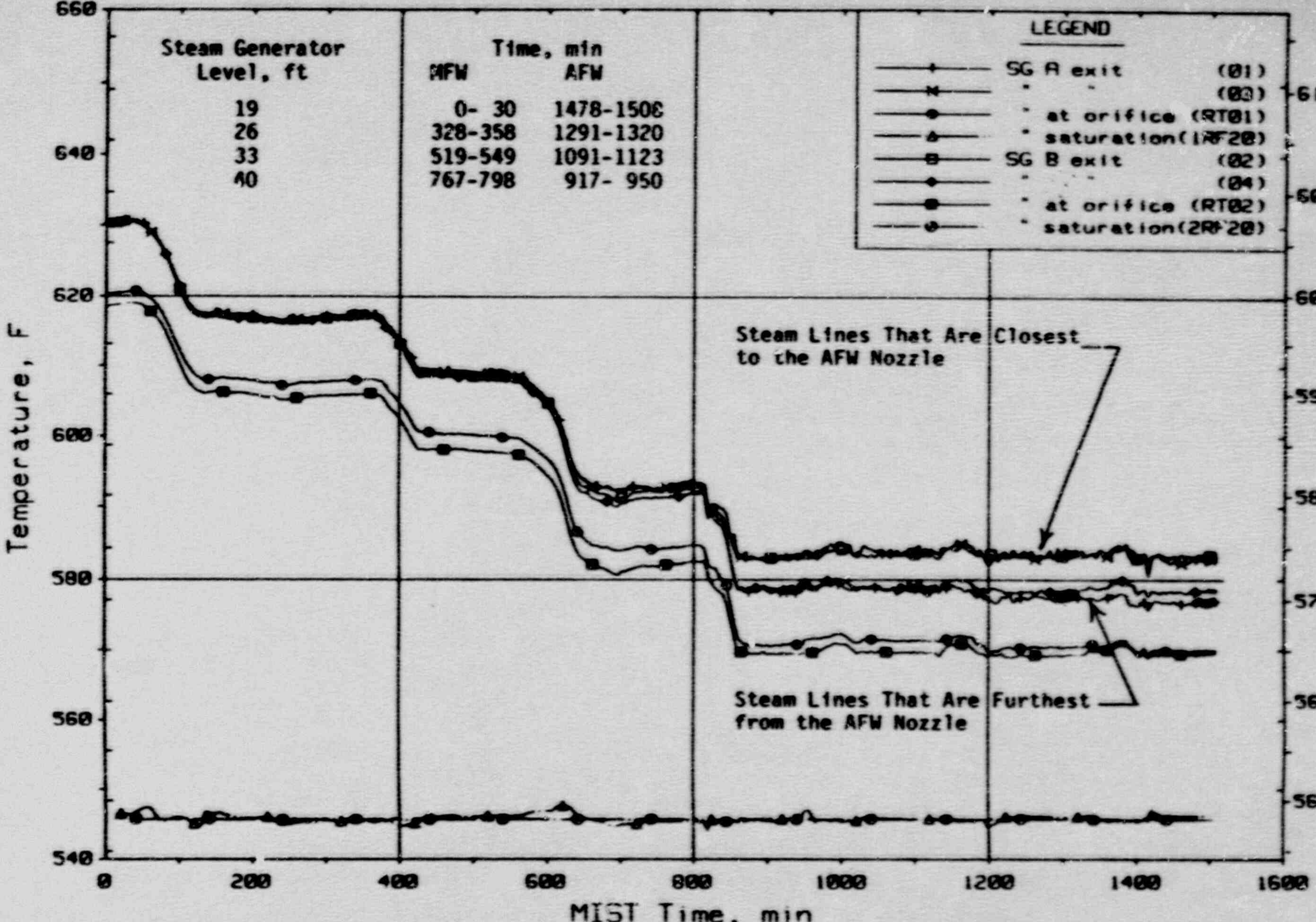



Figure 5.97 Steam Generator Steam Outlet Temperatures (SSTCs)

5-135

Thu Jun 9 13:08:49 1988

SCRT2

Figures for Test 4SGPF2

Steam Generator Performance - AFW

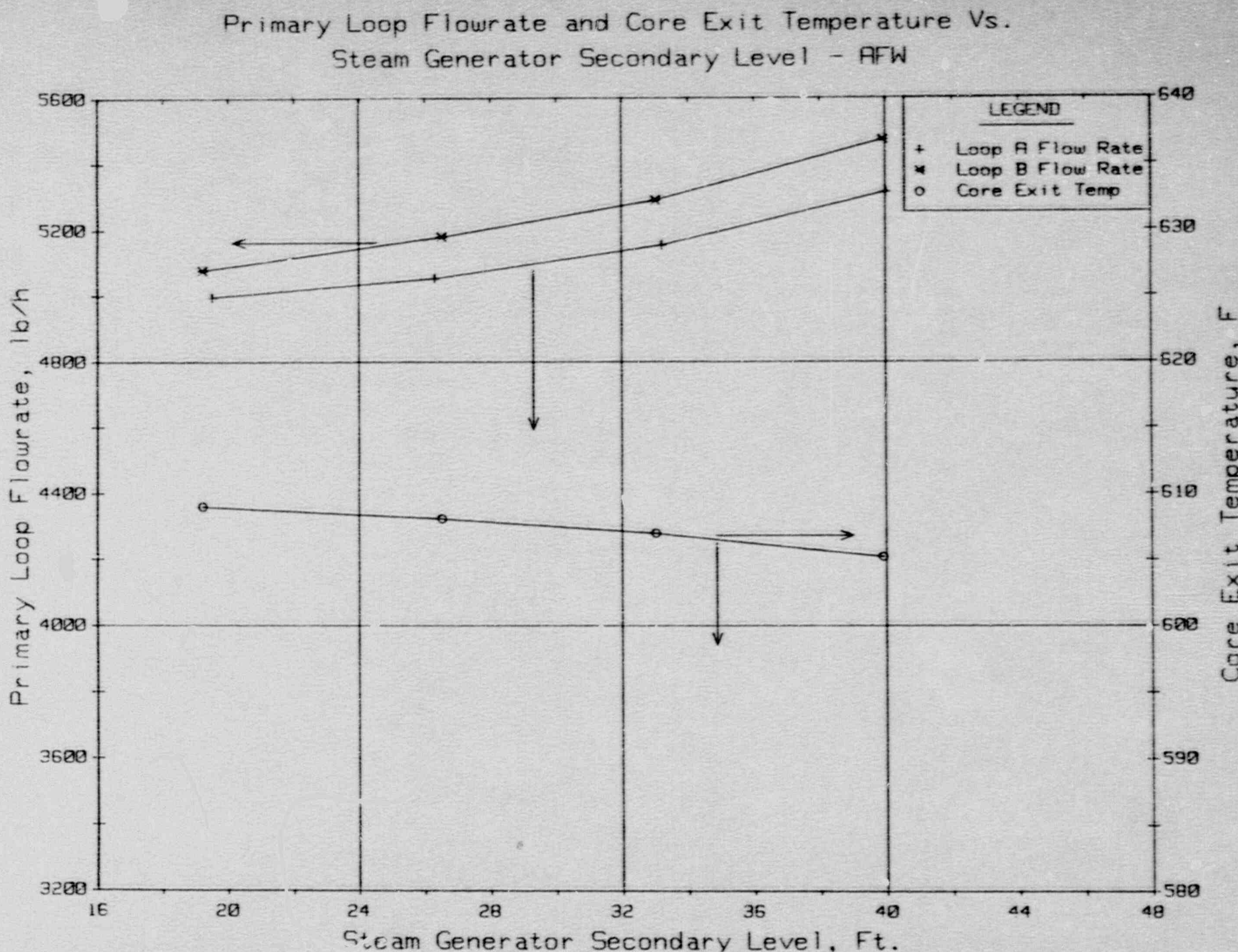
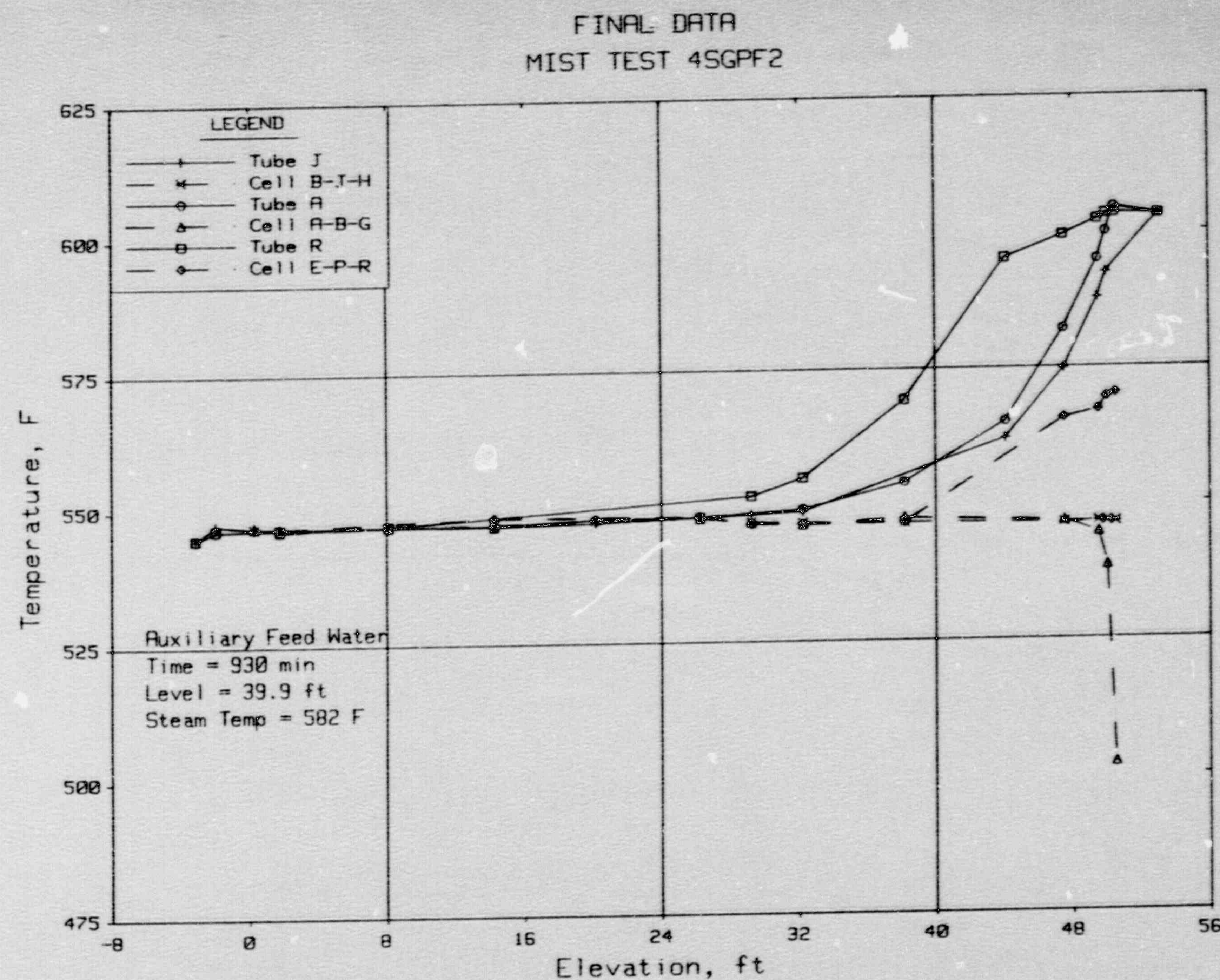



**Figure 5.98 Primary Loop Flow Rate and Core Exit Temperature Vs Steam Generator Secondary Level - AFW**

Fri Sep 30 11:37:24 1988




5-137

Figure 5.99 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 17:20:47 1988

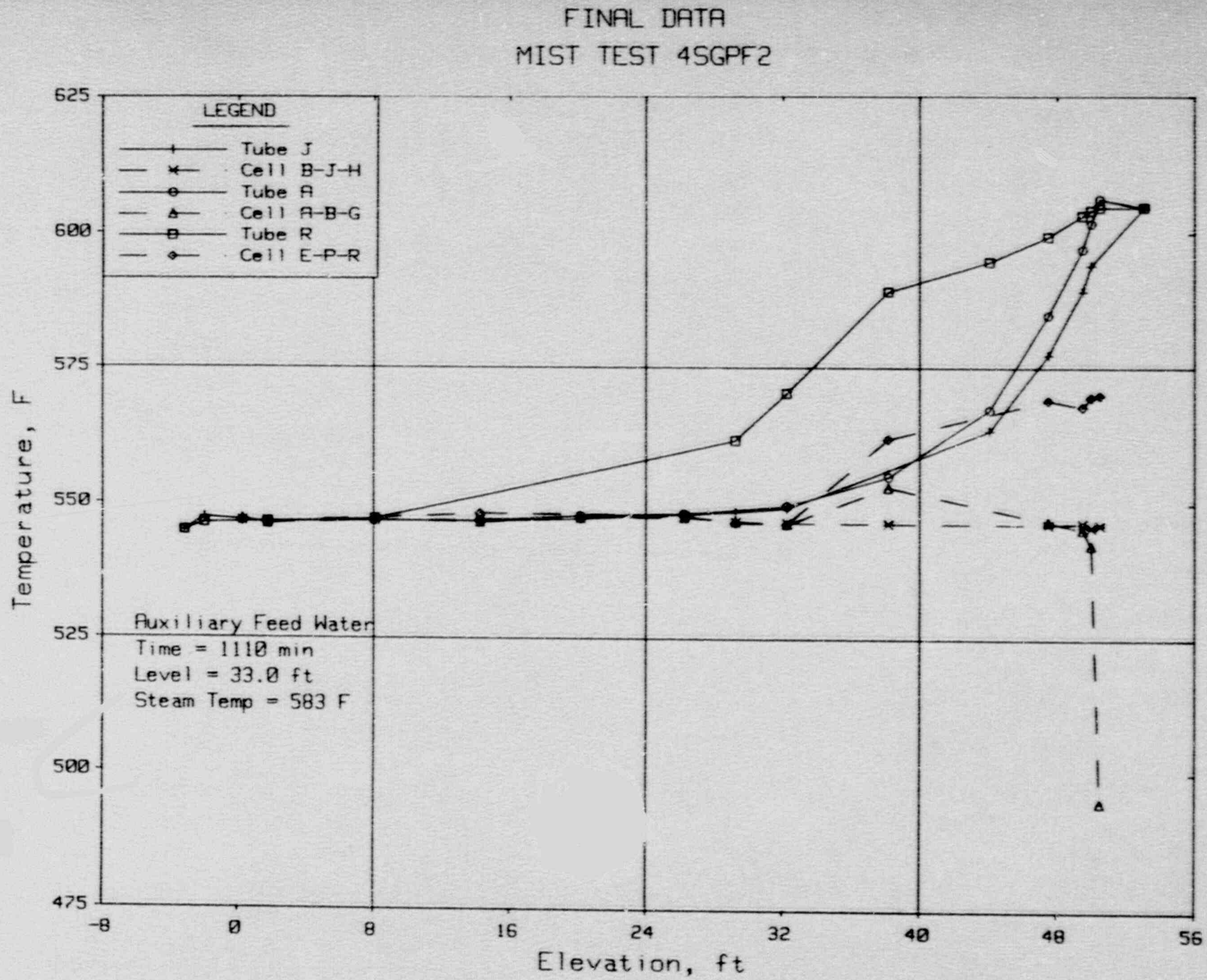



Figure 5.100 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 16:05:46 1988

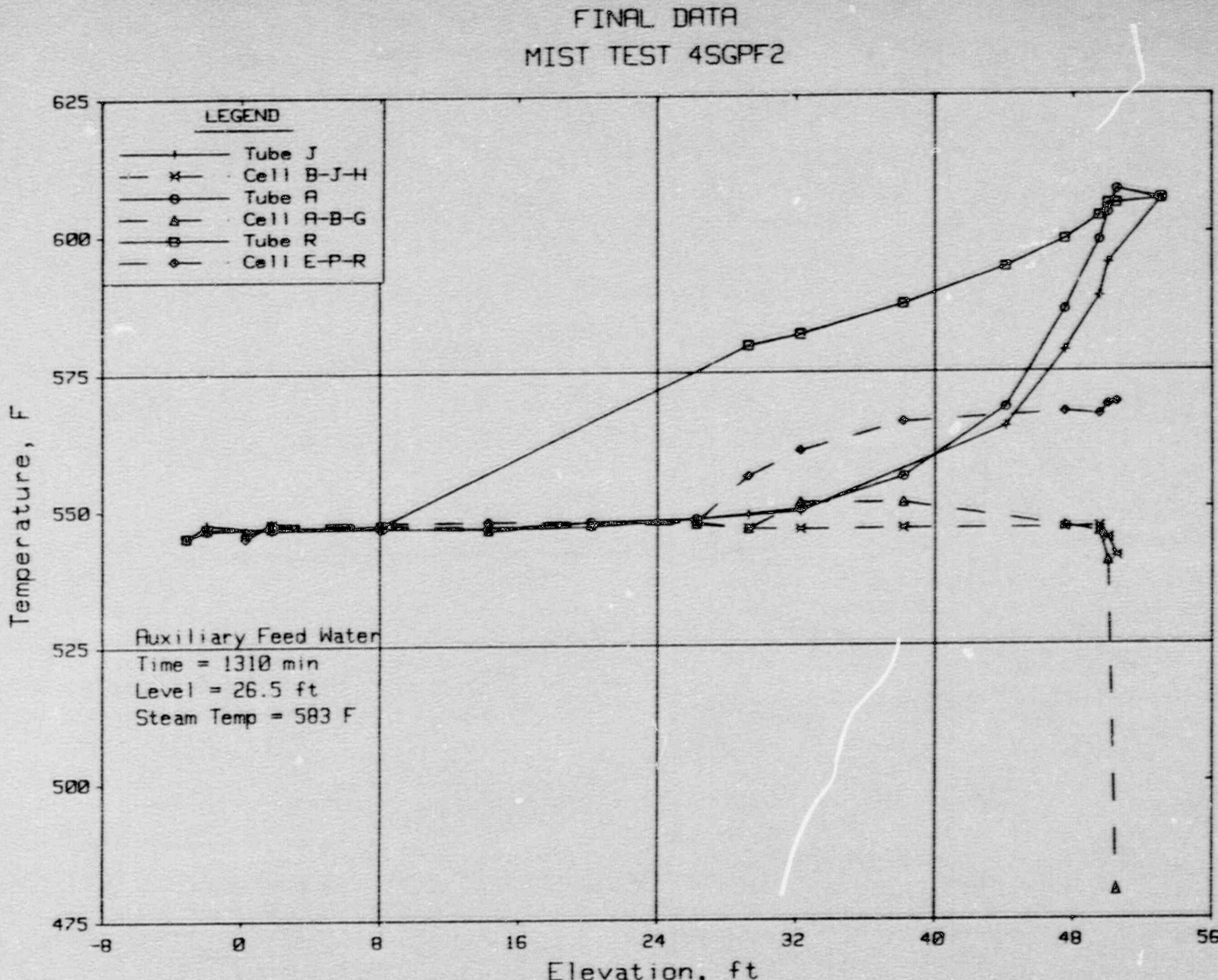



Figure 5.101 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 16:03:10 1988

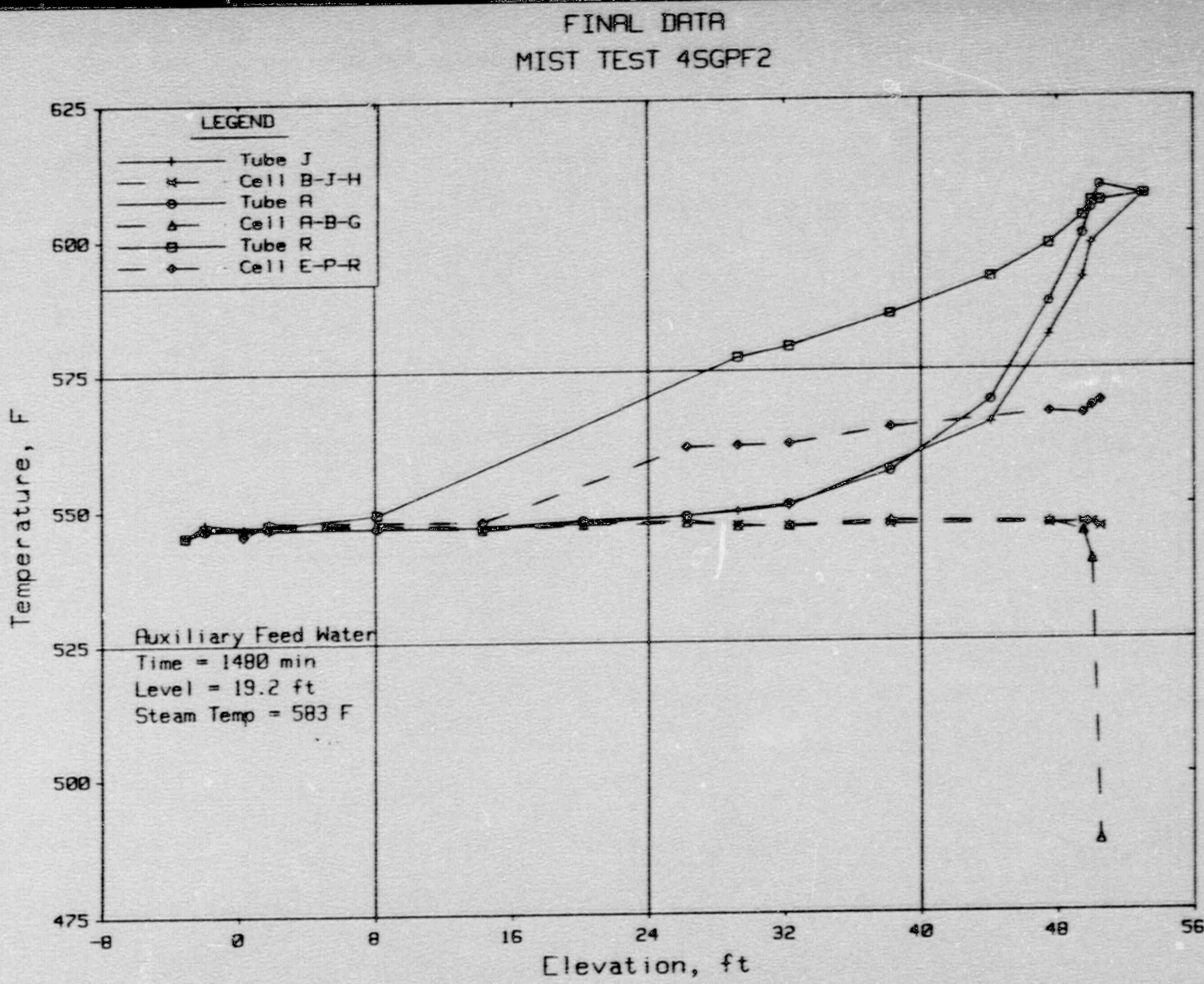



Figure 5.102 Steam Generator B Primary and Secondary Axial Temperature Distribution

Mon Jun 6 17:16:40 1988

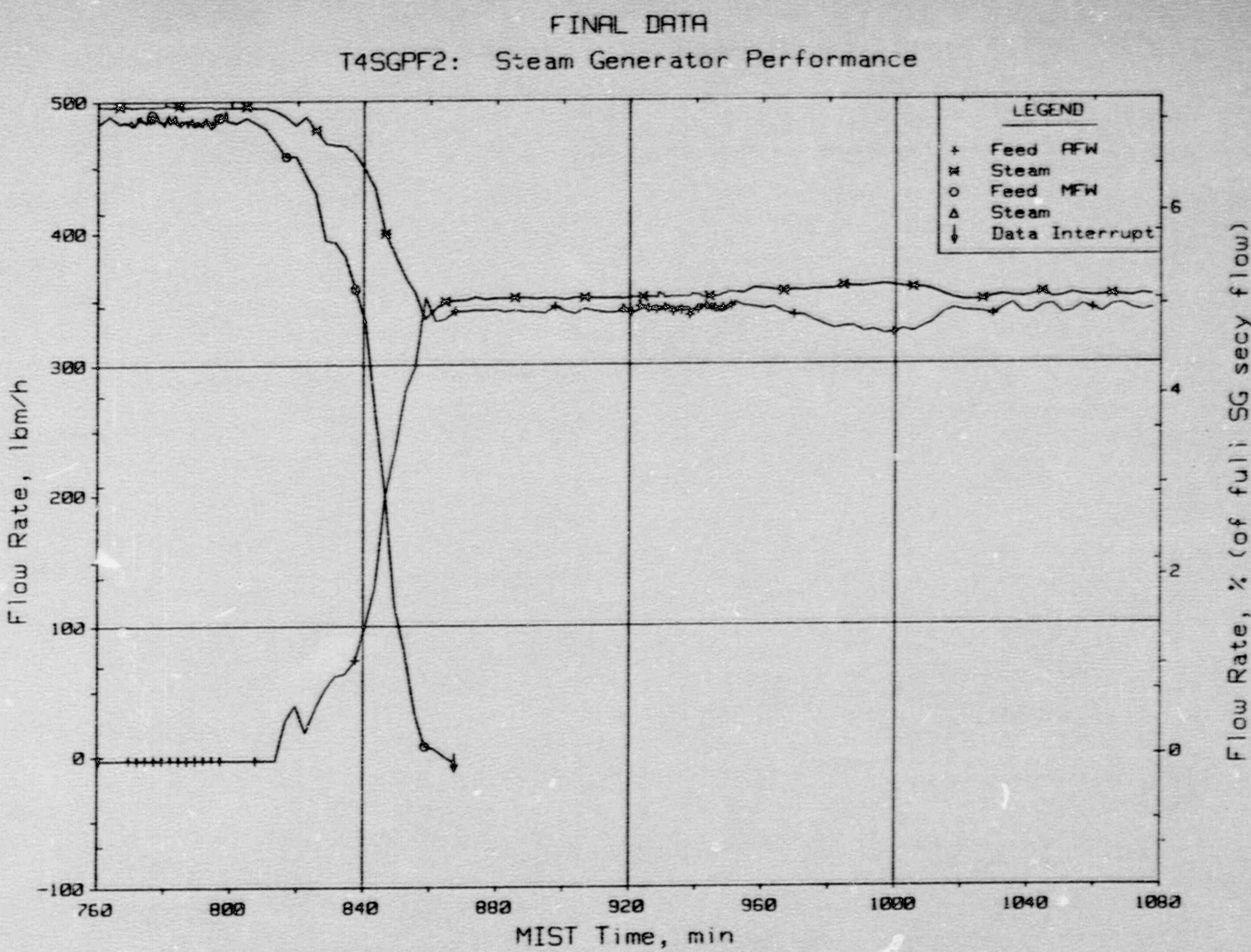


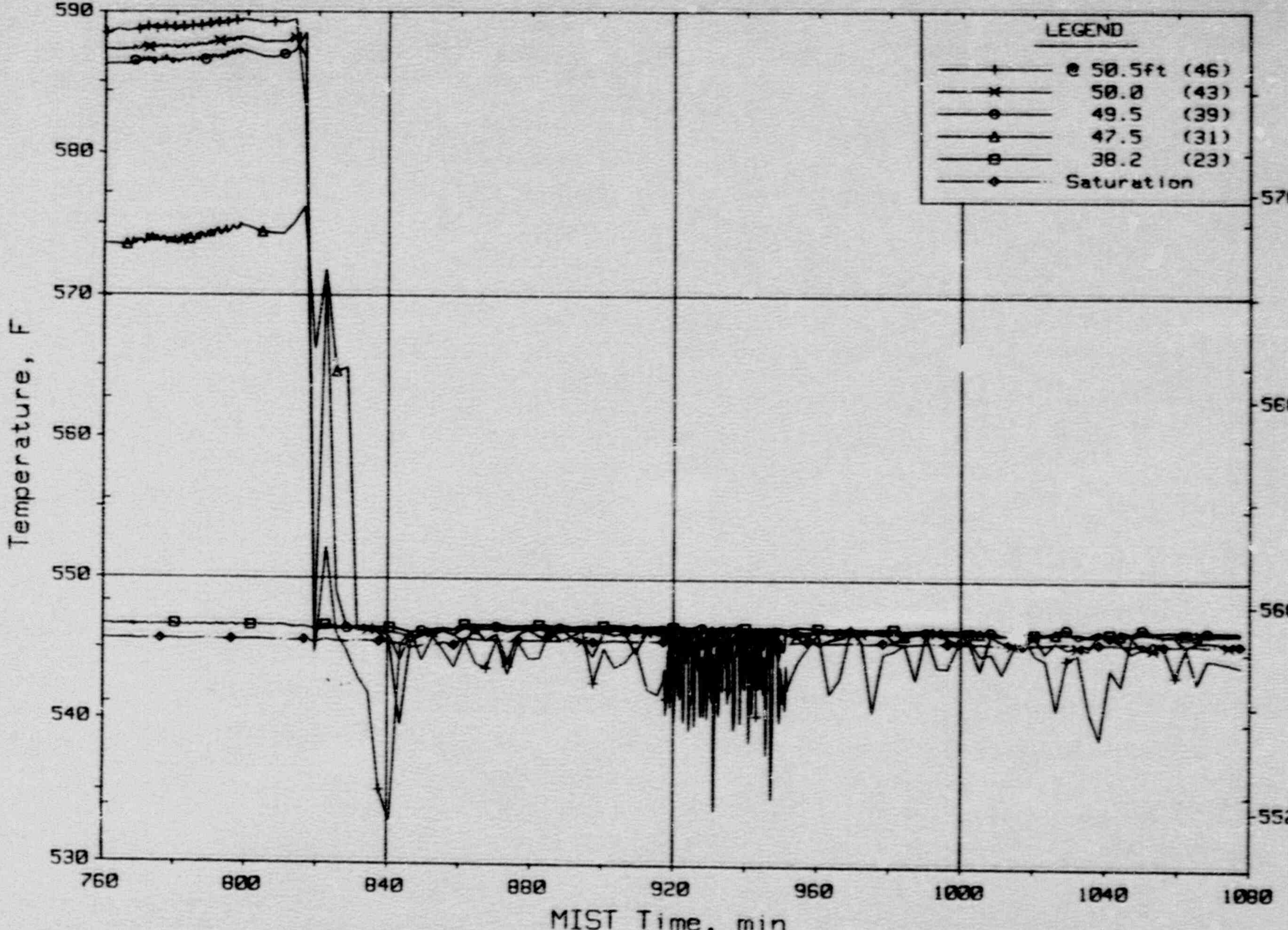

Figure 5.103 Steam Generator B Flow Rates

Wed Nov 16 10:20:38 1988

SCFL2

FINAL DATA

T4SGPF2: Steam Generator Performance

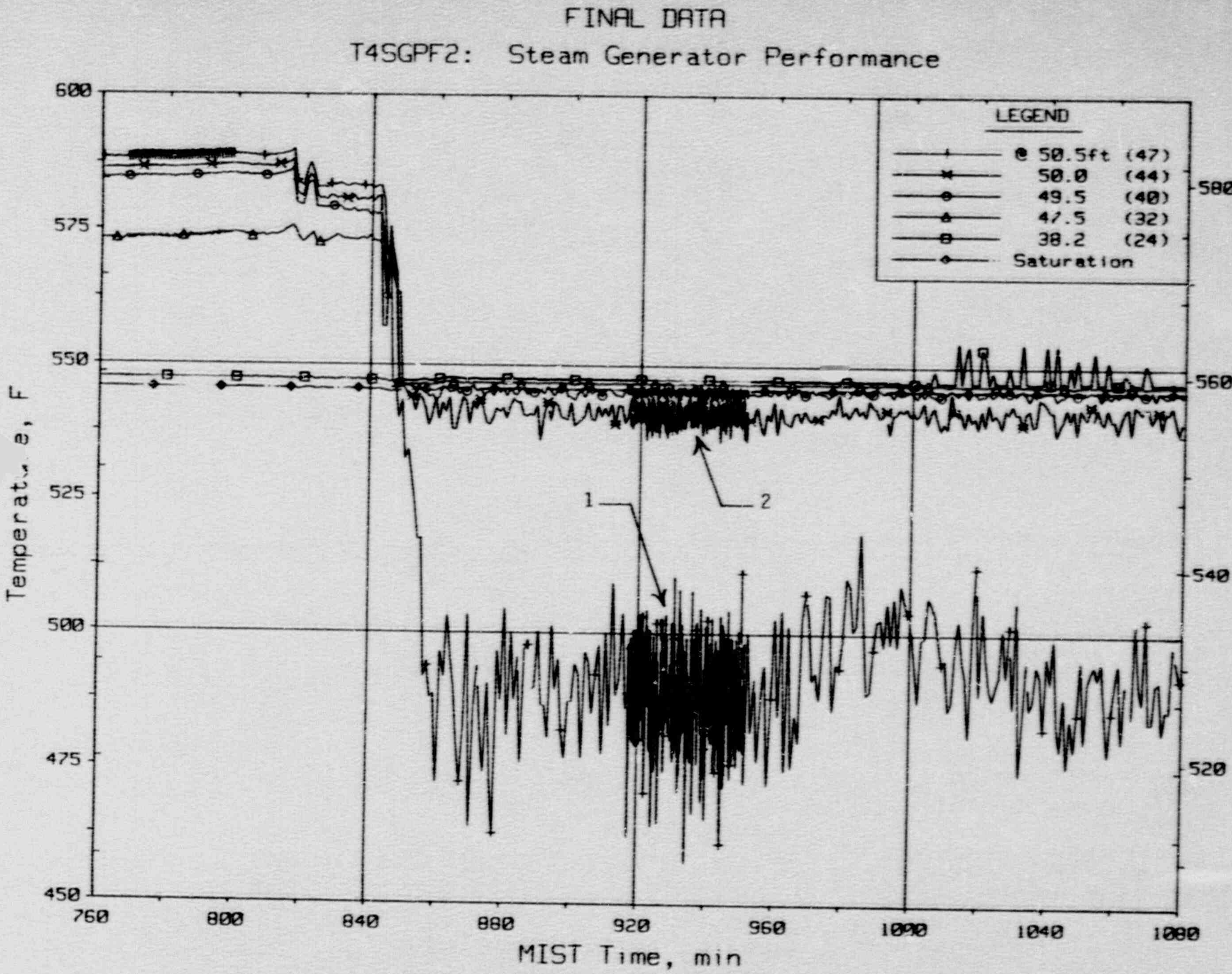



5-142

Figure 5.104 Steam Generator B Wetted Cell (B-J-H) Upper-Elevation Fluid Temperatures (S2TCs)

Thu Jun 9 13:40:57 1988

S2TC1




5-143

Figure 5.105 Steam Generator B Secondary Central Cell (A-B-G) Upper-Elevation Fluid Temperatures (S2TCs)

Thu Jun 9 11:59:14 1988

S2TC3

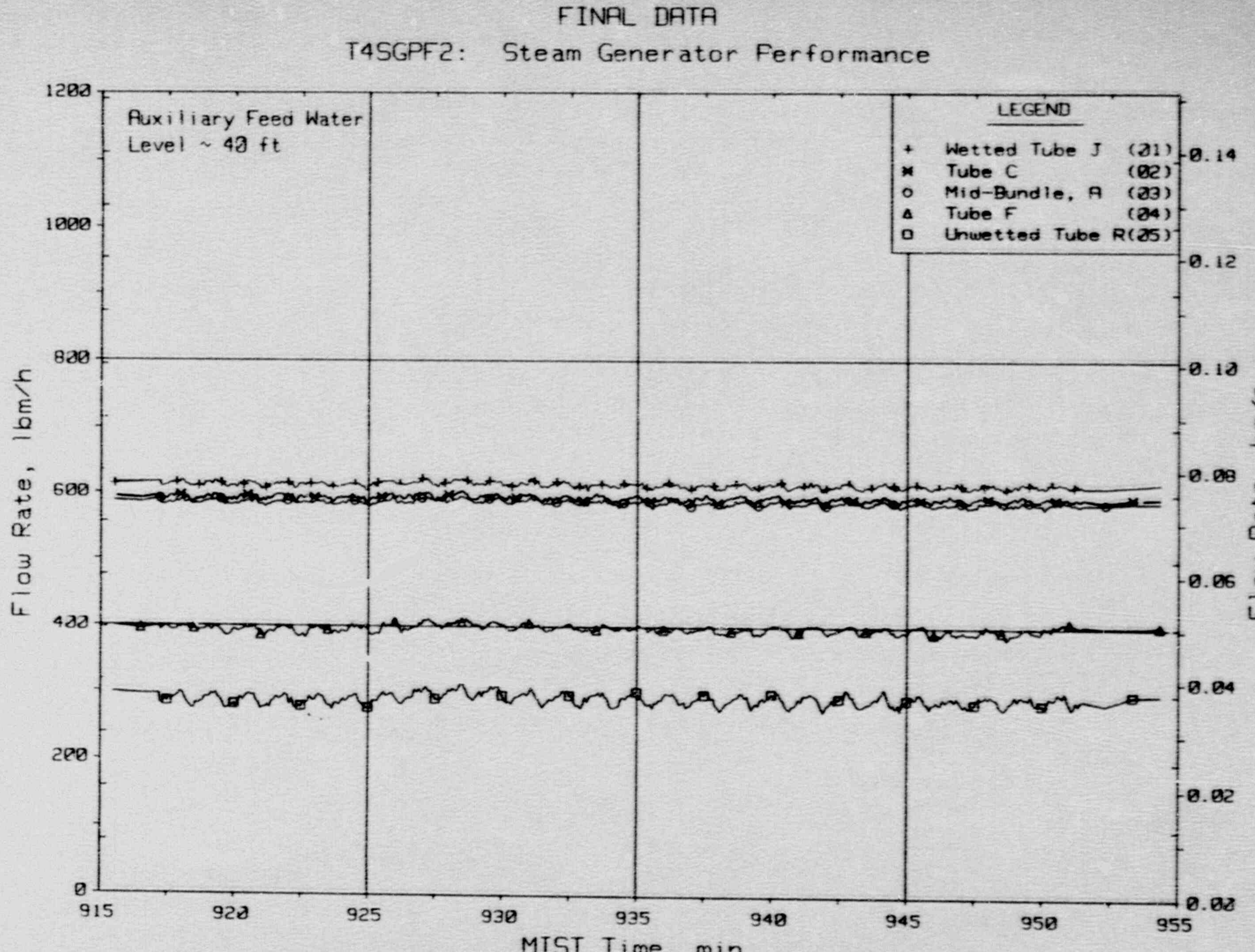



Figure 5.106 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

Fri Jun 10 14:02:20 1988

P2FL1

FINAL DATA

T4SGPF2: Steam Generator Performance

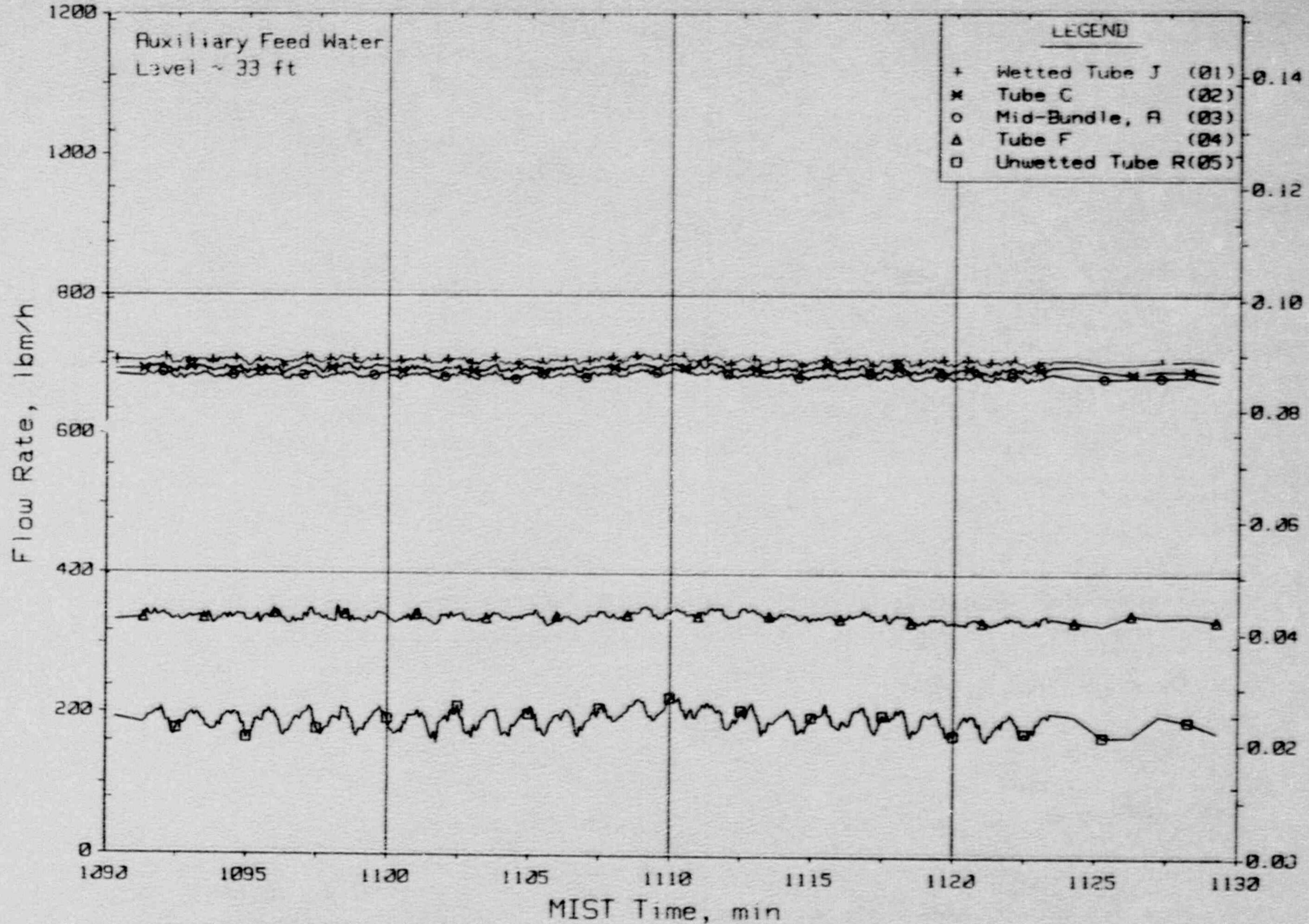



Figure 5.107 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

Fri Jun 10 14:20:58 1988

P2FLI

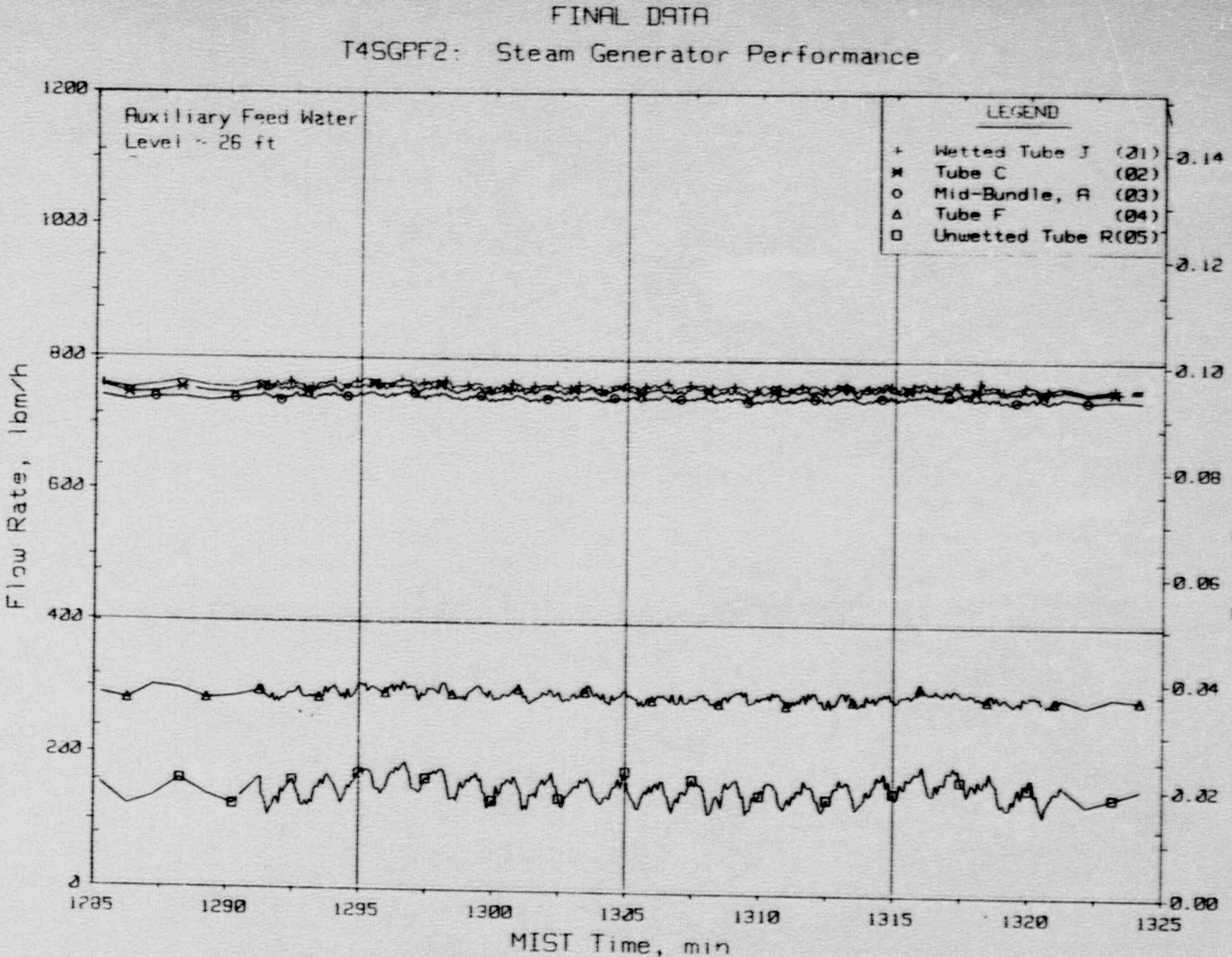
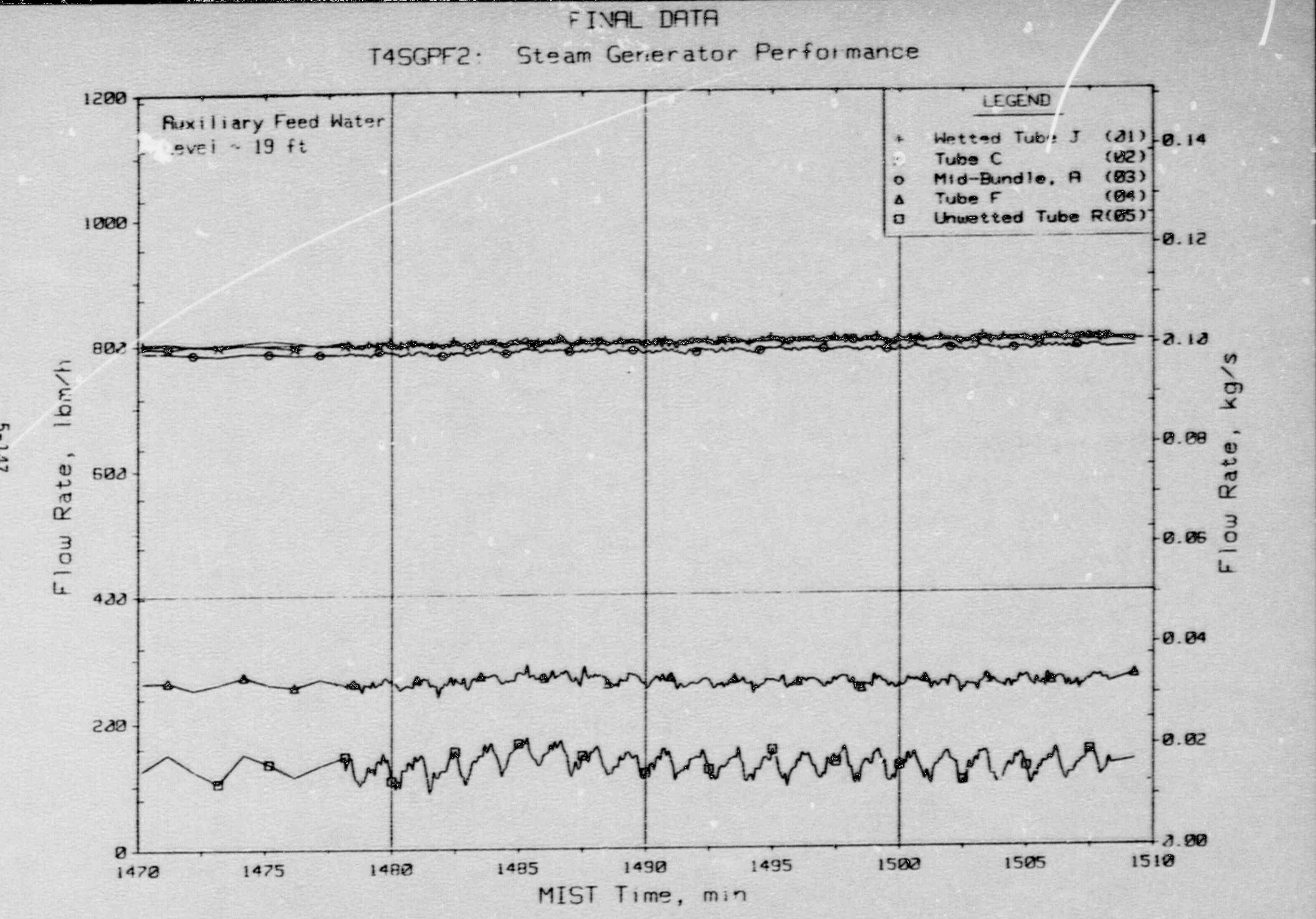



Figure 5.108 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

Fri Jun 10 14:27:51 1988

P2FL1




5-147

Figure 5.109 Steam Generator B (Pitot Tube) Mass Flow Rates (P2PTs)

P2FL1

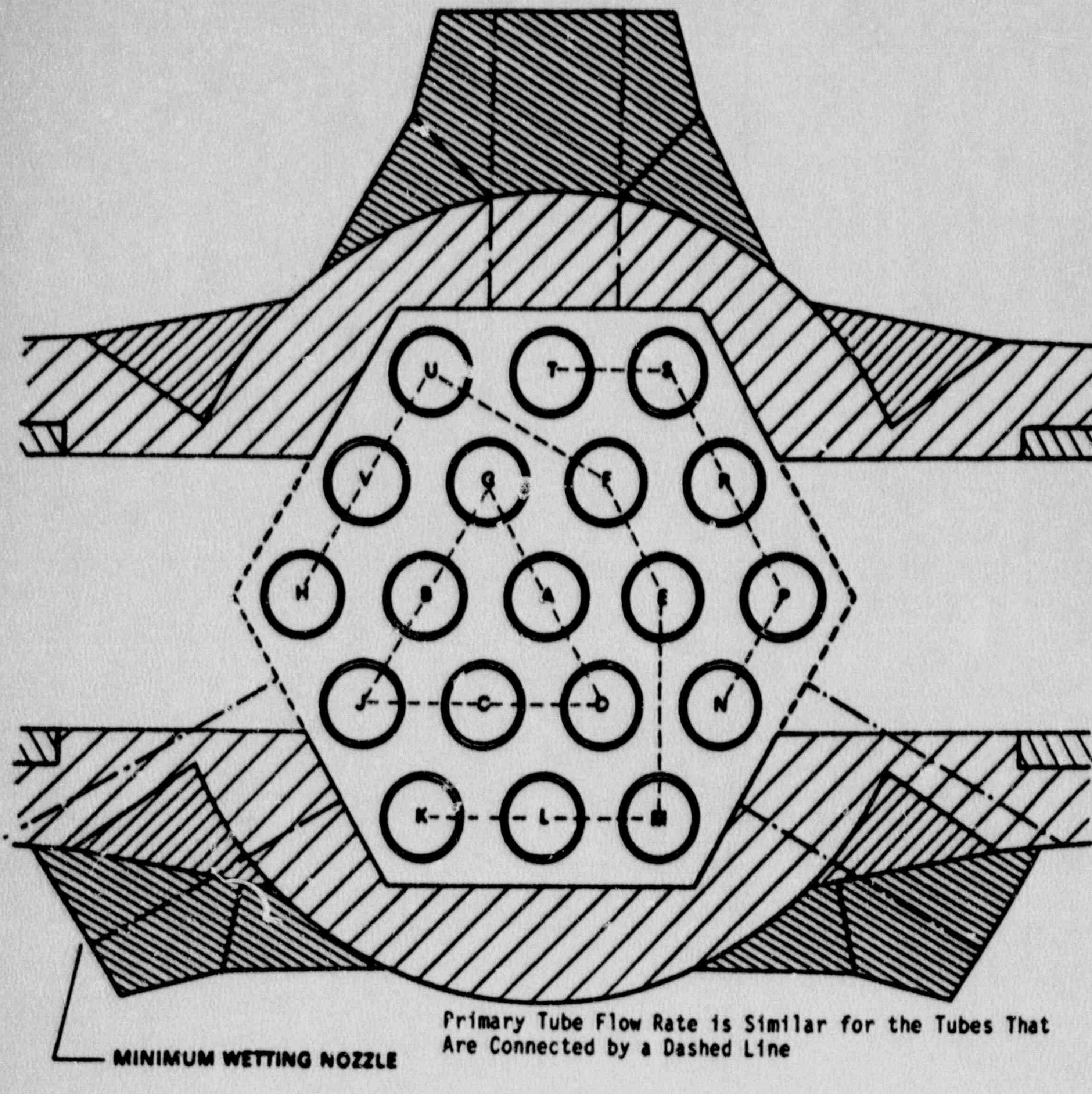



Figure 5.110 Proposed Flow Distribution for AFW Steady-State Tests

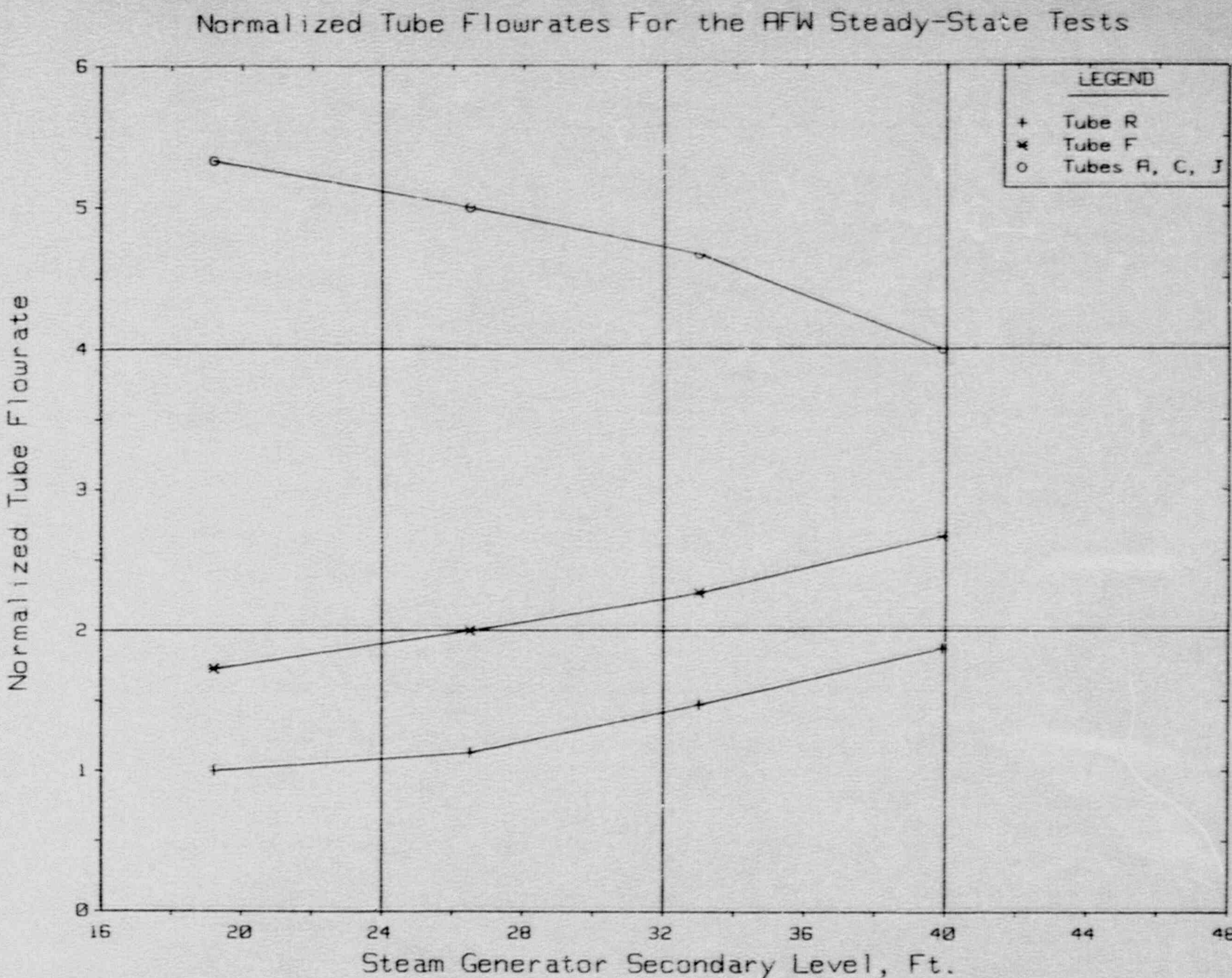



Figure 5.111 Normalized Tube Flow Rates for the AFW Steady-State Tests

Fri Sep 30 10:09:35 1988

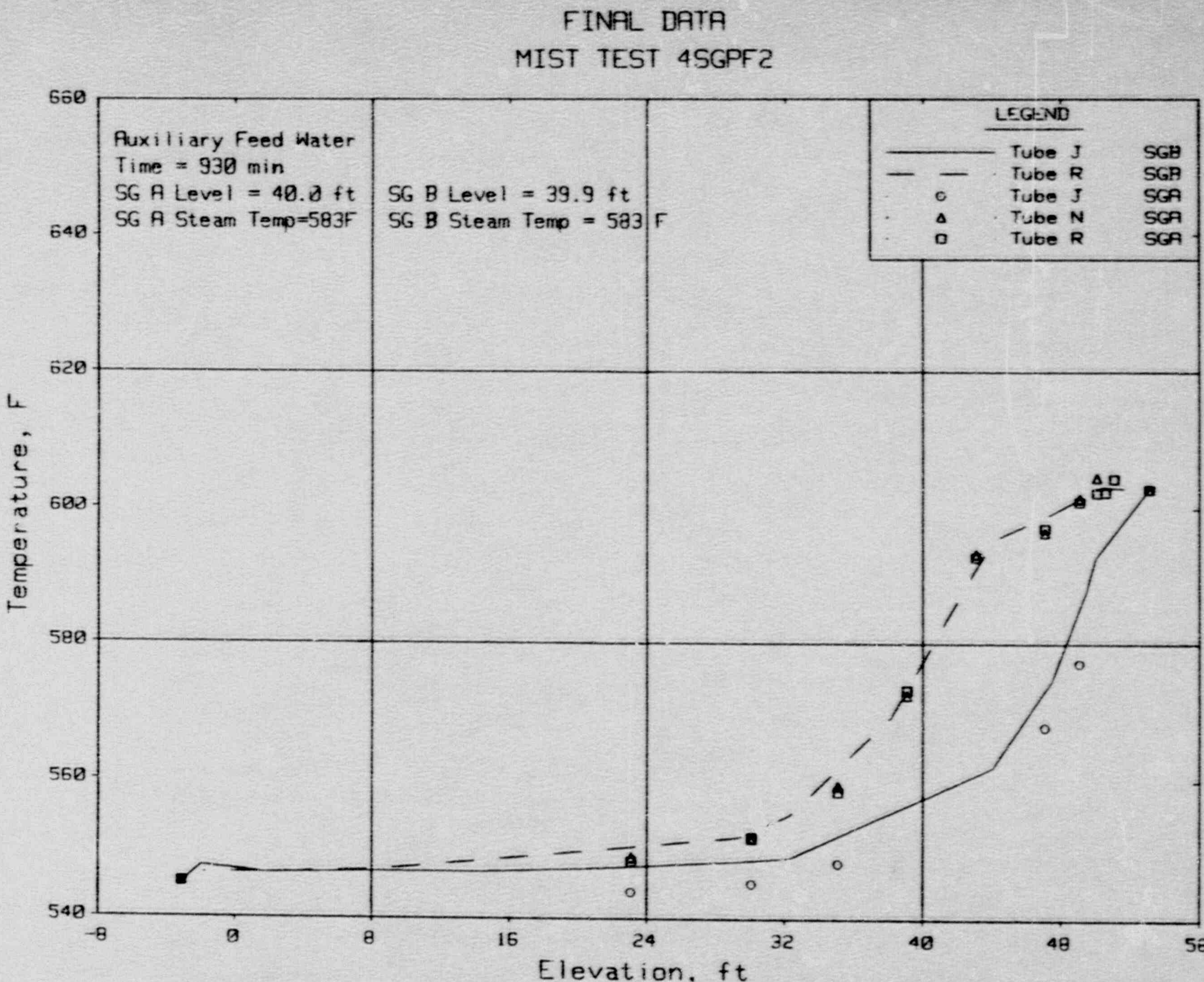



Figure 5.112 Comparison of Steam Generator A and B Primary Axial Temperature Distribution

Fri Jun 10 09:53:55 1988

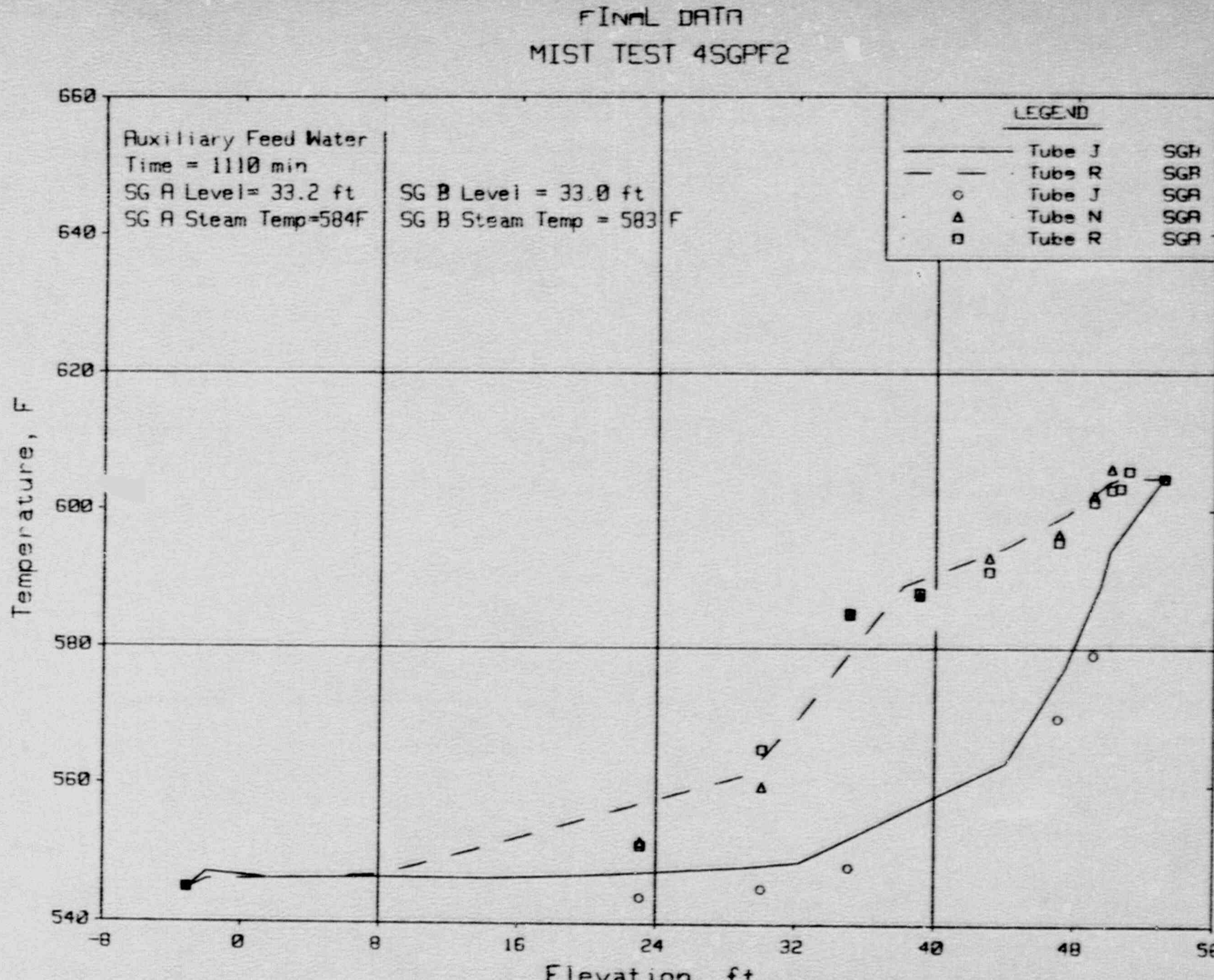



Figure 5.113 Comparison of Steam Generator A and B Primary Axial Temperature Distribution

Fri Jun 10 09:52:01 1988

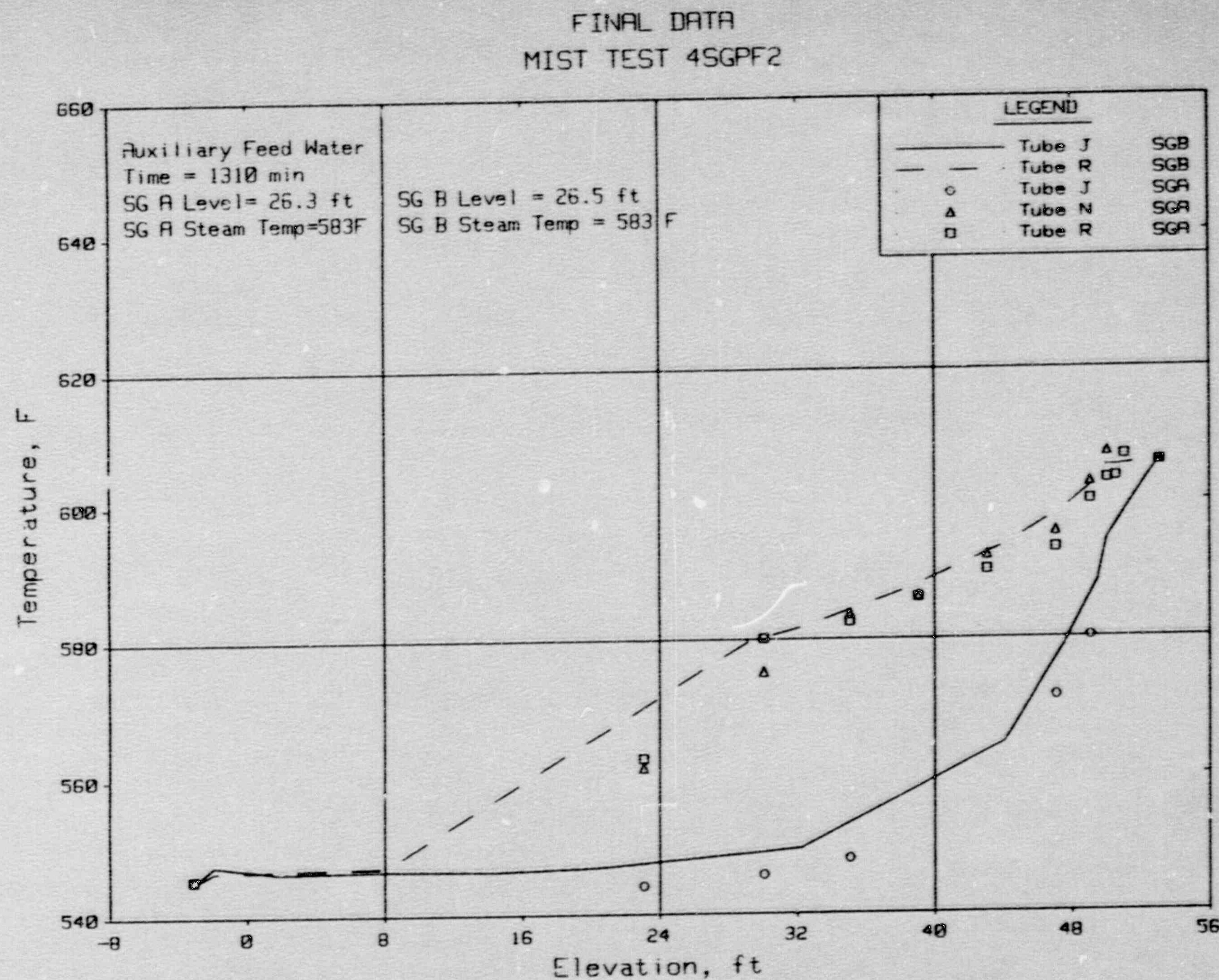
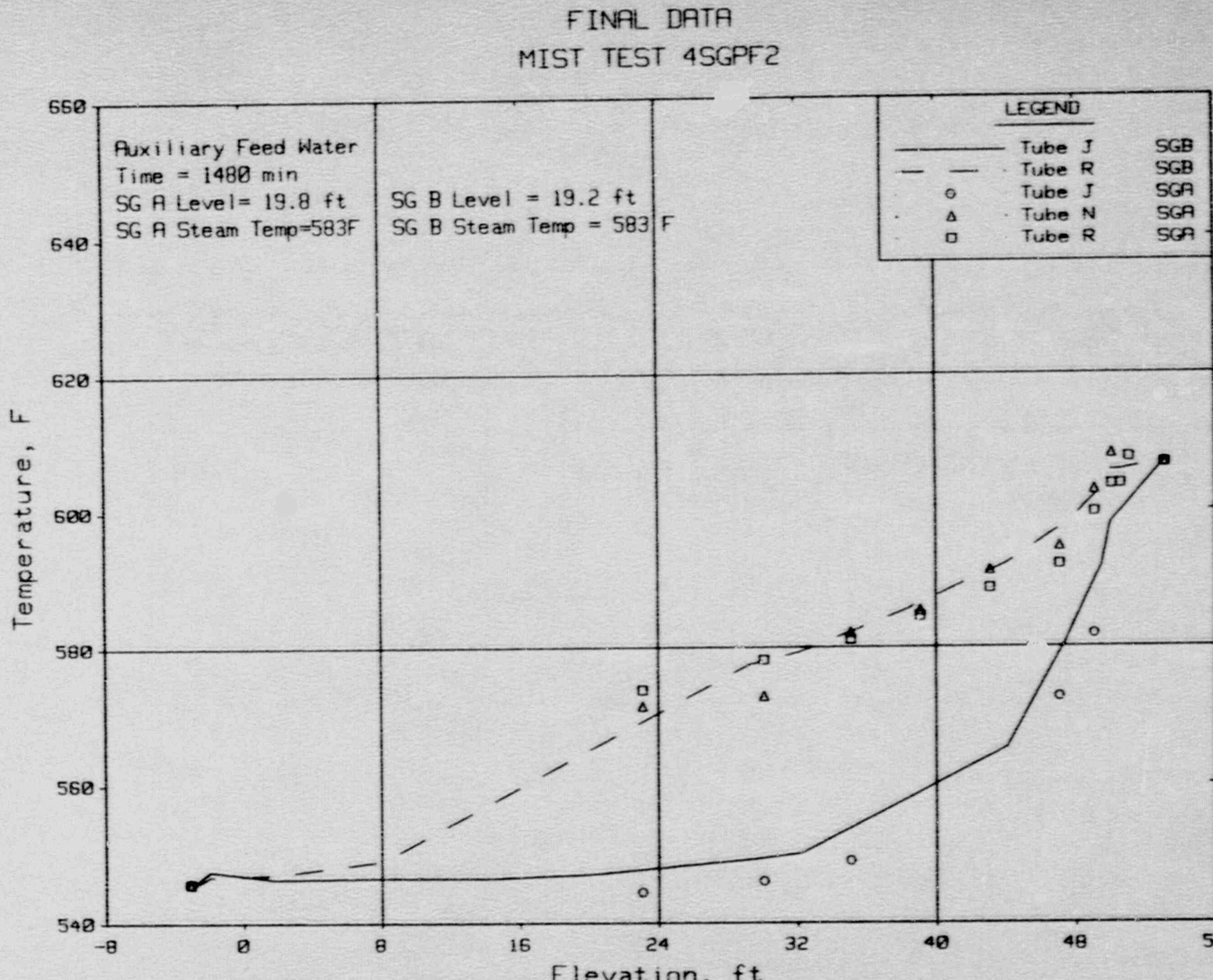



Figure 5.114 Comparison of Steam Generator A and B Primary Axial Temperature Distribution

Fri Jun 10 09:50:03 1988




5-153

Figure 5.115 Comparison of Steam Generator A and B Primary Axial Temperature Distribution

Mon Jun 13 09:19:45 1988

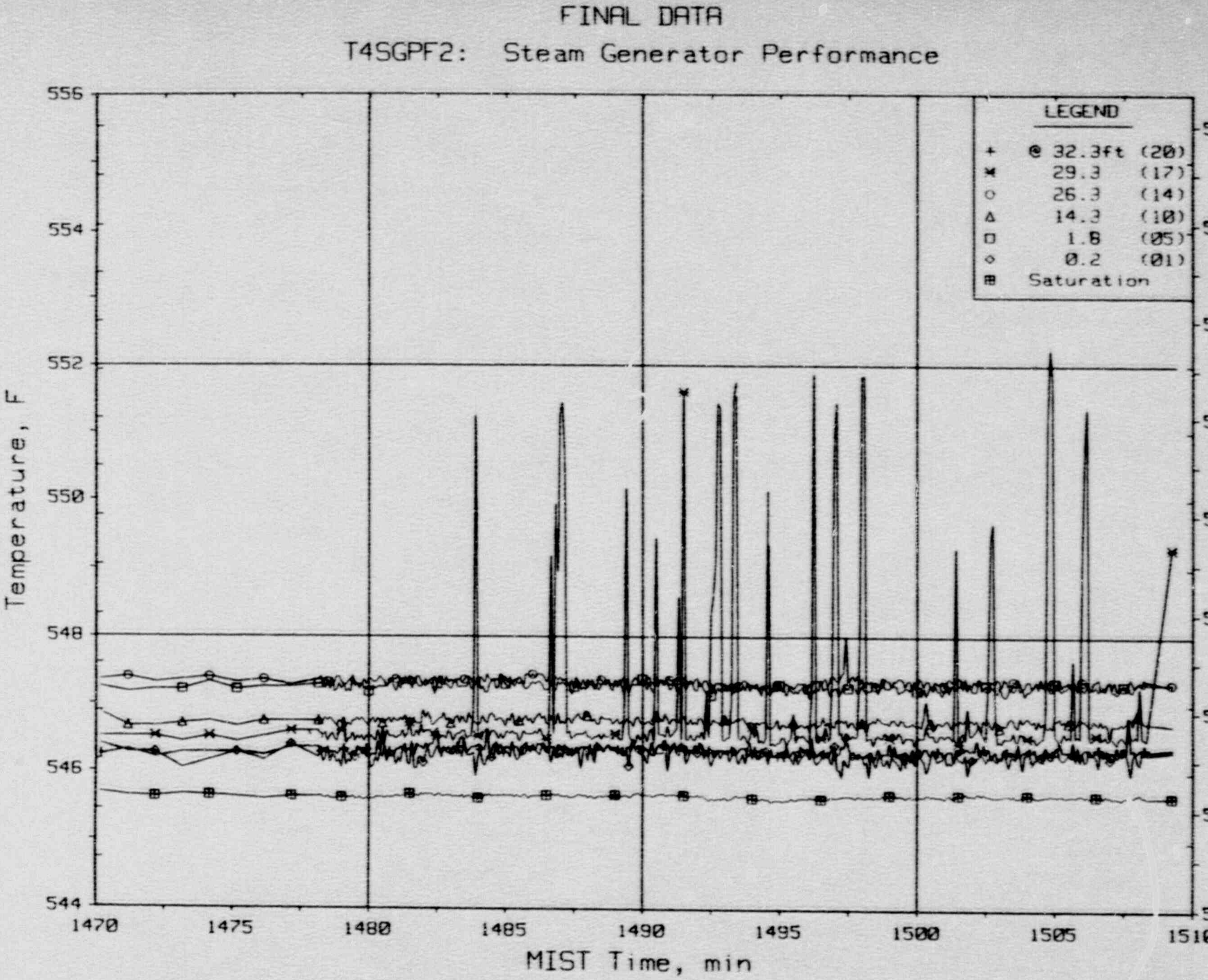



Figure 5.116 Steam Generator B Secondary Wetted Cell (B-J-H) Lower-Elevation Fluid Temperatures (S2TCs)

Mon Jun 13 14:09:38 1988

S2TC2

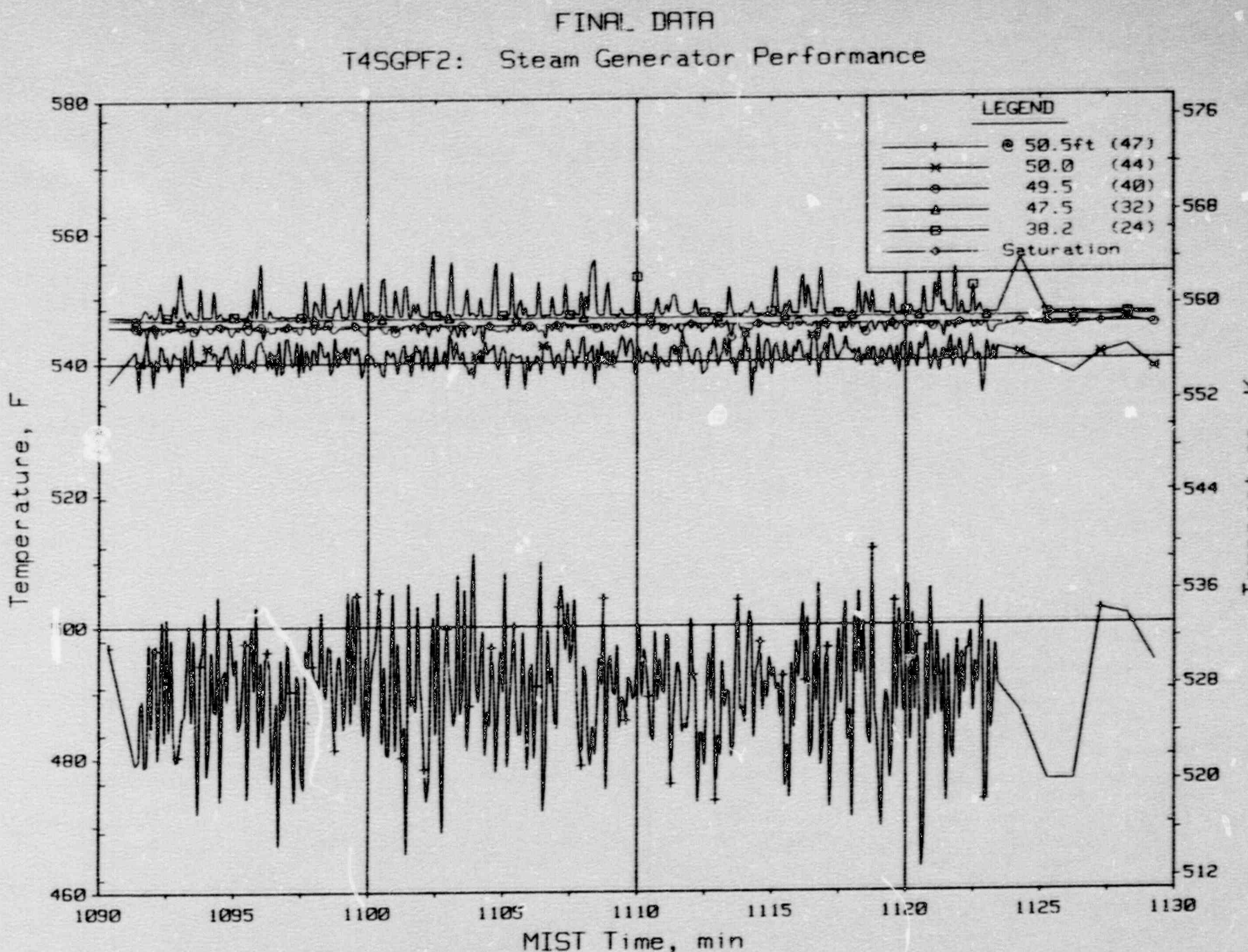



Figure 5.117 Steam Generator B Secondary Central Cell (A-B-G) Upper-Elevation Fluid Temperatures (S2TCs)

S2TC3

Mon Jun 13 12:16:07 1988

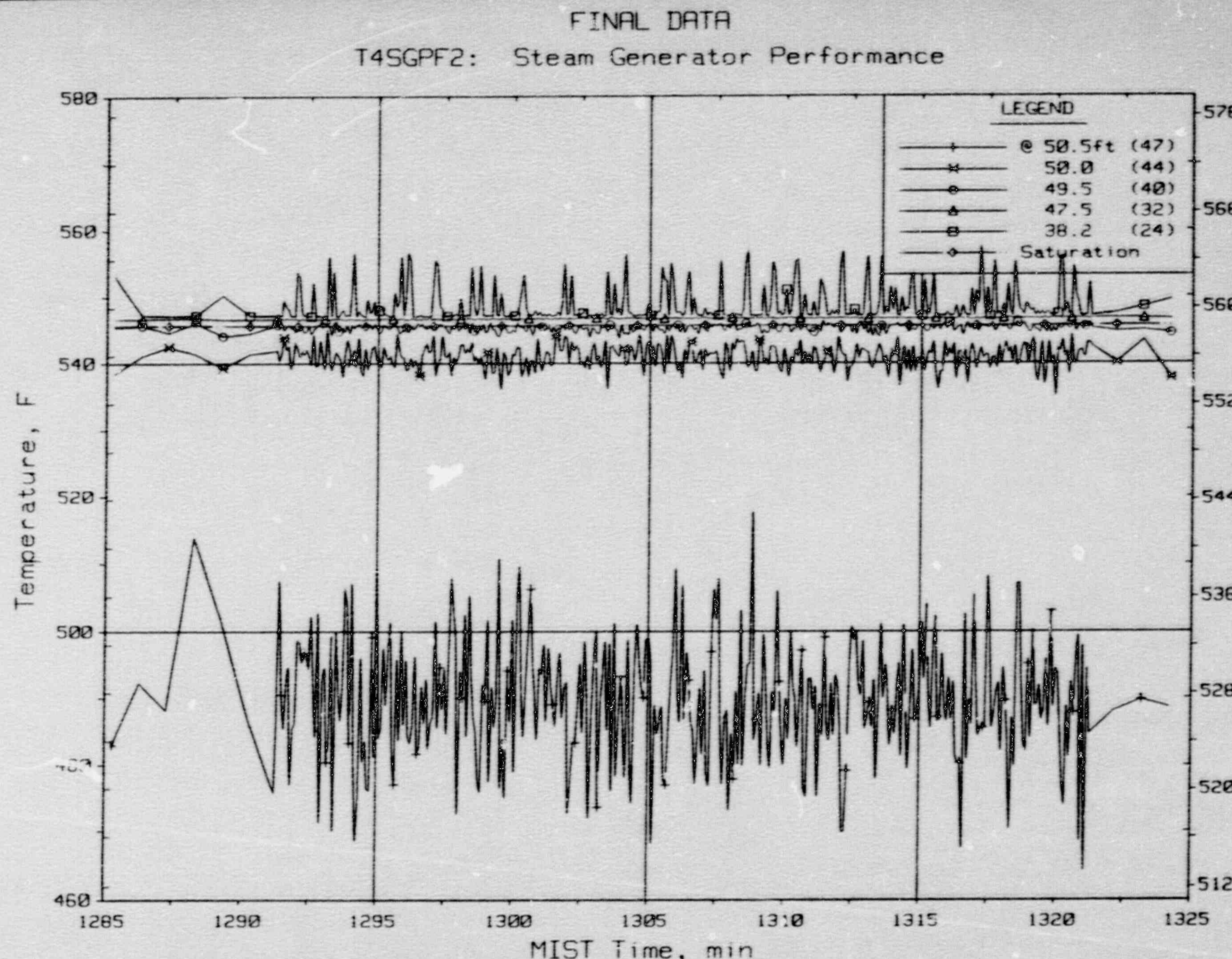


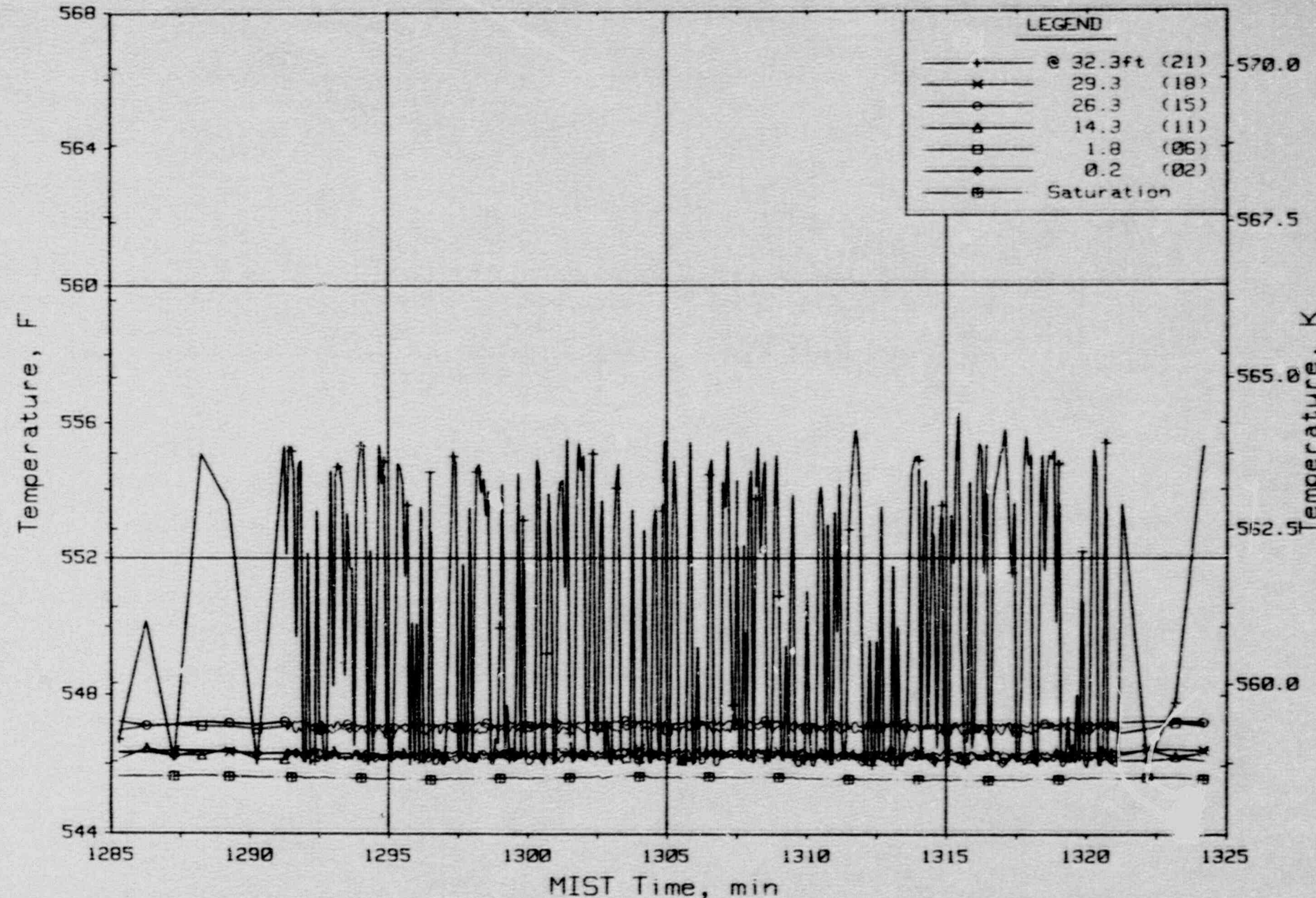

Figure 5.118 Steam Generator B Secondary Central Cell (A-B-G) Upper-Elevation Fluid Temperatures (S2TCs)

Mon Jun 13 12:20:39 1988

S2TC3

FINAL DATA

T4SGPF2: Steam Generator Performance




5-157

Figure 5.119 Steam Generator B Secondary Central Cell (A-B-G) Lower-Elevation Fluid Temperatures (S2TCs)

Mon Jun 13 12:57:37 1988

S2TC4

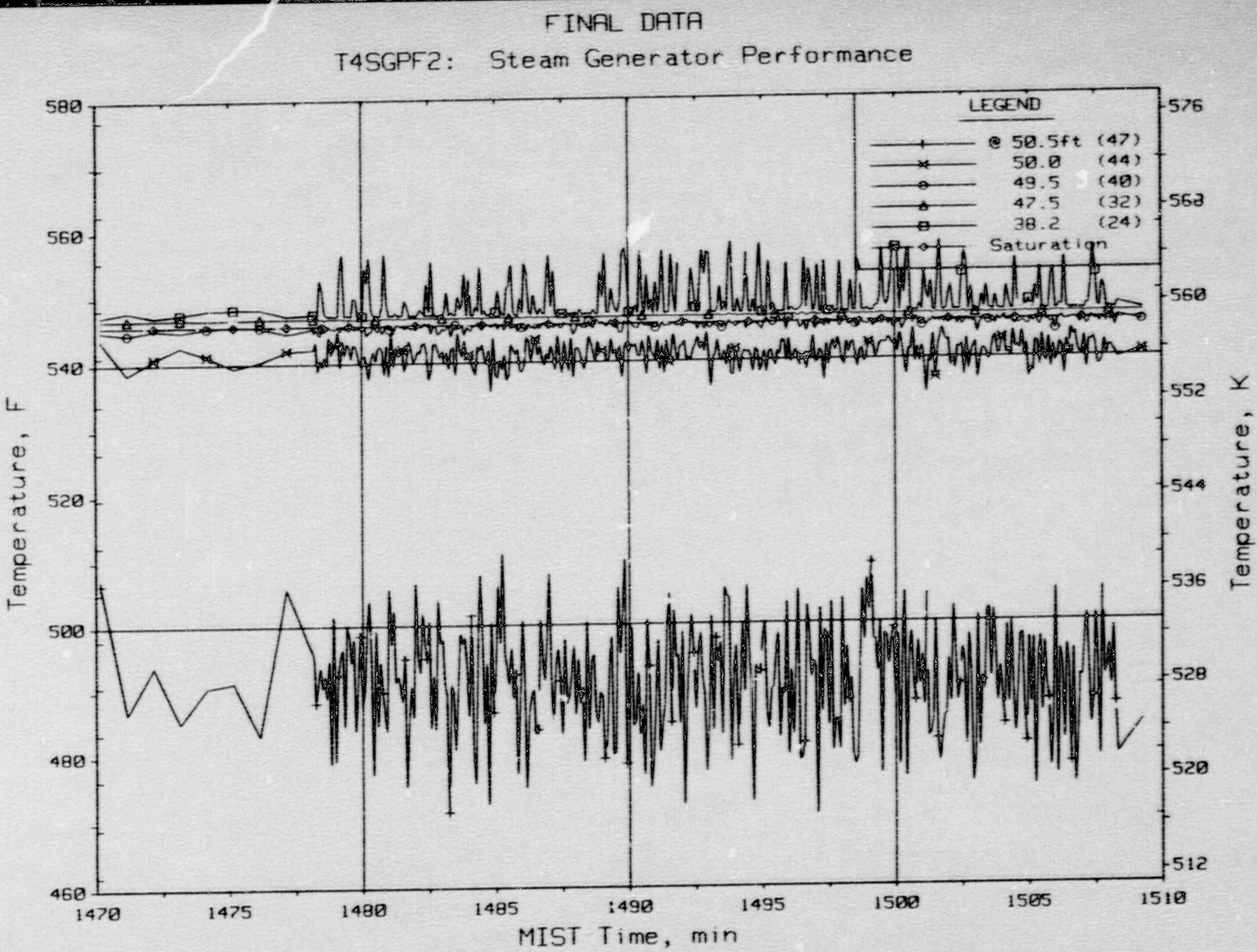



Figure 5.120 Steam Generator B Secondary Central Cell (A-B-G) Upper-Elevation Fluid Temperatures (S2TCs)

S2TC3

Mon Jun 13 12:25:45 1988

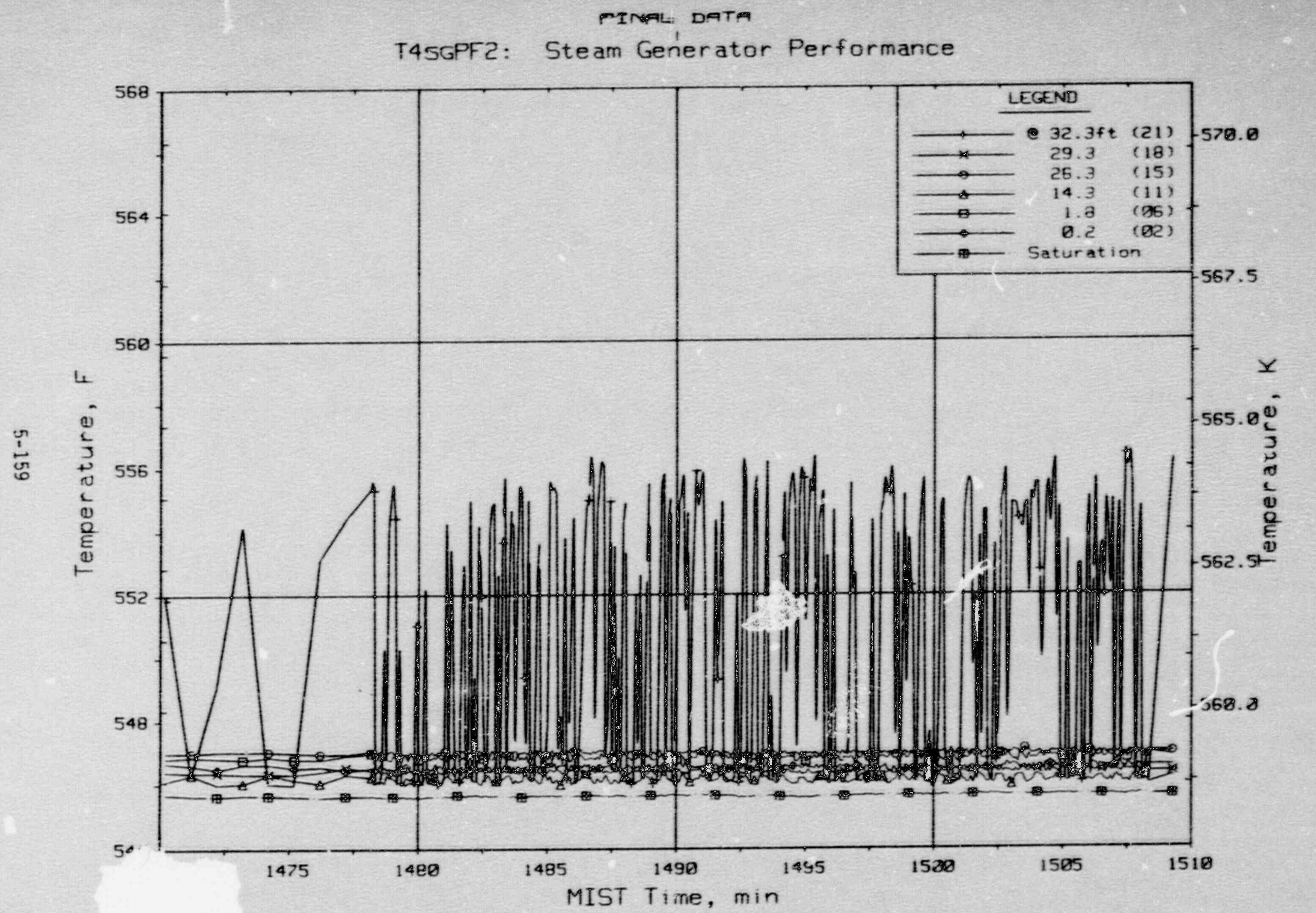



Fig. .121 Steam Generator B Secondary Central Cell (A-B-G) Lower-Elevation Fluid Temperatures (S2TCs)

Mon Jun 13 13:06:56 1988

S2TC4

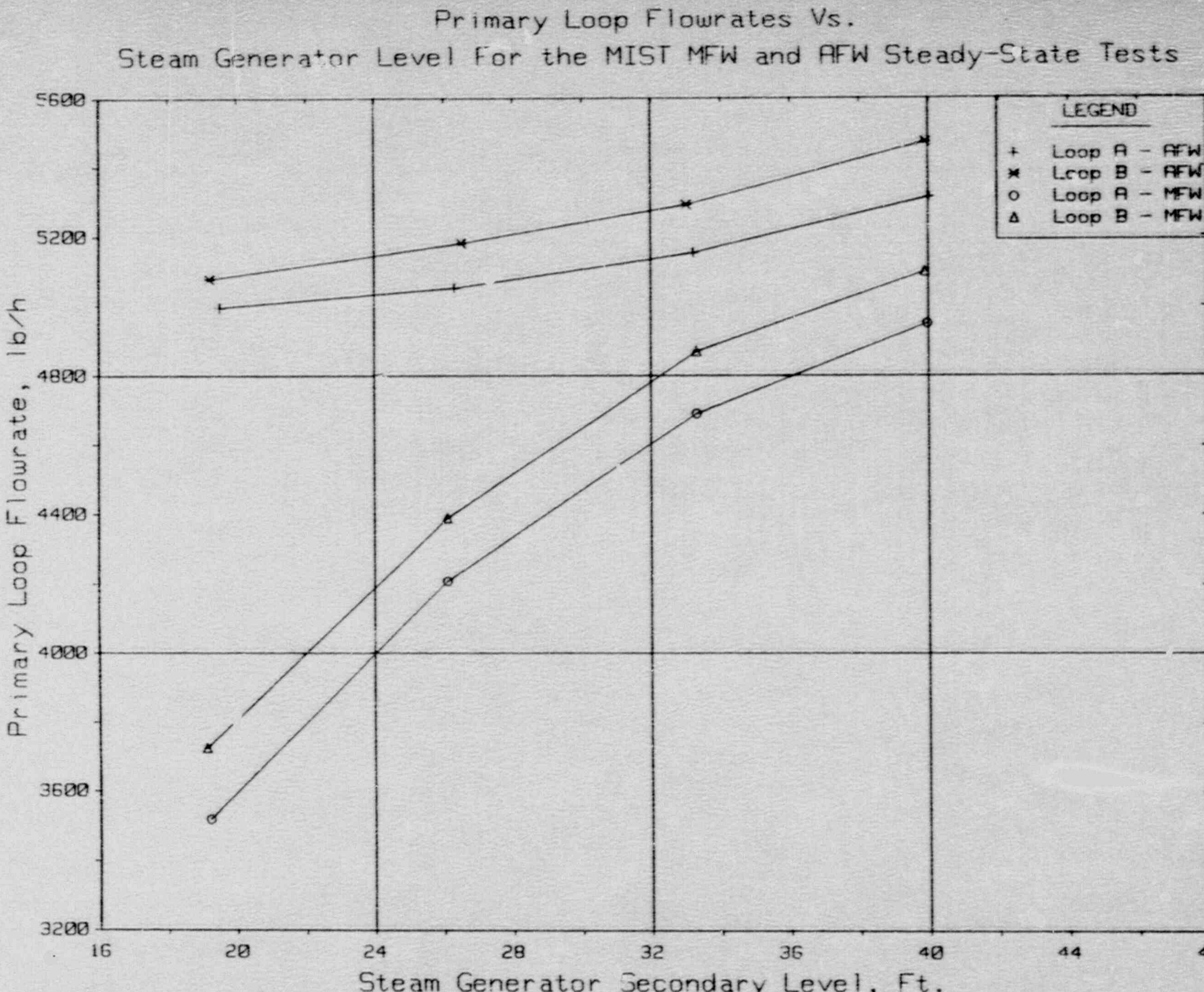



Figure 5.122 Primary Loop Flow Rates Vs Steam Generator Level for the MIST MFW and AFW Steady-State Tests

Fri Sep 30 11:40:43 1988

Figures for Test 4CR3T2

Crystal River 3 Scaling Transient

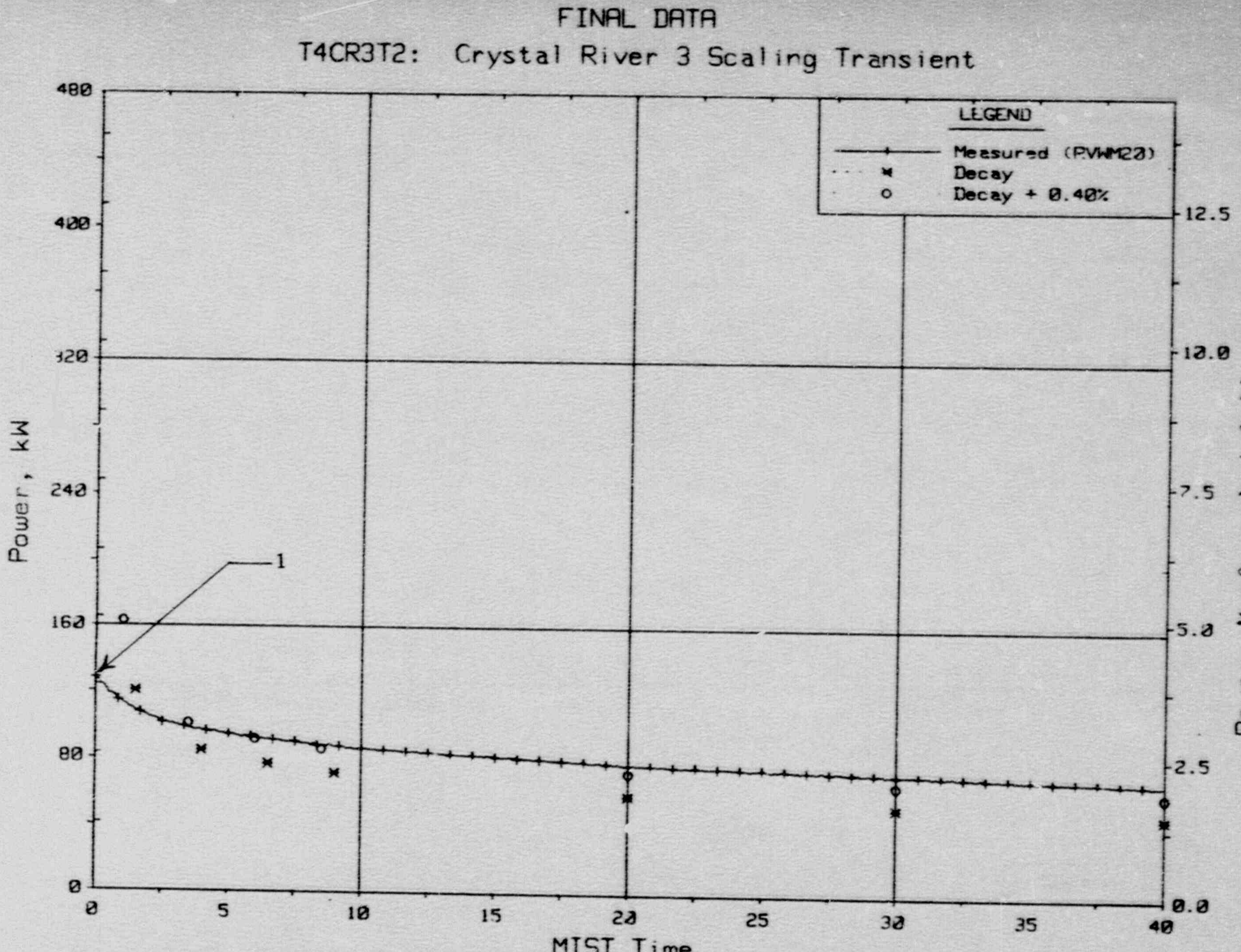



Figure 5.123 Core Power

Tue Oct 25 12:44:52 1989

RVKW1

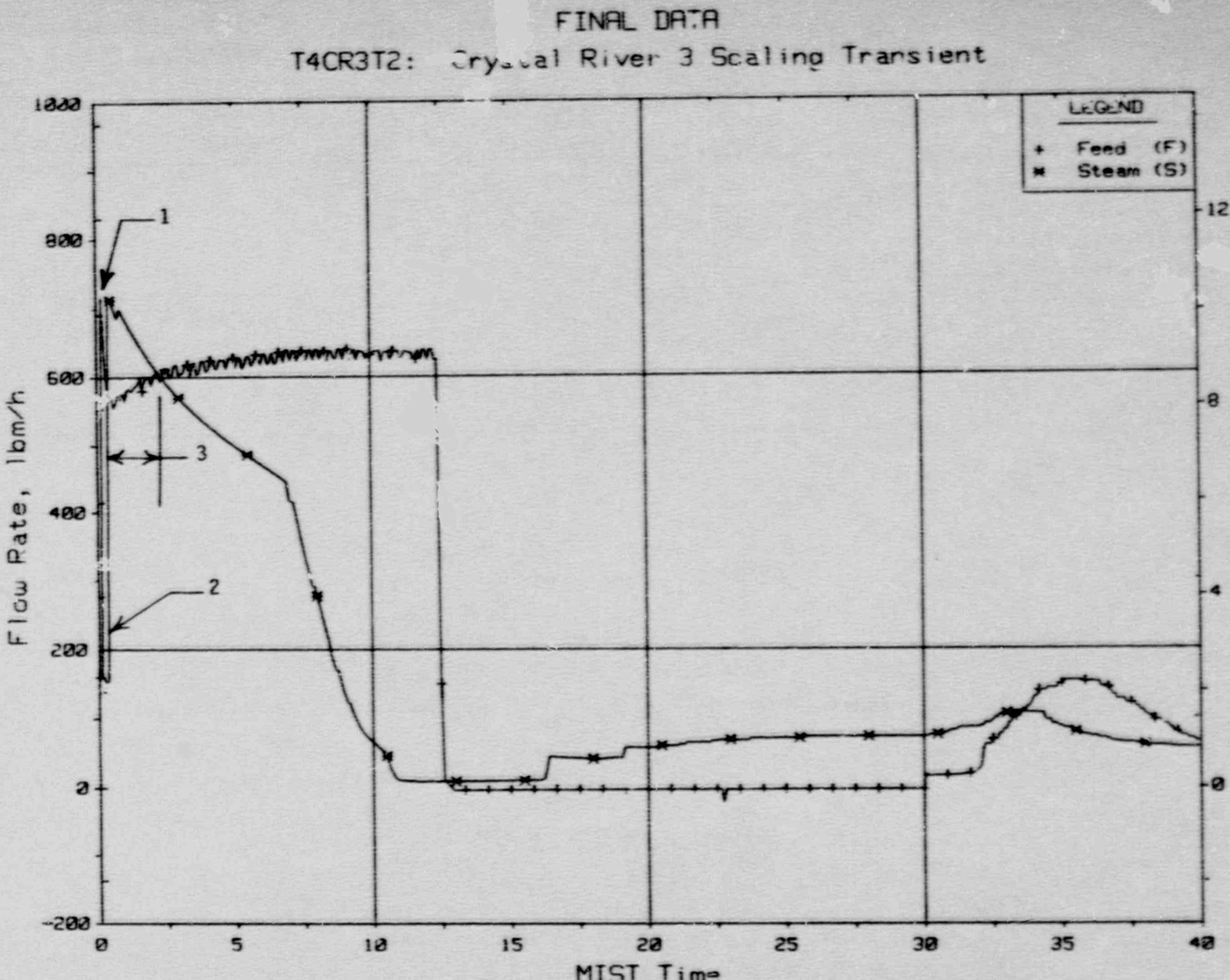



Figure 5.124 Steam Generator A Flow Rates (SaOR20s)

Tue Oct 25 12:27:06 1988

SGFL1

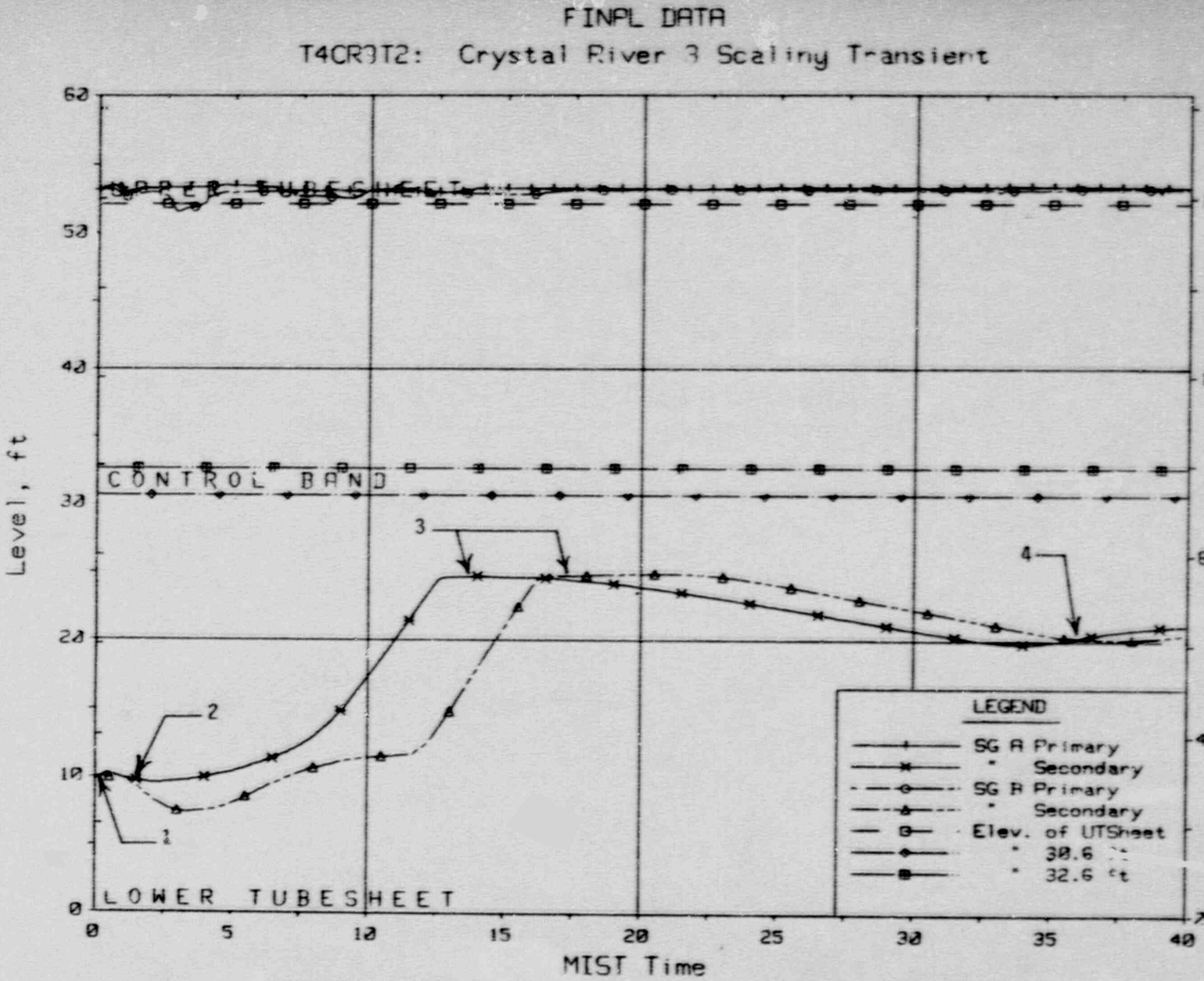



Figure 5.125 Steam Generator Collapsed Liquid Levels

Tue Oct 23 12:11:14 1986

SGLV2

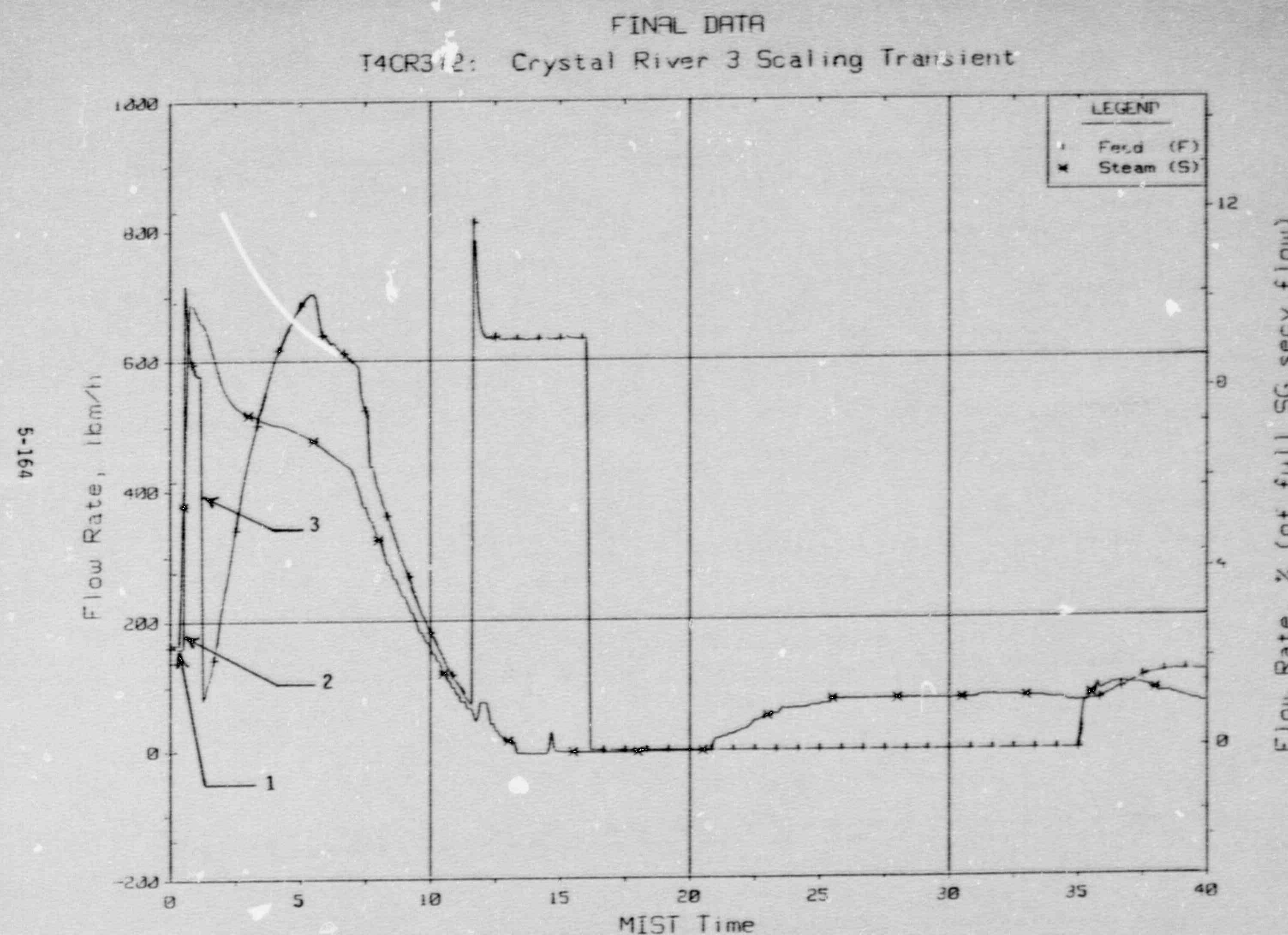



Figure 5.126 Steam Generator B Flow Rates (SaOR21s)

SCFL2

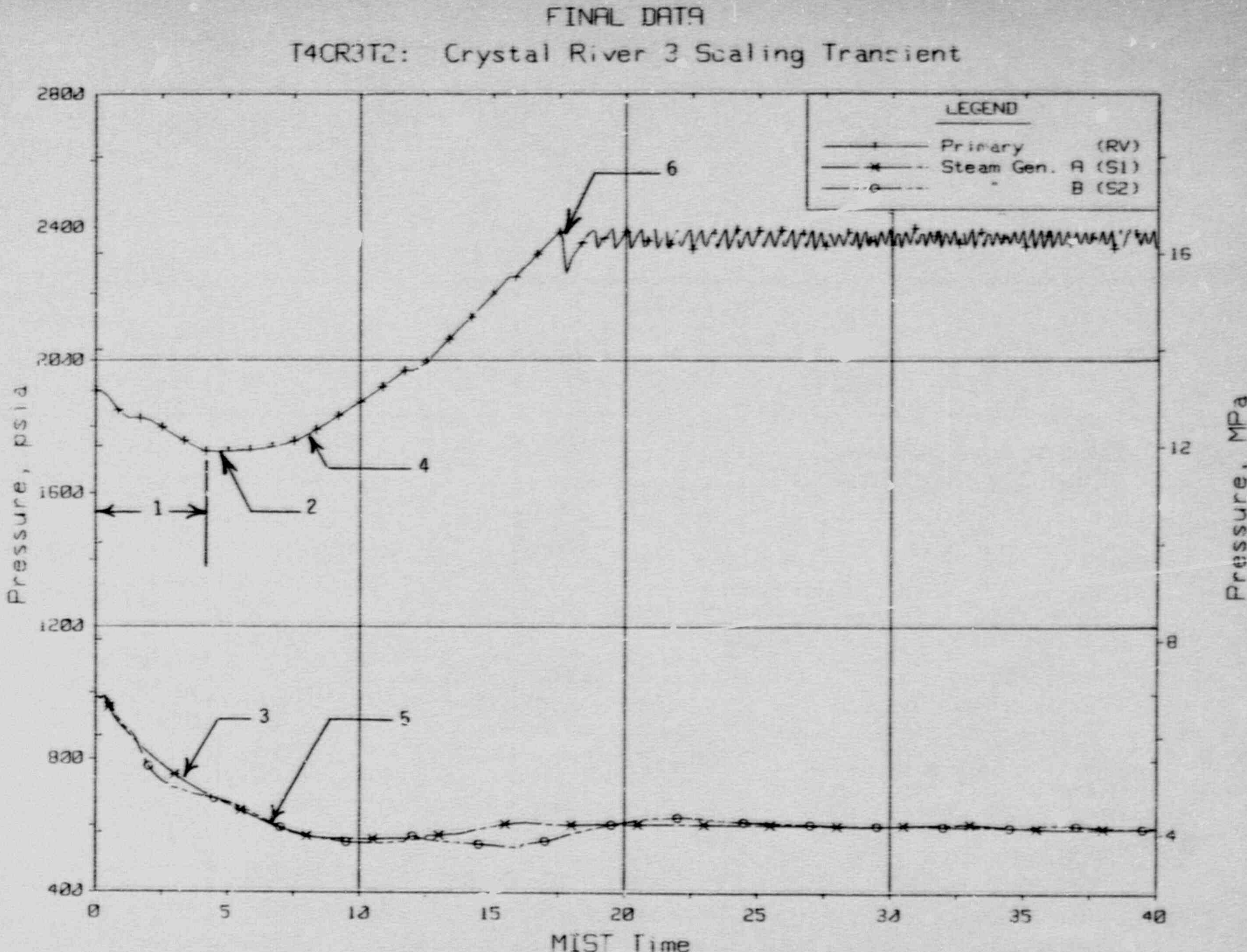



Figure 5.127 Primary and Secondary System Pressures (GPOIs)

PSGP1

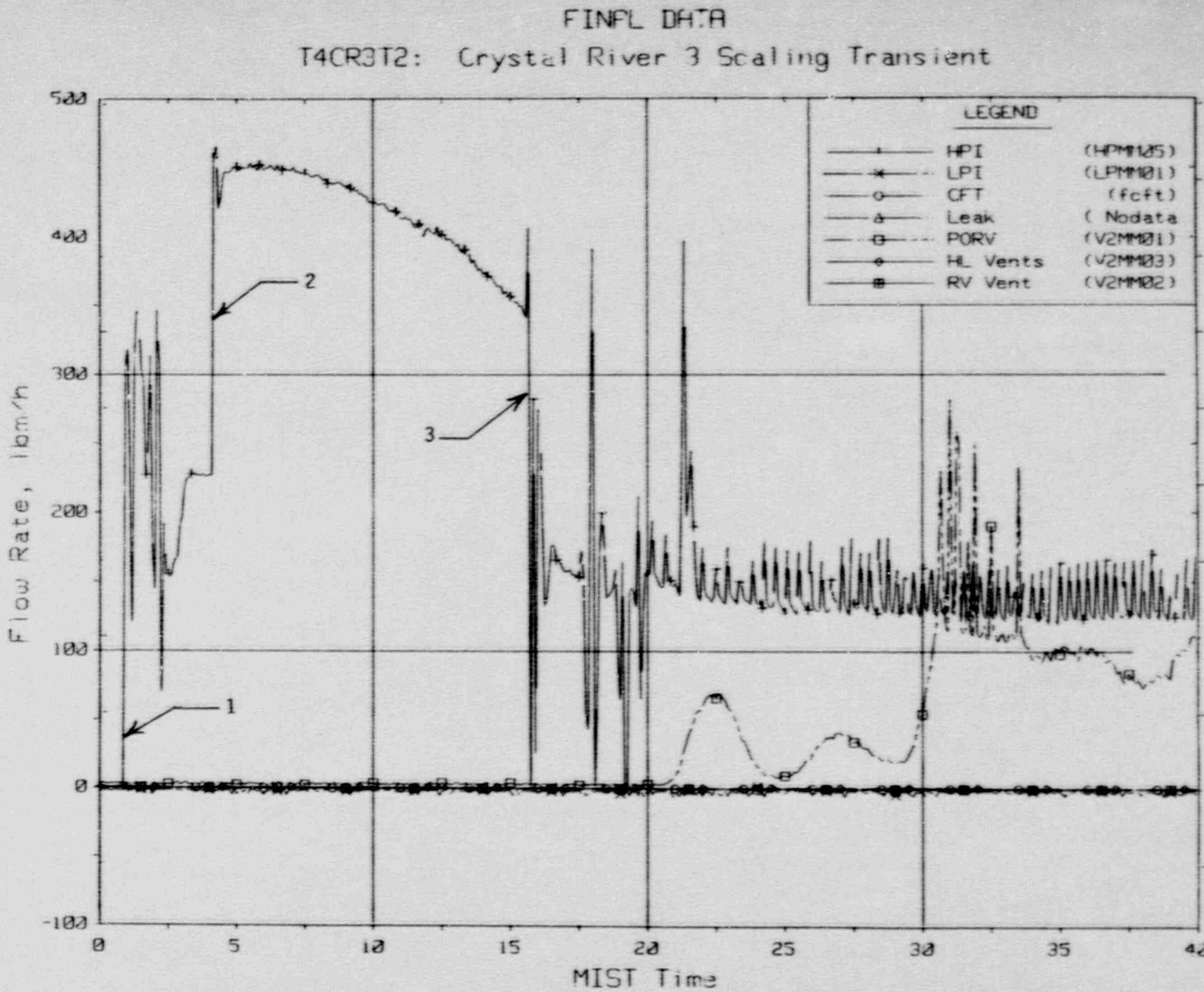



Figure 5.128 Primary System Boundary Flow Rates

PRFL3x

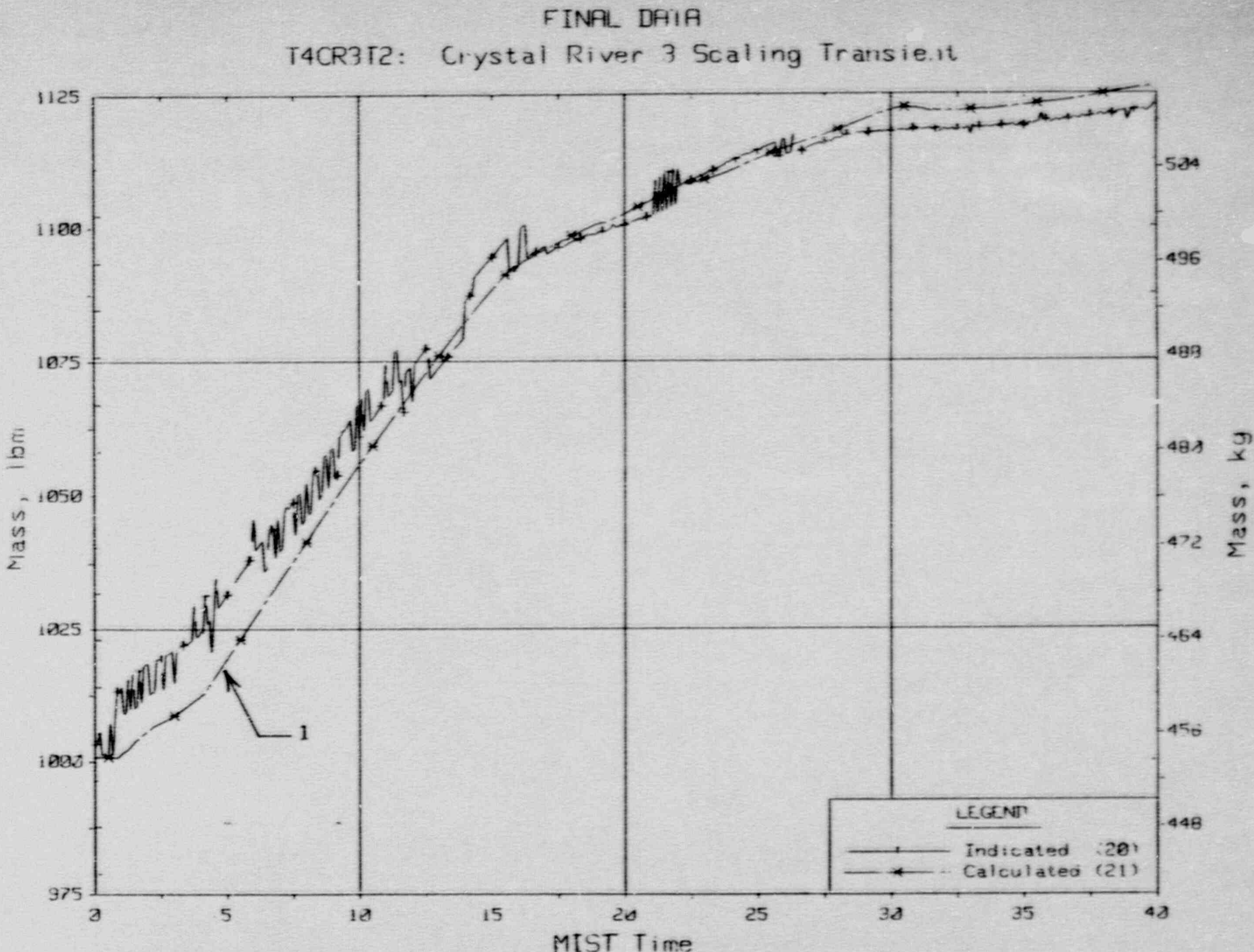



**Figure 5.129 Primary System Total Fluid Mass (PLMLs)**

PPML1

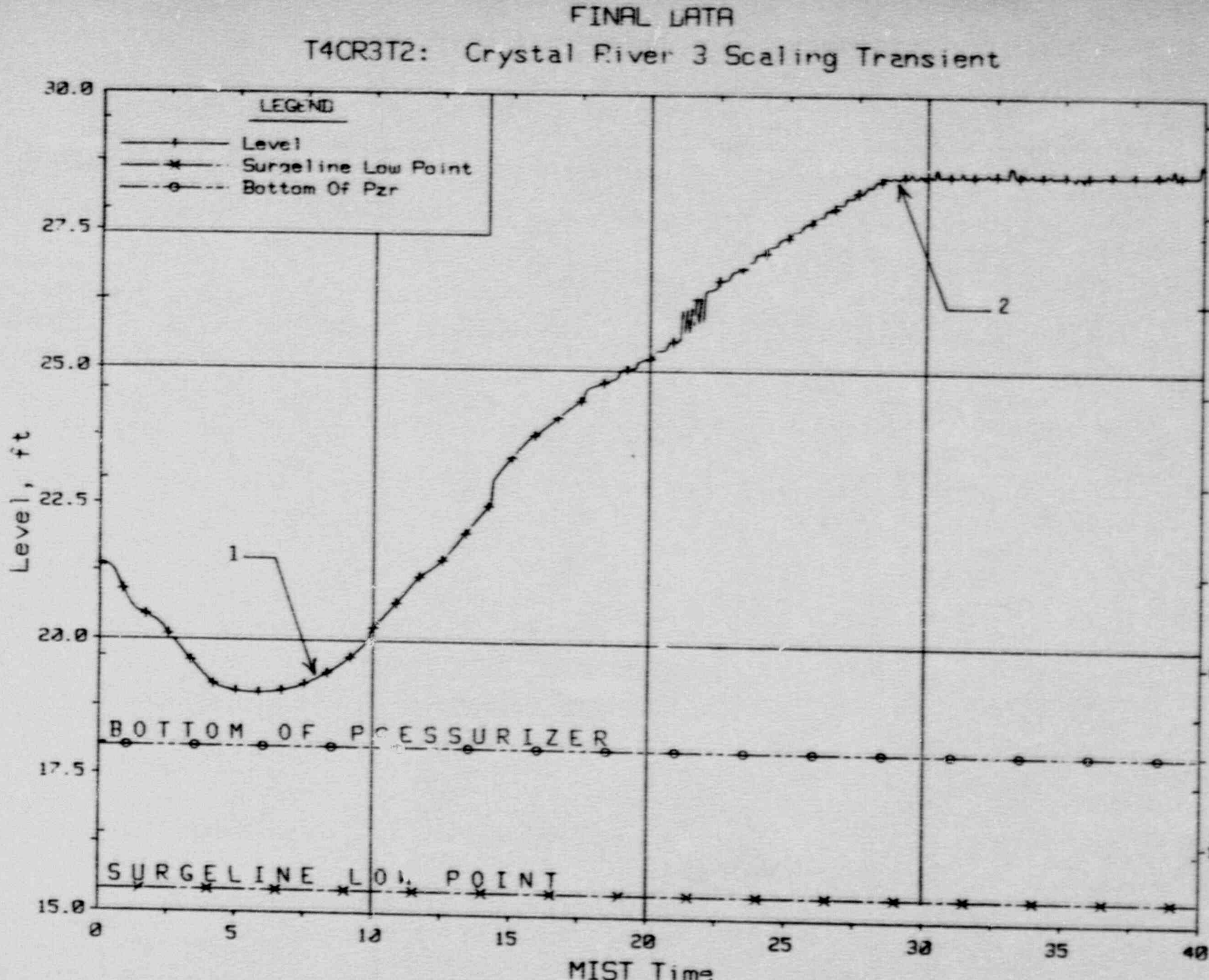



Figure 5.130 Pressurizer Collapsed Liquid Level (PZLV20)

Tue Oct 25 12:27:20 1988

PZLV1

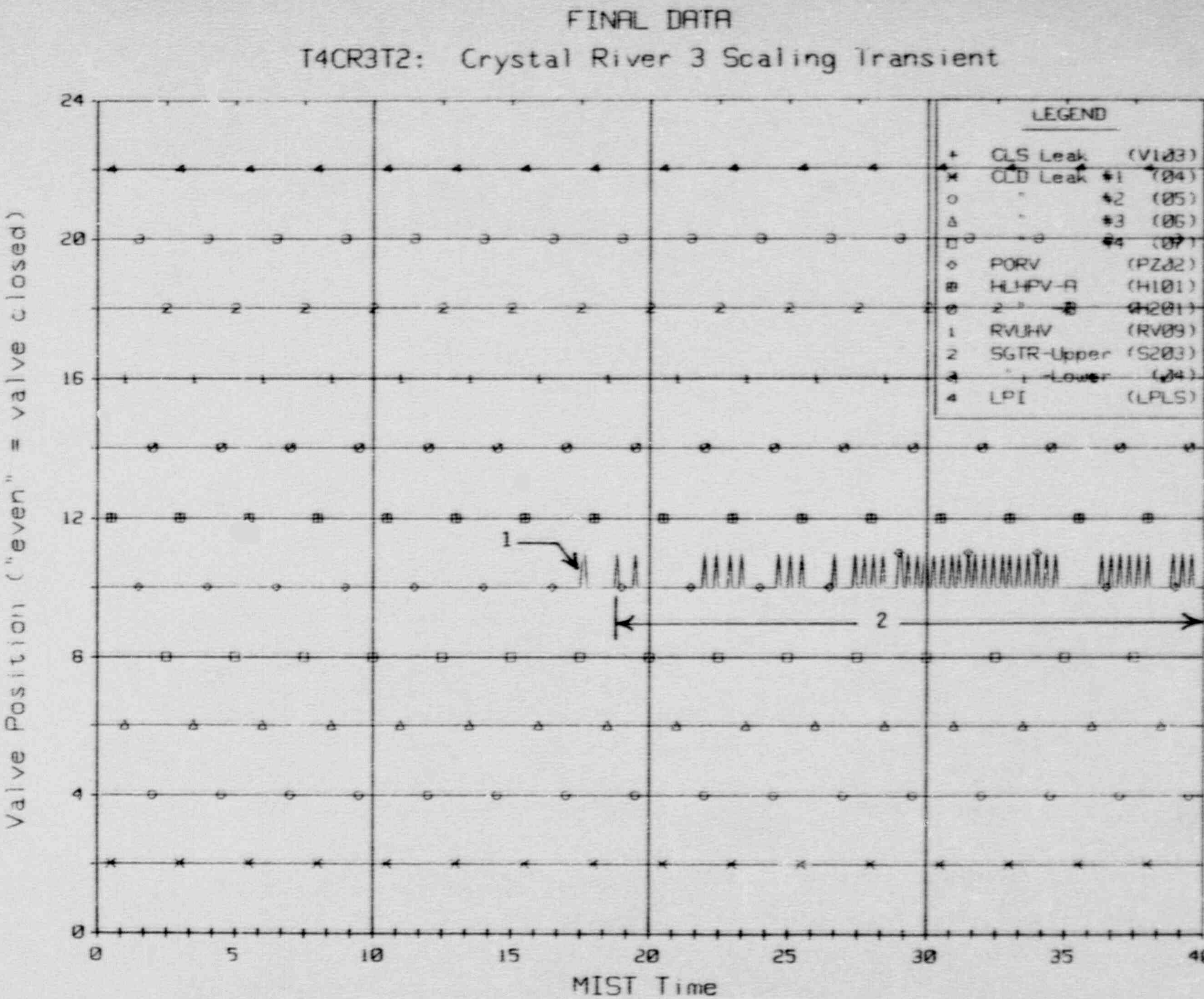



Figure 5.131 Primary System Discharge Limit Switch Indications (LSs)



PRLSI

Figures for Test 4SEC02

Rancho Seco Scaling Transient

FINAL DATA

T4SEC02: Rancho Seco Scaling Transient

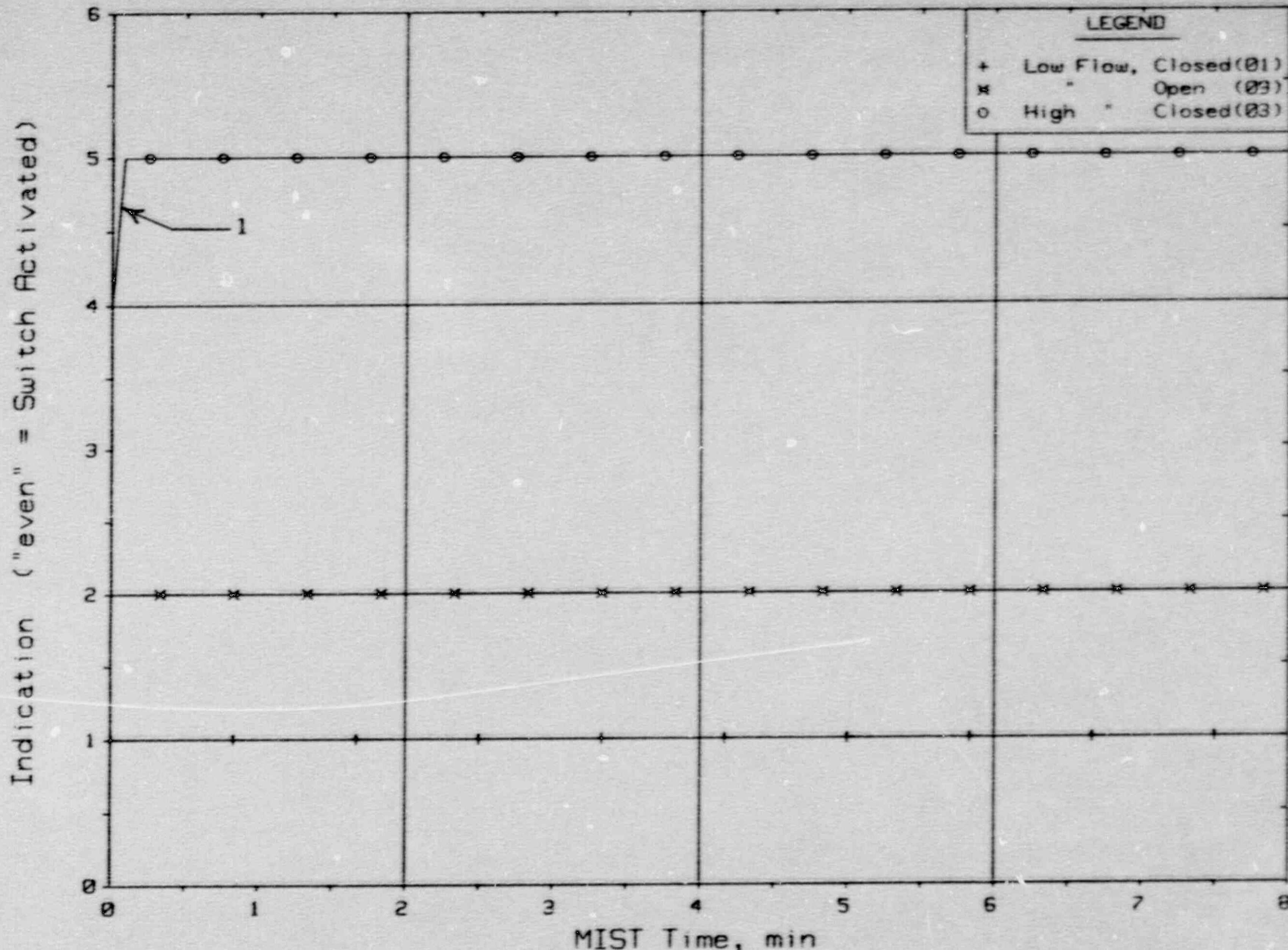





Figure 5.132 Steam Generator A Steam Flow Control Valve Limit Switch Indications (SSLSs)

Fri Oct 21 16:24:32 1988

SILS1

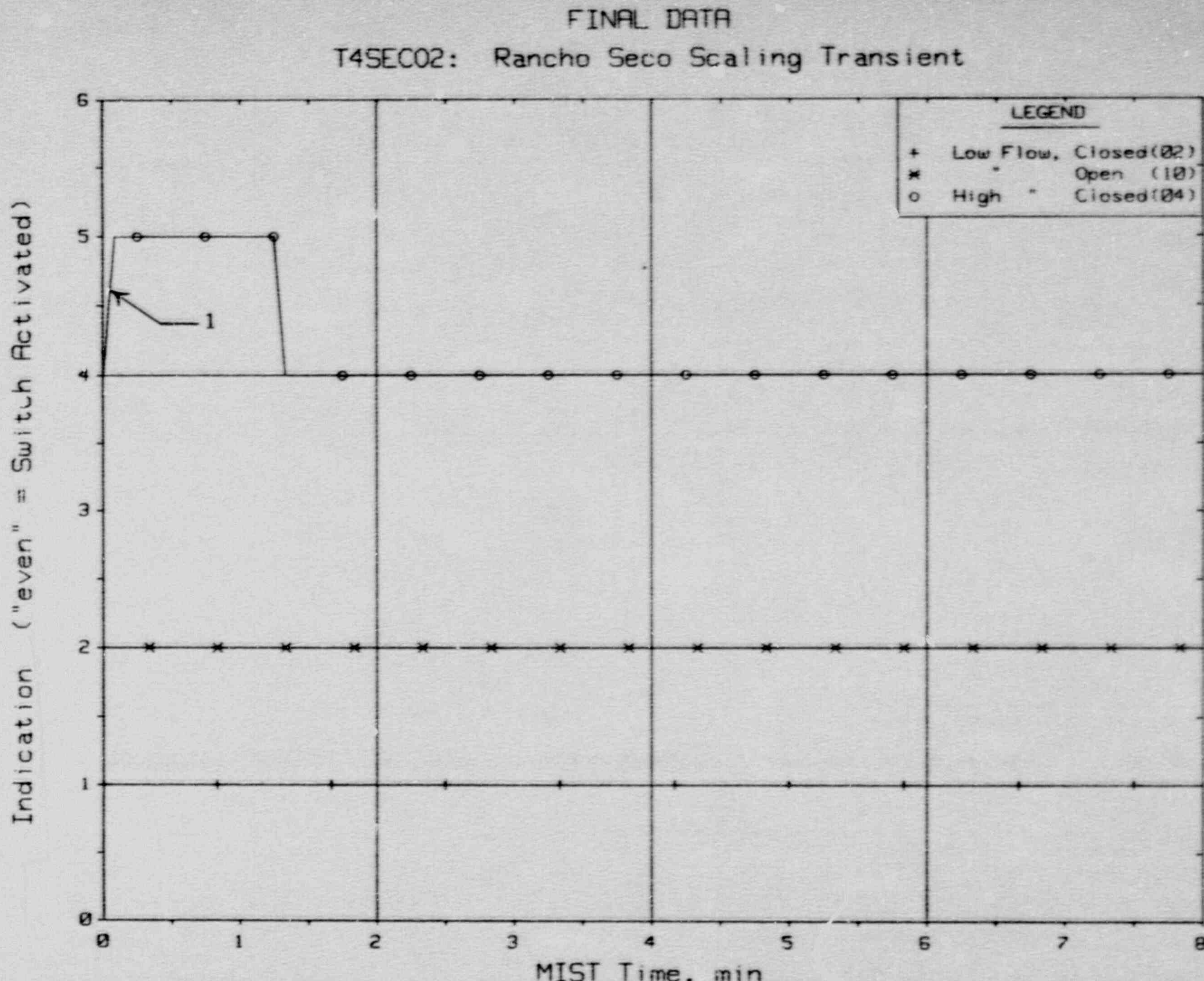



Figure 5.133 Steam Generator B Steam Flow Control Valve Limit Switch Indications (SSLSs)

Fri Oct 21 16:26:17 1988

S2LS1

FINAL DATA

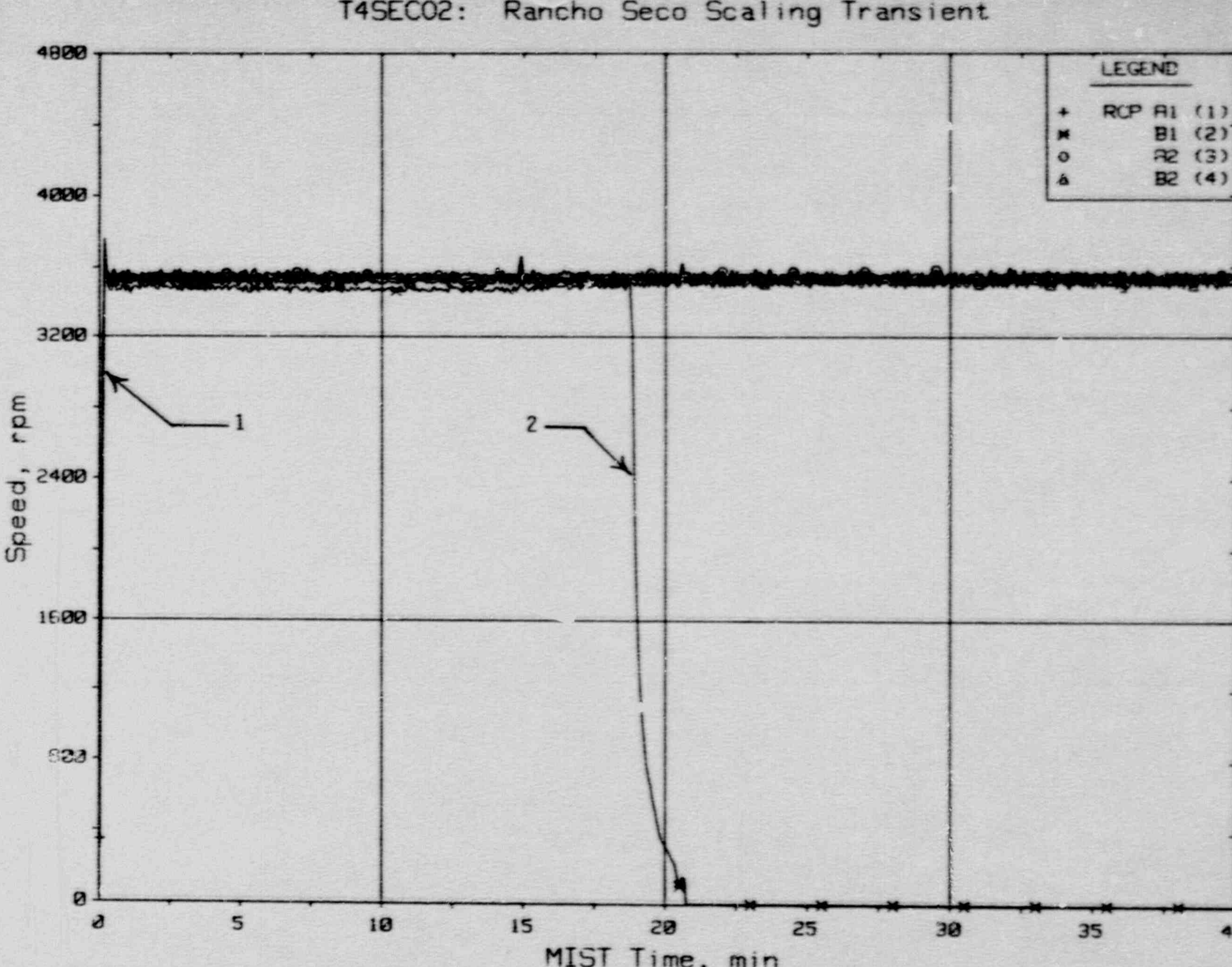



Figure 5.134 Pump Speed (CnTA20s)

Tue Oct 18 17:01:39 1988

PUTA0

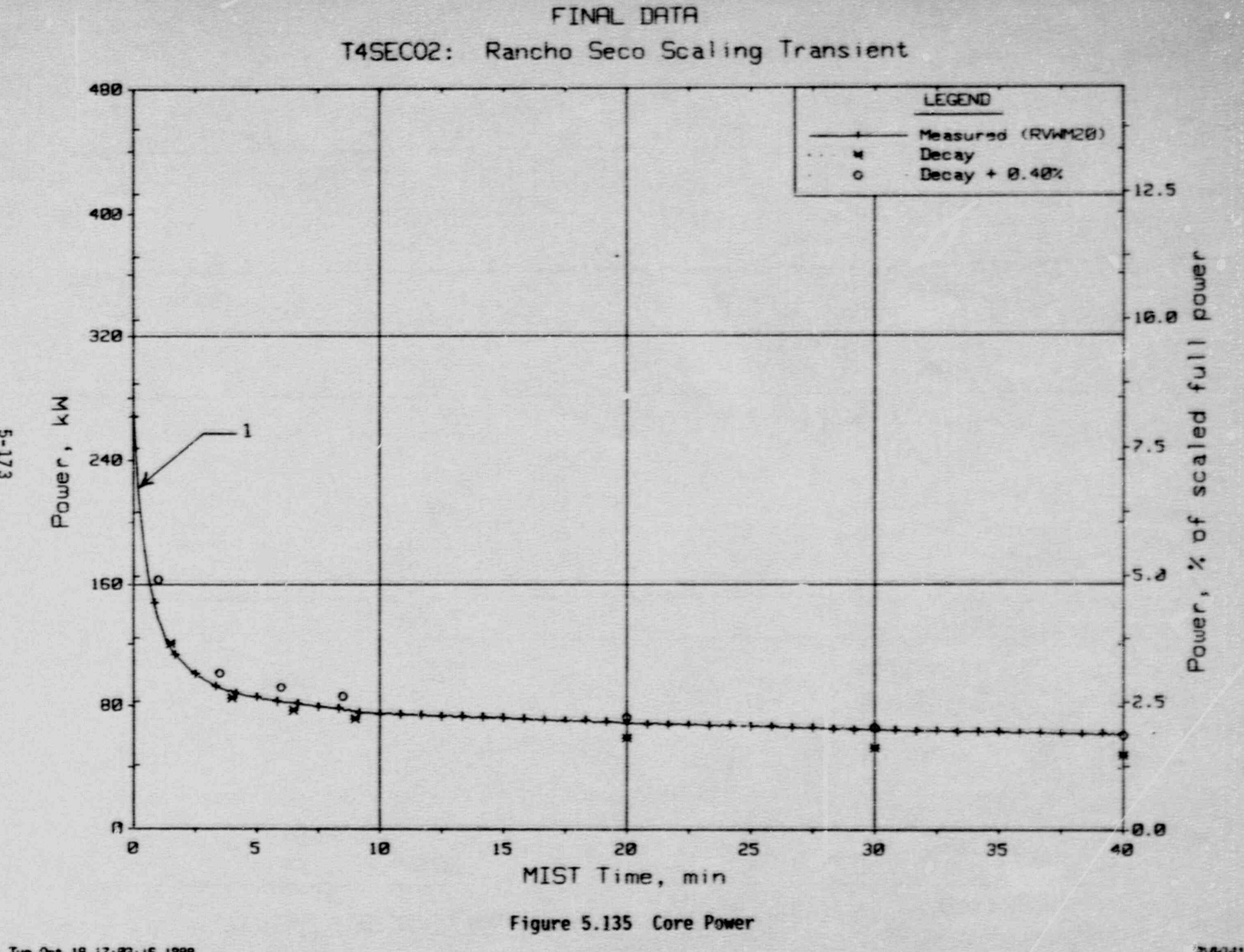



Figure 5.135 Core Power

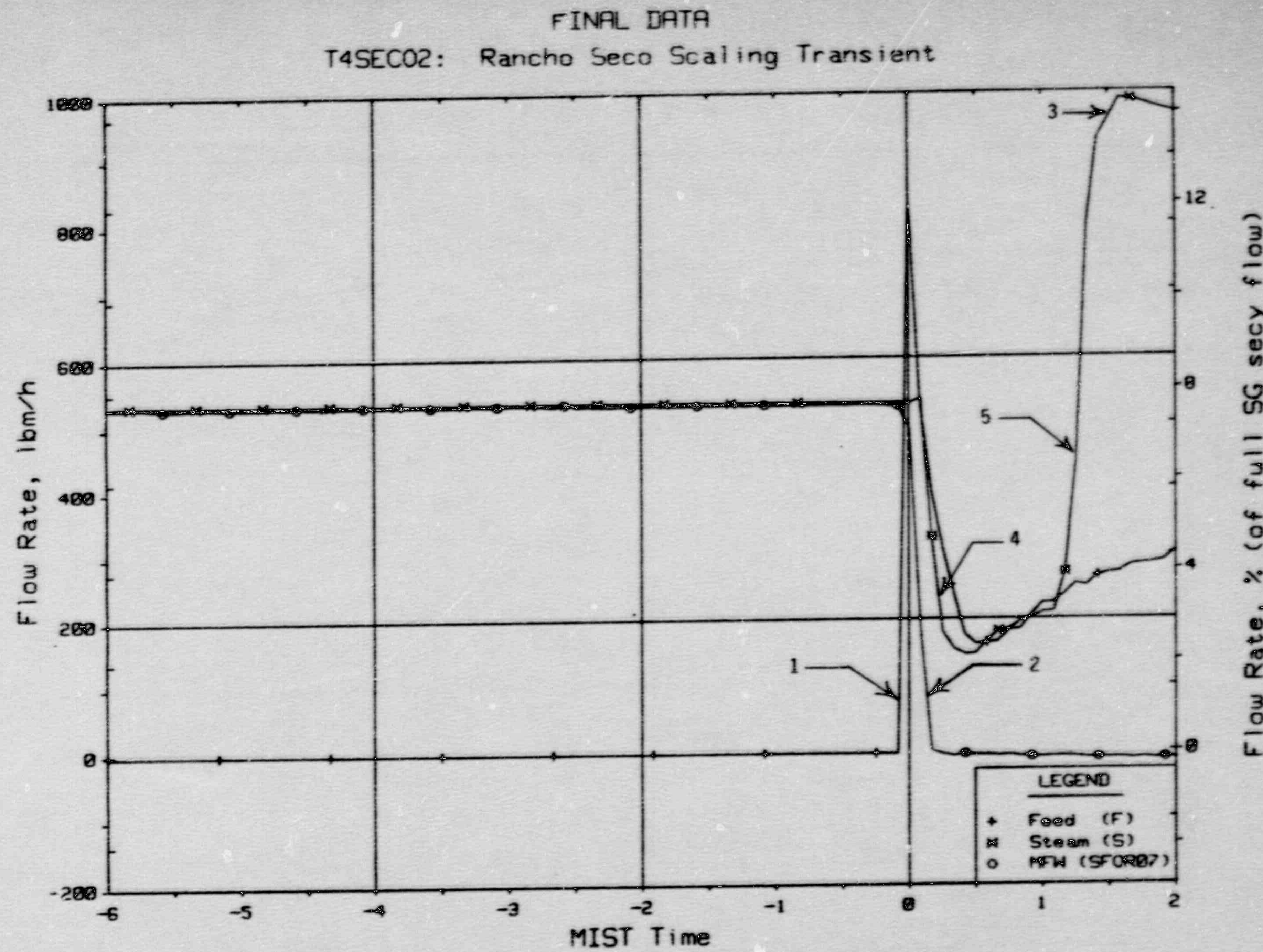



Figure 5.136 Steam Generator A Flow Rates (SaOR20s)

Tue Oct 10 17:03:94 1988

SCFL0

FINAL DATA

T4SEC02: Rancho Seco Scaling Transient

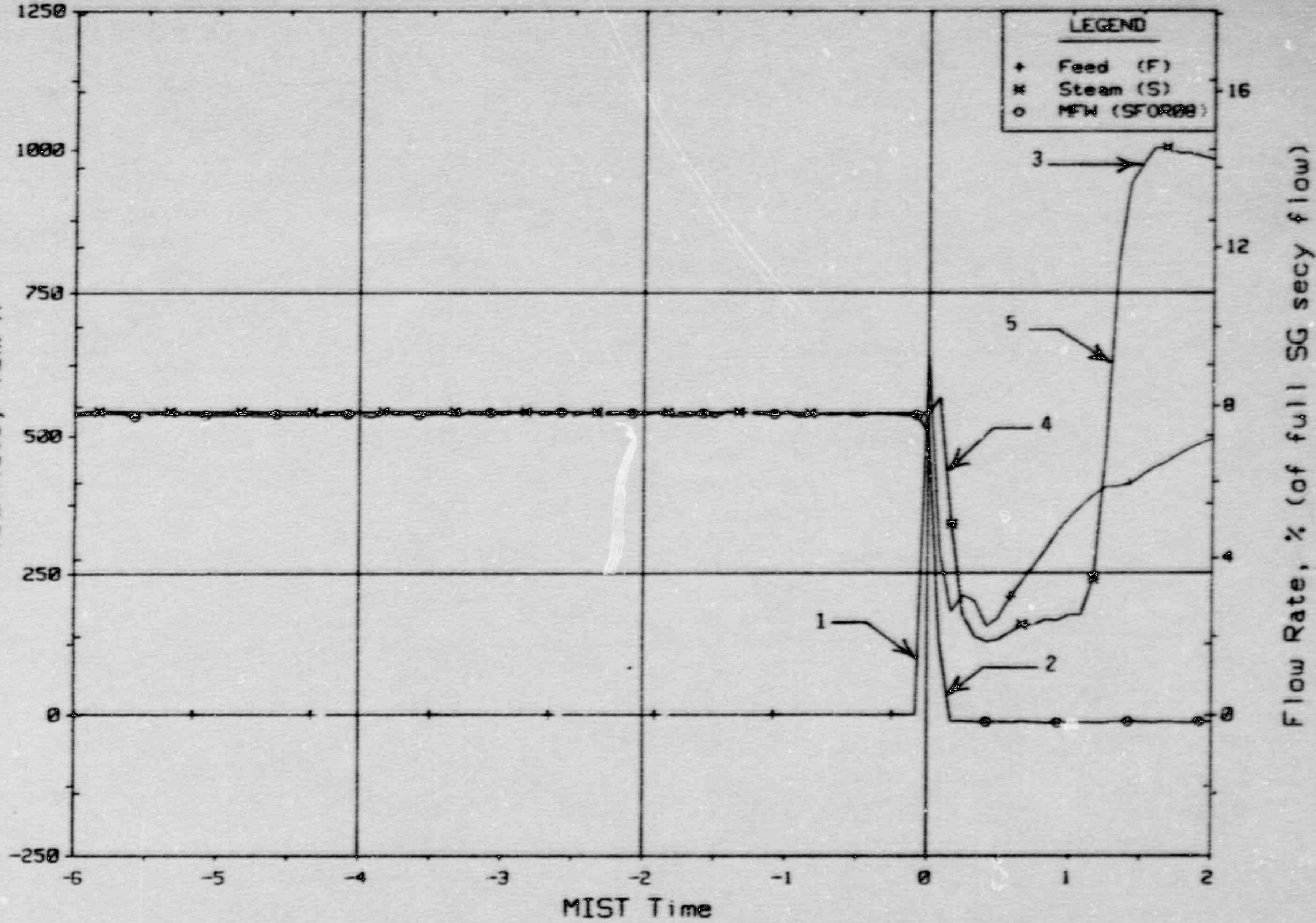



Figure 5.137 Steam Generator B Flow Rates (SaOR21s)

Tue Oct 18 17:08:53 1988

SCFL9

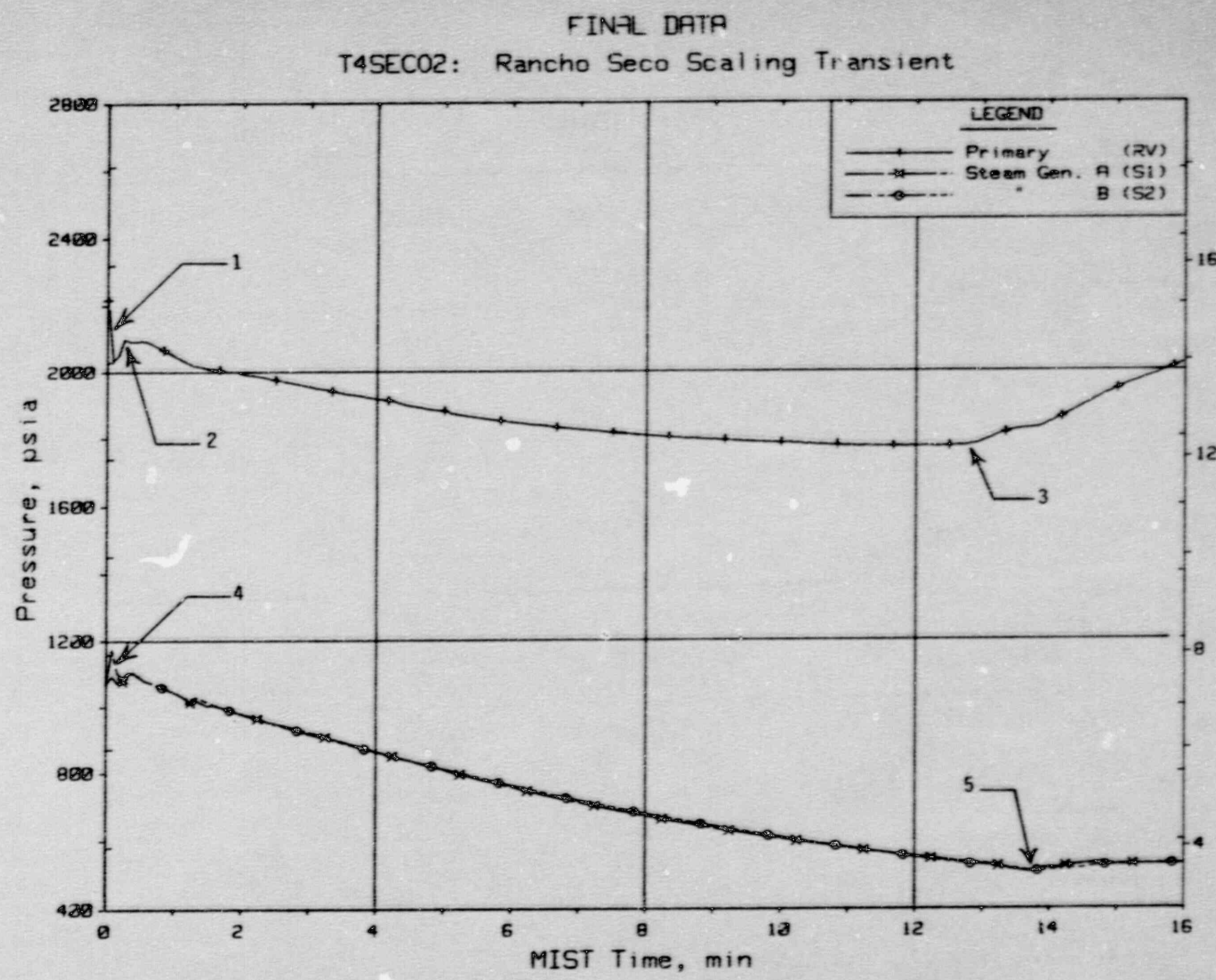



**Figure 5.138 Primary and Secondary System Pressures (GPOIs)**

Tue Oct 18 17:08:54 1988

PSGP1

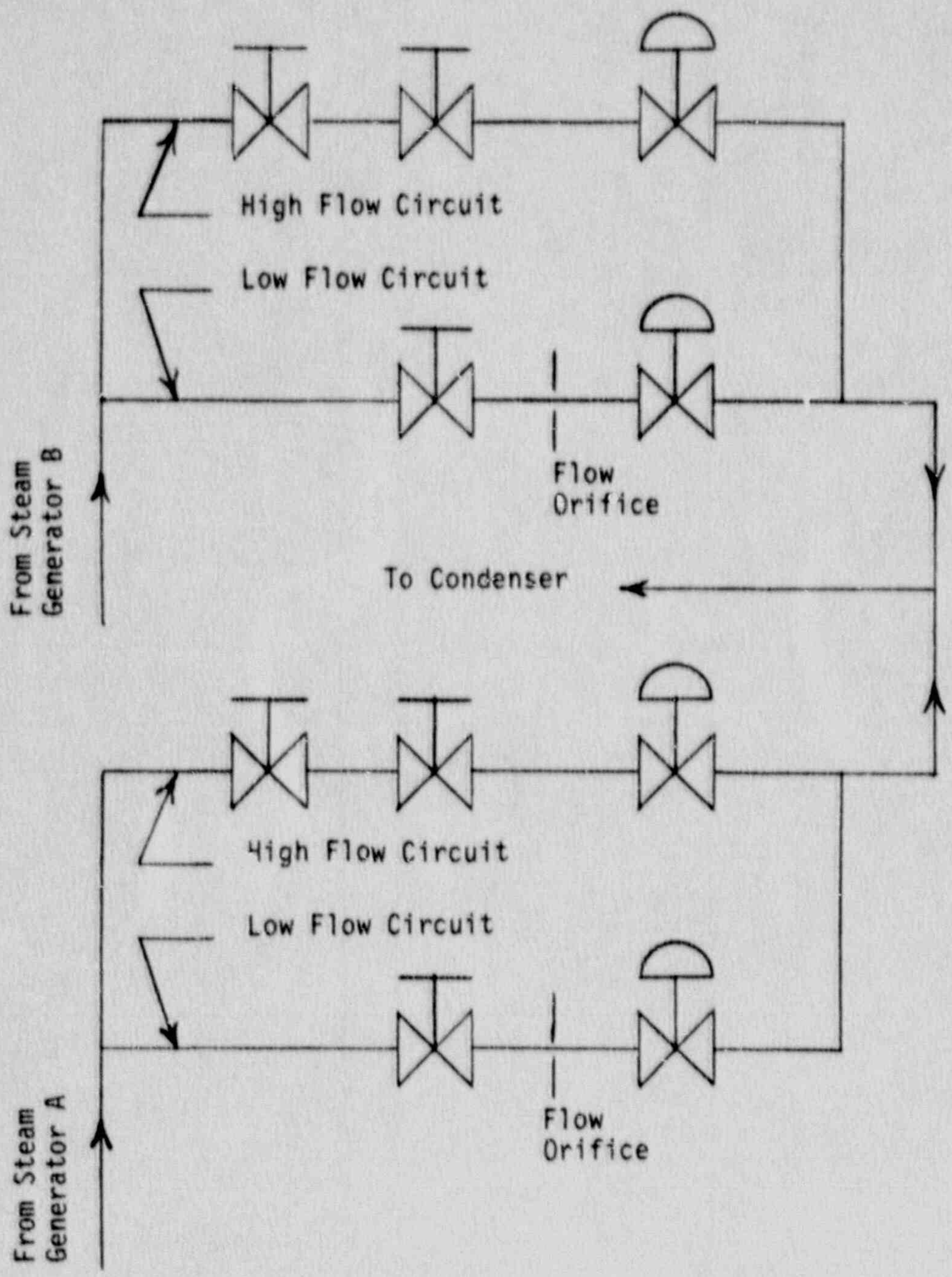



Figure 5.139 Schematic of MIST Steam Flow Circuits

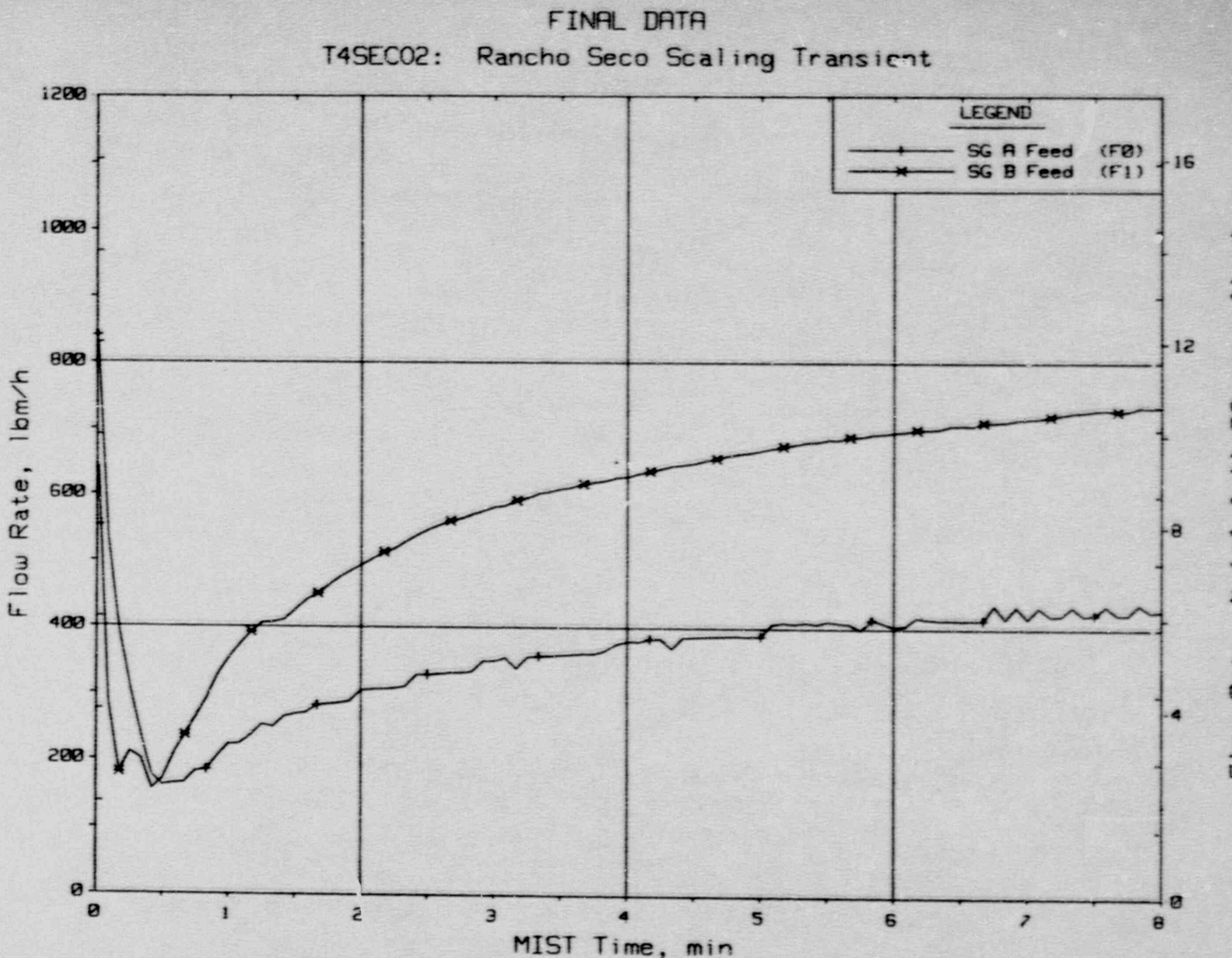



Figure 5.140 Steam Generator Secondary Flow Rates (SaOR2ns)

Thu Oct 20 17:19:11 1988

SCFL0

FINAL DATA

T4SEC02: Rancho Seco Scaling Transient

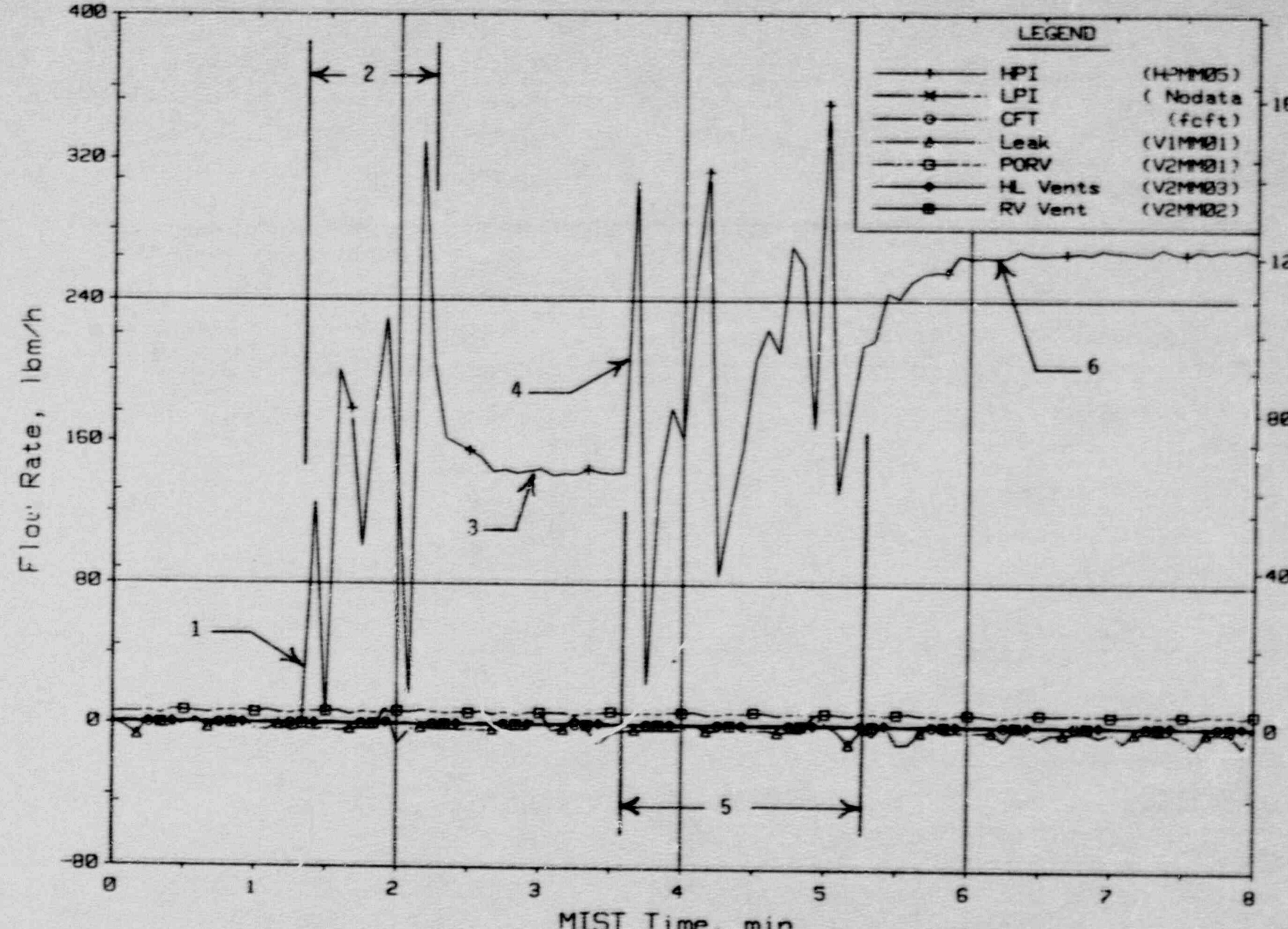



Figure 5.141 Primary System Boundary Flow Rates

Thu Oct 20 17:23:18 1988

PRFL3x

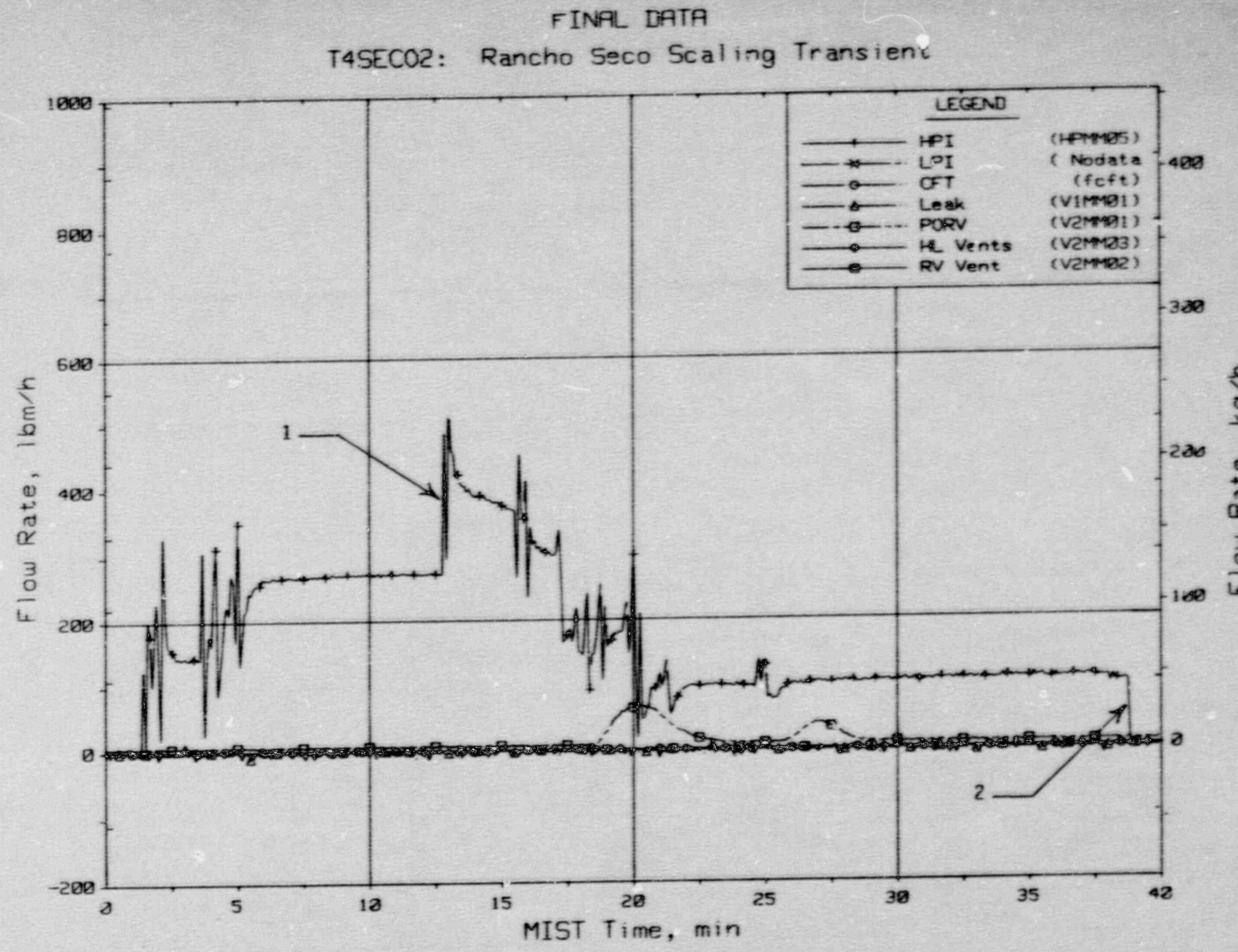



Figure 5.142 Primary System Boundary Flow Rates

PPFL3x



Tue Oct 18 17:15:58 1988

rINAL DATA

T4SEC02: Rancho Seco Scaling Transient

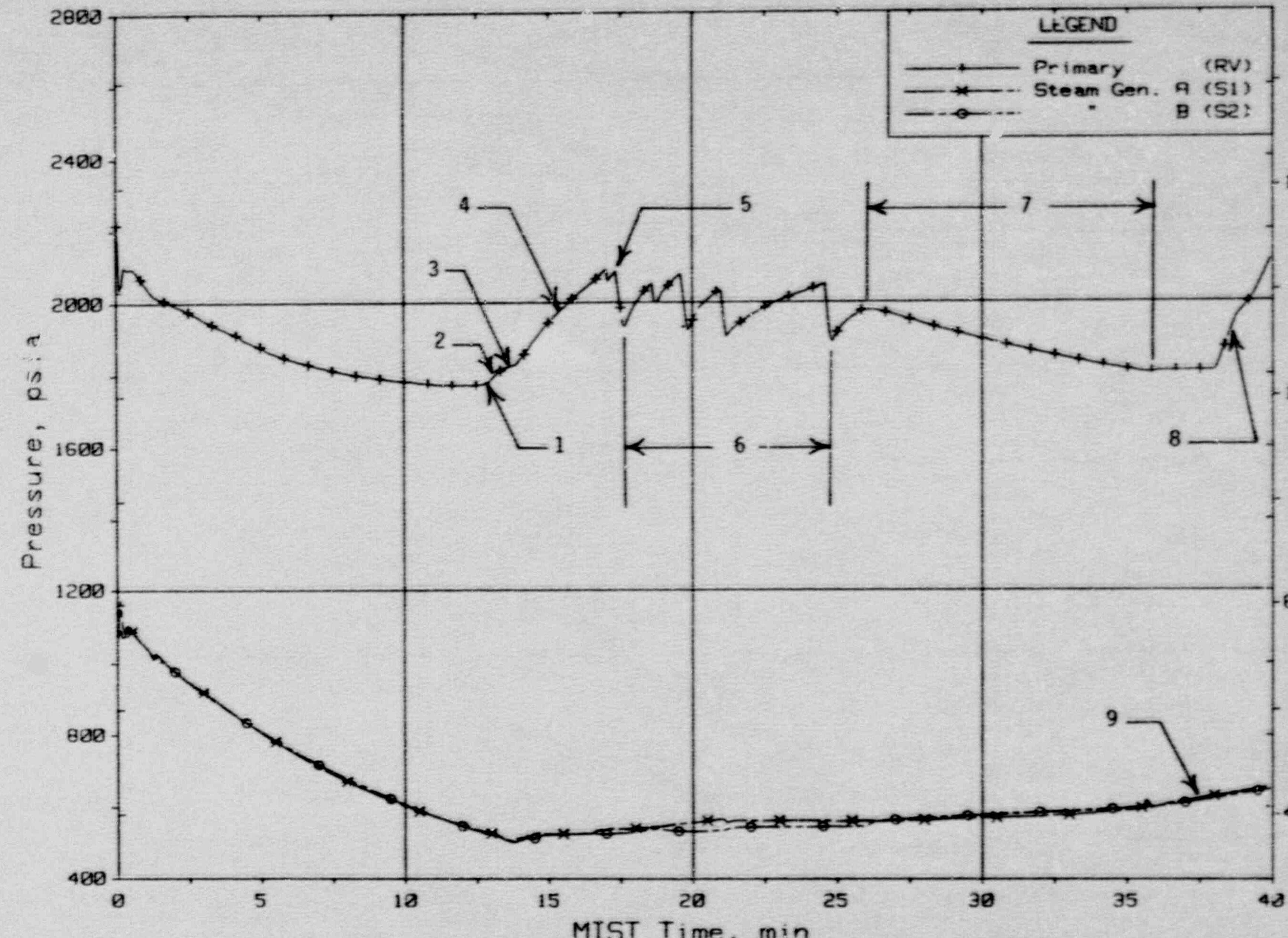



Figure 5.143 Primary and Secondary System Pressures (GPOIs)

Tue Oct 18 17:18:22 1988

PSGP1

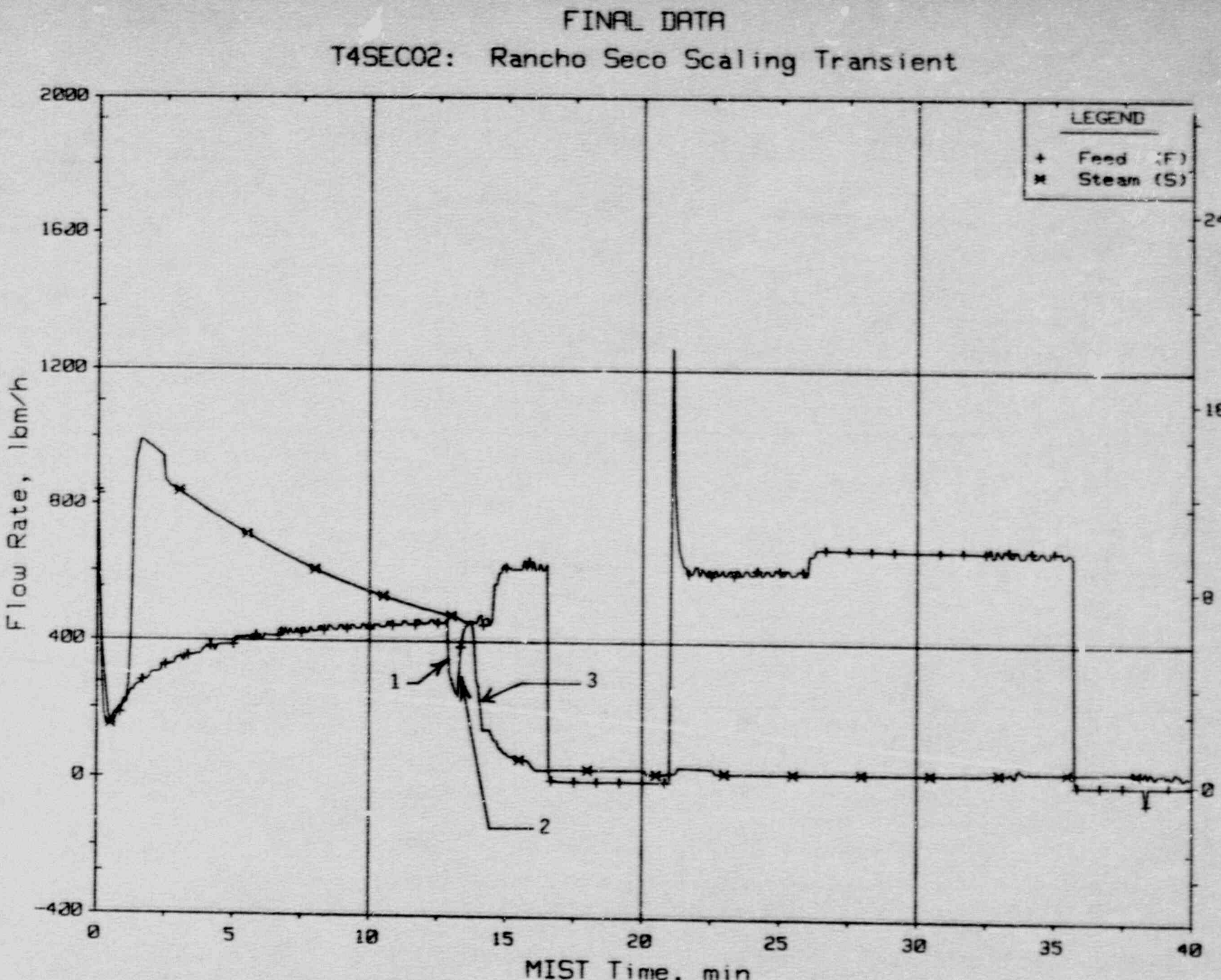



Figure 5.144 Steam Generator A Flow Rates (SaOR20s)

Thu Oct 20 17:36:17 1988

SCFL1

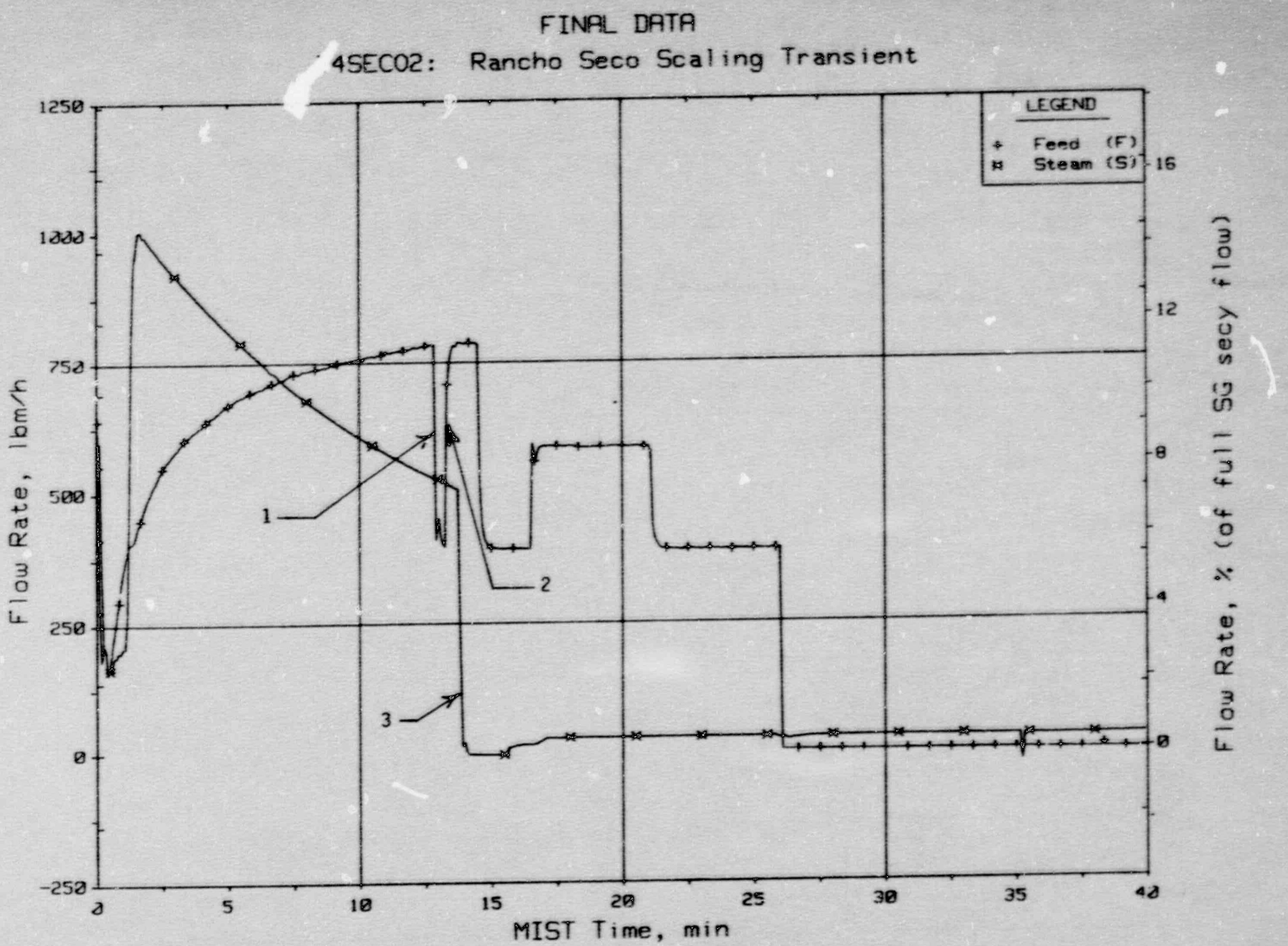



Figure 5.145 Steam Generator B Flow Rates (SaOR21s)

SCFL2

Thu Oct 20 17:38:12 1988

FINAL DATA

T4SEC02: Rancho Seco Scaling Transient

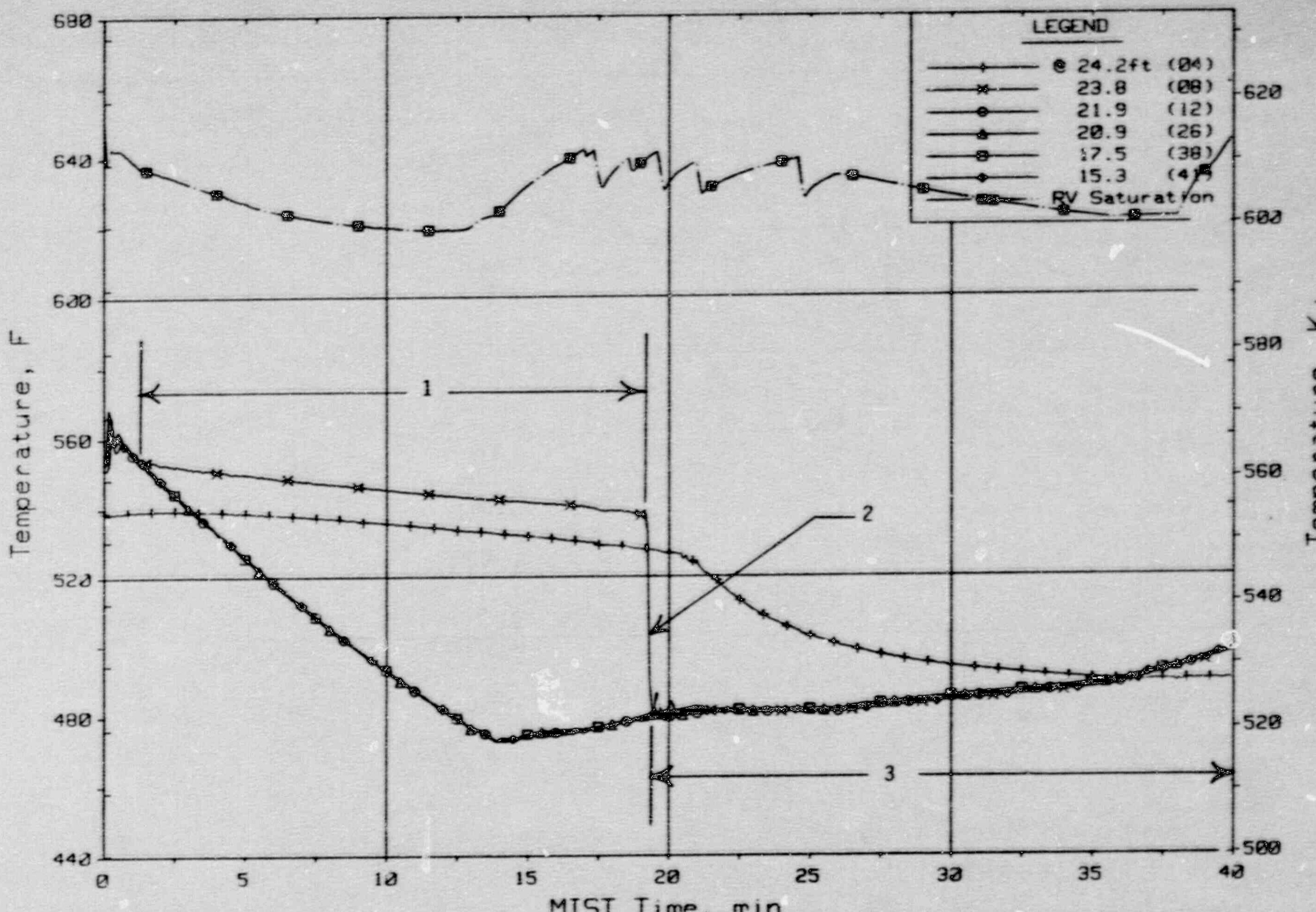



Figure 5.146 DC Quadrant B2 Upper-Elevation Fluid Temperatures (DCTCs)

Thu Oct 20 17:40:58 1988

DCTC4

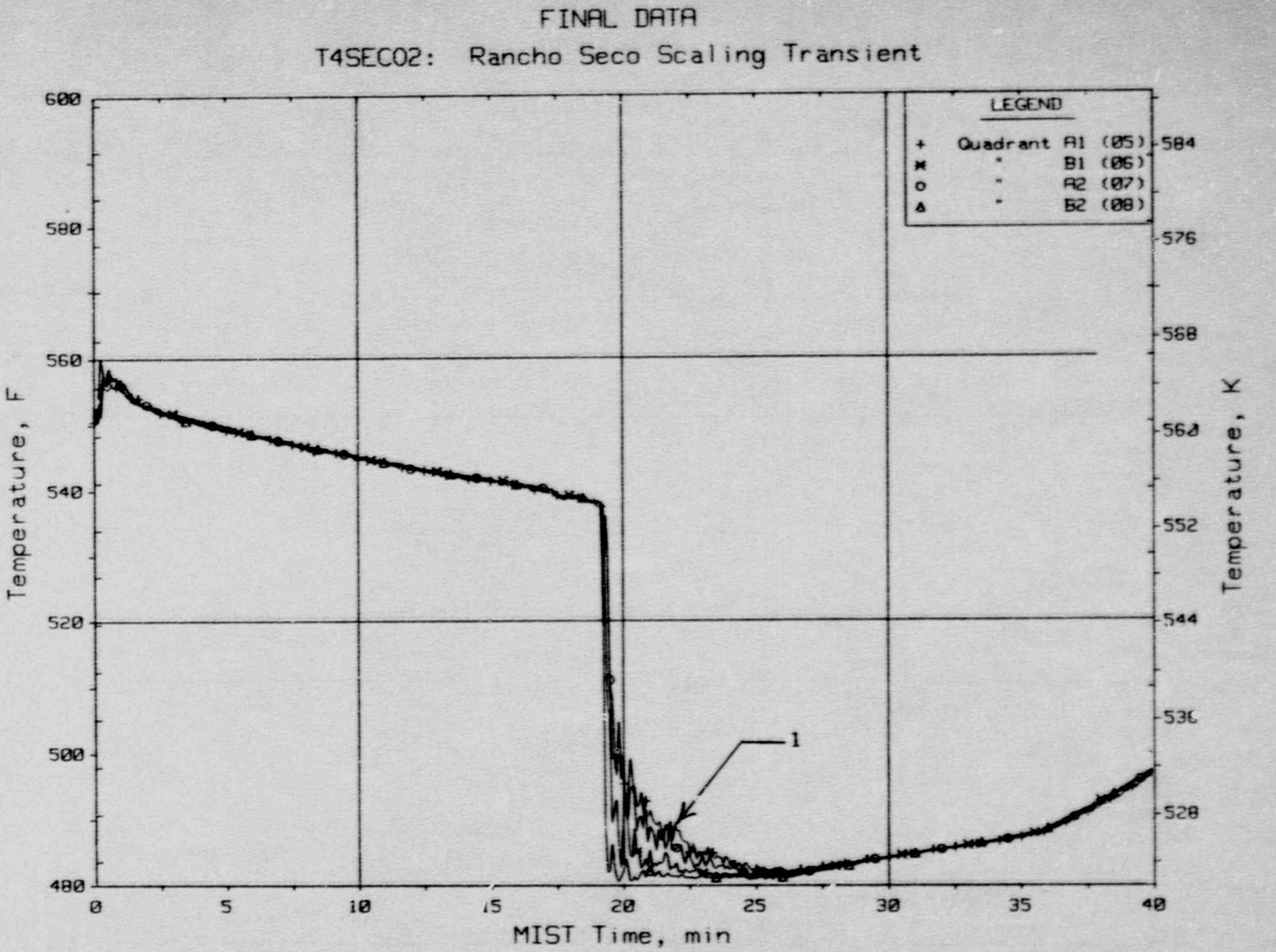



Figure 5.147 Downcomer Fluid Temperatures Below RVVVs, Elevation 23.8 ft (DCTCs)

Thu Oct 20 17:45:42 1988

DCTR5

FINAL DATA

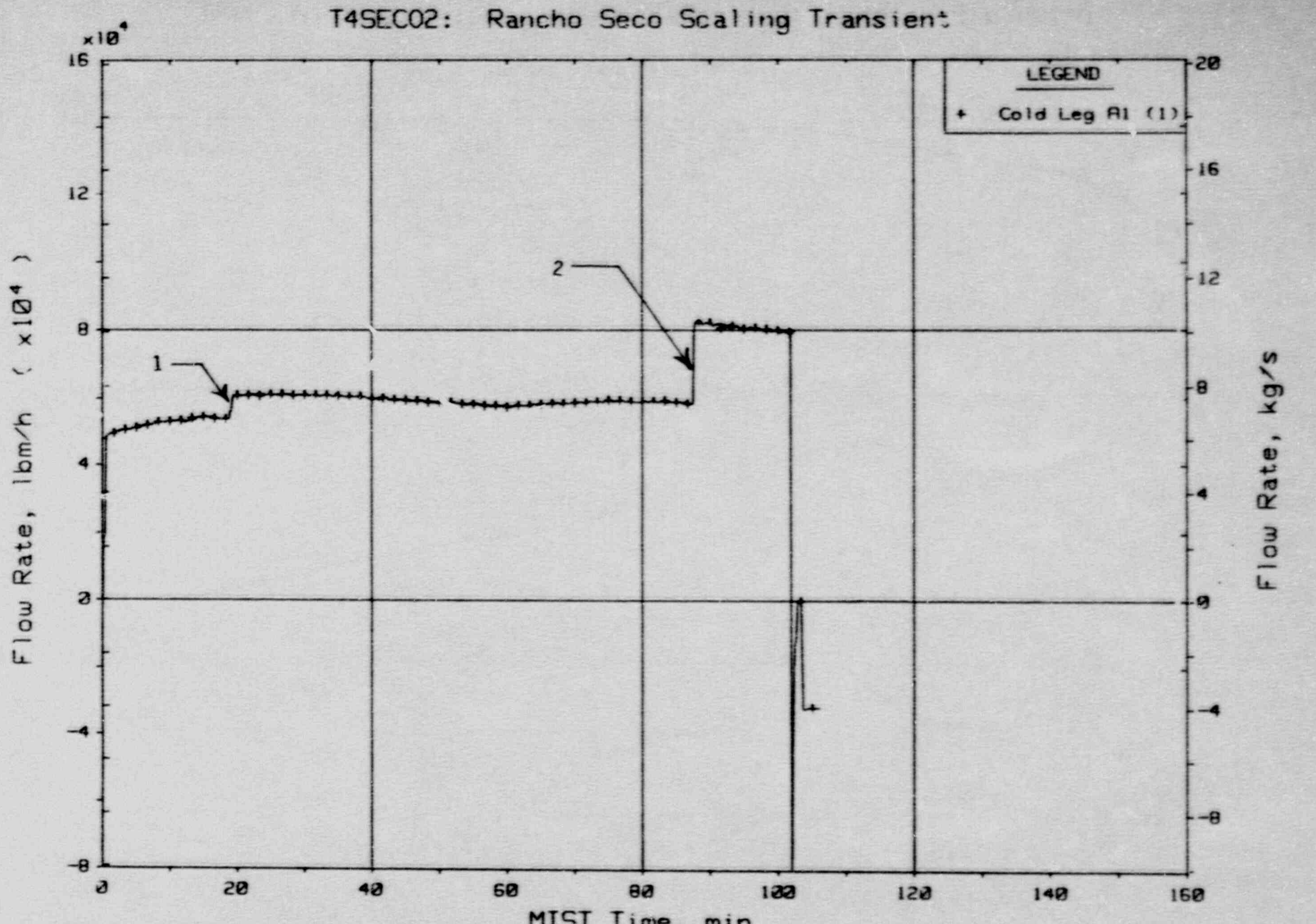
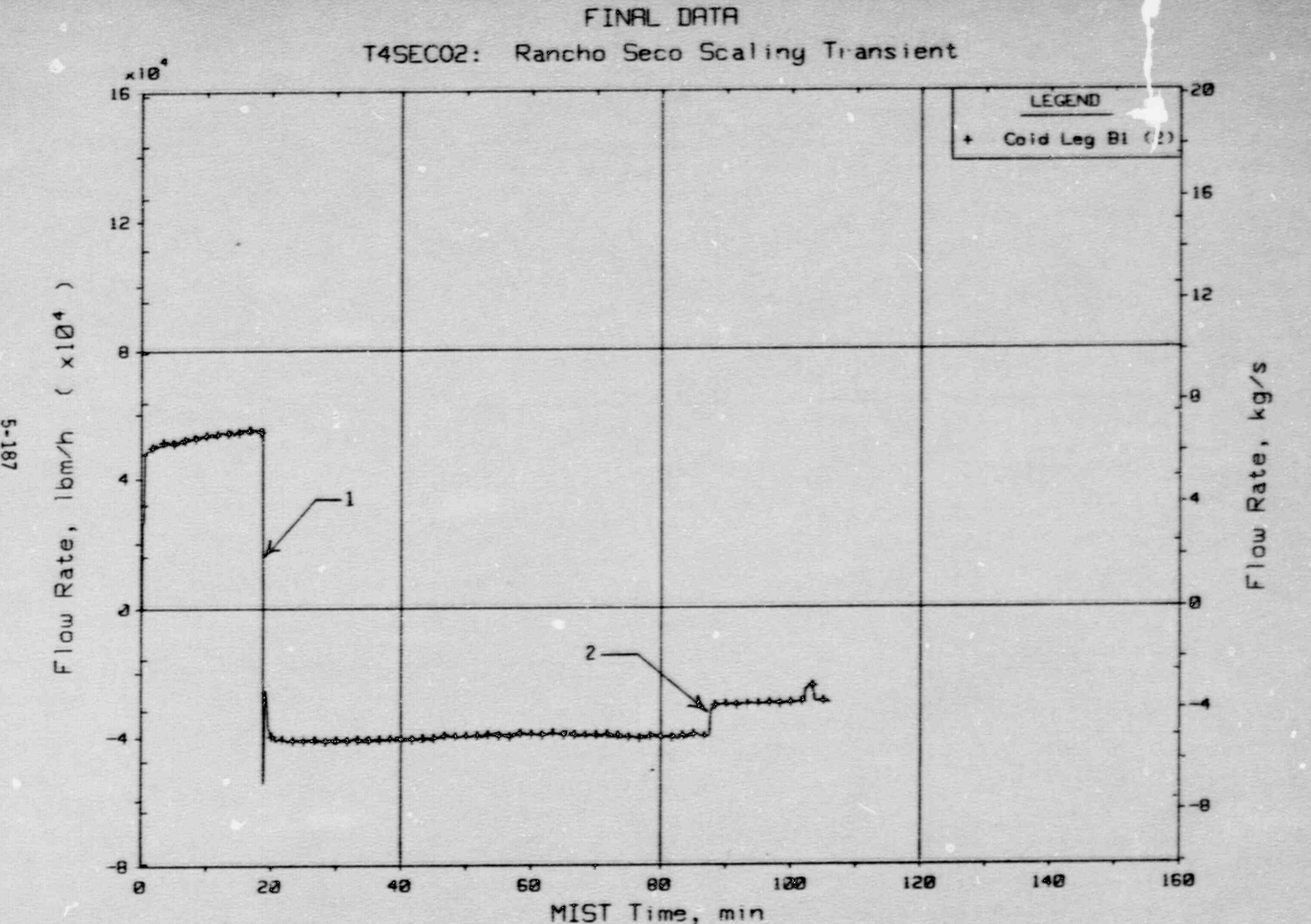



Figure 5.148 Cold Leg (Turbine Meter) Flow Rates (CnTM01s)

Mon Oct 24 11:10:53 1988

CLTM1




5-187

Figure 5.149 Cold Leg (Turbine Meter) Flow Rates (CnTM01s)

Mon Oct 29 11:18:48 1990

CLTM1

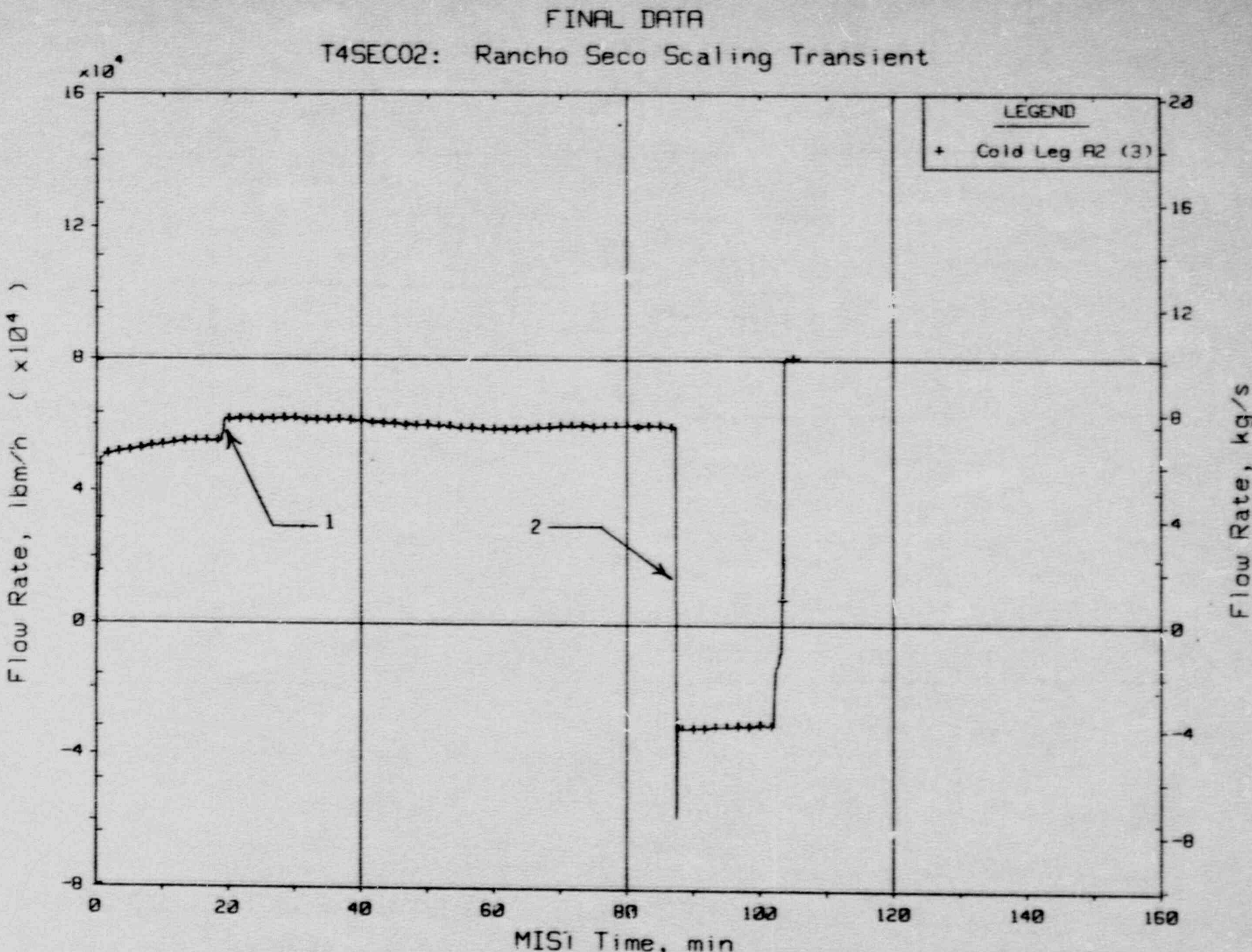



Figure 5.150 Cold Leg (Turbine Meter) Flow Rates (CnTM01s)

Mon Oct 24 11:23:58 1988

CLTM1

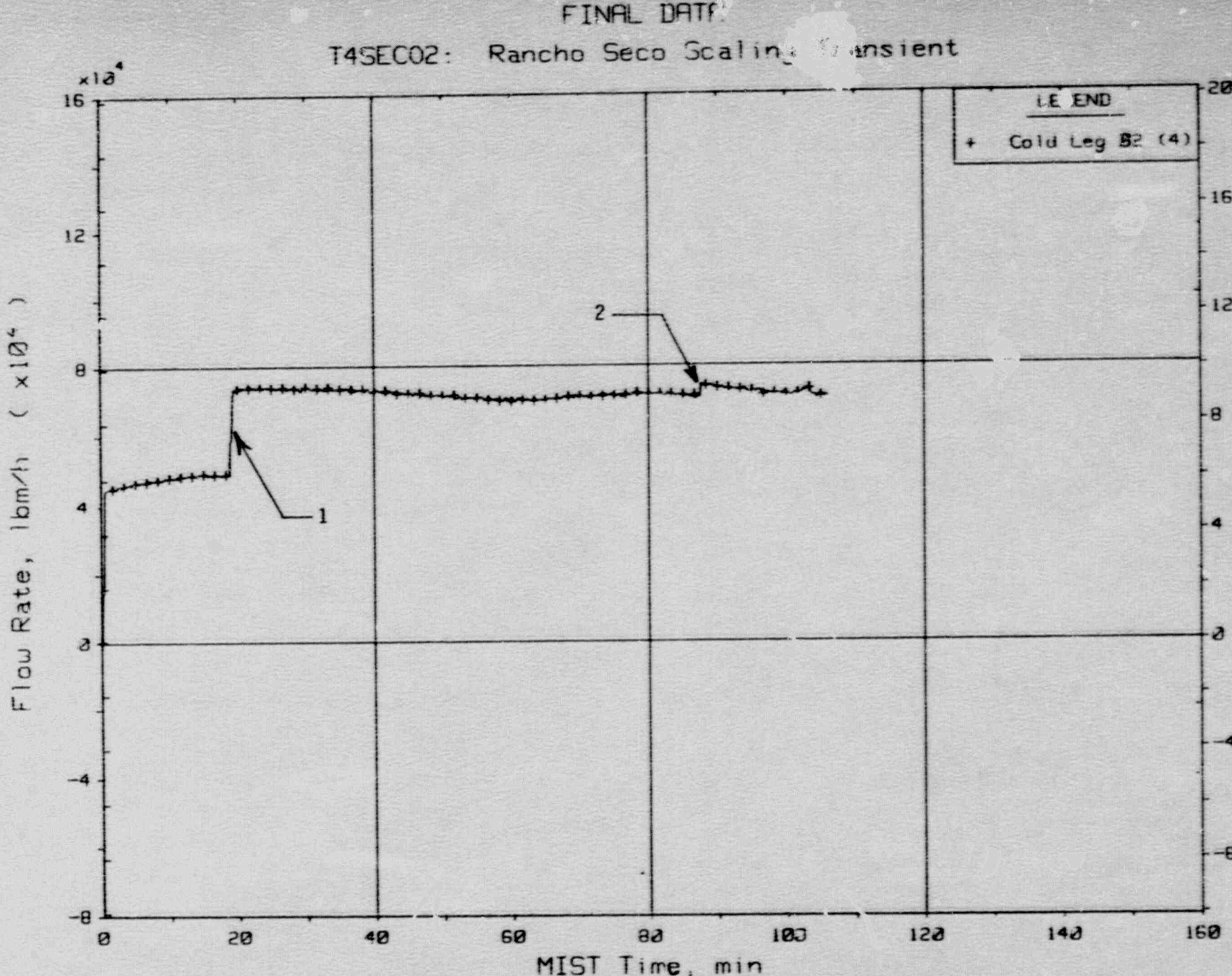



Figure 5.151 Cold Leg (Turbine Meter) Flow Rates (CnTM01s)

Mon Oct 24 11:27:30 1988

CLTM1

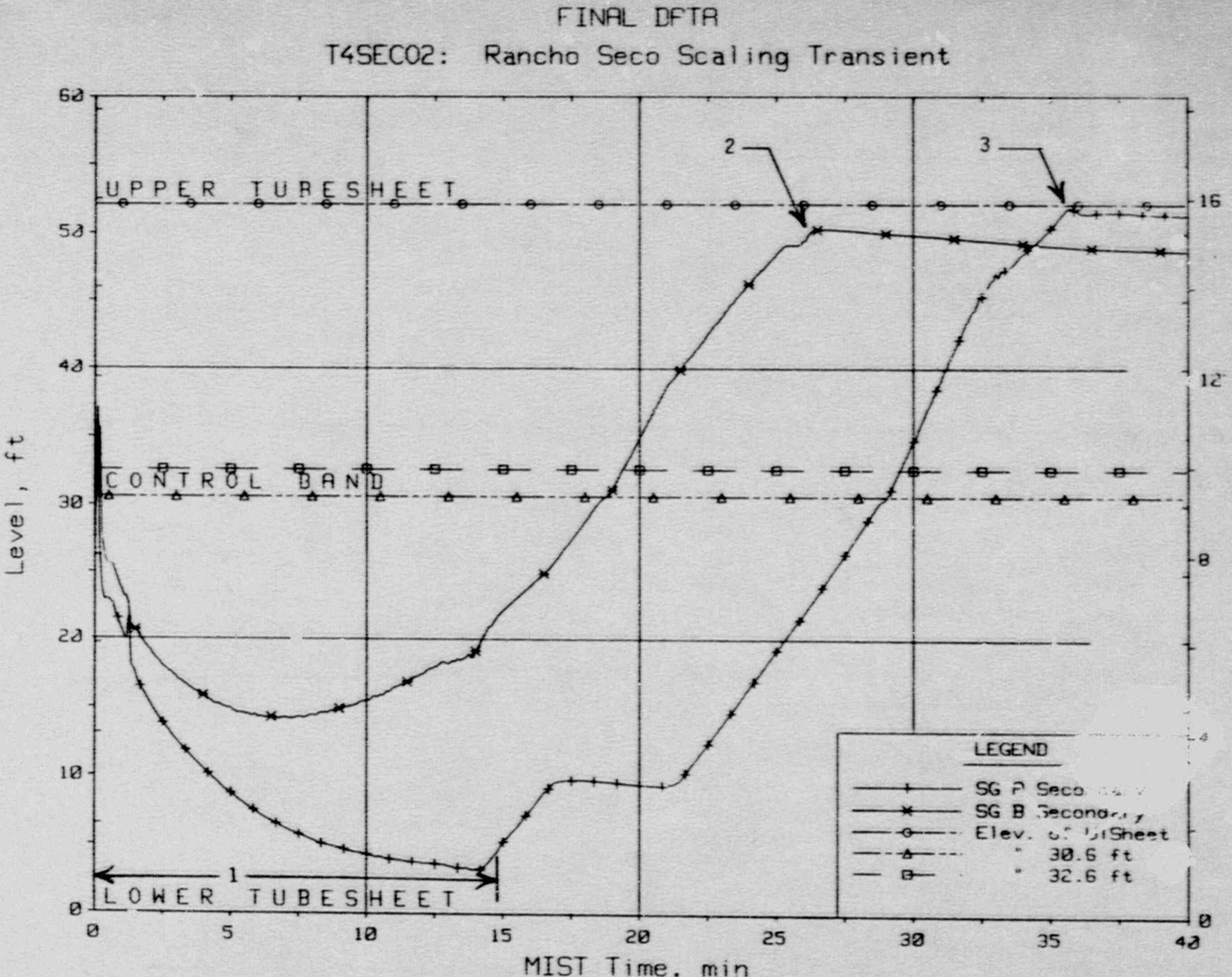



**Figure 5.152 Steam Generator Collapsed Liquid Levels**

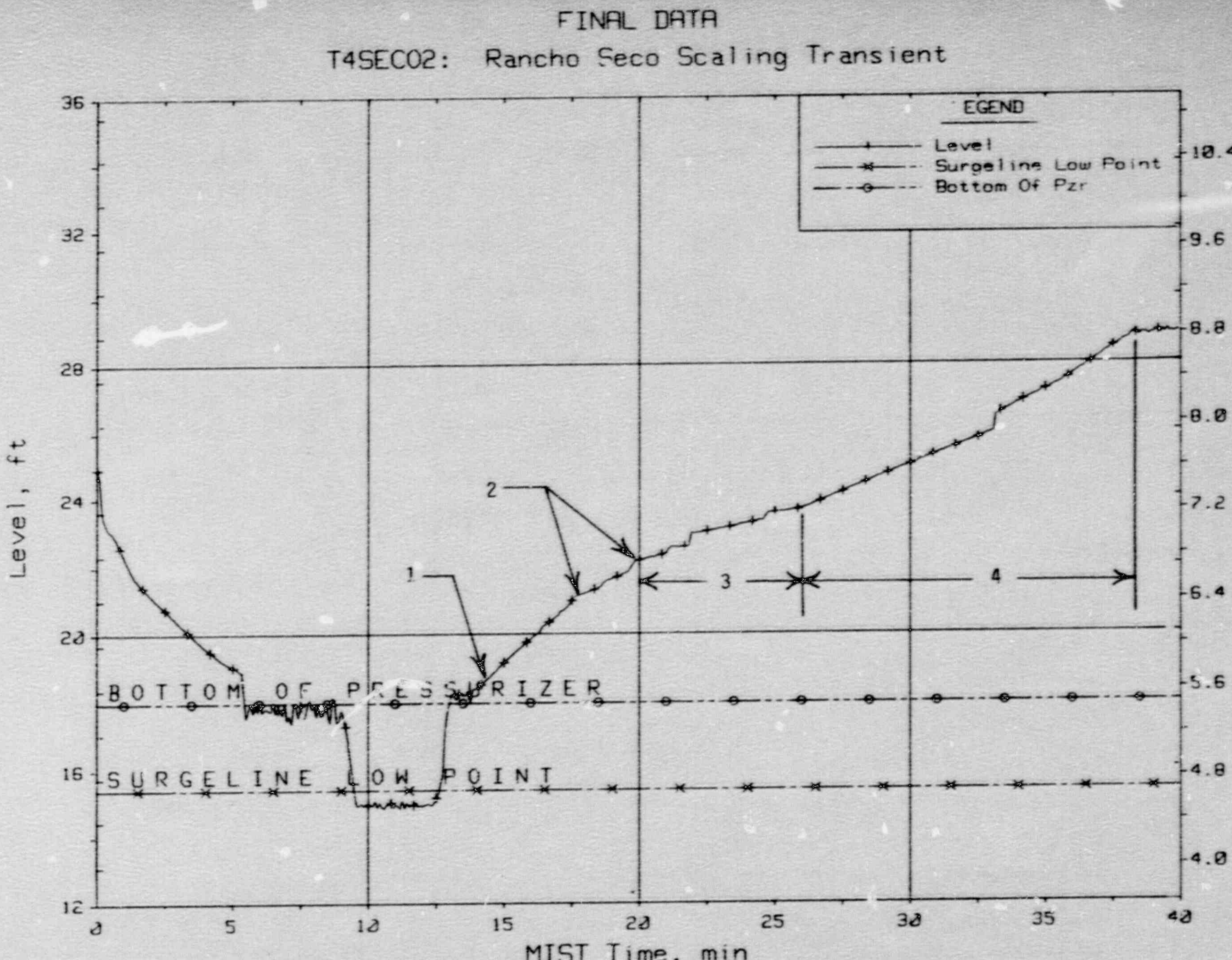



**Figure 5.153 Pressurizer Collapsed Liquid Level (PZLV20)**

Thu Oct 20 17:51:12 1988

PZLV1

# FINAL DATA

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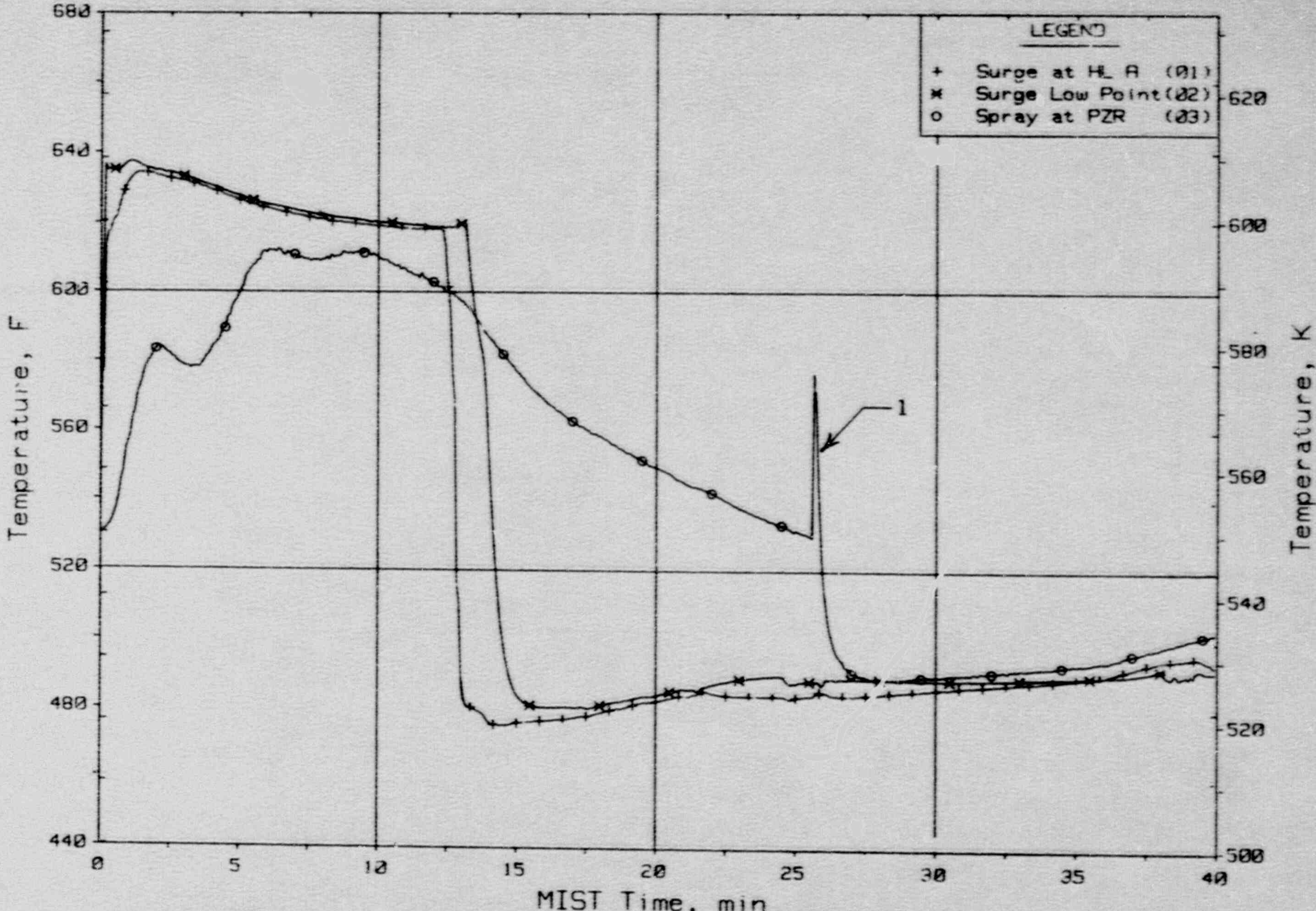



Figure 5.154 Pressurizer Surge and Spray Fluid Temperatures (PZTCs)

Thu Oct 20 17:43:20 1988

PZTC1

5-193

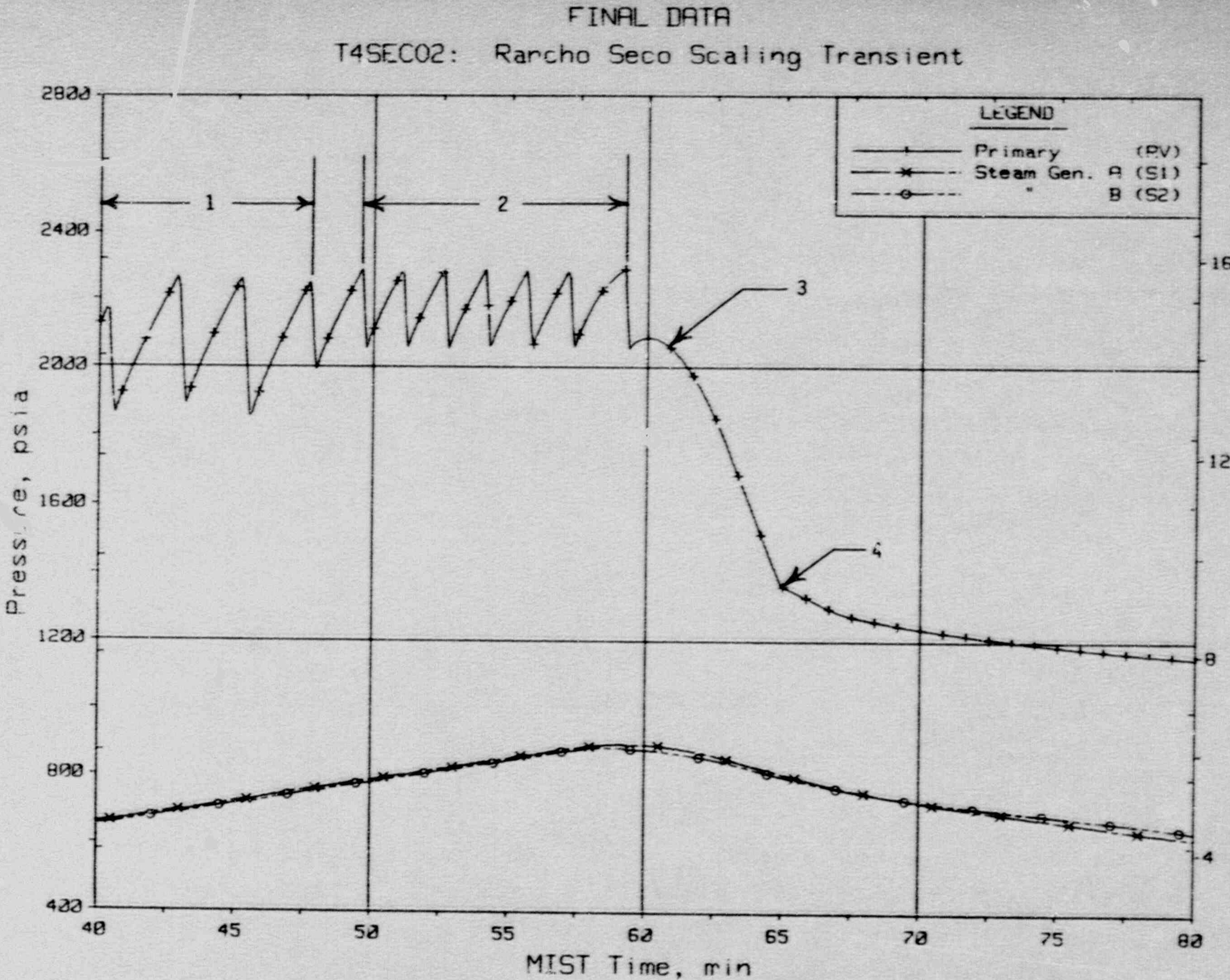



Figure 5.155 Primary and Secondary System Pressures (C...)

Mon Oct 24 11:32:06 1988

PSGP1

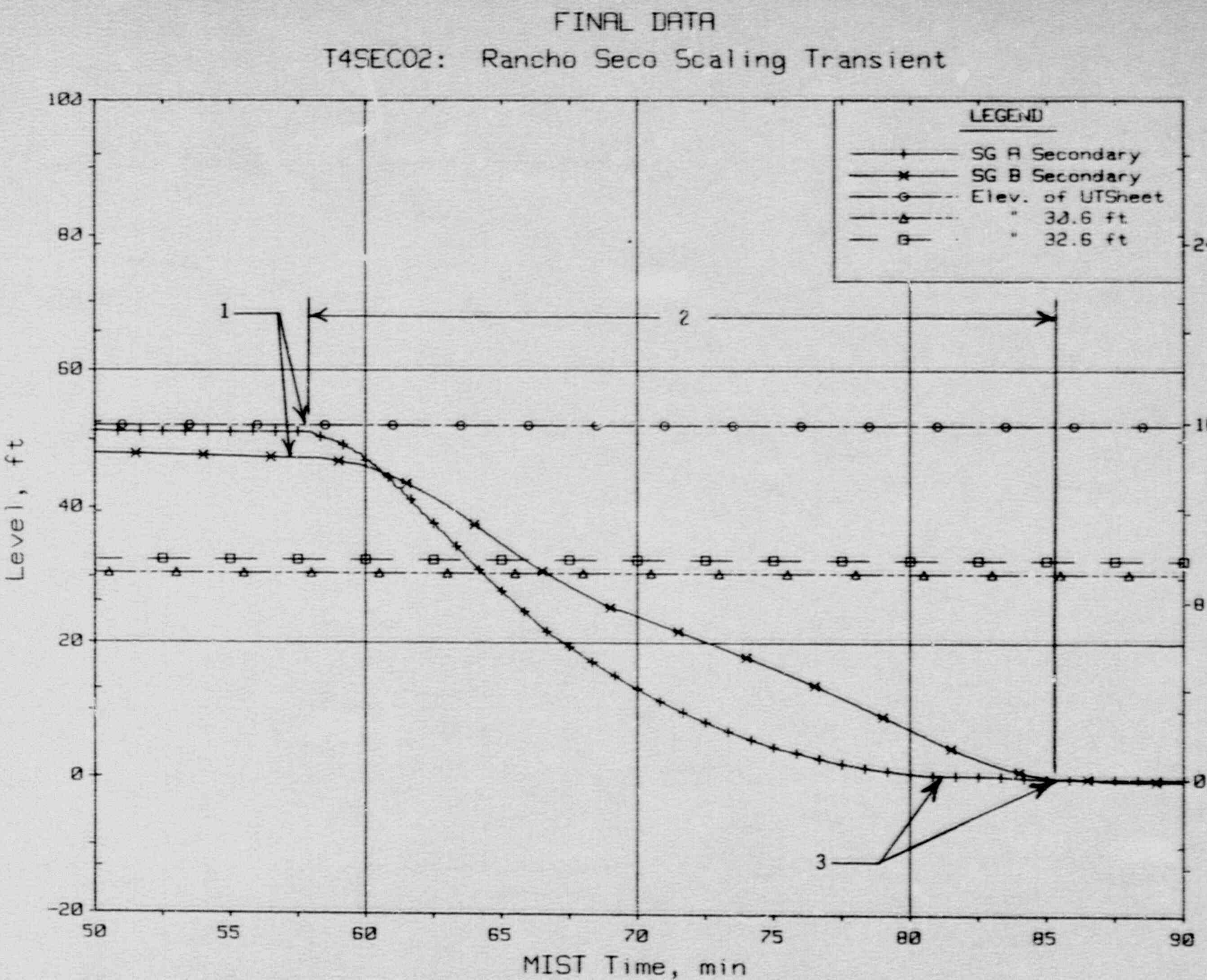
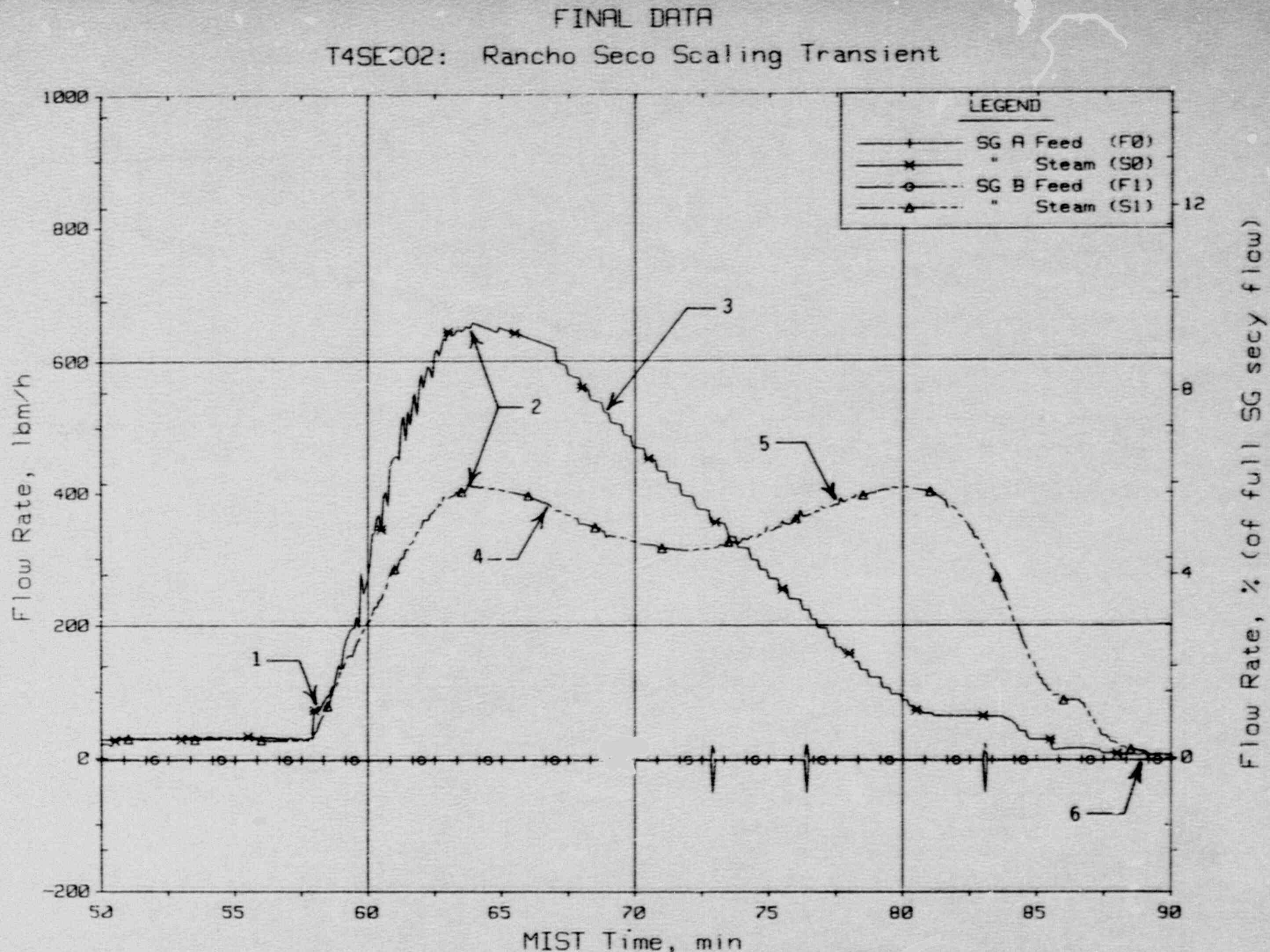



Figure 5.156 Steam Generator Collapsed Liquid Levels

Thu Oct 20 18:39:49 1988

SGLV2




5-195

**Figure 5.157 Steam Generator Secondary Flow Rates (5aOR2ns)**

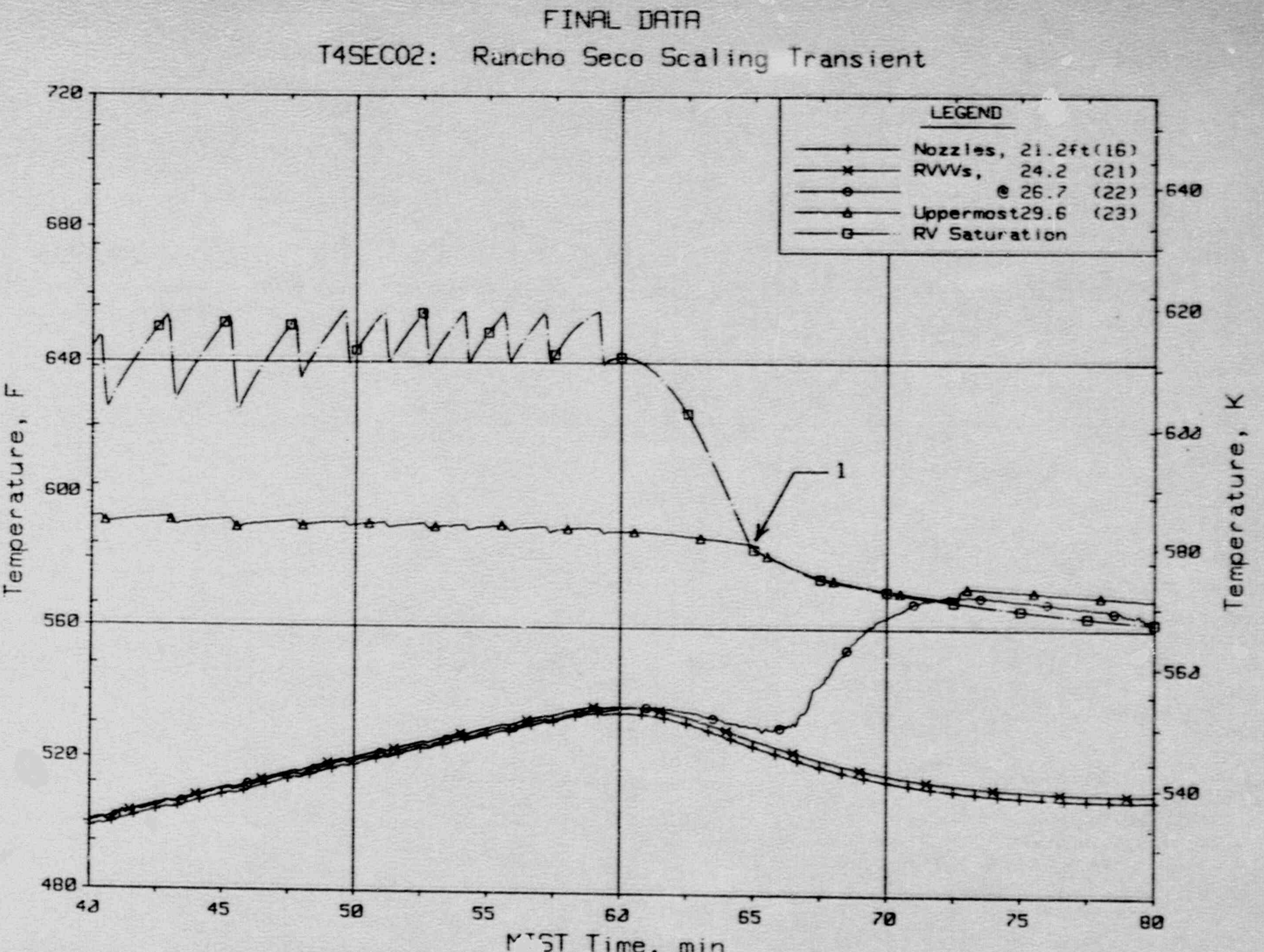



Figure 5.158 Reactor Vess . Upper-Elevation Fluid Temperatures (RVTCs)

Thu Oct 20 18:22:08 1988

RVTC3

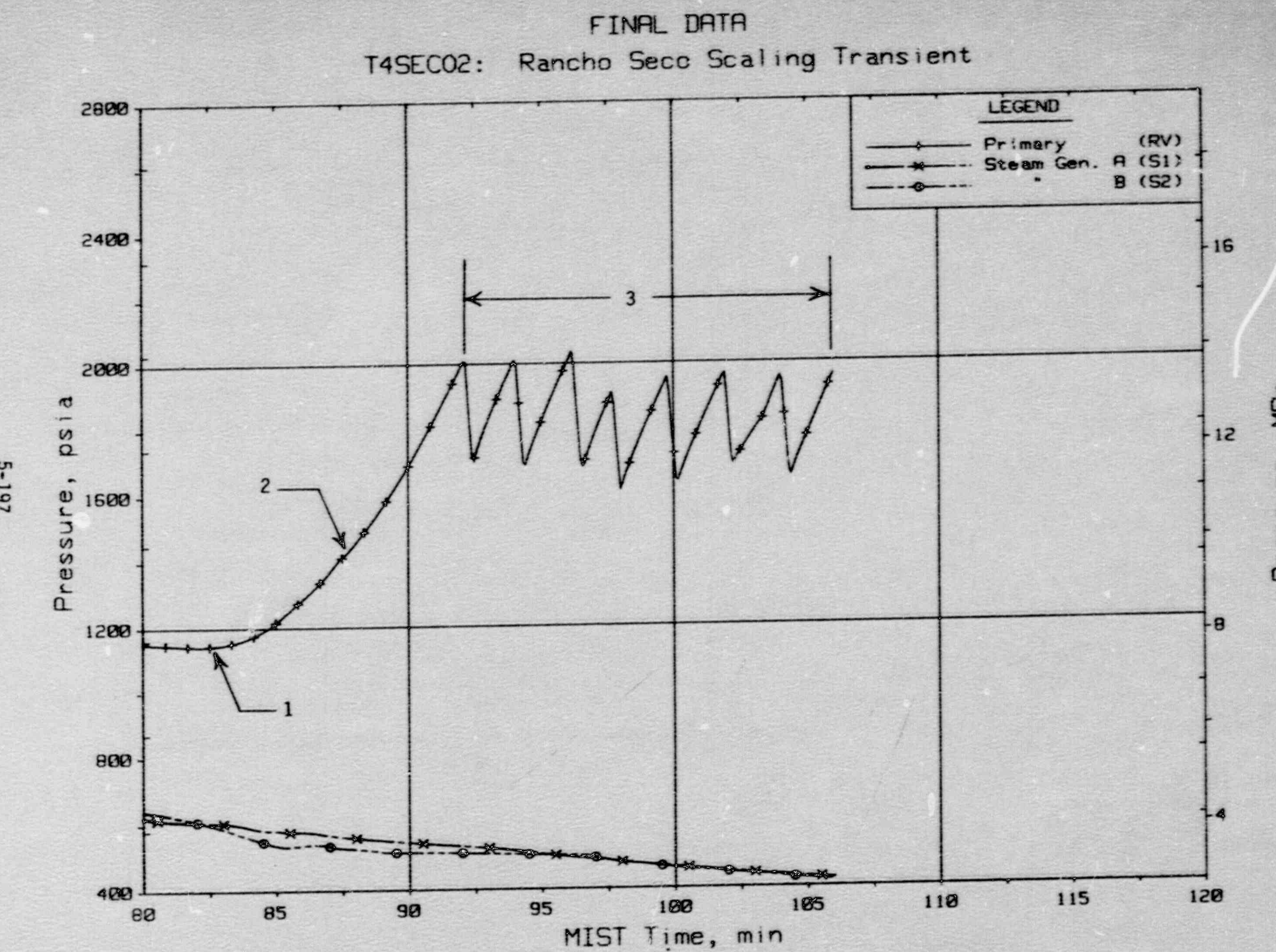



Figure 5.159 Primary and Secondary System Pressures (GP01s)

PSGP1

Fri Oct 21 09:44:54 1988

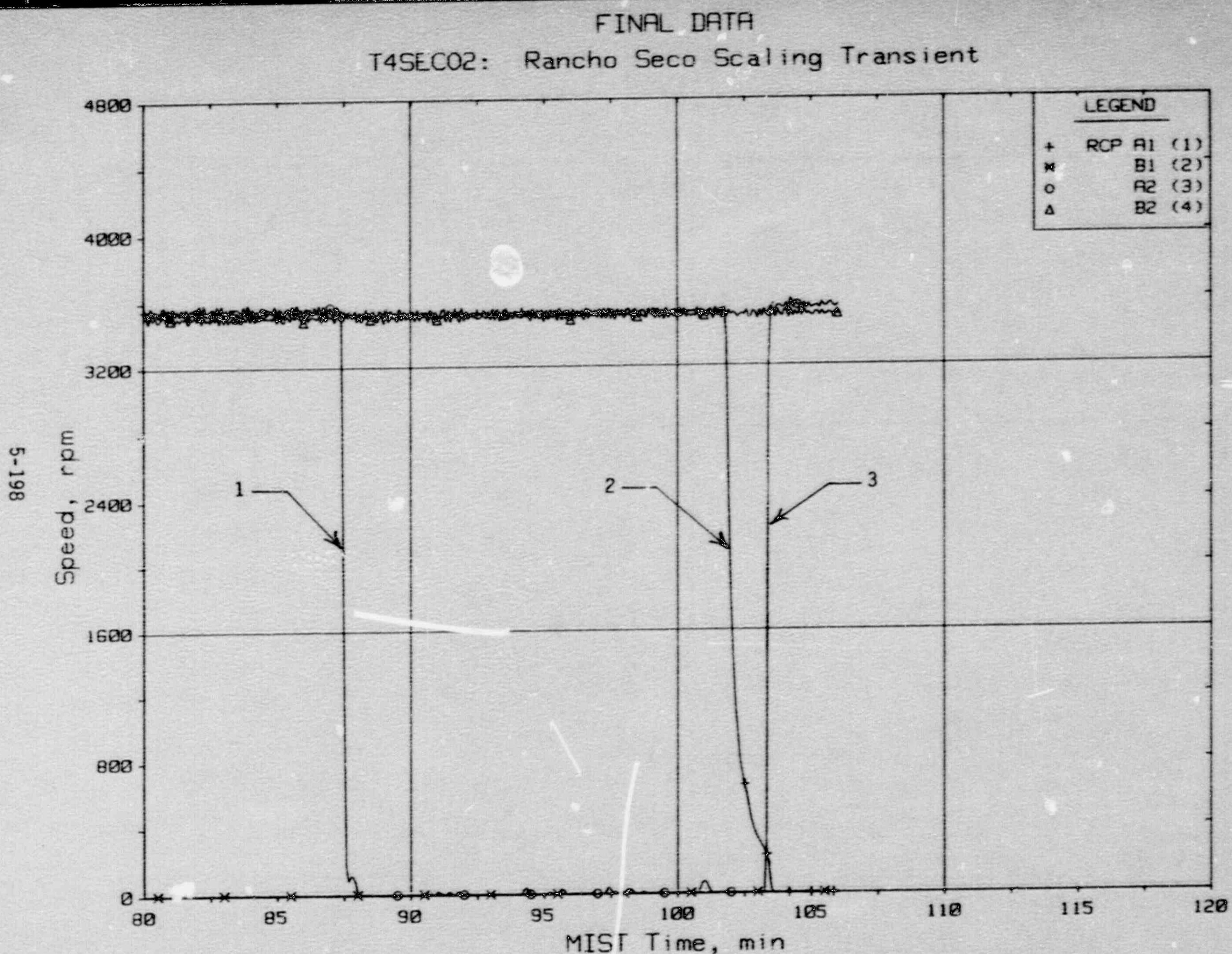



Figure 5.160 Pump Speed (CnTA20s)



Fri Oct 21 16:33:33 1988

PUTA0

# 6. TEST COMPARISONS

Several of the MIST Phase IV tests lend themselves to comparative purposes with either other Phase IV tests or previously conducted Phase III tests. Selected data comparisons have been performed for tests that have somewhat similar primary and secondary boundary conditions (various nominal tests, larger SBLOCA tests, station blackout, and mapping tests). Data comparisons are also presented that delineate the effects of variations in primary and secondary boundary conditions on the transient response.

## 6.1. Comparison of Phase IV Nominal Test With Phase III Nominal Tests 3109AA and 311000

A comparison of the primary system pressure response for these three nominal tests indicated that Test 4NOML3 was more representative of Test 311000 than of Test 3109AA. Through approximately the first 50 minutes of these transients, the primary system pressure response of Test 4NOML3 was similar to that of Test 311000 (See 1, Figure 6.1). Test 4NOML3 saturated at a higher pressure (as a result of the higher core power level) and then depressurized by means of leak-HPI cooling. Test 311000 had periods of steam generator B heat transfer during this time (resulted from the initiation of the ATOG cooldown in steam generator B). However, the impact of the steam generator B heat transfer was minimal (the primary pressures for Tests 311000 and 4NOML3 diverged approximately 60 psi during this time), therefore the depressurization for Tests 311000 was also predominantly leak-HPI cooling.

The primary pressure response for Test 3109AA differed significantly from the other Nominal Tests during this same period. During the first approximately 6 minutes of the transient, the primary pressure response for both Phase III Nominal Tests was identical (See 2, Figure 6.1). However, a comparison of the loop B flow rates after approximately 6 minutes for each test shows that for Test 3109AA, both cold leg B flow rates were approximately equal (See 1, Figure 6.2), whereas Test 311000 indicated asymmetric cold leg B flow rates

(See 1, Figure 6.3). The magnitude of the cold leg B flow rates was also significantly higher for Test 3109AA. Test 3109AA maintained flow in loop B and resulted in a subcooled natural circulation condition in loop B that depressurized the primary system.

At approximately 5 minutes, the ATOG controller initiated a cooldown ramp in Test 3109AA. The continued flow in loop B maintained primary-to-secondary heat transfer (See 1, Figure 6.4). When the steam generator B pressure equaled the ATOG control pressure, the steam valve opened and a cooldown of 100F/h began (See 2, Figure 6.4). Therefore, steam generator B heat transfer was established that enforced the predominant flow path in loop B. The ATOG cooldown continued in an intermittent manner as the difference between the core exit temperature and the steam generator saturation temperature fluctuated about the control setpoint of 50F (ATOG cooldown is initiated when the temperature difference is equal to or less than 50F). A heatup of the core occurred and when the core exit saturated, the ATOG cooldown terminated and the primary system depressurization rate decreased (See 3, Figure 6.1). The depressurization was then by means of leak-HPI cooling.

When the ATOG cooldown was initiated in both steam generators, each test exhibited an increase in the depressurization rate (See 4, Figure 6.1). Test 4NOML3 quickly depressurized to the secondary side pressure and followed the ATOG cooldown rate (See 5, Figure 6.1). Both Phase III tests did not depressurize to the secondary side pressure. The minimum pressure attained during the depressurization for each test and the time at which it occurred were as follows:

| | | |
|---|---|---|
| 3109AA | 560 psia | 89 min |
| 311000 | 465 psia | 83 min |
| 4NOML3 | 490 psia | 109 min |

The additional time required to reach the minimum pressure for Test 4NOML3 appears to be a result of the reduced ATOG cooldown rate (75F/h).

Each test also repressurized to approximately 625 psia as leak-HPI equilibrium was established (See 6, Figure 6.1).

A comparison of the Phase IV Nominal Test (4NOML3) to Phase III Nominal Tests 3109AA and 311000 revealed that a relatively symmetric performance of the steam generator secondary sides occurred in the Phase IV test that was not observed for either of the Phase III tests. For Test 4NOML3, the steam generator A secondary pressure decreased in a similar manner as observed in the Phase III tests (See 1, Figure 6.5) as the secondary side level was increased to 31.6 ft. However, upon completion of the secondary side refill, the steam generator A secondary pressure increased (See 2, Figure 6.5) and stabilized at approximately 800 psia (See 3, Figure 6.5) for Test 4NOML3. This response was significantly different from that observed in either of the Phase III Nominal Tests. A heatup of hot leg A had occurred that apparently created a sufficient amount of driving head to cause flow (See 1, Figure 6.6), therefore, primary-to-secondary heat transfer occurred and resulted in the increase of the steam generator A secondary pressure.

The steam generator B secondary pressure for Test 4NOML3 responded in a manner similar to that observed for Test 311000 (See 3, Figure 6.4) but repressurized to a lesser extent. Both steam generators A and B stabilized at approximately the same pressure for Test 4NOML3.

The response of the steam generators for Test 4NOML3 appears to be related to the increased core power that (1) causes the primary system to saturate at a higher pressure and (2) causes flow to occur in both loops after the refill of the steam generator secondary side was completed, therefore resulting in an increase in the secondary side pressure for both steam generators. The combination of the two effects above delays the initiation of the ATOG cooldown for Test 4NOML3 when compared to the Phase III Nominal Tests.

A comparison of the primary system pressure and the secondary pressure for each steam generator for the duration of each Nominal Test is shown on Figures 6.7, 6.8, and 6.9. The test duration for Test 4NOML3 appears to have been extended as a result of the increased core power level. Each Nominal Test exhibited a similar response during the refill of the hot legs (the hot leg A riser refilled to the spillover elevation, a heatup of the hot leg commenced, and when a sufficient amount of driving head was established a flow pulse occurred in loop A that subcooled the core exit temperature). For the three Nominal Tests examined, the time when the phenomena above first occurred appears to be directly related to the core power level. The sequence of this occurrence is Test 311000 (See 1, Figure 6.7), Test 3109AA (See 2, Figure 6.7), and 4NOML3 (See 3, Figure 6.7). The core power level for each test is shown on Figure 6.10. As can be observed from this figure, the test that exhibited this phenomenon first (311000) had the lowest core power level and the test that exhibited this phenomenon last (4NOML3) had the highest power level. Also, the core power when the phenomenon occurred was approximately equal for these three tests.

The difference between the core power for Test 4NOML3 and all other MIST tests is small (Figure 6.10). Therefore, if this small difference affected the test duration time, the impact of core power augmentation (0.4 to 0.57% of full power) would have a greater effect on test duration time. For example, between 200 and 700 minutes, the core power augmentation is approximately 30 to 37% (augmentation of 0.4% of full power) and 37 to 46% (augmentation of 0.57% of full power) of the total core power. Since the loop fluid temperatures decrease with time, the uncompensated heat losses also decrease. Therefore, if the core power augmentation were reduced during this time, it appears that the hot leg refill process would occur earlier and the time required to depressurize the primary system should decrease. Thus, the test duration time should also decrease. However, the decreased core power will alter the loop driving head and may inhibit the ability to establish natural circulation flow in the primary loops.

## 6.2. Comparison of Phase IV Tests 4NOML3 (Nominal Transient With Distorted Core Power), 410AT3 (10-$cm^2$ SBLOCA Without HPI, ATOG Cooldown), and 410BD1 (10-$cm^2$ SBLOCA Without HPI, Steam Generator Blowdown)

These tests were initiated at approximately the same conditions. Subsequent to test initiation only Test 4NOML3 exhibited a continuous depressurization trend as a result of having HPI available (See 1, Figure 6.11). The other two tests exhibited repressurization trends (See 2, Figure 6.11) as a result of the unavailability of HPI. When some form of steam generator heat transfer was established, the primary system pressure also decreased for Tests 410AT3 and 410BD1 (See 3, Figure 6.11).

The nominal test then established a leak-HPI equilibrium condition (See 4, Figure 6.11), while the two tests without HPI eventually depressurized to the LPI setpoint, approximately 200 psia (See 5, Figure 6.11). The LPI actuation rapidly increased the primary system inventory, however, the lack of a sufficient temperature gradient between the hot leg and the steam generator primary prevented the establishment of a positive driving head. Thus, natural circulation was not established and the primary system repressurized for both tests where HPI was not available.

The results of these tests indicate that, under the conditions experienced on the MIST facility, LPI by itself cannot establish natural circulation and the primary system will experience repressurization cycles.

Had HPI been available after the actuation of LPI in these two tests (410AT3 and 410BD1), complete refill of the primary system may have occurred and the subsequent heatup may have established a sustained natural circulation condition. Additionally, as discussed previously in Section 6.1, consideration should be given to the reduction of the core power augmentation for ambient heat losses. The reduced power may aid the refill process and the potential for the establishment of natural circulation may be enhanced.

The potential for removing energy from the steam generators was limited for Tests 410AT3 and 410BD1 after completion of the ATOG cooldown and blowdown phases. After the completion of these phases of the tests the steam generator secondary pressures were very low (See 1, Figures 6.12 and 6.13) and, therefore, the ability of the operator to initiate a cooldown or a blowdown of the steam generators is significantly limited. Consideration should be given to allow repressurization of the steam generators subsequent to the loss of primary-to-secondary heat transfer, thereby increasing the potential for removing energy from the steam generators when primary-to-secondary heat transfer is re-established.

The primary and secondary pressures for Tests 4NOML3 and 410BD1 are compared on Figures 6.14 through 6.16. The test termination time limits the comparison of these two tests. The primary system pressure response indicates that a continuous addition of liquid inventory is required to result in an essentially decreasing primary system pressure trend. Therefore, the use of HPI accomplishes this trend; however, LPI alone results in intermittent inventory addition and repeated repressurization cycles that are controlled by the leak size and the core power. Had a decay heat system been simulated on the MIST facility, the depressurization of both tests may have been enhanced. However, plant-typical fluid conditions that permit the startup of the decay heat system were not attained prior to test termination.

## 6.3. Comparison of Phase IV Test 4100B2 (100 $cm^2$) and Phase III Test 320202 (50 $cm^2$)

The primary system pressure response of the Phase III and IV transient tests that employed larger leak sizes exhibited similar trends (Figure 6.17). Each test experienced the same phenomena, with the major difference being the timing when the events occurred.

The scaled 100-$cm^2$ leak depressurized more rapidly than the scaled 50-$cm^2$ leak (See 1, Figure 6.17). Both tests experienced a period of reverse heat transfer (secondary-to-primary), which was then followed by an ATOG blowdown (50 psi/min) of the steam generator secondary that resulted in a primary system depressurization (See 2, Figure 6.17).

The Phase IV test incorporated both HPI and LPI, whereas the Phase III test had only HPI available. As the primary system depressurized, due to the steam generator blowdown, a lower minimum primary system pressure was attained in Test 4100B2 and LPI actuated. However, the 100-$cm^2$ leak test then repressurized and attained essentially the same pressure as the 50-$cm^2$ leak test (See 3, Figure 6.17).

The Phase III 50-$cm^2$ leak test achieved a leak-HPI equilibrium condition and, similarly, the 100-$cm^2$ leak test achieved a leak-HPI and/or LPI equilibrium condition as the primary system pressure for these tests converged.

Steam generator A and B secondary side pressure response for these two tests also showed similar trends (Figures 6.18 and 6.19), however, the Phase IV test exhibited a more symmetric behavior between steam generators A and B.

Both tests were terminated prior to the complete refill of the primary system. If future testing is performed it should consider extending the test duration until complete refill of the primary system occurs and natural circulation is established in both loops.

## 6.4. Comparison of Phase IV Station Blackout Test (4SB011) and Phase III Mapping Test With HPI Inactive (3004CC)

These tests were very similar in trend and phenomena observed through the flow interruption and the subsequent repressurization phase. The major differences between these tests were the initial conditions, core power, leak size and leak location. Test 4SB011 was initialized at a higher pressure (2000 psia) than Test 3004CC (1750 psia). The initial decay heat power for Test 4SB011 was greater than that for Test 3004CC (3.5% versus 1%). Test 4SB011 had two scaled 0.25-$cm^2$ leaks in the reactor coolant pumps (one leak in pump A1 and another in pump B2) while Test 3004CC had a scaled 1-$cm^2$ leak in the lower downcomer-to-reactor vessel line. HPI was not available for either test.

The primary system pressure response (Figure 6.20) was similar for both tests, with the major difference being the timing of events. The difference in the timing of events was a direct result of the previously discussed differences in the test boundary conditions. Both tests experienced intermittent loop flow (Test 3004CC, See 1 and Test 4SB011, See 2 on Figure 6.20) prior to complete flow interruption (See 3 on Test 3004CC, and See 4 on Test 4SB011 of Figure 6.20).

Subsequent to flow interruption, the secondary side boundary conditions were altered for Test 4SB011 to investigate one possible procedure for mitigating a station blackout event. The results from these tests indicate that without steam generator control instrumentation and the imposition of a fixed AFW flow rate and steam relief capability, the potential for steam generator overfill exists. When hot leg heatups that are sufficient to establish natural circulation occur, primary-to-secondary heat transfer can result in rapid increases in the steam generator secondary side pressure (Figures 6.21 and 6.22) that can result in lifting the safety valves and discharging liquid through these valves. Based upon the results of these tests, further investigation of procedures to mitigate a station blackout event is required.

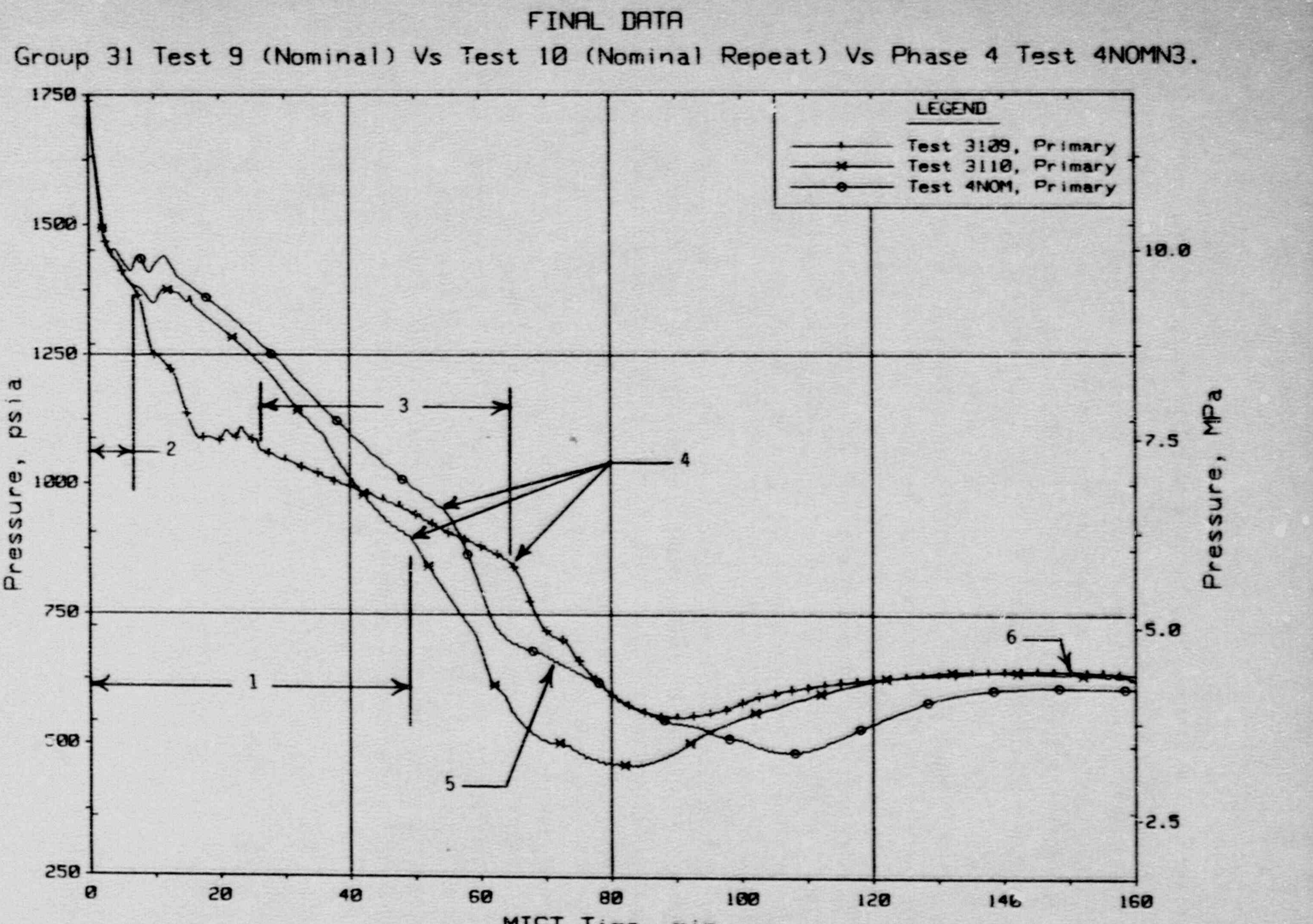



Figure 6.1 Primary System Pressures (GP01s)

Thu Sep 8 10:59:59 1986

34PSGP1

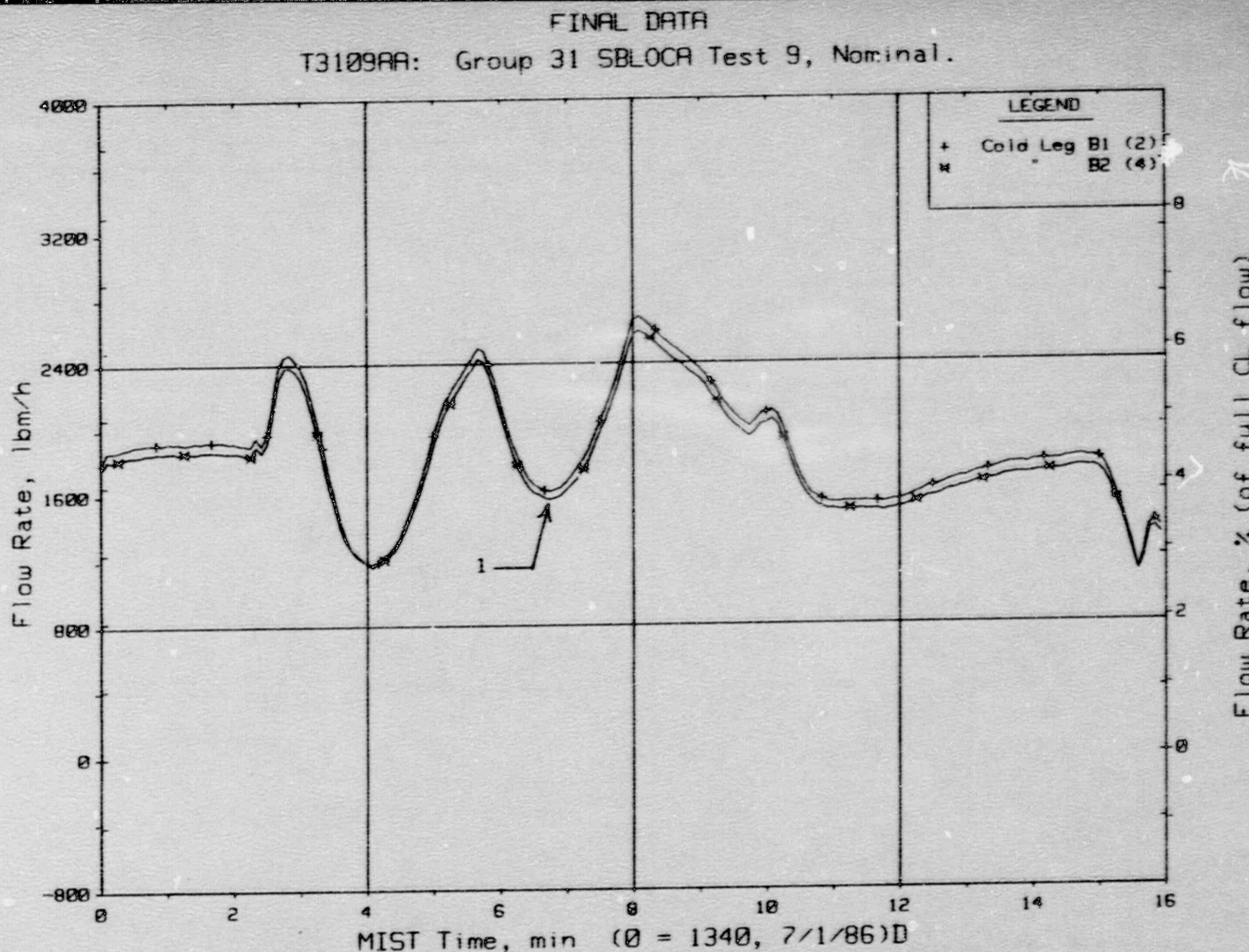



Figure 6.2 Loop B Cold Leg (Venturi) Flow Rates (CnVN20s)

PRFL6

Tue Sep 6 10:29:49 1988

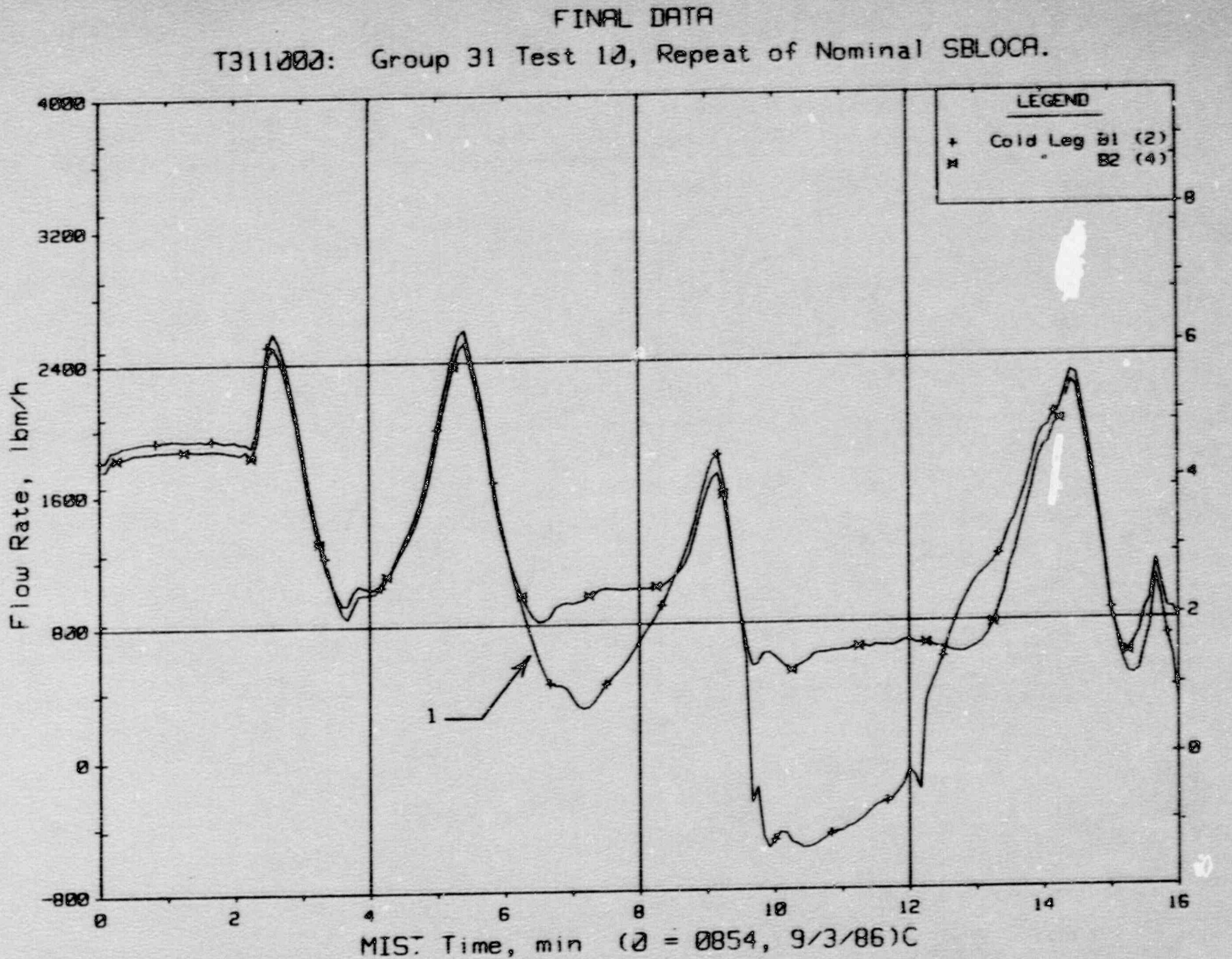



Figure 6.3 Loop B Cold Leg (Venturi) Flow Rates (CnVN20s)

PRFL6

Thu Sep 8 13:27:57 1988

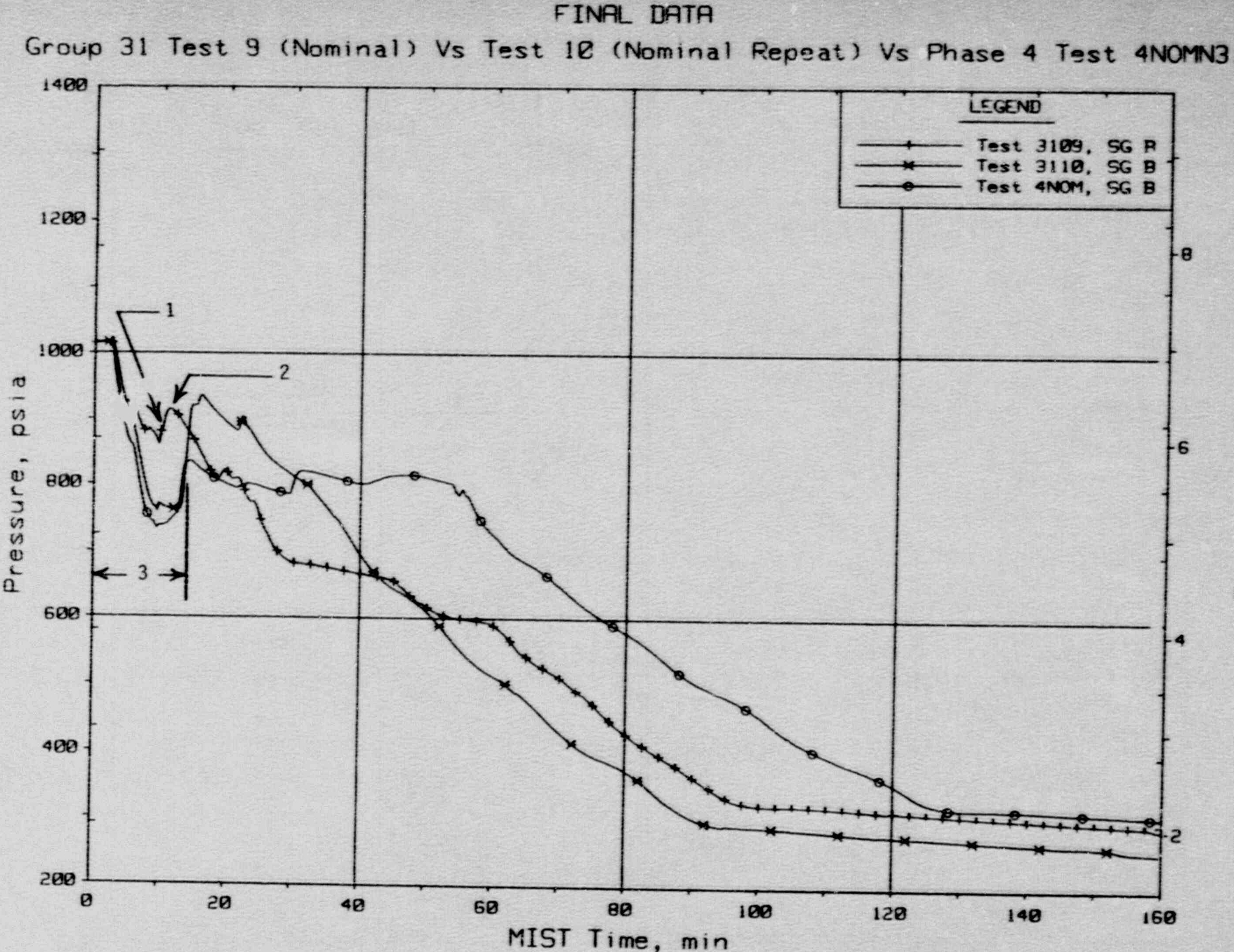



Figure 6.4 Secondary B System Pressures (GP01s)

Thu Sep 8 11:02:36 1988

34S2GP1

FINAL DATA

Group 31 Test 9 (Nominal) Vs Test 10 (Nominal Repeat) Vs Phase 4 Test 4NOMN3.

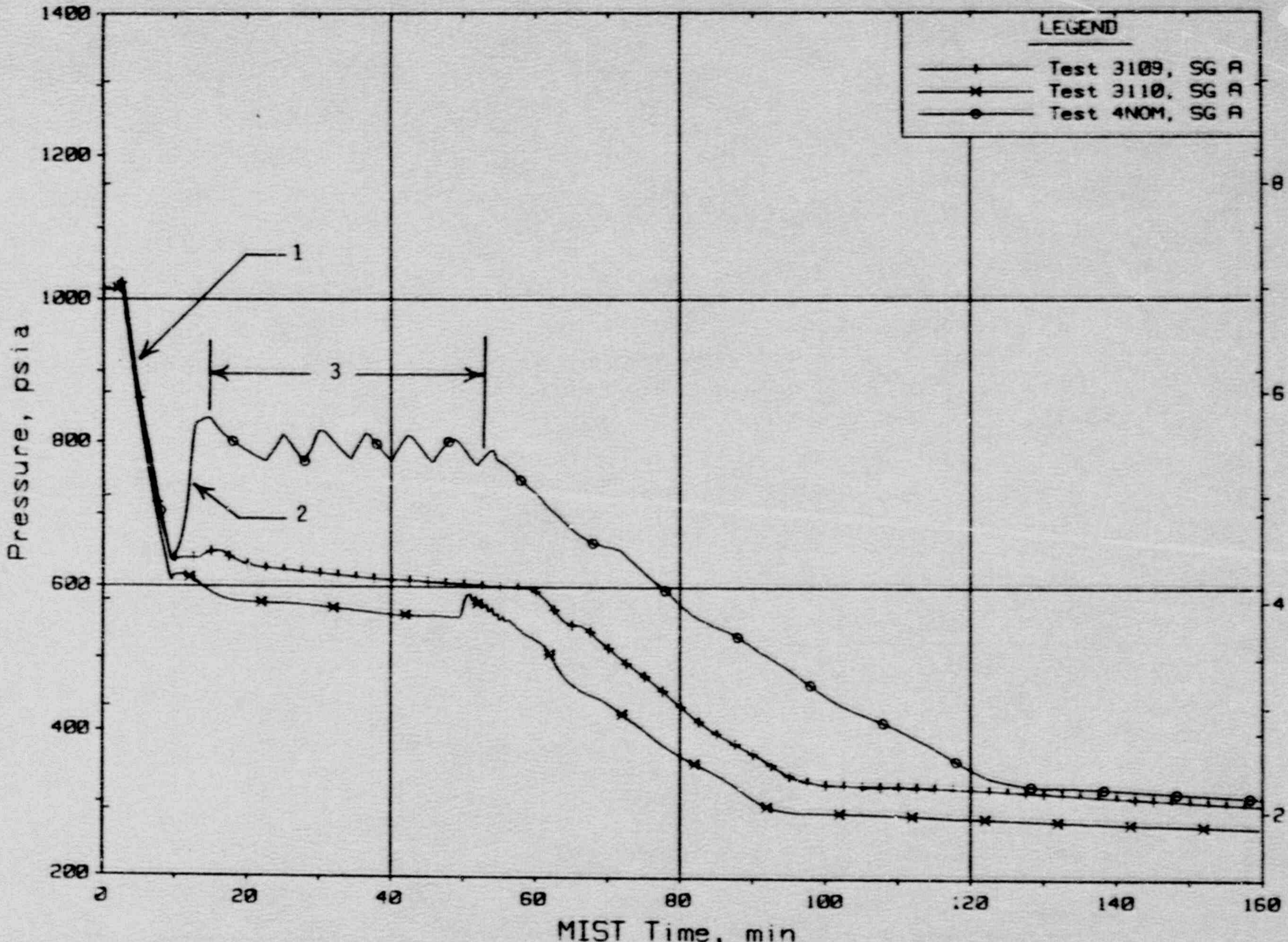



Figure 6.5 Secondary A System Pressures (GP01s)

Thu Sep 8 11:05:10 1988

3451GP1

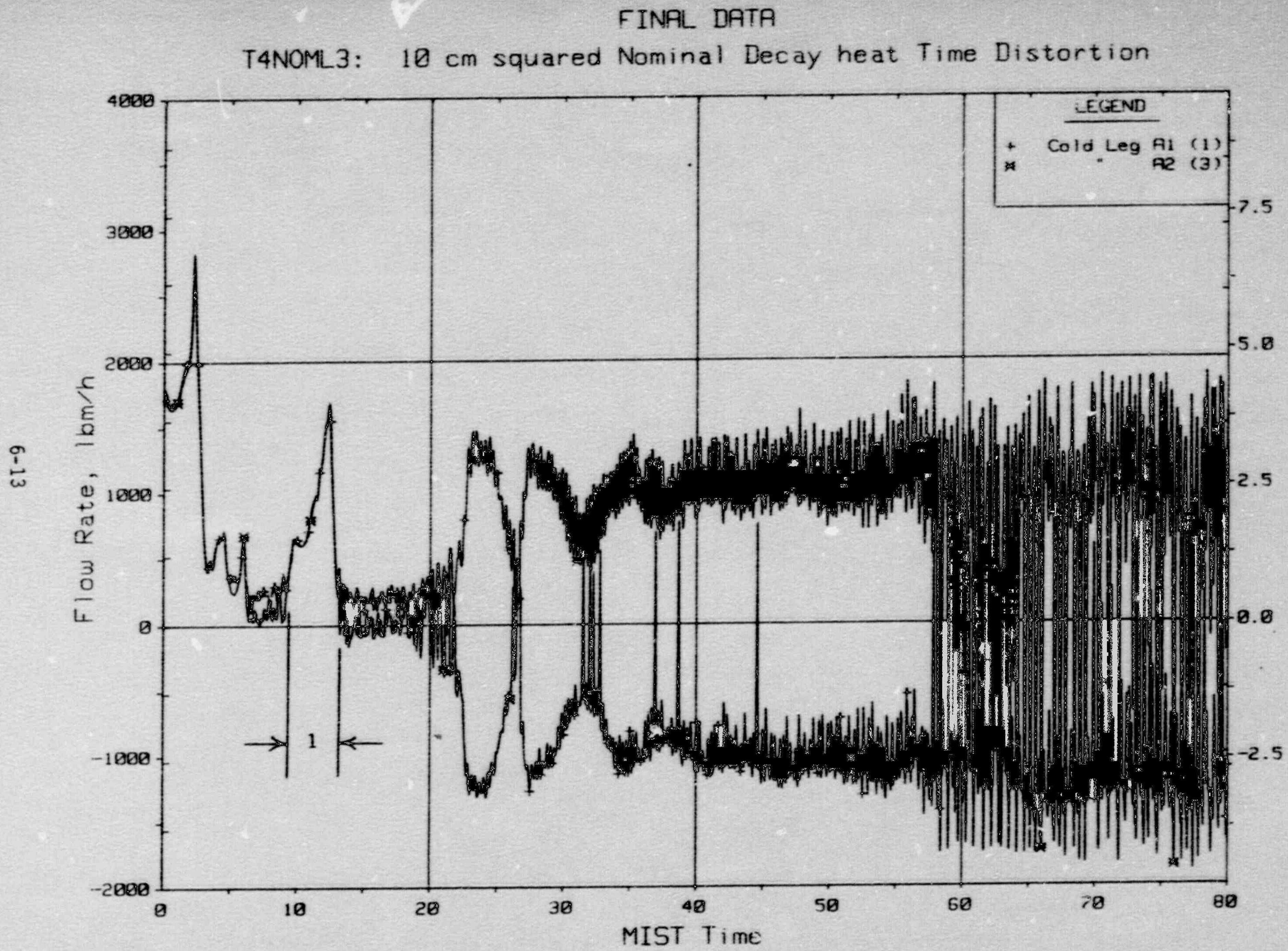



**Figure 6.6 Loop A Cold Leg (Venturi) Flow Rates (CnVN20s)**

Mon Nov 7 09:51:26 1988

PRFL5

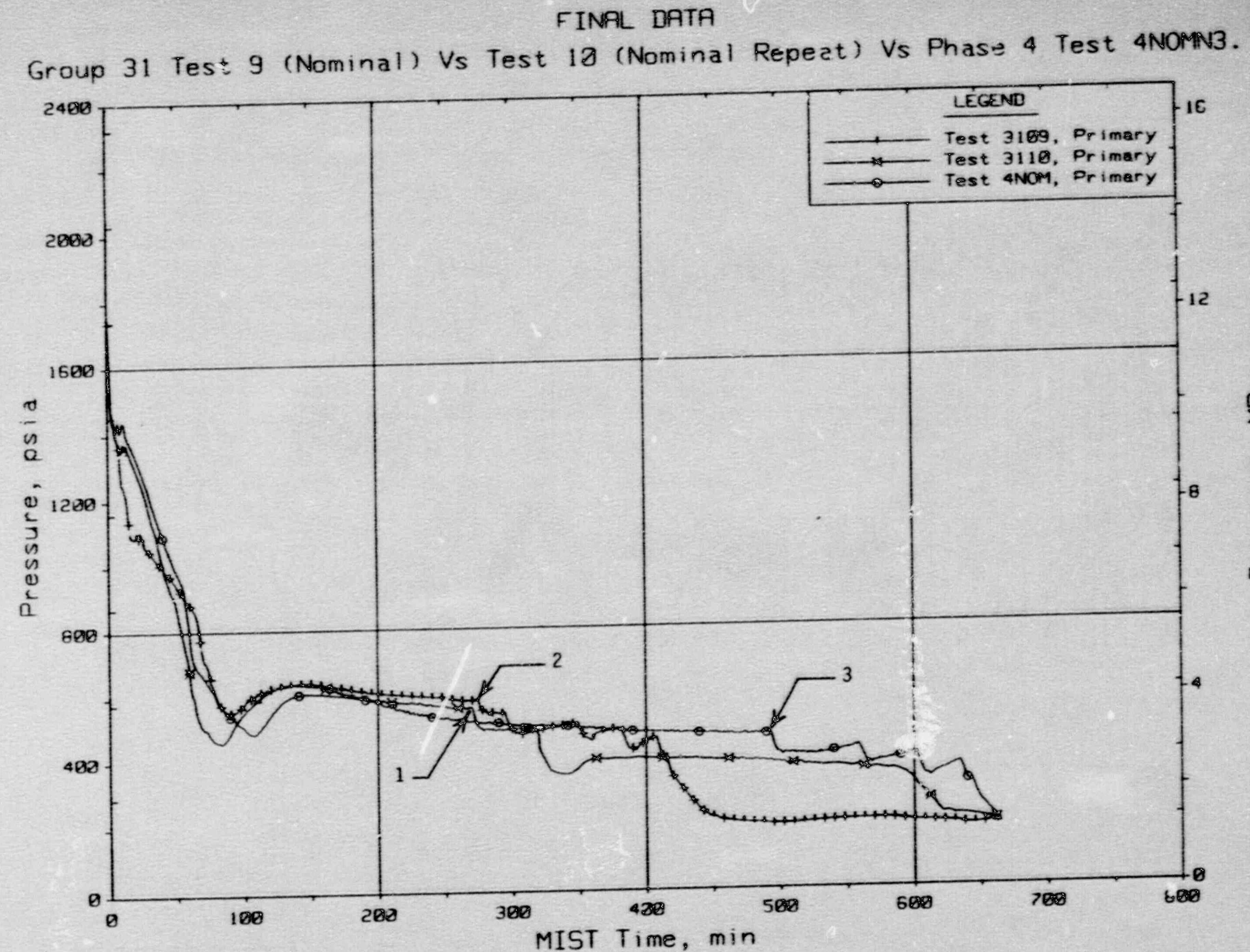



Figure 6.7 Primary System Pressures (GP01s)

34PSGP1

Thu Sep 8 11:19:48 1988

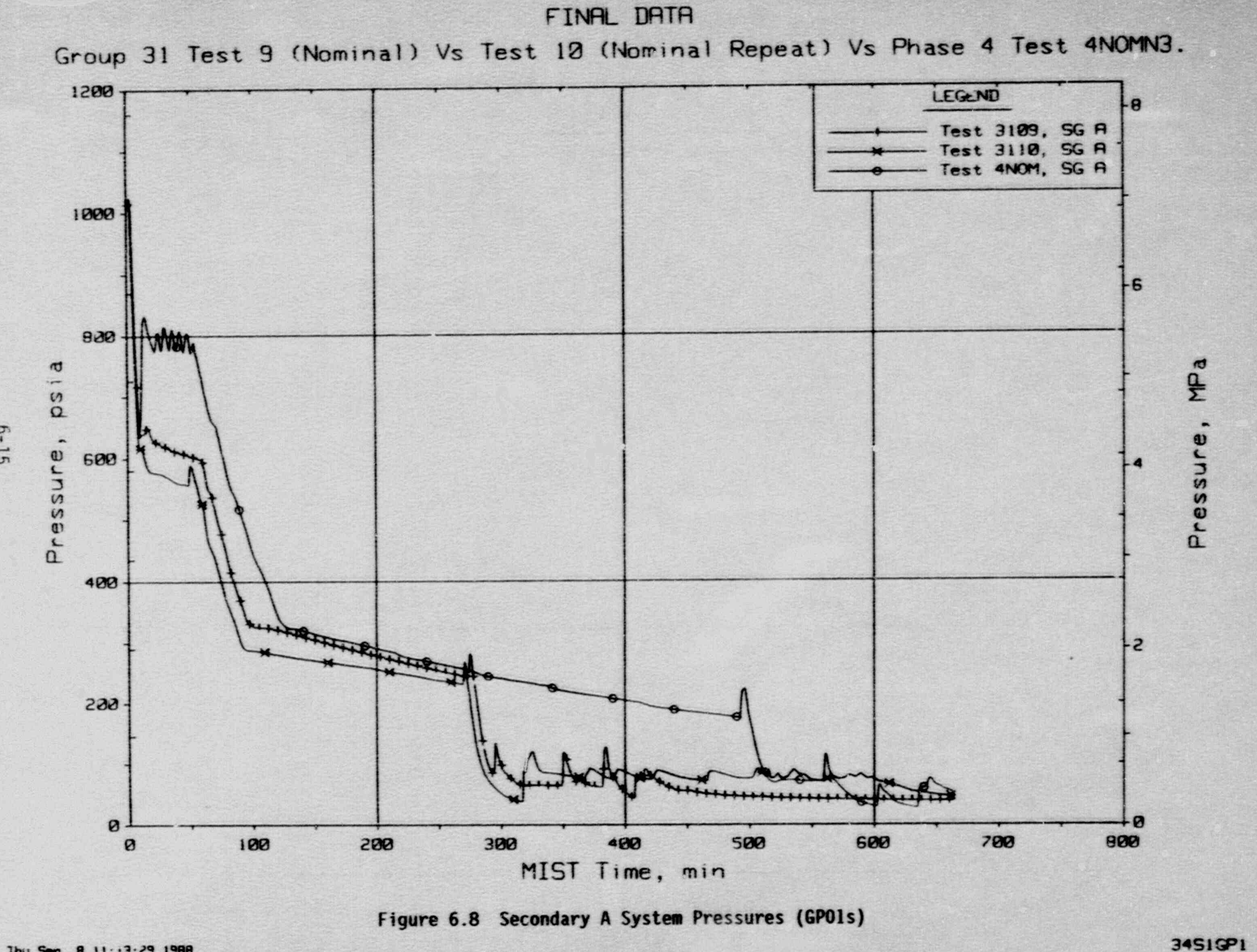



Figure 6.8 Secondary A System Pressures (GP01s)

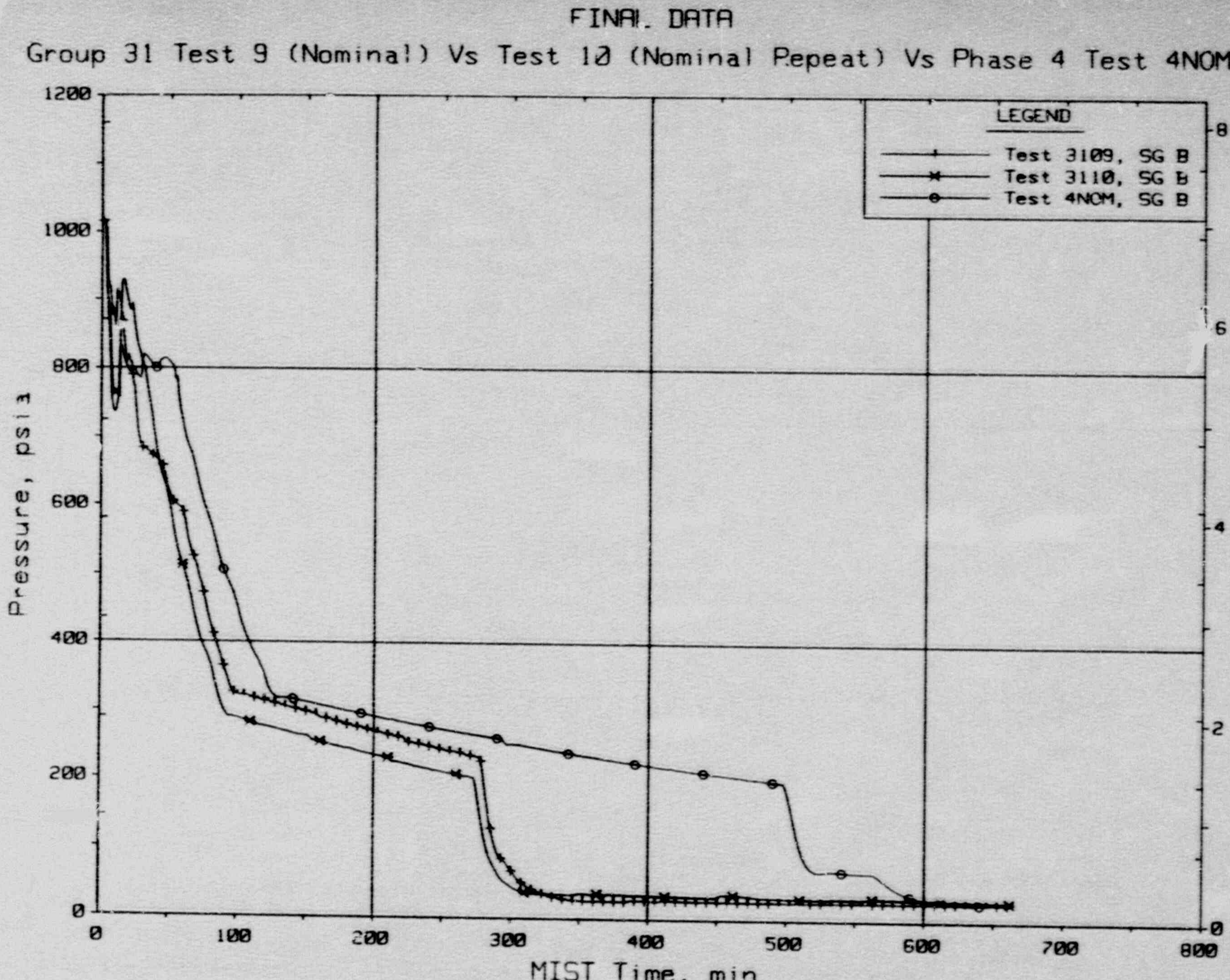



Figure 6.9 Secondary B System Pressures (GP01s)

Thu Sep 8 11:22:34 1988

34S2GP1

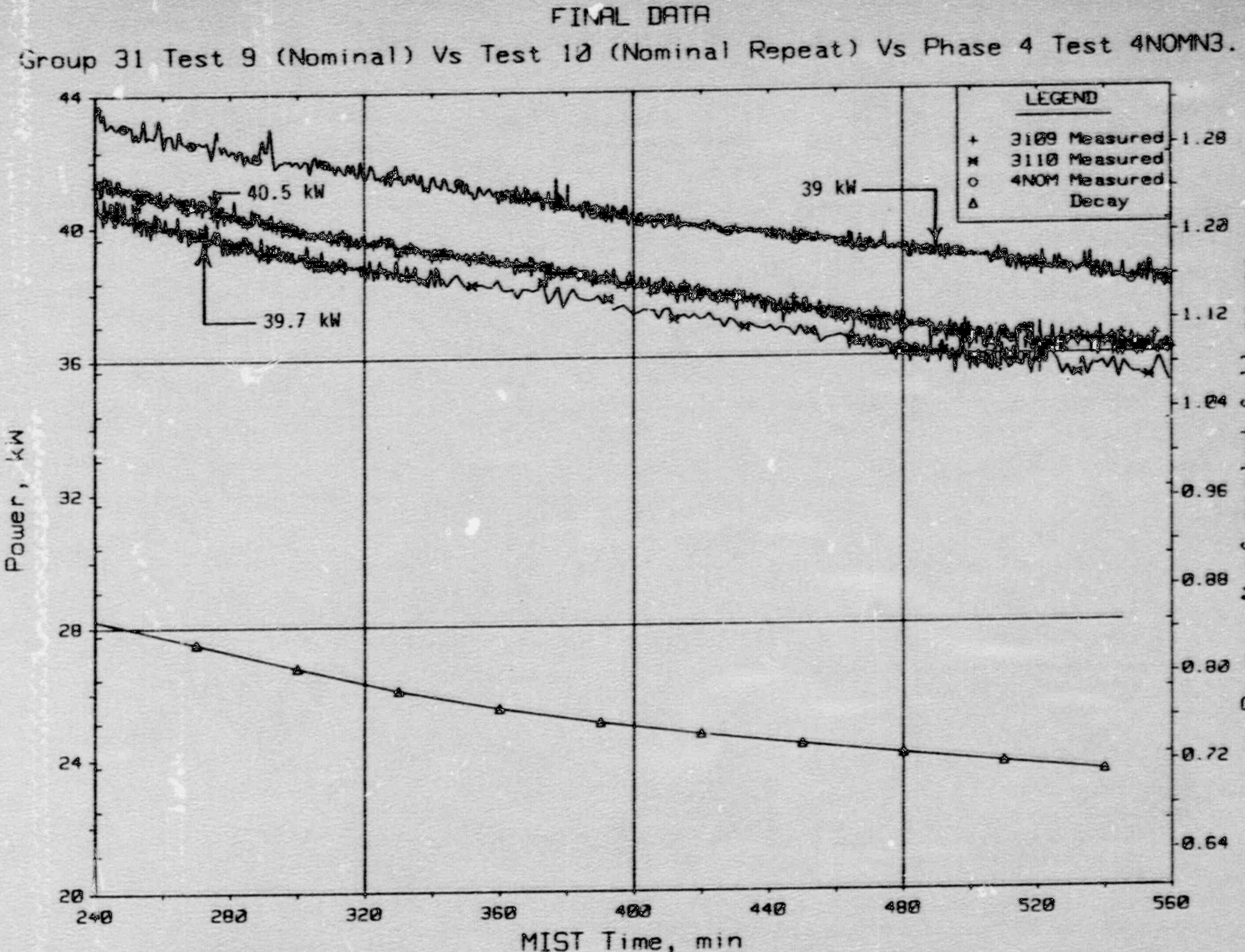



Figure 6.10 Core Power

34RVKW1

Thu Sep 6 11:41:41 1988

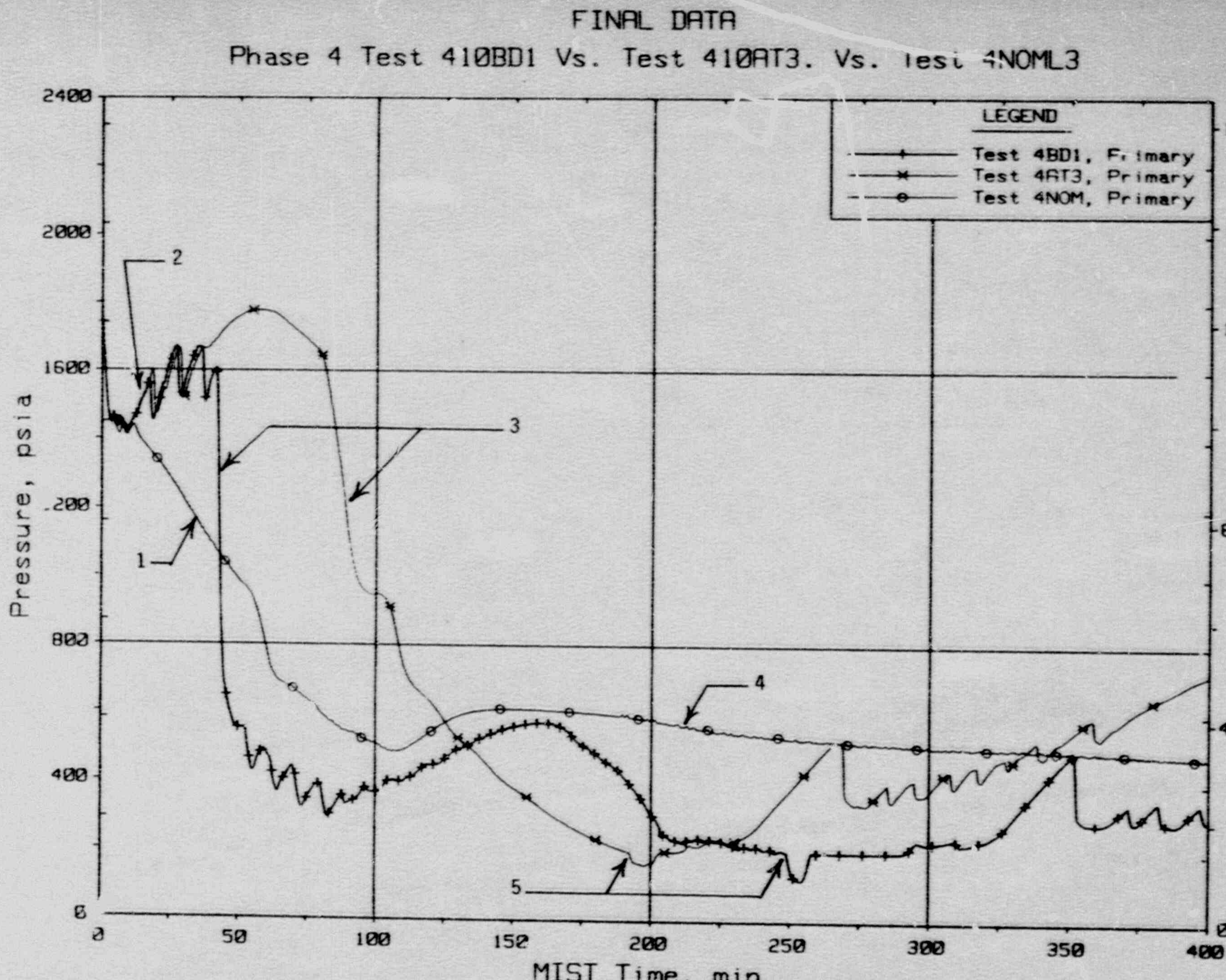



Figure 6.11 Primary System Pressures (RVGP01)

Thu Oct 13 11:55:55 1988

abnPSGP1

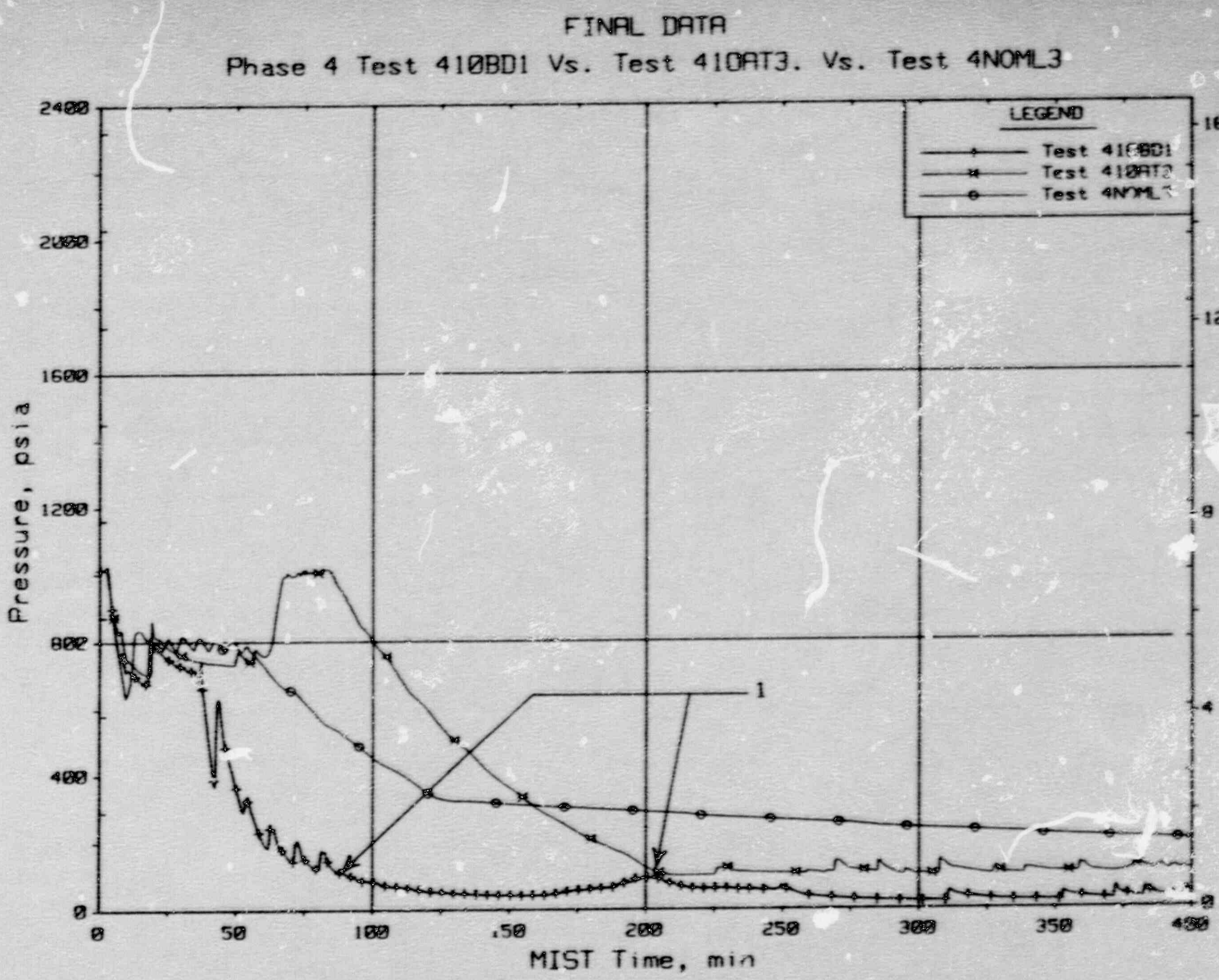



Figure 6.12 Steam Generator A System Pressures (S1GP01)

Thu Oct 13 12:01:35 1988

abnPSGP1

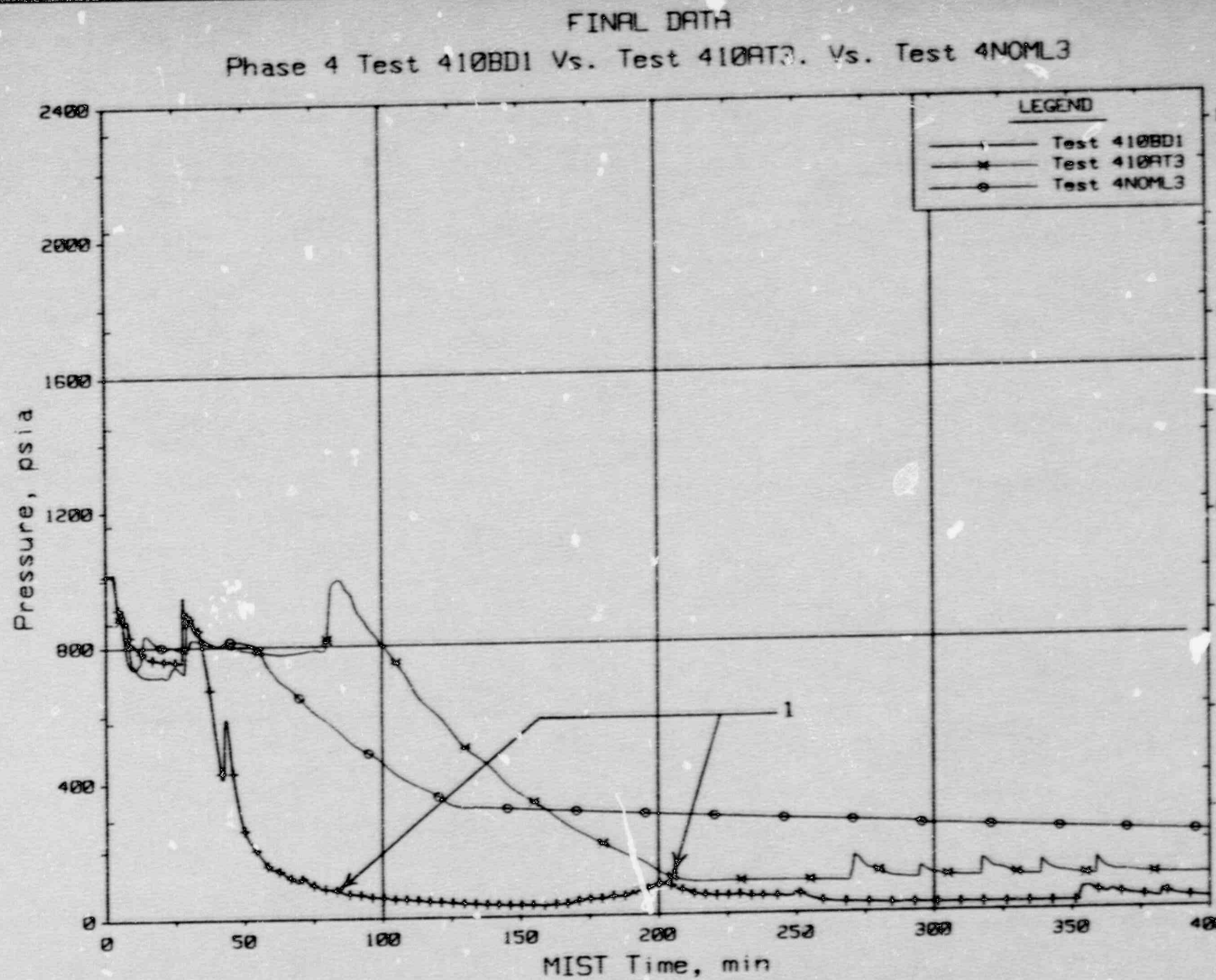



Figure 6.13 Steam Generator B System Pressures (S2GP01)

abnPSGP1

Thu Oct 13 11:58:46 1988

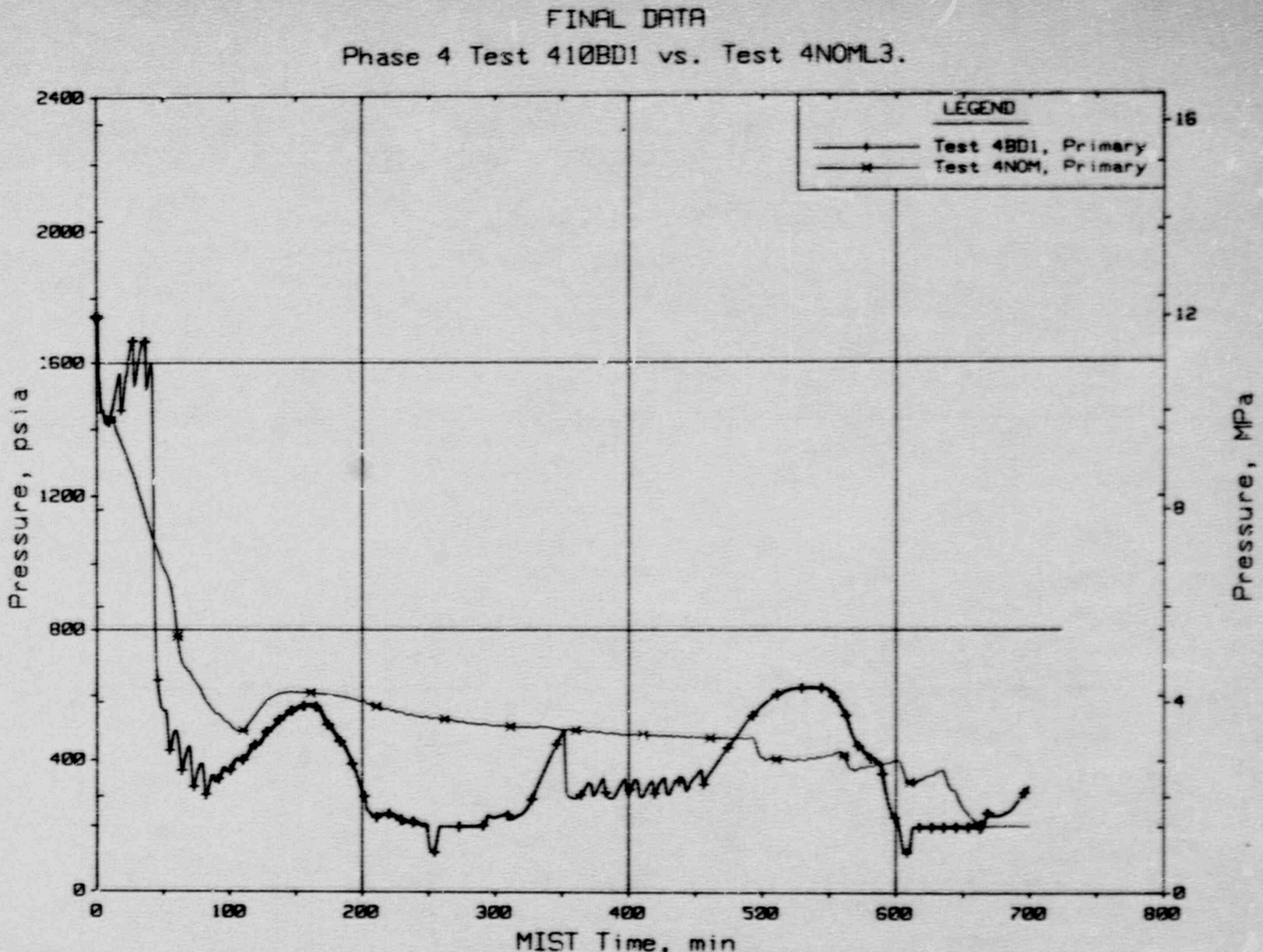



Figure 6.14 Primary System Pressures (GPOls)

Tue Nov 1 14:20:26 1988

abPSGP1

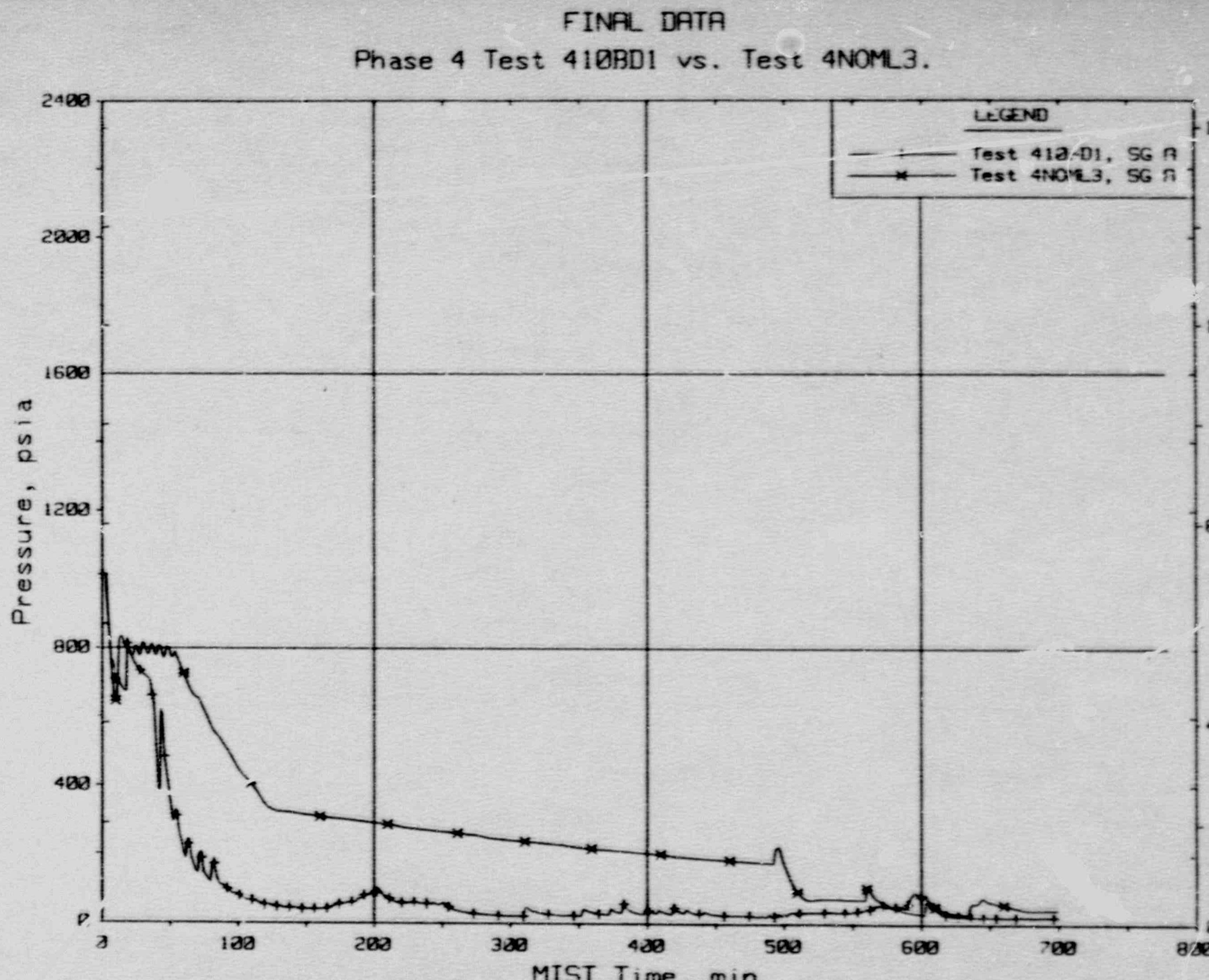



Figure 6.15 Secondary A System Pressures (GPOIs)

Thu Nov 3 15:09:04 1988

ahS1GP1

FINAL DATA

Phase 4 Test 41ØBD1 vs. Test 4NOML3.

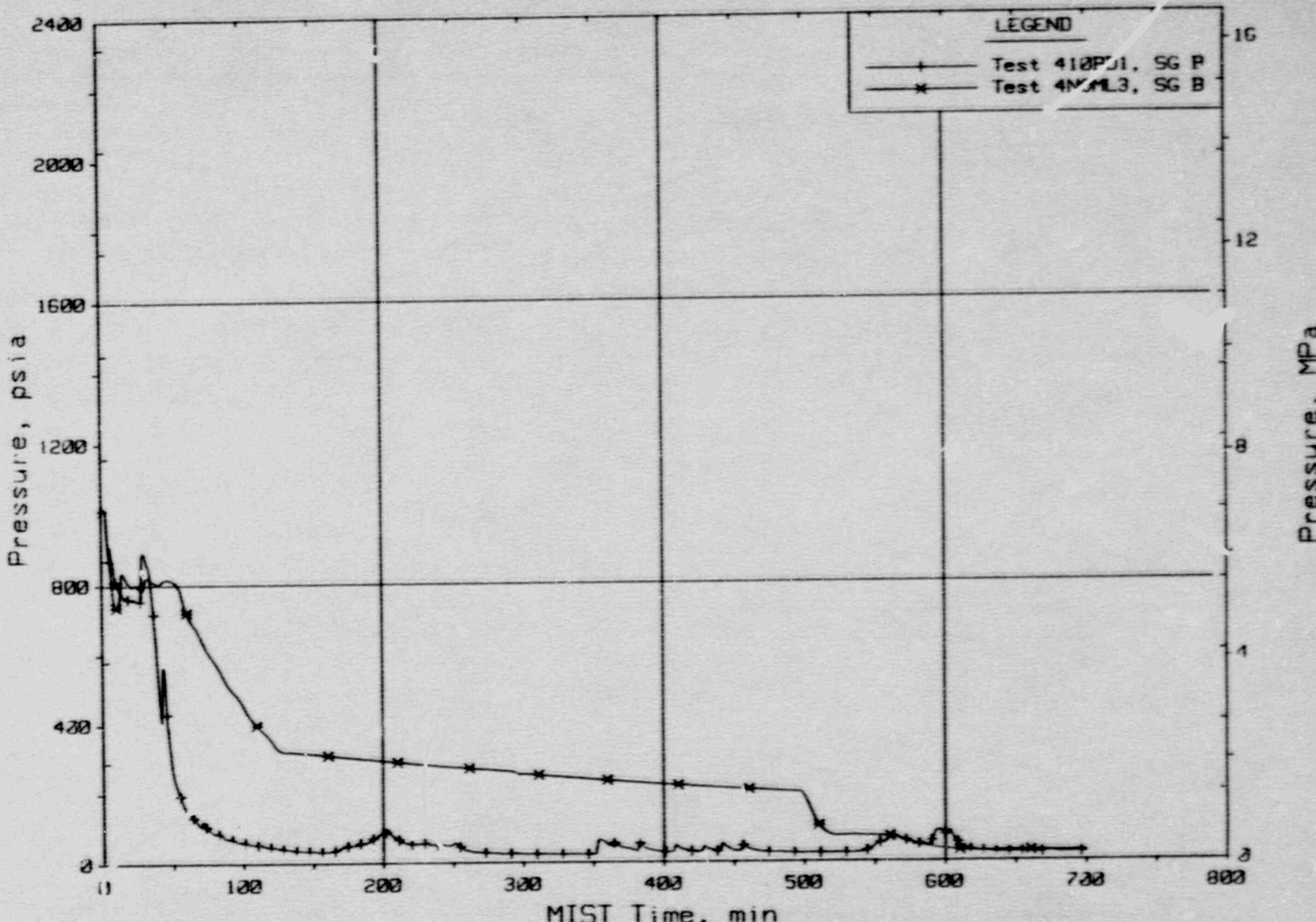



**Figure 6.16 Secondary B System Pressures (GPOls)**

Thu Nov 3 15:06:50 1988

abS2GP1

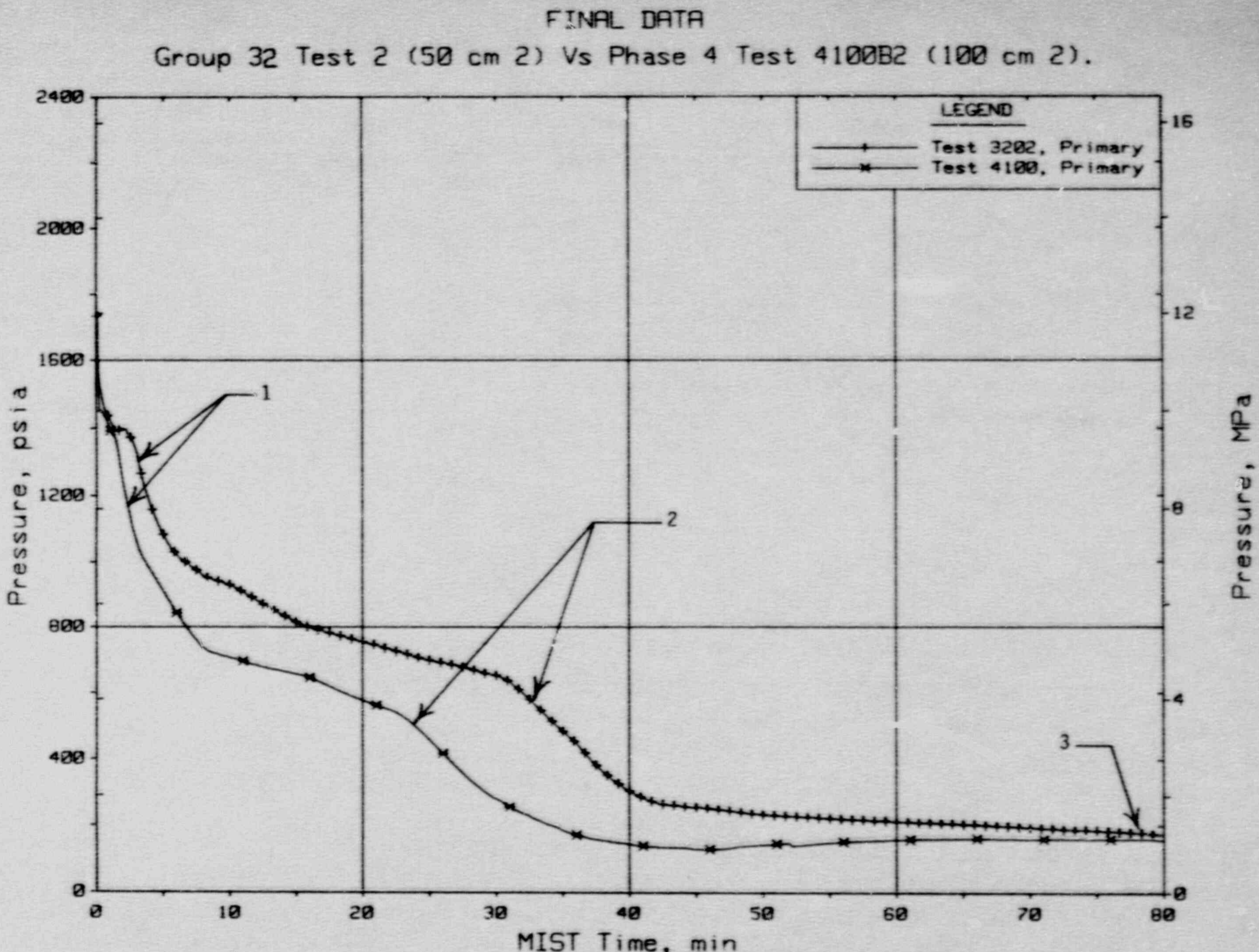



Figure 6.17 Primary System Pressures (GP01s)

Tue Oct 18 10:22:09 1988

43PSGP1

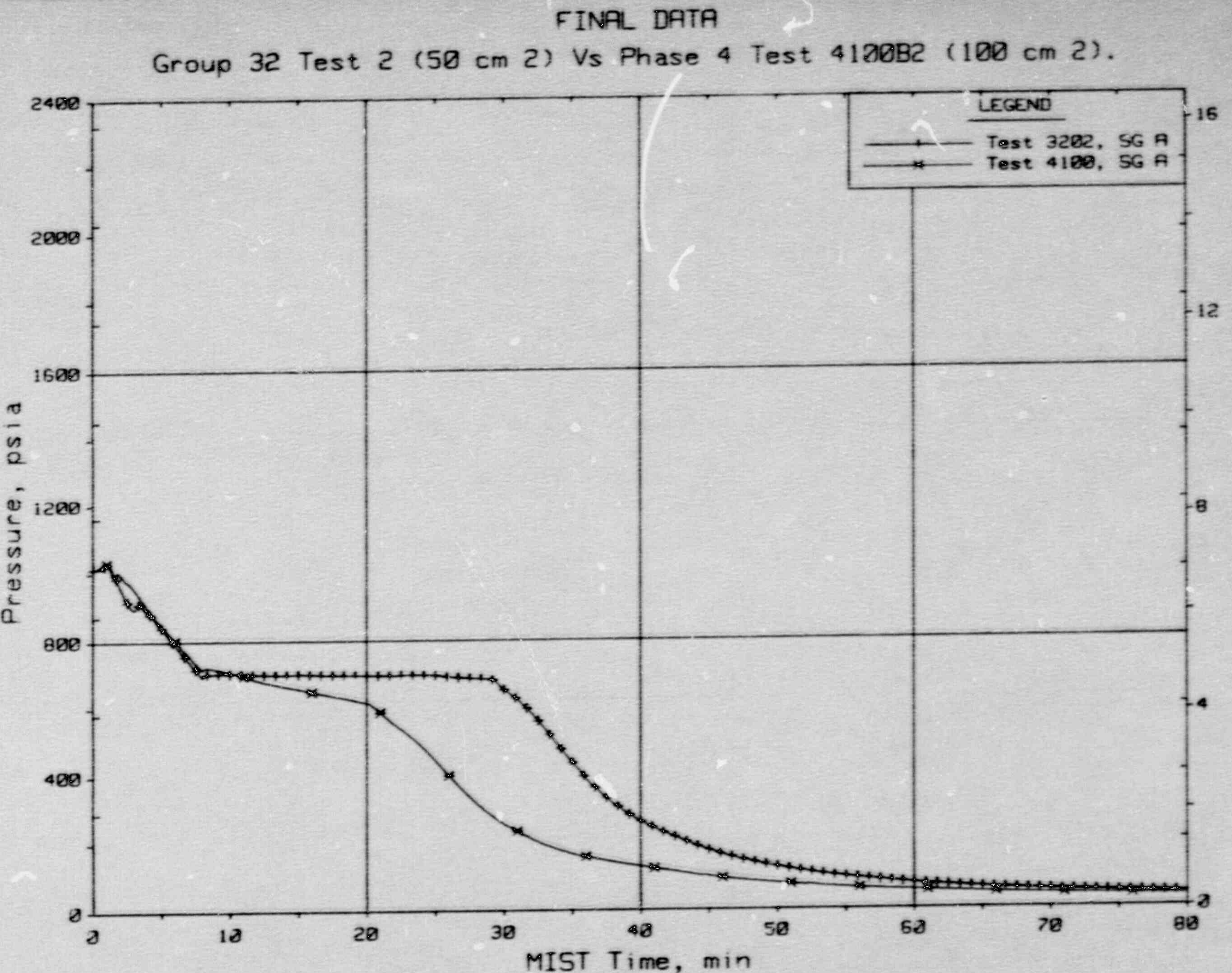


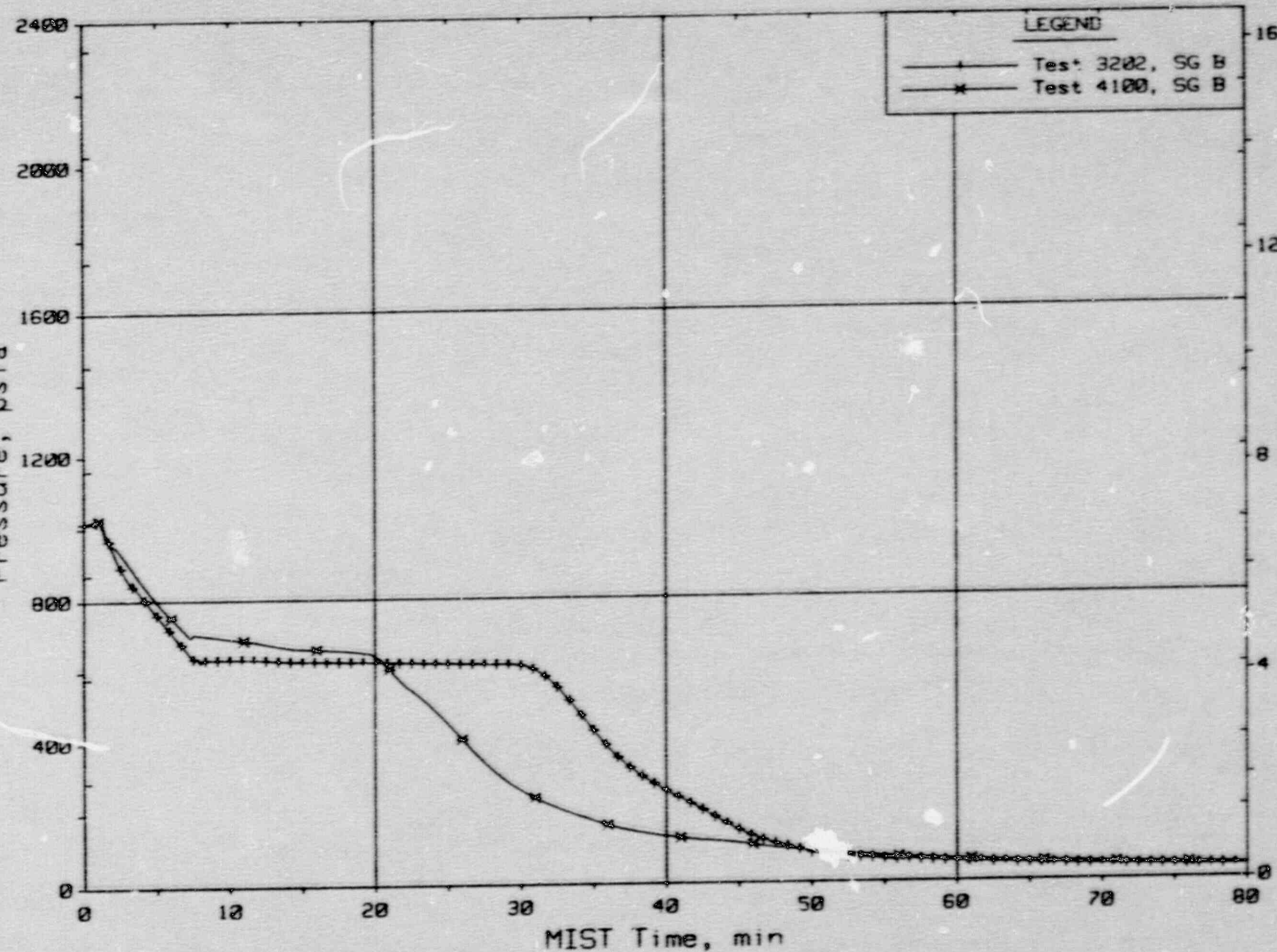

Figure 6.18 Secondary A System Pressures (GP01s)

43S1GP1

Tue Oct 18 10:36:00 1988

FINAL DATA

Group 32 Test 2 (50 cm 2) Vs Phase 4 Test 4100B2 (100 cm 2).




92-6

Figure 6.19 Secondary B System Pressures (GP01s)

43S2GP1

Tue Oct 18 10:39:41 1988

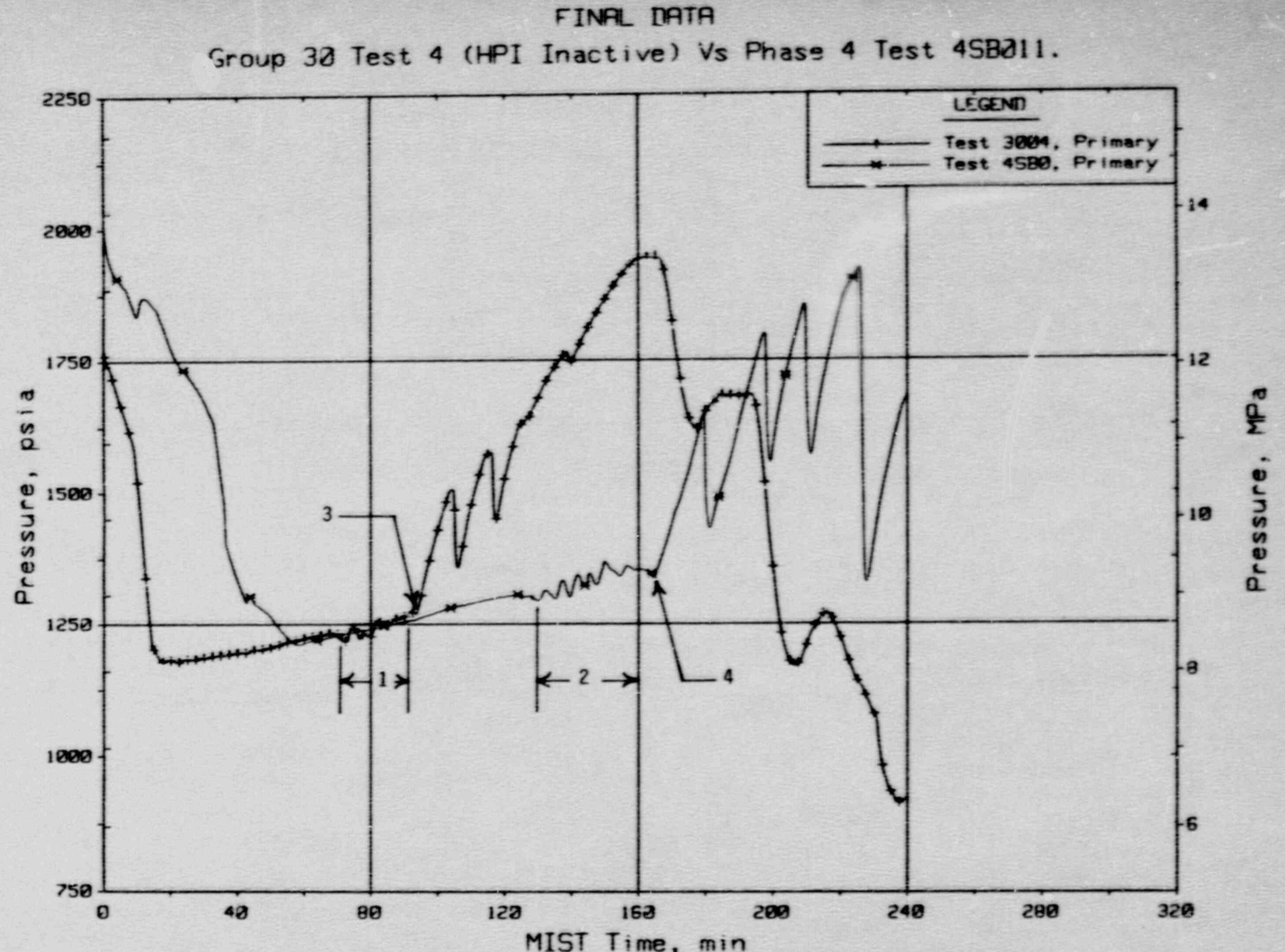



Figure 6.20 Primary System Pressures (GP01s)

Mon Oct 17 10:34:04 1988

43PSGP1

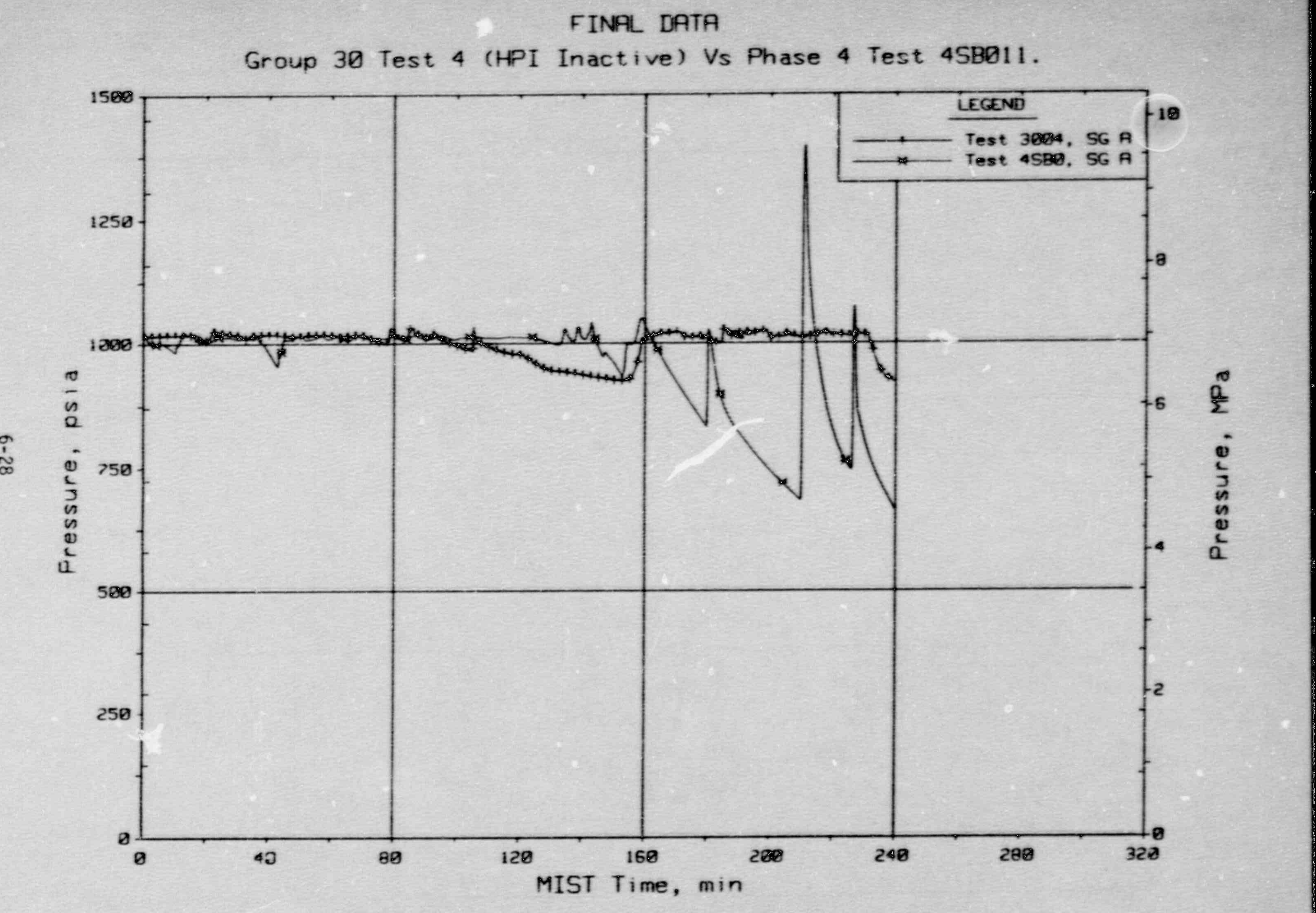
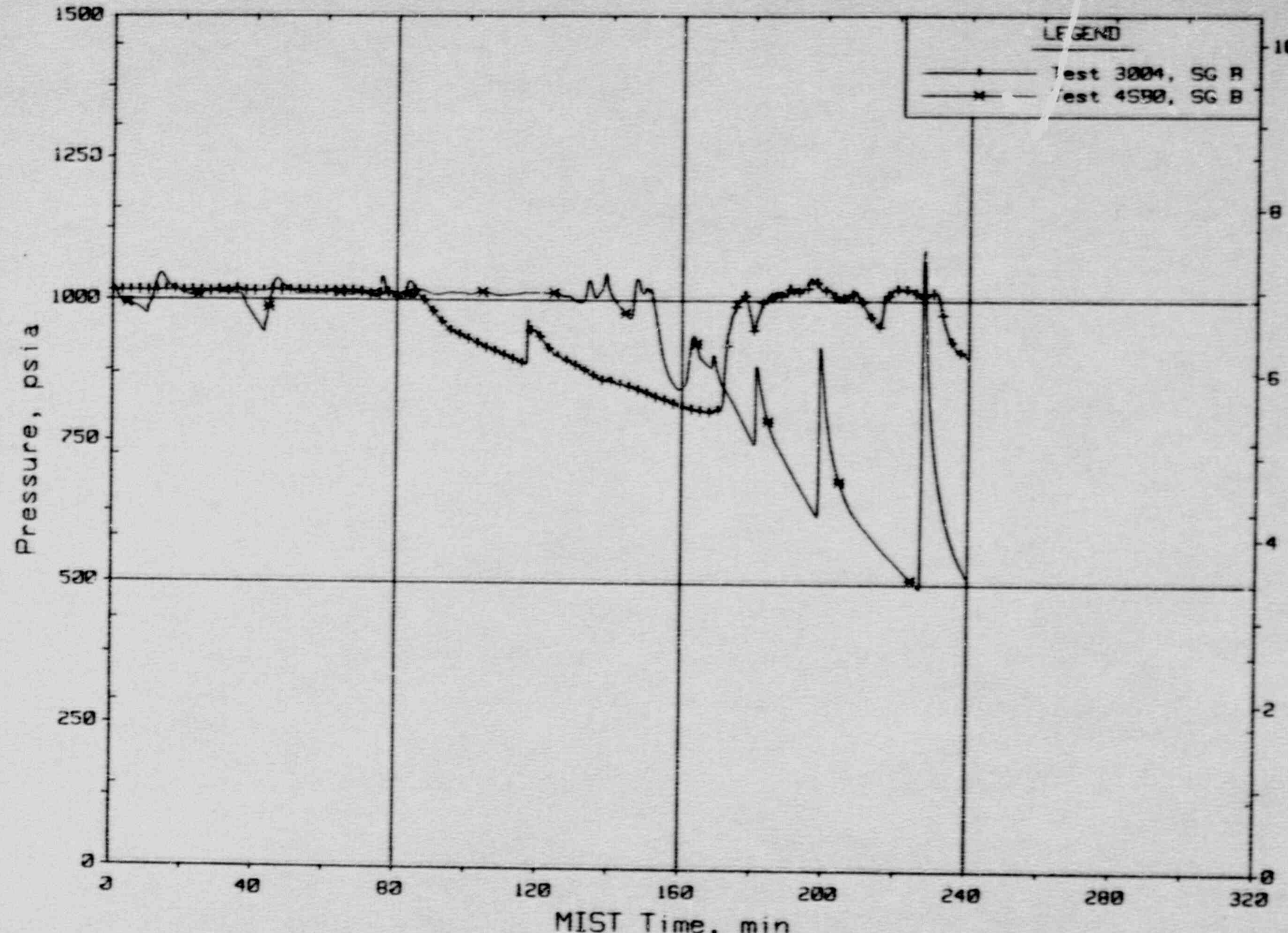



Figure 6.21 Secondary A System Pressures (GPOIs)

FINAL DATA

Group 30 Test 4 (HPI Inactive) Vs Phase 4 Test 4SB0i1.




C-79

Figure 6.22 Secondary B System Pressures (GP01s)

Mon Oct 17 10:51:10 1988

4352GP1

# 7. SUMMARY

The MIST Phase IV Test Program complemented the Phase III Test Program by providing additional insight on SBLOCA transient response and phenomena. Each of the Phase IV tests provided data that can be used for computer code benchmarking purposes. The Phase IV Test Program also provided:

- Information on a larger break size (100 $cm^2$)
- Performance characteristics of the model 19-tube OTSG using main feedwater and auxiliary feedwater
- Transient response for a simulated station blackout event
- Valuable experience in understanding the necessity to precisely establish the primary and secondary boundary conditions when actual plant transient simulations are attempted on a model test facility such as MIST.

A number of the MIST Phase IV tests employed a simulated LPI system. These tests indicated that actuation of the LPI system resulted in a rapid but incomplete refill of the primary system. With only LPI available (HPI unavailable) natural circulation cooldown was not established and repeated primary system repressurizations occurred.

The MIST Phase IV tests, including the nominal test (4NOML3) with HPI, highlighted the similarity of the flow interruption phenomena with that observed for the Phase III Mapping Tests (Group 30). The flow interruption phenomena were observed to be a direct result of the loss of a positive natural circulation driving head. The loss of the positive driving head was caused by increases in the primary loop flow rate, which result from various reasons, and thus a fluid density distribution in the reactor vessel and hot leg(s) results that either decreases primary loop flow or cannot maintain primary loop flow. Core region fluid was therefore diverted to the cold legs via the reactor vessel vent valves and the downcomer, thus further diminishing or eliminating the ability of re-establishing a positive natural circulation driving head in the primary loop. These occurrences eventually resulted in primary loop flow interruption, voiding of the cold legs, and the establishment of reverse (or intra-cold leg) flow in the cold legs.

The Phase IV tests also highlighted the significance of hot leg heatups to re-establish a positive natural circulation driving head and, thus, primary loop flow. As discussed in Section 2.2, the scaling criteria used for the MIST facility resulted in oversized hot legs, cold legs, and upper downcomer. The excess volume in the cold legs and the upper downcomer may have retarded the voiding of the cold legs. The excess volume in the hot legs retarded the hot leg heatup rate and, therefore, affected the establishment of a positive natural circulation driving head.

Therefore, the phenomena associated with flow interruption, the establishment of primary loop flow and, thus, the loss or establishment of primary-to-secondary heat transfer may have been affected by the oversized hot legs, cold legs, and upper downcomer. A reassessment of the scaling criteria and the effect of these oversized components on the transient response appears warranted.

The following sections provide a summary of the individual MIST Phase IV tests.

## 7.1. Test 4NOML3 -- Nominal Transient With Distorted Core Power

MIST Test 4NOML3 was a repeat of the MIST Phase III Nominal Test with modified post-trip core power and a reduced ATOG cooldown rate. In general, Test 4NOML3 was more similar to Test 311000 than to Test 3109AA. Slight differences in the timing of events occurred during the initial 150 minutes of these tests. The differences appear to be a result of the modified core power and reduced cooldown rate.

Test 4NOML3 established sustained natural circulation in loop A subsequent to refill. As a result of the loop A circulation, the primary system depressurized sufficiently to actuate LPI. The loop B hot leg riser and steam generator primary initially flashed, as a result of the depressurization, and then began to fill subsequent to the LPI actuation. The complete refill of loop B did not occur prior to test termination. Natural circulation flow was maintained in loop A and intra-cold leg flow was established in loop B prior to test termination.

The time distortion imposed on the core decay heat for Test 4NOML3 did not affect the typical small-break loss-of-coolant phenomena observed in the MIST test program. Only the timing of events was altered. During the refill of the primary system, the increased core power appeared to have lengthened the test time as a result of prolonging the refill process.

Core power augmentation, to account for uncompensated heat losses, should be decreased at some later time in these tests. The augmentation is based upon heat losses when the fluid temperatures are approximately 550F. As these tests progress, fluid temperatures decrease, therefore the heat losses also decrease. By decreasing the core power augmentation, perhaps as a function of temperature, the test duration times should decrease, the ability to refill the loops should be enhanced, and the potential for establishing natural circulation cooldown in both loops may increase.

## 7.2. Test 41OAT3 -- 10-cm$^2$ SBLOCA Without HPI, ATOG Cooldown

MIST Test 41OAT3 examined the effect of no HPI flow on the MIST Phase III Nominal Test. The response of this test differed significantly from that observed on the MIST Phase III or Phase IV Nominal Tests. The lack of HPI flow resulted in the voiding of the cold leg discharge pipes and the leak site early in the transient, which subsequently resulted in a repressurization of the primary system and significantly delayed the actuation of the ATOG cooldown.

The primary system inventory decreased and steam generator heat transfer occurred when the steam generator primary levels descended to the secondary pool elevation. The repressurization then terminated and a depressurization of the primary system occurred. This depressurization resulted in the actuation of the ATOG cooldown and the primary system continued depressurizing as it essentially tracked the secondary side pressure.

The primary system depressurized sufficiently to actuate LPI and a rapid increase of the primary system inventory occurred. However, primary loop flow was not established and the primary system repressurized, which terminated LPI flow. The primary system continued to lose inventory and repressurized until the steam generator primary level descended to the steam generator secondary level. Steam generator heat transfer was then established and a slight depressurization was observed. The test was terminated at this time.

This test highlighted the flashing of liquid in the cold leg suction pipes when the primary system was depressurizing and tracking the steam generator secondary pressure. The flashing of liquid in the primary system can occur during a depressurization (high depressurization rates increase the potential for flashing). The flashing of liquid can be a violent perturbation that could result in water hammer and high dynamic loads on the primary system components.

Test 410AT3 exhibited the same phenomena observed in the MIST Phase III Mapping Tests during the repressurization phases of the test.

### 7.3. Test 410BD1 -- 10-cm$^2$ SBLOCA Without HPI, Steam Generator Blowdown

MIST Test 410BD1 examined the effect of no HPI flow in conjunction with a more aggressive depressurization of the secondary system on a 10-cm$^2$ small-break LOCA transient. The actuation of a 50-psi/min blowdown of the steam generator secondary side 30 minutes after test initiation identified the inability of this action, by itself, to induce primary-to-secondary heat transfer. The primary fluid conditions must be such that a positive natural circulation driving head exists in the primary loop prior to the establishment of primary loop flow. When the steam generator blowdown was actuated, the primary fluid conditions did not yield a positive natural circulation driving head; therefore, primary-to-secondary heat transfer was not established. Subsequently, a hot leg heatup provided the necessary reduction in the hot leg fluid density, and a positive natural circulation driving head was established that resulted in primary loop flow. The primary loop flow established primary-to-secondary heat transfer and a rapid depressurization of the primary system occurred. This rapid depressurization caused flashing and superheating of primary system fluid.

When Test 410BD1 is compared to Test 410AT3 (ATOG 100F/h cooldown), the primary system pressure initially decreased more rapidly; however, due to the superheating of the leak site, the minimum pressure attained was considerably higher for Test 410BD1 and LPI did not actuate. The response of Test 410BD1 indicates that a reduced cooldown rate would permit the primary system to depressurize in a more controllable manner and minimize and perhaps eliminate flashing and superheating of primary system fluid. The elimination of these conditions may enhance the MIST test facility's ability to achieve natural circulation cooldown conditions.

Test 410BD1 exhibited the same phenomena as were observed in the MIST Phase III Mapping Tests and Test 410AT3 during the repressurization phases of the test. As discussed previously for Test 4NOML3, core power augmentation may have had a significant effect on the repressurizations observed during Test 410BD1. Through a reduction of the core power augmentation, the magnitude of the repressurizations may be reduced and the potential for establishing natural circulation cooldown may be enhanced.

The test provided useful information on the effects of no HPI, steam generator secondary side blowdown, PORV actuation, and reactor coolant pump bump. The ability to actuate LPI by means of the PORV actuation and the reactor coolant pump bump was also demonstrated.

## 7.4. Test 4100B2 -- Larger SBLOCA, 100 $cm^2$

MIST Test 4100B2 provided information and data for a larger break size, 100 $cm^2$ scaled. The test depressurized rapidly, initially as a result of the large leak size and then as a result of the steam generator blowdown, and actuated LPI. The primary system pressure remained below the LPI setpoint and leak/LPI equilibrium was established and maintained through the test termination. Complete refill of the primary system was not attained and natural circulation flow was not established prior to test termination. Subsequent to establishing leak/LPI equilibrium, the primary system pressure remained essentially constant and appeared to be governed by the fluid temperature in the hot legs. The hot leg fluid temperatures remained near saturation while the remainder of the primary system was generally experiencing a cooling trend.

The rapid depressurization obtained during this test highlighted the flashing of primary fluid and the contribution of metal heat to the superheating of primary fluid within various components of the primary system.

7.5. Test 4SB011 -- Station Blackout

MIST Test 4SB011 examined the thermal-hydraulic behavior of a station blackout transient and investigated one possible procedure for mitigating it. The response of this test was similar to the response observed for the Phase III Mapping Tests (in particular MIST Test 3004CC).

Initially, the primary system depressurized. When the core region saturated, the primary system repressurized. Loop flow continued on a decreasing magnitude trend until the cold leg discharge pipes began voiding. Intra-cold leg flow was established and cold leg flow interruption then occurred in a sequential manner, eventually resulting in complete flow interruption. The primary system then repressurized at a faster rate. The procedure used to mitigate the station blackout transient resulted in the fill of the steam generator secondary side, and during periods of primary-to-secondary heat transfer, secondary side pressure excursions occurred. When the magnitude of the pressure excursions repeatedly exceeded the facility design limit, the test was terminated.

Upon test termination, the primary system pressure appeared to be on an increasing trend while the secondary side pressures were on a decreasing trend.

The test highlighted the need to model the secondary side safety valves to prevent exceeding facility design limits. However, the procedure used for mitigating the station blackout transient resulted in the refill of the steam generator secondary side. Therefore, the safety valves (prototypical or model) must be capable of handling both steam and liquid discharge to prevent secondary side pressure excursions.

Had the test continued beyond the termination time, it appears that, based upon the trends of the primary and secondary pressures, the primary-to-secondary differential pressure design limit of the test facility would have been exceeded. Therefore, even if the secondary safety valves were modelled, the test also would have been terminated prematurely.

Consideration should be given to revising the procedure employed for mitigating the station blackout transient, the modeling of the secondary side safety valves in the MIST facility, and the reduction of core power augmentation as a function of time or temperature (as discussed previously for Test 4NOML3) prior to determining the disposition of the station blackout test.

## 7.6. Test 4SGPF2 -- Steam Generator Performance

Test 4SGPF2 provided steady-state steam generator performance data. The tests provided information regarding the effect of using main or auxiliary feedwater on the primary system natural circulation flow rate with various steam generator secondary levels.

The results obtained from these steady-state tests indicated that for the MFW steady-state tests, the primary system natural circulation flow rate was highly dependent upon the driving head established by the steam generator secondary side level. For the AFW steady-state tests, the primary system natural circulation flow rate was essentially independent of the driving head established by the steam generator secondary side level.

The injection of relatively cold AFW at a high elevation in the steam generator resulted in the establishment of a driving head that provided primary loop flow rates in excess of those obtained from the MFW steady-state tests over the entire range of steam generator secondary levels investigated.

Relatively symmetrical loop performance was observed for the MFW and AFW steady-state tests. A maximum variation of approximately 200 lb/h was observed between the loop A and loop B flow rates, thus attesting to the loop symmetry. Symmetrical performance was also observed between the steam generators as highlighted by similar primary and secondary fluid axial temperature distributions, feedwater and steam flow rates, and steam temperatures.

The MFW steady-state tests resulted in primary fluid axial temperature profiles that were similar for each instrumented steam generator tube. Therefore, similar flow rates were obtained in each steam generator tube.

The AFW steady-state tests resulted in primary fluid axial temperature profiles that varied dependent on the relative location of the tube with respect to the AFW nozzle. Therefore, the tubes that were wetted by the AFW spray had higher flow rates than the tubes that were not wetted by the AFW spray. The effect of the AFW, for the conditions tested, was observed to descend to approximately the 29-ft level in the B-J-H cell and the 32-ft level in the A-B-G cell, i.e., the effect was observed over approximately 20 ft of the tube length.

The data obtained from the MFW and AFW steady-state tests can be used to verify natural circulation driving heads, loop pressure drop, and the effect of wetting, when using AFW, on the primary flow distribution within the steam generator tubes.

## 7.7. Test 4CR3T2 -- Crystal River 3 Scaling Transient

MIST Test 4CR3T2 was intended to simulate a plant transient on the scaled MIST facility. The results from the test were to provide insight into the scaling compromises that are known to exist in the facility.

The response of this test differed significantly from the response of the plant transient. The primary and secondary pressure and the pressurizer level response indicated that the specified test boundary conditions did not represent the actual conditions that occurred during the plant transient. Therefore, a direct assessment of the ability of the MIST facility to simulate a plant transient cannot be made from the results of Test 4CR3T2.

The test initiation simulated a loss-of-offsite power event. The steam generator secondary side was blown down in excess of that experienced during the plant transient and the AFW flow rate was less than that which occurred at the plant. The inventory added to the primary system via HPI exceeded that which occurred during the plant transient. The effect of these differences resulted in the observed deviations in the primary and secondary pressure response that occurred during the initial approximately 15 minutes of the test. The excess inventory addition resulted in the filling of the pressurizer and repeated PORV actuations as the primary pressure stabilized at the PORV setpoint after approximately 15 minutes until test termination.

## 7.8. Test 4SEC02 -- Rancho Seco Scaling Transient

MIST Test 4SEC02 was intended to simulate a plant transient on the scaled MIST facility. The results from the test were to provide insight into the scaling compromises that are known to exist in the test facility.

The response of MIST Test 4SEC02 differed significantly from the response of the plant transient. The pressure response of both the primary and secondary systems indicated that the test boundary conditions did not represent the actual conditions that occurred during the plant transient. Therefore, a direct assessment of the ability of the MIST facility to simulate a plant transient cannot be made from the results of Test 4SEC02.

The test initiation simulated a loss of ICS power event. The steam generator depressurization rate was less than that experienced during the plant transient. The difference was apparently caused by the design of the MIST steam lines and the less-than-desired steam generator A AFW flow rate. The inventory added to the primary system was apparently greater than that which occurred during the plant transient. The excess inventory in conjunction with the lack of sufficient primary-to-secondary heat transfer resulted in a liquid full primary system and numerous PORV actuations, neither of which occurred during the plant transient.

## 8. REFERENCES


1. H. R. Carter and J. R. Gloudemans, "An Experimental Study of the Post-Small Break Loss-of-Coolant Accident Phenomena in a Scaled Babcock & Wilcox System," NUREG/CP-0058, Vol. 1, pp. 113-135. Proceedings of the U.S. Nuclear Regulatory Commission, Twelfth Water Reactor Safety Research Information Meeting, October 1984.

2. J. R. Gloudemans, "Simulation of Reactor Vessel Vent Valves," Paper presented at the 106th ASME Winter Annual Meeting, November 1985.

3. "Multi-Loop Integral System Test (MIST) Facility Specification," RDD:84:4091-01-01:01 (distributed November 1984, revision pending).

4. "Multi-Loop Integral System (MIST) Instrumentation -- Revision 3," RDD:84:4127-30-01:03, March 1987.

5. "MIST Phase IV Test Specifications," BAW-2020, April 1988.

6. G. O. Geissler and J. R. Gloudemans, "MIST Test Specifications," BAW-1894, Babcock & Wilcox, Lynchburg, Virginia, October 1985.

7. "Transient Assessment Program Report on Crystal River Unit 3 Reactor Trip on June 16, 1981," Report No. CR-3-81-10 (B&W No. 12-1127044-00), prepared by Florida Power Corporation.

8. "Trip Report Number 75, Reactor Trip on December 26, 1985, Loss of ICS Power," prepared by Grant Simmons, March 21, 1986.

9. "MIST Conversion Factors and Pump Characteristics," B&W Document No. 32-1149143-00, July 18, 1987.

10. "MIST Facility Specifications -- System Characteristics," B&W Document No. 86-11422637-00, p. 34, Babcock & Wilcox, Lynchburg, Virginia, May 16, 1983.

11. "MIST HPI," B&W Document No. 32-1149145-00, p. 24, Babcock & Wilcox, Lynchburg, Virginia, August 1, 1984.

12. "Trip Report #75, Reactor Trip on December 26, 1985, Loss of ICS Power," Prepared by Grant Simmons, Revised July 22, 1986.

APPENDIX A

Standard Plots

MIST Phase IV Test 4NOML3

Nominal Transient With Distorted Core Power

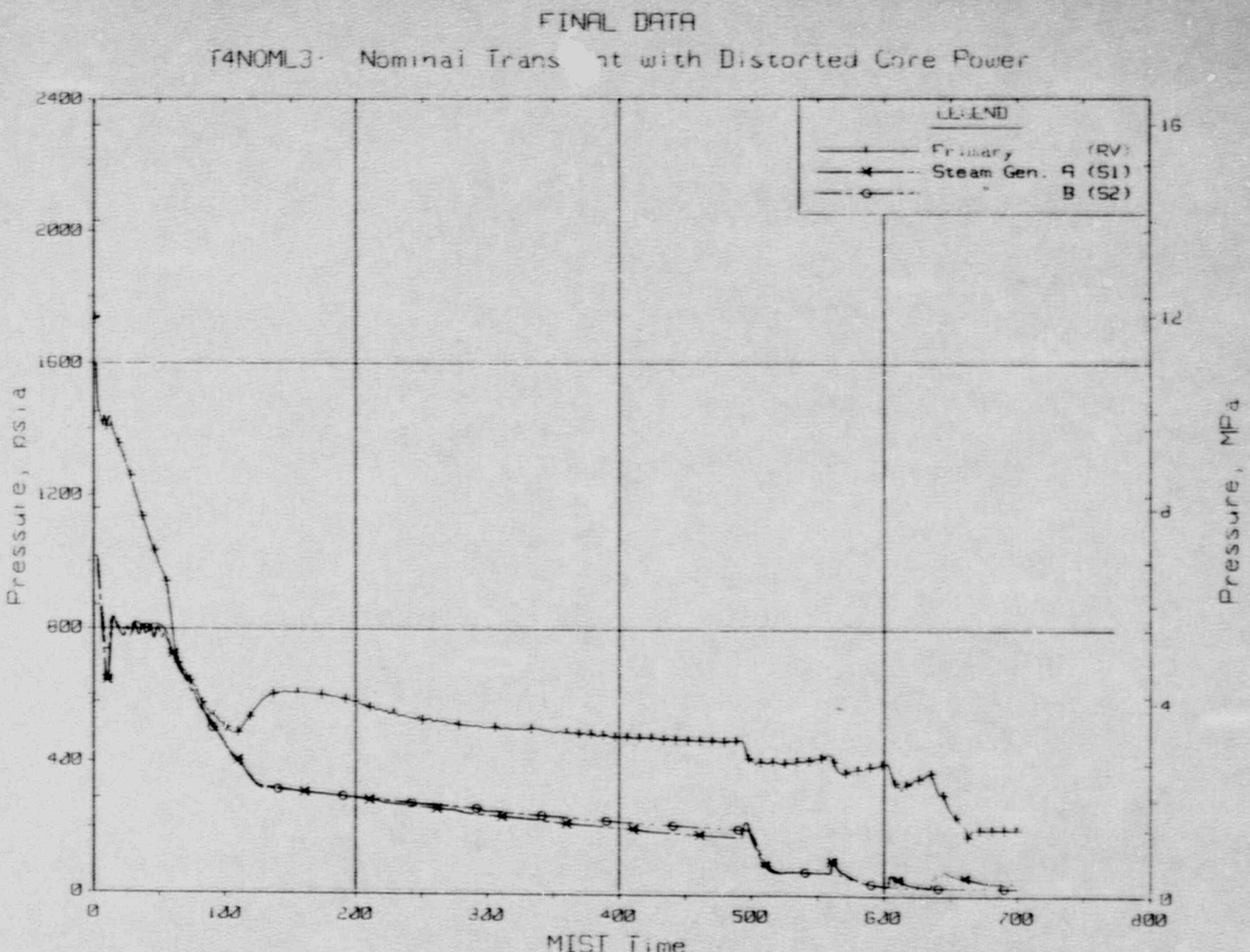
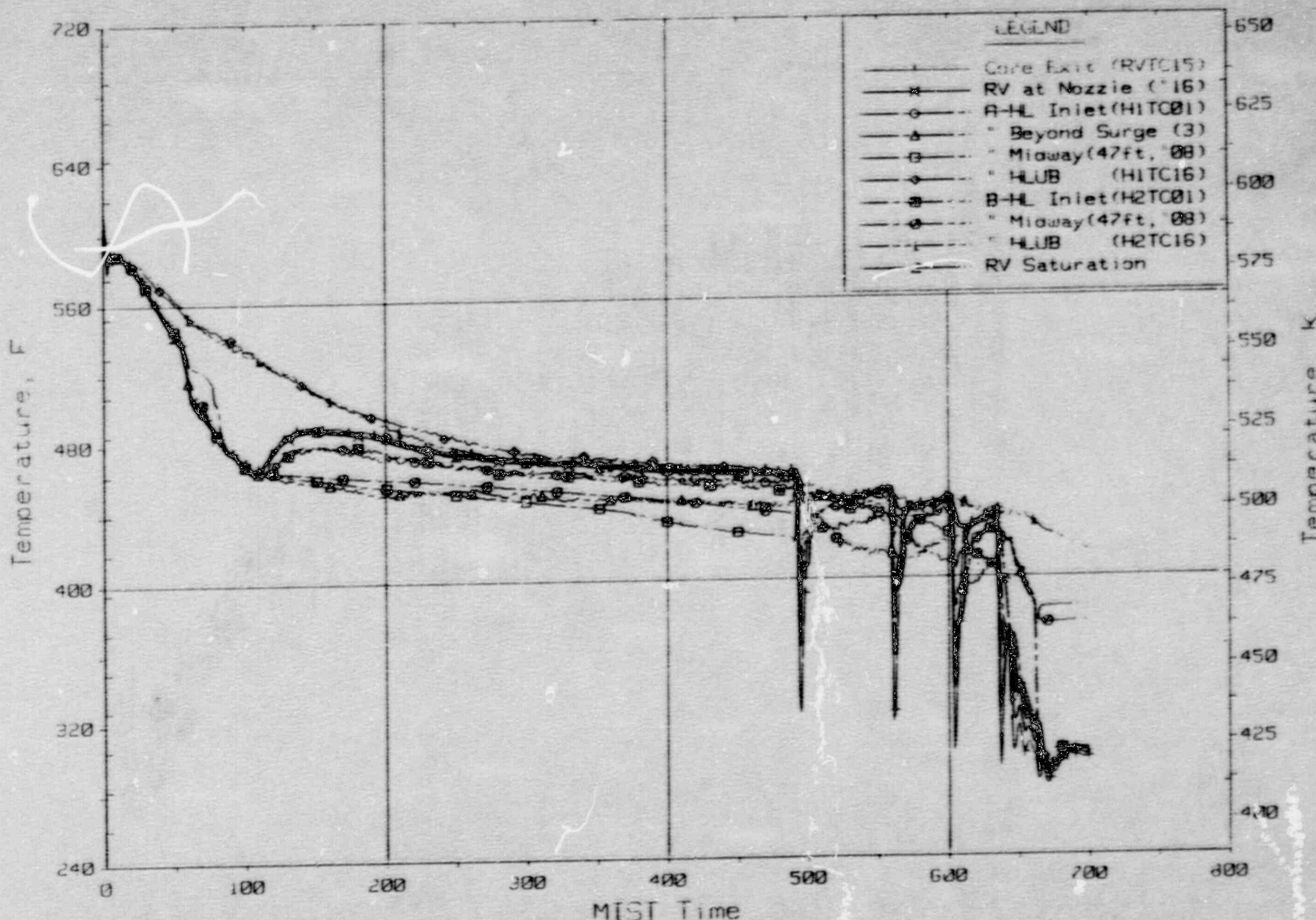



Figure A.1 Primary and Secondary System Pressures (GPOIs)

FINAL DATA

T4NOML3· Nominal Transient with Distorted Core Power




A-3

Figure A.2 Composite Core Exit and Hot Leg Fluid Temperatures

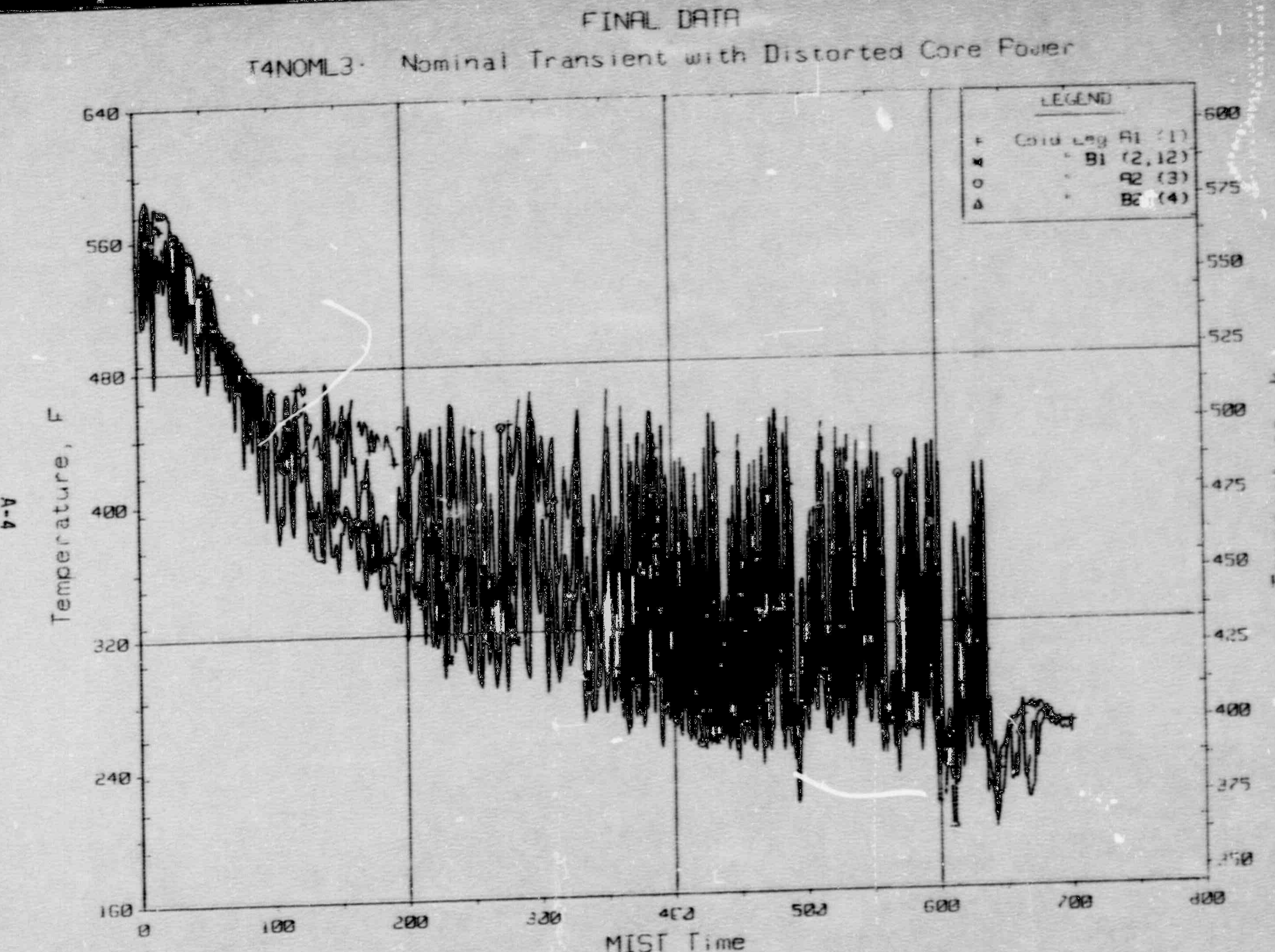



Figure A.3 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC1ls)

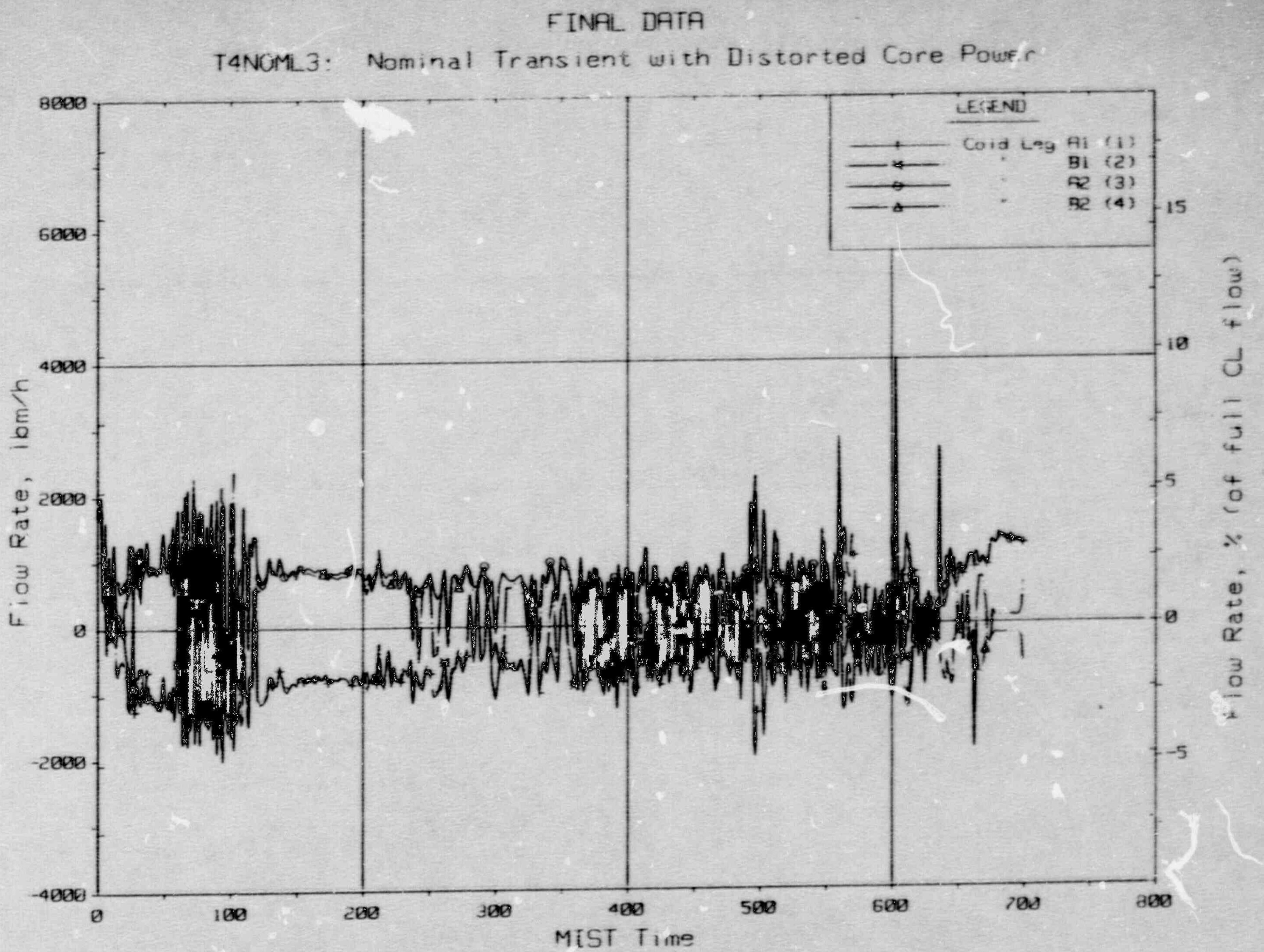



Figure A.4 Cold Leg (Venturi) Flow Rates (CnVN20s)

CLFL0

Wed Nov 16 12:07:07 1988

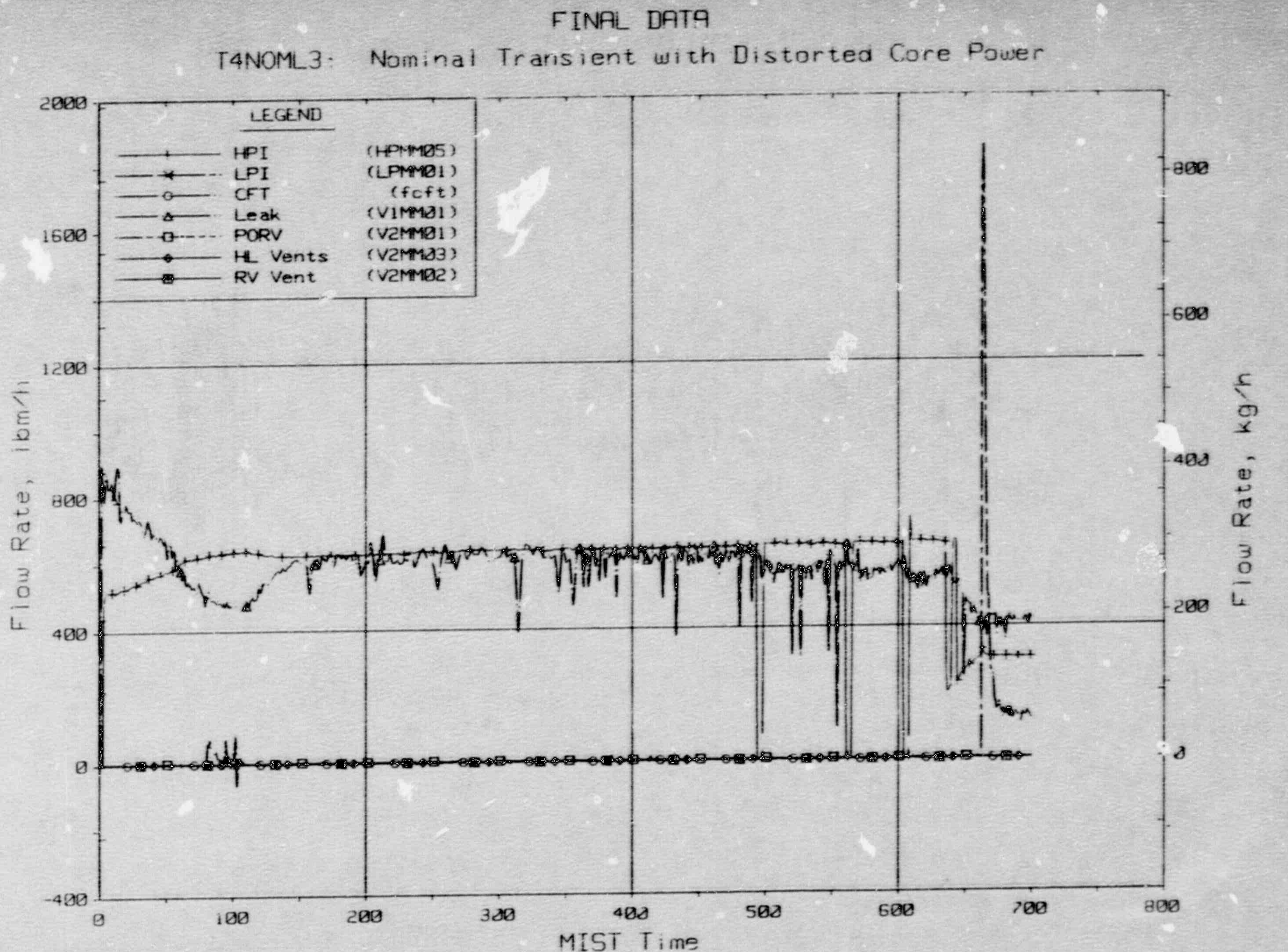



**Figure A.5 Primary System Boundary Flow Rates**

Wed Nov 16 12:02:12 1988

PRFL3x

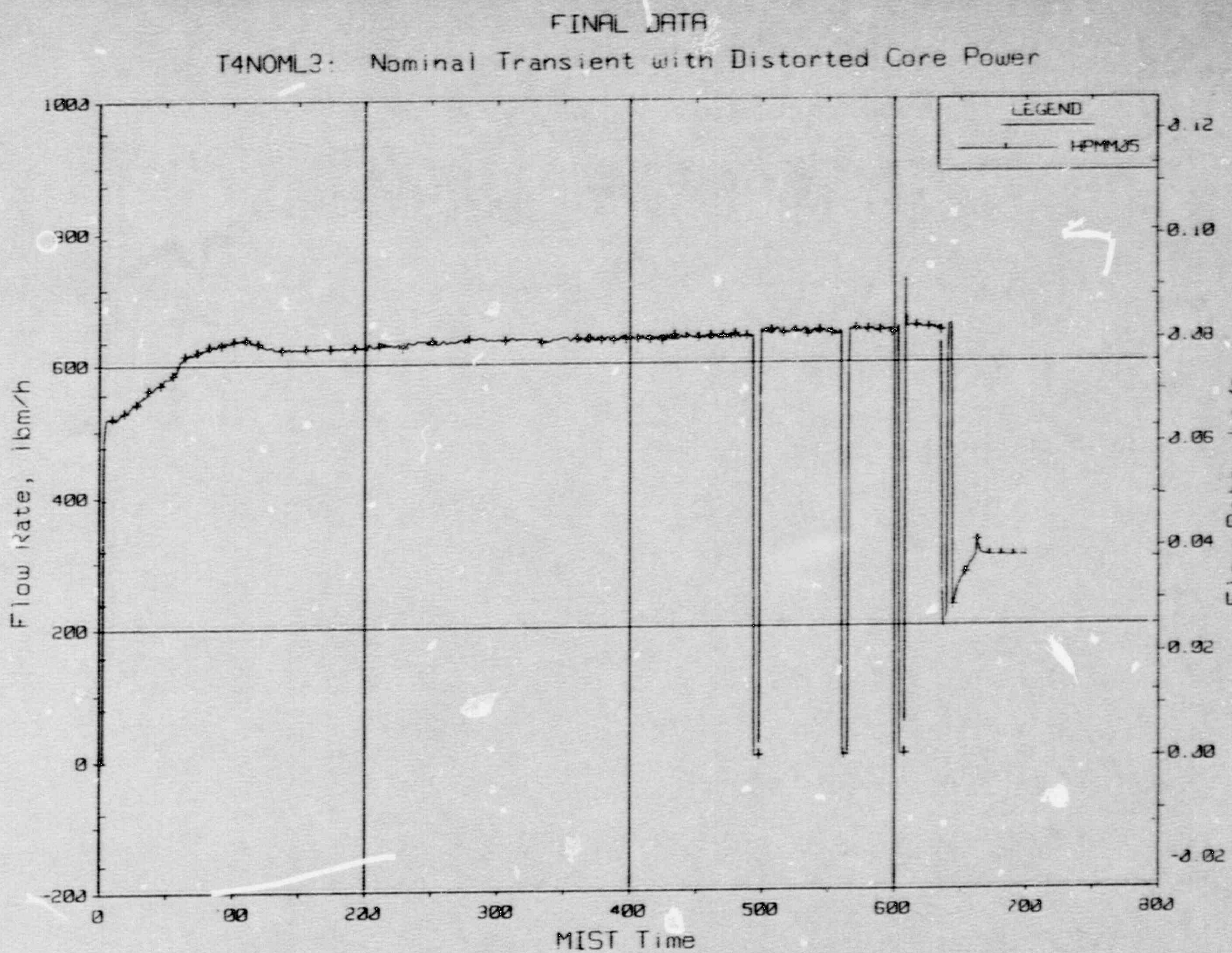



Figure A.6 HPI Total Flow Rate

FINAL DATA

T4NOML3: Nominal Transient with Distorted Core Power

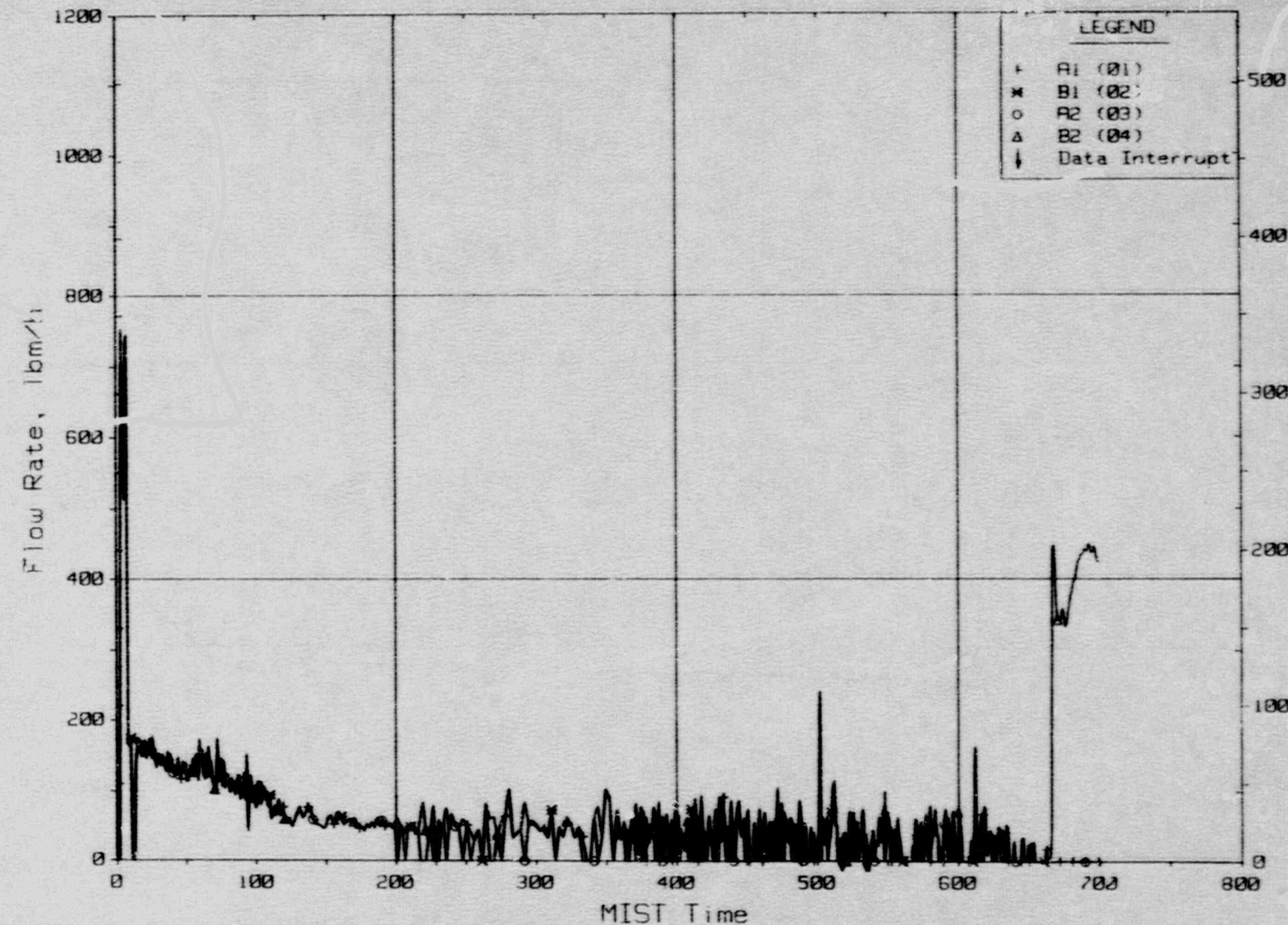



Figure A.7 Reactor Vessel Vent Valve Flow Rates (RVORs)

Wed Nov 16 11:54:26 1988

VVFL1

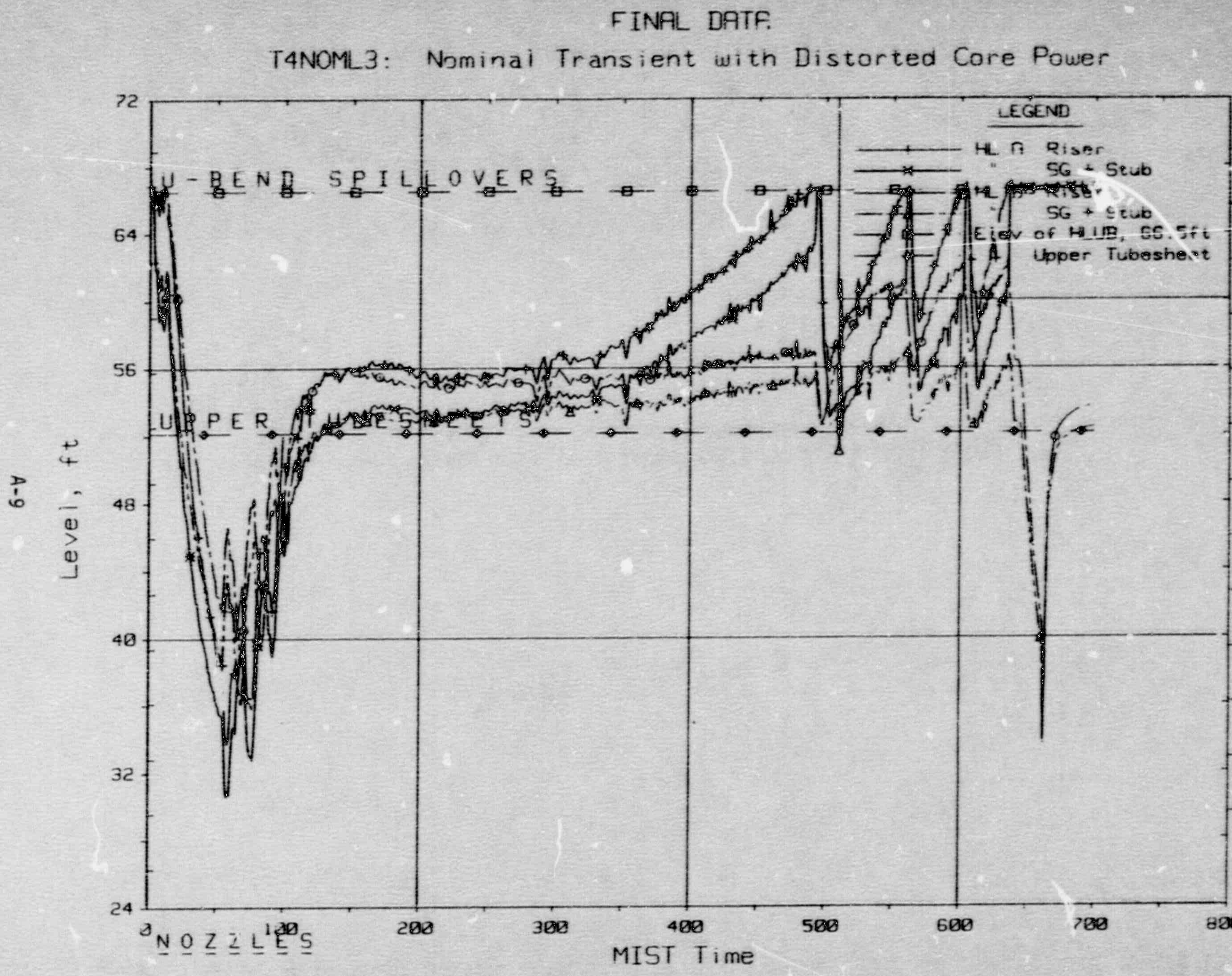



Figure A.8 Hot Leg Riser and Stub Collapsed Liquid Levels

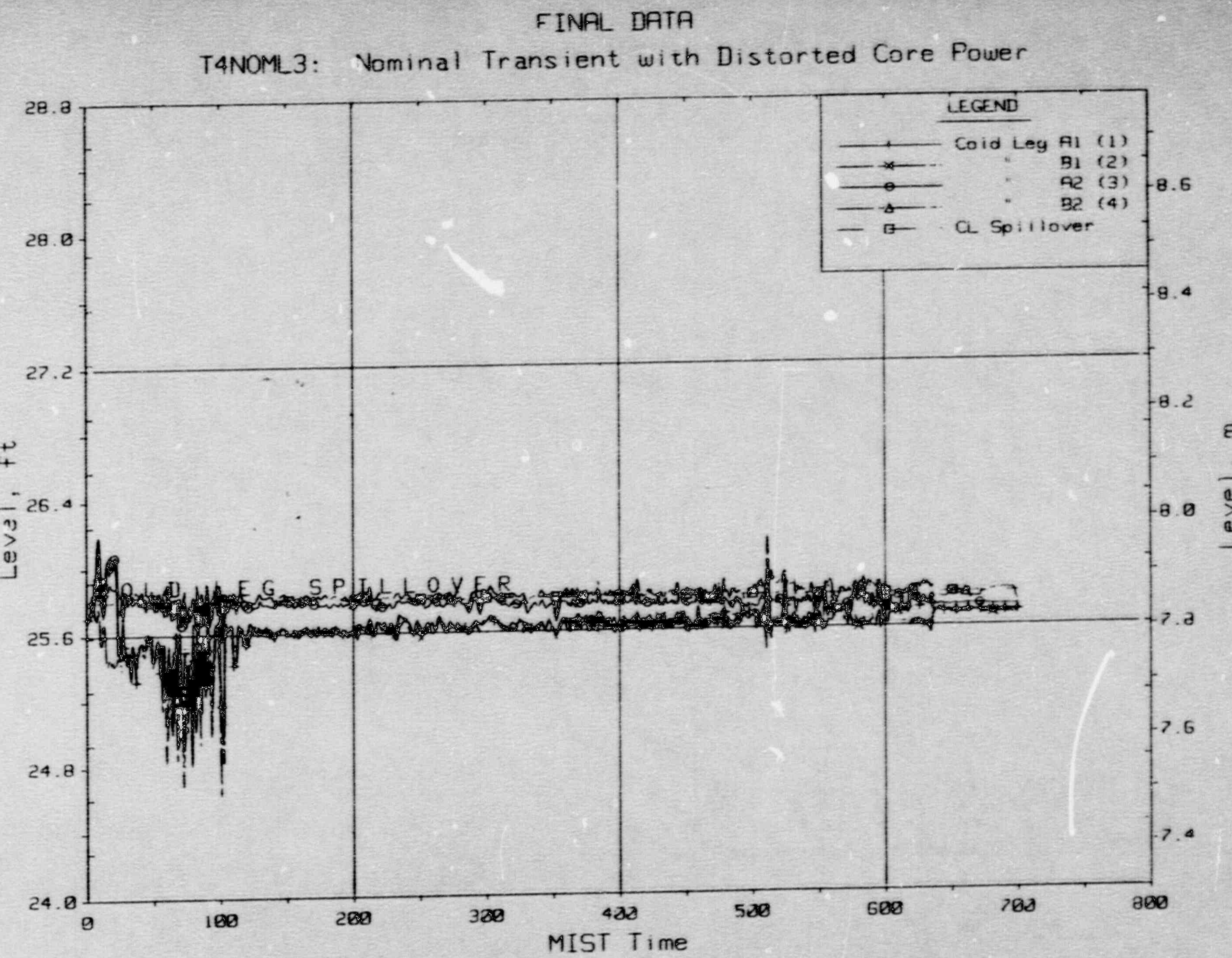





**Figure A.9 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)**

CLLV5

Wed Nov 16 11:47:04 1988

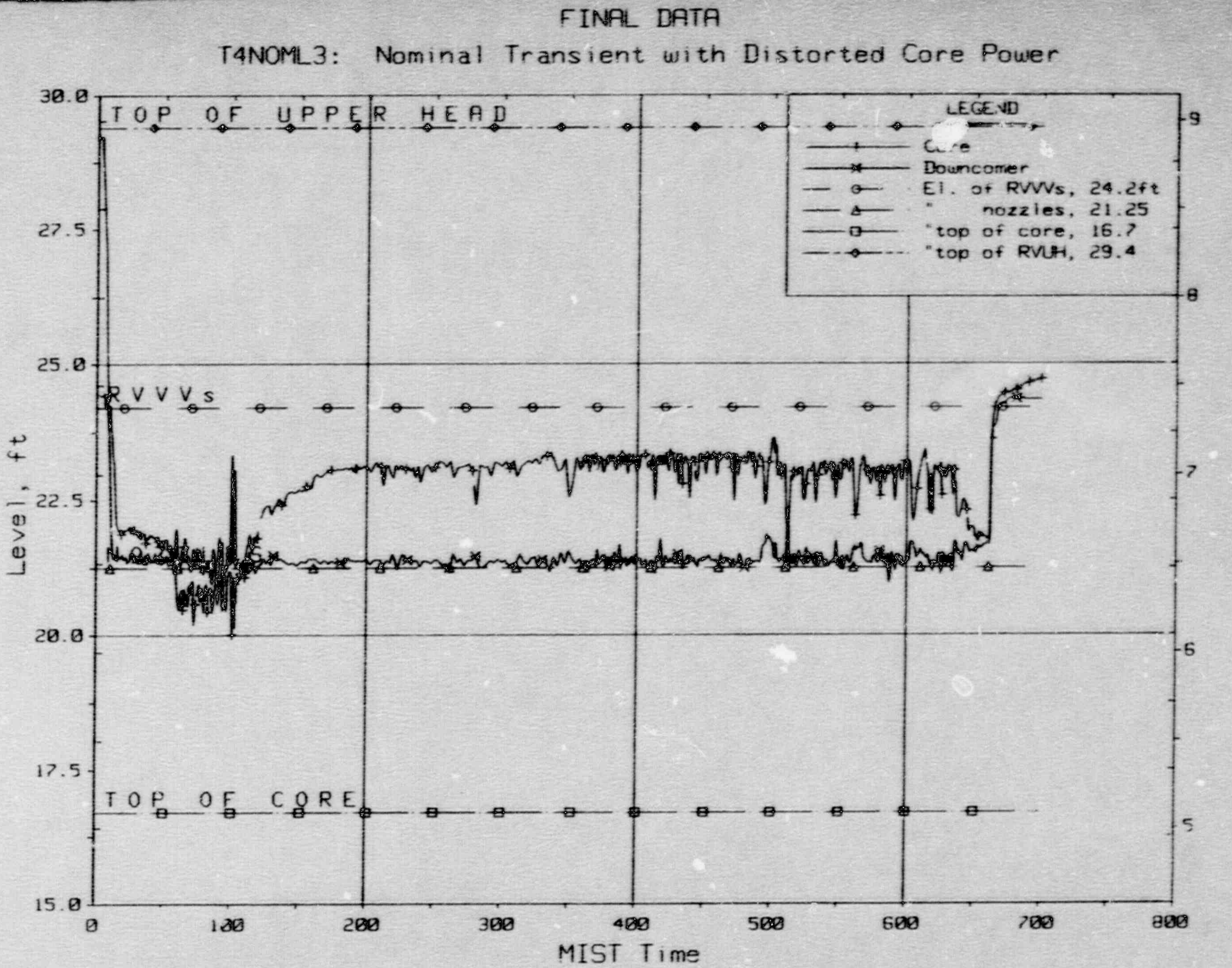



Figure A.10 Core Region Collapsed Liquid Levels

Wed Nov 16 11:43:25 1988

COLV1

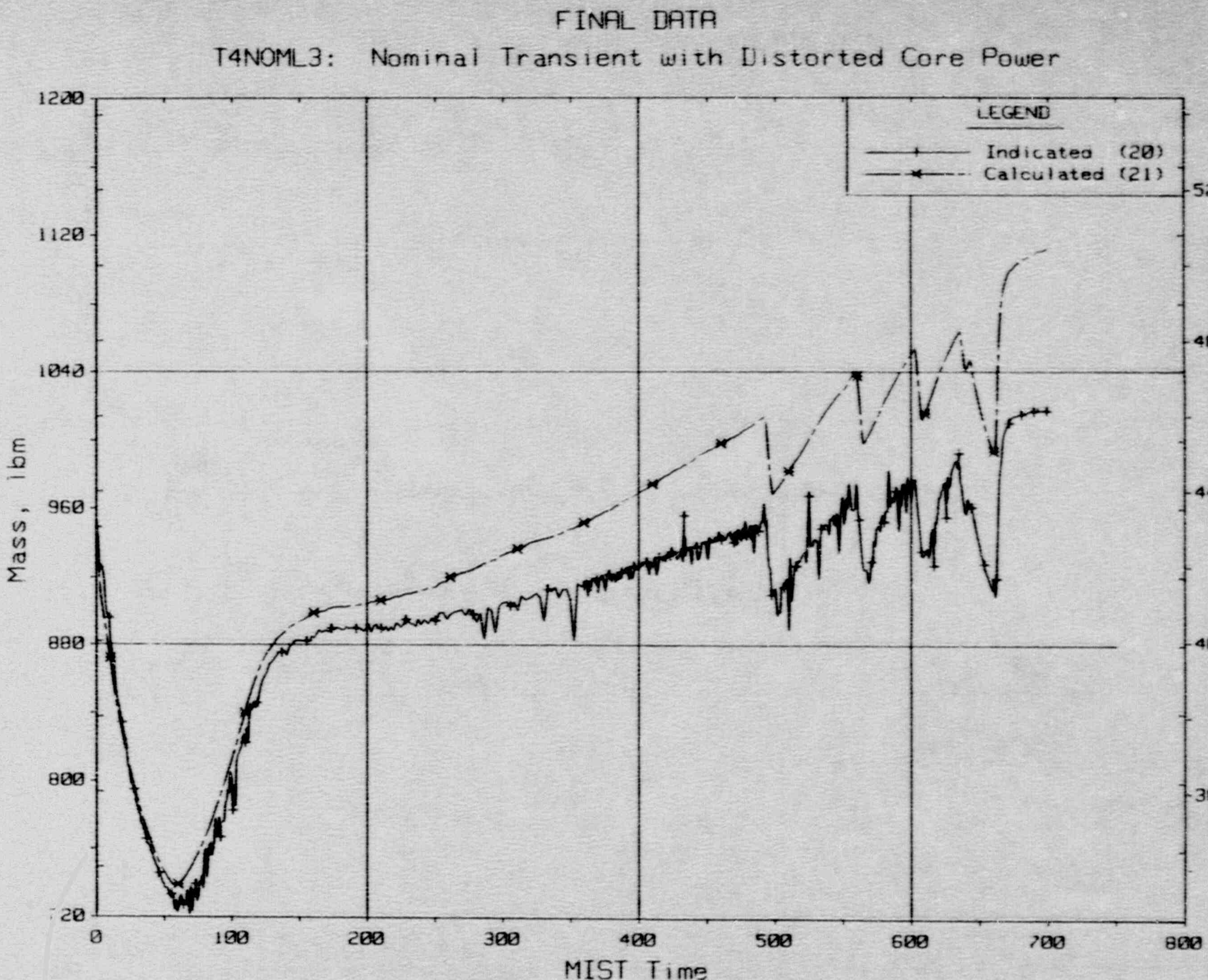



Figure A.11 Primary System Total Fluid Mass (PLMLs)

Wed Nov 16 11:39:56 1988

PRML1

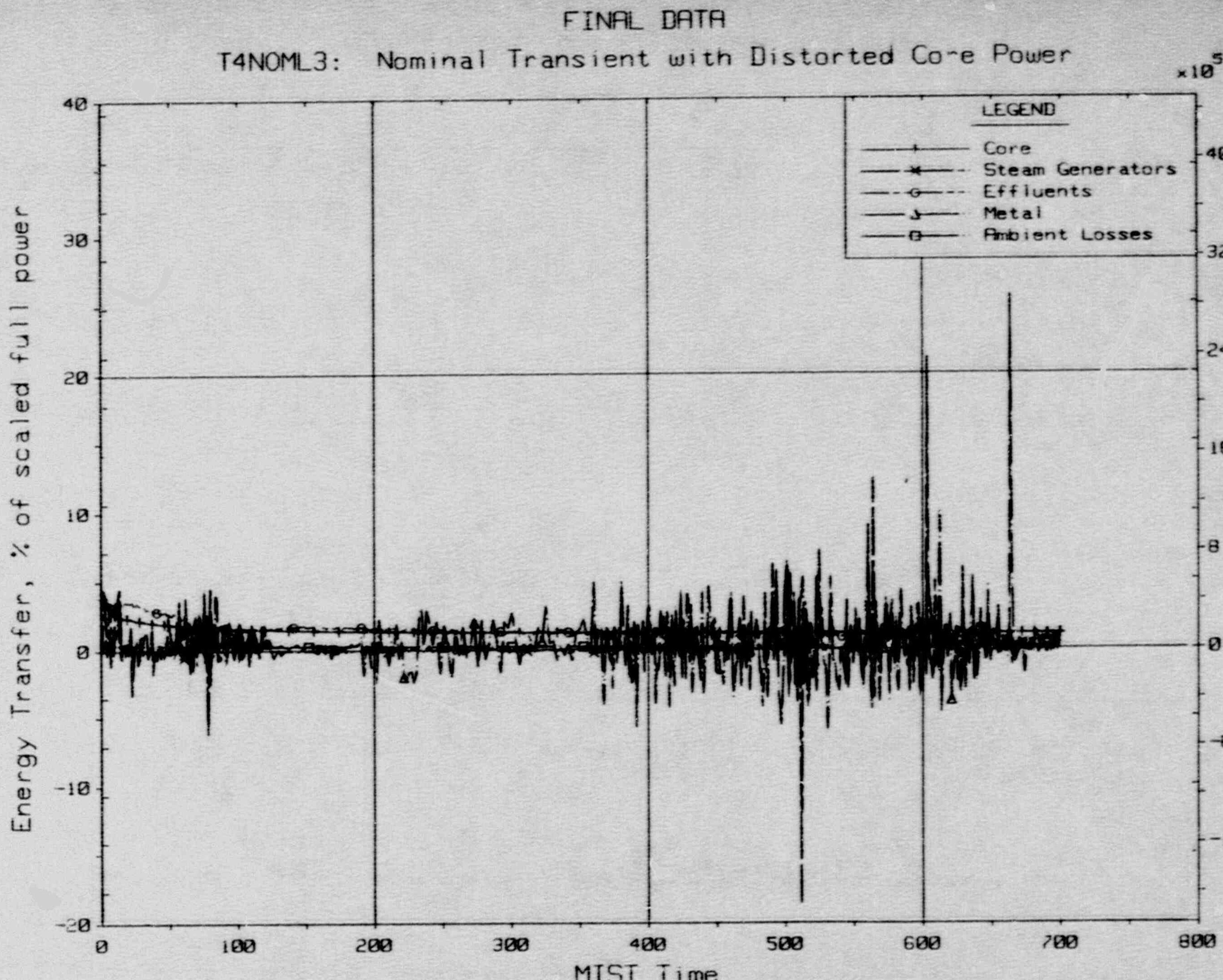



**Figure A.12 Primary System Energy Transfer**

Wed Nov 16 11:37:27 1988

PROEIX

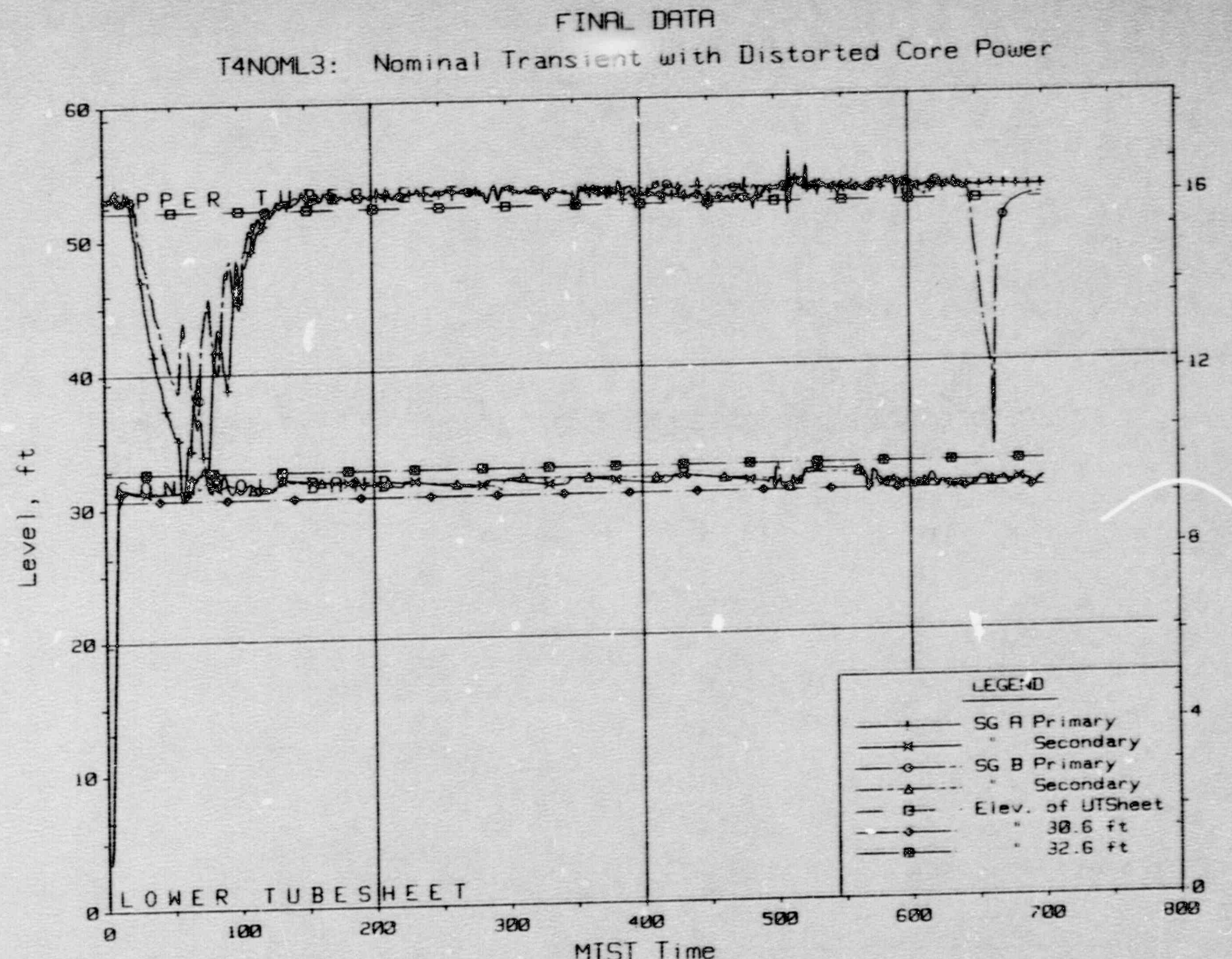



Figure A.13 Steam Generator Collapsed Liquid Levels

SGLV2

Wed Nov 16 11:33:06 1988

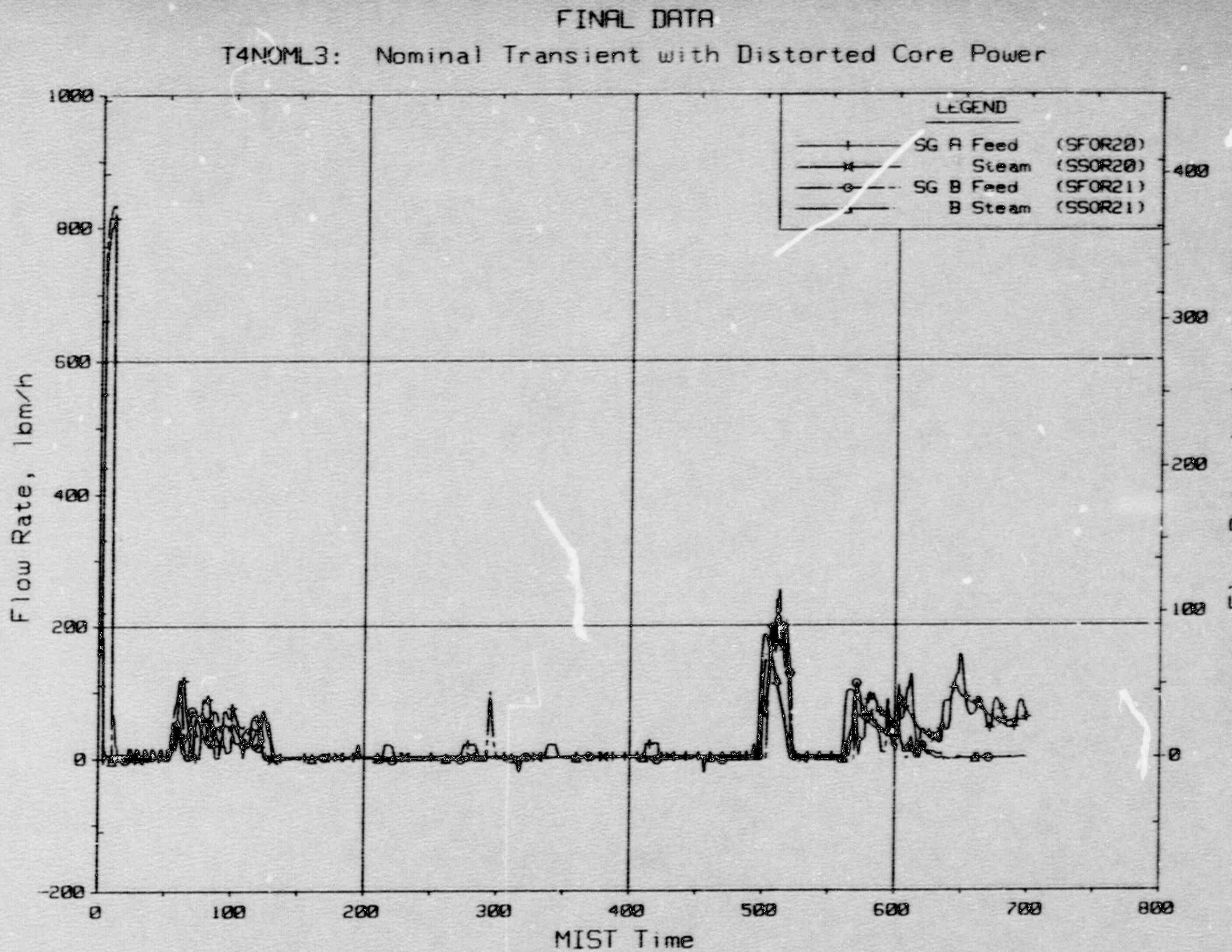



Figure A.14 Steam Generator Secondary Flow Rates

Wed Nov 16 11:28:53 1988

SGFL0

MIST Phase IV Test 410AT3

10-$cm^2$ SBLOCA Without HPI, ATOG Cooldown

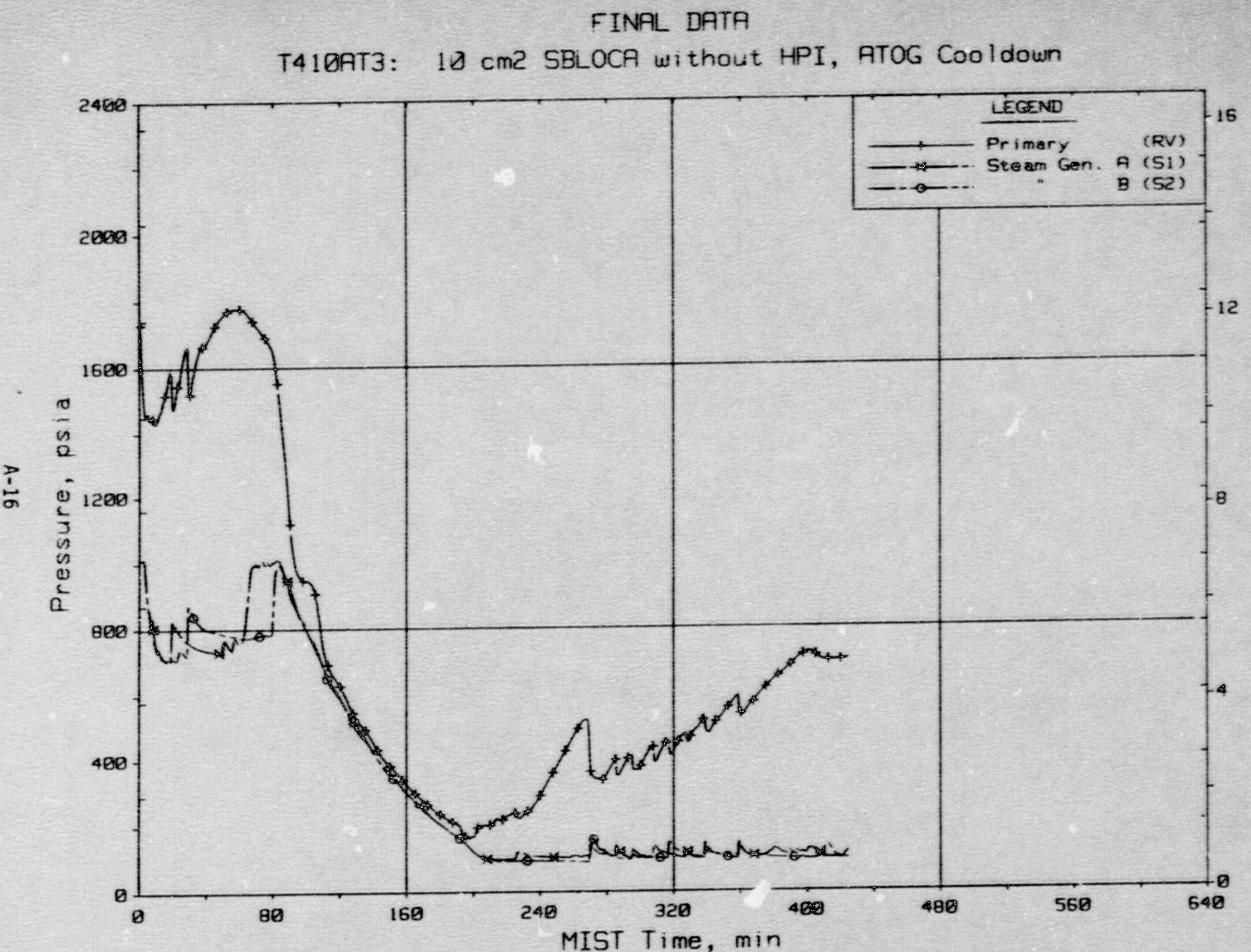



Figure A.15 Primary and Secondary System Pressures (GP01s)

PSGP1

Fri Nov 11 15:06:14 1988

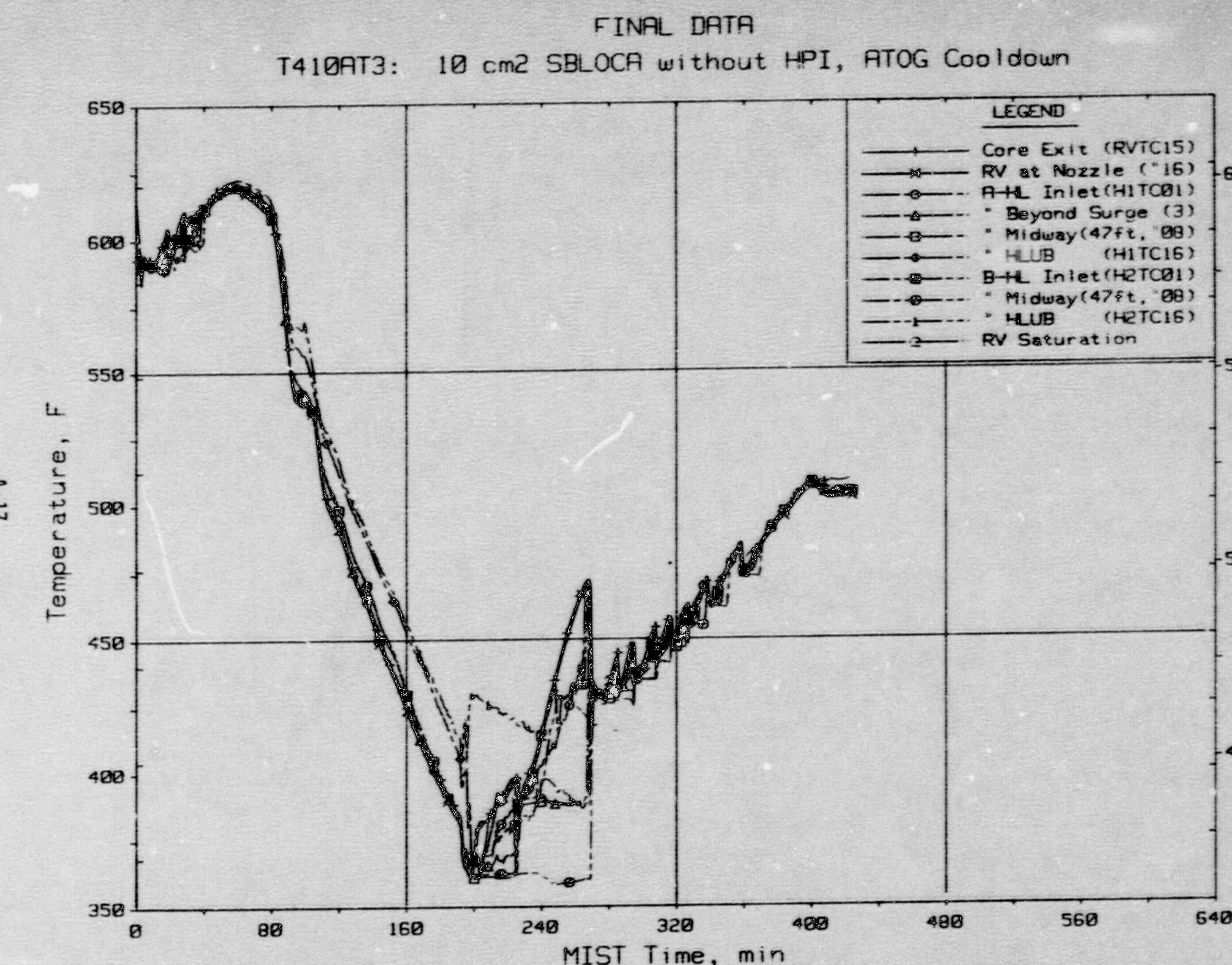
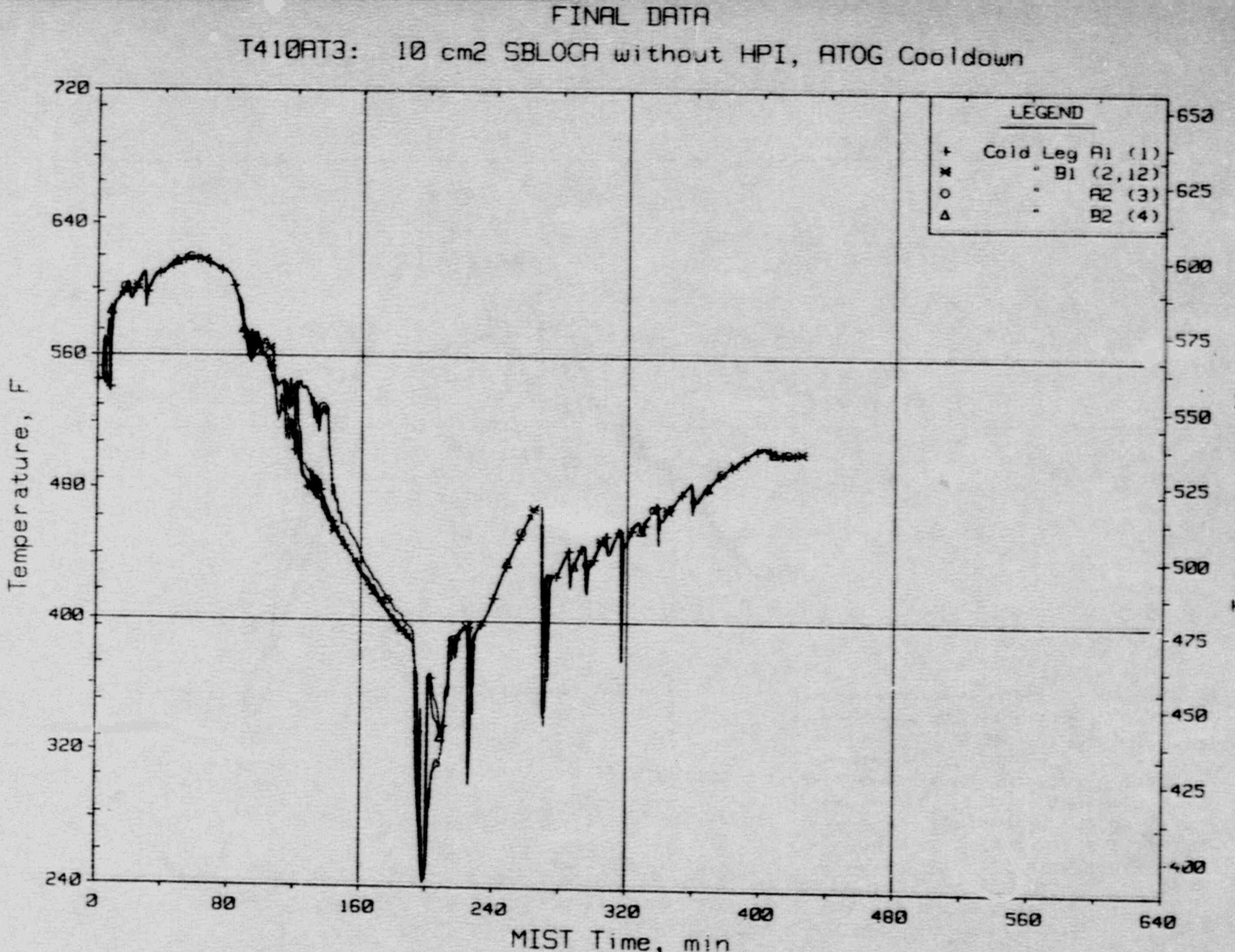



Figure A.16 Composite Core Exit and Hot Leg Fluid Temperatures

Fri Nov 11 15:03:12 1988

PRKT1




A-18

Figure A.17 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

Fri Nov 11 14:58:10 1988

CLTC1

FINAL DATA

T410AT3: 10 cm2 SBLOCA without HPI, ATOG Cooldown

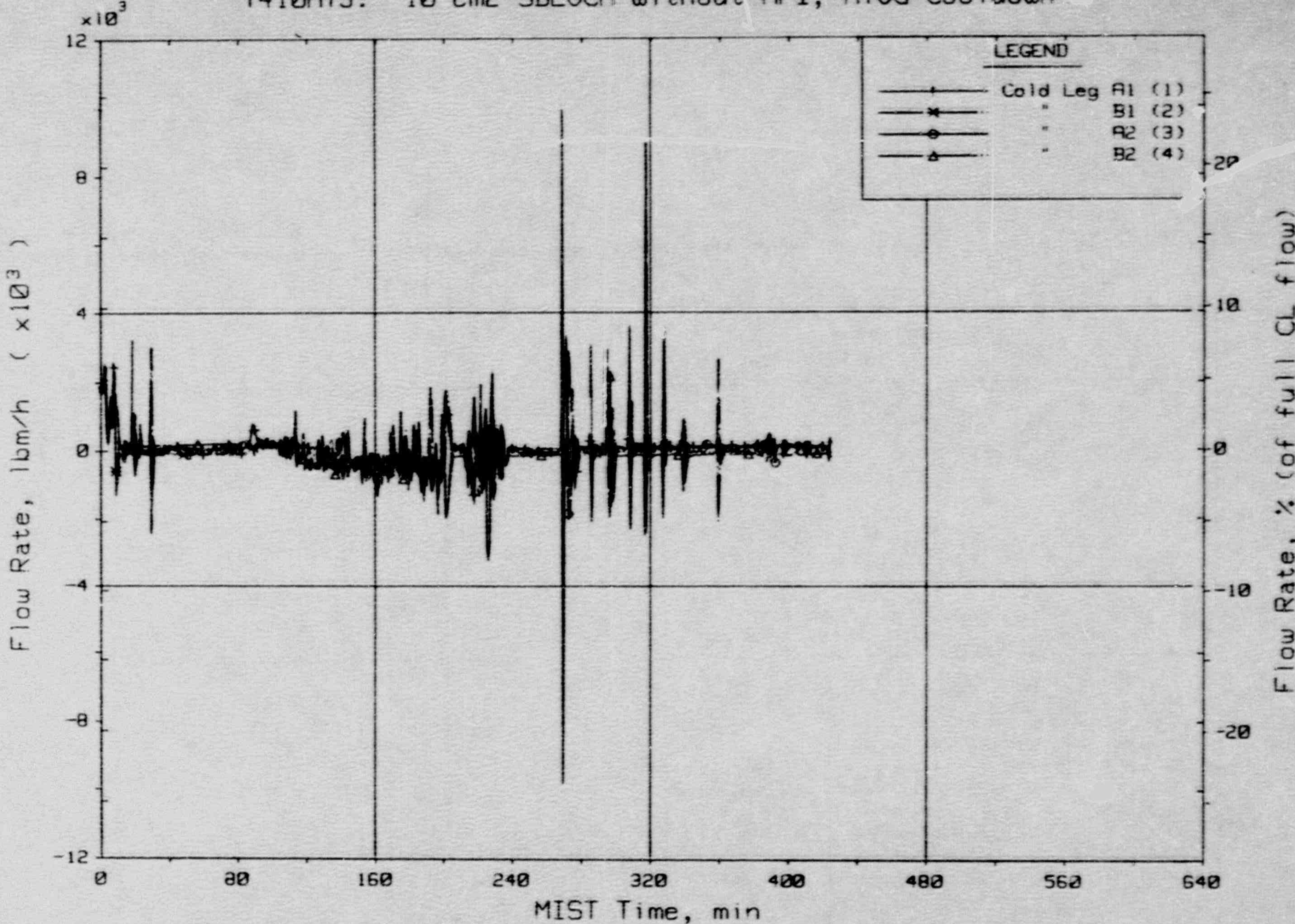



Figure A.18 Cold Leg (Venturi) Flow Rates (CnVN20s)

Fri Nov 11 14:55:19 1988

CLFL0

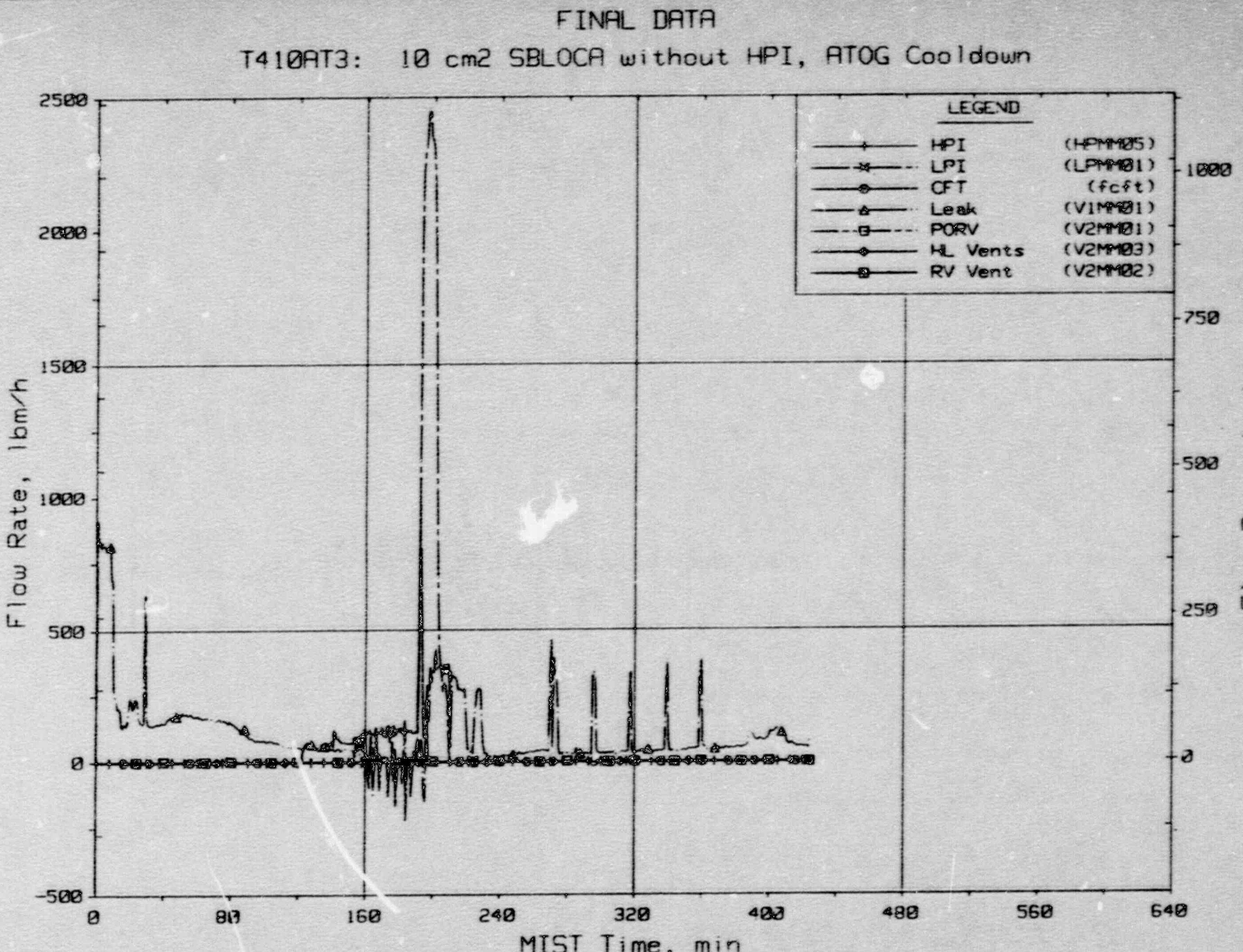



Figure A.19 Primary System Boundary Flow Rates

Tue Nov 15 13:34:11 1988

PRFL3x

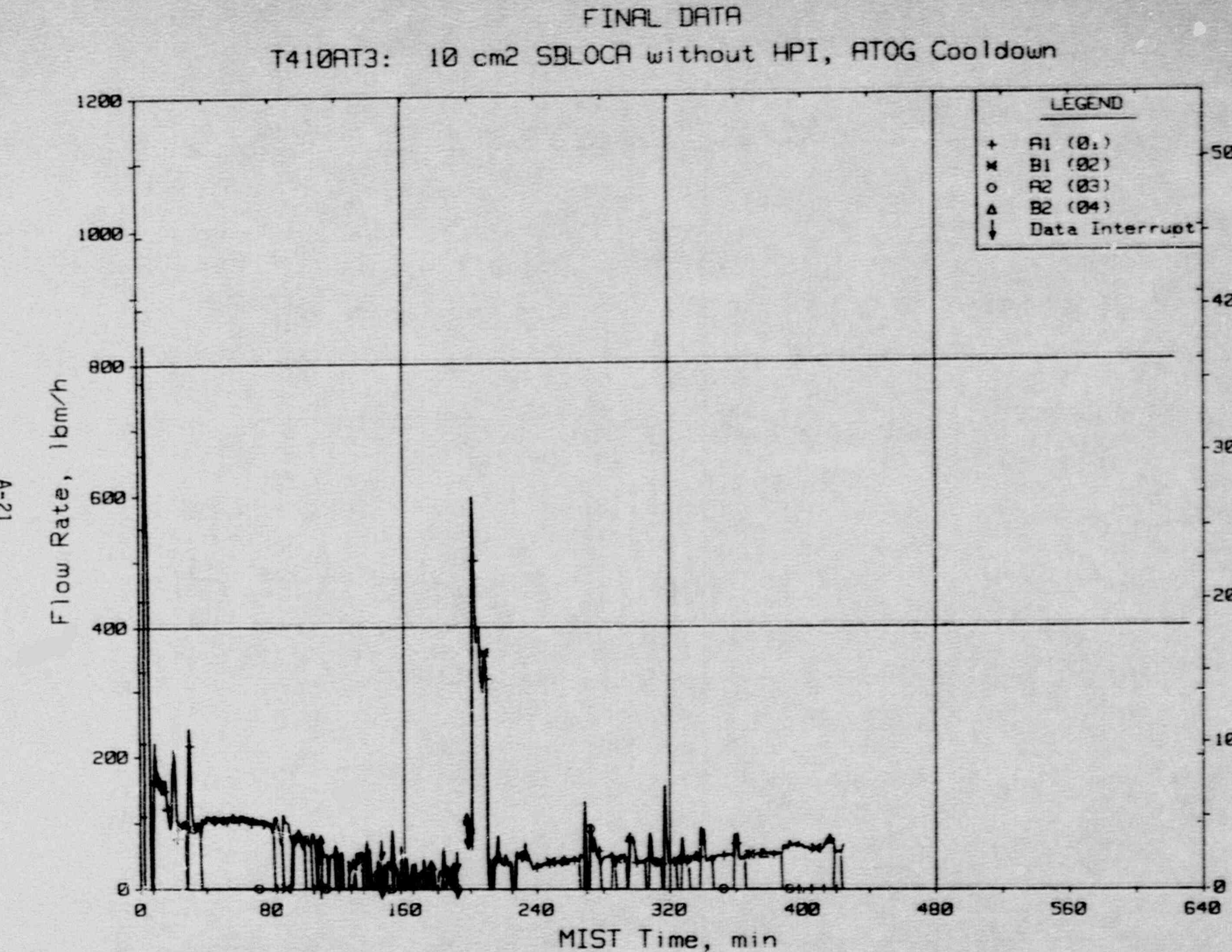
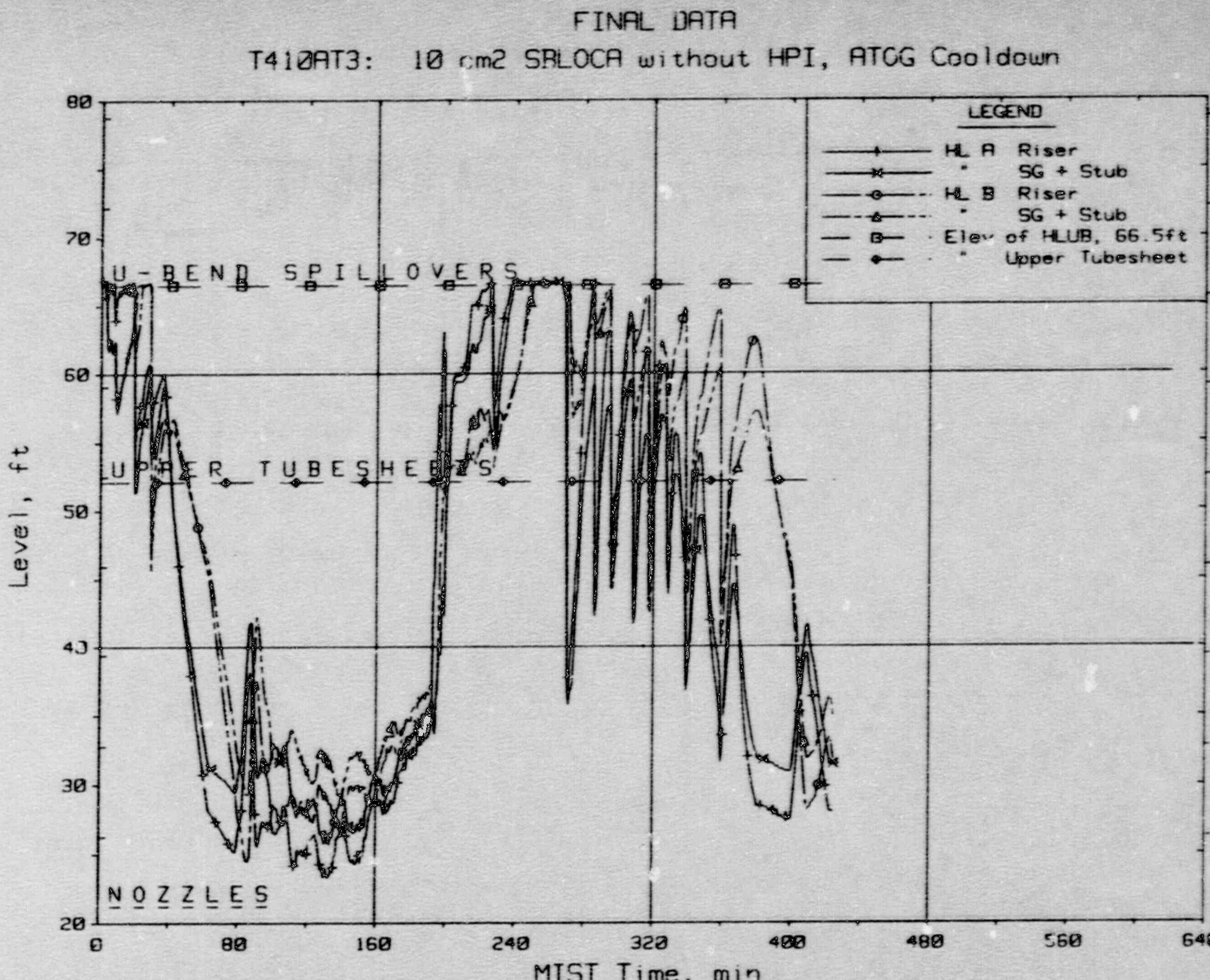



Figure A.20 Reactor Vessel Vent Valve Flow Rates (RVORs)

Fri Nov 11 14:42:17 1988

VVFL1




A-22

Figure A.21 Hot Leg Riser and Stub Collapsed Liquid Levels

Fri Nov 11 14:30:08 1988

HLLV1

FINAL DATA

T410AT3: 10 cm2 SBLOCA without HPI, ATOG Cooldown

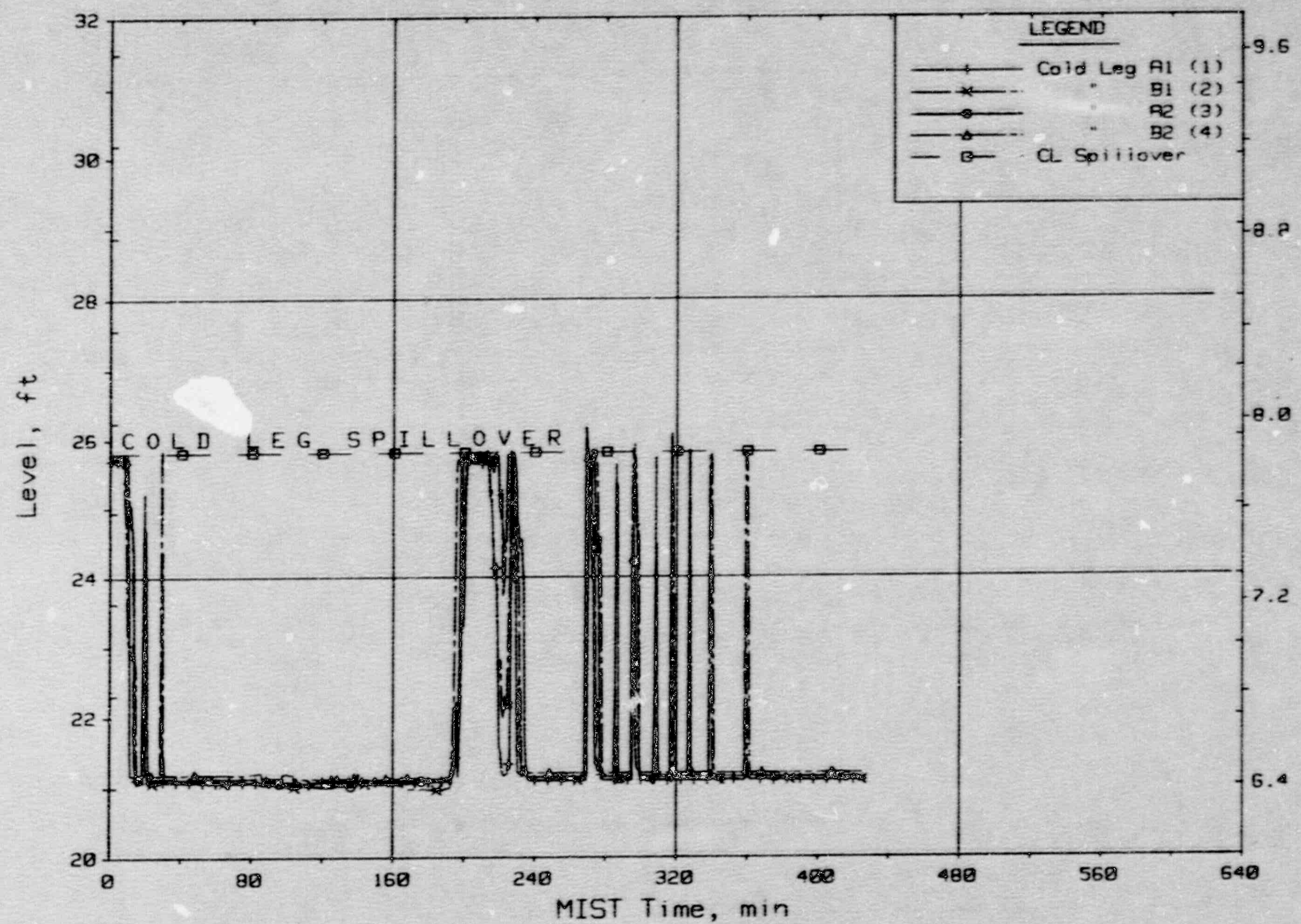



Figure A 22 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Fri Nov 11 14:33:31 1988

CLLV5

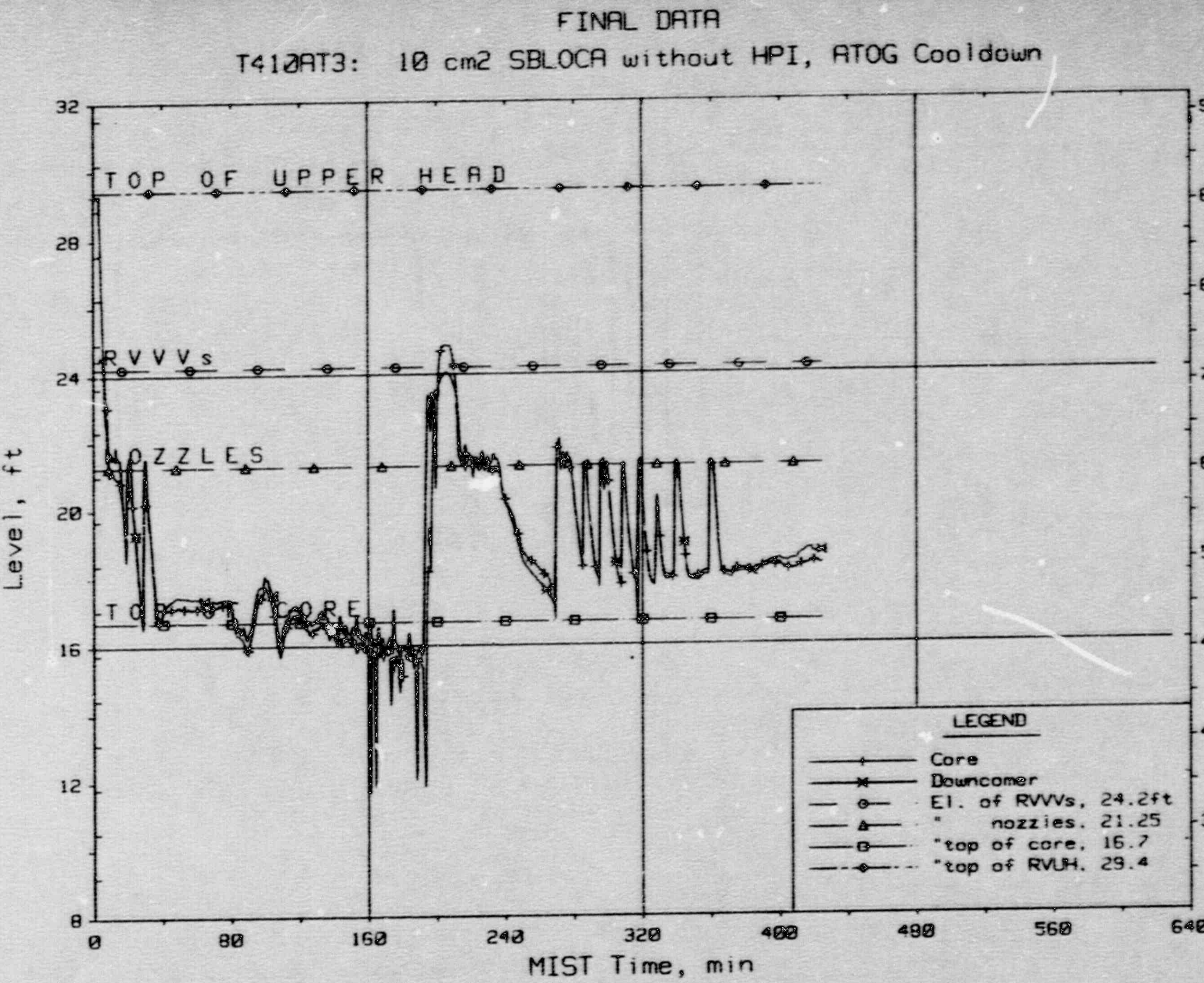



Figure A.23 Core Region Collapsed Liquid Levels

COLV1

Fri Nov 11 14:29:50 1988

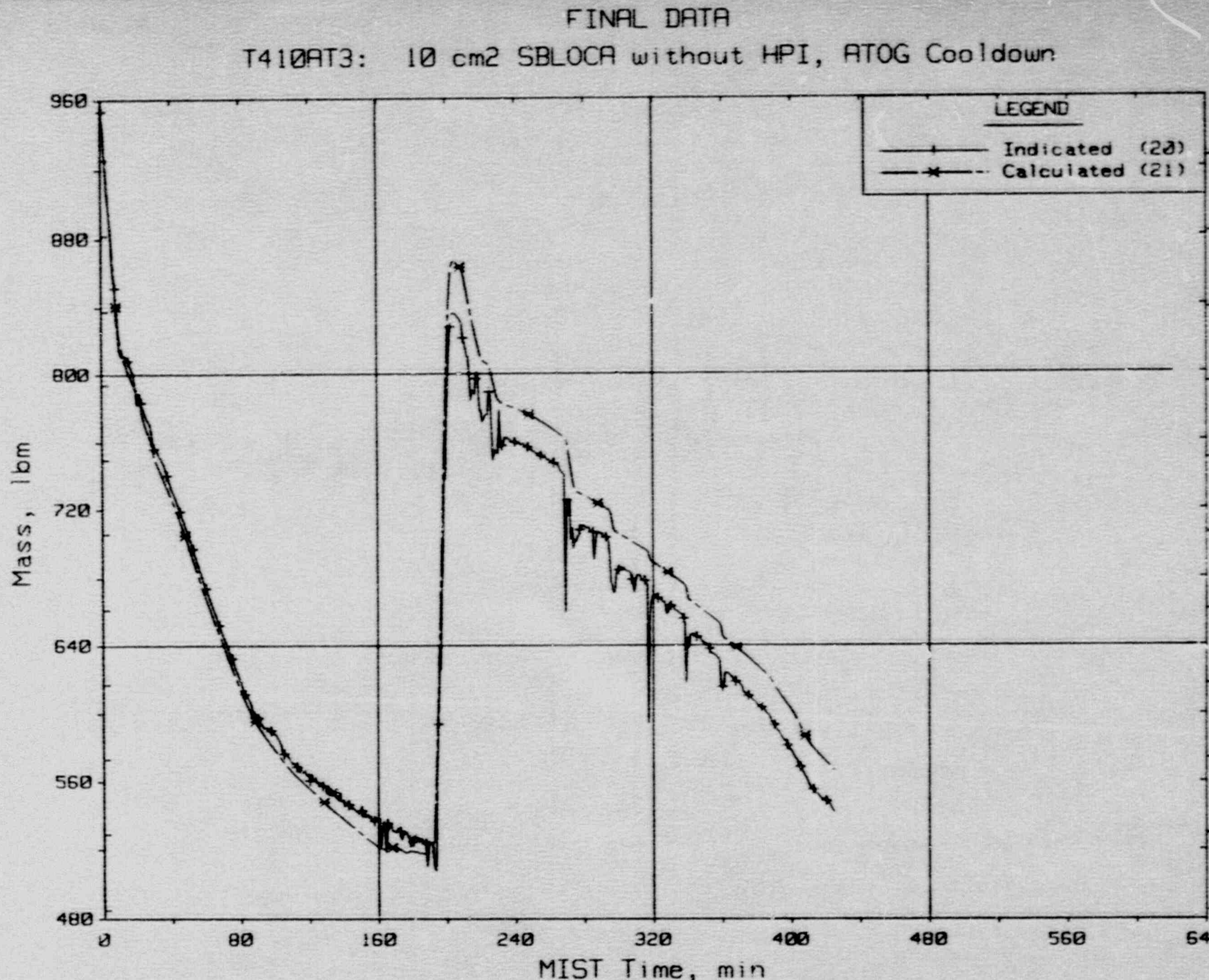



**Figure A.24 Primary System Total Fluid Mass (PLMLs)**



Fri Nov 11 14:26:33 1988

PRML1

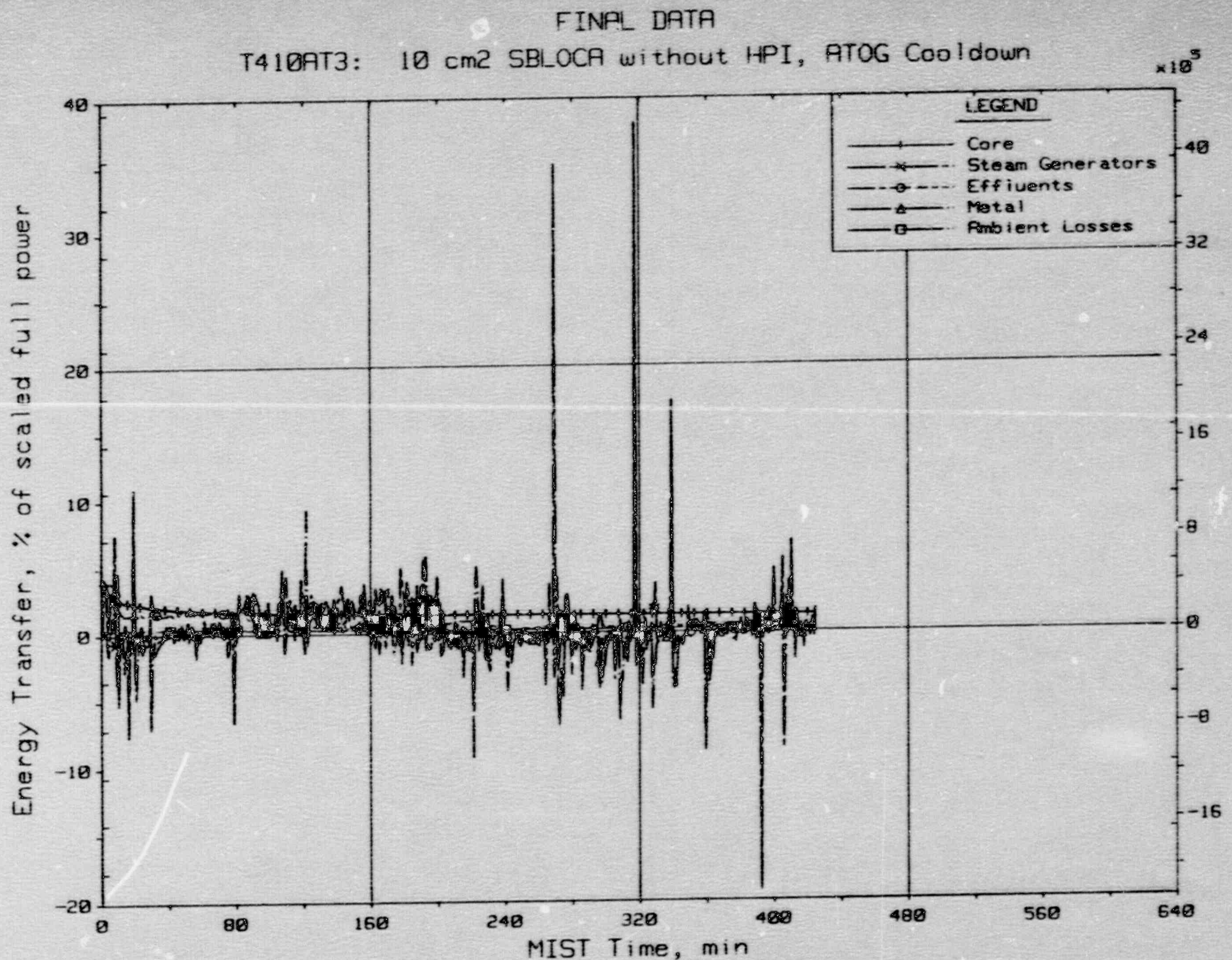



Figure A.25 Primary System Energy Transfer

PRQE1X

Fri Nov 11 14:24:09 1988

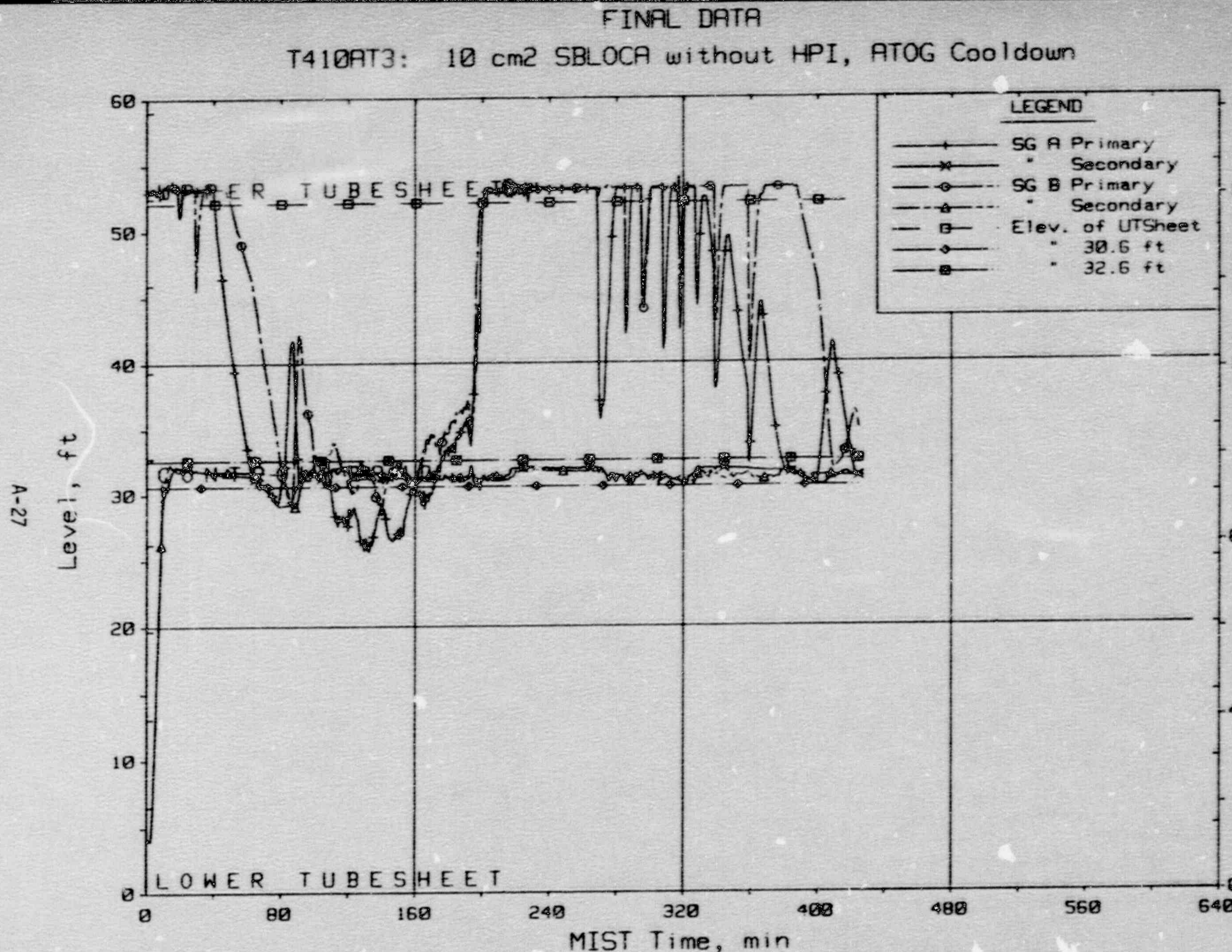



Figure A.26 Steam Generator Collapsed Liquid Levels

Fri Nov 11 13:43:25 1988

SGLV2

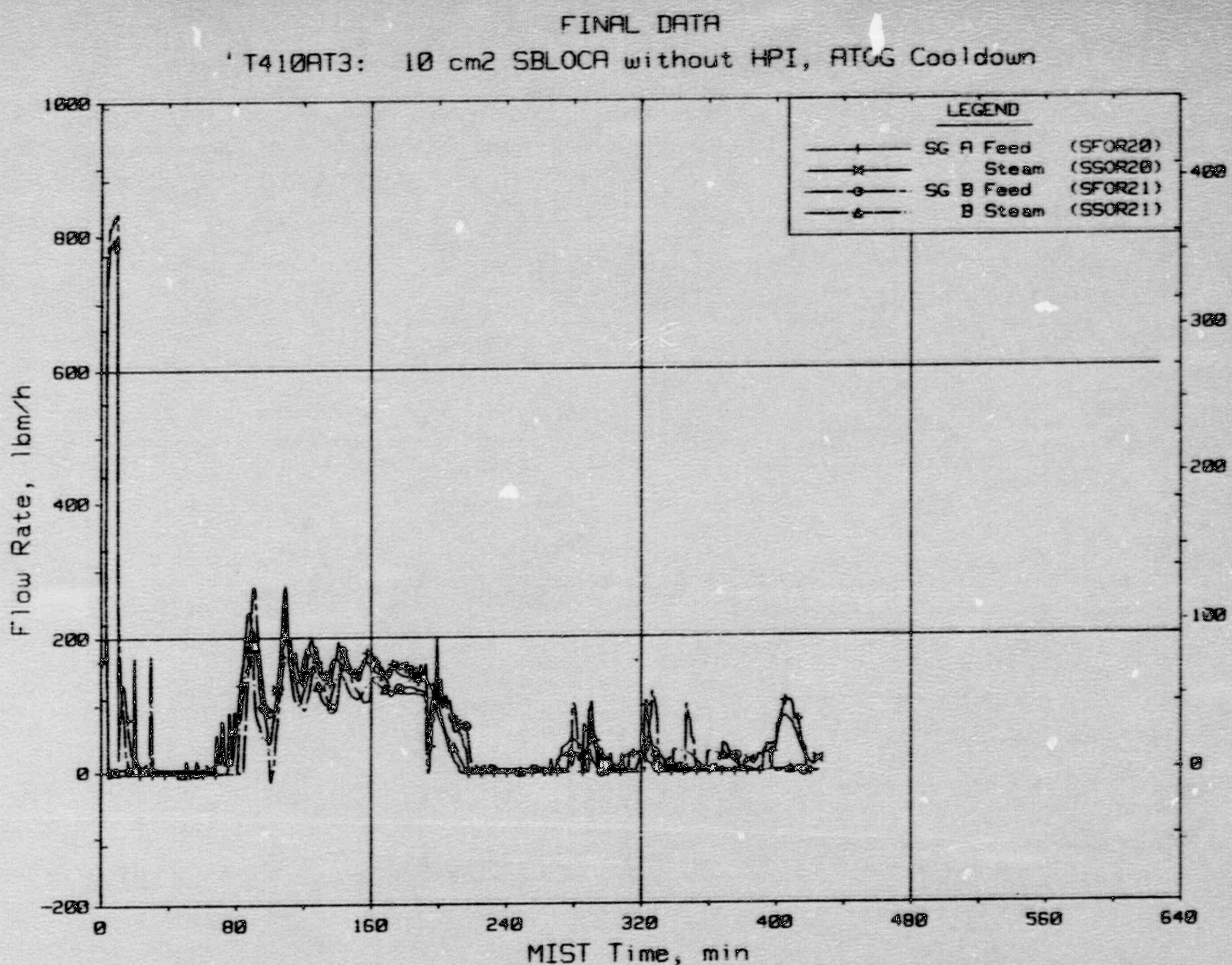



Figure A.27 Steam Generator Secondary Flow Rates

SGFL0

Fri Nov 11 13:39:32 1988

MIST Phase IV Test 410BD1

10-cm$^2$ SBLOCA Without HPI, Steam Generator Blowdown

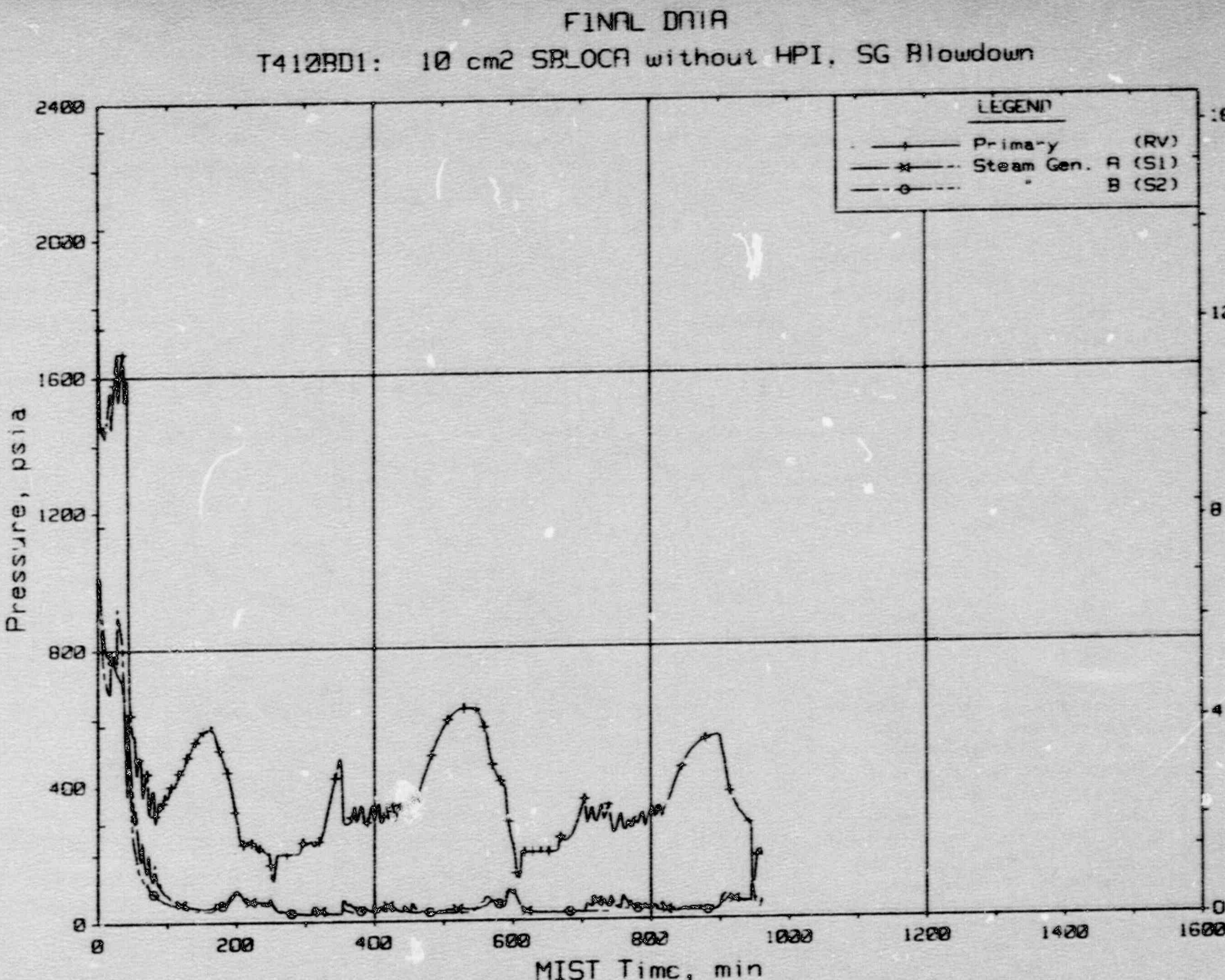



Figure A.28 Primary and Secondary System Pressures (GP01s)

Tue Nov 1 16:55:56 1988

PSGP1

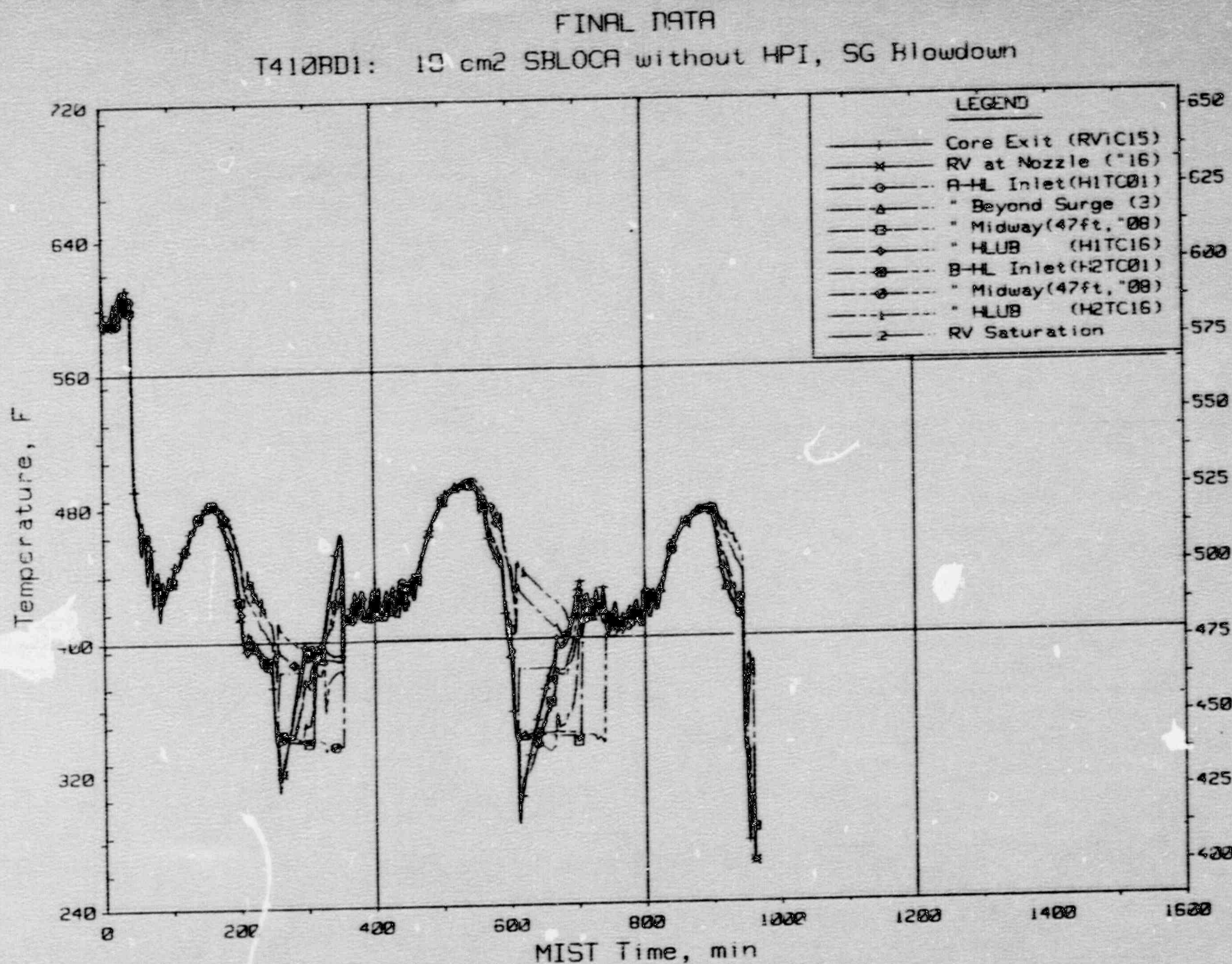



Figure A.29 Composite Core Exit and Hot Leg Fluid Temperatures

PPKT1

Tue Nov 1 10:49:44 1988

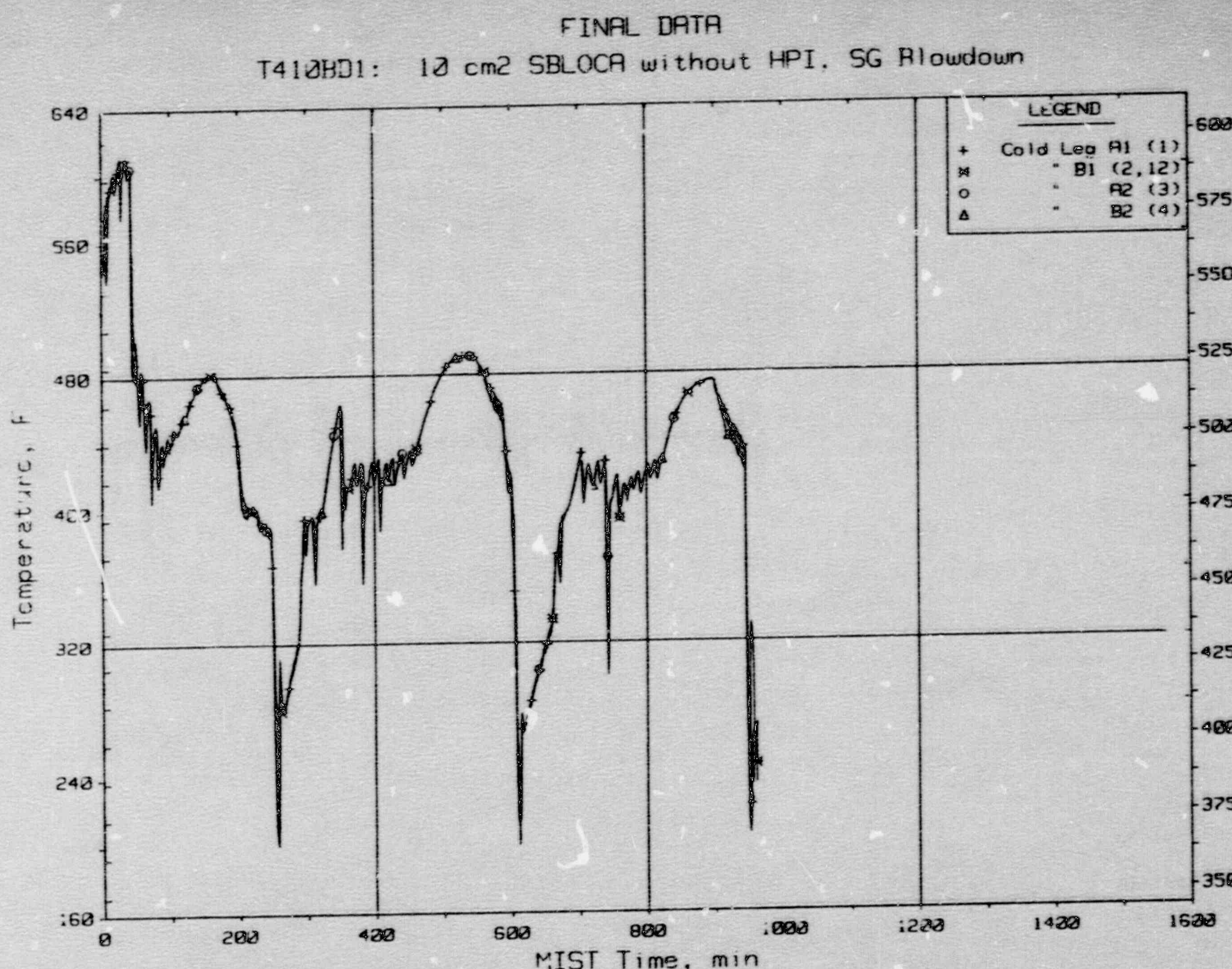



Figure A.30 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

CLTC1

Tue Nov 1 10:34:37 1988

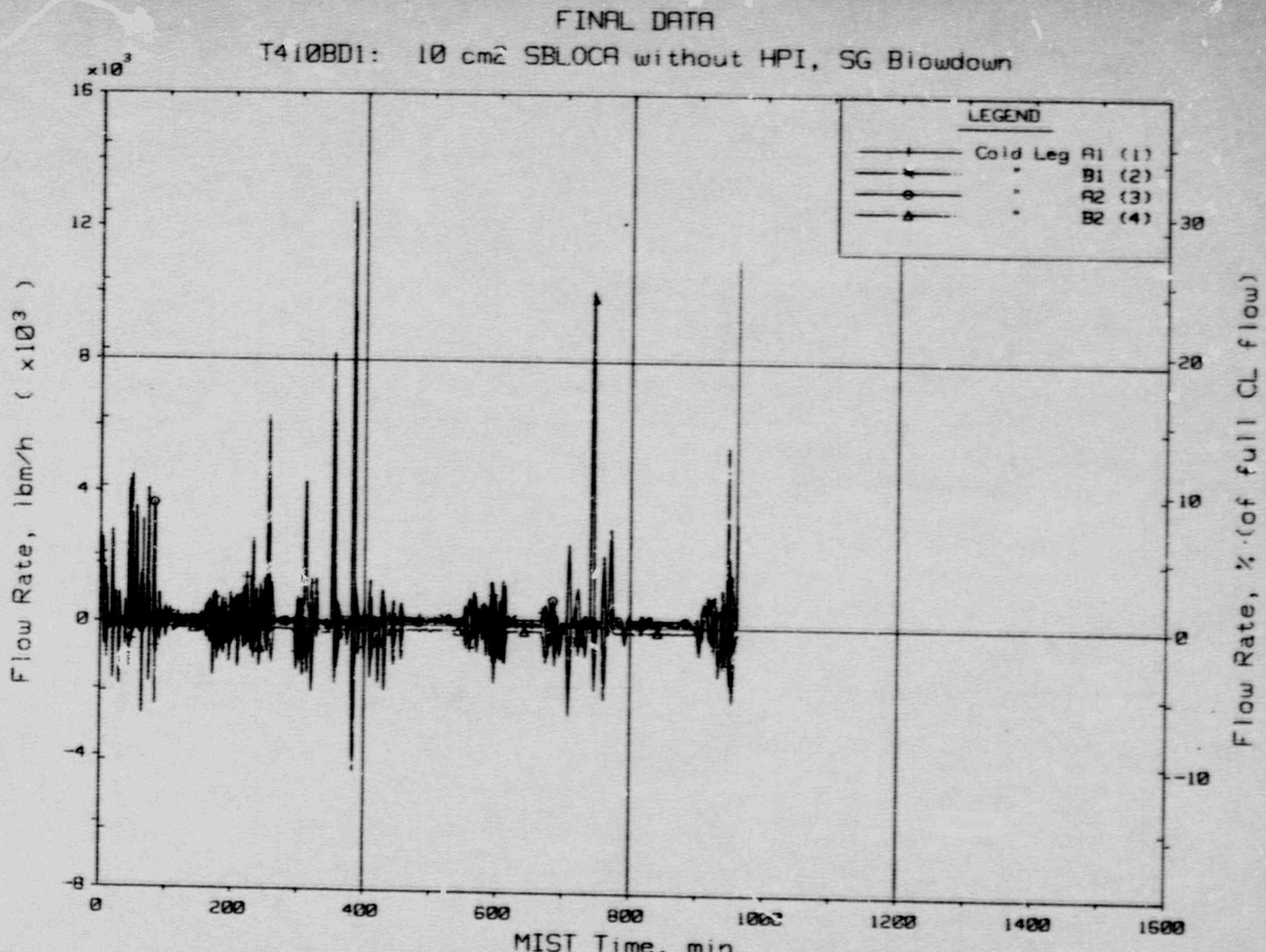



Figure A.31 Cold Leg (Venturi) Flow Rates (CnVN20s)

Tue Nov 1 10:07:15 1988

CLFL0

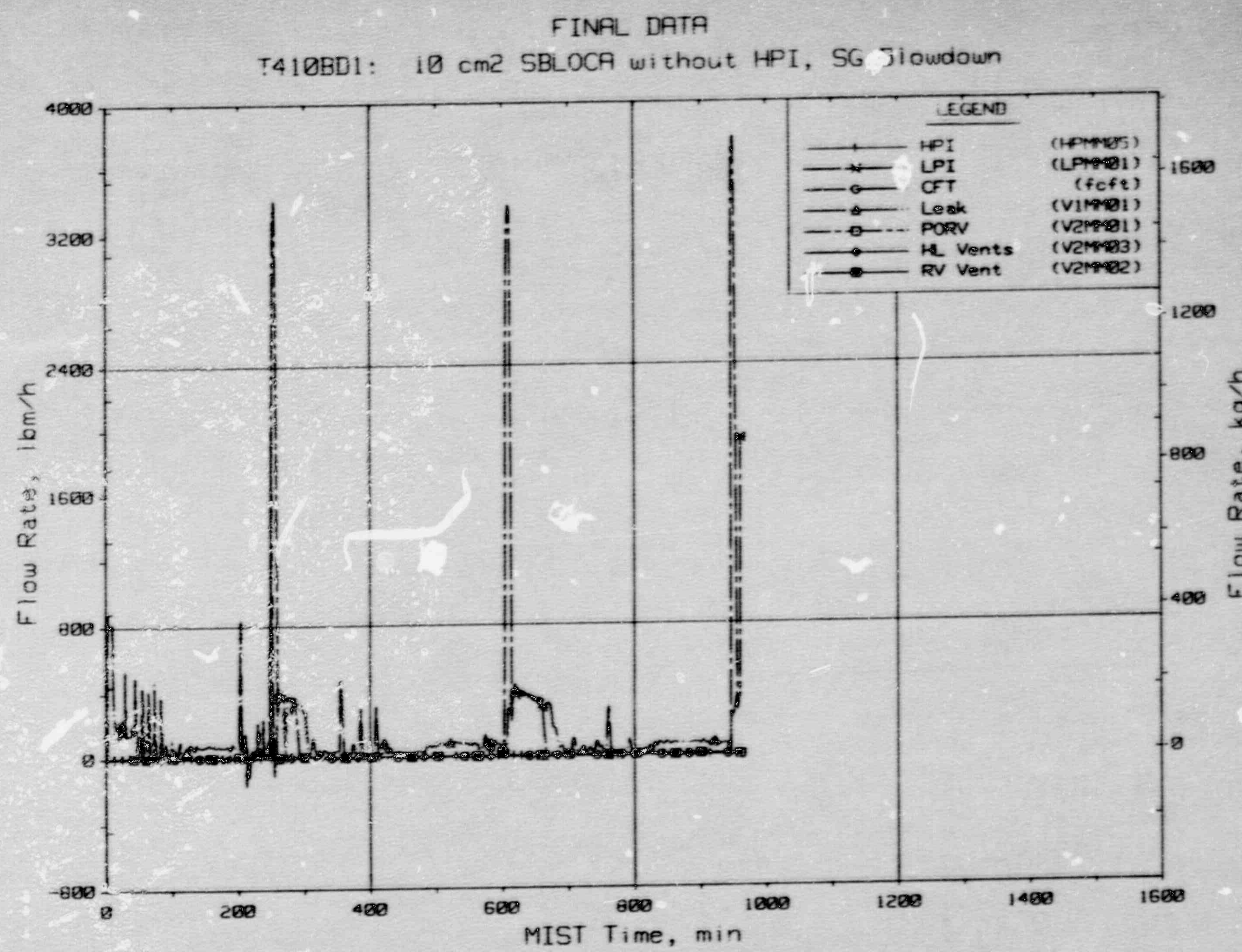



Figure A.32 Primary System Boundary Flow Rates

PRFL3x

Tue Nov 1 09:57:59 1988

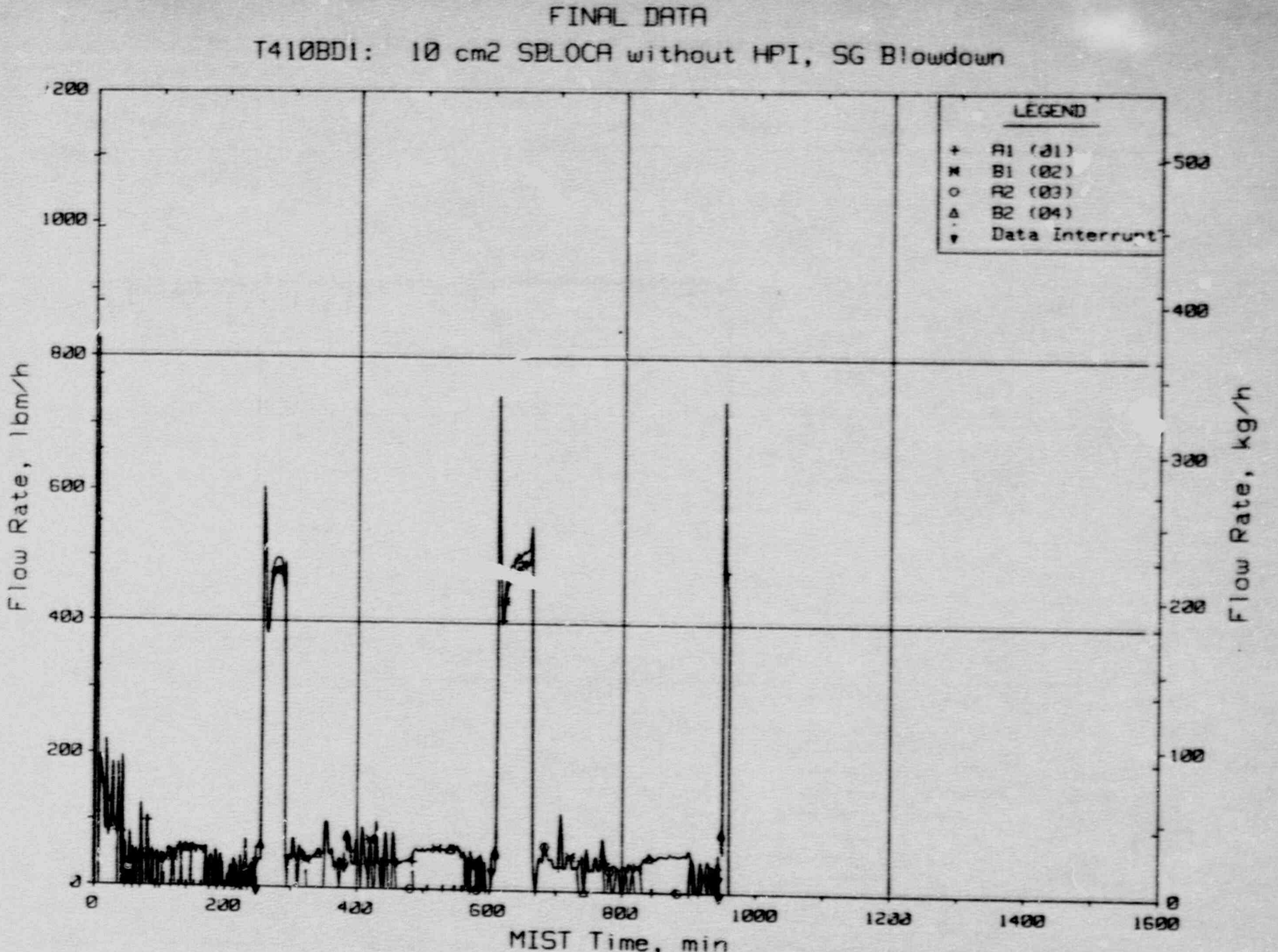



Figure A.33 Reactor Vessel Vent Valve Flow Rates (RVORs)

Sun Oct 30 15:54:47 1988

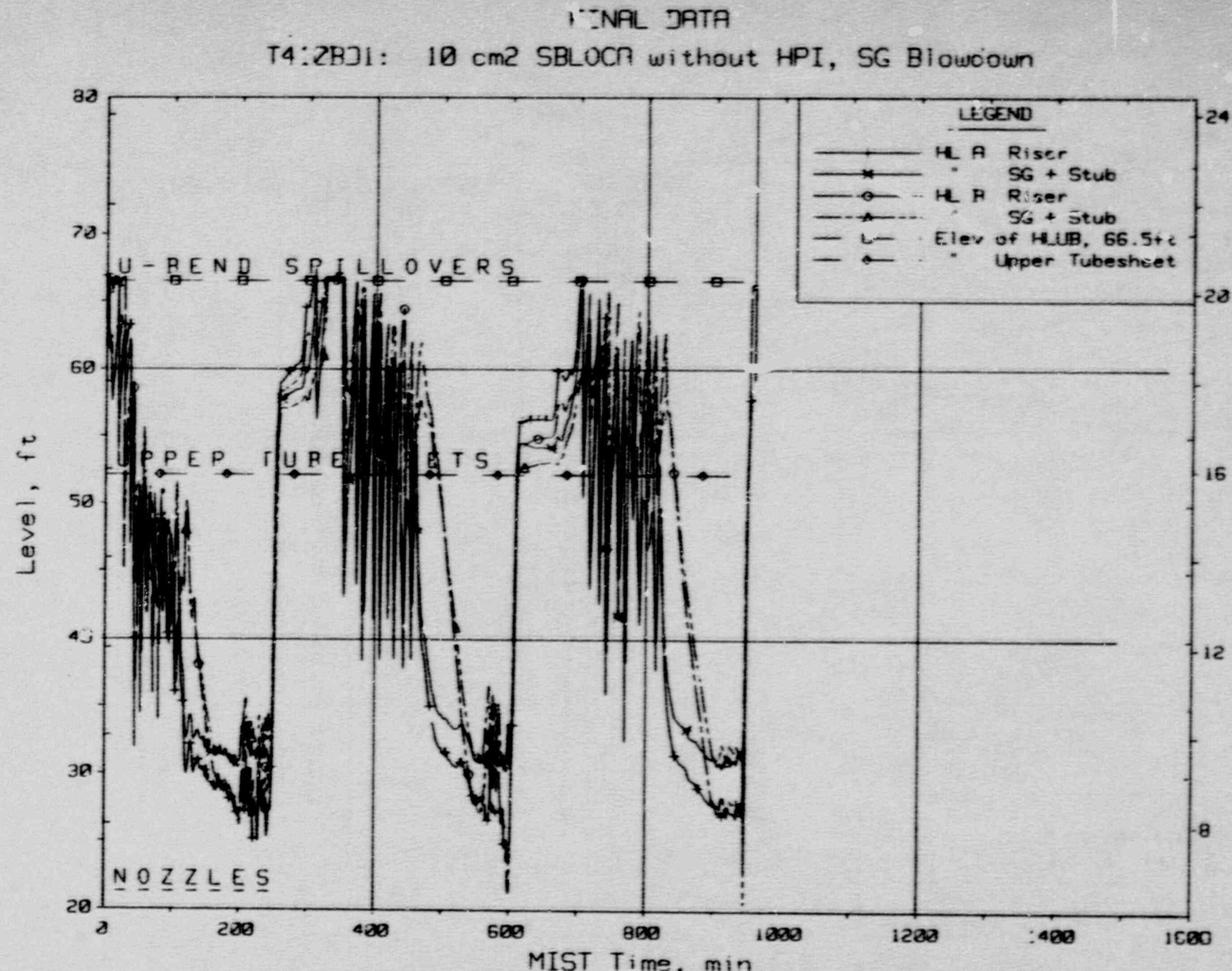



Figure A.34 Hot Leg Riser and Stub Collapsed Liquid Levels

Tue Nov 1 11:36:00 1988

HLLV1

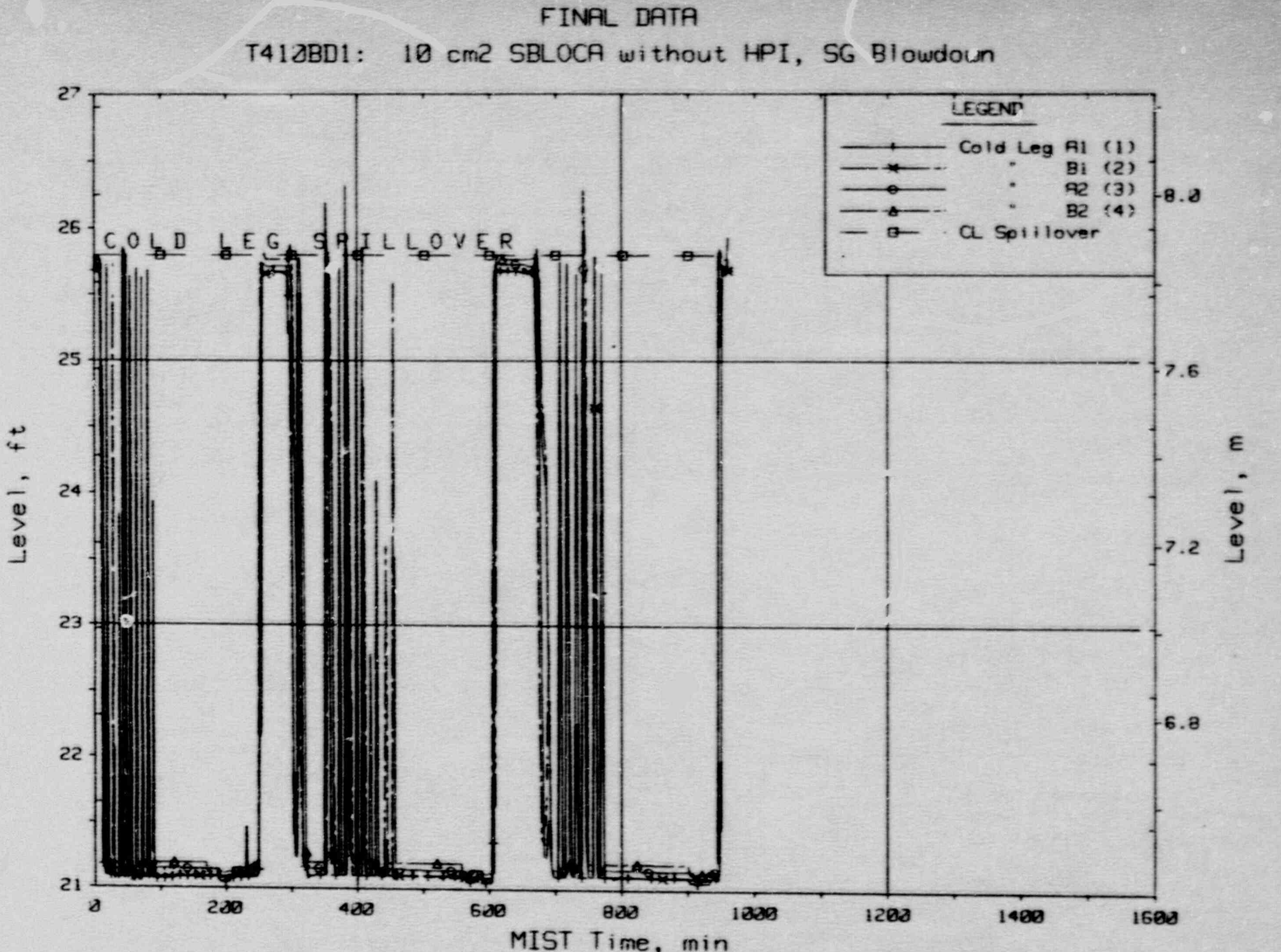



Figure A.35 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Sun Oct 30 15:47:59 1988



CLL·5

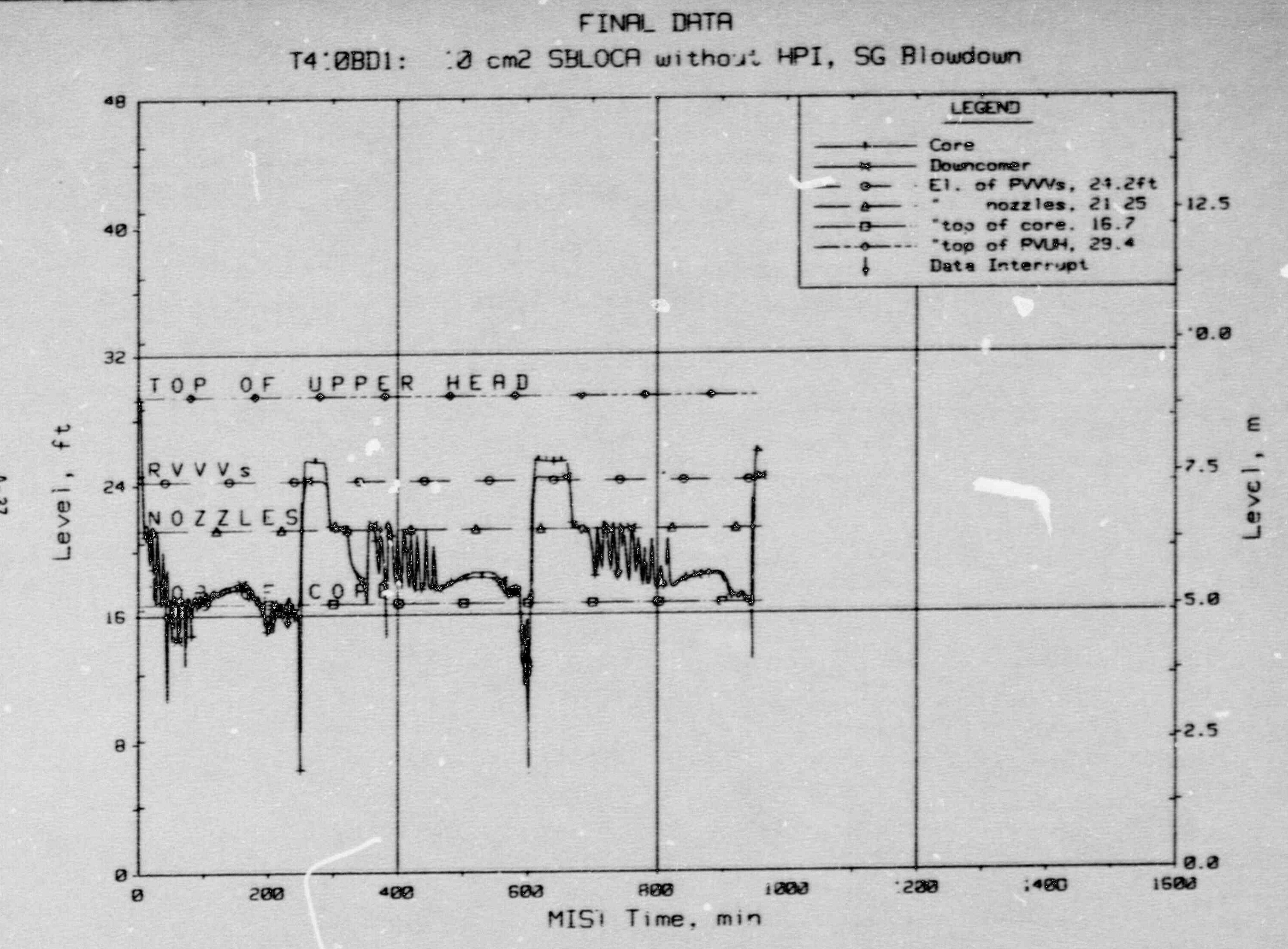



Figure A.36 Core Region Collapsed Liquid Levels

A-37

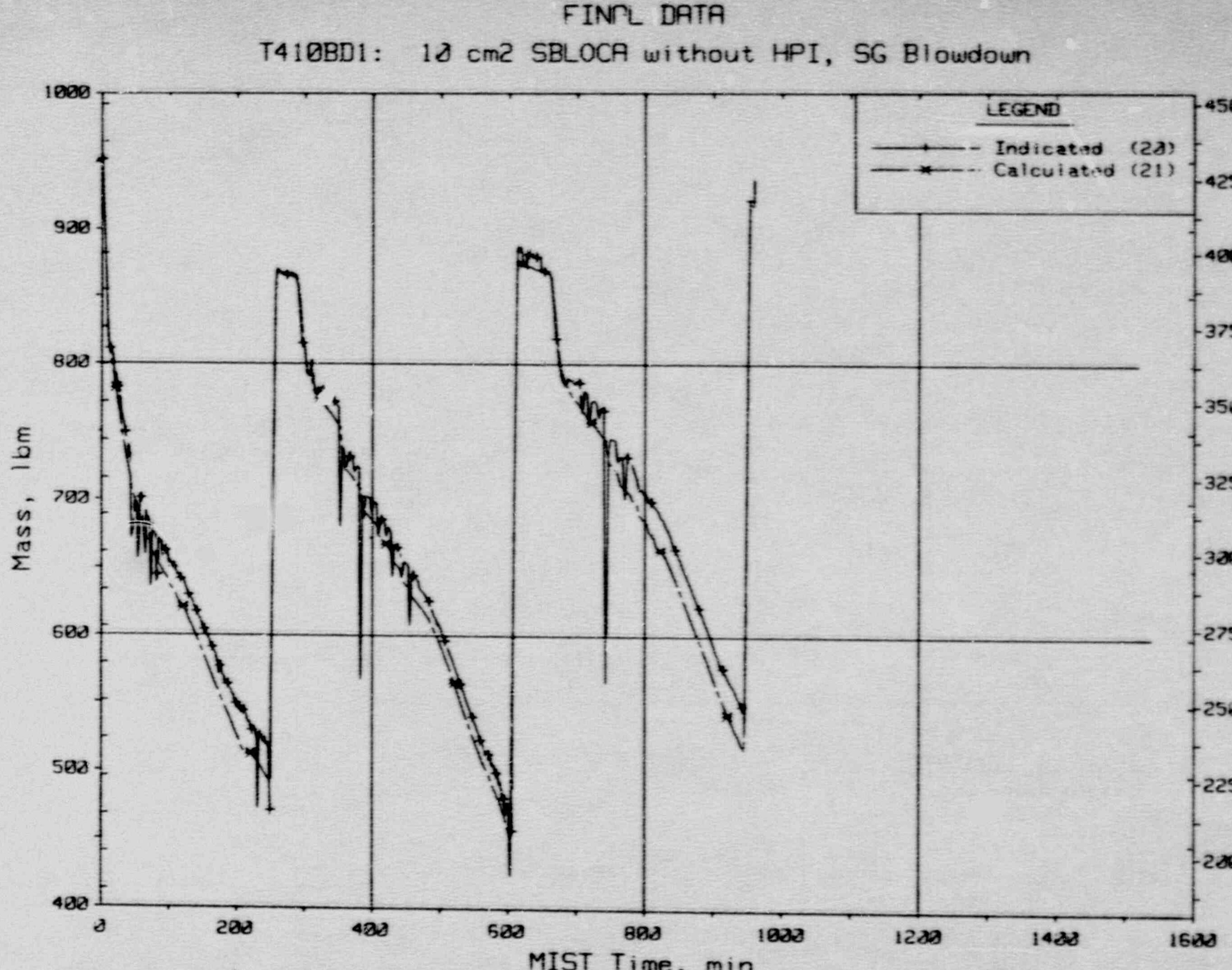





Figure A.37 Primary System Total Fluid Mass (PLMLs)

Sun Oct 30 15:40::0 1988

PRML1

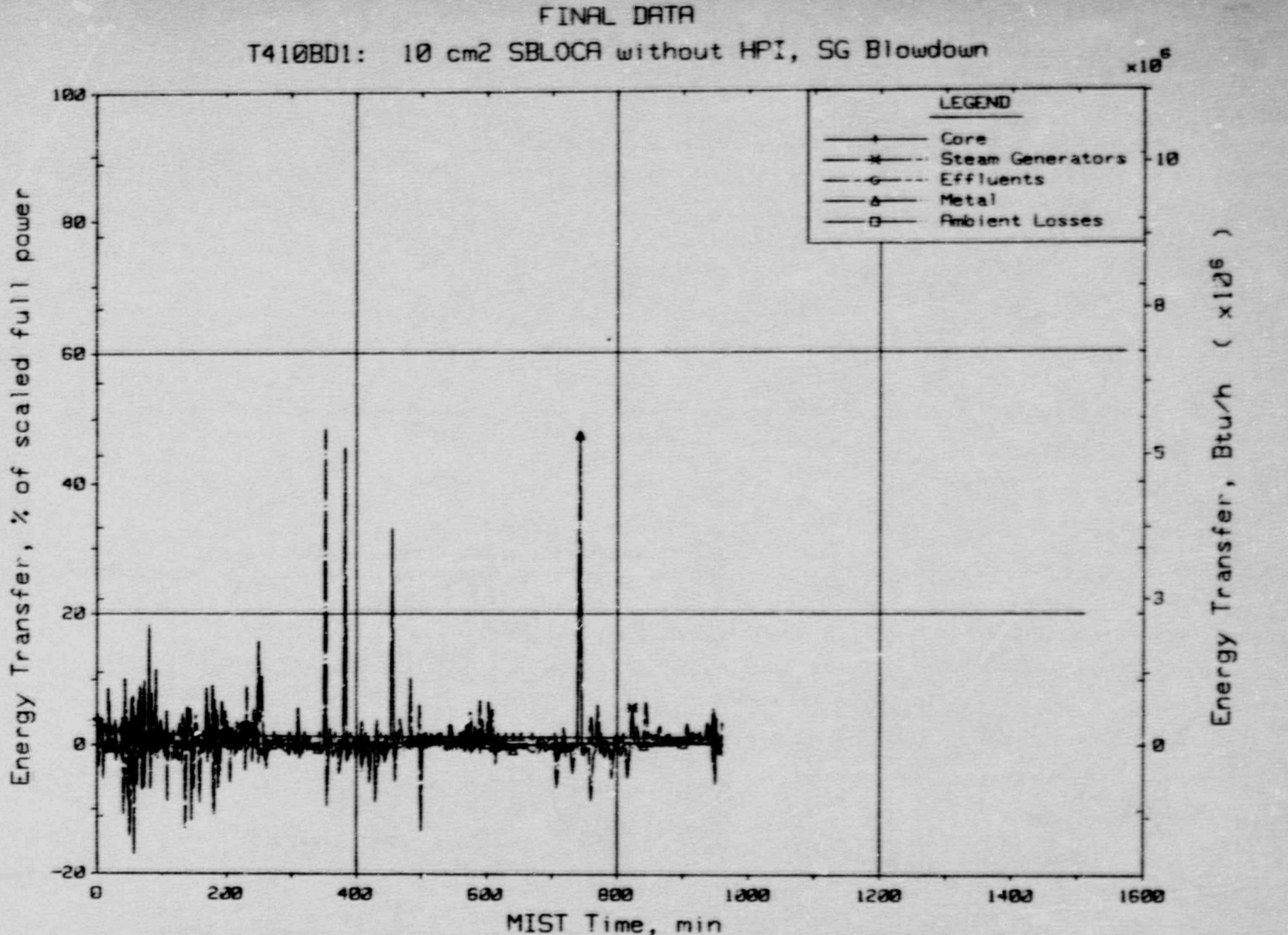



Figure A.38 Primary System Energy Transfer

Sun Oct 30 15:37:59 1988

PROE1X

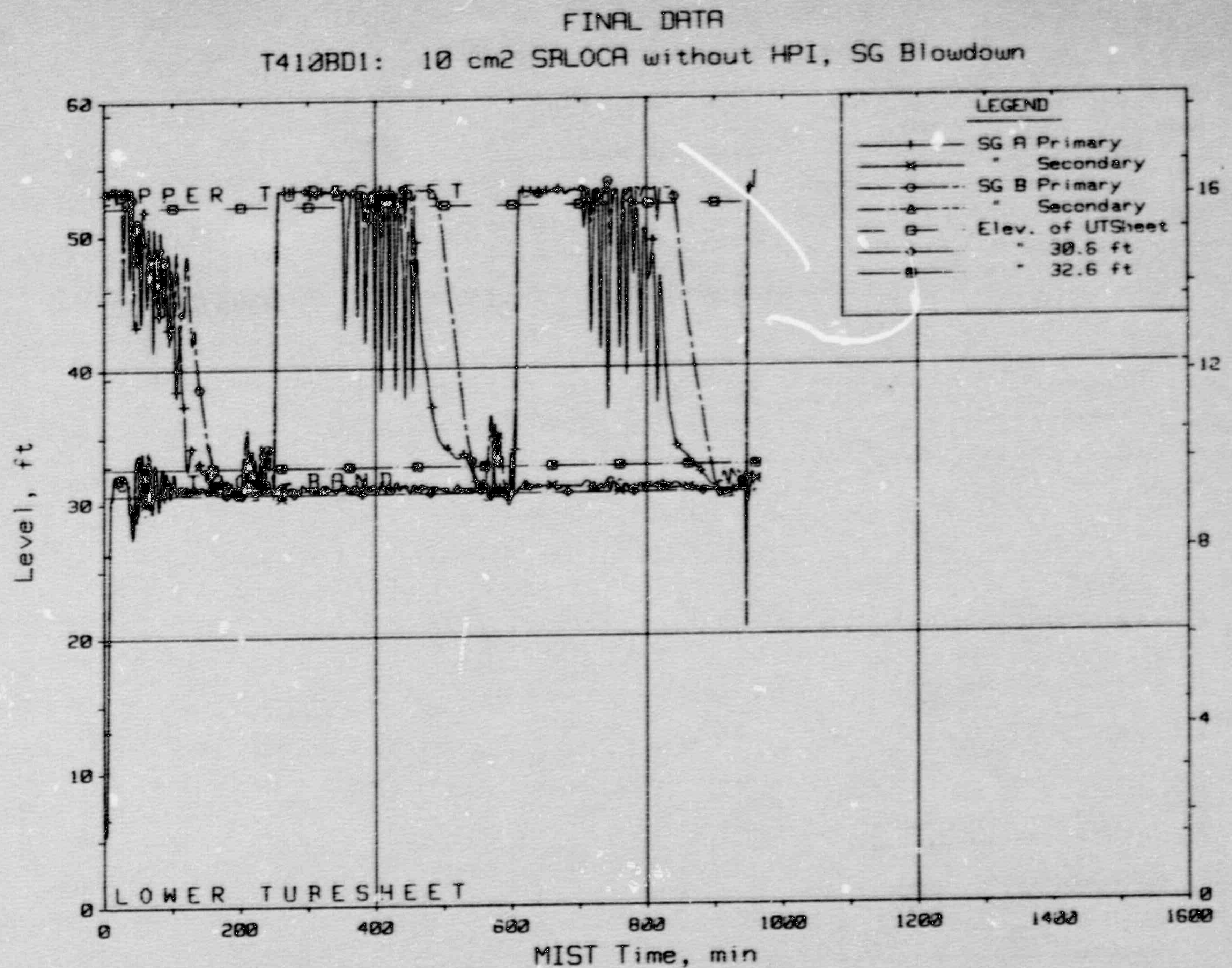



Figure A.39 Steam Generator Collapsed Liquid Levels

SGLV2

Sun Oct 30 15:34:01 1988

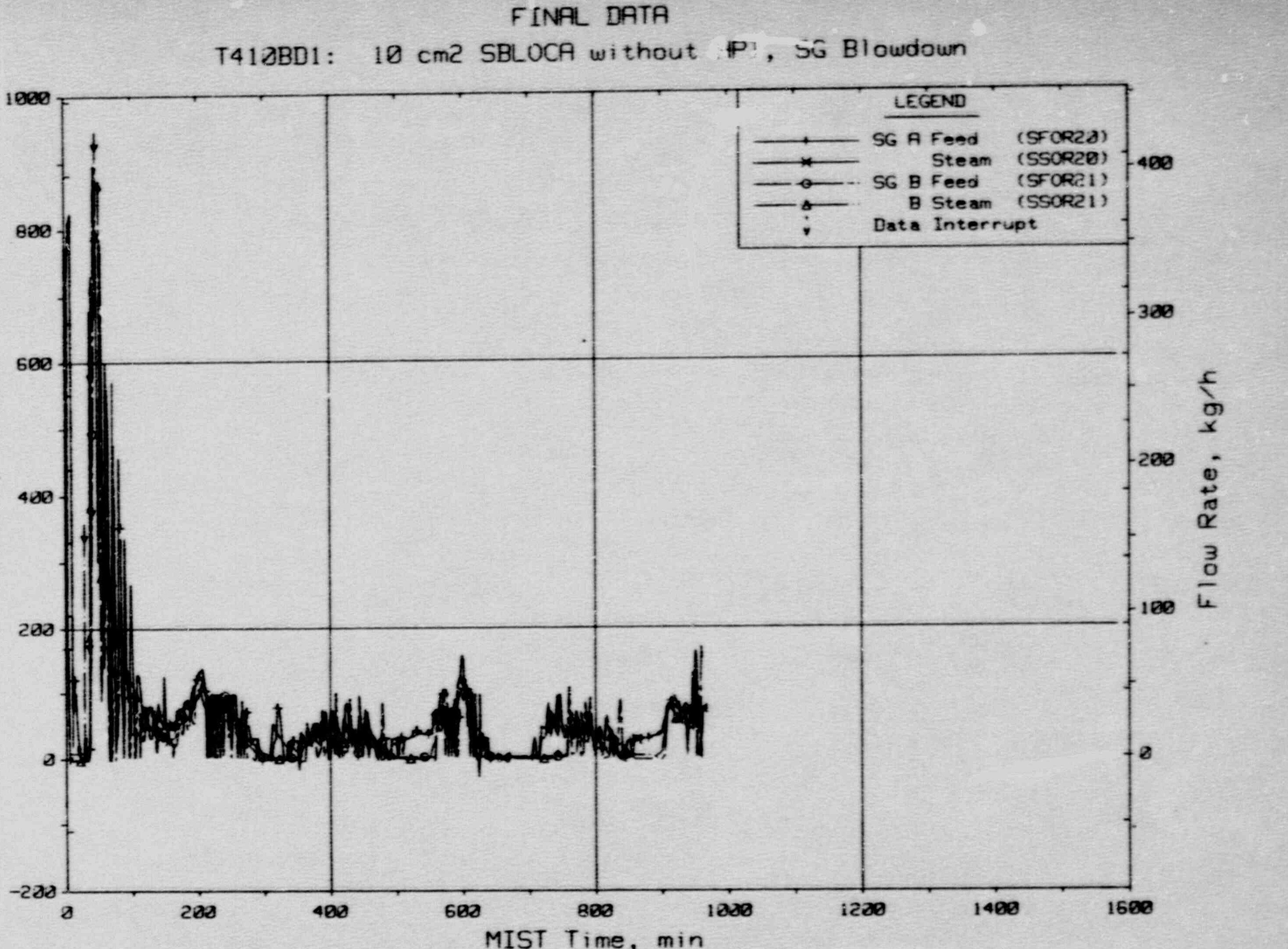



Figure A.40 Steam Generator Secondary Flow Rates

Sat Oct 29 16:43:13 1988

SGFL3

MIST Phase IV Test 4100B2

Larger SBLOCA, 100 $cm^2$

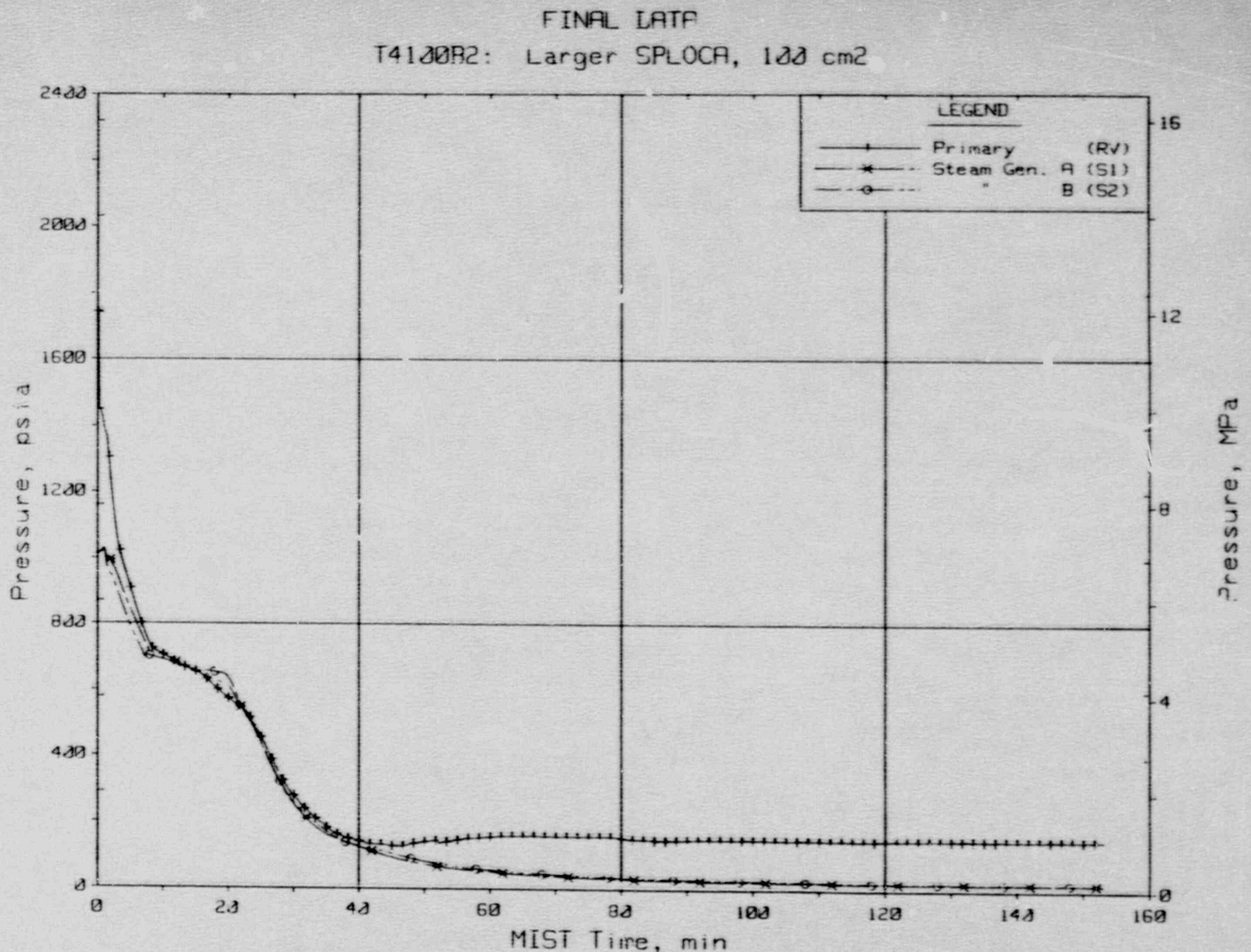



Figure A.41 Primary and Secondary System Pressures (GP01s)

Thu Oct 27 14:37:20 1988

PSGP1

FINAL DATA

T4100B2: Larger SBLOCA, 100 cm2

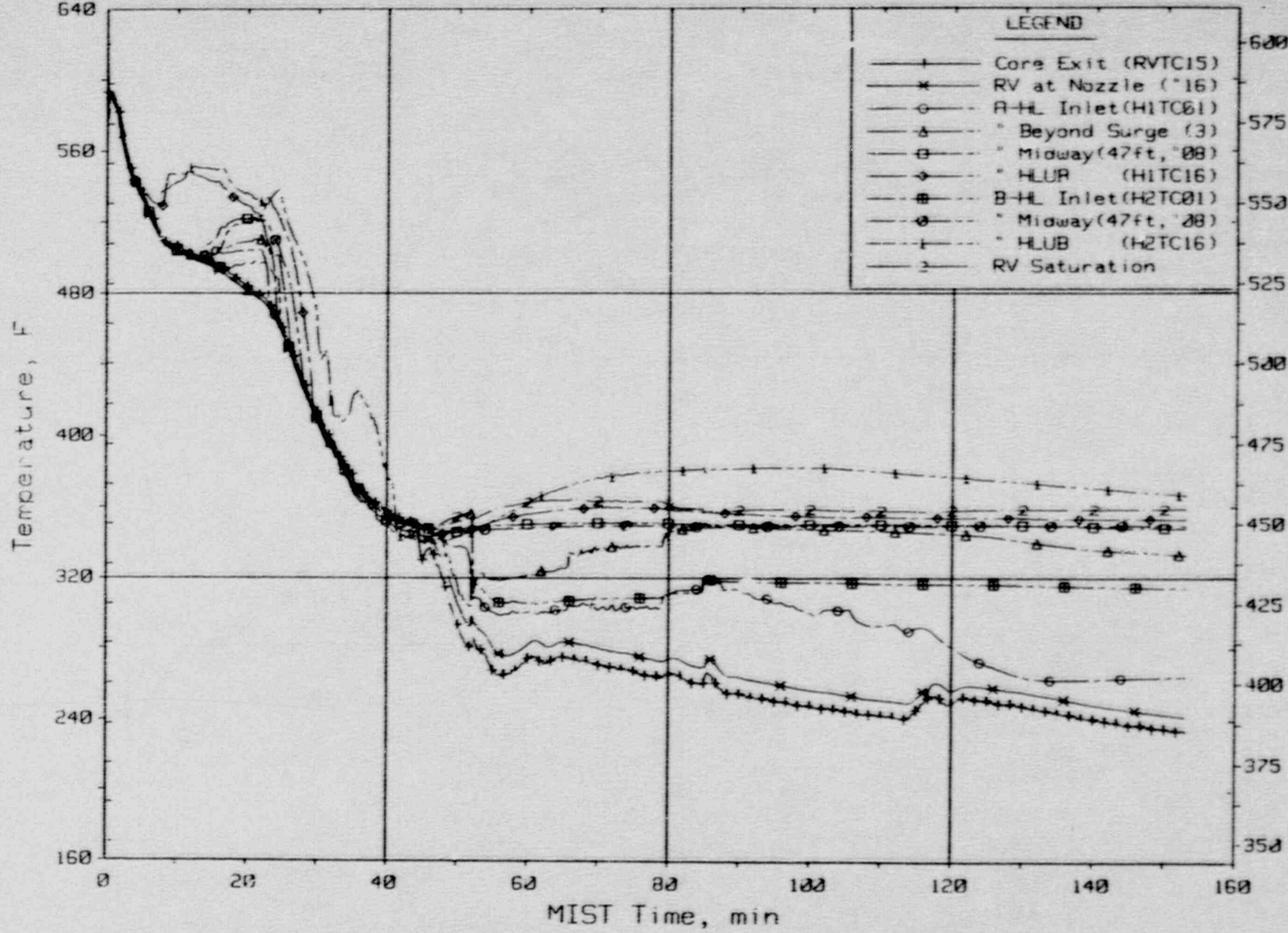



Figure A.42 Composite Core Exit and Hot Leg Fluid Temperatures



PRKT1

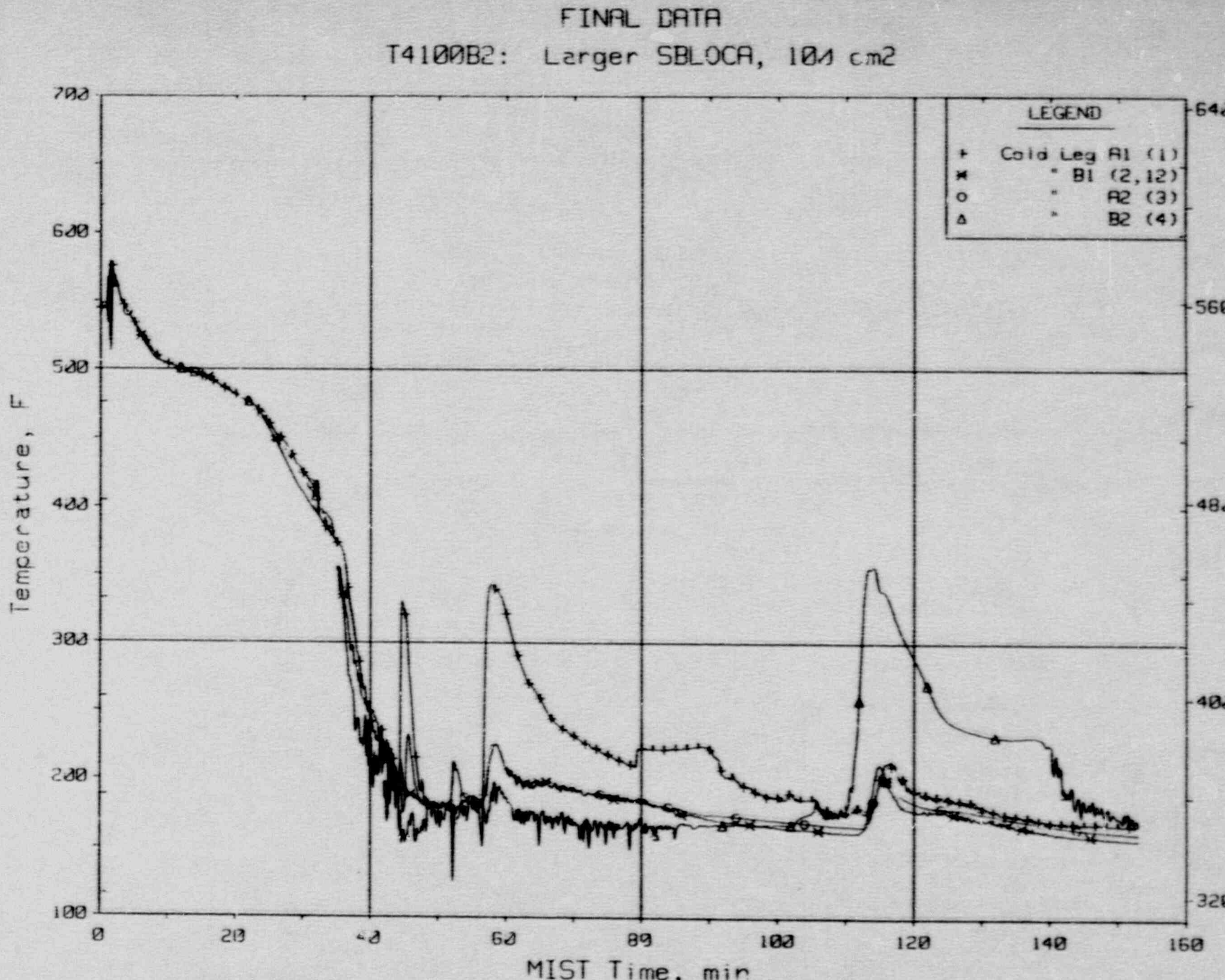



Figure A.43 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

CLTC1

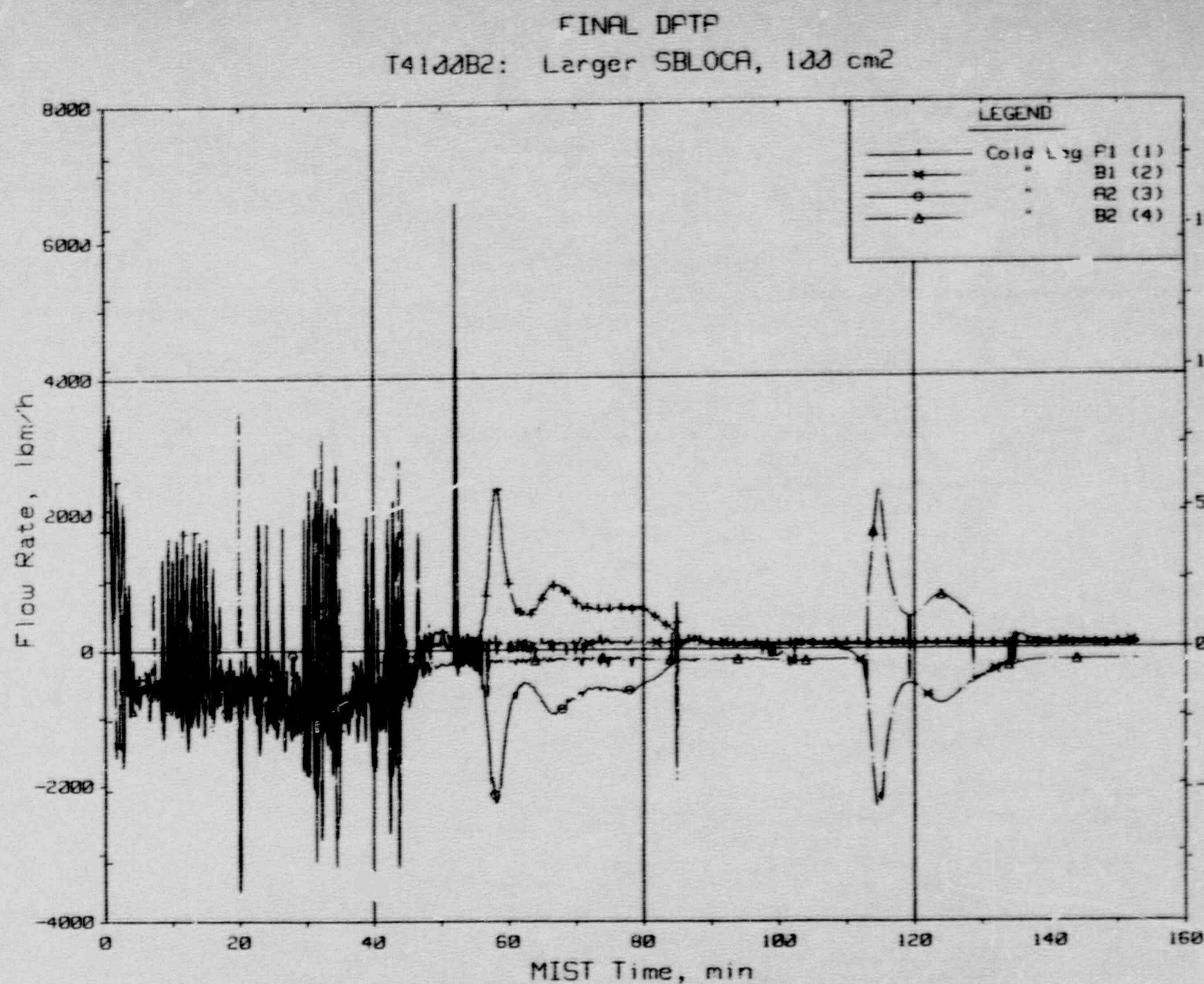



**Figure A.44 Cold Leg (Venturi) Flow Rates (CnVN20s)**

Thu Oct 27 10:25:09 1988

CLFL0

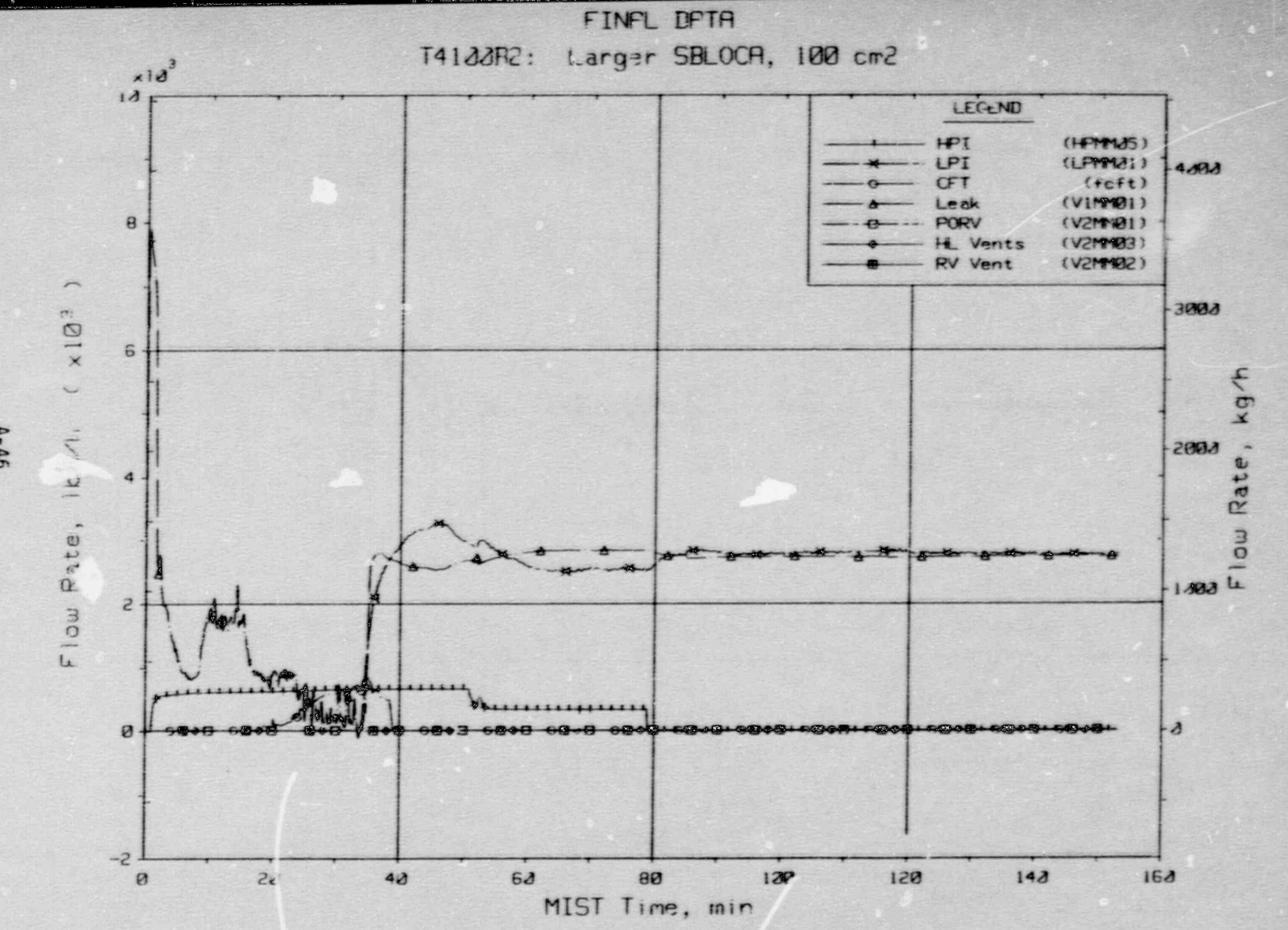



Figure A.45 Primary System Boundary Flow Rates

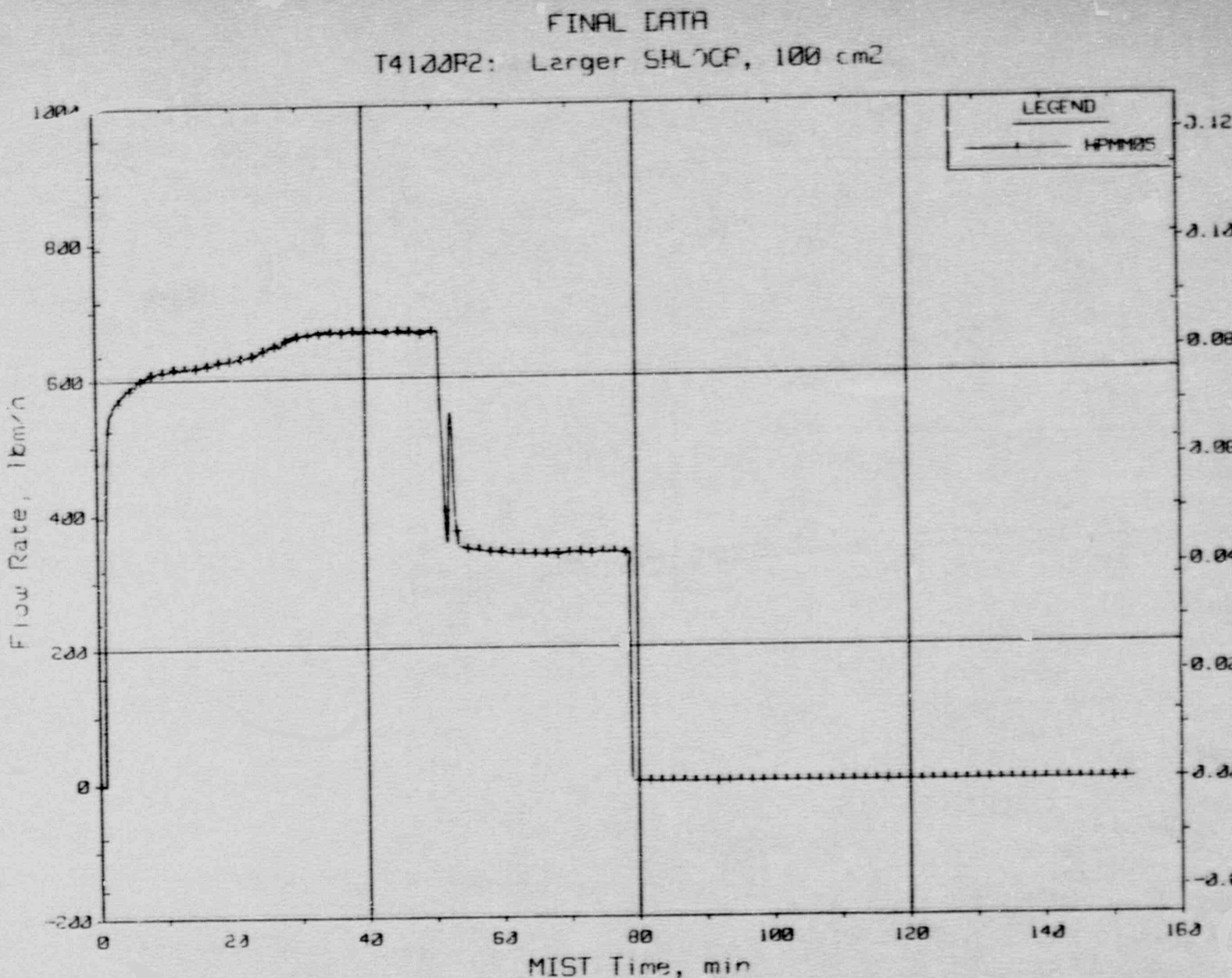



Figure A.46 HPI Total Flow Rate

HPFL3

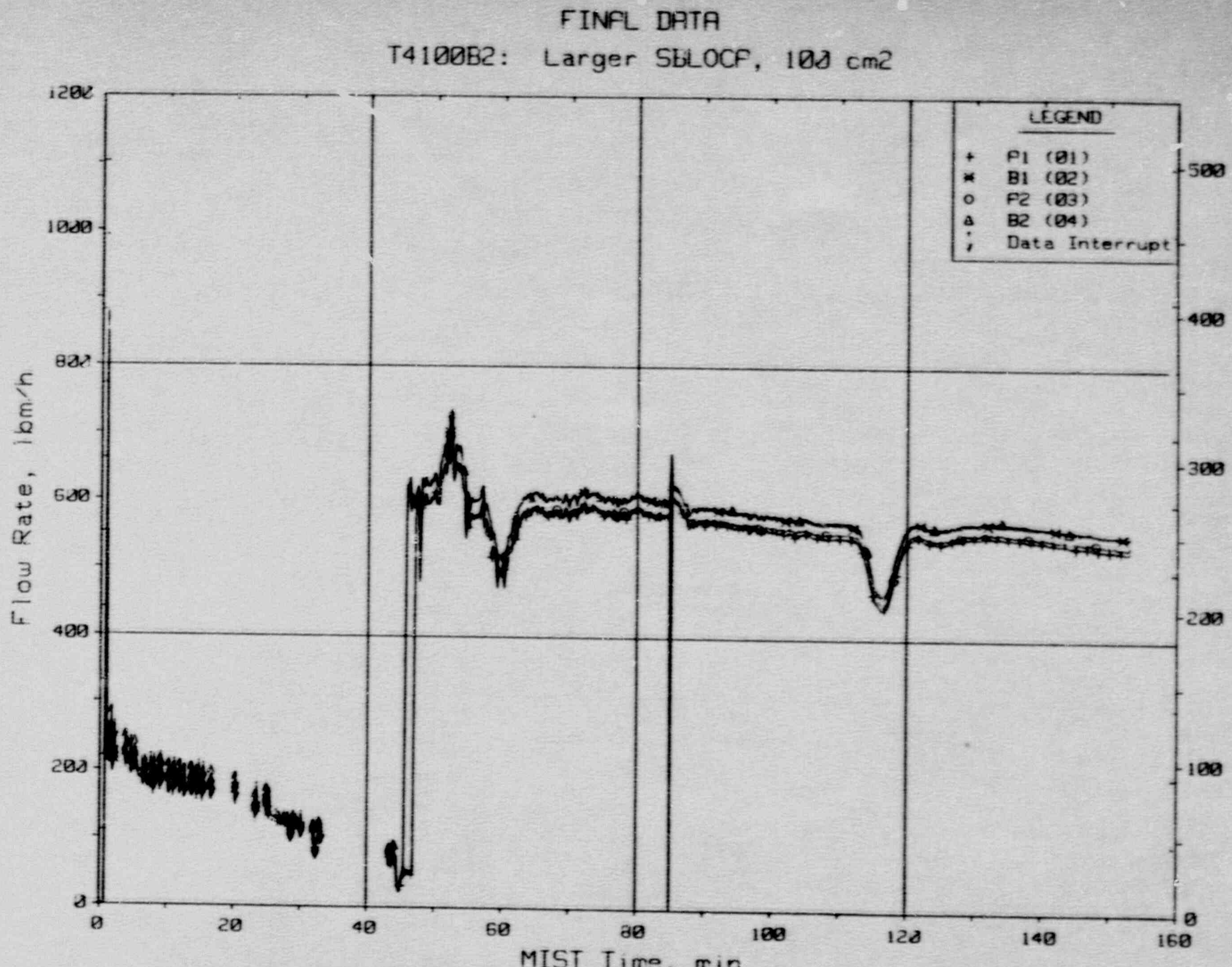



**Figure A.47 Reactor Vessel Vent Valve Flow Rates (RVORs)**

Thu Oct 27 10:10:50 1988

VVFL1

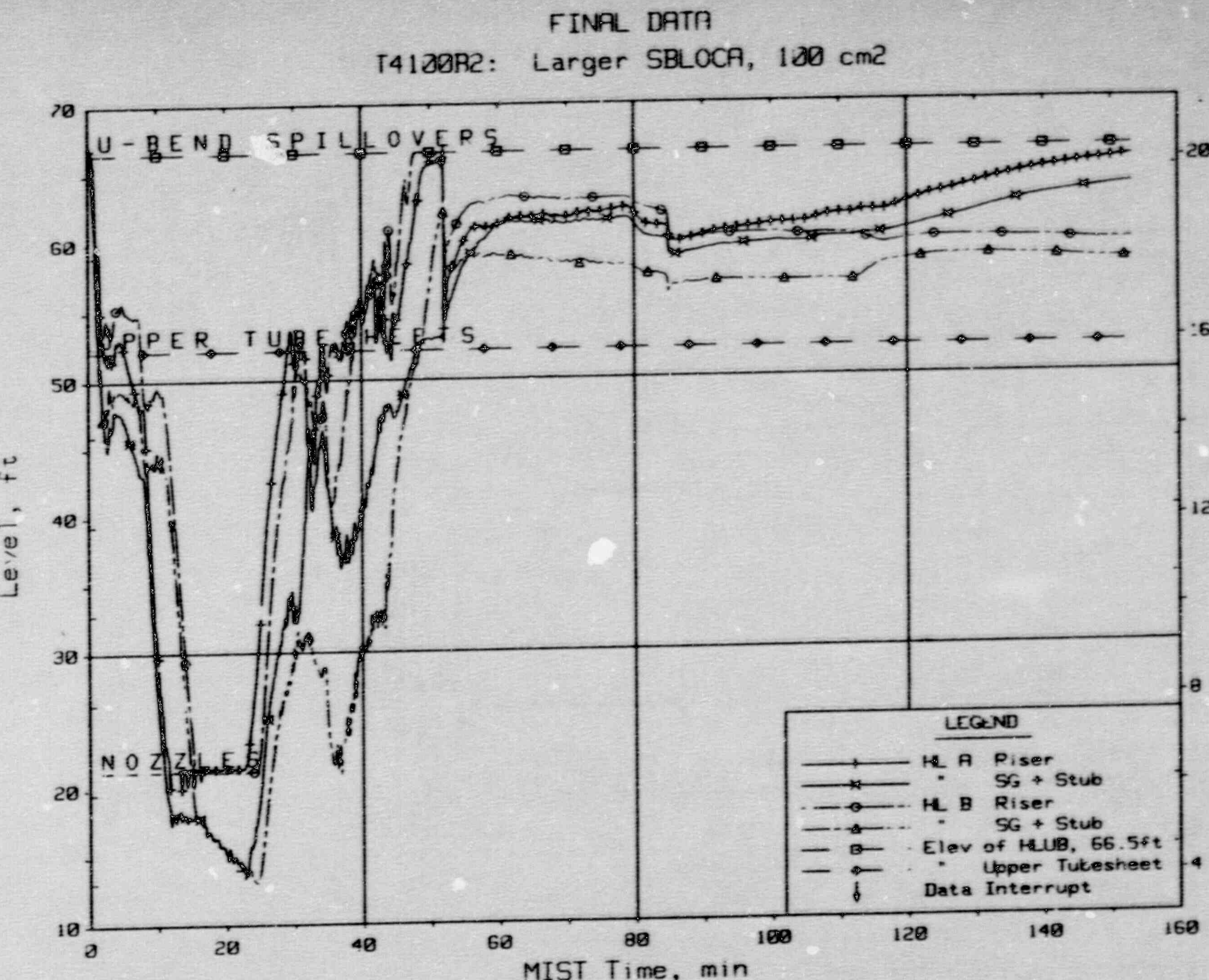



Figure A.48 Hot Leg Riser and Stub Collapsed Liquid Levels

HLLV1

thu Oct 27 12:57:06 1988

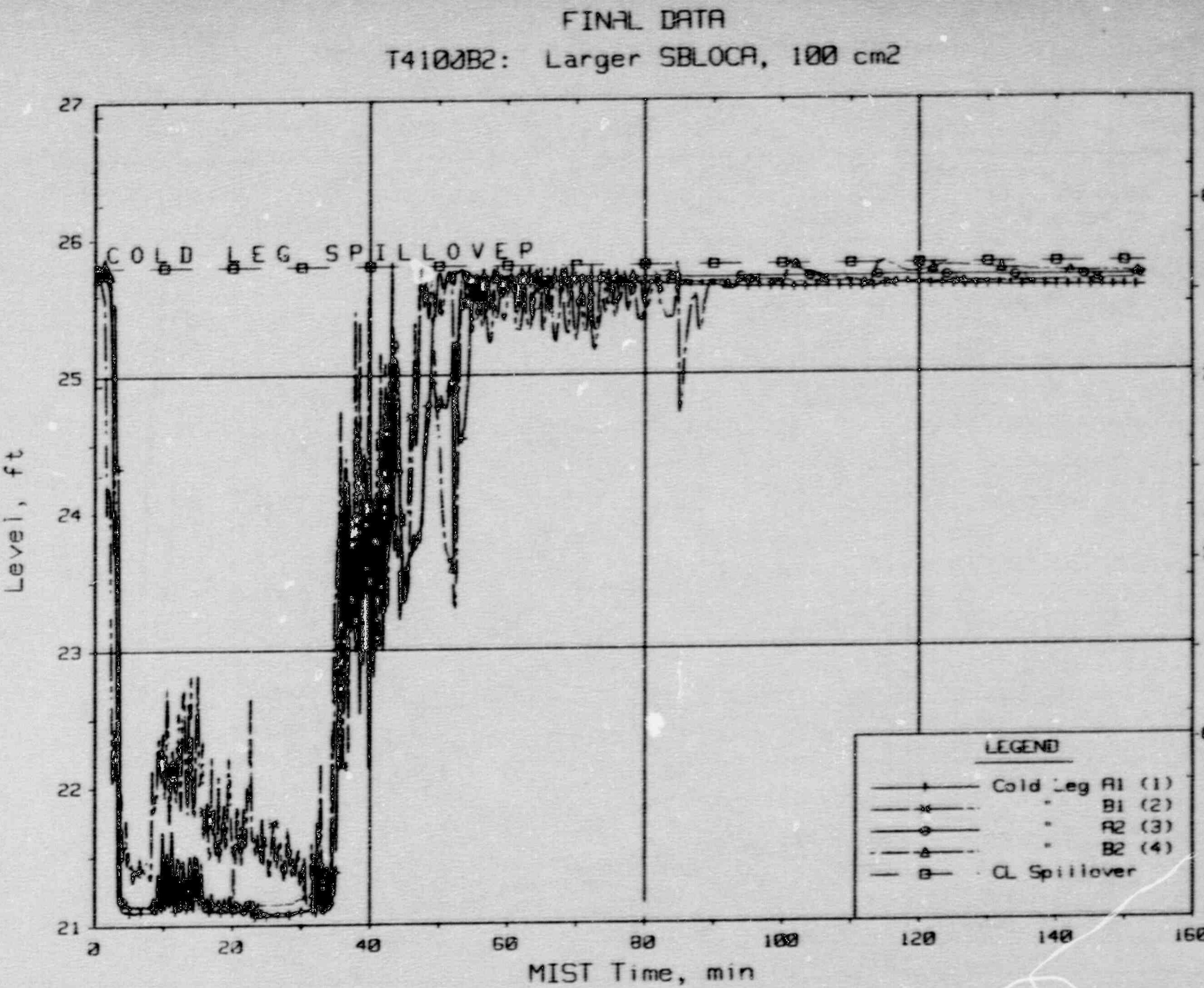



Figure A.49 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

CLLV5

Thu Oct 27 13:23:27 1988

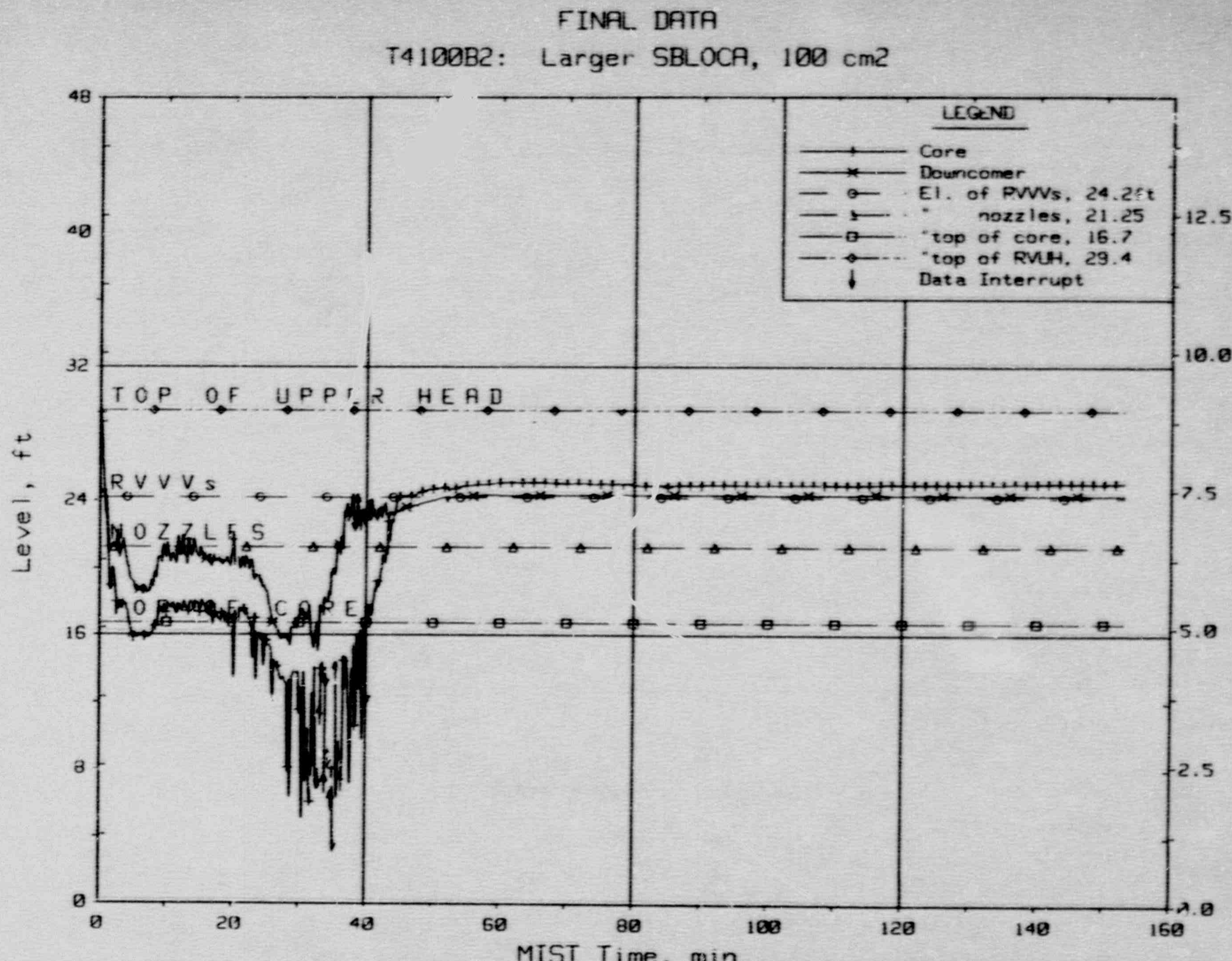



Figure A.50 Core Region Collapsed Liquid Levels

Thu Oct 27 13:09:18 1988

COLV1

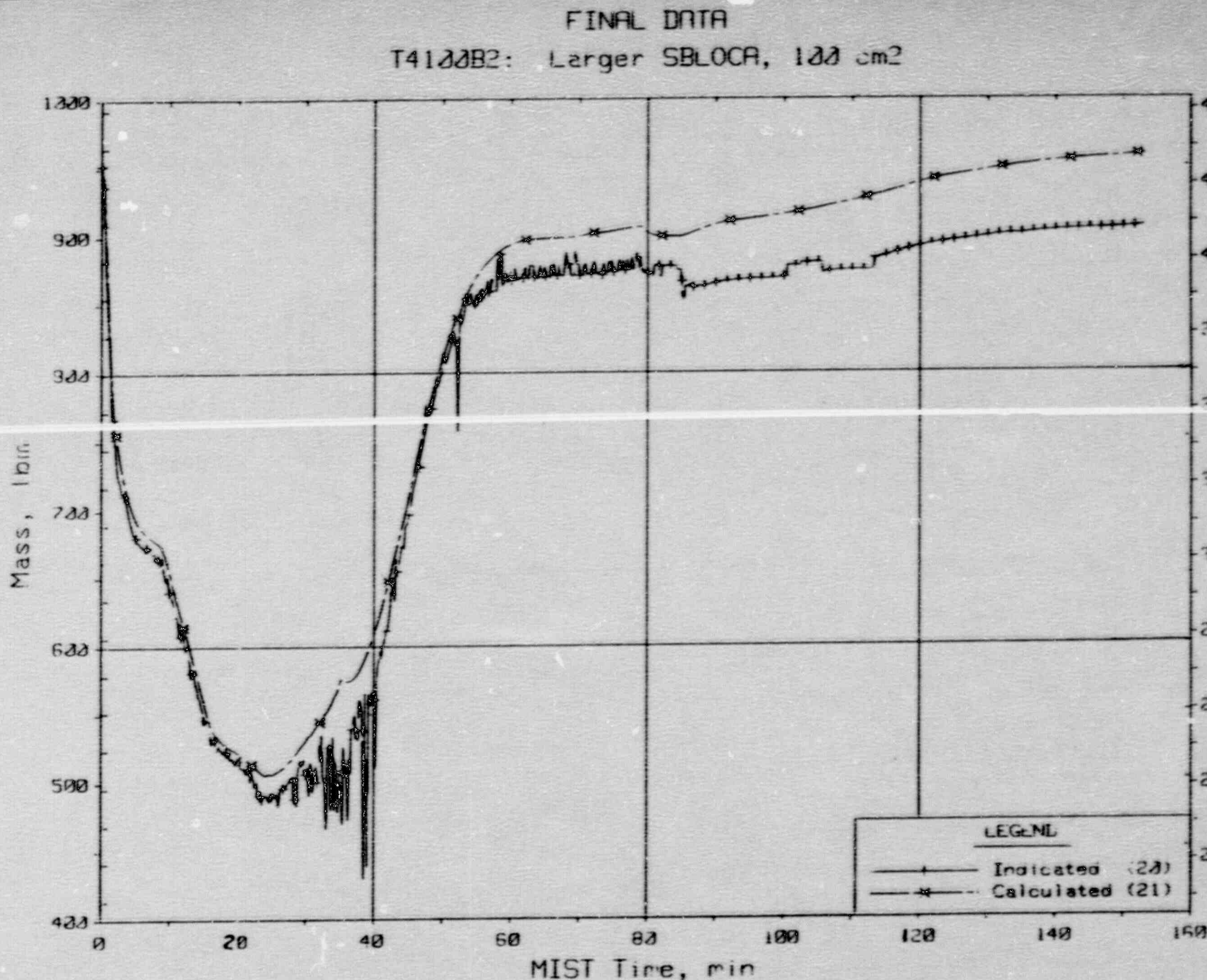



**Figure A.51 Primary System Total Fluid Mass (PLMLs)**

PRML1

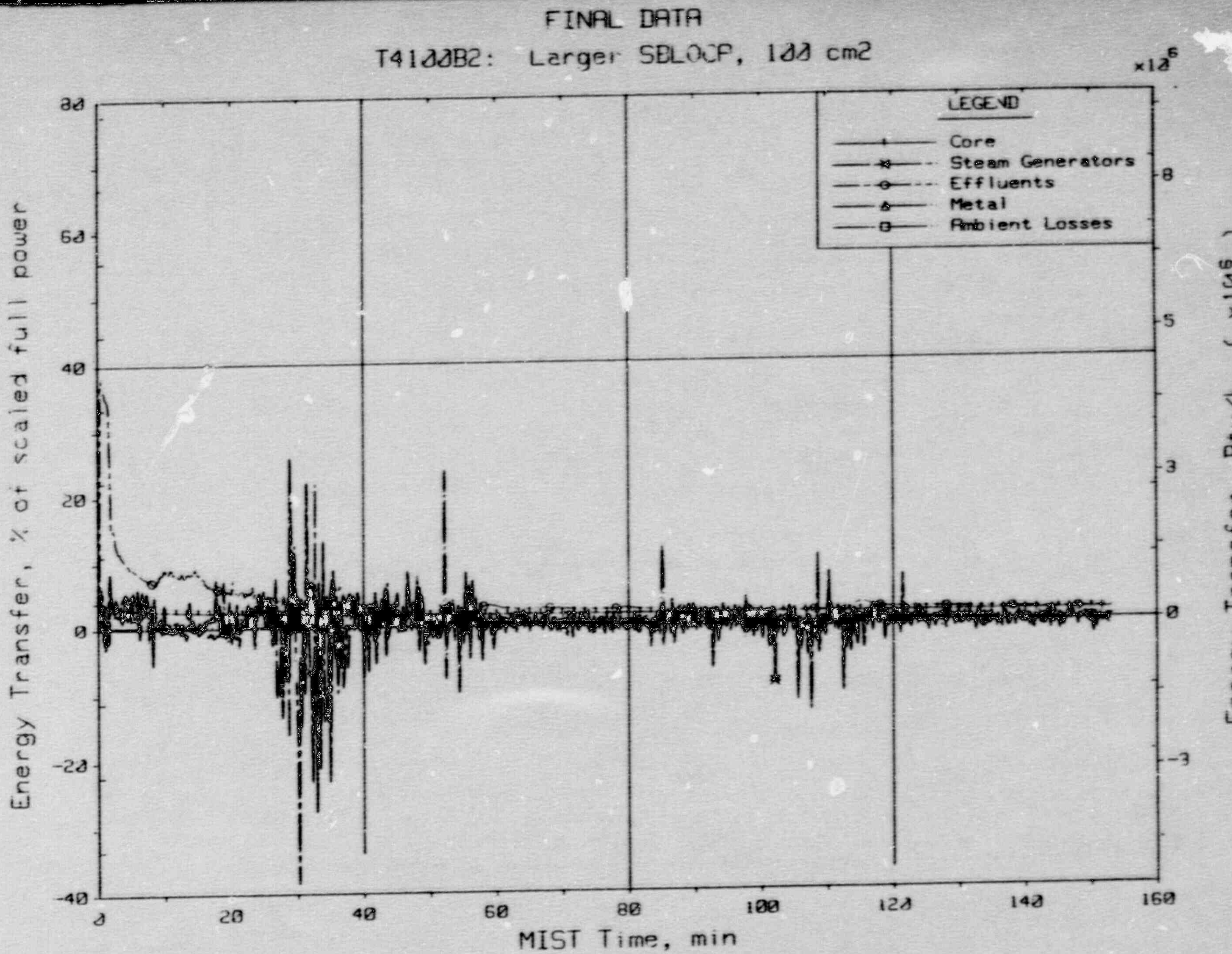
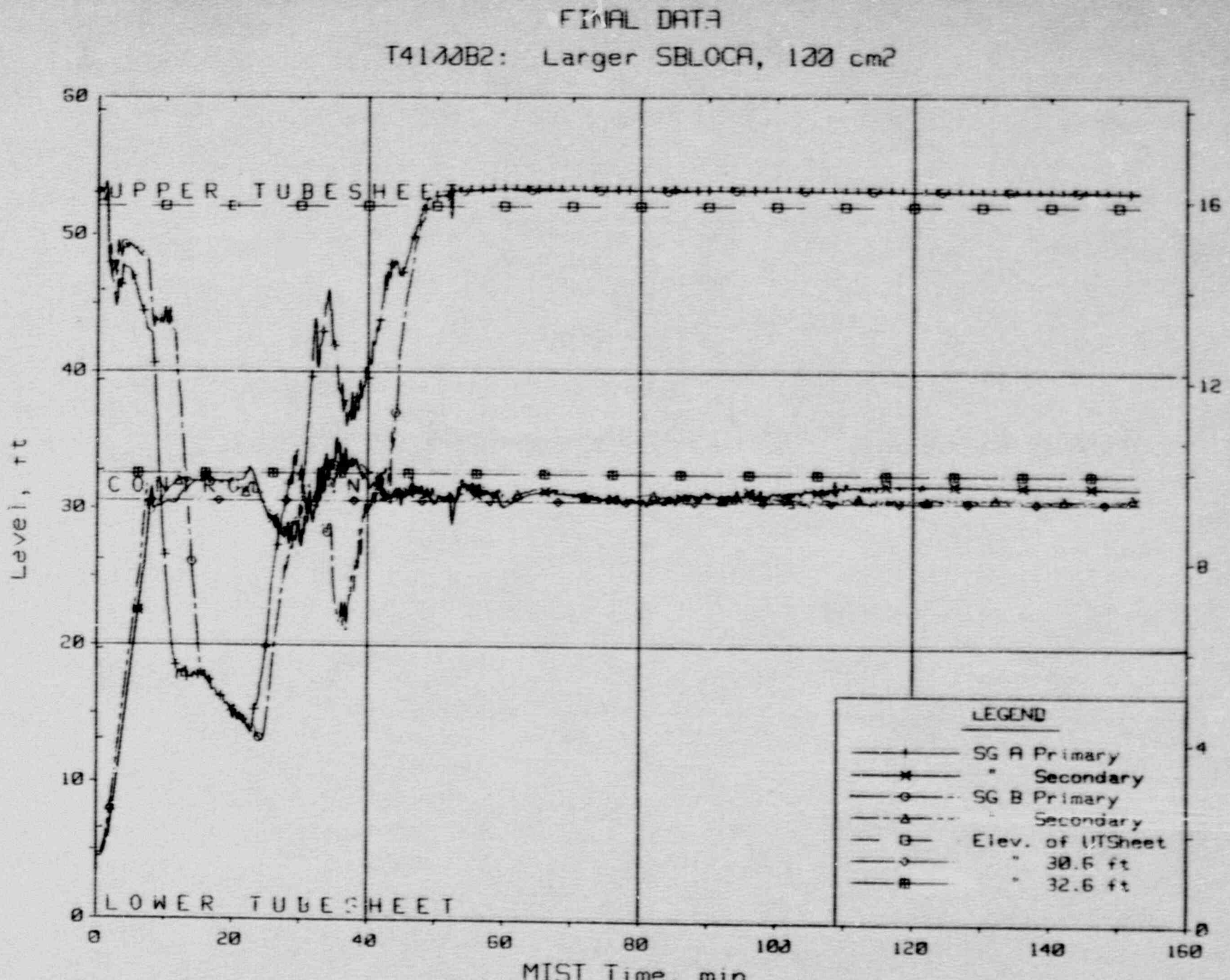



**Figure A.52 Primary System Energy Transfer**

PROE1X

Thu Oct 27 09:46:11 1988




A-54

Figure A.53 Steam Generator Collapsed Liquid Levels

SGLV2

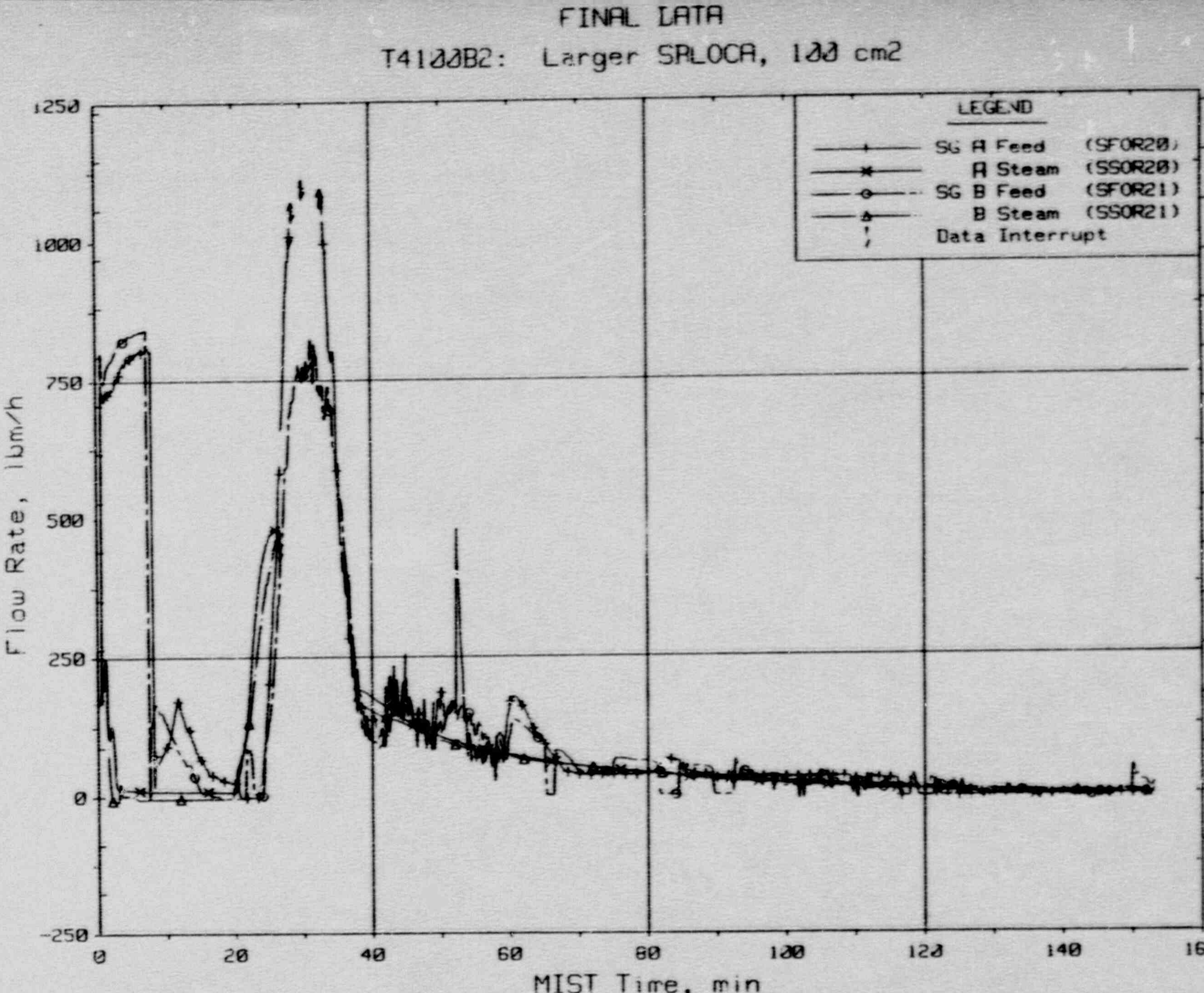



**Figure A.54 Steam Generator Secondary Flow Rates**

Thu Oct 27 09:36:48 1988

SGFL0

MIST Phase IV Test 4SB011

Station Blackout

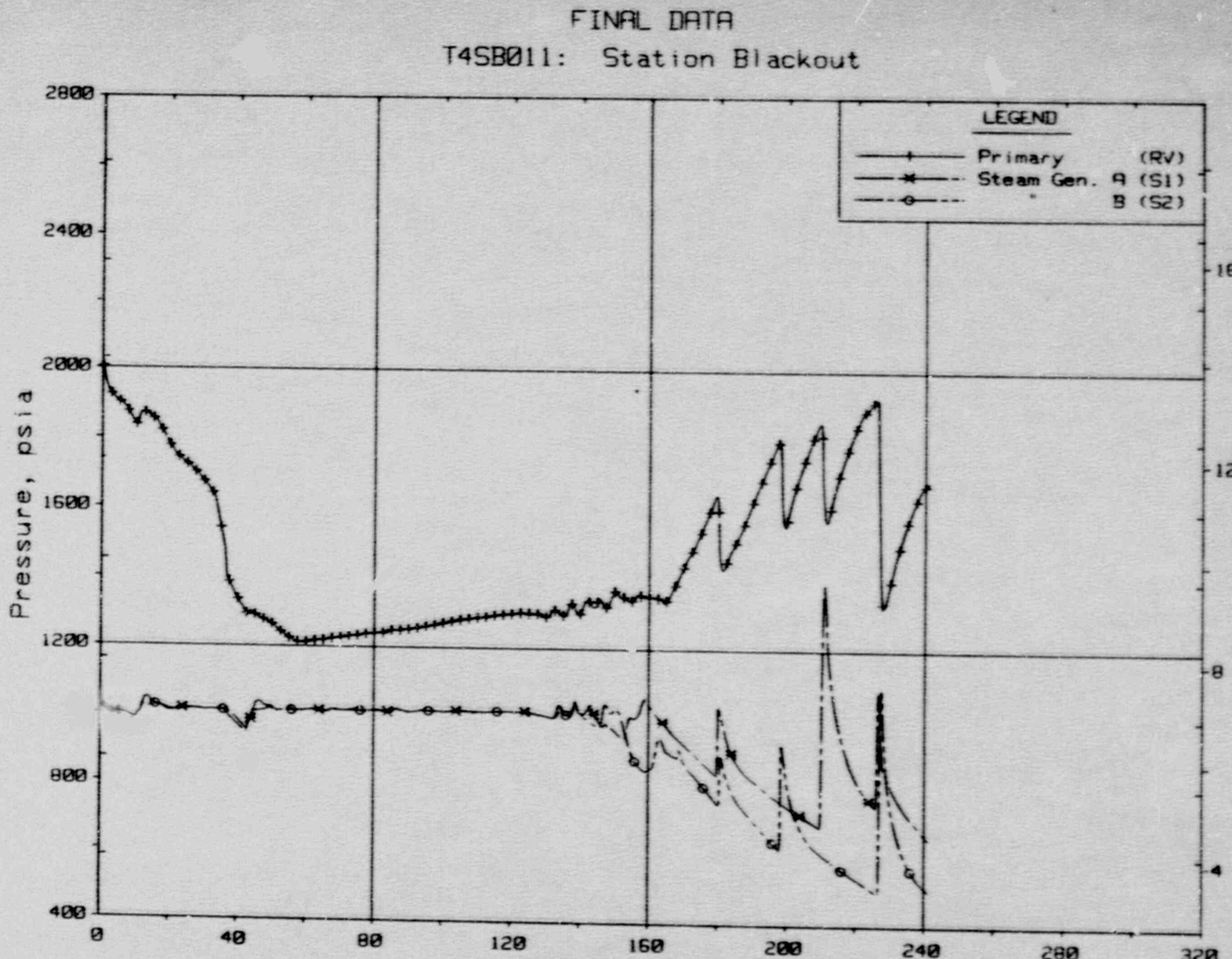



Figure A.55 Primary and Secondary System Pressures (GP01s)

Wed Nov 9 16:41:32 1988

PSGP1

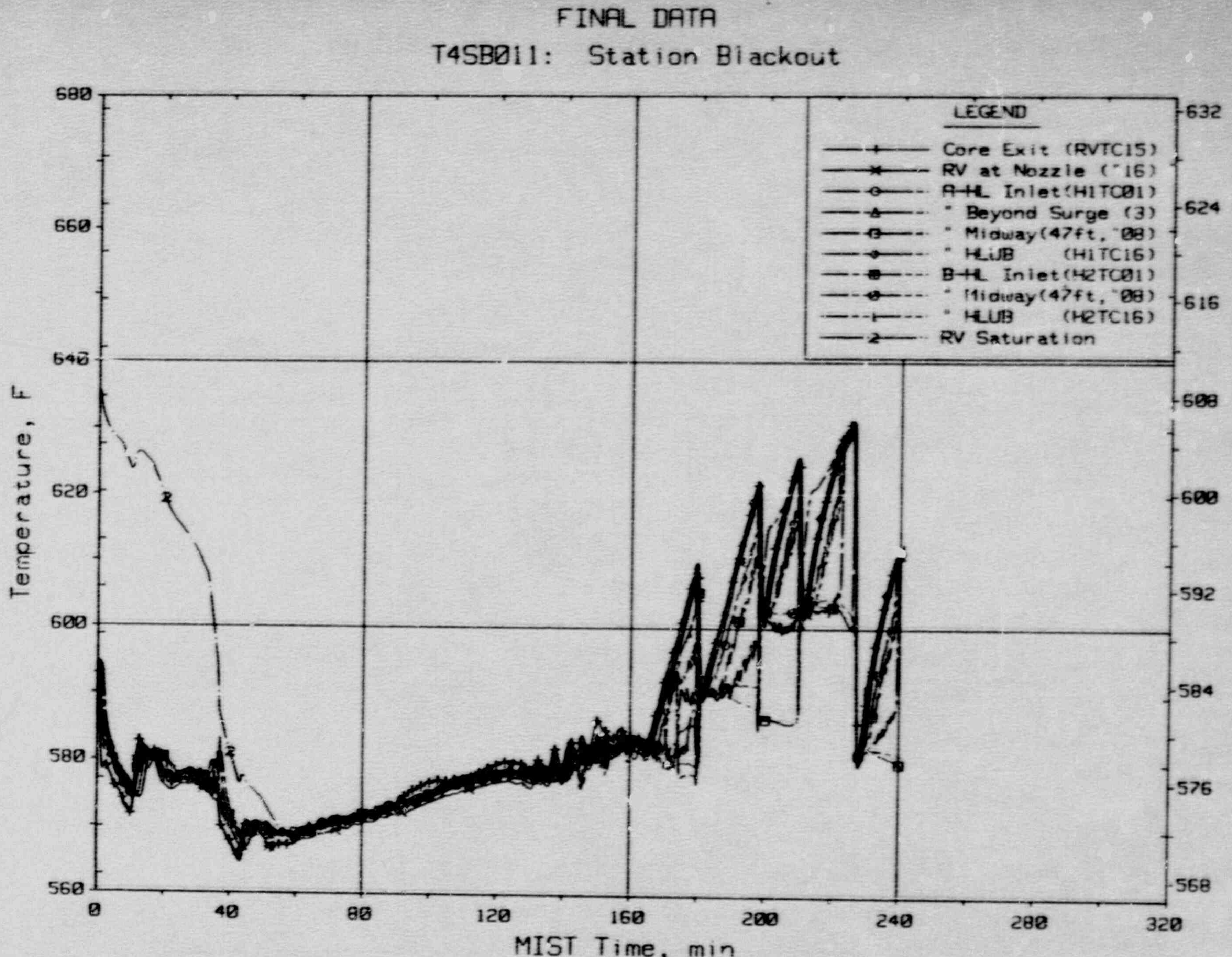



Figure A.56 Composite Core Exit and Hot Leg Fluid Temperatures

d Nov 9 16:37:50 1988

PRKT1

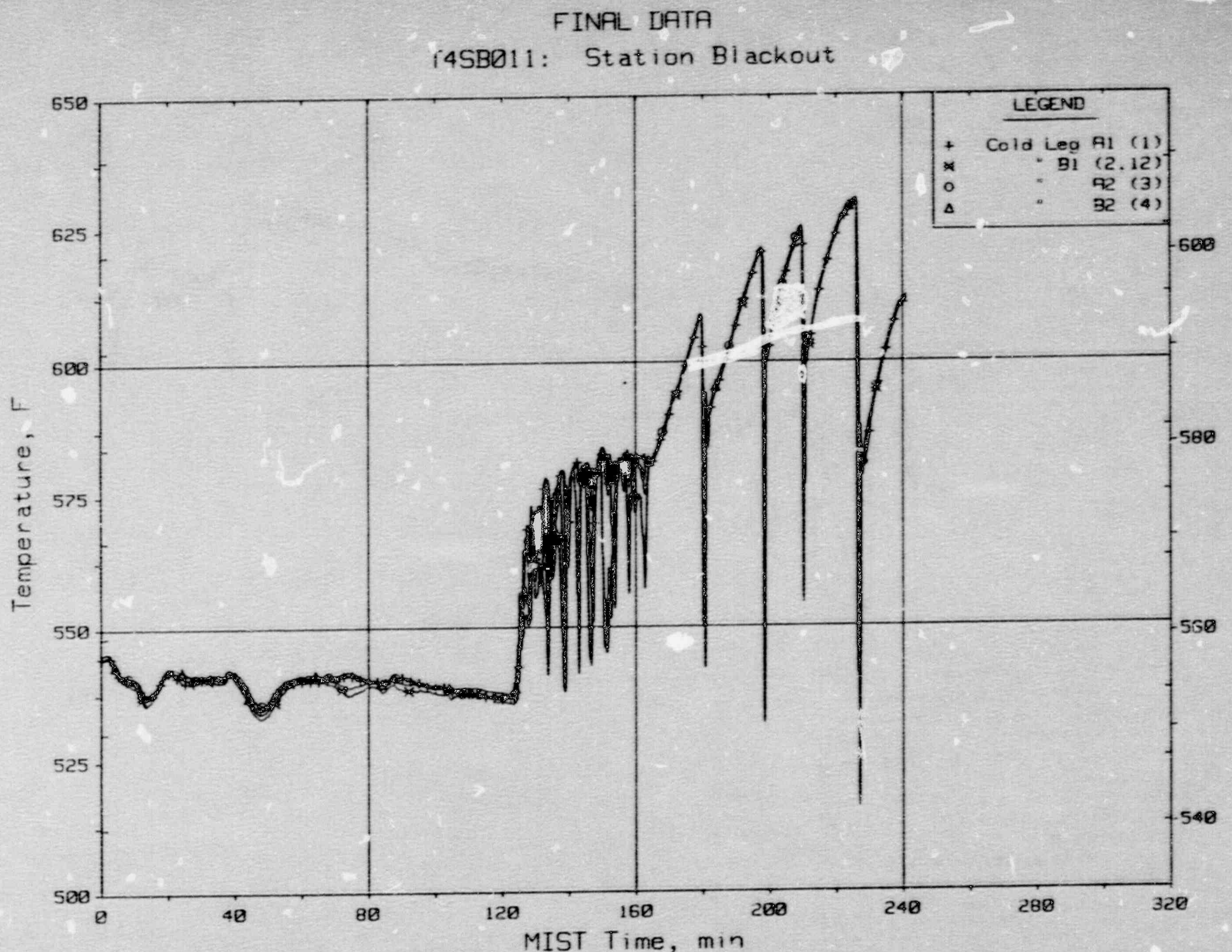



Figure A.57 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

CLTC1

Wed Nov 9 16:30:46 1988

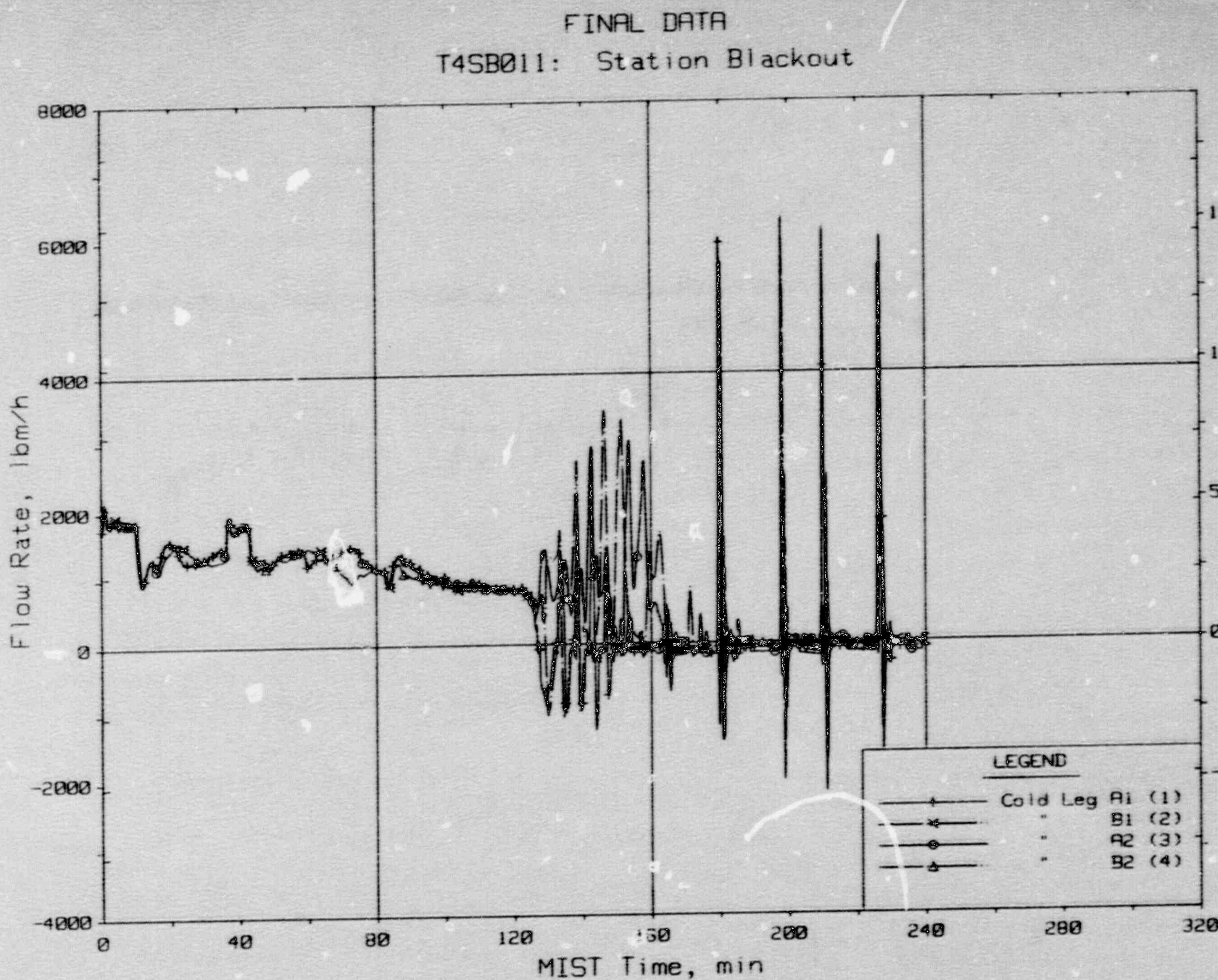



Figure A.58 Cold Leg (Venturi) Flow Rates (CnVN20s)

CLFL0

Wed Nov 9 16:26:39 1988

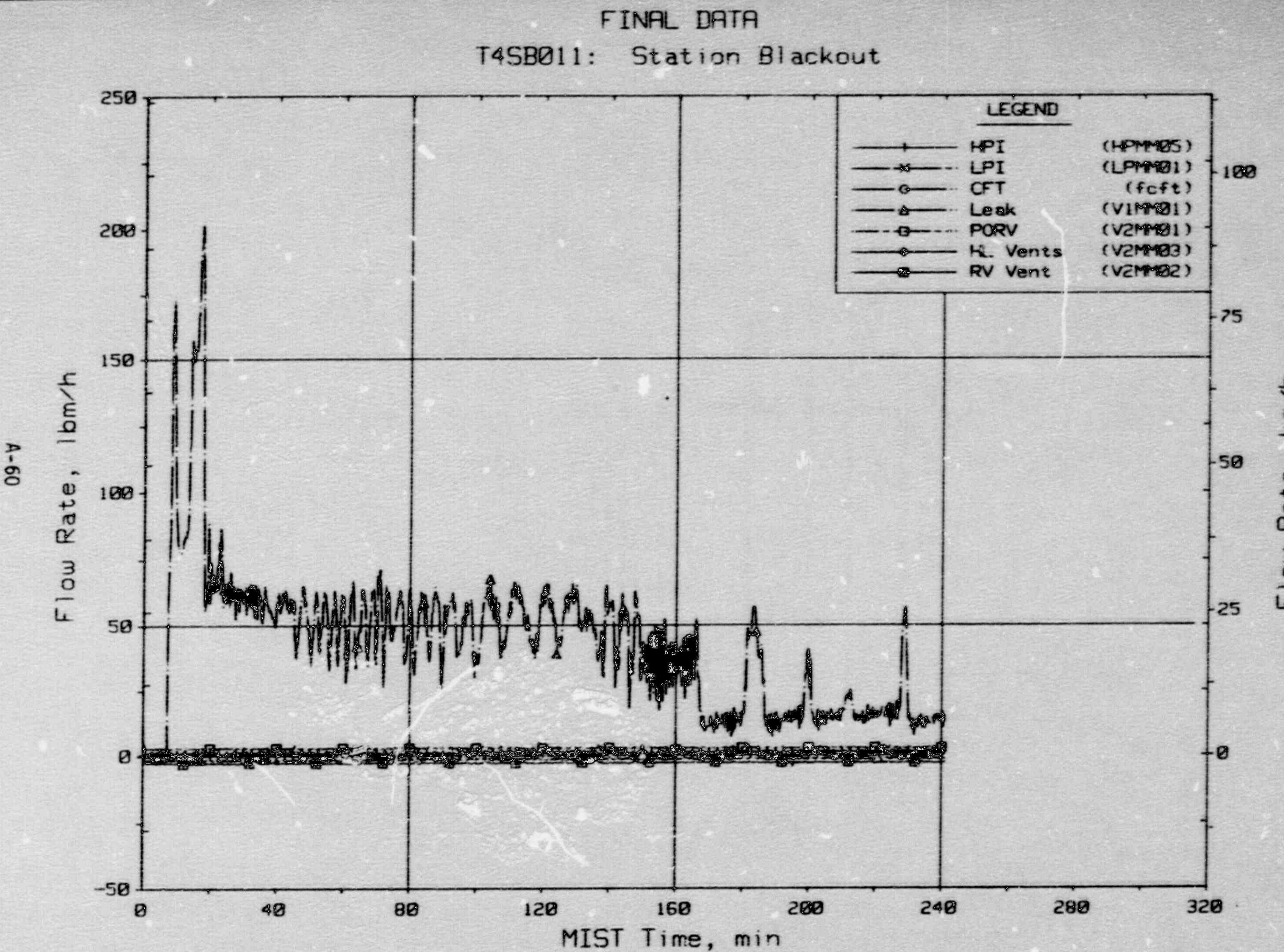



Figure A.59 Primary System Boundary Flow Rates

Wed Nov 9 11:22:30 1988

PRFL3x

FINAL DATA

T4SB011: Station Blackout

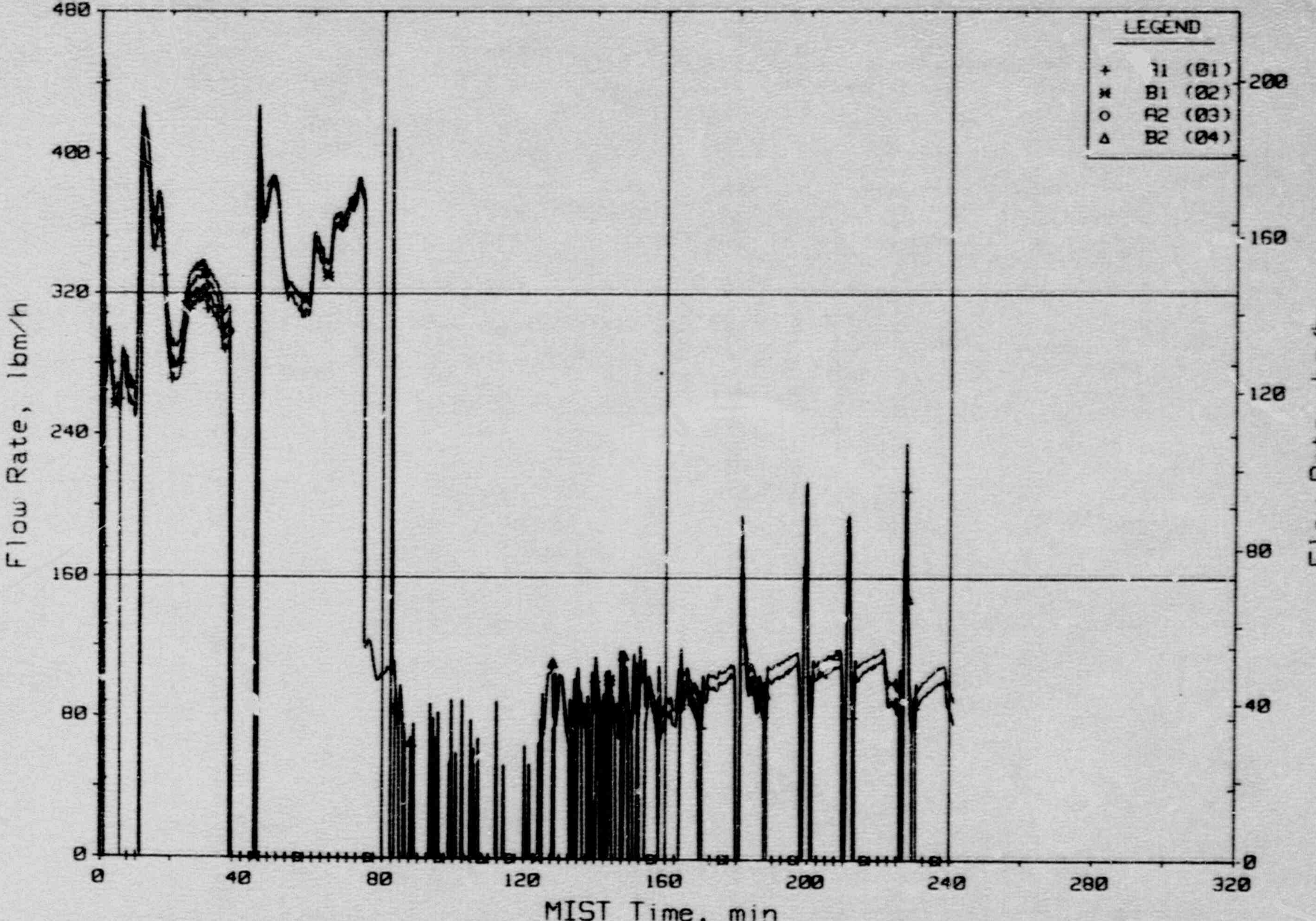



Figure A.60 Reactor Vessel Vent Valve Flow Rates (RVORs)

Wed Nov 9 16:03:16 1988

VVFL1

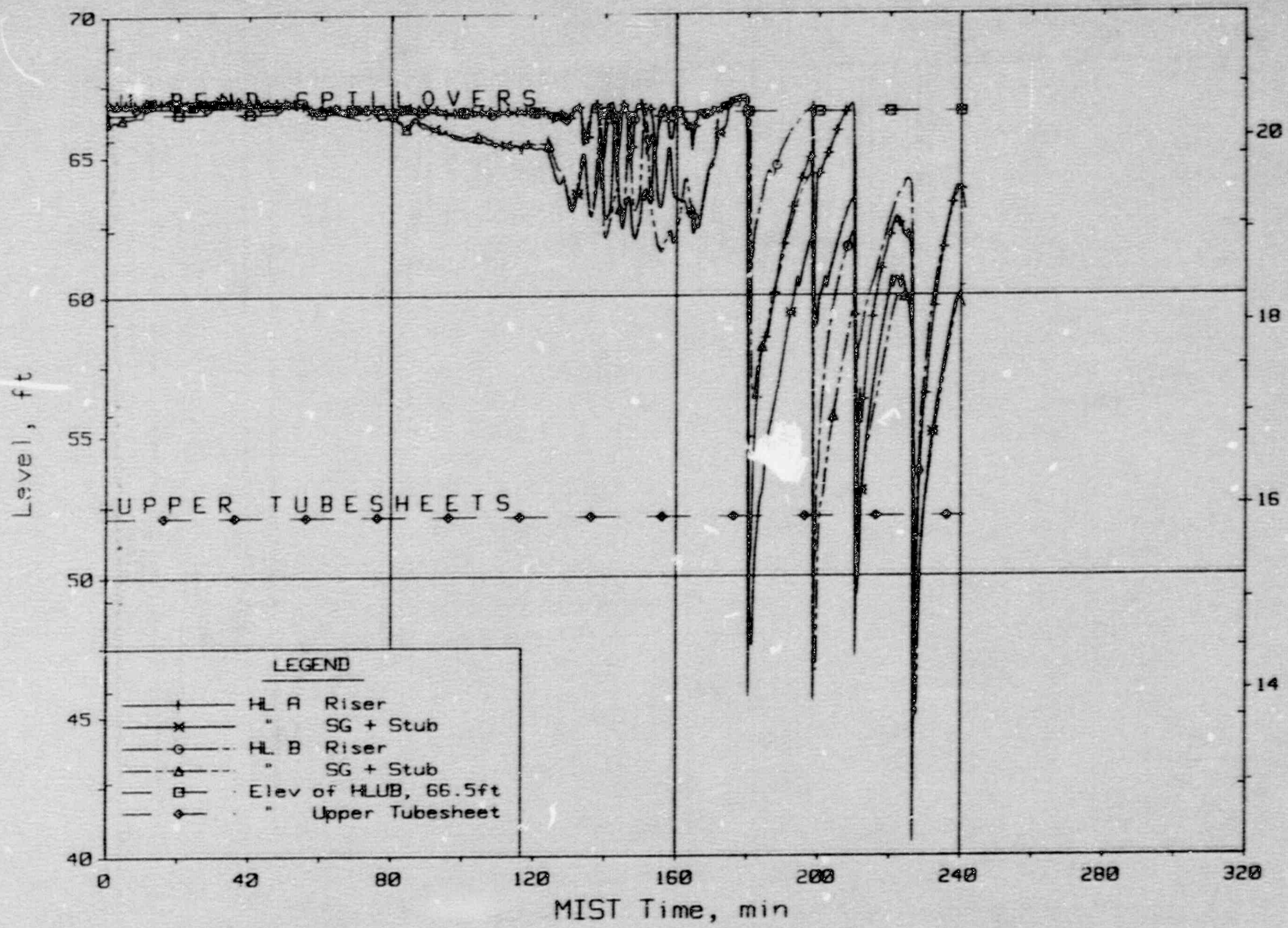



Figure A.61 Hot Leg Riser and Stub Collapsed Liquid Levels

Wed Nov 9 15:55:36 1988

HLLV1

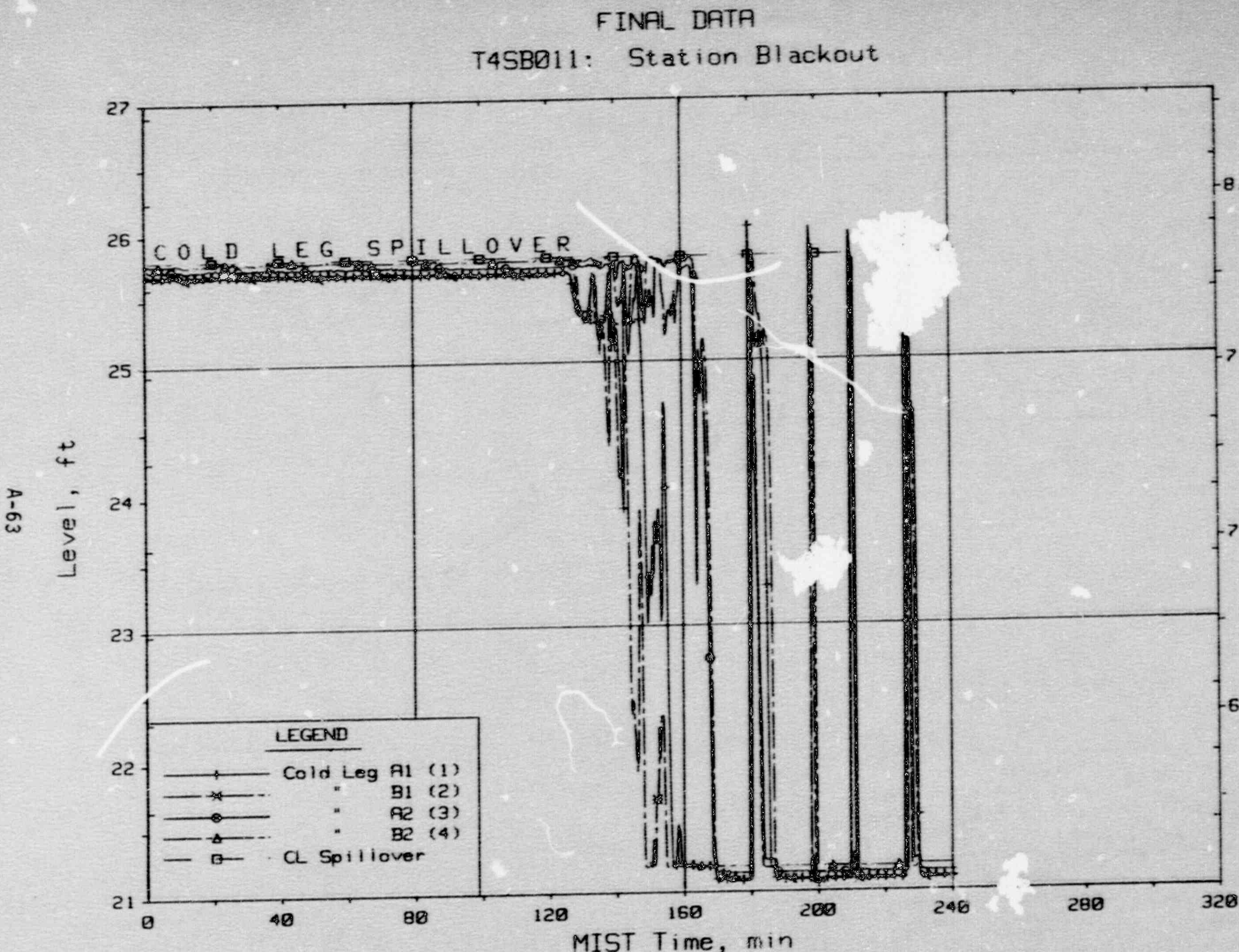



Figure A.62 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

CLLV5

A-63

Wed Nov 9 15:47:29 1988

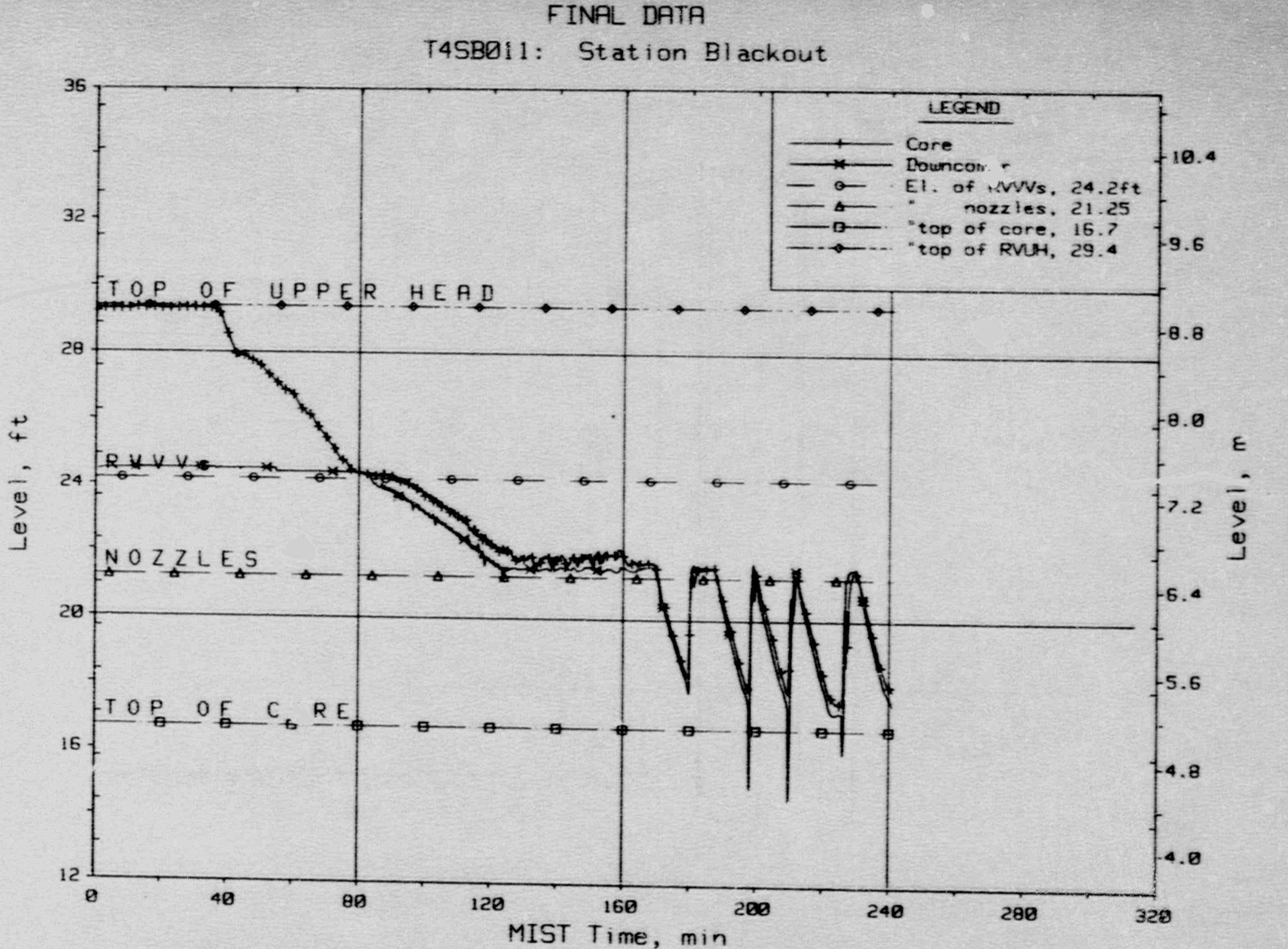



Figure A.63 Core Region Collapsed Liquid Levels

Wed Nov 9 15:21:51 1988

COLV1

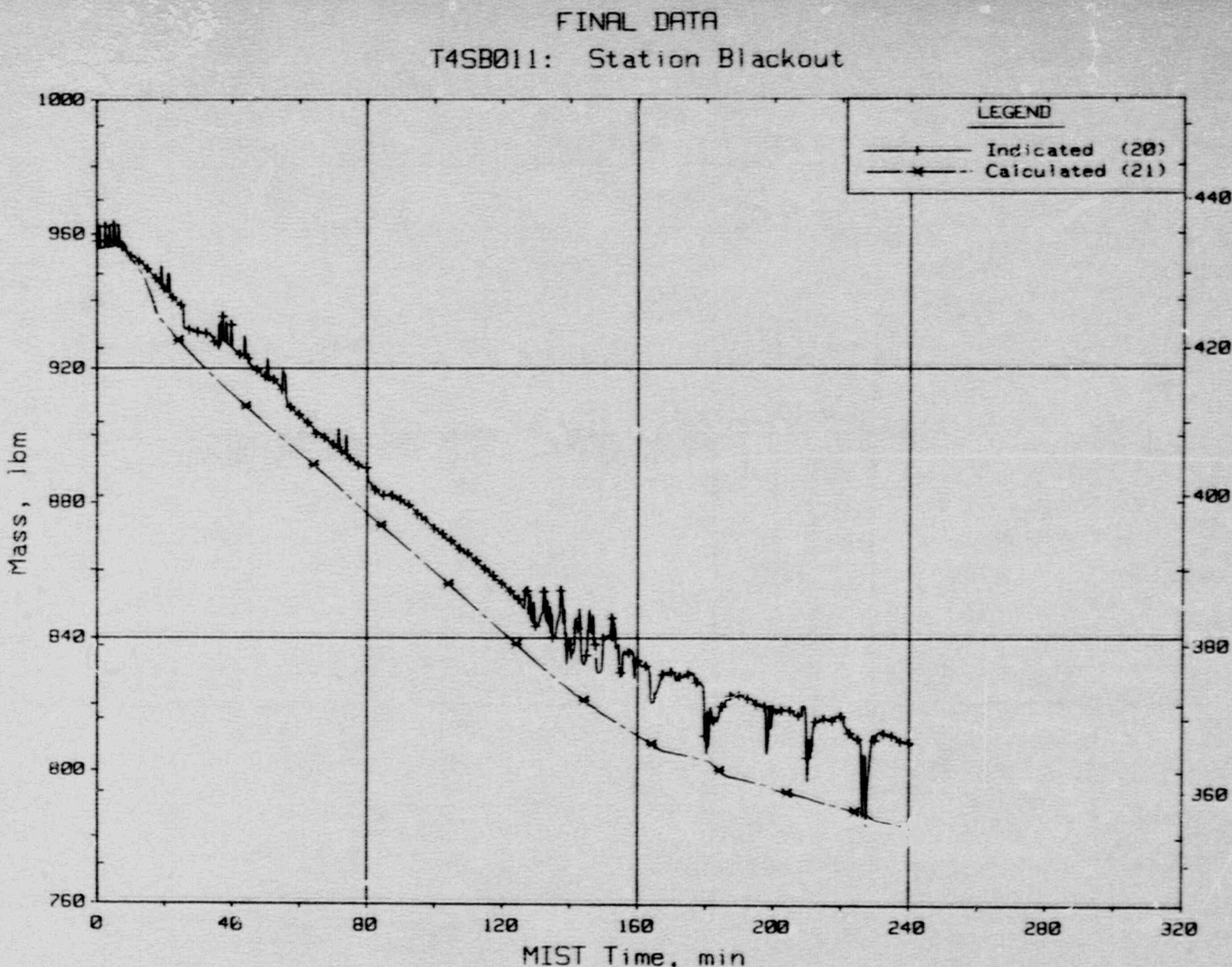


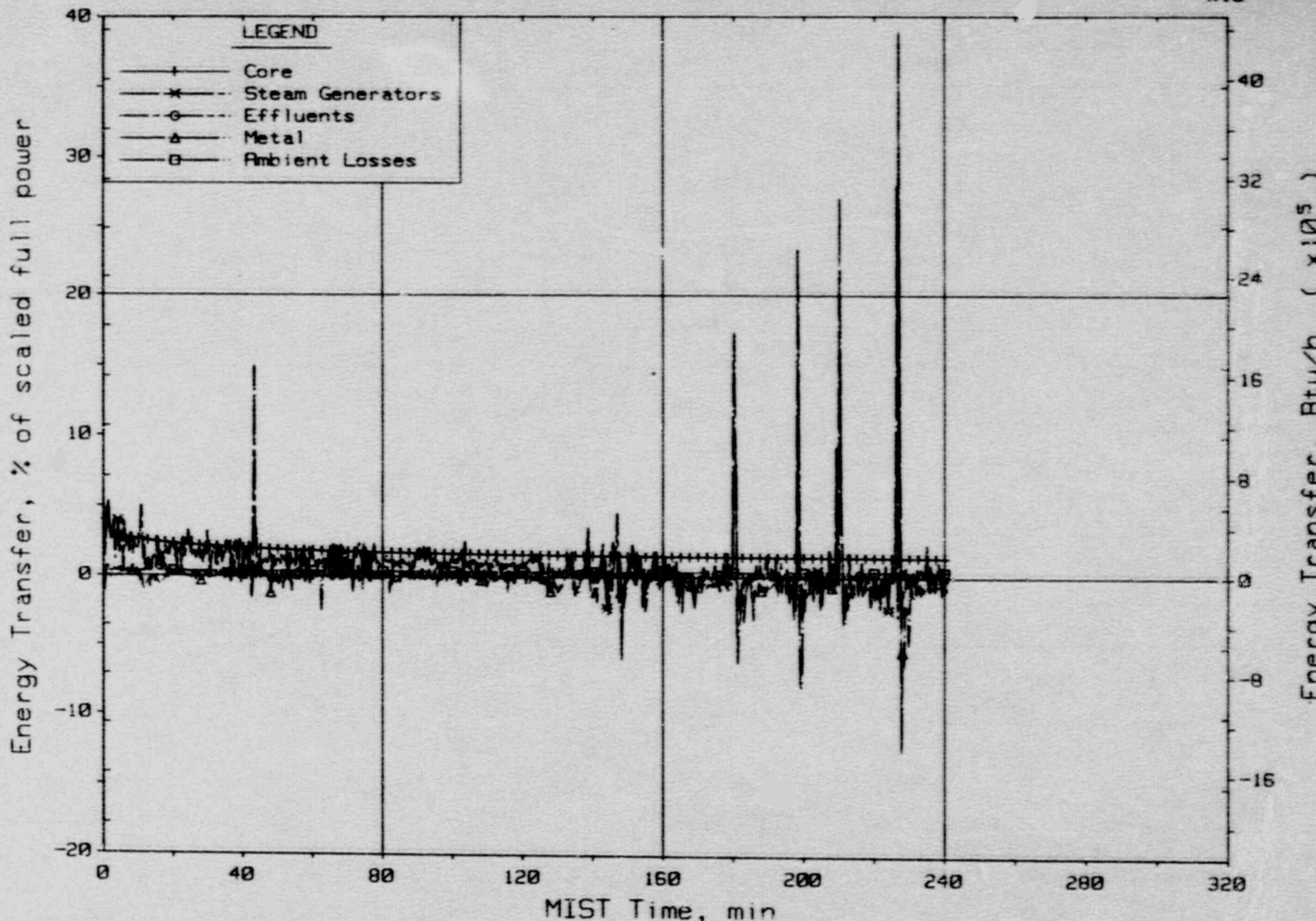

Figure A.64 Primary System Total Fluid Mass (PLMLs)

Wed Nov 9 15:14:27 1988

PRML1

FINAL DATA

T4SB011: Station Blackout




A-66

**Figure A.65 Primary System Energy Transfer**

Wed Nov 9 15:11:33 1988

PROE1X

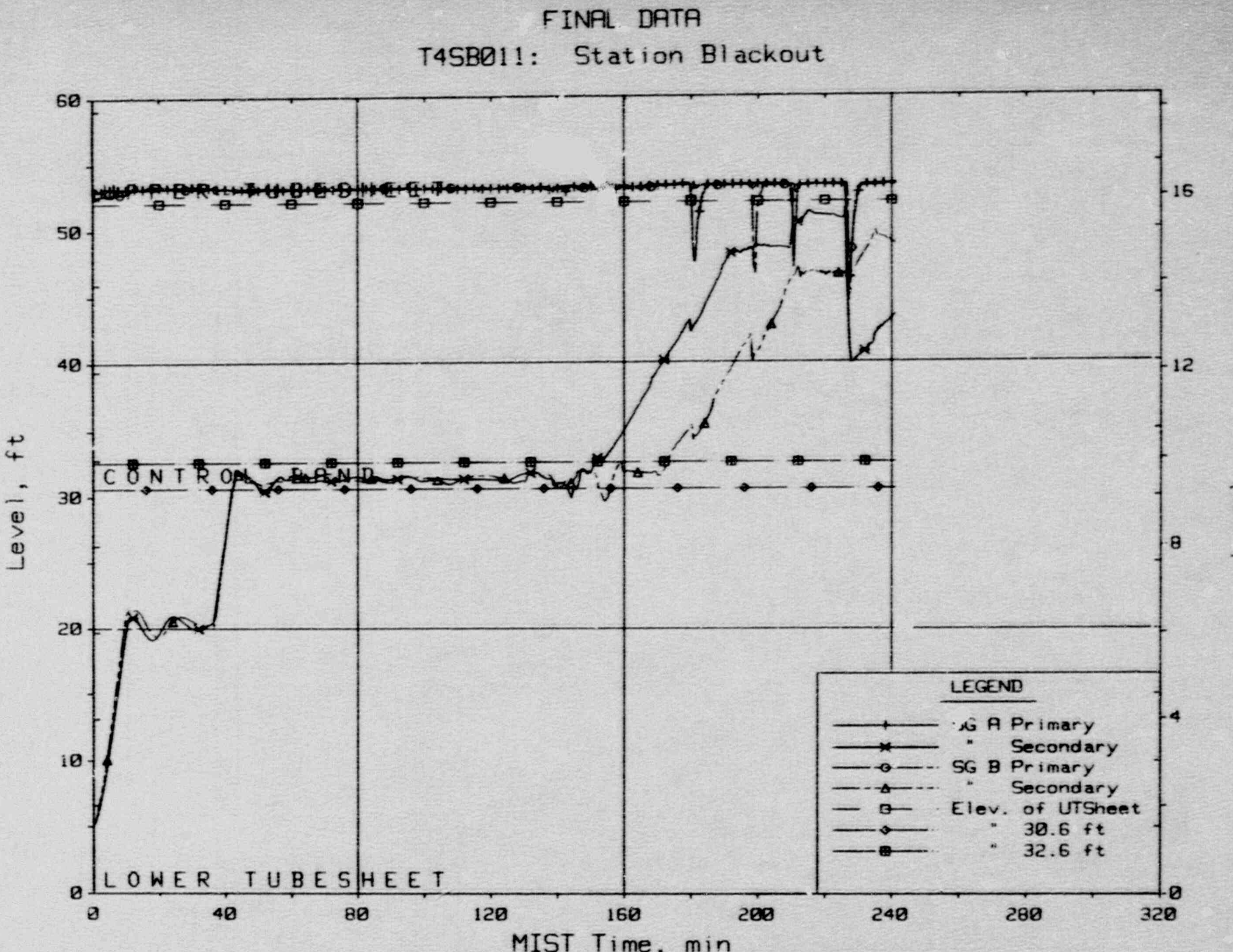
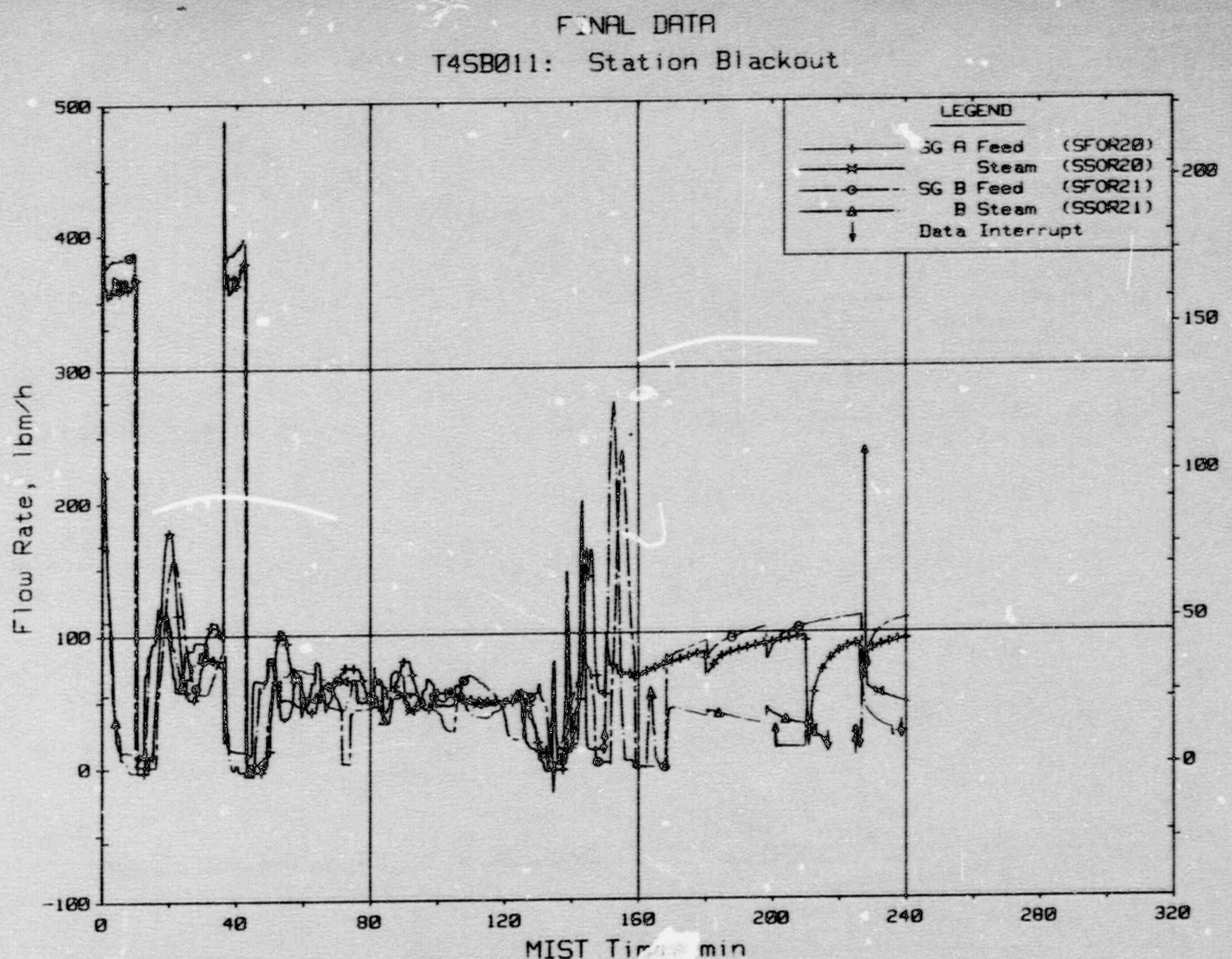



Figure A.66 Steam Generator Collapsed Liquid Levels

Wed Nov 9 15:03:23 1988

SGLV2




A-68

Figure A.67 Steam Generator Secondary Flow Rates

SGFL0

Wed Nov 9 14:50:27 1988

MIST Phase IV Test 4SGPF2

Steam Generator Performance

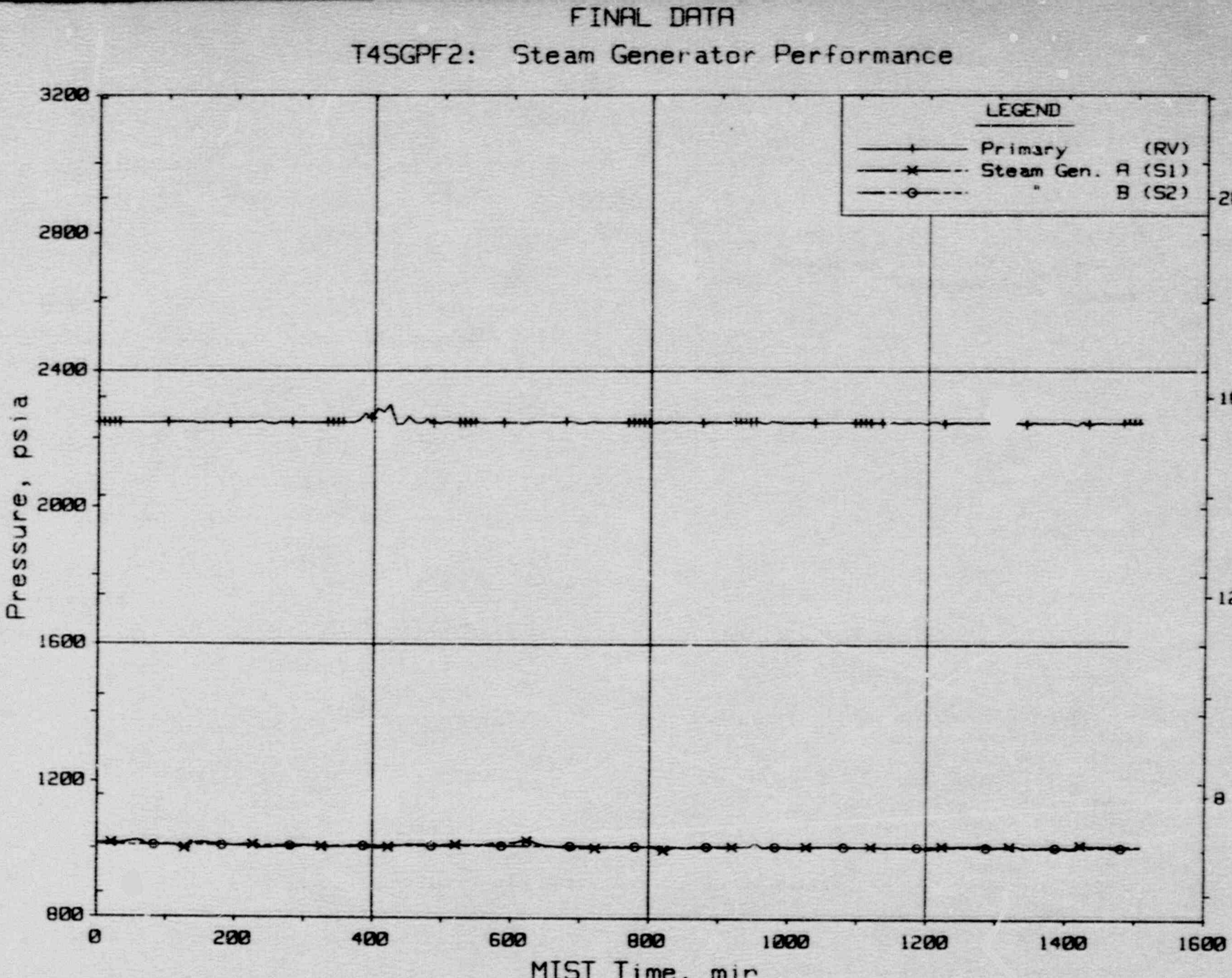



Figure A.68 Primary and Secondary System Pressures (GP01s)

Tue Nov 15 16:25:33 1988

PSGP1

FINAL DATA

T4SGPF2: Steam Generator Performance

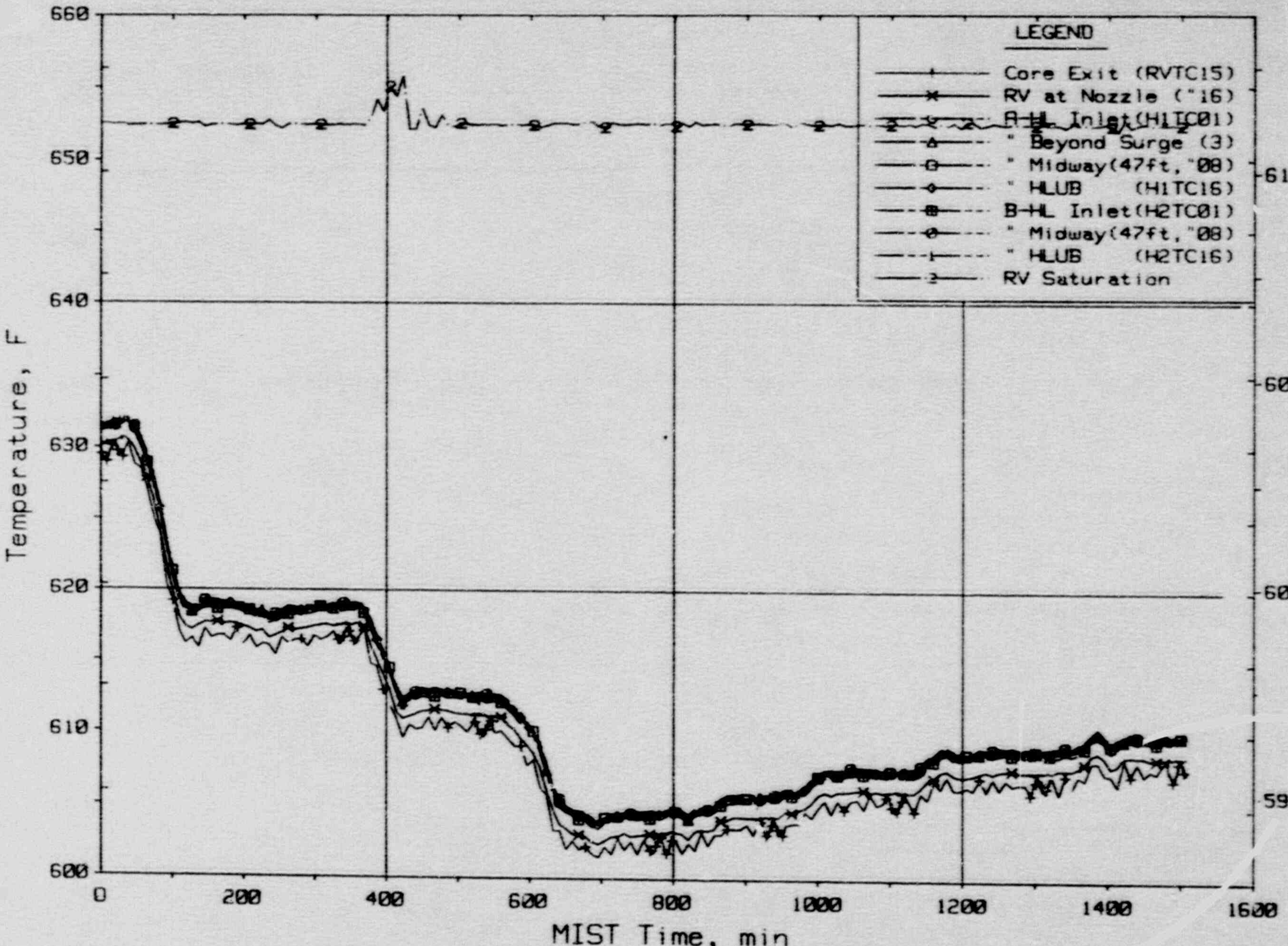



Figure A.69 Composite Core Exit and Hot Leg Fluid Temperatures

Tue Nov 15 15:21:56 1988

PRKT1

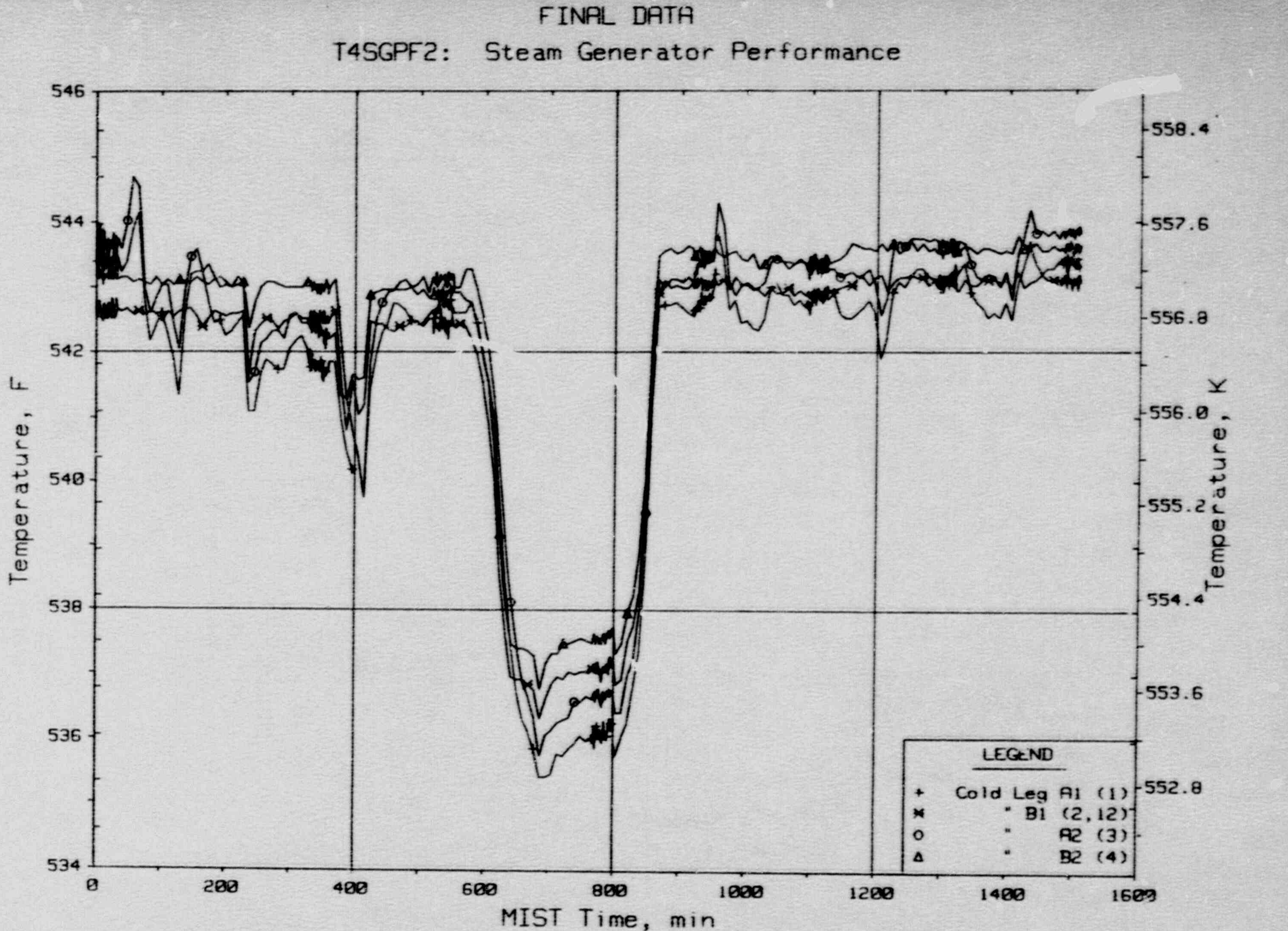



Figure A.70 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

Tue Nov 15 16:17:05 1988

CLTC1

FINAL DATA

T4SGPF2: Steam Generator Performance

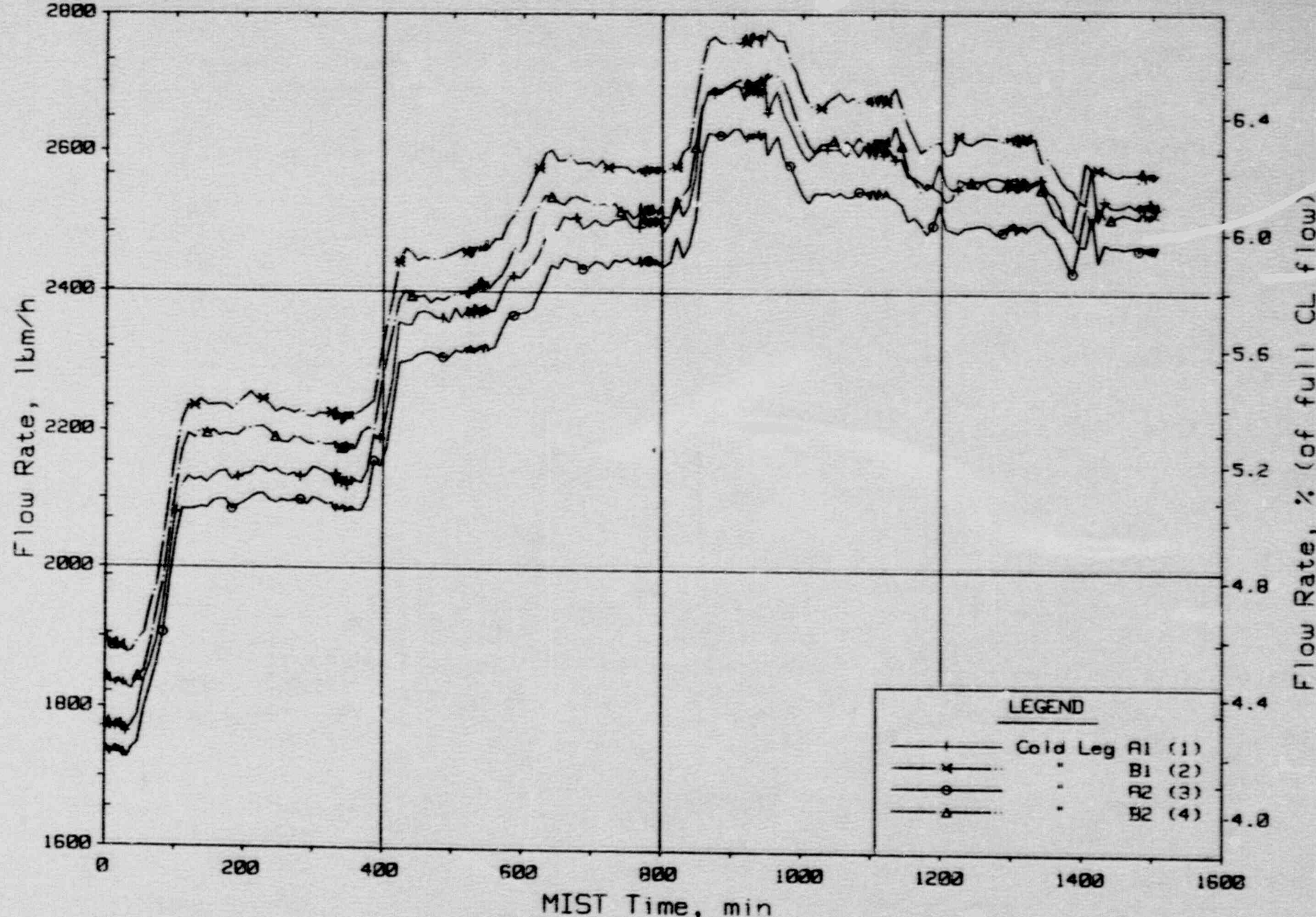



Figure A.71 Cold Leg (Venturi) Flow Rates (CnVN20s)

Tue Nov 15 16:13:48 1988

CLFL0

FINAL DATA

T4SGPF2: Steam Generator Performance

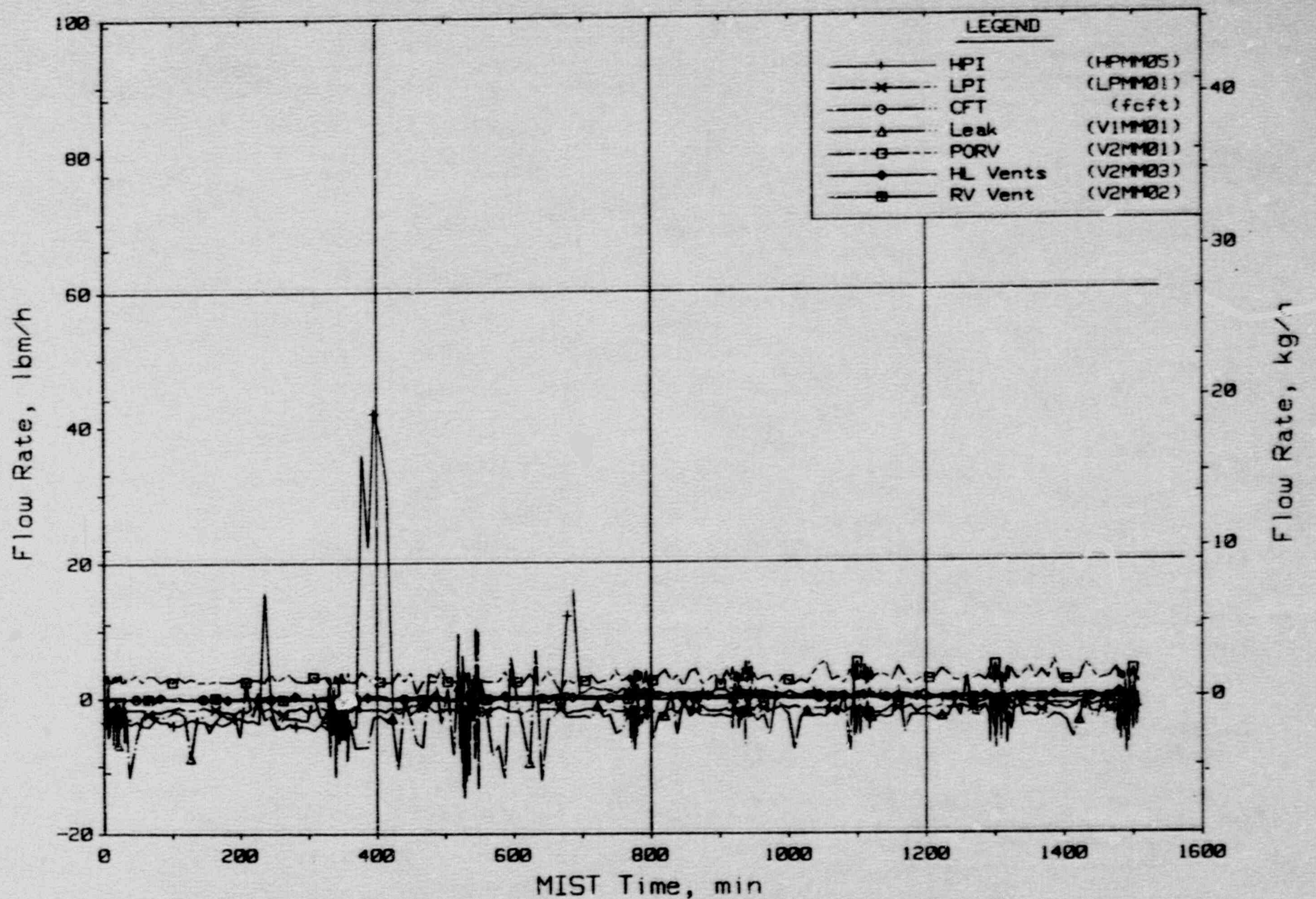




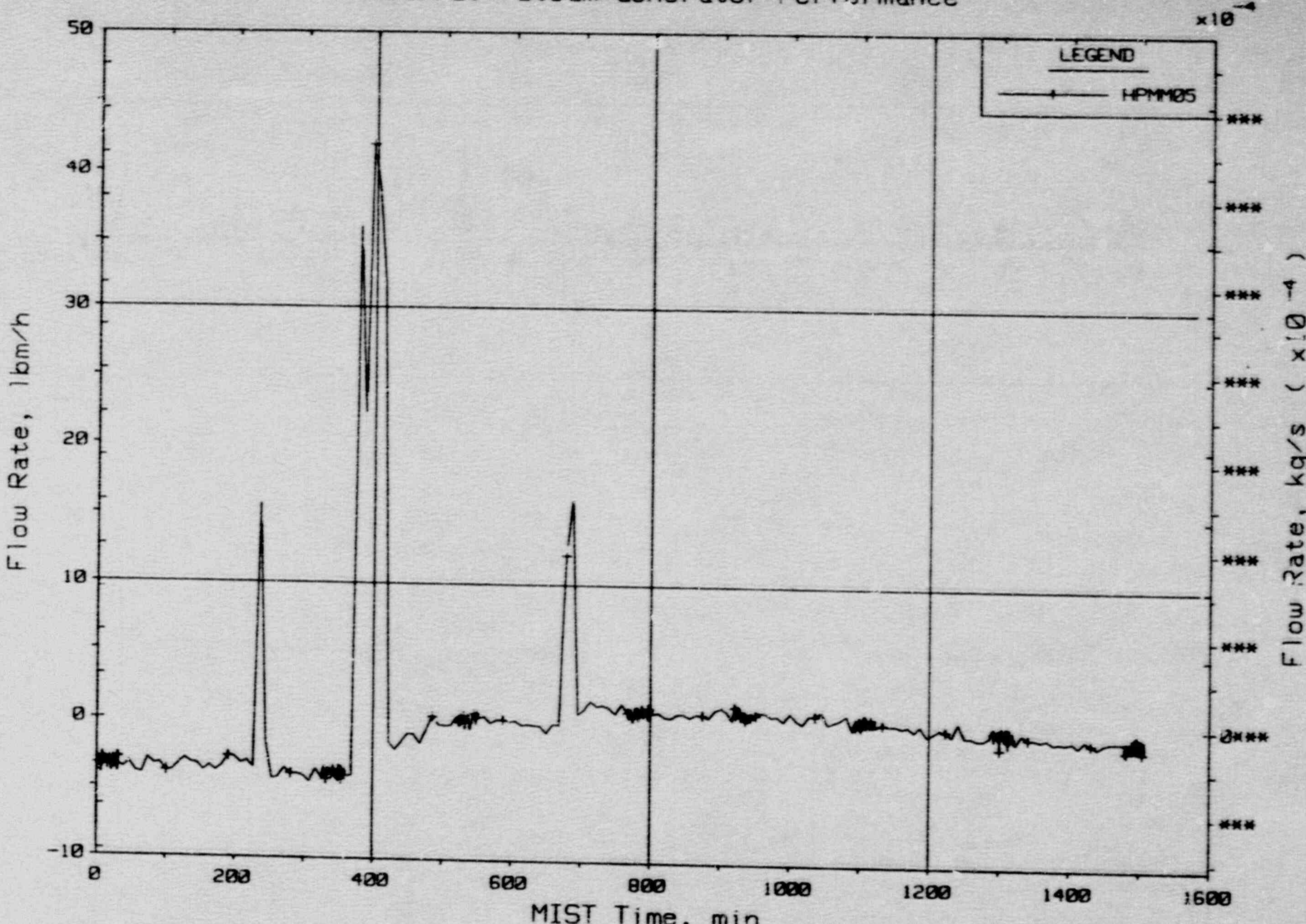

Figure A.72 Primary System Boundary Flow Rates

Tue Nov 15 16:10:44 1988

PRFL3x

FINAL DATA

T4SGPF2: Steam Generator Performance




A-74

Figure A.73 HPI Total Flow Rate

Tue Nov 15 16:03:47 1988

HPFL3

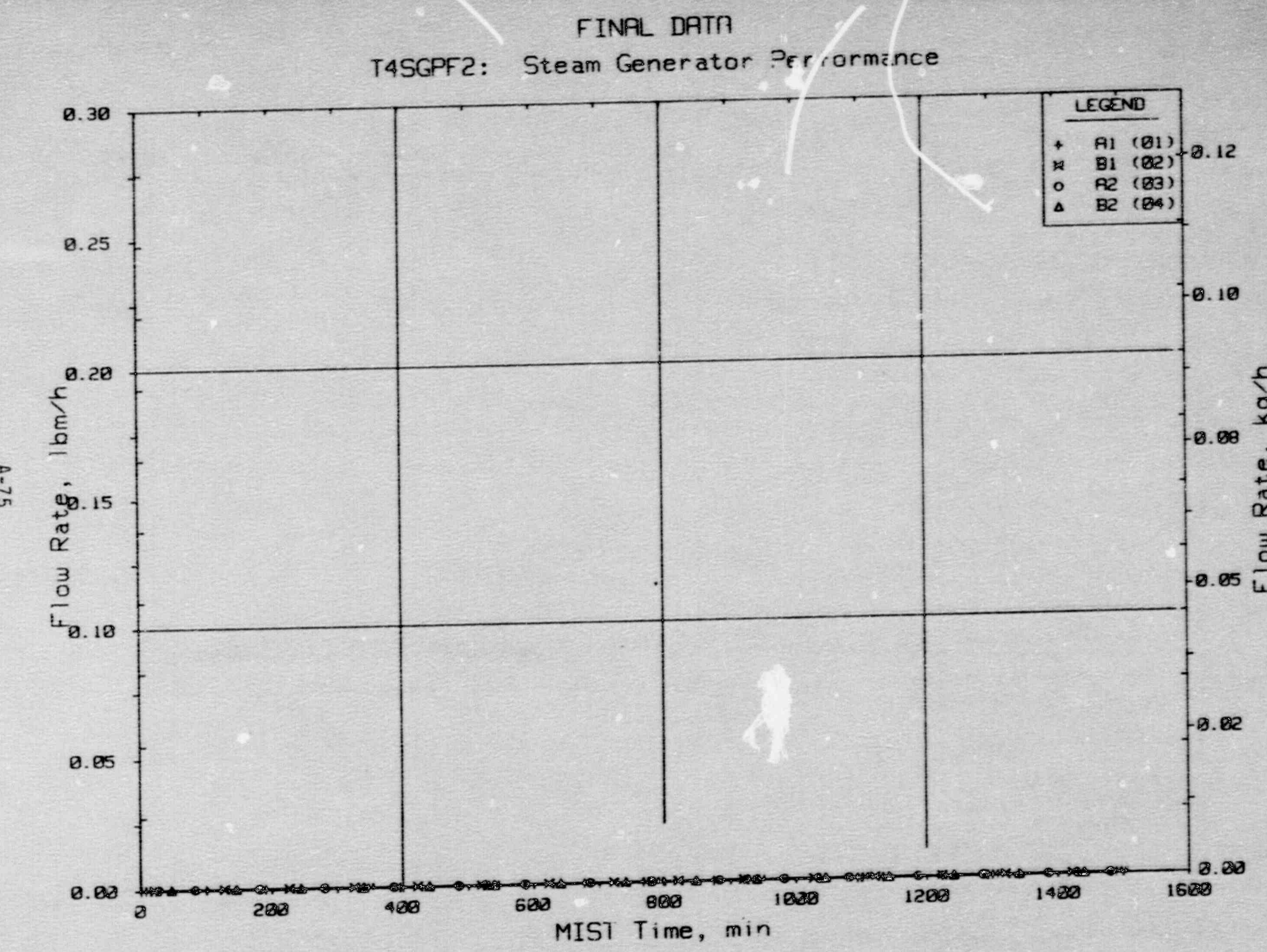



Figure A.74 Reactor Vessel Vent Valve Flow Rates (RVORs)

VVFL1

Tue Nov 15 16:01:50 1988

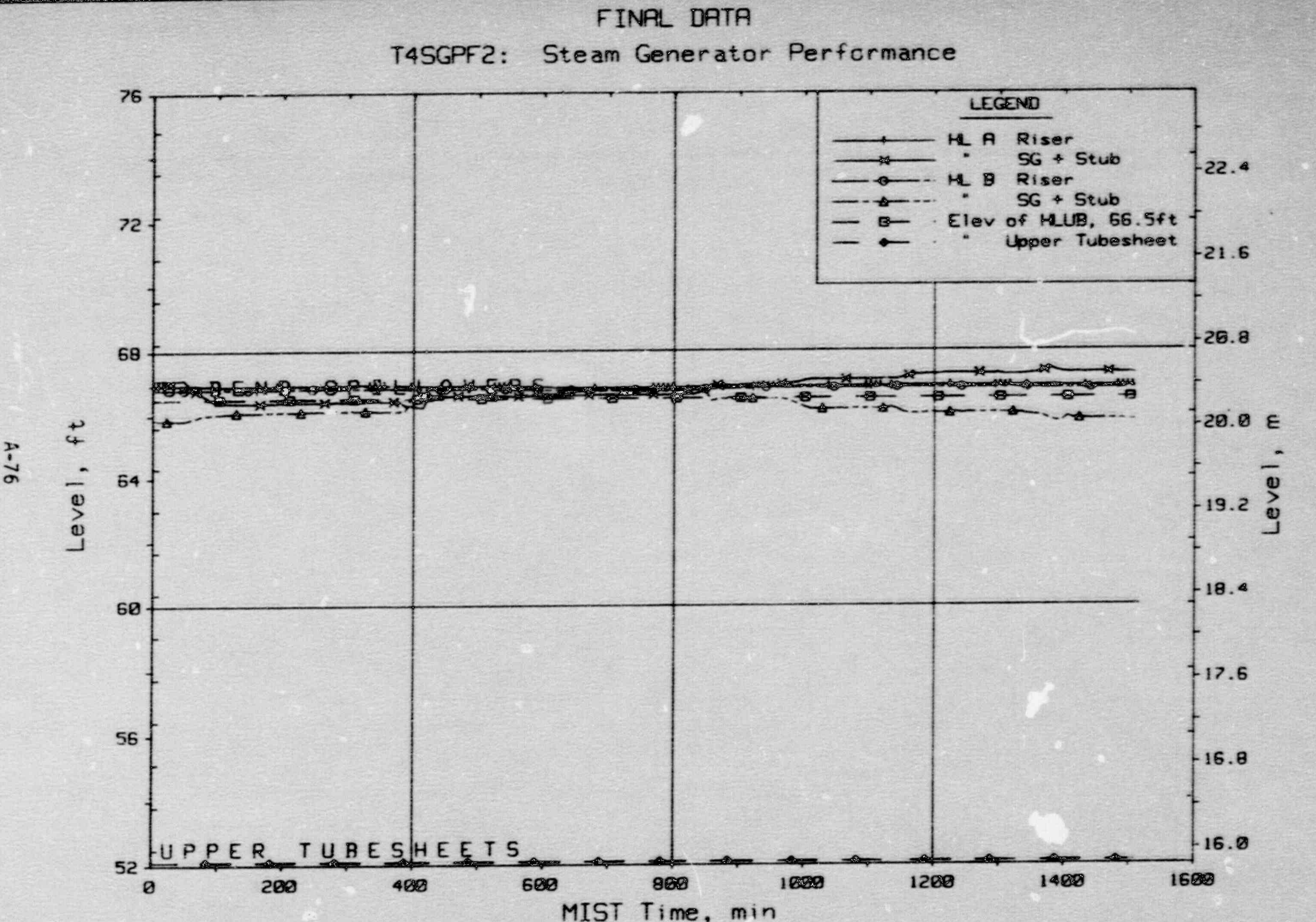



Figure A.75 Hot Leg Riser and Stub Collapsed Liquid Levels

Tue Nov 15 15:50:33 1988

HLLV1

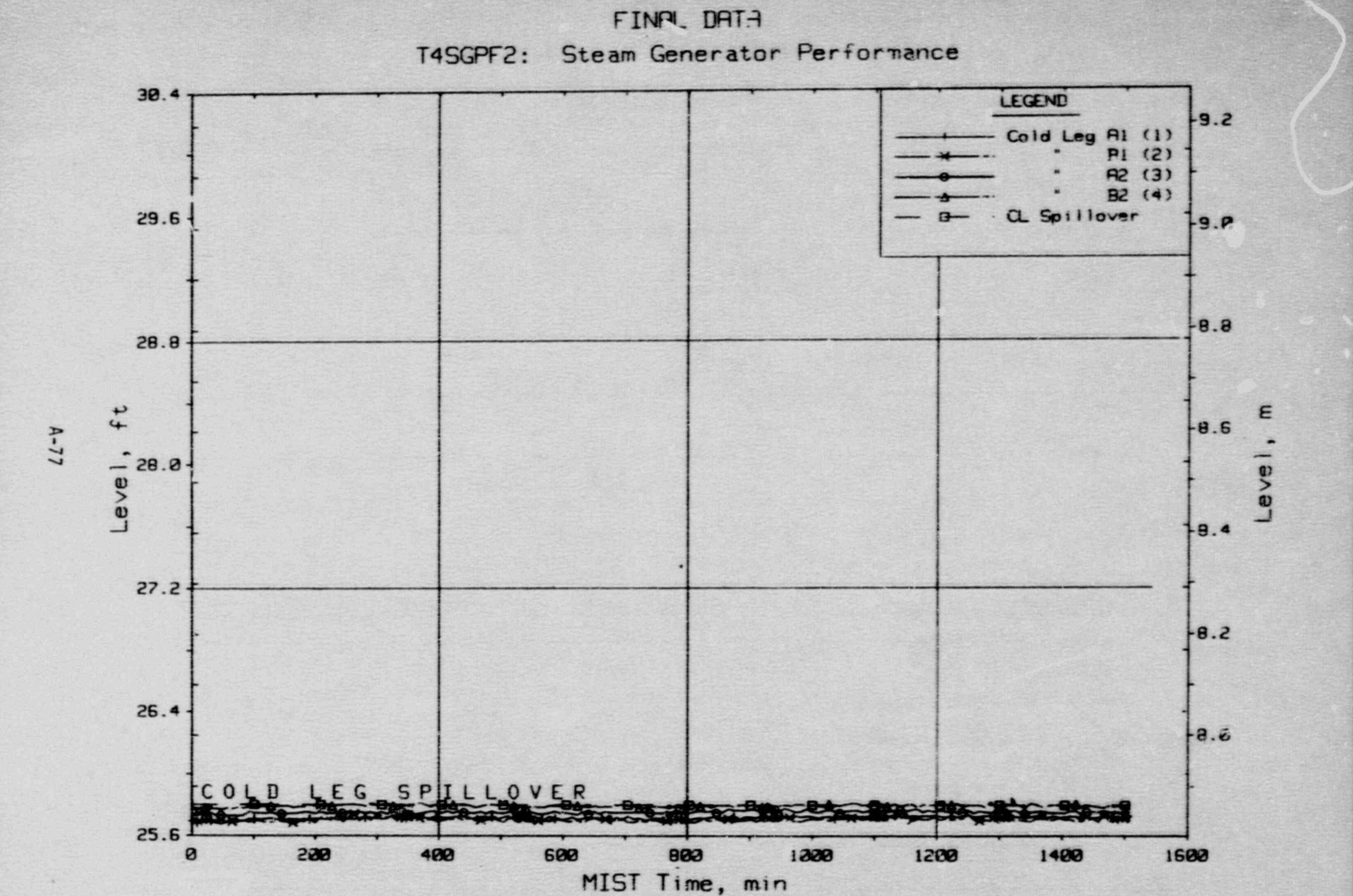



Figure A.76 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Tue Nov 15 15:54:52 1988

CLLV5

FINAL DATA

T4SGPF2: Steam Generator Performance

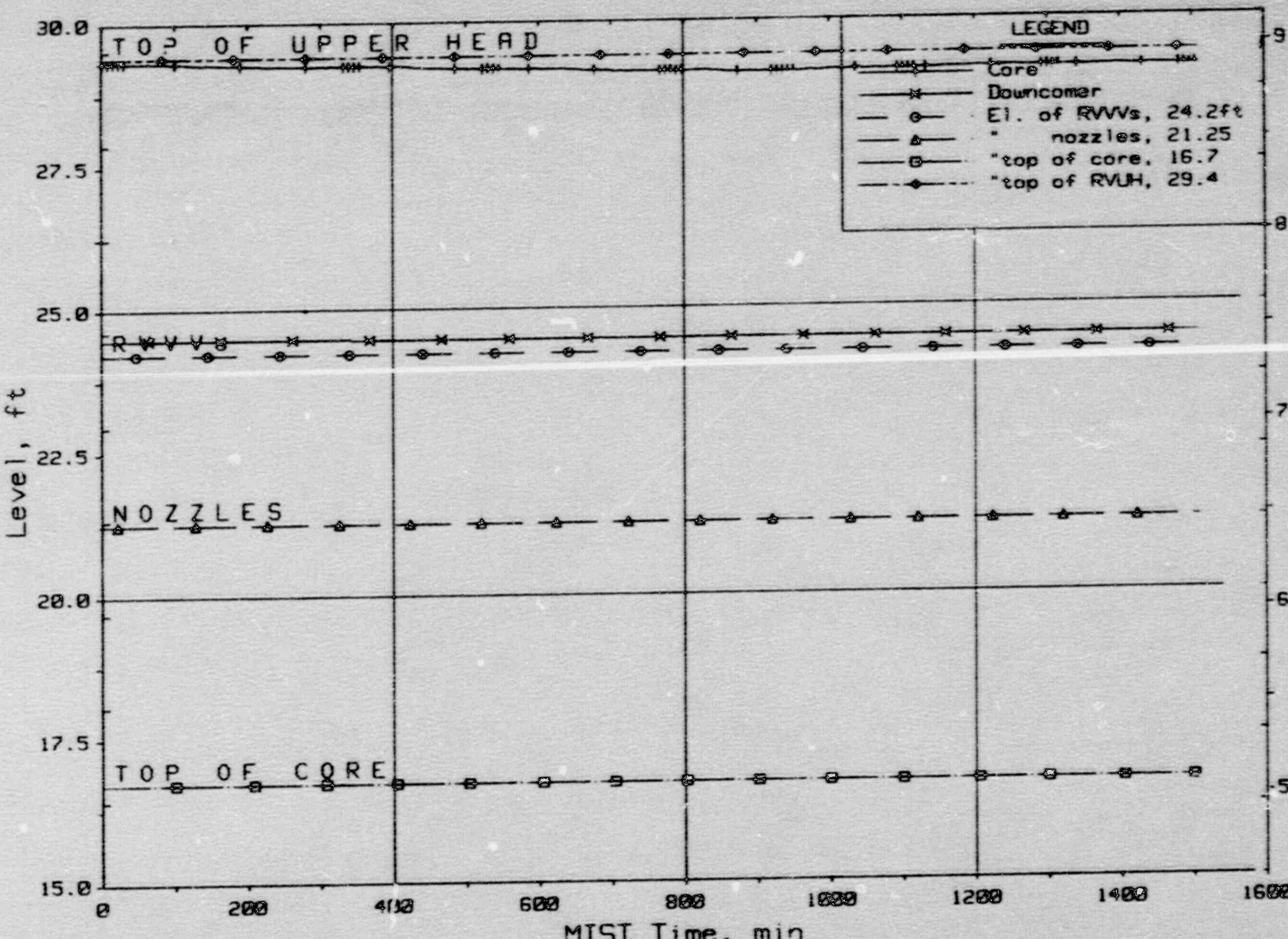





Figure A.77 Core Region Collapsed Liquid Levels

COLV1

Tue Nov 13 15:51:36 1990

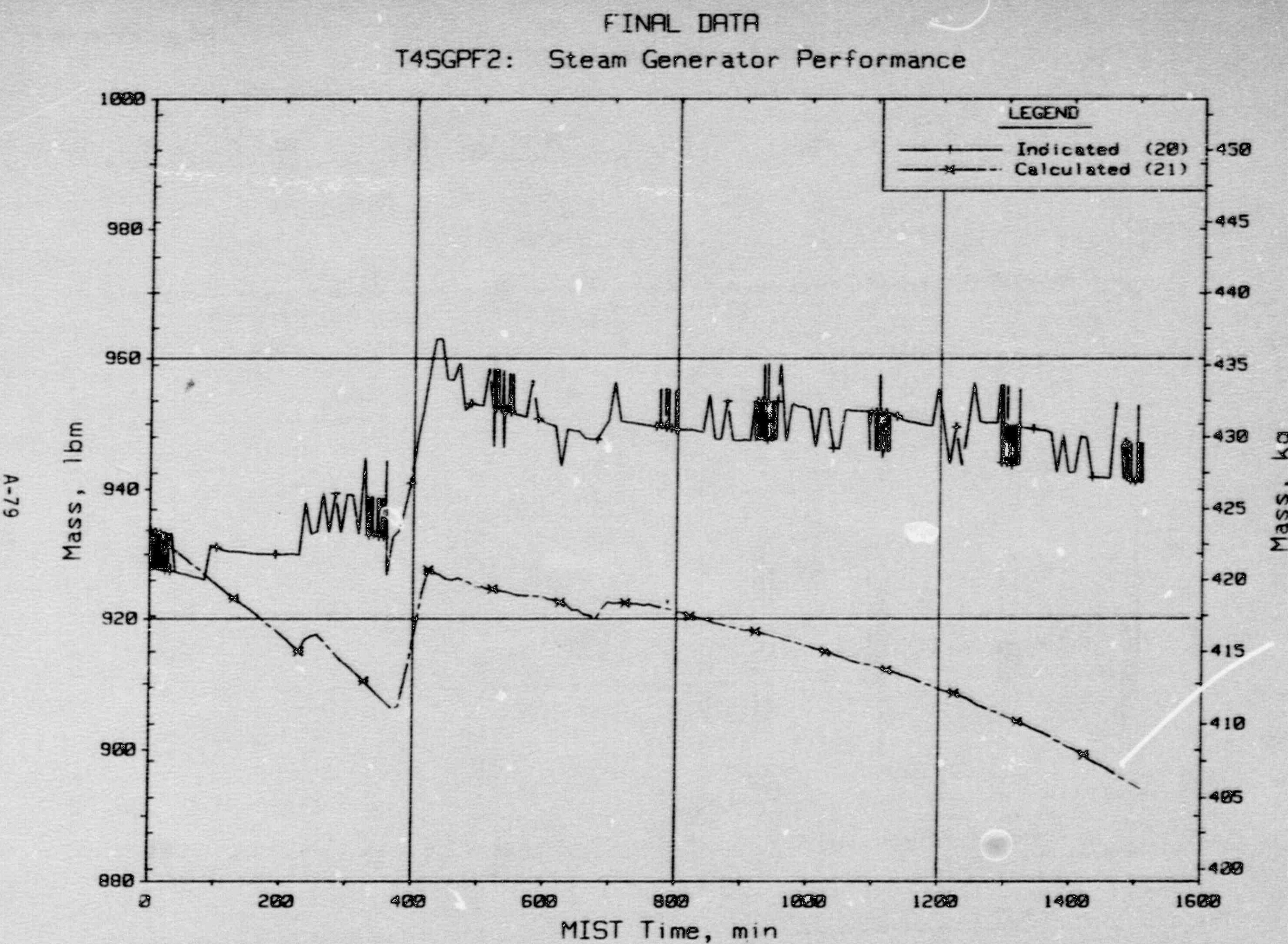



Figure A.78 Primary System Total Fluid Mass (PLMLs)

Tue Nov 15 15:48:15 1988

PRML1

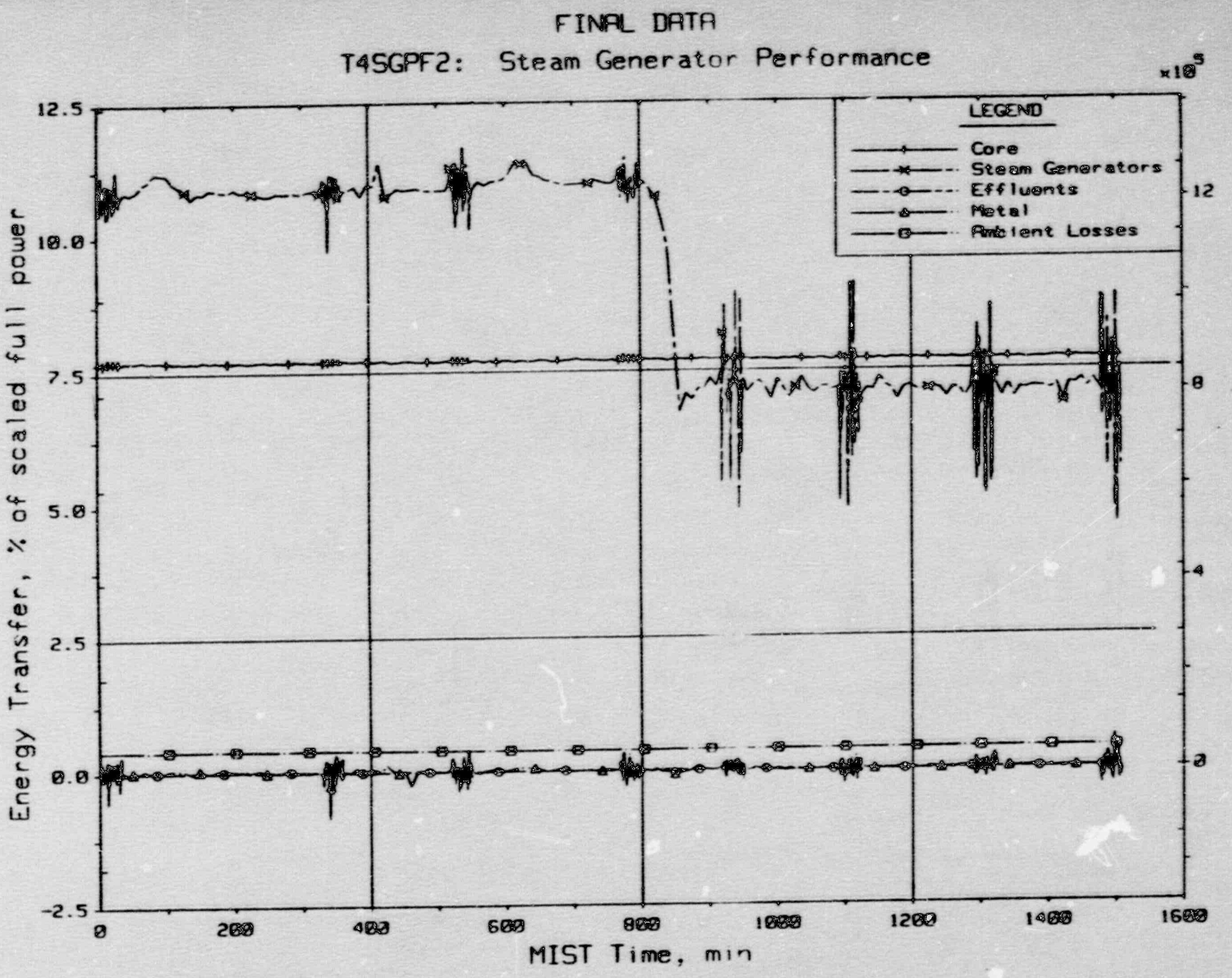



Figure A.79 Primary System Energy Transfer

PROE1X

Tue Nov 15 13:45:19 1988

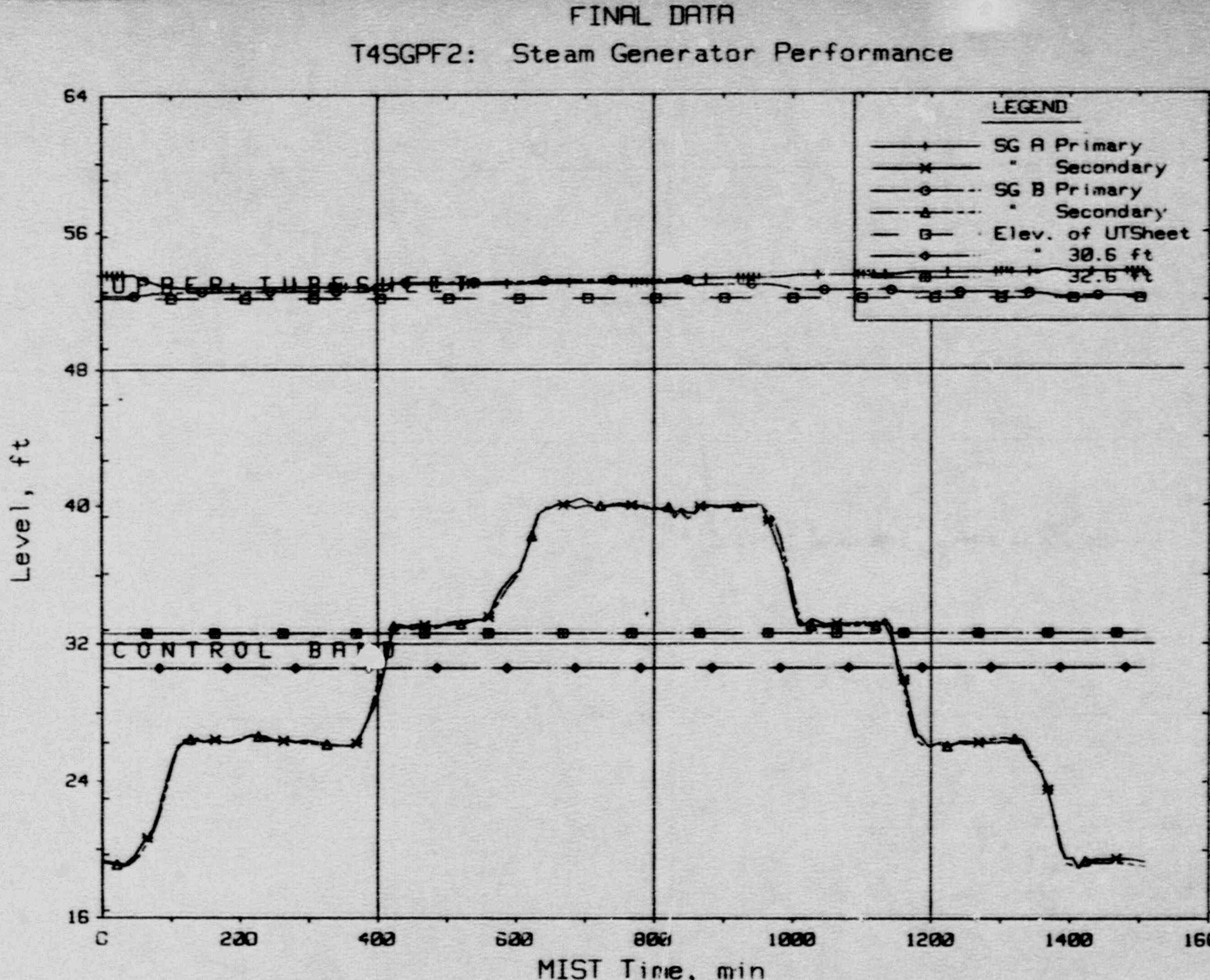



Figure A.80 Steam Generator Collapsed Liquid Levels

Tue Nov 15 15:41:30 1988

SGLV2

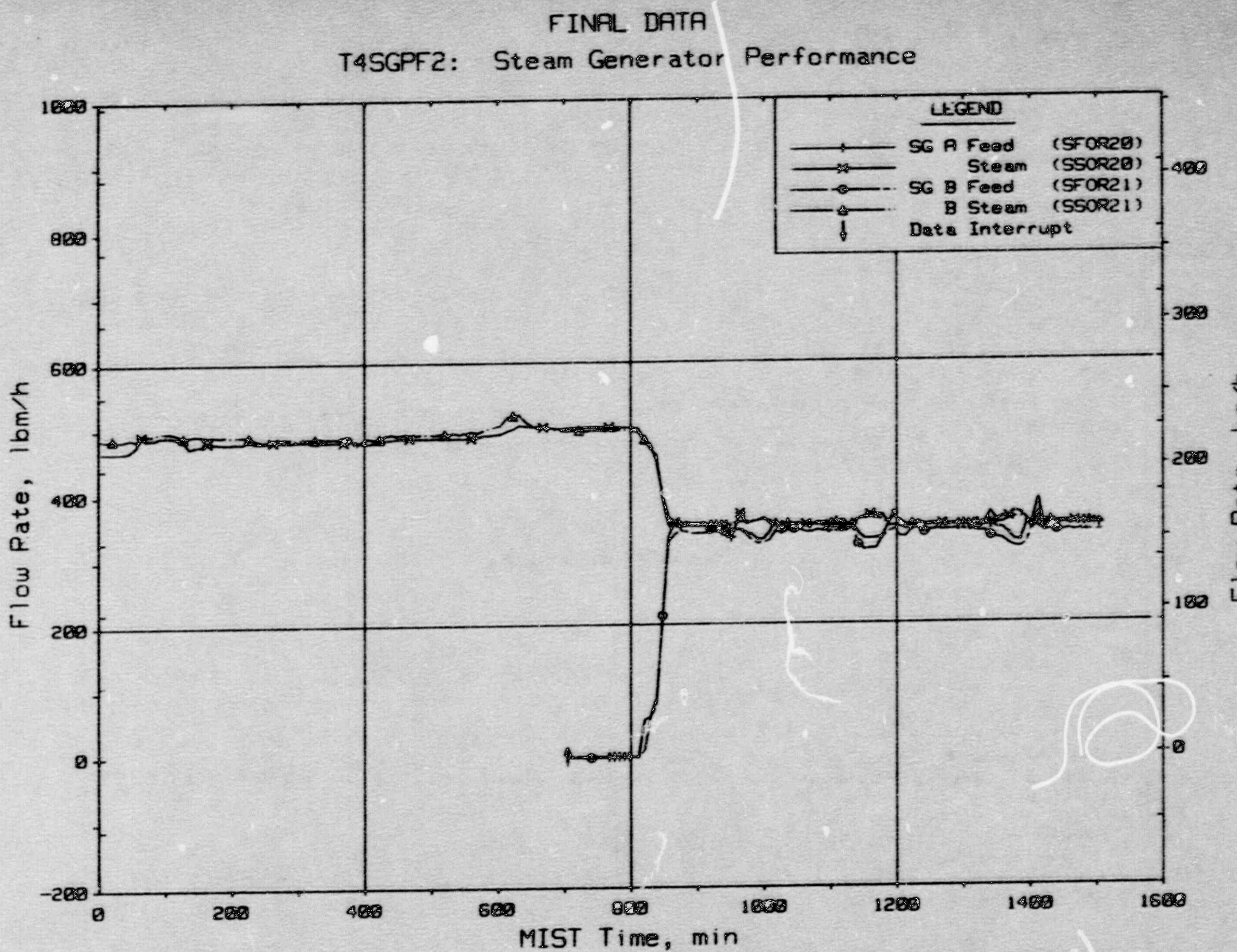



Figure A.81 Steam Generator Secondary Flow Rates



Tue Nov 15 15:37:47 1988

SGFL0

MIST Phase IV Test 4CR3T2

Crystal River 3 Scaling Transient

FINAL DATA

T4CR3T2: Crystal River 3 Scaling Transient

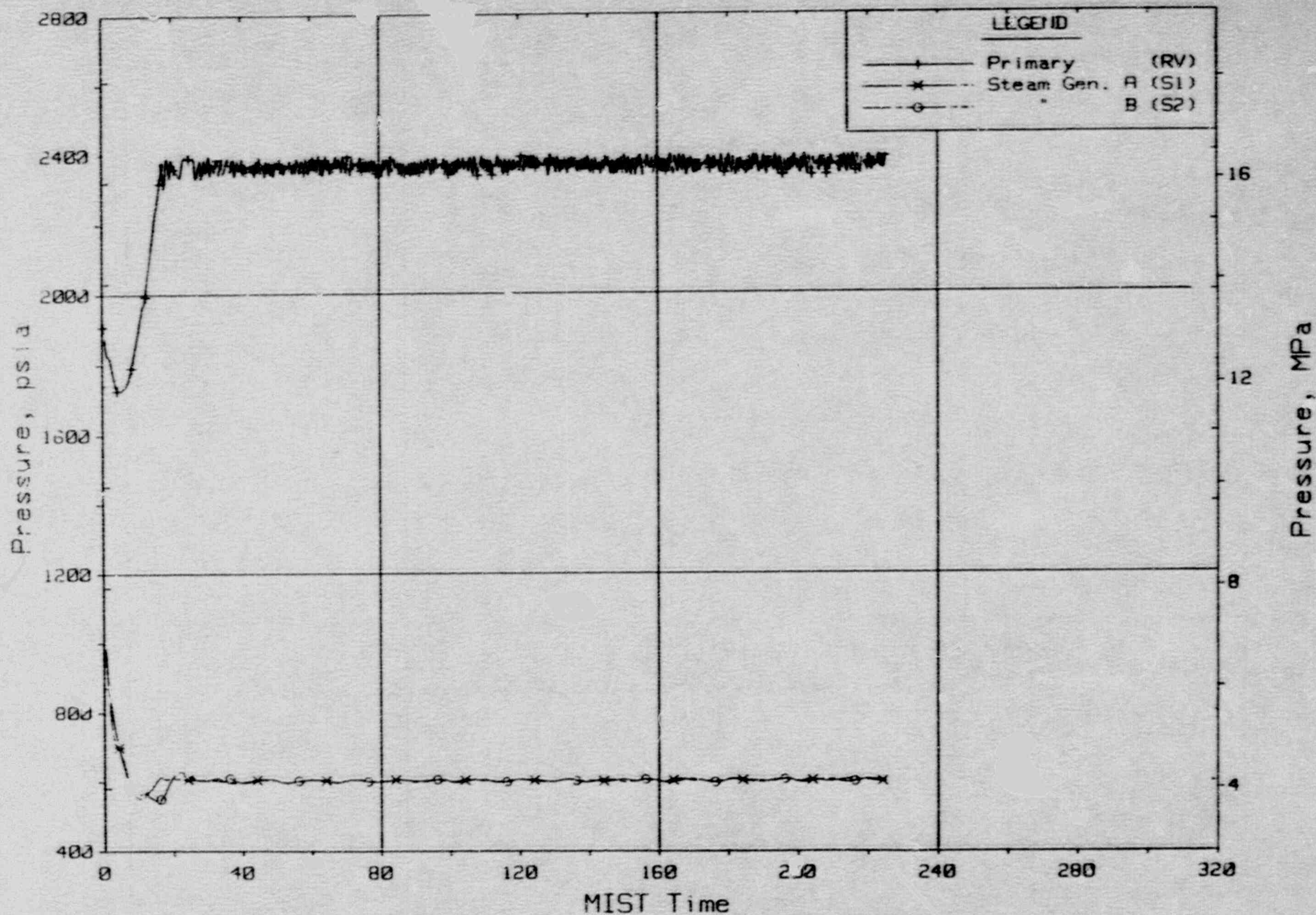



Figure A.82 Primary and Secondary System Pressures (GP01s)

Mon Oct 24 10:44:17 1988

PSGP1

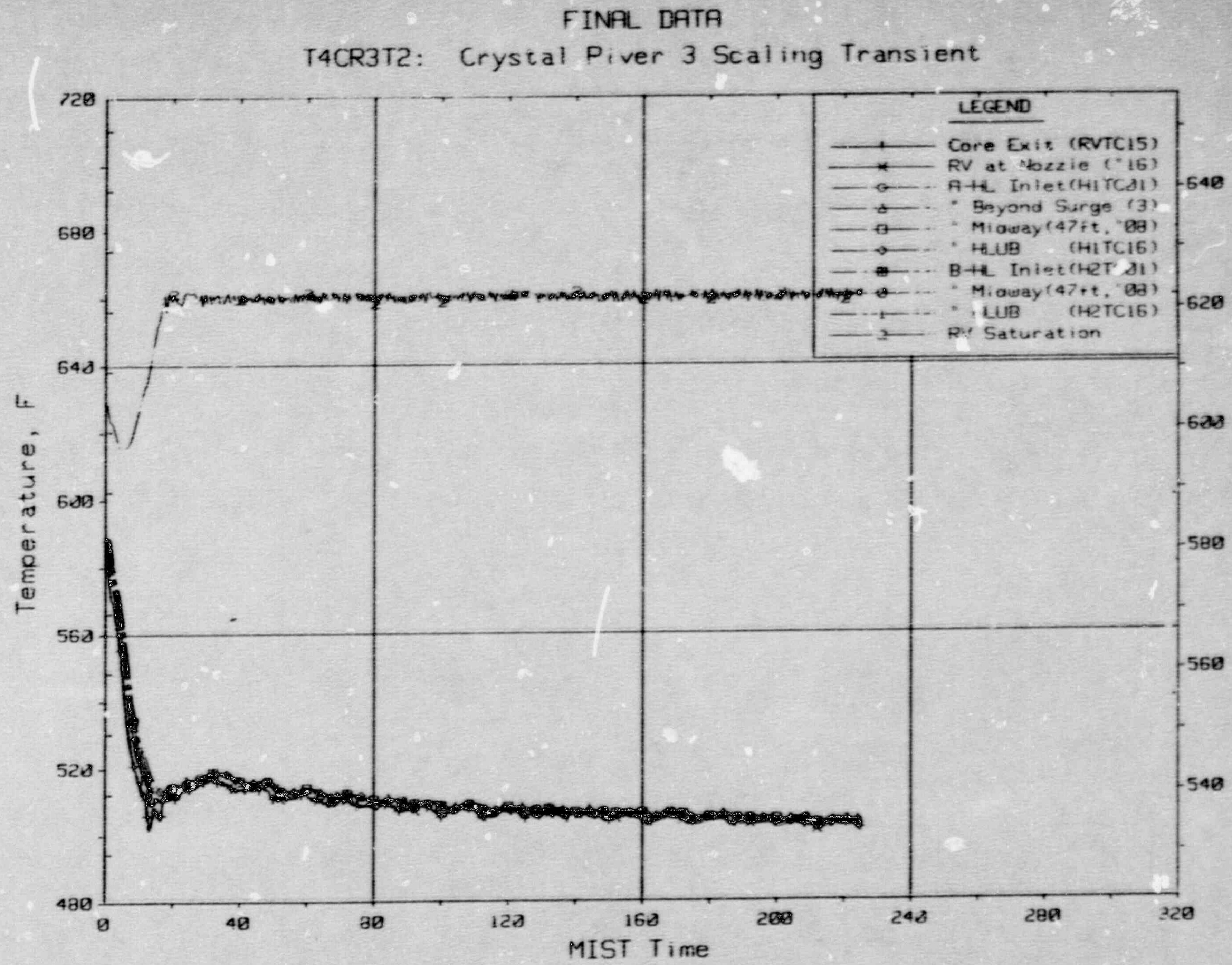
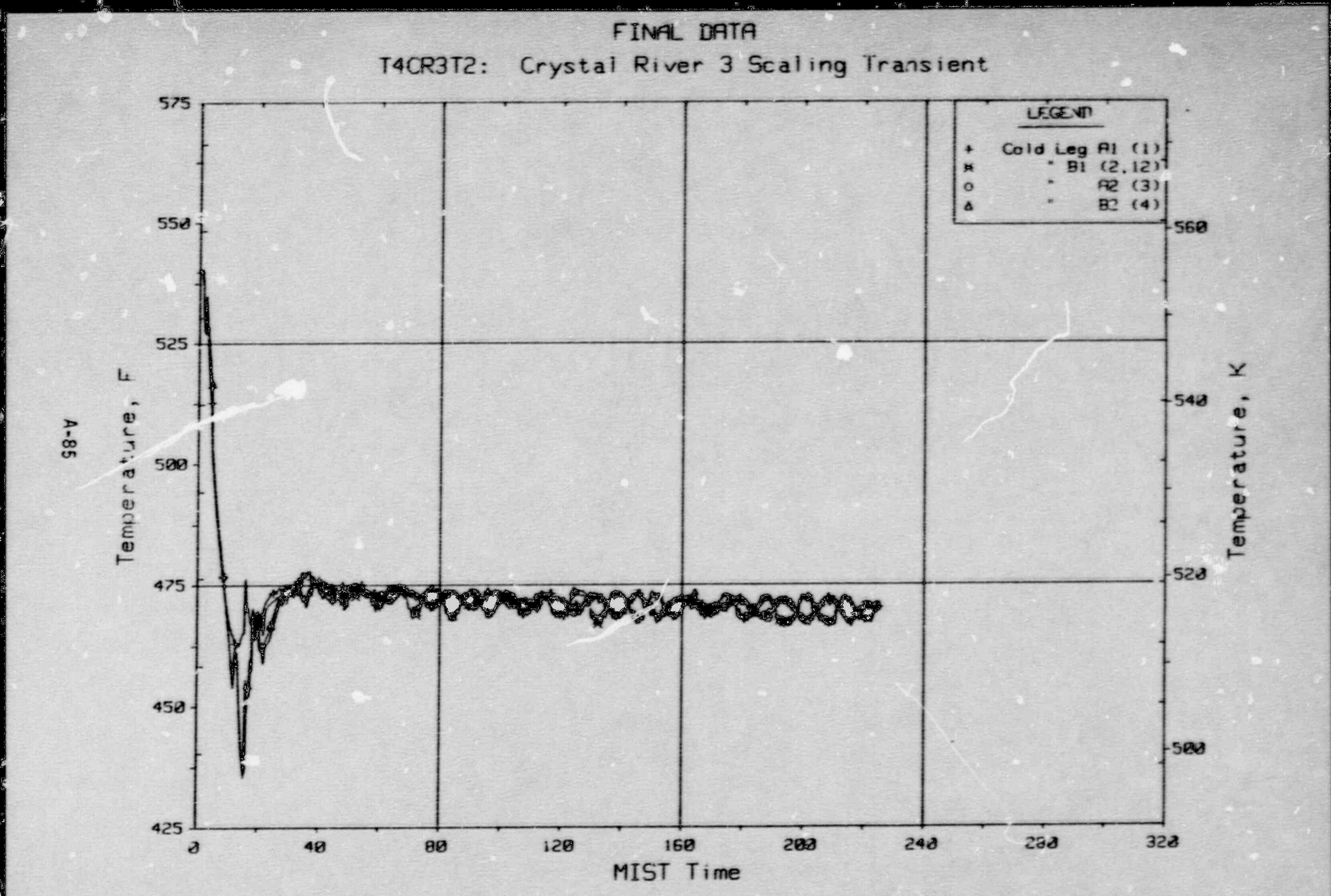



Figure A.83 Composite Core Exit and Hot Leg Fluid Temperatures

Mon Oct 24 10:41:18 1988




A-85

Figure A.84 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

Mon Oct 24 10:36:53 1988

CLTC1

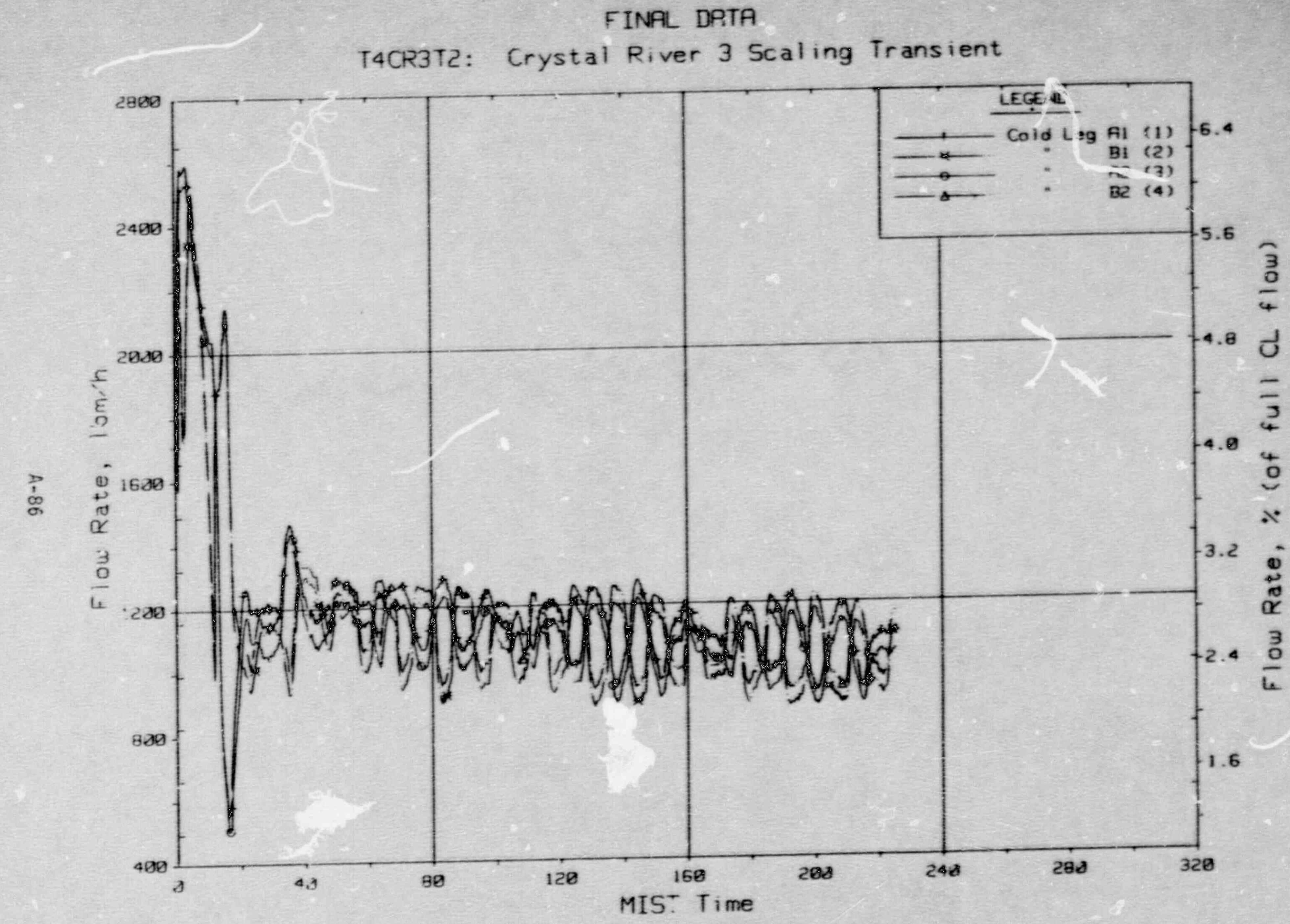



Figure A.85 Cold Leg (Venturi) Flow Rates (CnVN20s)

CLF20

A-86

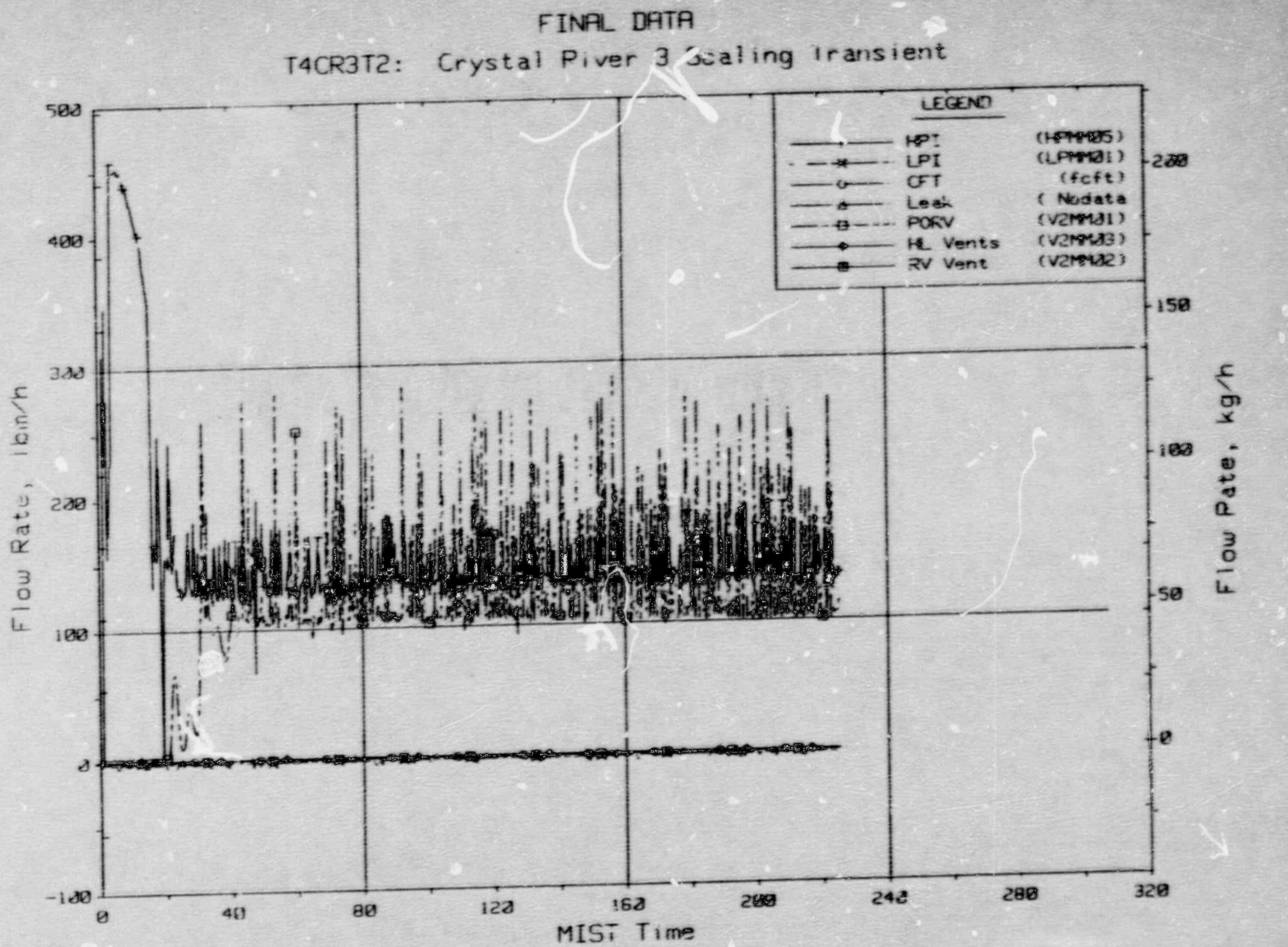



Figure A.86 Primary System Boundary Flow Rates

PPFL3x

Mon Oct 24 10:21:03 1988

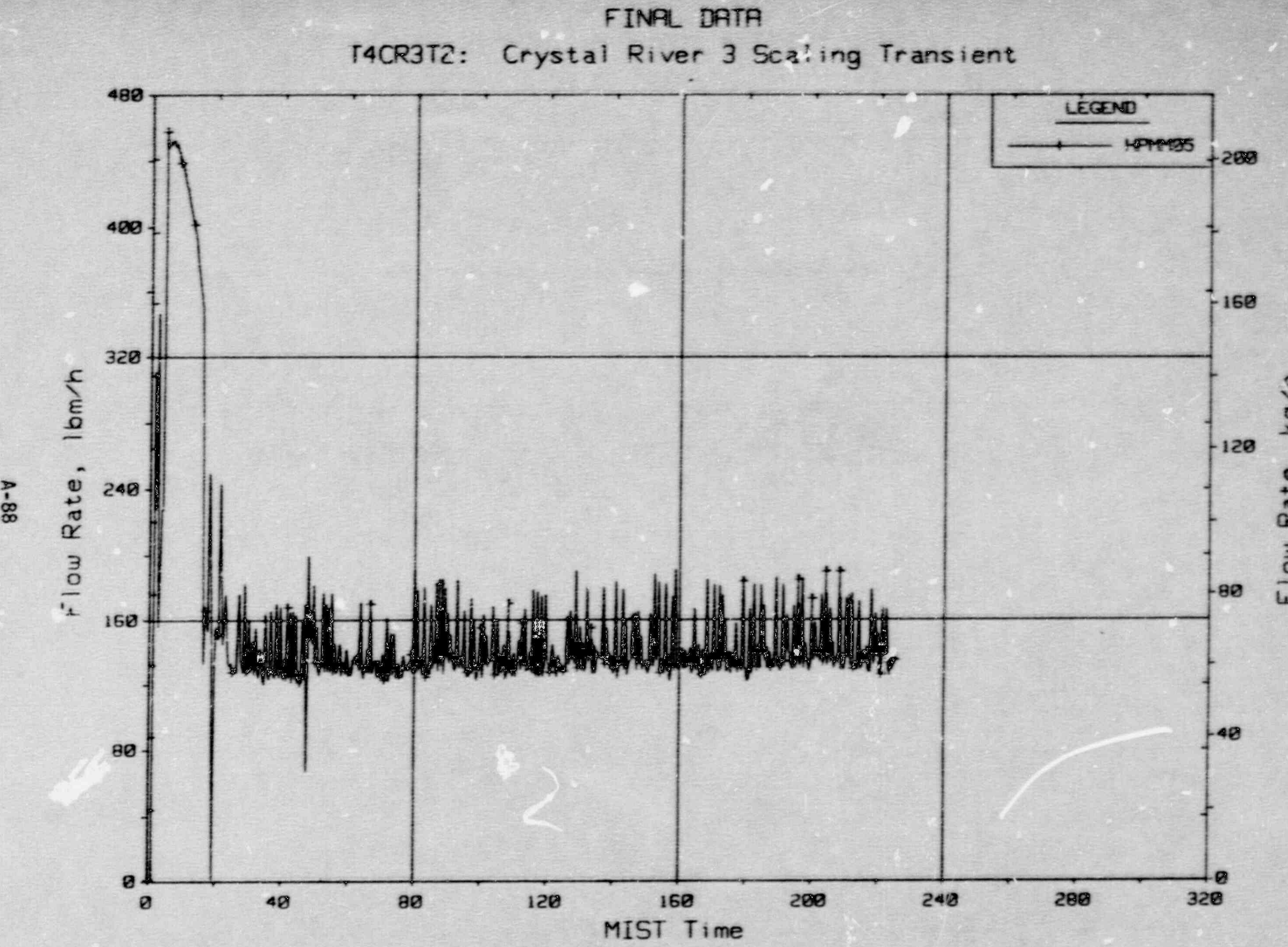



Figure A.87 HPI Total Flow Rate

Tue Oct 25 14:09:36 1988

HPFL3

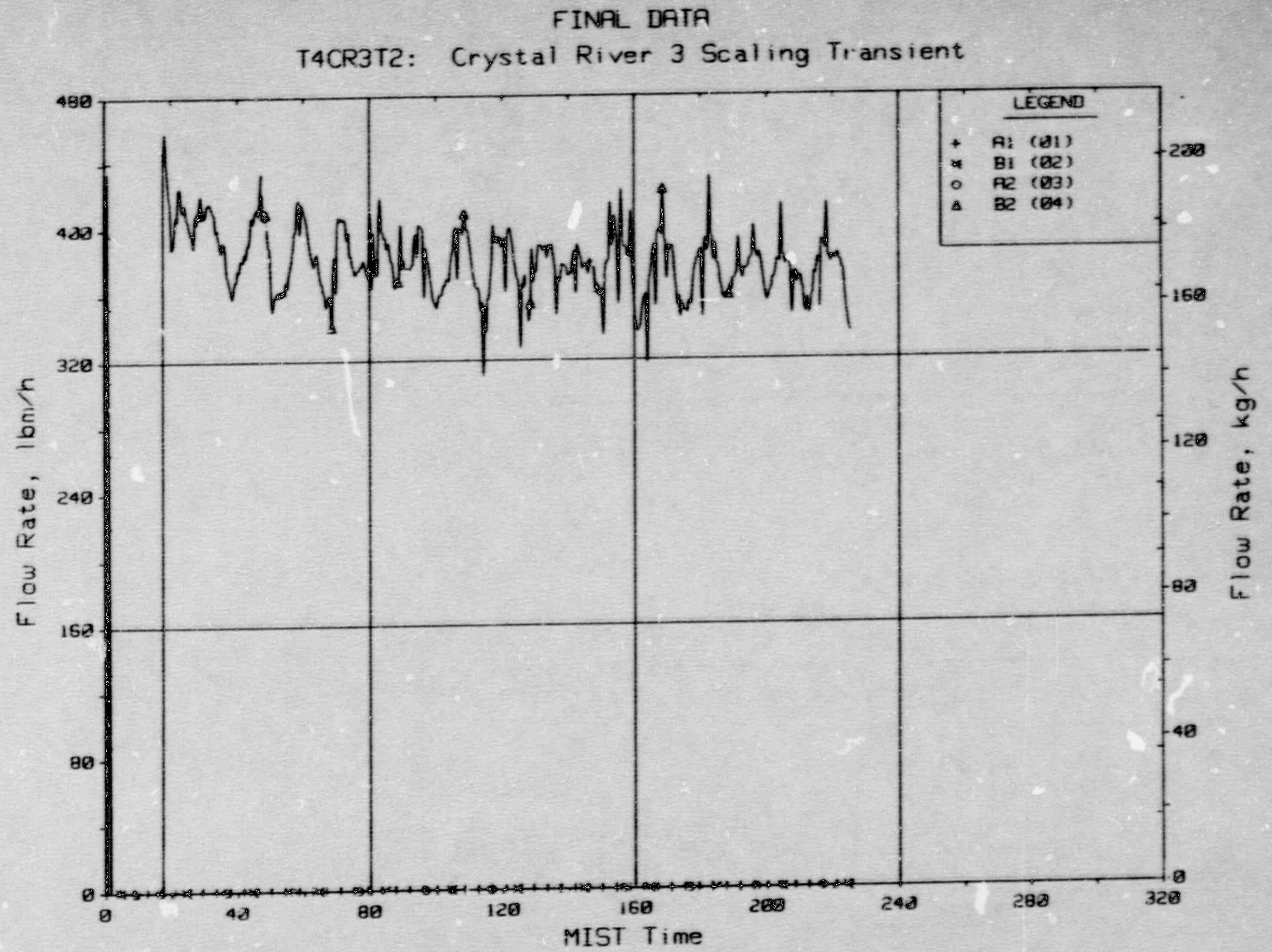



Figure A.88 Reactor Vessel Vent Valve Flow Rates(RVORs)

VVFL1

Mon Oct 24 10:20:36 1988

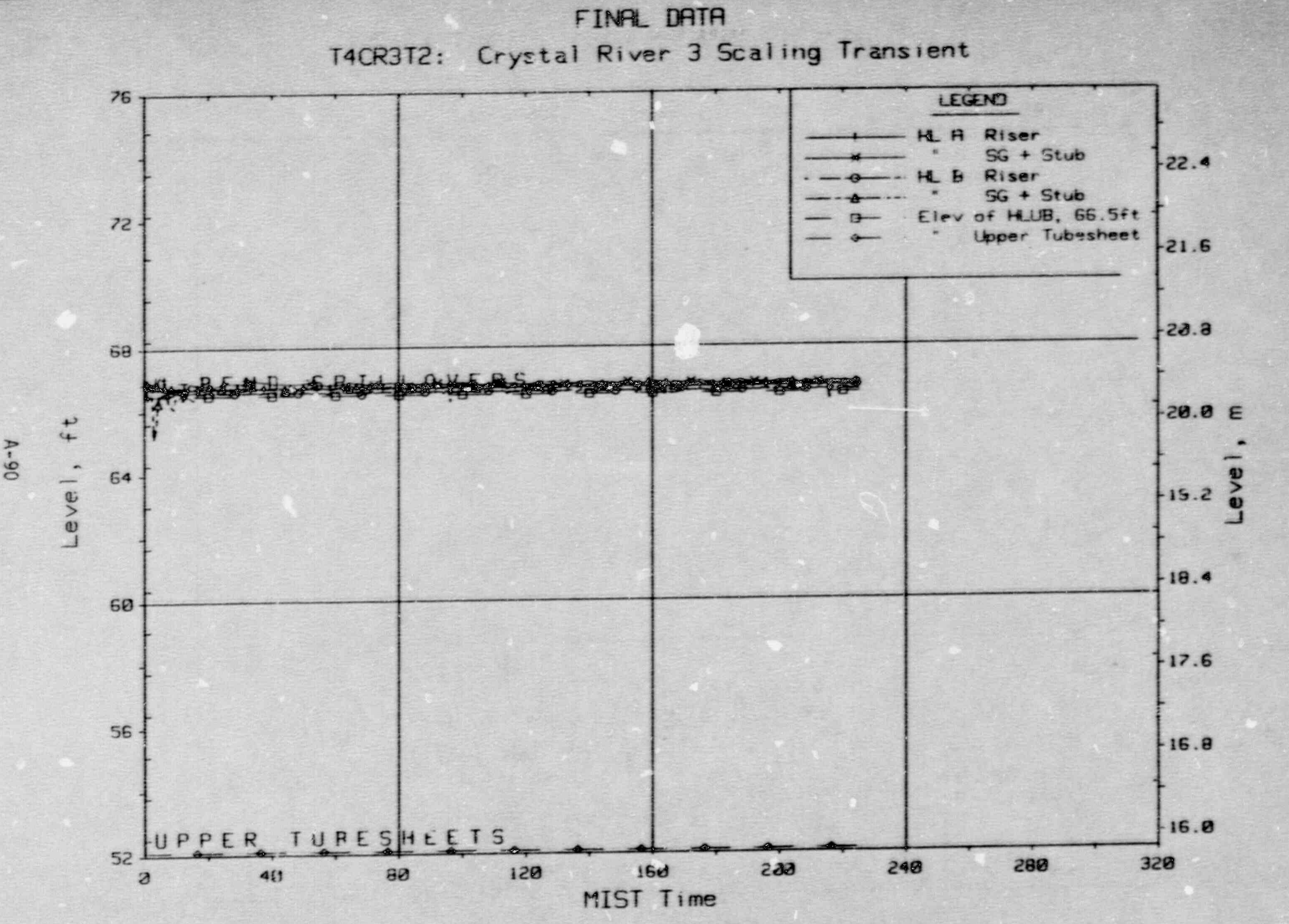



Figure A.89 Hot Leg Riser and Stub Collapsed Liquid Levels

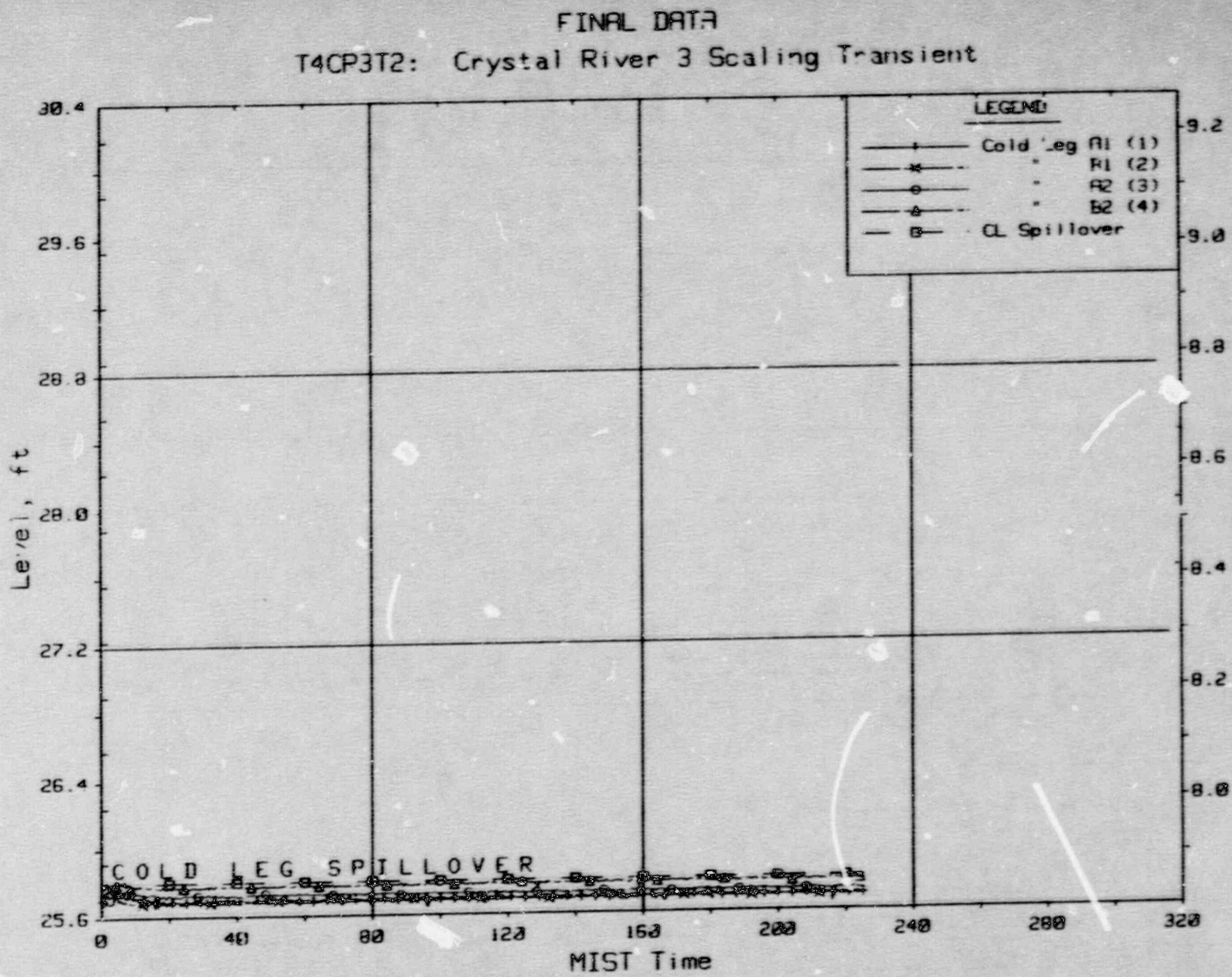



Figure A.90 Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

CLLV5

Mon Oct 24 12:14:29 1988

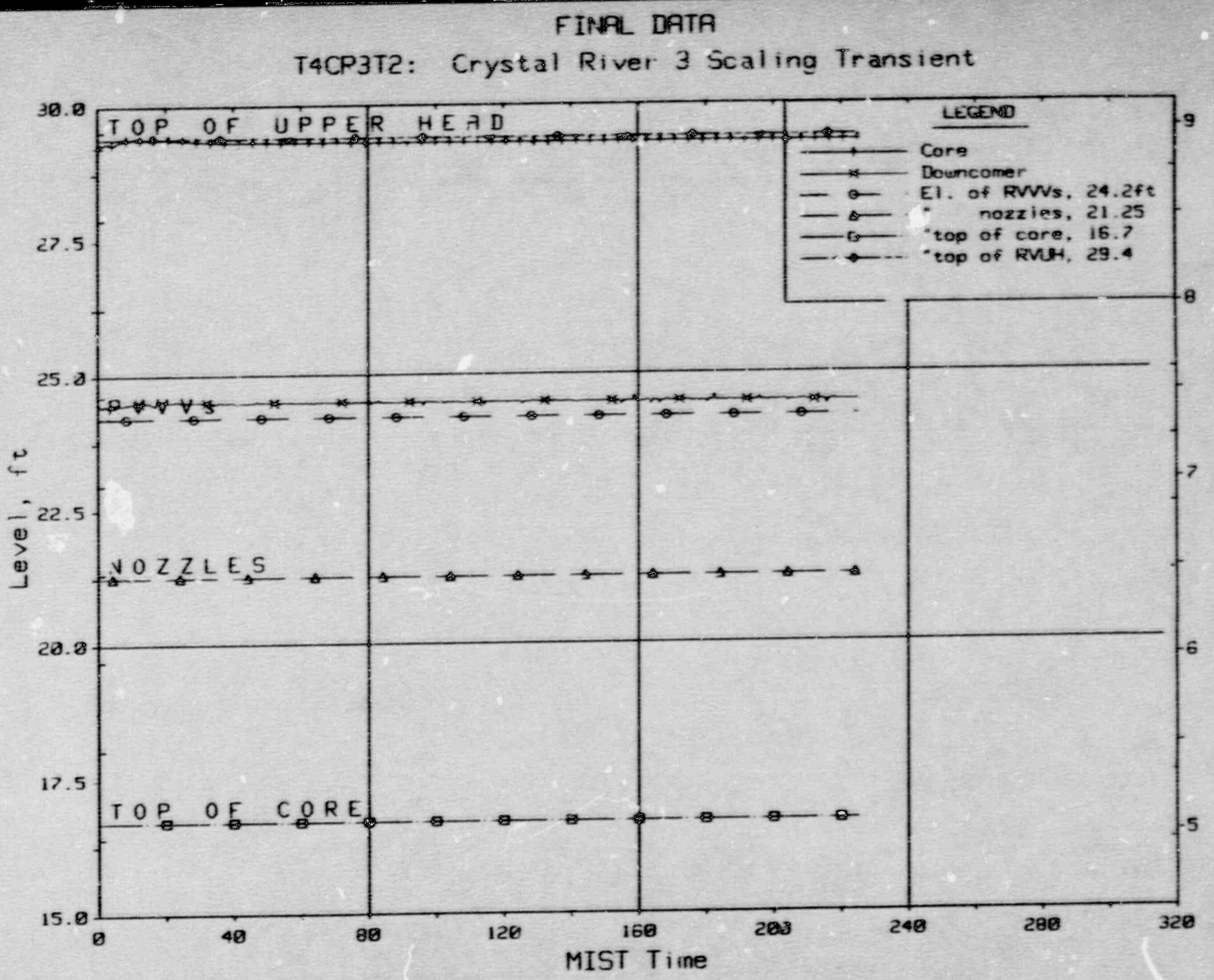



Figure A.91 Core Region Collapsed Liquid Levels

Mon Oct 24 10:11:30 1988

COLV1

FINAL DATA

T4CR3T2: Crystal River 3 Scaling Transient

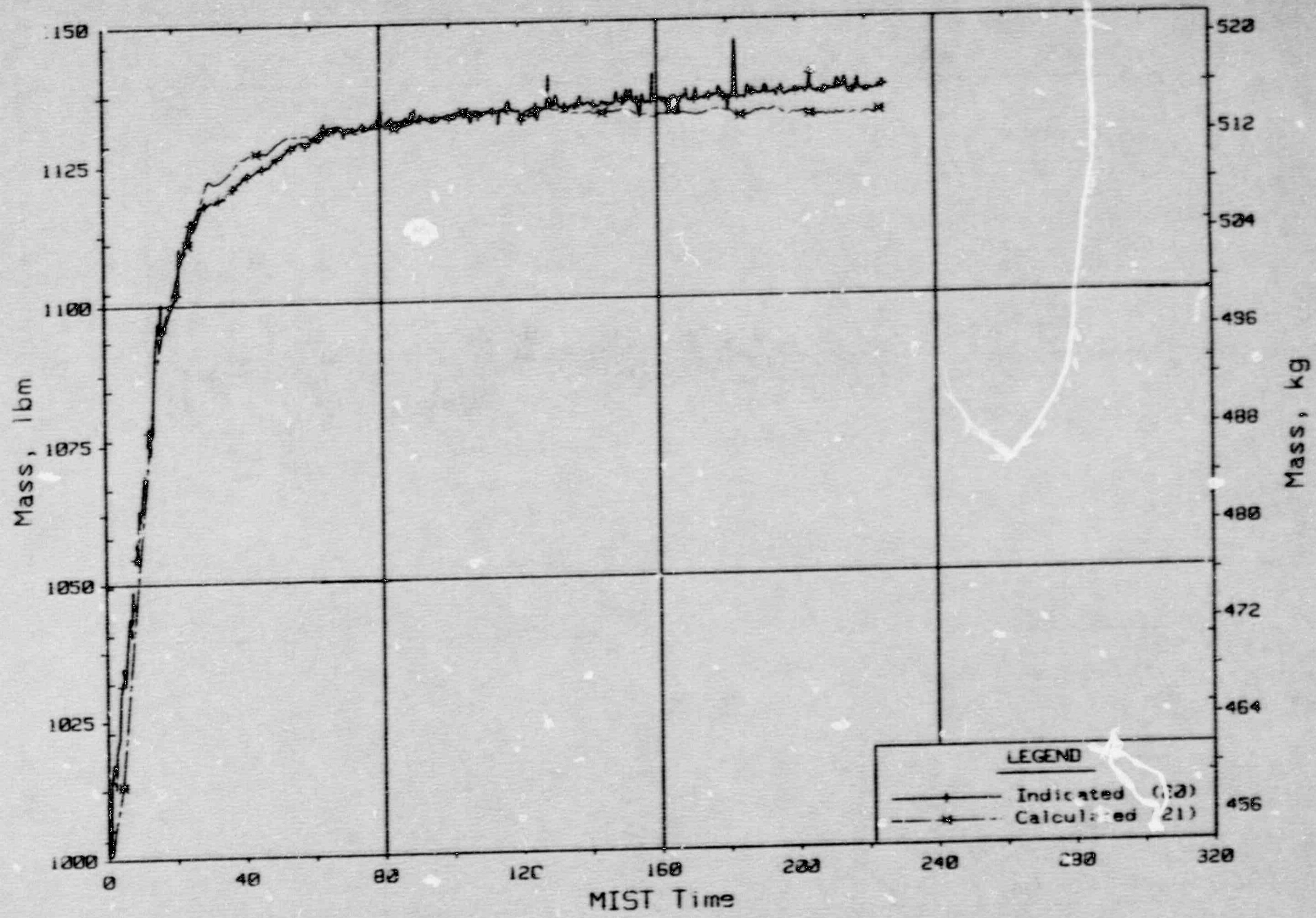



Figure A.92 Primary System Total Fluid Mass (PLMLs)

PRML1

Mon Oct 24 10:08:24 1988

FINAL DATA

T4CR3T2: Crystal River 3 Scaling Transient

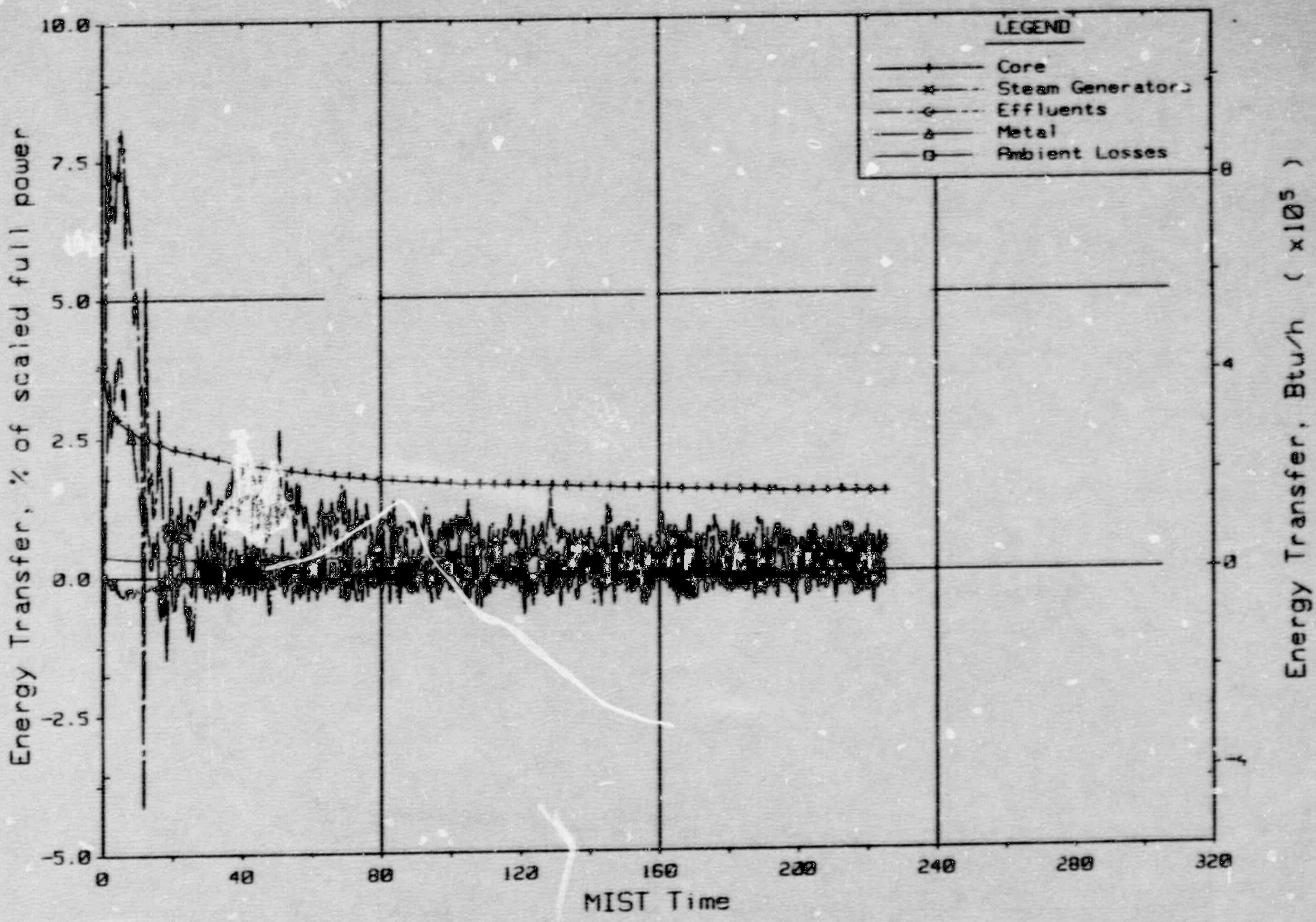



Figure A.93 Primary System Energy Transfer

PROE1X

Mon Oct 24 10:06:01 1988

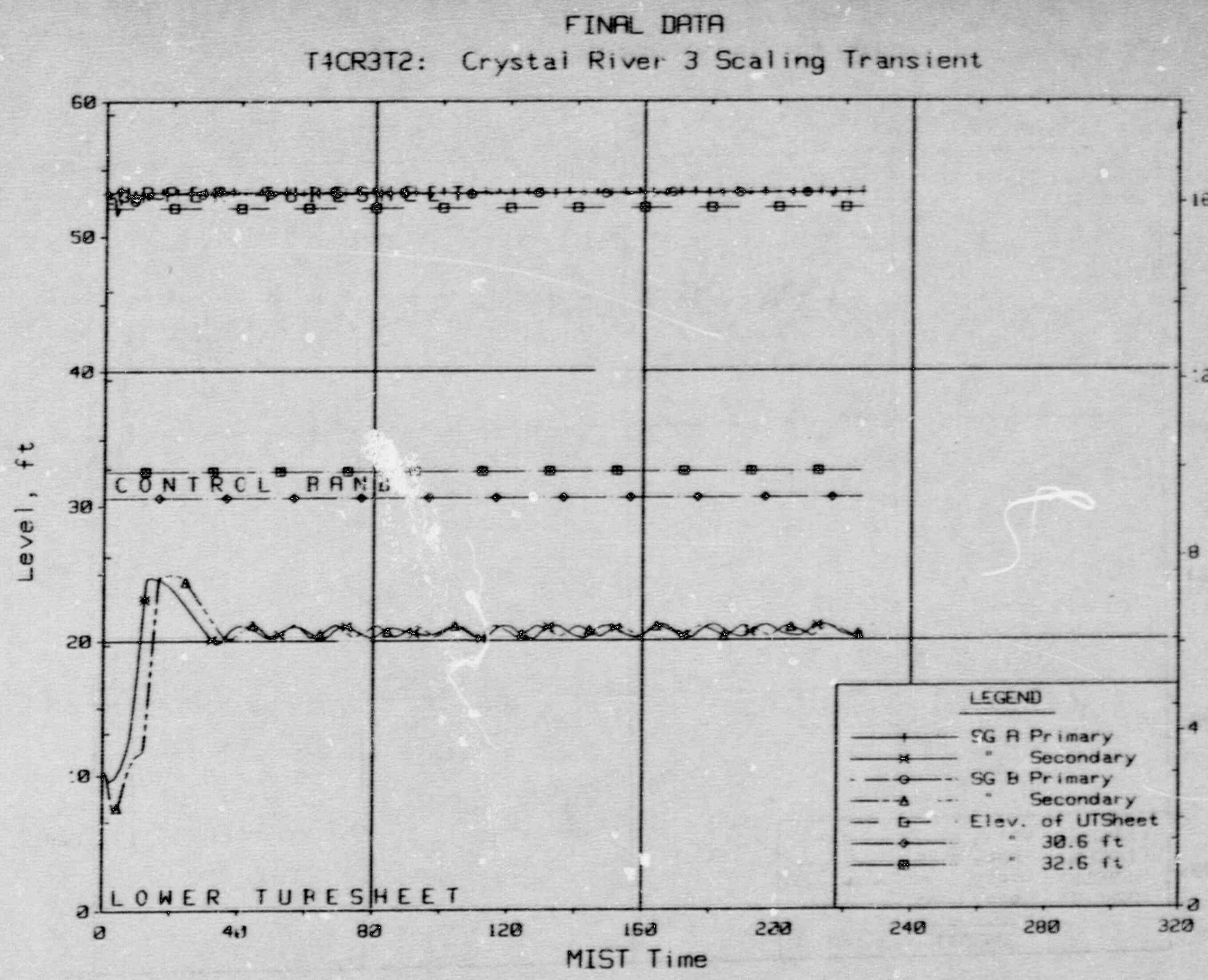



Figure A.94 Steam Generator Collapsed Liquid Levels

SGLV2

FINAL DATA

T4CR3T2: Crystal River 3 Scaling Transient

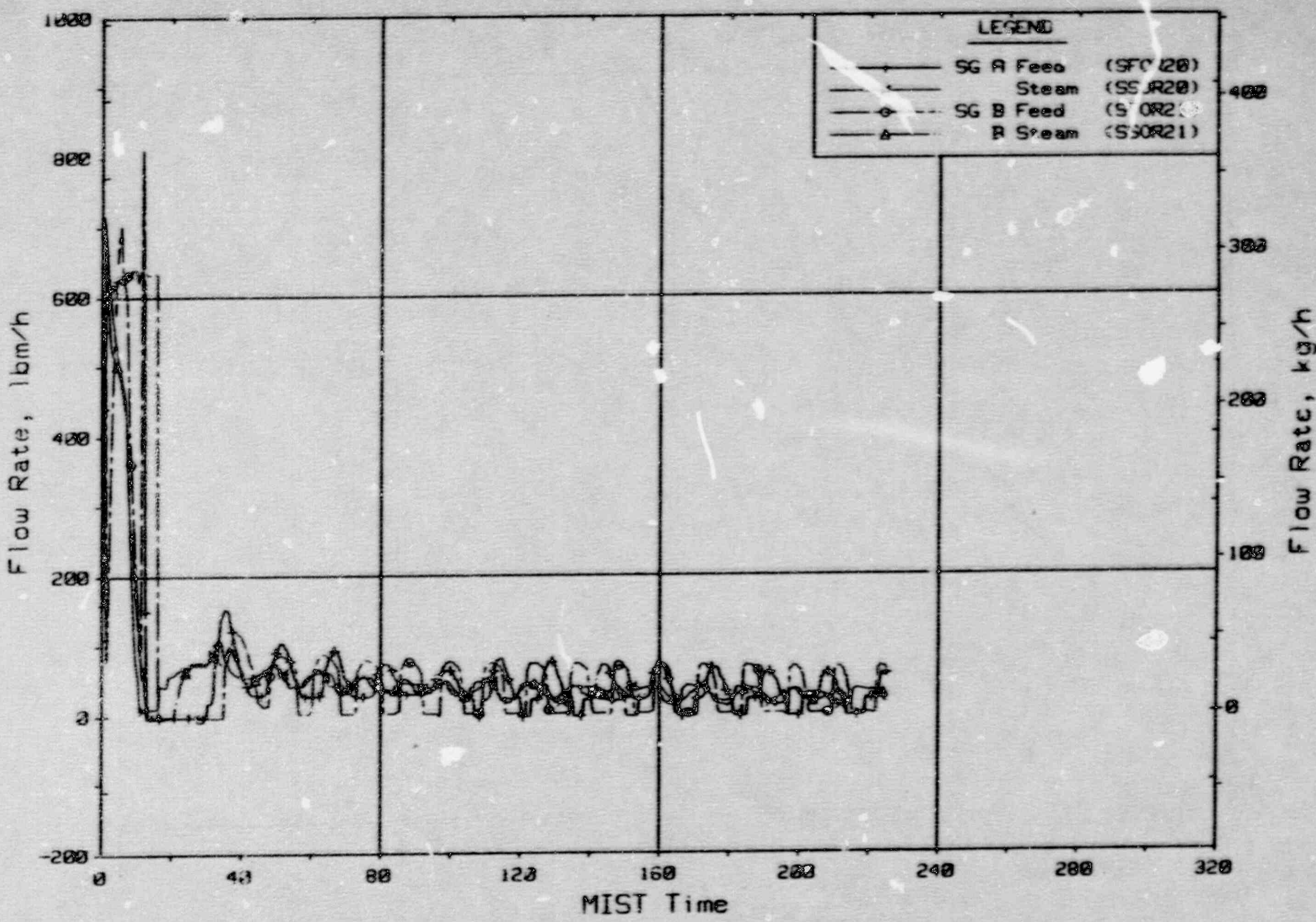


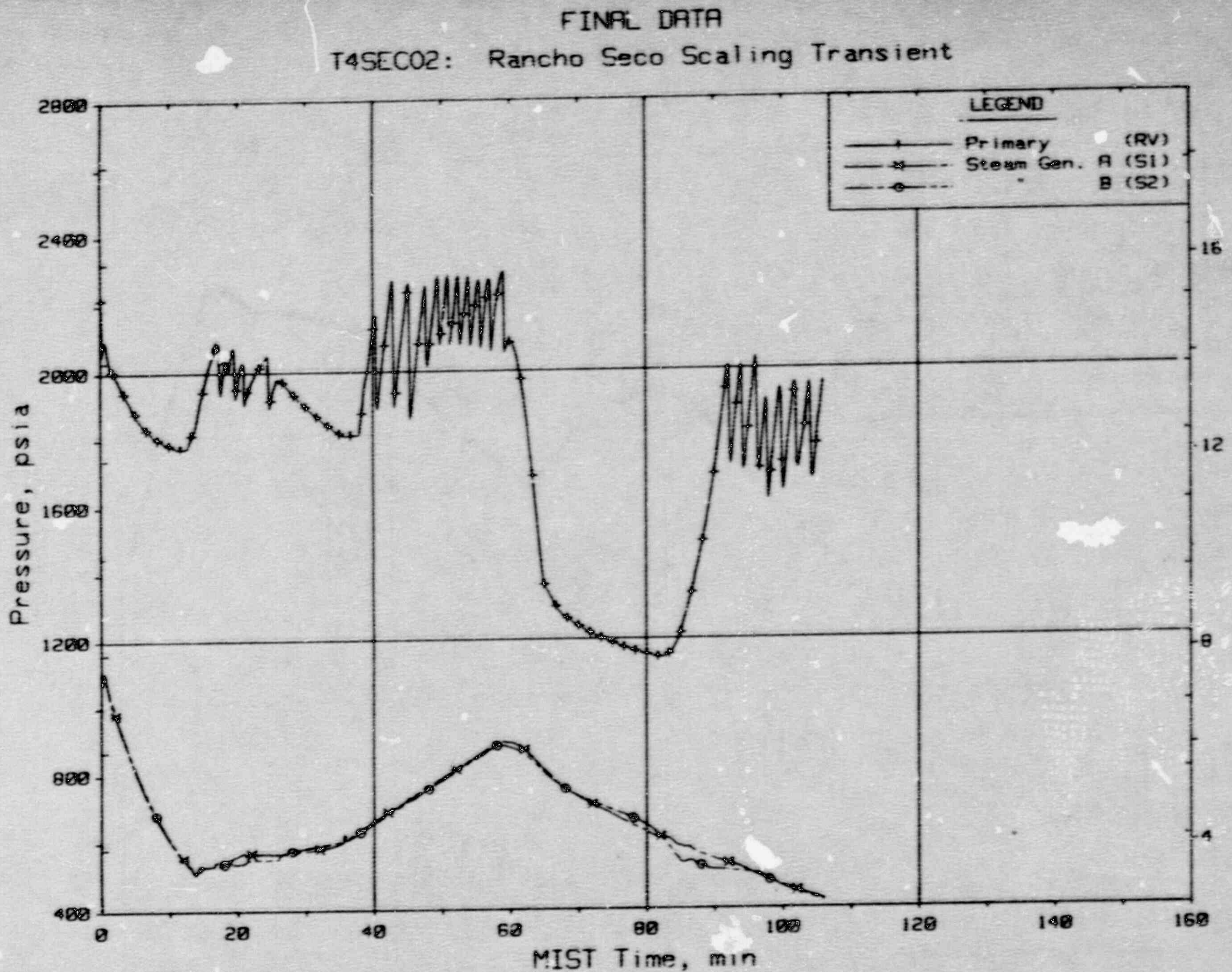

**Figure A.95 Steam Generator Secondary Flow Rates**

SGFL0

Mon Oct 24 09:58:09 1988

MIST Phase IV Test 4SEC02

Rancho Seco Scaling Transient




A-97

Figure A.96 Primary and Secondary System Pressures (GP01s)

PSGP1

Tue Oct 10 16:04:15 1988

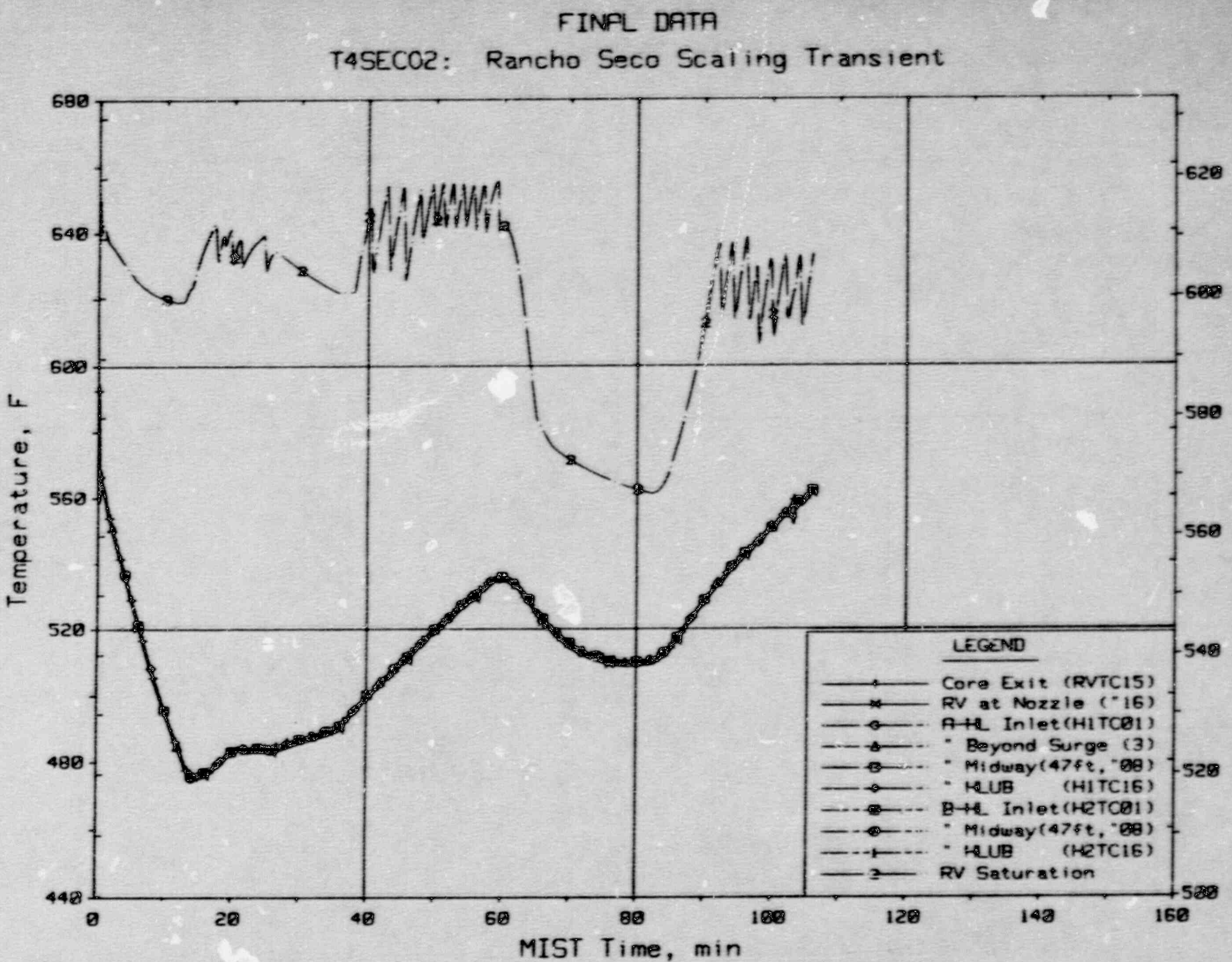
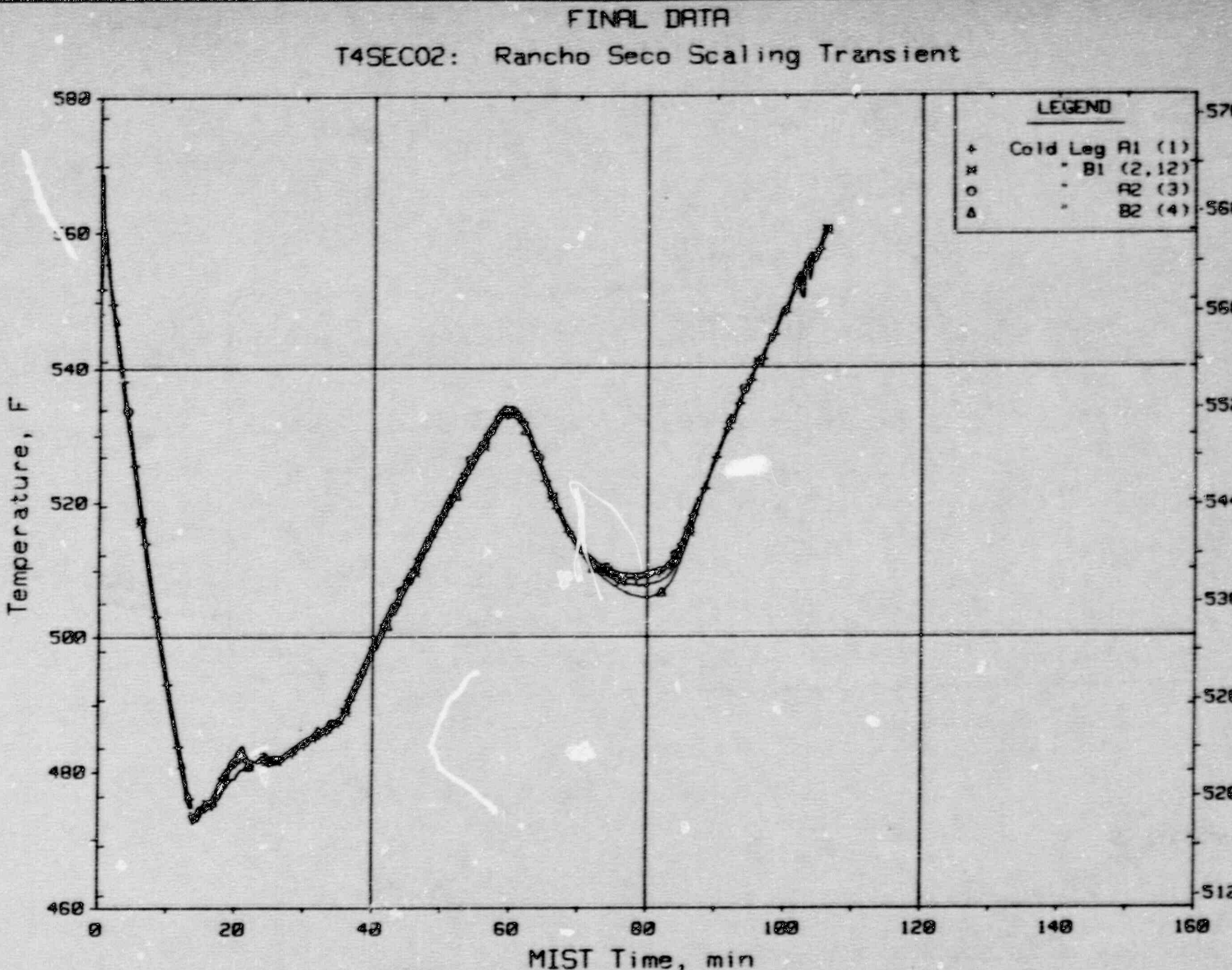



Figure A.97 Composite Core Exit and Hot Leg Fluid Temperatures

Tue Oct 10 16:08:50 1960

PFKTi




A-99

Figure A.98 Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3 ft, CnTC11s)

Tue Oct 18 13:55:56 1988

CLTC1

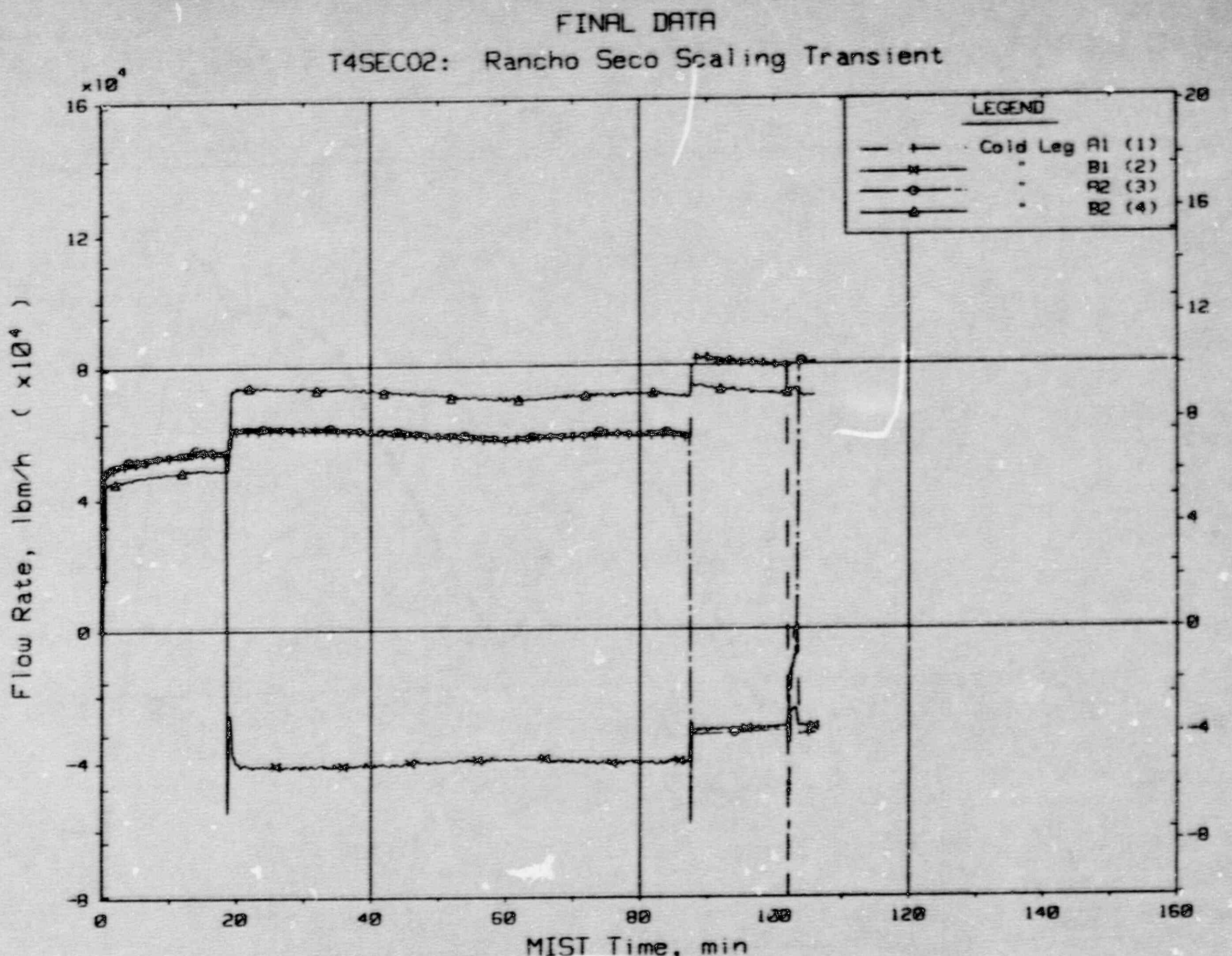



Figure A.99 Cold Leg (Turbine Meter) Flow Rates (CnTM01s)

CLTM1

Thu Oct 20 17:02:30 1988

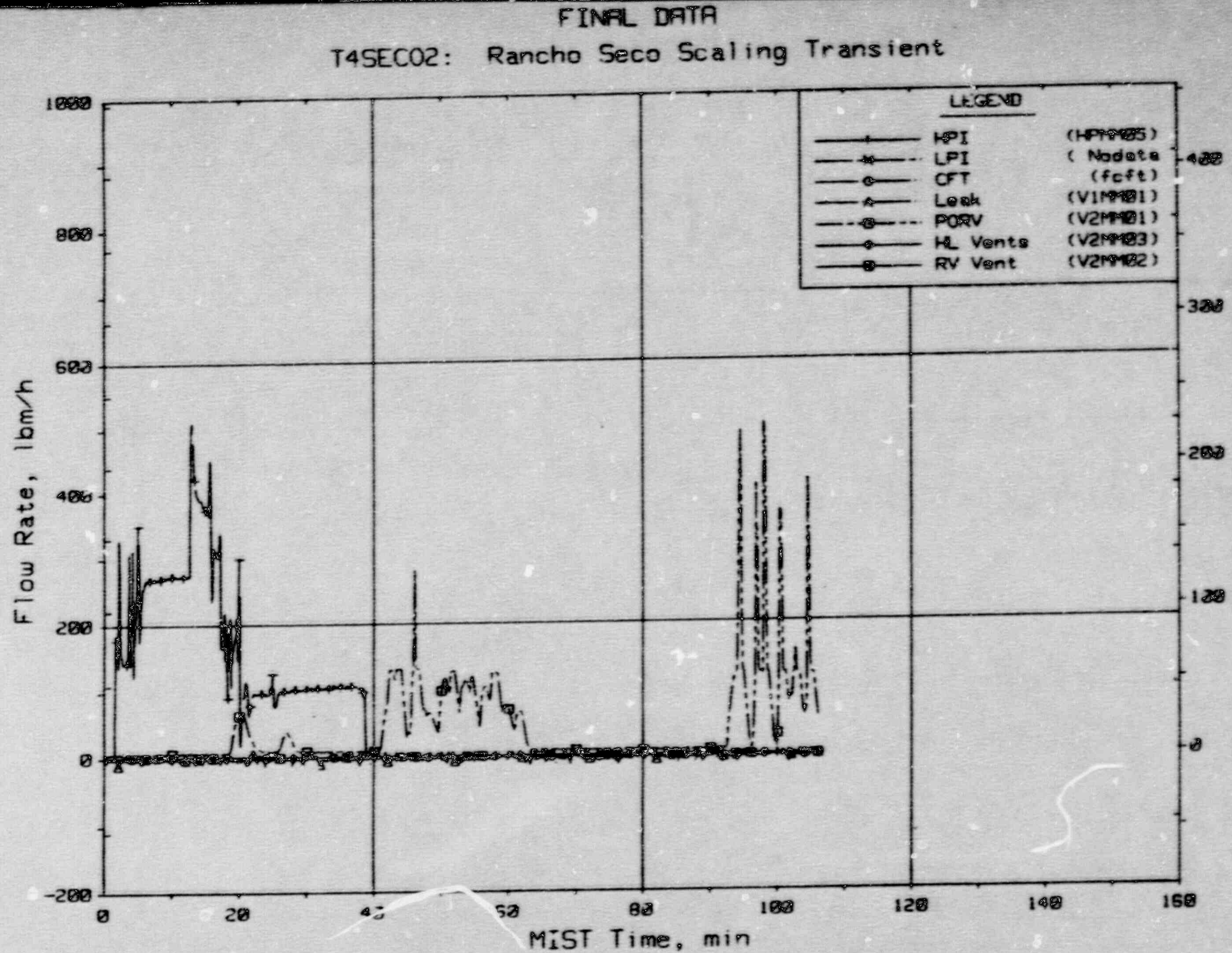



Figure A.100 Primary System Boundary Flow Rates

PRFL3x

Tue Oct 18 15:48:51 1988

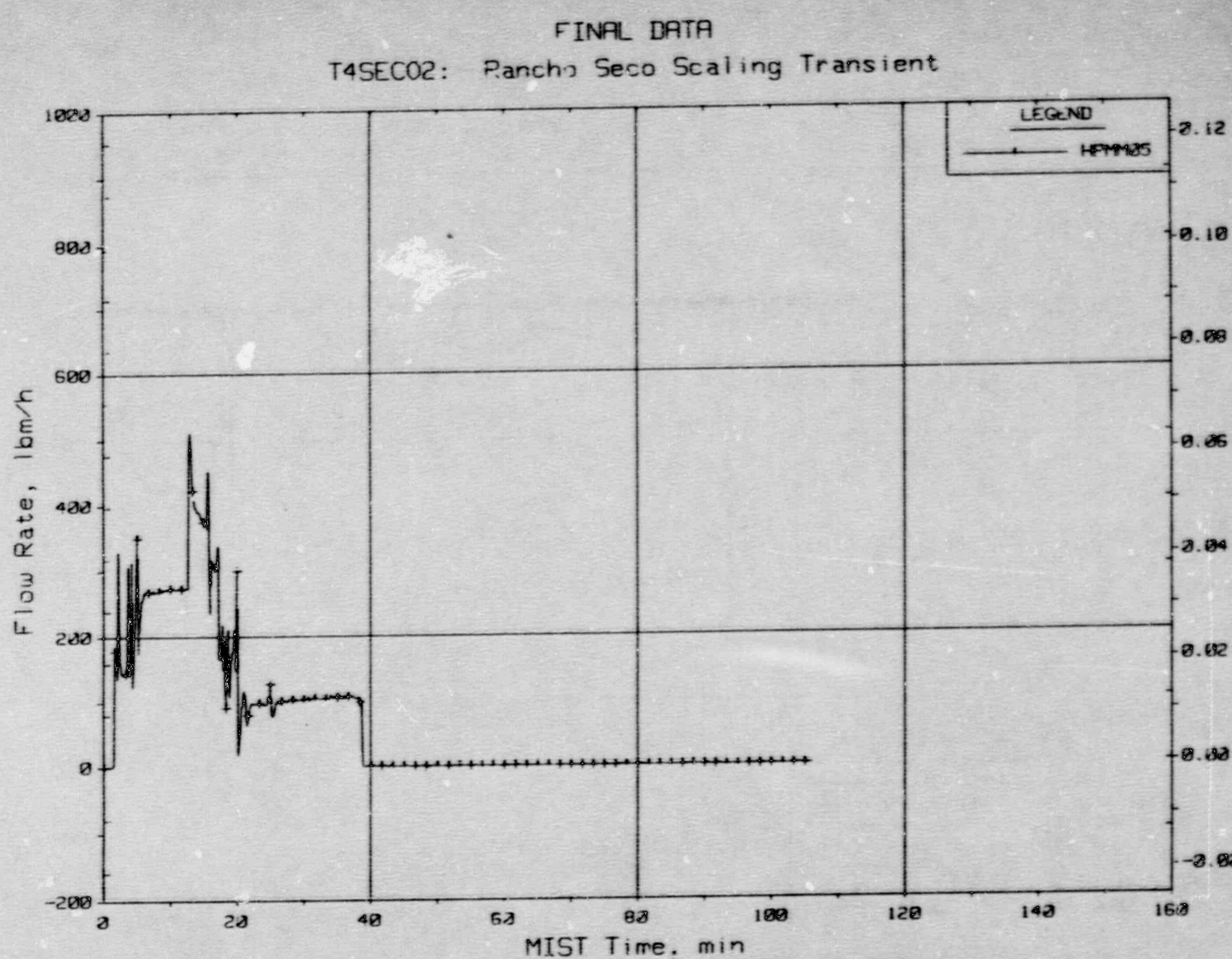


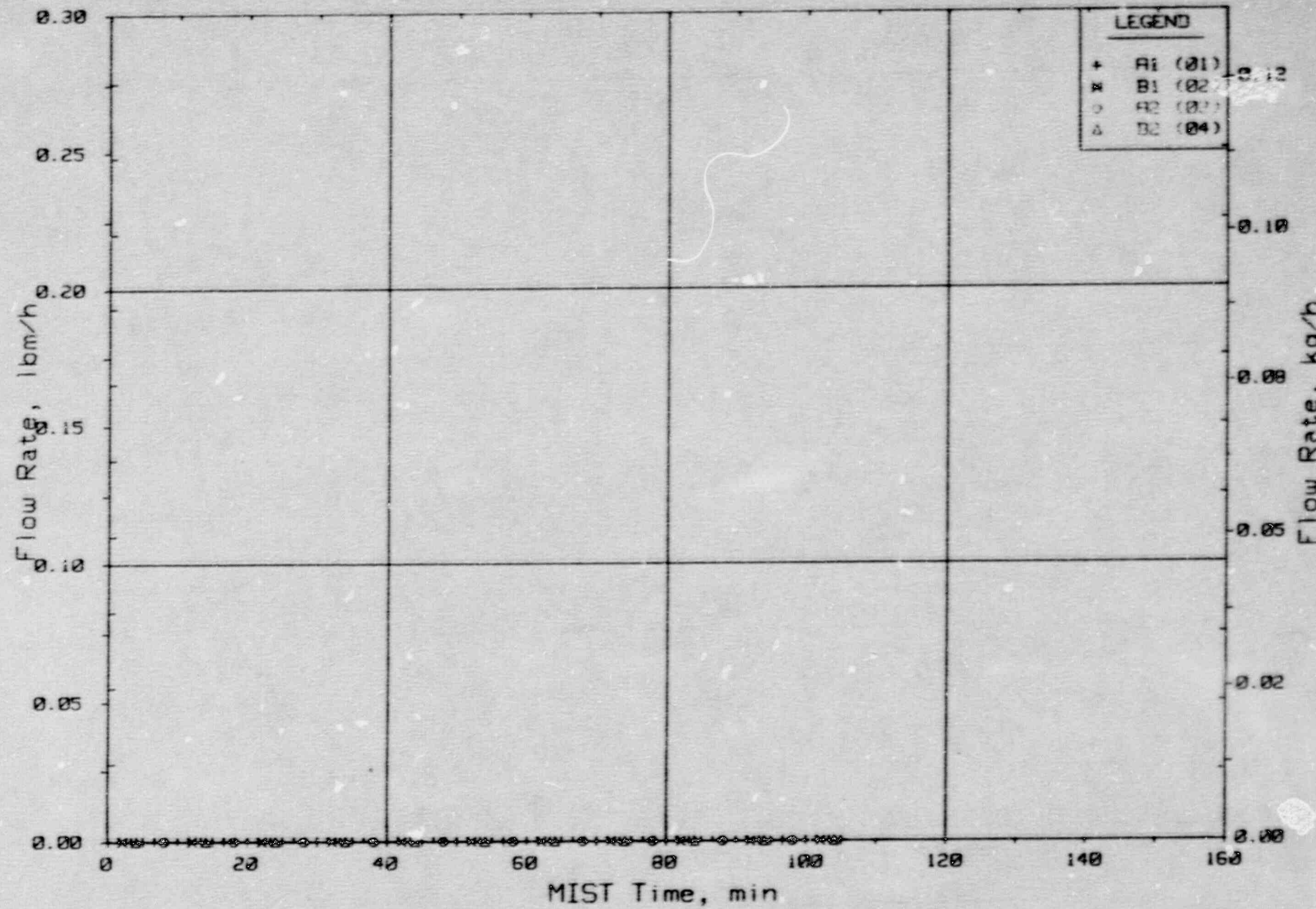

Figure A.101 HPI Total Flow Rate

Tue Oct 18 15:41:35 1988

HPFL3

FINAL DATA

T4SEC02: Rancho Seco Scaling Transient




A-103

Figure A.102 Reactor Vessel Vent Valve Flow Rates (RVORs)

Tue Oct 18 15:39:02 1988

VVFL1

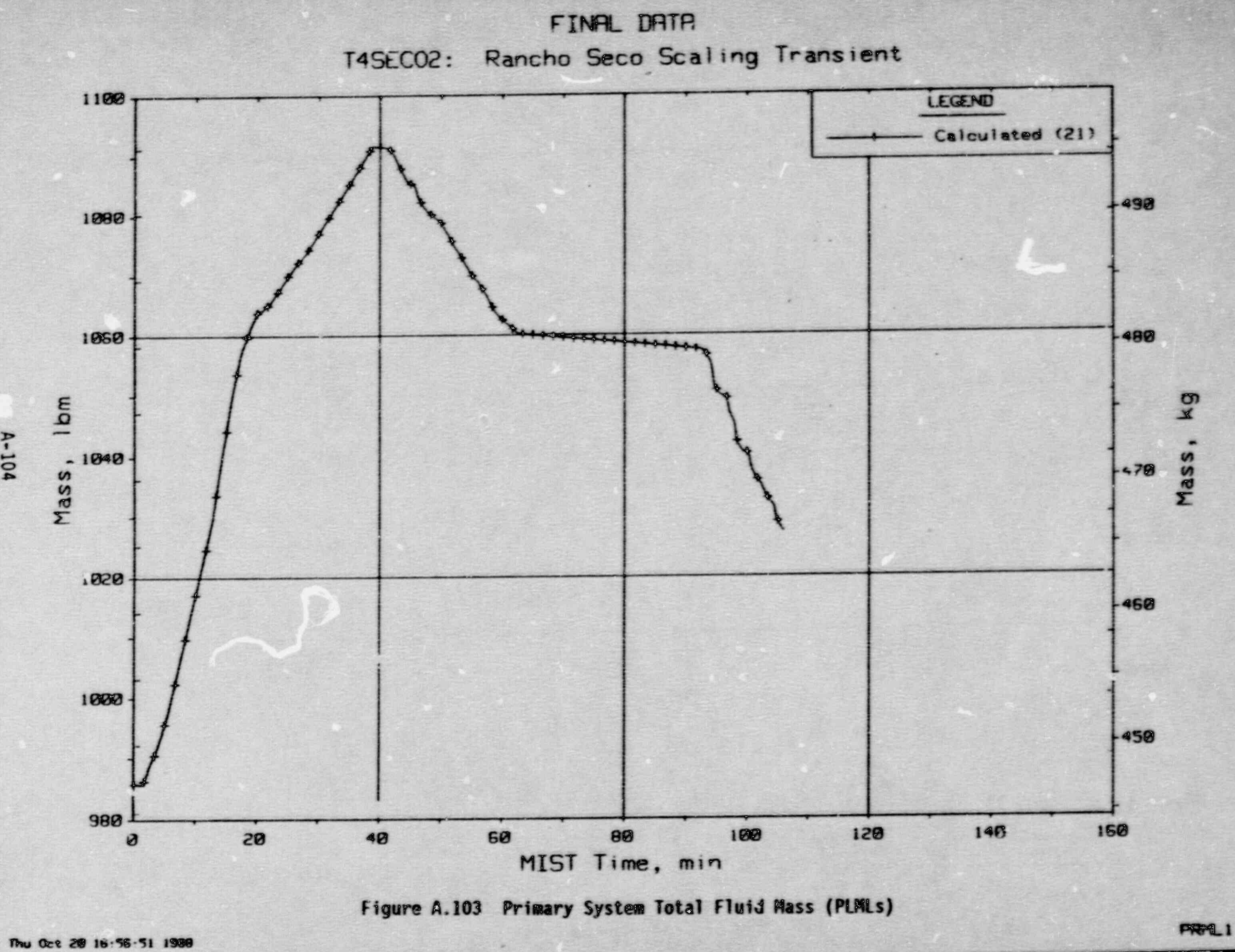
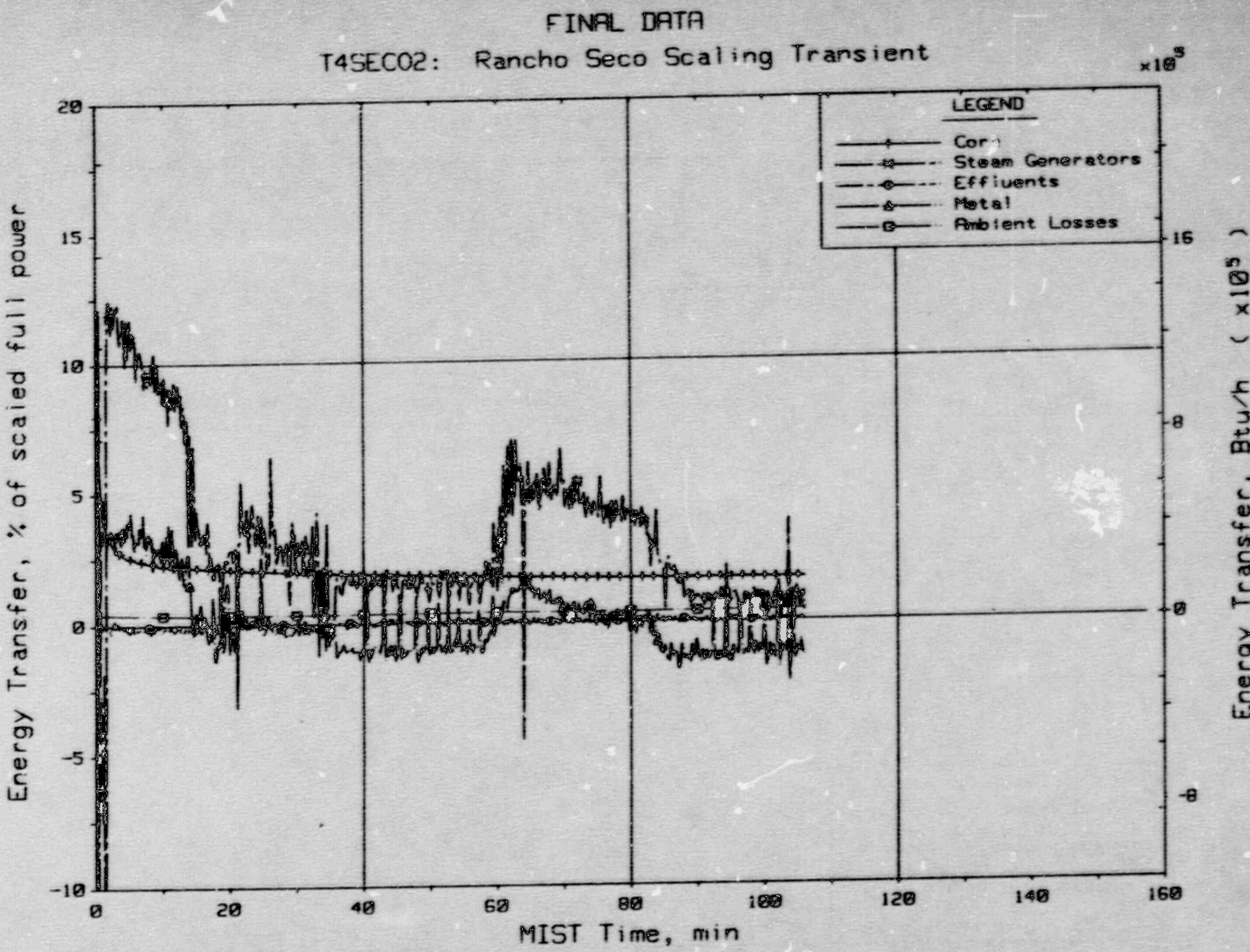



Figure A.103 Primary System Total Fluid Mass (PLMLs)




A-105

Figure A.104 Primary System Energy Transfer

PROEIX

Thu Oct 20 16:40:03 1988

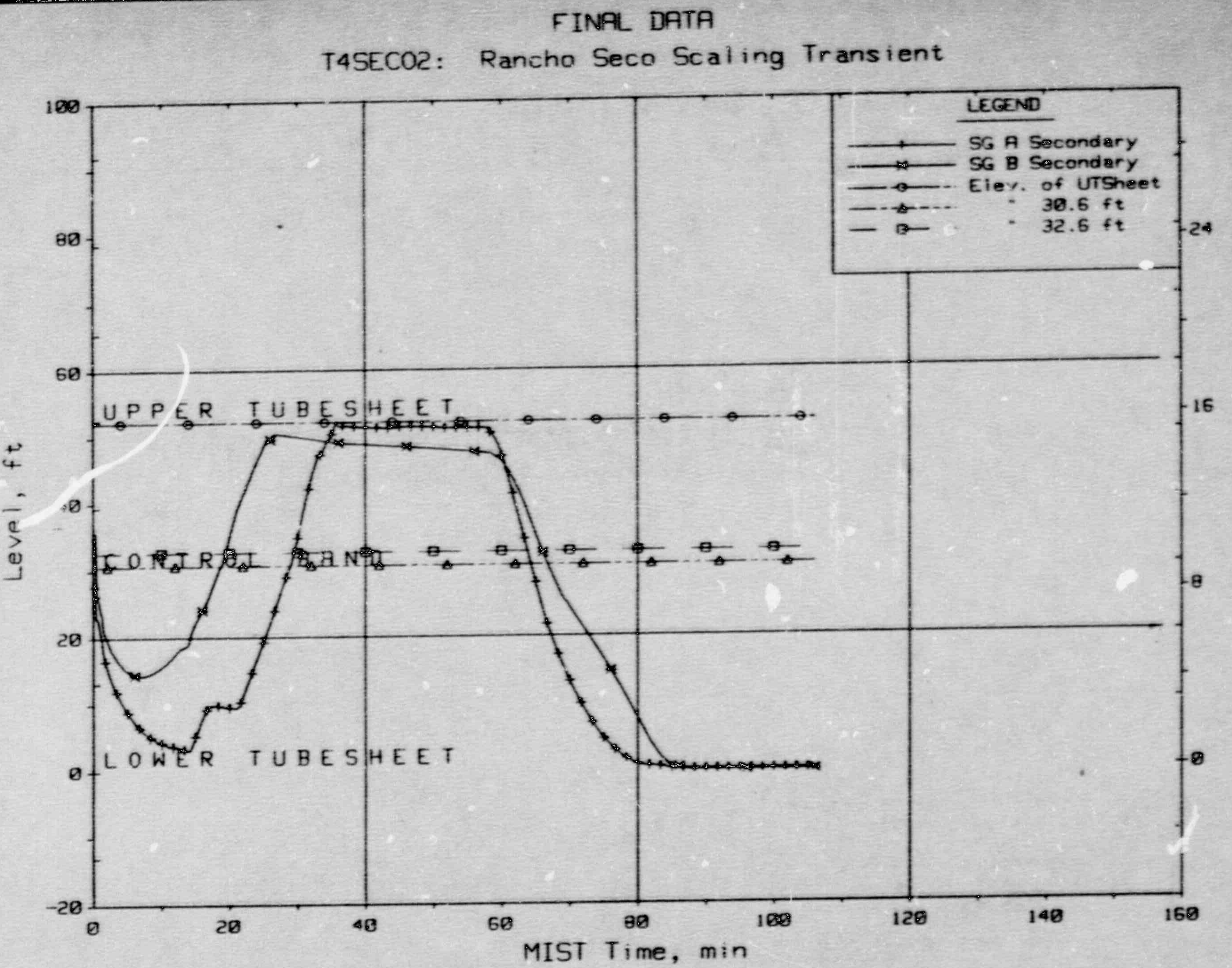



Figure A.105 Steam Generator Collapsed Liquid Levels

SGLV2

Thu Oct 20 16:16:38 1988

FINAL DATA

T4SEC02: Rancho Seco Scaling Transient

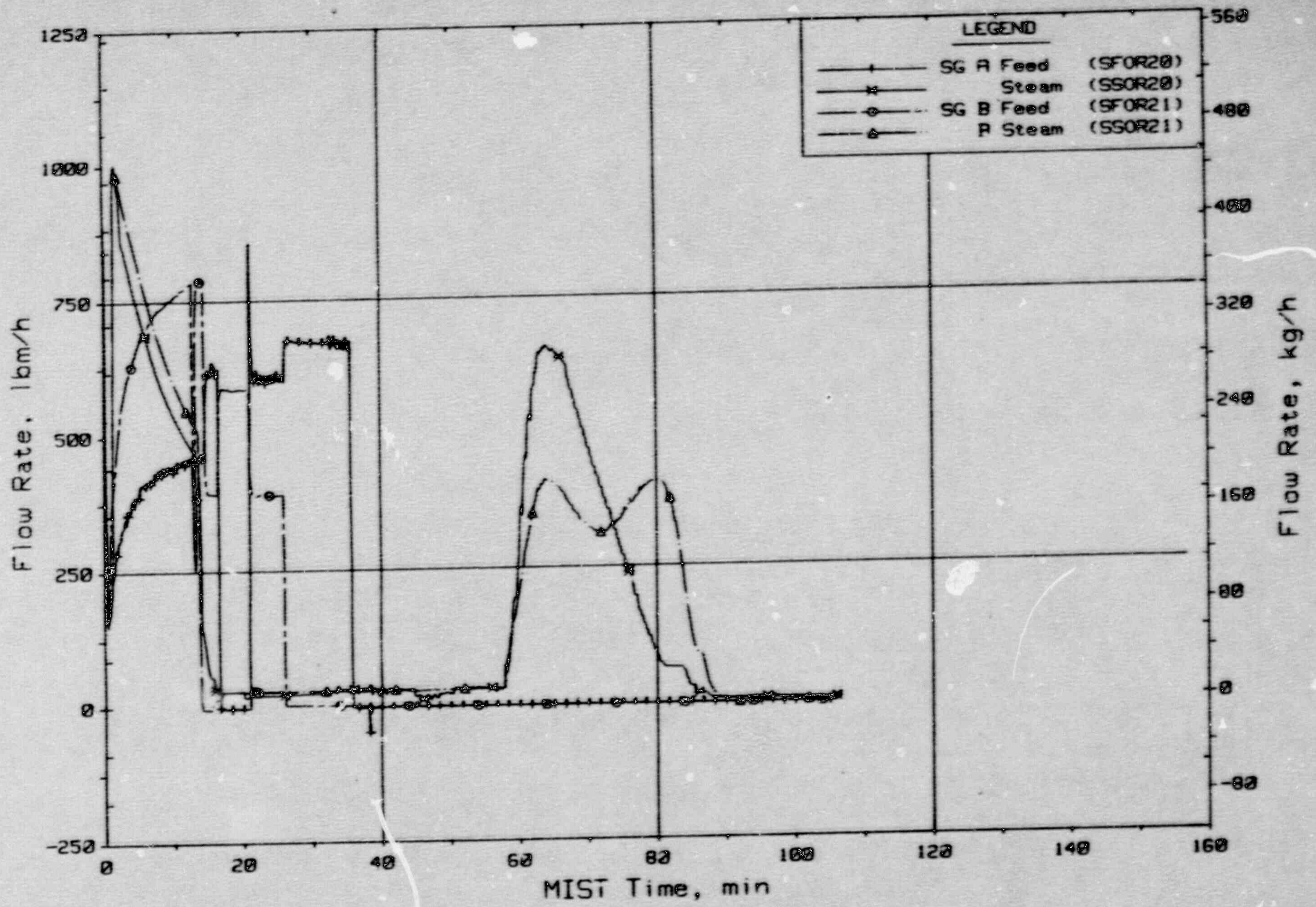



Figure A.106 Steam Generator Secondary Flow Rates

SGFL0

Tue Oct 18 15:16:22 1988

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U.S. NUCLEAR REGULATORY COMMISSION

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Nuclear Power Division
3315 Old Forest Road
Lynchburg, VA 24506-0935

Babcock [illegible]
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Division of Systems Research
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555

[illegible] Research Institute
P. O. Box 10412
Palo Alto, CA 94303

Babcock & Wilcox
Owners Group
P. O. Box 10935
Lynchburg, VA 24506-0935

**10. SUPPLEMENTARY NOTES**

**11. ABSTRACT** (200 words or less)


The Multiloop Integral System Test (MIST) is part of a multiphase program started in 1983 to address small-break loss-of-coolant accidents (SBLOCAs) specific to Babcock and Wilcox designed plants. MIST is sponsored by the U. S. Nuclear Regulatory Commission, the Babcock & Wilcox Owners Group, the Electric Power Research Institute, and Babcock and Wilcox. The unique features of the Babcock and Wilcox design, specifically the hot leg U-bends and steam generators, prevented the use of existing integral system data or existing integral facilities to address the thermal-hydraulic SBLOCA questions. MIST and two other supporting facilities were specifically designed and constructed for this program, and an existing facility--the Once Through Integral System (OTIS)--was also used. Data from MIST and the other facilities will be used to benchmark the adequacy of system codes, such as RELAP5 and TRAC, for predicting abnormal plant transients.

The MIST program is reported in 11 volumes. The program is summarized in Volume 1; Volumes 2 through 8 describes groups of tests by test type; Volume 9 presents inter-group comparisons; Volume 10 provides comparisons between the calculations of RELAP5/MOD2 and MIST observations, and Volume 11 presents the later Phase 4 tests. This Volume 11 pertains to MIST Phase IV tests performed to investigate risk dominant transients and non-LOCA events.


**12. KEY WORDS/DESCRIPTORS** (List words or phrases that will assist researchers in locating the report.)

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steam generator tube rupture, station black out
Two-phase flow, SBLOCA without HPI injection

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