NUREG/CR-5395
EPRI/NP-6480
BAW-2064
Vol. 5

Multiloop Integral System Test (MIST): Final Report

Test Group 33, HPI–PORV Cooling

Prepared by J. R. Gloudemans/B&W

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

8911070297 890731
PDR NUREG
CR-5395 R PDR

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW, Lower Level, Washington, DC 20555

2. The Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082

3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Information Resources Management, Distribution Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

DISCLAIMER NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expresed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NUREG/CR-5395
EPRI/NP-6480
BAW-2064
Vol. 5

Multiloop Integral System Test (MIST): Final Report

Test Group 33, HPI-PORV Cooling

Date Published: July 1989

Principal Author
J. R. Gloudemans

Major Contributors

ARC		NPD
D. P. Birmingham	T. F. Habib	G. O. Geissler
J. E. Blake	F. Karimi-Azad	K. W. Turner
H. R. Carter	C. G. Koksal	
M. T. Childerson	T. E. Moskal	
R. P. Ferron	G. C. Rush	

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
NRC FINs B8909, D1734

Electric Power Research Institute
P. O. Box 10412
Palo Alto, CA 94303

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

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

ABSTRACT

The multiloop integral system test (MIST) was part of a multiphase program started in 1983 to address small-break loss-of-coolant accidents (SBLOCAs) specific to Babcock & Wilcox-designed plants. MIST was sponsored by the U.S. Nuclear Regulatory Commission, the Babcock & Wilcox Owners Group, the Electric Power Research Institute, and Babcock & 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 system 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 RELAP-5 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 describe 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 is Volume 5 pertaining to Test Group 33. The four tests of Test Group 33 dealt with HPI-PORV cooling. The specifications, conduct, observations, and results of these tests are described.

CONTENTS

Contents (Cont'd)

List of Tables

List of Figures

Figures (Cont'd)

Figure | Page

Figures (Cont'd)

Figure | Page

<u>Figures (Cont'd)</u>

Figures (Cont'd)

EXECUTIVE SUMMARY

Introduction

The multiloop integral system test (MIST) was a scaled 2-by-4 (2 hot legs and 4 cold legs) physical model of a Babcock & Wilcox (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-small-break loss-of-coolant accident (SBLOCA) testing are used for computer code benchmarking. The MIST interactions are of intrinsic interest because they may provide insight into expected plant behavior. MIST was necessarily atypical of a plant in certain important respects, however. The MIST interactions therefore are not to be applied directly to a plant.

MIST consisted of two 19-tube, once-through steam generators, a reactor, a pressurizer, 2 hot legs, and 4 cold legs with scaled reactor coolant pumps. Other loop components 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 (HPI), 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 used on all primary system components as well as the steam generator secondaries. MIST is illustrated in Figure 1.

Boundary Systems

The MIST boundary systems were sized to power-scale the plant boundary conditions. HPI and auxiliary feedwater (AFW) characteristics were based on composite plant characteristics. Scaled model vents were included in both hot legs and in the reactor vessel upper head. Leaks were located in the cold leg suction and discharge piping, and the upper and lower elevations of steam generator B (for tube rupture simulation). The desired vent and leak flows were obtained using power-scaled restrictors.

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-sectional area and placing insulating blocks between load-bearing surfaces. The reactor coolant system piping and vessels were covered with passive insulation, active insulation (or guard heaters), and an outer-sealed jacket (to prevent chimney effects). The guard heaters were divided into 42 zones, each controlled by a zonal temperature difference and pipe metal temperature.

Instrumentation

MIST had approximately 850 instruments. These 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 rates at the system boundaries were measured using Coriolis flowmeters and weigh scales. Loop mass flow rates were measured using venturis or turbines.

Transient Test Program

The MIST transient tests were defined to generate integral system data for code benchmarking. The transient test series was divided into the following seven groups:

- Mapping
- Boundary systems
- Leak-HPI configuration
- HPI-PORV cooling (feed and bleed)
- Steam generator tube rupture
- Noncondensible gas (NCG) and venting
- Reactor coolant pump (RCP) operation

The mapping tests were intended to examine the initial post-SBLOCA transient interactions. In these tests, the primary system inventory was carefully controlled and slowly varied to allow the examination of the normally rapid and overlapping post-SBLOCA events.

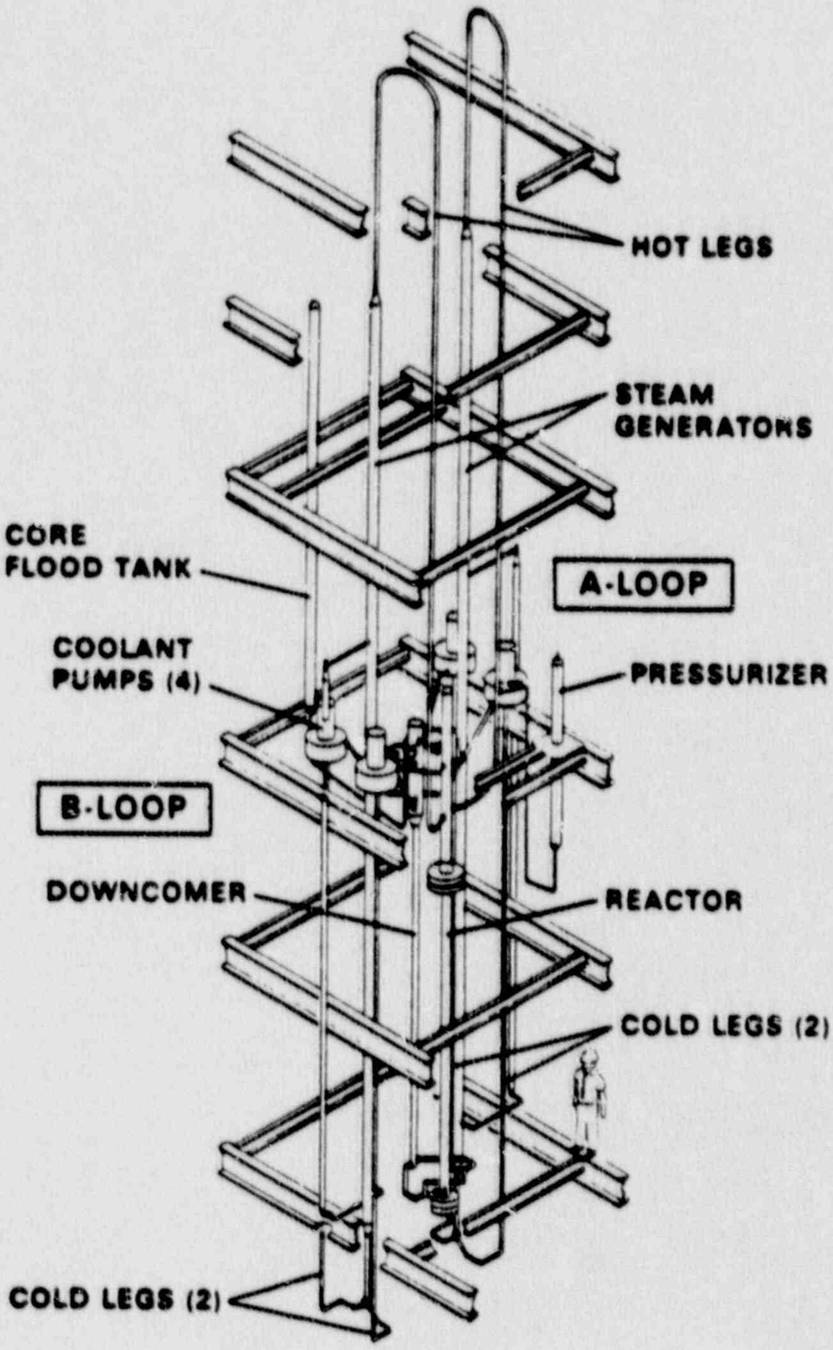
The boundary system controls, such as guard heating and steam generator secondary level controls, were varied in Test Group 31. The leak size, location, and isolation status, as well as HPI capacity, were varied singly in Test Group 32. Test Group 33 addressed HPI-PORV cooling. Steam generator feed was interrupted to initiate the tests. The steam generators were subsequently isolated and pressurized with nitrogen, thus effectively nulling primary-to-secondary heat transfer. Three of the four Group 33 tests were initiated in natural circulation. The PORV was kept open by manual switch actuation as the valve actuated on high pressure. In the nominal HPI-PORV cooling test, full-capacity HPI was activated as the PORV actuated. The PORV actuation depressurized the primary system sufficiently to saturate the upper reactor vessel and hot leg fluid. The pressurizer quickly filled with liquid, causing the PORV mass flow rate to increase. The uppermost pressurizer fluid was subcooled due to the finite pressurizer transit time and the preceding primary system heatup; thus, the PORV mass flow rate first increased due to PORV site subcooling, then subsided as the PORV site liquid approached saturation. The reduced PORV mass flow rate approximately matched the full-capacity HPI flow rate, thus the primary system total fluid mass approximately stabilized in the Nominal Test. The core region gradually refilled and the core exit fluid subcooled, thus the HPI was throttled to maintain a core exit subcooling margin (SCM) of 75F. The primary system lost fluid mass as the HPI flow rate was throttled, but the system conditions realigned to restore the mass balance. The hot leg levels descended to uncover the pressurizer surge line, causing the PORV site fluid subcooling as well as the PORV discharge mass flow rate to diminish. The core exit fluid remained 75F subcooled.

Reduced HPI capacity was used in the second HPI-PORV cooling test. The system responded by uncovering the surge line relatively early, while the core exit remained saturated. The PORV site fluid state became vapor. As a result of this state change, the PORV discharge mass flow rate decreased toward the (reduced) HPI flow rate, whereas the PORV volumetric flow rate increased sufficiently to obtain primary system depressurization.

HPI activation was delayed 20 minutes beyond PORV actuation in the third HPI-PORV cooling test. The primary system repressurized intermittently during the period without HPI and the PORV site fluid subcooled upon repressurization, exacerbating the primary system mass loss. Upon HPI reactivation, the core-region liquid level resided near the top of the core while the hot leg levels were descending toward the elevation of the surge line. The primary system depressurized relatively rapidly upon HPI activation. The ensuing transient conditions resembled those of the nominal HPI-PORV cooling test.

The fourth HPI-PORV cooling test was conducted unlike the other three. The test was initialized in forced flow, and the PORV was allowed to cycle with pressure rather than being held open. Ten minutes after the hot leg fluid temperature exceeded 590F, the PORV was kept open, the hot leg high-point vents were opened, and makeup injection was activated. Core power was subsequently varied manually, based primarily on primary system pressure. This unusual method of core power control was used in an attempt to isolate the effects of surge line uncovery. The resulting interactions documented the depressurization upon surge line uncovery and the link between the primary system fluid volume balance and primary system pressure. Core uncovery data were also generated.

Figure 1. Reactor Coolant System -- Multiloop Integral System Test (MIST)



1. INTRODUCTION

The multi-loop integral system test (MIST) was a scaled 2-by-4 (2 hot legs and 4 cold legs) physical model of a Babcock & Wilcox (B&W), lowered-loop, nuclear steam supply system (NSSS). MIST was sponsored by the U.S. Nuclear Regulatory Commission, the B&W Owners Group, the Electric Power Research Institute, and B&W. The MIST results are presented in the following eleven volumes:

1. Summary
2. Mapping Tests, Group 30
3. SBLOCA Tests With Varied Boundary Conditions, Group 31
4. SBLOCA Tests With Altered Leak and HPI Configurations, Group 32
5. HPI-PORV Cooling Tests, Group 33
6. Steam Generator Tube Rupture Tests, Group 34
7. Noncondensible Gas and Venting Tests, Group 35
8. Pump Operation Tests, Group 36, and Core Uncovery Test 3801
9. Inter-Group Comparisons
10. RELAP5/MOD2 Calculations Versus MIST Observations
11. Phase 4 Tests

This is Volume 5 of the MIST Final Report. The HPI-PORV cooling tests of Group 33 are reported herein.

The MIST design, features, and instruments are outlined in section 2. The Group 33 Test Specifications are provided in section 3; the four tests of Group 33 dealt with high-pressure injection (HPI) power-operated relief valve (PORV) cooling. Test 1, the Nominal Test, used full-capacity HPI and no delay of HPI activation. Reduced capacity HPI was used in Test 2, whereas

HPI was delayed for 20 minutes in Test 3. Test 4, unlike the other three tests, focused on surge line uncovery.

The control of these tests and instrument performance are described in section 4. Section 5 provides a brief narrative description of each test, inter-test comparisons, and, in section 5.7, a summary of major observations. Key data plots are provided with each test. A complete plot set for each test is provided in the enclosed microfiche. These microfiched plots are described and indexed in Appendix A of Volume 9.

Figures 1.1 through 1.4 provide an overview of the HPI-PORV cooling tests. Each trace presents primary system pressure versus primary system total fluid mass, showing key events and timing.

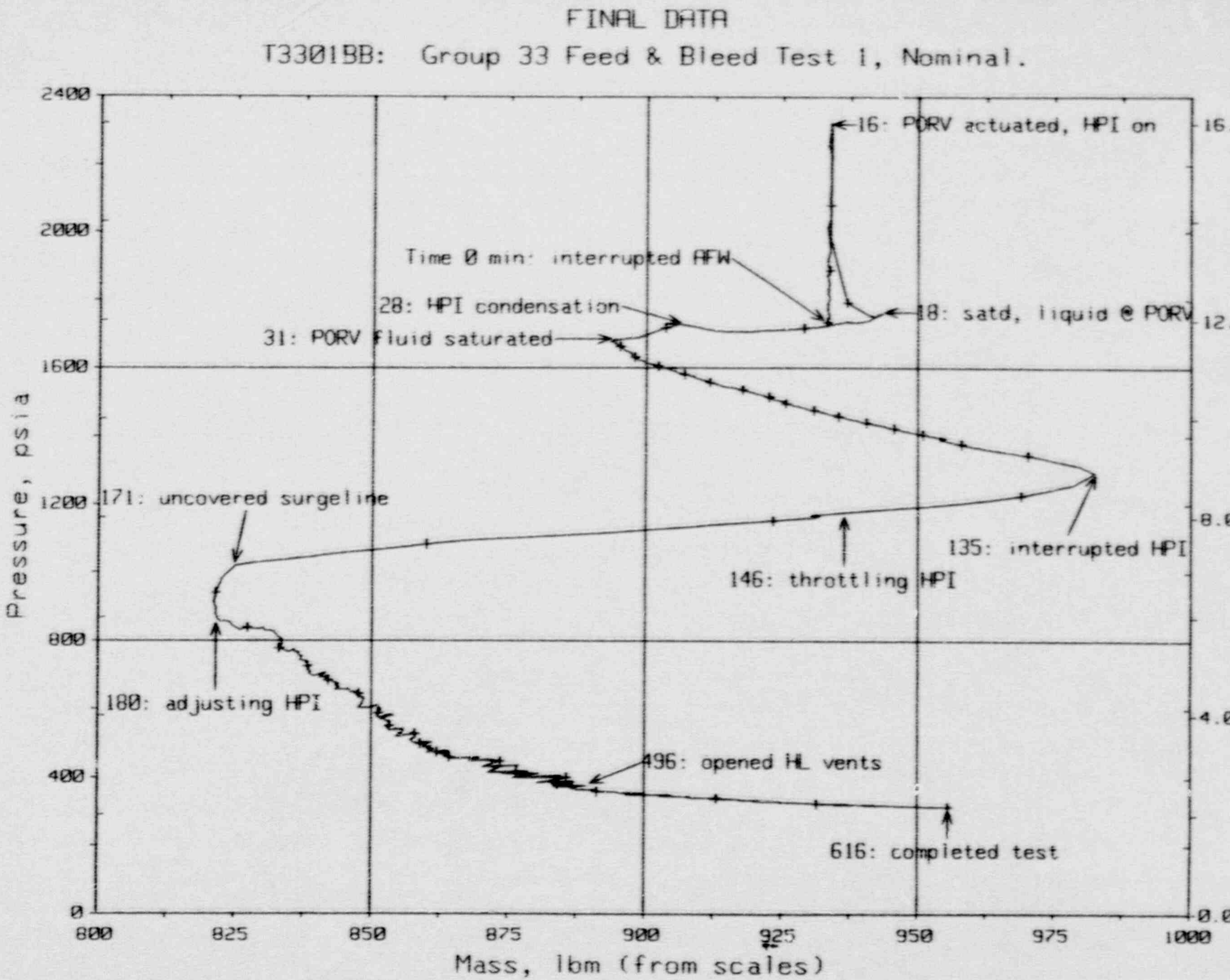


Figure 1.1 Primary System Pressure Vs Primary System Total Fluid Mass

Wed May 4 11:21:27 1988

PPvPM

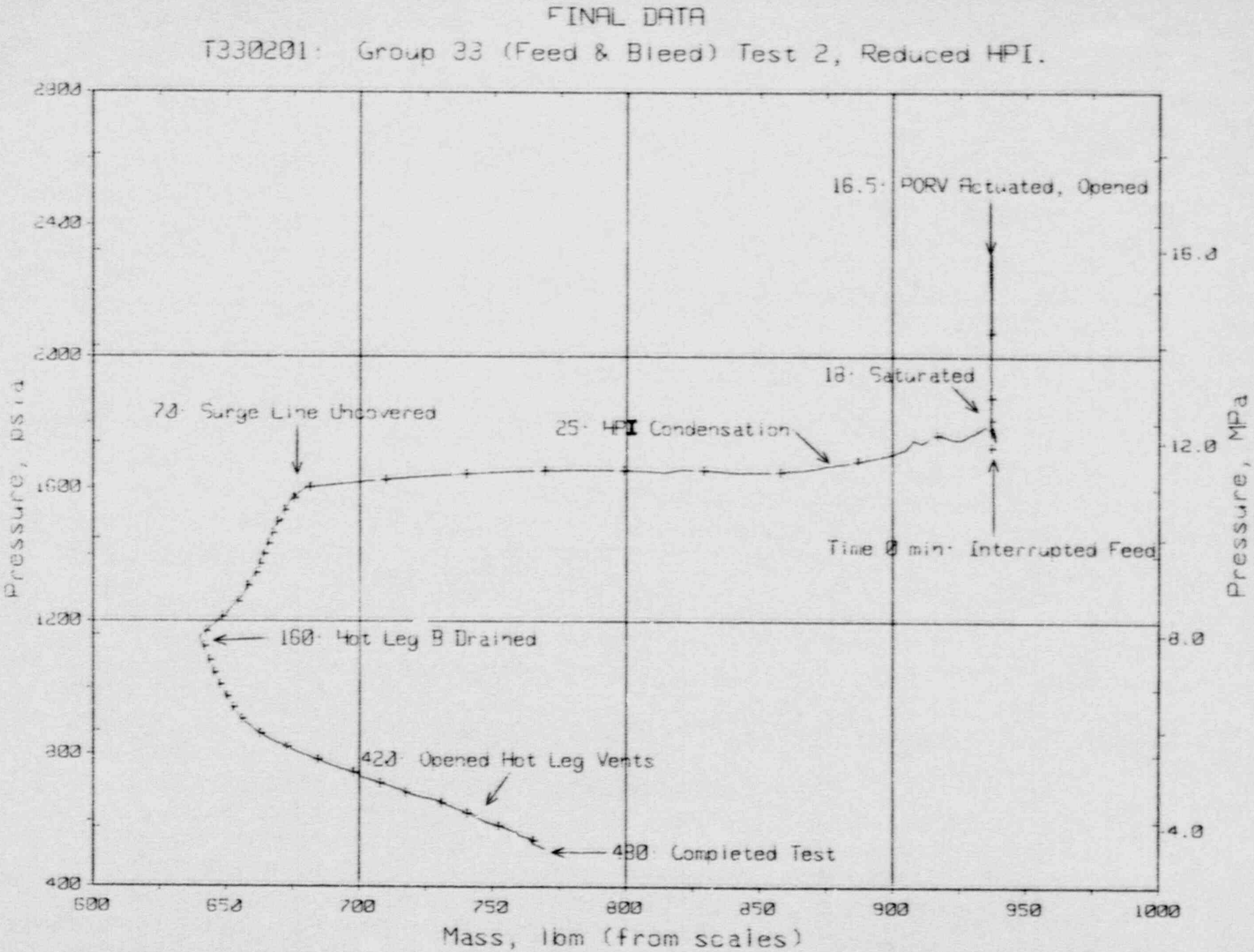


Figure 1.2 Primary System Pressure Vs Primary System Total Fluid Mass

Mon Aug 30 09:20:45 1988

PPVPM

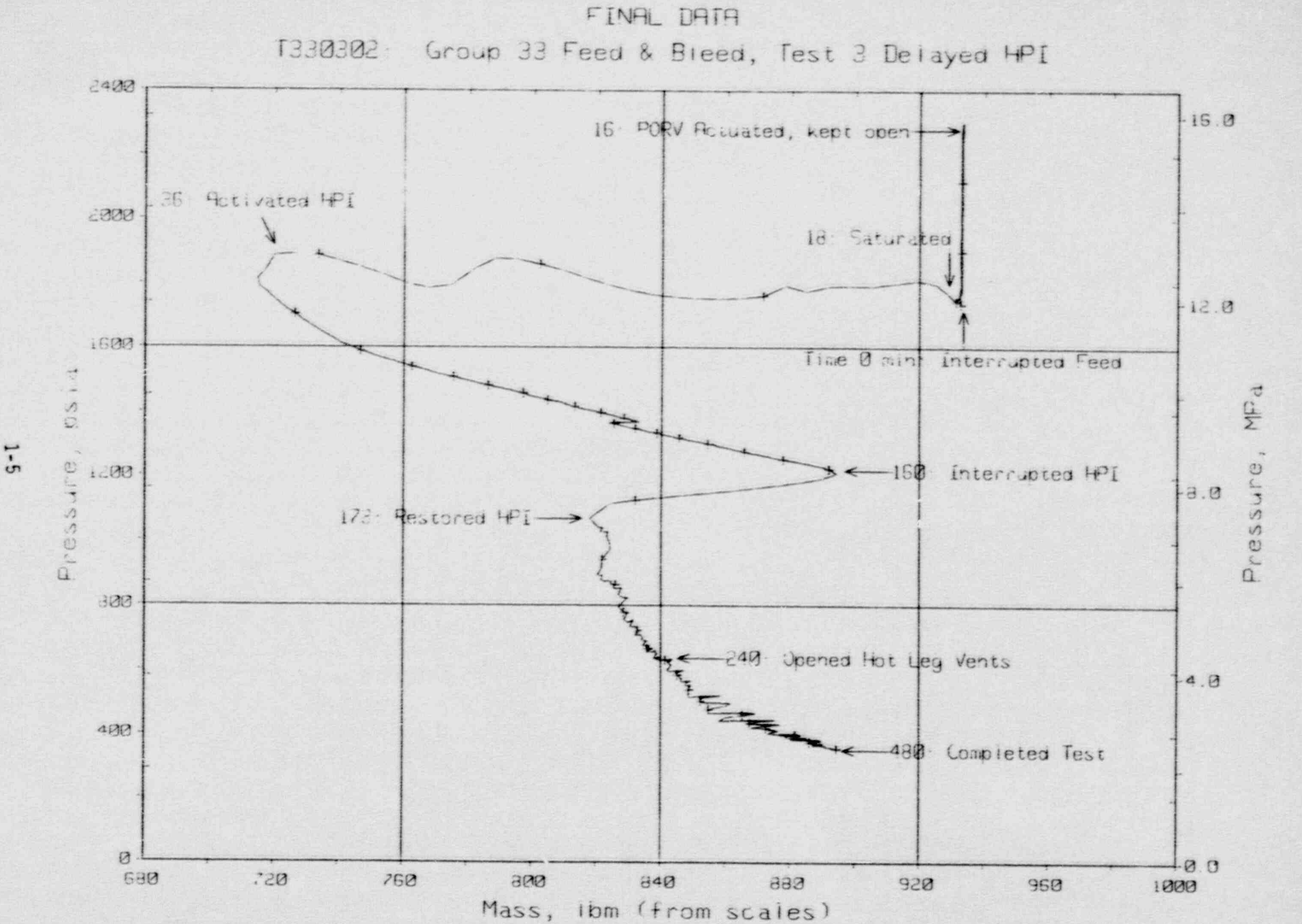


Figure 1.3 Primary System Pressure Vs Primary System Total Fluid Mass

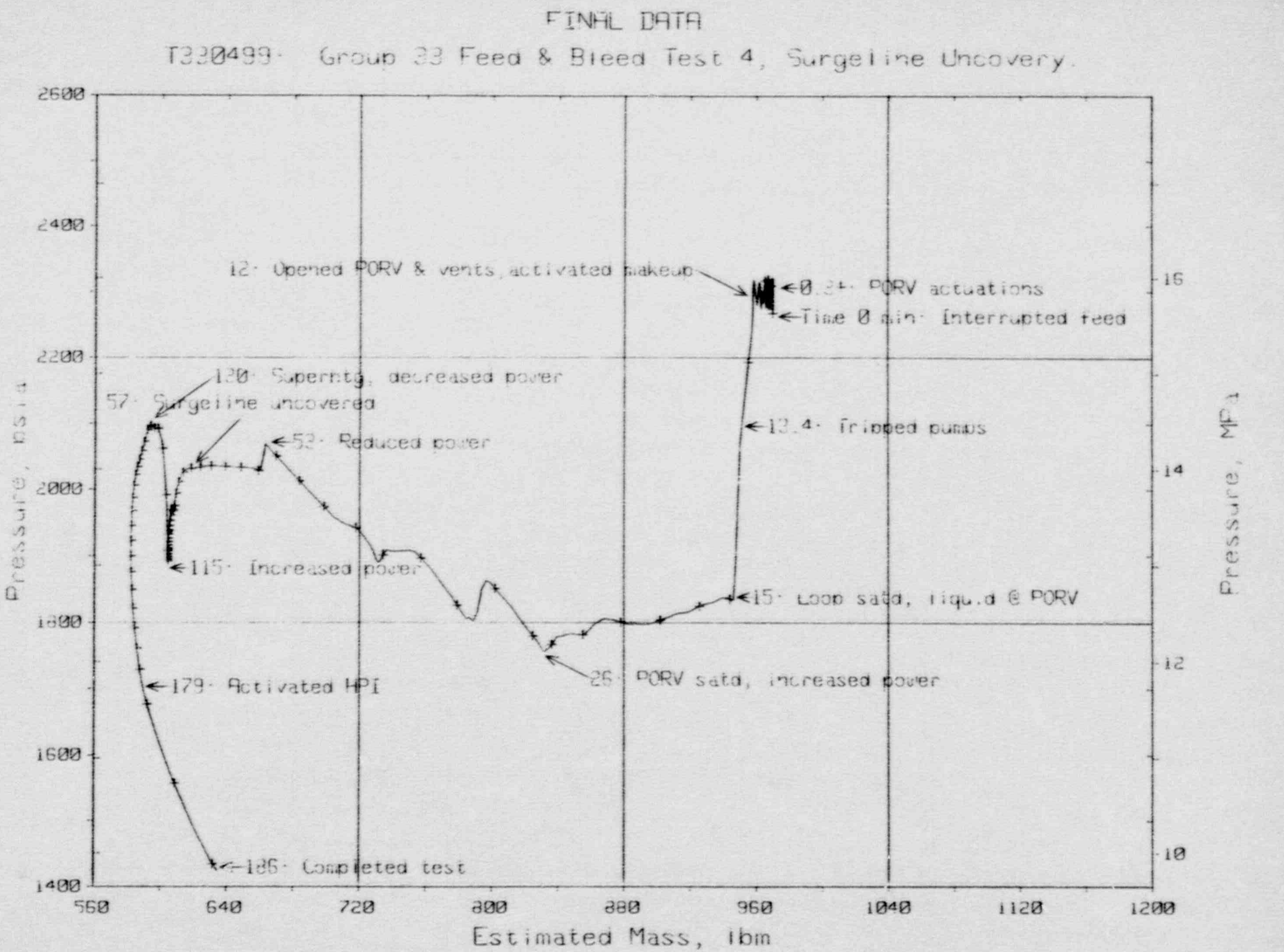


Figure 1.4 Primary System Pressure Vs Primary System Total Fluid Mass

Fri Nov 4 11:51:52 1988

PPVPM2

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 decreasing 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 vents and reactor vessel upper-head vents, high-pressure injection (HPI), 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 and a cooled thermocouple, 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.

The 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 retained full plant elevations throughout the primary system and the steam generator secondaries. Only the elevations of several non-flow regions were compromised, primarily to optimize power-to-volume scaling. 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. The MIST hot leg pipes 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 requirements 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 usually minor compared to the long-term impact on system energy of leak-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 817:1.) A fixed, axial heat flux profile and a flat, radial heat flux profile were used. The axial peak-to-average flux ratio was 1.25:1.

The steam generators, shown in Figure 2.3, each contained 19 full-length tubes. The tubing diameter (5/8-inch OD), material, and triangular pitch of the tube bundle (7/8 inch, tube centerline to centerline) were prototypical. The geometry of the tube support plates (TSPs) was similar to that of the plant TSPs and provided equivalent flow areas and irrecoverable pressure losses. The MIST steam generators contained 16 TSPs, versus 15 in the plant. The flow holes of the MIST TSPs were drilled rather than broached. Also, the thicknesses of the MIST and plant steam generator tubesheets were unequal.

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 were approximately 1 foot long to accommodate the gamma densitometers. The pipe diameters of the hot leg U-bends maintained the pipe diameters of the hot leg risers and stubs. The radii of curvature of the hot leg U-bends were 1.61 ft. This curvature was chosen to match the horizontal displacement between the riser and stub while preserving the elevation of the U-bend spillover and approximating a power-scaled U-bend volume. Phase separation at the U-bend was predicted to occur at and below approximately 18% of scaled full power in MIST, versus 8% in the plant.[2] 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 inlet plenum for the plant steam generator.

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 influenced the mixing of the 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. The specific speeds of the model pumps were only one-tenth of those of the plant pumps. Therefore, the two-phase characteristics of the model pumps did not simulate those of the plant pumps.

The MIST reactor vessel employed an external annular downcomer. Inter-cold leg coupling was restricted toward that of a plant by using fins in the downcomer annulus to form quadrants, as shown in Figure 2.4. The annular gap was 1.4 inches and the gap at each fin was 0.4 inches. Each downcomer quadrant was connected to a separate RVVV simulation and a cold leg. The two core flood tank nozzles were each located at an 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 approximately the power-scaled fluid volume over the elevation of the core. Four model RVVVs were used to simulate eight plant valves. 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 approximated the head-flow response of the plant valves.[3] However, partially open operation was not possible in MIST; therefore, the detailed valve dynamics of the plant swing check valves were absent.

The MIST pressurizer was power-to-volume scaled. It contained heaters, spray, and a PORV. 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 its diameter, thus lessening atypical fluid stratification and the likelihood of spray impinging on 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 nozzles on the downcomer was sized to preserve plant-typical irrecoverable losses, and the nozzles were 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 and auxiliary feedwater (AFW) head-flow characteristics were based on composite plant characteristics. Model vents were included in both hot legs 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.

A steam generator tube rupture was simulated by opening a flow circuit across either the upper or the lower tubesheet of steam generator B. This circuit is shown in Figure 2.5. It consisted of a flow control orifice, isolation valves, and measurements of fluid temperature and differential pressure. The tube rupture simulation flow circuit did not preserve the complex flow path geometry of an actual tube rupture.

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-sectional area and by placing ceramic blocks between load-bearing surfaces. The reactor coolant system piping and components were covered with passive insulation, guard heaters, and a sealed outer jacket (to prevent chimney effects). The insulation arrangement is illustrated in Figure 2.6. The guard heaters were divided into 42 zones, each controlled by a zonal temperature difference and a pipe metal temperature. This system provided differential temperature control as a function of temperature. A 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 temperatures would have generated atypically large metal stored energies as well as undesirable local effects. The total MIST primary system heat loss at 650F was approximately 18 kW or 0.55% of scaled full power. The post-trip core power commonly simulated in MIST ranged from 3.5 down to 1% of scaled full power; the uncompensated heat losses of 0.55% of scaled full power thus represented from 16 to 55% of these post-trip power levels. Core power was increased to offset these 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, indications 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 local 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. The vent valve mass flow rates were obtained by synthesizing RVVV differential pressures, valve positions, and indications of fluid state.

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 fluid 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. The downcomer flow rate was measured using a venturi and a cooled thermocouple probe.

Table 2.1 MIST Instrumentation by Component

Component	Number of Instruments
Cold legs	164
Core flood	7
Hot legs	121
Pressurizer	25
Primary boundary systems	72
Reactor vessel and core	169
Steam generators	249
Steam generator feedwater and steam circuit	44
TOTAL	851

Table 2.2 MIST Instrumentation by Measurement Type

Measurement Type	Number of Instruments
Conductivity probes	36
Cooled thermocouple	12
Differential pressure	133
Differential temperature	42
Fluid temperature	381
Gamma densitometer	12
Limit switches	79
Mass flow	9
Metal temperature	69
Miscellaneous	17
Power	48
Pressure	9
Volumetric flow	4
TOTAL	851

Cold leg instrumentation provided fluid and metal temperatures, differential temperatures, total guard heater power, and differential pressures. Gamma densitometers indicated pump suction fluid density. Cold leg flow rates were measured using venturis located in the suction piping of each cold leg. For tests requiring full forced flow, turbine meters were used in place of the venturis. In addition, the reactor coolant pump power, speed, and head rise were measured. Thermocouple rakes were installed in the cold legs, upstream and downstream of the HPI injection points, to indicate thermal stratification and counterflow near the junctions 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 regimes. The placement 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 hot leg U-bend region, provided additional information regarding loop refill and spillover. Gamma densitometers in the hot leg horizontals, downstream of the reactor vessel outlet nozzles, and viewports at the 29-foot elevation and at the U-bend high points, provided information regarding fluid state and flow conditions. Viewports in the hot leg horizontals near the densitometers probed the developing flow regimes upstream of the hot leg risers.

The boundary systems, which included HPI, 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[2] and in the Instrument Report.[4]

2.6. Conversion Factors

The key MIST conversion factors are listed below.

Power: 1% of scaled full power (2700. mW)

= 33. kW = 31.3 Btu/s

Primary Flow Rate (Total Primary System):

1% of scaled full flow (135. x 10^6 lbm/h)

= 0.46 lbm/s = 1660. lbm/h = 0.21 kg/s

Secondary Flow Rate (Total Secondary System, i.e., 2 steam generators)

1% of scaled full flow (11.3 x 10^6 lbm/h)

= 0.0384 lbm/s = 138. lbm/h = 0.0174 kg/s

MIST piping was larger than power-to-volume scaled in consideration of two-phase phenomena and hydraulic losses. Whereas the plant-to-MIST power scaling factor was 817, the corresponding volume scaling factor was 620 for the total primary system volume (CFT excluded), and 600 for the primary system excluding the pressurizer.

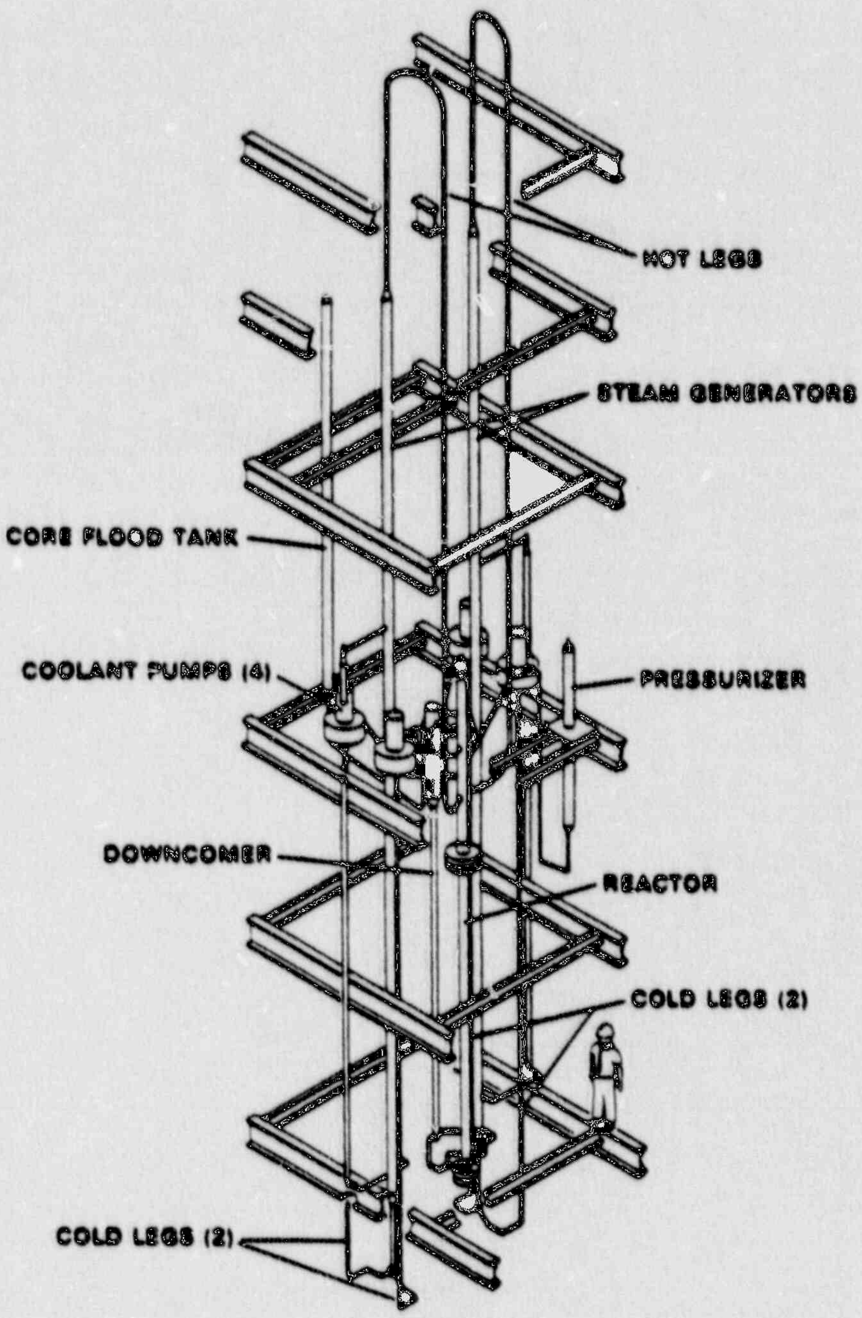


Figure 2.1. Reactor Coolant System -- MIST

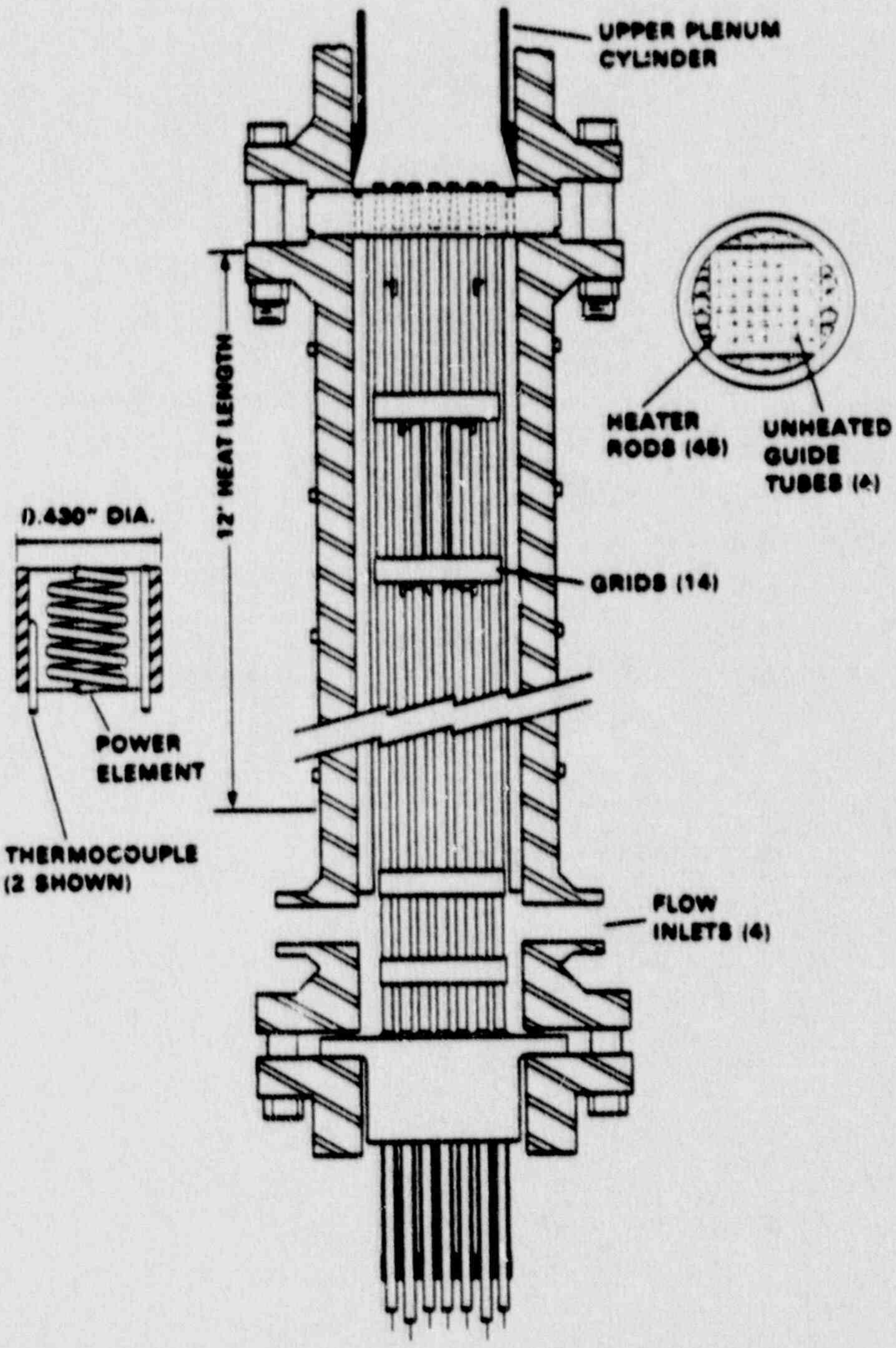


Figure 2.2. MIST Core Arrangement

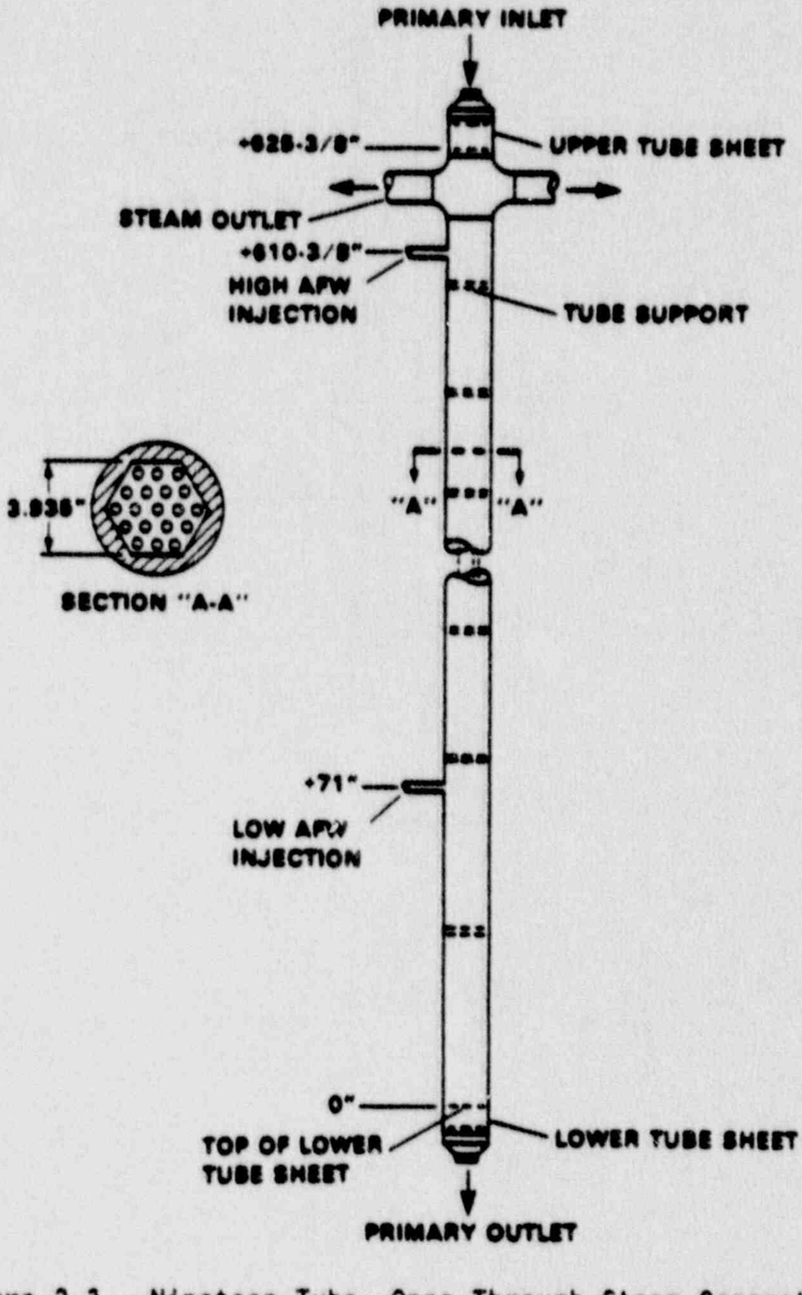


Figure 2.3. Nineteen-Tube, Once-Through Steam Generator

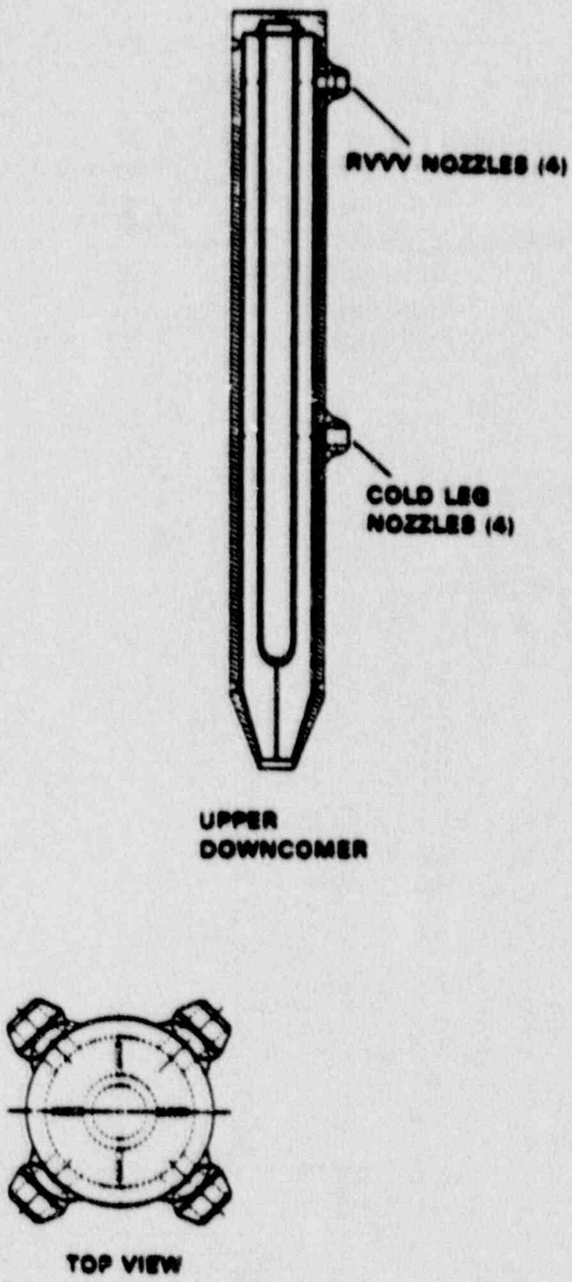


Figure 2.4. Upper Downcomer Arrangement

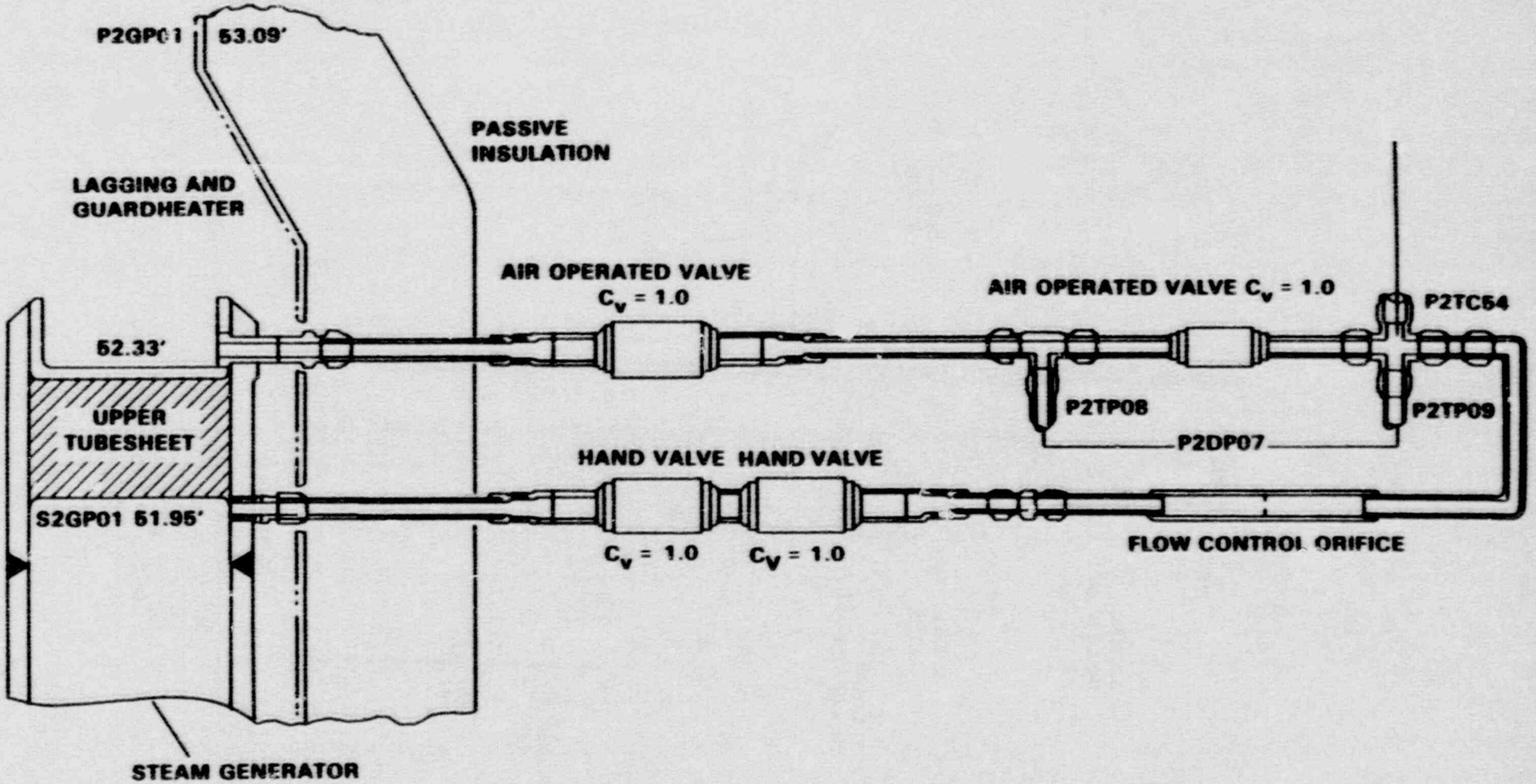


Figure 2.5 Primary-to-Secondary Tube Leak at Upper Tubesheet (Similar Arrangement at Lower Tubesheet)

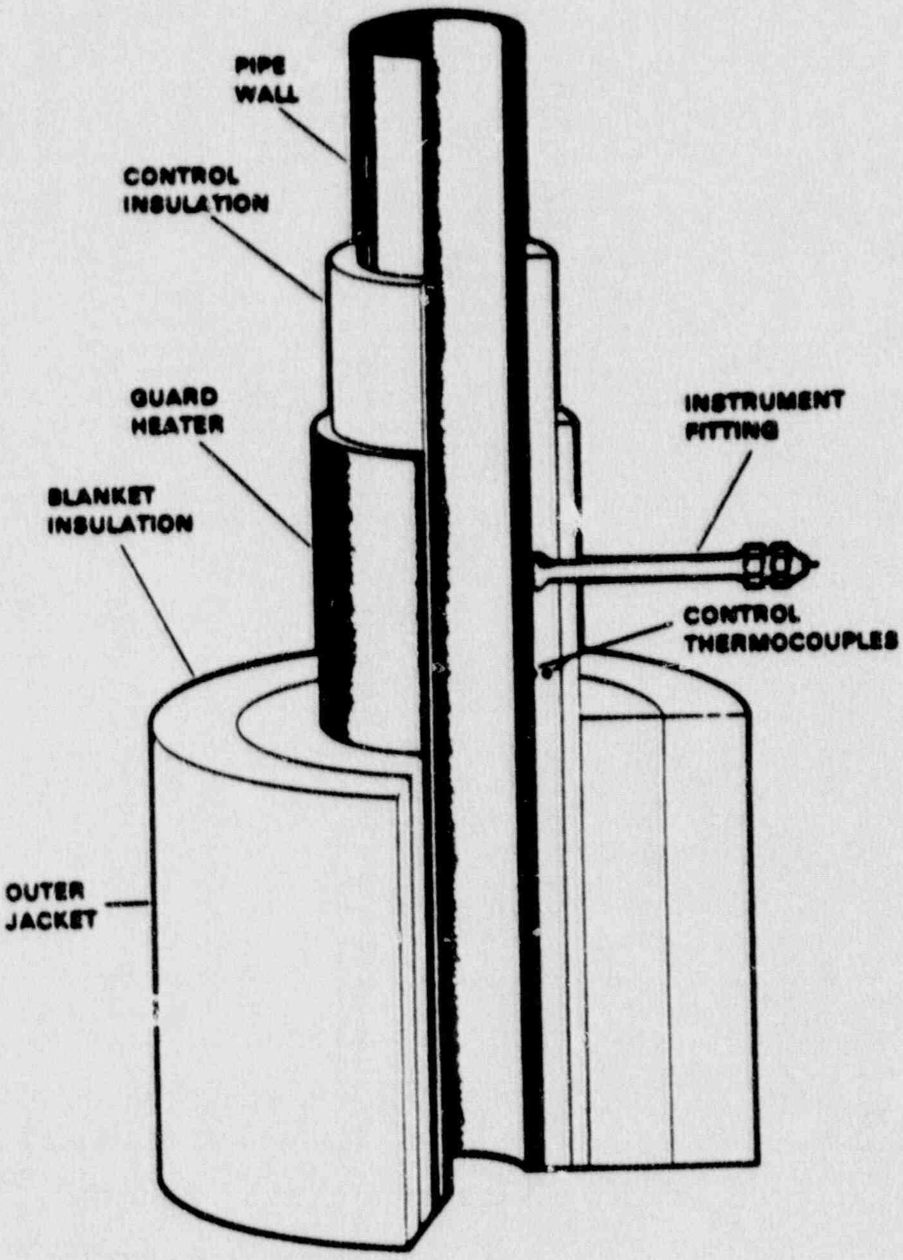


Figure 2.6 MIST Insulation Arrangement

3. TEST SPECIFICATIONS

3.1. Introduction

The specifications for the Group 33 tests have been excerpted from the MIST Test Specifications[5] and, for Test 330499, from PMG Correspondence Number 652 dated 9 March 1987. These specifications were formulated and distributed before the tests were conducted, as is reflected in their tense.

MIST Test Group 33 examines HPI-PORV (feed and bleed) cooling. Four tests are planned, as outlined in Table 3.1. Another feed-and-bleed test with reactor coolant pump (RCP) operation is included in Test Group 36 and will be described in that Group Report. The first three tests of Group 33 simulate conditions during which the RCPs are not available. No leaks are used in these tests. In each test a complete loss of feedwater is simulated. The steam generators are boiled dry, and then pressurized with nitrogen to maintain the primary-to-secondary differential pressures within the limits of the facility. The complete depletion of the steam generator secondary inventories best simulates the plant conditions upon a complete loss of feedwater. The inventory depletion also facilitates code benchmarking by almost eliminating primary-to-secondary heat transfer.

Test 1 (3301BB) is the Nominal Feed-and-Bleed Test. Full HPI characteristics are used; HPI is activated when the PORV lifts. No venting is to be performed during the test transient, which is to be continued for at least 8 hours if the standard test termination criteria are not met. Test 2 uses the Evaluation Model (EM) rather than the full HPI head-flow characteristics. This HPI capacity is about half of nominal. The initial depressurization as well as hot leg voiding will be accentuated, but the conditions later in the transient may approach those of the Nominal Test in which HPI may be throttled to maintain subcooling.

The third test imposes delayed HPI activation. For the first 20 minutes, the PORV discharge will be the only available energy removal mechanism other than fluid and metal heat capacity. The subsequent activation of HPI will cause a precipitous condensation event. Hot leg venting is to be employed later in this test transient.

Test 4 addresses surge line uncovery. The test institutes several of the operator actions and system characteristics relevant to Davis-Besse. The test is initiated in forced circulation.

3.2. Nominal Feed-and-Bleed, Test 1 (3301BB)

The Nominal Feed-and-Bleed Test uses full HPI capacity. HPI is to be activated upon PORV lift.

3.2.1. Purpose

The Nominal Feed-and-Bleed Test examines HPI-PORV cooling with minimal loop operator interaction. The system interactions accompanying feed-and-bleed cooling should thus be obtained in an ideal format for code benchmarking. The loop is expected to undergo several depressurization trends, HPI throttling as the hot leg U-bend (HLUB) fluid reaches saturation, and perhaps extensive hot leg voiding.

3.2.2. Description

Primary pressure will decrease fairly rapidly when HPI-PORV cooling is begun. The discharge of vapor out the PORV and HPI cooling will both contribute to this depressurization. After the pressurizer has filled and begins to cool, pressure may decay more gradually in response to the change in the pressure of leak-HPI equilibrium. Shortly thereafter, the primary pressure will reach the saturation pressure corresponding to the temperature of the fluid in the HLUBs. (The flow of HPI-cooled fluid up hot leg A to the pressurizer surge line connection is expected to cause the conditions to differ in hot legs A and B.) Voiding at the HLUBs will suppress further primary depressurization. Because the fluid conditions at the PORV will no longer predominate the system pressure-temperature trends, the PORV discharge fluid state may fluctuate as the HPI and PORV mass flow rates become imbalanced. RVVV

The continued HPI flow at constant system pressure will gradually subcool the core exit fluid. When the subcooling control point of 75F is reached, HPI throttling will further upset the HPI-PORV mass balance. Because the upper hot leg fluid enthalpy will exceed that of the pressurizer fluid, HPI throttling may promote increased hot leg voiding and level reduction. Should the hot leg A level reach the surge line elevation, the resulting condensation event may be pronounced. Even without an uncovery of the surge line, the fluid conditions of hot legs A and B are likely to be unequal. The lower hot leg A fluid will be cold compared to the hot leg B fluid. However, the implied level imbalance between the hot legs will be resisted by the flashing of upper hot leg fluid. Hot leg A may thus be more readily refilled. Should periodic displacements of loop fluid cool the upper fluid and metal in both hot legs, depressurization will proceed regularly and permit hot leg refill. Otherwise, the post-termination hot leg venting may permit hot leg refill by discharging the residual hotter fluid and by causing the HLUB metal to quench.

3.2.3. Conduct

Pretest Steady State

The Nominal Feed-and-Bleed Test is to be initialized exactly as MIST Nominal Test 3109AA. These conditions can be summarized as follows: The primary is in subcooled natural circulation of 22F at 3.5% of scaled full power (plus losses to ambient) with a 2.5-ft level within the pressurizer. The primary boundary systems are inactive. The steam generator secondaries are stabilized at 1010 psia with 5-ft levels. Steady-state data at these conditions are recorded for at least 10 minutes.

Test Initiation

The test is to be started after recording at least 10 minutes of steady-state data at the specified conditions; the timing of test initiation is otherwise arbitrary. Initiation consists of three steps, namely (1) feed interruption, (2) PORV actuation, and (3) steam generator isolation. These steps are listed in Table 3.2.

Step 1

Initiation step 1 begins with the connection of a pressurized nitrogen supply to both steam generators. The nitrogen supply (950 psia) will be used to sustain secondary pressure after the steam generators have boiled dry following the interruption of AFW. The MIST steam generators cannot be subjected to primary-to-secondary pressure differentials in excess of 1500 psia, therefore the steam generator secondaries must be maintained above 900 psia until the primary system pressure has subsided. After the nitrogen supply has been connected, the remaining four actions of step 1 are to be performed in rapid succession. These steps are as follows: deenergize the pressurizer main heaters, stop AFW, log test initiation, and transfer RVVV control. The pressurizer main heaters are manually deenergized to transfer primary system pressure control to system interactions. The AFW interruption is the first step toward deleting the steam generator heat sinks; the isolation of the steam generators is completed in step 3. Finally, RVVV control is shifted from manually closed to automatic/independent. The nominal actuation setpoints are to be used; these are 0.125 psi to open and 0.04 psi to close.

The cessation of AFW will immediately shift the steam generator thermal center downward toward the secondary pool, thus slowing primary loop flow. The secondary inventory will boil off at about 2 ft/min. The primary will begin to heat and to pressurize as loop flow slows and as core power begins to exceed steam generator heat removal. Initiation step 2 is triggered on the actuation of the PORV on overpressure; step 3 is begun when the steam generator secondaries depressurize upon loss of inventory. The numbering of these steps may not coincide with their occurrence; that is, the steam generator depressurization may occur before PORV actuation. In this event, perform step 3 before step 2. Both events will occur within a few minutes of feed interruption. Also, and as noted in Table 3.2, the nitrogen supply can be connected to the steam generators at any time in the initiation sequence.

Step 2

Test initiation step 2 is to be performed when the PORV actuates on overpressure. Transfer PORV control to manually open and activate full HPI.

HPI-PORV cooling is now activated -- HPI flow to the loop will begin about 10 to 15 seconds after HPI is activated. Simultaneously activate the core power decay ramp simulating decay from 1 minute 40 seconds after reactor trip.

Step 3

Test initiation step 3 is to be performed as the steam generator secondaries begin to depressurize toward 950 psia (which is the pressure of the nitrogen supply that was connected in step 1). If the steam generators depressurize unequally, perform step 3 when the second steam generator reaches 975 psia. In this step, the isolation of the steam generators is completed. First, the steam generator steam pressure control setpoint is increased to 1300 psia to interrupt steam generator steaming. After the steam generators have been so isolated, complete their isolation by closing the appropriate isolation valves. (The steam generators are now pressurized with nitrogen but are unavailable for heat transfer, other than through changes in the metal and gas stored energy.)

Test initiation is now completed. HPI-PORV cooling has been instituted with the steam generators unavailable for heat transfer. However, note that the initiation timing is specified for ease of reproducibility and modeling rather than for plant typicality. For example, HPI-PORV cooling is usually instituted by manually opening the PORV and activating HPI rather than by waiting for the PORV to open on overpressure.

Control During Testing

Control during testing is summarized in Table 3.3. Few operator actions are required. The steam generators are to be maintained isolated and pressurized by the nitrogen supply.

The PORV is to be manually maintained open. The automatic core power decay ramp is to be continued. The hot leg high-point vents (HLHPV) are to be kept closed until after test termination, as described below. Scaled full HPI and automatic throttling are to be used to obtain a subcooling of 75F. If the primary depressurizes below 600 psia, manual HPI control is required when the core exit subcooling reaches 100F; the operator is then to manually interrupt HPI and to restore it when the subcooling has decreased to 50F, for a maximum of three cycles (leave on thereafter). The operator is to manually isolate the core flood tank (CFT) when the following three conditions are met concurrently: the core exit subcooling has been maintained at 50F or more for at least one-half hour, the primary system pressure is less then 715 psia, and the primary system is not repressurizing. The MIST CFT will automatically isolate on low CFT level. The MIST CFT will also isolate automatically when the primary system pressure exceeds 650 psia and vice versa.

Test Termination

The test may be terminated, at the discretion of the Test Engineer, using any one of three criteria; these criteria parallel those of the Nominal Test and pertain to refill, depressurization, and test duration. The test may be terminated when the loop is full, at least 50F subcooling has been maintained for 2 hours or more, and the primary system pressure is below 400 psia. (Filling of the "loop" refers to the hot leg and cold leg piping; the pressurizer and reactor vessel upper head may remain voided.) Test termination may also be based on low pressure -- 200 psia or less for 2 hours. In this case, the loop is to be filled expeditiously while continuing to gather data.

If loop refill is not completed after 8 hours of testing, and at the discretion of the Test Engineer, the test is to be terminated. Termination is to be performed in the following manner: enter the test termination time in the log, then open the hot leg high-point vents simultaneously while continuing to record data. If loop refill is not achieved after 2 hours of venting, the Test Engineer is to refill the loop expeditiously. Data recording is to continue uninterrupted until the loop has been refilled. The maximum allowable test duration is generally 8 hours but selected tests may be prolonged. This first feed-and-bleed test is so extended; the other two feed-and-bleed tests are constrained to the 8-hour limit.

Measurements and Acceptance Criteria

The required measurements and acceptance criteria for the feed-and-bleed tests parallel those for the Nominal Test. Dense data scans are to be used before and during the first few minutes of the manual hot leg venting specified above.

3.3. Reduced HPI Capacity, Test 2 (330201)

The Evaluation Model HPI characteristics[5] are used in Test 2.

3.3.1. Purpose

Test 2 will provide HPI-PORV cooling data with the reduced (Evaluation Model) HPI capacity. As discussed in the following section, hot leg voiding will be more pronounced than with full HPI, and CFT actuation is more likely.

3.3.2. Description

The reduced HPI capacity of the Evaluation Model (EM) HPI, compared to that of full HPI used in Test 1, will alter the transient from the onset. The pressurizer refill rate may be less, the period of the intermittent change of phase of the fluid being discharged by the PORV may be greatly prolonged. When the hot leg void pressure is achieved, the rate of hot leg inventory decrease is expected to be greater than nominal. The displacement of hot leg fluid to the pressurizer may overwhelm the pressurizer level differences due to the altered HPI capacity. The tendency to obtain a core exit subcooling that is sufficient to cause HPI throttling will be reduced. Indeed, the conditions with EM HPI may approach those with HPI throttled during the Nominal Feed-and-Bleed Test. However, subsequent primary system depressurization will again highlight the inter-test differences.

3.3.3. Conduct

The loop is to be initialized as in the Nominal Feed-and-Bleed Test. Upon PORV actuation, HPI is to be activated with the Evaluation Model HPI head-flow characteristics. Test specifications are otherwise exactly those of the Nominal Feed-and-Bleed Test (Test 1). Test duration is the exception. Although the first feed-and-bleed test was allowed to continue for as much as 10 hours of testing, Test 2 is to be tailored to the generally applicable limit of 8 hours. To effect this shortened test duration, terminate the test at 7 hours rather than after 8 hours as in Test 1; then, open the hot leg high-point vents for an additional hour and proceed as in Test 1.

3.4. Delayed HPI, Test 3 (330302)

HPI is not activated until 20 minutes after PORV actuation. Full HPI is used. Venting is used late in this test.

3.4.1. Purpose

Test 3 will examine an extended period of PORV actuation without makeup (and with the steam generators unavailable). Extensive primary voiding is expected to occur. The subsequent activation of HPI may cause a major perturbation of system conditions due to condensation and depressurization, as discussed below. The effects of high-point vent actuation will also be observed.

3.4.2. Description

The deactivation of the steam generators will cause the primary system to pressurize rapidly, as in the other tests. But PORV actuation without HPI will require a balance between the loop fluid volume expansion due to heating and the fluid volume discharged from the PORV. The initial discharge of vapor through the PORV will depressurize the system. When the PORV begins to discharge liquid, however, the volumetric discharge rate will just exceed the fluid expansion due to heatup. The PORV can accommodate the heatup corresponding to 3% of scaled full power, therefore pressure control will be delicate for the first few minutes of power decay. MIST does not have simulated primary safeties; the operational MIST safety valve is designed for test facility overpressure protection and should not be challenged intentionally. If the MIST PORV is not sufficient to control pressure, the test must be aborted (by deenergizing the core) and restarted at a lower initial core power.

The continuing PORV discharge without makeup will generate extensive system voiding. Approximately 20% of the total system volume will be voided. With the pressurizer filled with liquid, the voided regions may include the hot legs and steam generator primaries (to the surge line elevation), the cold leg discharge piping, and the upper downcomer and reactor vessel to the vicinity of the nozzles.

The subsequent actuation of HPI to the voided cold legs is likely to abruptly alter the system conditions. The depressurization due to HPI-caused condensation will flash the hotter loop fluid and may briefly uncover the core. A portion of the pressurizer inventory may be displaced to the loop. The core region inventory should be quickly regained. Continued HPI-PORV cooling is expected to change the loop conditions toward those observed in the Nominal Test.

High-point vent actuation is planned for the later stages of Test 3. Vent actuation is expected to cool the upper hot leg fluid and therefore to facilitate system depressurization and refill.

3.4.3. Conduct

HPI activation is delayed in Test 3. Rather than activating HPI when the PORV actuates as in the Nominal Feed-and-Bleed Test (as shown in step 2, Table 7.2), activate full HPI 20 minutes after PORV actuation (and manual PORV opening). The remaining test initiation steps are the same as those of the Nominal Feed-and-Bleed Test, as are the initial conditions, required measurements and acceptance criteria.

The HLHPVs are to be actuated in Test 3. The time to open the vents is to be based on the time required to complete loop (hot leg) refill in Test 1. If more than 5 hours were required to achieve refill in Test 1, or if the loop was not refilled, then open the vents at 4 hours. If refill was achieved at 3 to 5 hours, open the vents one hour earlier than refill was completed. If refill was achieved in less than 3 hours, do not vent during the Test 3 transient. Other controls during testing are the same as nominal (see Table 7.3). Should the usual test termination criteria not be met after 8 hours of testing, then the test is to be terminated at the discretion of the Test Engineer. The test termination time is to be entered in the log, then the loop is to be refilled expeditiously while continuing to record data.

3.5. Surge Line Uncovery, Test 4 (330499)

The purpose, description, and conduct of Test 4 (330499) are given in the following sections. The test transient is patterned after a RELAP prediction of a loss-of-feedwater (LOFW) transient.

3.5.1. Purpose

Test 330499, Surge Line Uncovery, institutes several of the operator actions and system characteristics relevant to Davis-Besse. The test is conducted to characterize long-duration feed-and-bleed cooling with a complete loss of feed and, in particular, to document the integral system interactions that occur as the declining hot leg level uncovers the surge line-to-hot leg connection.

3.5.2. Description

Predicted Events

The plant events predicted by RELAP are summarized in Table 3.4. Note that the reactor is tripped approximately 15 seconds after the LOFW, but the reactor coolant pumps are kept operating until the subcooling margin decreases to 20F at 11.7 minutes (after the LOFW). Also note that the primary system first depressurizes after the PORV is manually kept open, but subsequently repressurizes (with the PORV still open). This repressurization occurs after the pumps are tripped, the rate of introduction of subcooled fluid into the core diminishes, and hence the core void generation rate increases markedly. (This repressurization lifts the primary safeties.)

MIST Initial Conditions

MIST is initialized, and the test is initiated, to simulate as closely as possible the conditions of the loss-of-feedwater code prediction. This prediction was initiated from 102% initial power and modelled operator actions 10 minutes after the hot leg temperature exceeded 600F.

Three MIST characteristics bear on this simulation, namely the maximum core power, the PORV characteristics, and the absence of a safety valve simulation. The maximum MIST core power is 10% of scaled full power. This sets the earliest time in the transient that can be simulated in MIST. Because the reactor is tripped well before the pumps are deenergized (on loss of subcooling margin), the MIST core power constraint should have little impact on the simulation.

The MIST PORV flow area is the power-scaled equivalent of 10 cm^2, rather than the 11 to 20 cm^2 required to match the code prediction. This flow area discrepancy is perceived to be sufficiently small to preserve the sought-after interactions.

The MIST PORV setpoints are as high in pressure as possible without lifting the test loop code safety. The MIST PORV actuation and reset pressures, 2350 and 2300 psia, are 115 psi less than those of Davis-Besse. Because the transient of interest is governed by system fluid heatup and pressurization versus PORV actuation, the MIST transient must be modified to accommodate the lower PORV actuation pressures. The lower PORV setpoints of MIST are accommodated by lowering the initial temperatures and primary pressure in the test transient, by lowering the hot leg fluid temperature that triggers operator actions (from 600F in Davis-Besse to 590F in MIST), and by shifting the injection characteristics by 100 psi.

The MIST steady-state initial conditions are compared to those predicted to occur early in the plant transient in Table 3.5. The time of the listed plant conditions, 15 seconds after reactor trip, was selected based on the available code output edits and the similarity between the predicted plant core power (8.8%) and the maximum MIST core power (9.6% of scaled full power plus 0.4% to offset the uncompensated losses to ambient). The predicted plant conditions reflect an ongoing transient, whereas the MIST conditions are at steady state. Even if MIST was initialized to replicate each of the more significant plant conditions at some particular time early in the transient, the MIST conditions during the subsequent transient would immediately diverge from those of the plant transient.

This disparity would be driven by the differences between the transient plant heat transfer and transient energy storage rates versus the rates in MIST at steady state. (Note that the MIST transient timing is also generally skewed from that of a plant, primarily due to the excess fluid volume in MIST compared to that of a power- and volume-scaled model.) MIST is initialized therefore to preserve those conditions that govern the ensuing primary system heatup and repressurization. These governing conditions include primary system power, pressure, flow, and average fluid temperature.

Core power is set to the MIST maximum, 9.6% of scaled full power (plus 0.4% to offset uncompensated losses to ambient). This simulates 10 seconds of post-trip decay. The reactor trip occurs 15 seconds after the LOFW in the plant prediction; therefore, the MIST core power decay ramp is to be activated 25 seconds after the LOFW is imposed. The MIST simulation of the predicted plant transient thus begins about one-half minute after the LOFW.

The MIST primary system pressure is set at 2250 psia. This pressure is based on the plant pressure at 15 seconds after reactor trip, 2350 psia, less 100 psi to accommodate the lowered PORV setpoints in MIST. The initial MIST primary system average fluid temperature (580F) is similarly based on the plant temperature (590F) less 10F to compensate for the lowered PORV setpoints. This primary average fluid temperature is obtained by adjusting the steam generator secondary pressure. The MIST primary flow rate is set to the MIST four-pump design point; this obtains 110% of scaled full flow in MIST, which is similar to the corresponding plant flow rate.

The absence of a primary safety valve simulation in MIST requires that the test sequence deviate from that of the plant prediction. This will occur after the depressurization following manual PORV actuation. The intent of the MIST control adjustments is to preserve the effects of surge line uncovery while maintaining primary system pressure within the range of the test facility. Core power is to be held constant, manually, as primary system pressure stabilizes following the manual PORV actuation. (This stabilization of primary system pressure occurred at 14 minutes in the prediction.) When the primary system begins to repressurize, core power is to be manually reduced and adjusted to restabilize primary system pressure. (The primary system repressurization began at ~15 minutes in the prediction.) Ideally, the necessary core power adjustments will be completed before the surge line is uncovered. (The surge line uncovery was predicted to occur at approximately 35 minutes, nearly 10 minutes after the safeties began to lift.) After the surge line has been uncovered and the primary system has begun to depressurize because of vapor flow through the surge line, the programmed core power reduction is to be resumed.

3.5.3. Conduct

The initial conditions, initiation, and control during testing of Test 330499 are summarized in Tables 3.6 through 3.8.

Pretest Steady State

Stabilize MIST in forced flow at 10% of scaled full power (including 0.4% to offset uncompensated losses to ambient). Adjust the steam generator secondary pressures to obtain cold leg temperatures of 577F. Use 5-ft steam generator secondary and pressurizer levels. These initial conditions are summarized in Table 3.6.

Initiation

Record steady-state data at the specified initial conditions for at least 10 minutes, then initiate the test transient by terminating AFW. Mark the time of simulated reactor trip (on which to base the core power decay ramp) at 15 seconds after the termination of AFW. Isolate and inert the steam generator secondaries using the technique of the HPI-PORV cooling tests. Manually deenergize the pressurizer heaters. The pressurizer spray is not to be used during this test.

590F Hot Leg Fluid Temperature

Mark the time at which the (hotter) hot leg fluid temperature reaches 590F. Ten minutes after this time, institute the following actions (simulating those of the plant operator): Manually open the PORV and hot leg vents, and activate makeup/HPI. Inject makeup through only the loop A1 HPI nozzle.

20F SCM

When the core exit subcooling margin decreases to 20F, trip all four RCPs and perform a simulated four-pump coastdown.

Core Power

Core power is to be manually controlled after the PORV has been manually opened. The first control action is to be taken after the depressurization (due to PORV lift) has subsided. This will occur when the loop fluid approaches saturation. At this time, record the current primary system pressure and transfer the core heater power controller to manual. Hold the current core power level.

If the primary system begins to repressurize, reduce the core power level manually to stabilize primary system pressure. Begin this manual power reduction when the primary system has repressurized about half way from the minimum pressure (recorded above) and the PORV lift pressure. Adjust core power to approximately stabilize primary system pressure. Attempt to complete these power adjustments before the level in hot leg A has descended to the elevation of the pressurizer surge line correction. Bifurcation should be employed to quickly gain control of primary system pressure. For example, if the core power had been constant at 1.6% of scaled full power when the repressurization began, reduce core power to one-half of 1.6%, or 0.8%. If the primary system then begins to depressurize, increase core power to 1.2%, i.e. midway between the values that caused repressurization and depressurization. Continue this adjustment sequence until the primary system pressure approximately stabilizes and attempt to retain this adjusted power setting until the surge line uncovers. (Do not adjust core power to counter the primary depressurization that will occur when the surge line uncovers.) Approximately 15 minutes after the surge line uncovers and the primary system begins to depressurize, revert to the standard core power reduction sequence. Begin this sequence from the current core power level, if convenient.

HPI/Makeup

When primary pressure first decreases to approximately 1700 psia, transfer from injection through HPI nozzle A1 to injection through all four HPI nozzles. Select this transfer pressure so that HPI flowmeter A1 remains within its calibrated range. Retain four-nozzle injection for the duration of the test.

Termination

Continue testing for at least 3 hours, but for not more than 8 hours. After 3 hours of testing, the test may be terminated at the discretion of the Test Engineer when either of the following two criteria is met.

1. The core-region collapsed liquid level is more than 3 feet above its minimum value during the transient.

2. Primary system pressure is less than 1500 psia.

Measurements and Acceptance Criteria

Record the category "A" (always critical) and "C" (portion critical) instruments identified in Appendix F of the MIST Test Specifications[5]. Record at the minimum intervals also specified in Appendix F of the MIST Test Specifications. In addition, record and process data at intervals of not more than 15 seconds between scans during the following three phases of the test transient:

1. From test initiation until the PORV begins to actuate (from time 0 to approximately 2 minutes).

2. From the time at which the PORV is manually kept open and the RCPs are tripped until the primary system pressure stabilizes (from approximately 11 to 15 minutes).

3. From the time at which the primary system begins to repressurize or from the time at which the hot leg A level approaches the elevation of the surge line connection until the primary system begins to depressurize gradually (from approximately 30 to 45 minutes).

The test acceptance criteria are as follows:

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

2. The test is initiated, controlled, and terminated as specified. The simulated boundary systems perform as designed.

3. The critical measurements are recorded at the specified intervals.

Table 3.1 Feed-and-Bleed Tests, Group 33

(A feed-and-bleed test with RCP operation is included in Group 36.)

Tests 1 through 3: AFW is unavailable. No leak, NCG, or RCP operation. The PORV is kept open after actuation. Nominal RVVV control (automatic and independent actuation at 0.125 and 0.04 psi).

Automatic throttling of HPI to obtain a core exit subcooling of 75F.

Test Number	Description	Variable	Setting	Nominal Setting
1 3301BB	Nominal Feed and Bleed	(Nominal)	--	--
2 330201	Reduced HPI Capacity	HPI Capacity	Evaluation Model	Full
3 330302	Delayed HPI	Time of HPI Actuation	20 min	@ PORV Lift
4 330499	Surge Line Uncovery	(-------------See Text		-------------)

Table 3.2 Initiation of the Feed-and-Bleed Tests (Group 33)

The test initiation actions are listed for the Nominal Feed-and-Bleed Test; variations among tests are given in the text and in Table 3.3. For Test 330499, see Table 3.6.

The actions are to be performed in three steps. The timing of the first step is arbitrary; the second and third steps are then triggered by system conditions. Perform the actions of each step as simultaneously as possible. Steps 2 and 3 are listed in their expected order of occurrence, but they are to be performed when their individual criterion is met, regardless of order.

The first action of step 1 involves pressurizing the steam generators with nitrogen (back pressure permitting). The final unisolation of the nitrogen supply may be performed at the time perceived to be most appropriate in the initiation sequence. The only requirement for testing is that the steam generators be inerted during test initiation to minimize primary-to-secondary heat transfer.

Test Initiation Step 1

Perform step 1 after at least 10 minutes of steady-state data have been recorded at the specified initial conditions.

1. Connect a nitrogen supply that will maintain the steam generator secondaries at 950 $\pm$ 25 psia.
2. Deenergize the pressurizer main heaters.
3. Stop AFW.
4. Enter the test initiation time in the log.
5. Transfer RVVV control from manually closed to automatic/independent.

Test Initiation Step 2

Perform step 2 when the PORV actuates on overpressure.

1. Transfer PORV control from automatic to manually open.
2. Activate full HPI (Test 1 only)
3. Activate the core power reduction ramp (simulating decay from 1 minute 40 seconds after reactor trip).

Table 3.2 Initiation of the Feed-and-Bleed Tests (Group 33) (Cont'd)

Test Initiation Step 3

Perform step 3 when the steam generator secondaries depressurize below ~975 psia (see text).

1. Isolate the steam generators (increase the steam pressure control setpoint to 1300 psia).

2. Complete the manual isolation of the steam generators.

Table 3.3 Control of Feed-and-Bleed Tests 1 Through 3

Function	Control
Steam generator secondary pressure	Maintain a pressurized nitrogen supply connected to the steam generator secondaries. Maintain the isolation of the steam generator flow circuits.
Pressurizer main heaters	Off
AFW	Off
RVVV control	Automatic/independent
PORV	Manually open (after actuation)
HPI	• Nominal Test 1 (3301BB): Full after PORV actuation.
	• Reduced HPI Test 2 (330201): EM after PORV actuation.
	• Delayed HPI Test 3 (330302): Full after 20 minutes beyond PORV lift.
	• All tests: Throttle for 75F core exit subcooling.
Core power	Continue decay ramp
CFT	• The CFT will isolate automatically on low level.
	• The CFT is to be isolated manually when subcooling is regained (see text).
	• The MIST CFT will isolate automatically when primary system pressure exceeds 650 psia.
Vents (HLPVs)	See text.

Table 3.4 Predicted LOFW Events

Time After LOFW	Event
0	Loss of feedwater
15 to 16 seconds	Reactor and turbine tripped, PORV actuated
1.5 minutes	PORV began repeated actuations
1.6 minutes	Hot leg fluid temperature ≥ 600F
8.3 minutes	Pressurizer filled
11.6 minutes	Operator actions (10 minutes after T_{HOT} ≥ 600F)
	Opened PORV and vents, activated full makeup
11.7 minutes	Core region voiding began, tripped RCPs on SCM ≤ 20F
13.3 minutes	Hot legs voided briefly
14.2 minutes	Primary pressure stabilized at 2260 psia
15.3 minutes	Primary repressurizing
20 minutes	Hot leg levels began to decrease from nearly full
25.4 minutes	Primary safeties began actuating periodically, pressurizer level began to decrease from full
35 minutes	Hot leg level began to diverge, hot leg A level near surge line elevation
42 minutes	Hot leg B drained
47 minutes	Hot leg A drained, primary pressure began to decline, primary safeties ceased to actuate
1 hour	Core-region collapsed liquid level achieved a minimum value of approximately 12 feet

Table 3.5 Plant and MIST Conditions, Test 330499

The plant conditions are varying quite rapidly with time, and the MIST conditions are at steady state. See the text for details.

	Predicted Plant Conditions at 130.35s, Approximately 15s After Reactor Trip	MIST Initial Conditions
Core Power (%, based on 2700 MW)	8.8	9.6
Core Fluid Temperatures, F		
Inlet	586	577
Outlet	595	583
Average	590	580
Primary Pressure, psia	2350	2250
Pressurizer Level, ft*	~21	5
Primary Loop Flow Rate (%, based on 37500 lbm/s)	109	110

*Pressurizer level is in feet within the pressurizer, both the plant and MIST pressurizers are about half full.

Table 3.6 Initial Conditions, Test 330499

The primary system is in forced circulation with boundary systems inactive. The guard heaters, RVVVs, and PORV controls are in automatic. The CFT is charged to 600 psia and recirculated.

Quantity	Specification	Deviation	Derived
Primary			
Core power, % (1% = 33 kW, includes 0.4% to offset uncompensated losses to ambient)	10	0.05	
Pressure, psia	2250	25	
Flow rate, % (1% = 0.46 lbm/s)	110	6	
Fluid temperatures, F			
Hot			583
Cold	577	2	
Average			580
Pressurizer level, ft*	5	0.2	
Secondary			
The steam generators are balanced using high-elevation injection of AFW through the minimum wetting nozzles. The AFW temperature is 110 ± 20F.			
Pressure, psia			1275
Level, ft	5	1	
Flow rate, % (1% = 0.0384 lbm/s)			7.3

*Pressurizer level is specified in feet within the pressurizer.

Table 3.7 Initiation and Control of Test 330499

Initiate and control Test 330499 using the following steps. Initiate the test after recording at least 10 minutes of steady-state data at the specified initial conditions.

1. LOFW:

   (1) Stop AFW

   (2) 15 seconds later, mark the reactor trip time (for control of core power decay)

   (3) Pressurize the steam generators with nitrogen and isolate them

   (4) At 10 seconds decay time, begin the core power decay ramp from 9.6% of scaled full power (plus 0.4% to offset losses to ambient)

   (5) Manually deenergize the pressurizer heaters

2. Actions based on T_{HOT} > 590F:

   (1) Mark the time when T_{HOT} exceeds 590F

   (2) 10 minutes after T_{HOT} > 590F:

   - Manually open the PORV

   - Open the hot leg vents

   - Initiate makeup/HPI
     (Makeup is to be injected into cold leg A1.
     HPI is to be injected into all 4 cold legs when primary pressure decreases below 1700 psia.)

3. When the core exit subcooling margin decreases to 20F, initiate a four-pump coastdown.

4. When the primary system pressure stabilizes following PORV actuation, interrupt the core power reduction and hold core power constant.

5. When the primary system repressurizes, manually reduce and adjust core power to stabilize primary system pressure.

6. 15 minutes after the surge line has uncovered and the primary system has begun to depressurize, revert to automatic core power reduction.

Table 3.8 Control During Testing, Test 330499

Component	Control Mode		
	Automatic	Manual	Associated Initiation Step
Primary System			
Core power decay	X	X	1, 4, 5, 6
Pressurizer			
- Heaters		X (Off)	1
- PORV		X (Open)	2
- Spray		X (Inactive)	
Vents		X (Open)	2
RCPs		X (Off)	3
HPI/makeup	X		2 (Use scaled head/flow characteristics modified as required to observe the MIST limits on maximum HPI flow rate capacity and metering capability.)*
Secondary System			
Steam generators inserted and isolated.			

*Makeup is simulated early in the test by injecting only to cold leg A1. After the primary system has first depressurized below 1700 psia, HPI is simulated by injecting to all four cold legs.

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

4.1.1. Initial Conditions

Initial conditions for the tests were defined by the governing test procedure, ARC-TP-671, and are repeated in Table 4.1 along with the actual values at the test time equal to 0.0 minutes from each test. All initial conditions were within specification except for the following. The core flood tank pressure in Test 330302 exceeded the upper acceptable limit by 3.5 psia. The cold leg A2 pump speed in Test 330499 was low by 0.2 rpm. These deviations did not impact test performance. During the initiation of Test 330499, a measurement error resulted in the core power being greater than the upper tolerance by 4.05 kW. Although this exceeded specification, the initial power was known and can be modelled by the code. Test acceptability was not impacted. These deviations are underlined in Table 4.1 to aid in their identification.

4.1.2. Test Initiation

The test initiation actions were to be performed as follows within a time interval of 20 seconds:

1. Deenergize the pressurizer main heaters.
2. Stop auxiliary feedwater to the steam generators.
3. Switch the control of reactor vessel vent valves from manual to the automatic "independent" mode.
4. Fifteen seconds after stopping the feedwater, activate the decay core power ramp (for Test 330499 only).

The events were performed in a timely manner as required for all the tests in this group.

4.1.3. Control During Testing

The performance of automatic control systems and manual interactions during the test transients is described in this section. The controls for HPI, CFT, core power, PORV, and reactor coolant pump control (used during Test 330499 only) performed acceptably for all the tests in this group. The isolated deviations are summarized in this section.

Independent of the usual control actions, the manual control actions during Test 330499 deviated from the test procedure. The transition to surge line uncovery at a constant core power and stable primary pressure was performed to the best of the operator's ability. The expected rapid primary depressurization at the time of surge line uncovery did not result. The test operator deviated from the test procedure to ensure that surge line dryout was present. This deviation resulted in an increase to core power at about 112 minutes.

Steam Generator Secondary Level Control

Secondary level control was not required for the steam generators in any of the tests in this group. The inventory was allowed to boil off, after which the generators were isolated.

During Test 330201, an erroneous level was indicated from 231 to 248 minutes in the loop A generator, and from 241 to 335 minutes in the loop B generator. These steam generator level measurements will be removed from the data base during these times.

ATOG Steam Pressure Control

Abnormal transient operating guideline (ATOG) steam pressure control was not required in any of the tests in this group. The nitrogen overpressure was satisfactorily established following steam generator boiloff, maintaining the primary-to-secondary pressure differential within the 1500-psi maximum differential pressure guidelines established for structural integrity.

Steam Generator Auxiliary Feedwater

Auxiliary feedwater control was not required in any of the tests in this group. At test initiation, the feedwater was isolated to both steam generators as required.

Power-Operated Relief Valve

For all the tests in this group, the PORV was initially in automatic control with open/close setpoints of 2350 and 2300 psia, respectively. During Tests

3301BB, 330201, and 330302, the PORV opened shortly after the steam generator secondaries were isolated. The PORV was then switched to manual open and remained opened until test termination. For Test 330499, the PORV automatically cycled from about 0 to 12 minutes. At 12 minutes, 10 minutes after the hot leg temperature reached 590F, the PORV was switched to manual open, as required. Performance of PORV control was acceptable for all the tests except for Tests 330302 and 330499.

During Tests 330302 and 330499, the PORV opened automatically at actuation pressures of about 2299 and 2307 psia, respectively. These actuation pressures were lower than desired. For Test 330499, the closing pressure was about 2270 psia, also lower than desired. Since these differences were known and can be modelled by the code, test acceptability was not affected.

Reactor Coolant Pump Control

Reactor coolant pumps were used during Test 330499 only. Reactor coolant pumps were required to be tripped when the core exit subcooling decreased to 20F. The pumps were tripped 10 seconds after the required subcooling was obtained. All pumps were tripped within a period of 5 seconds and coasted down according to the required control curve. Control during coastdown was maintained to within about 100 rpm of the desired curve.

High-Pressure Injection

Automatic and manual control of HPI was performed according to the following:

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

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

3. Manual HPI shut off when subcooling increased to 100F and returned to automatic when subcooling decreased to 50F (3 times). HPI was left on automatic subcooling control when subcooling reached 100F for the fourth time.

Control of HPI during all the tests in this group was performed as required. During Tests 3301BB and 330201, HPI was initiated immediately following the PORV actuation. During Test 330302, HPI was initiated 20 minutes after the actuation of the PORV, and during Test 330499, HPI was initiated 10 minutes after the hot leg temperature reached 590F.

Tests 3301BB and 330302 were performed using "full capacity" HPI. Test 330201 was performed using EM HPI, and Test 330499 was performed using the makeup/HPI model as the head/flow characteristic. Control anomalies observed in the tests are summarized below.

During Test 3301BB, HPI was initiated at 18 minutes. At this time, control mode 1 was to automatically maintain the HPI flow rate in accordance with the head/flow characteristic. Instead, HPI was manually controlled from 18 to 43 minutes. At 43 minutes, HPI control was returned to automatic. The maximum deviation from the required head/flow characteristic during this time was 47 lbm/h (~10%). This error did not impact test acceptability.

During Test 330201, HPI was initiated at 17 minutes. From 17 minutes 40 seconds to 28 minutes 40 seconds, the HPI controller was unable to control to the required setpoint. During that time, deviations of $\pm$ 100 lbm/h about the head/flow characteristic were observed. At 28 minutes 40 seconds, the operator manually regained control and subsequently returned the control to automatic. This action did not impact test acceptability.

Core Flood Tank

Core flood tank control was acceptable during all the tests in this group. The core flood tank water inventory discharged to the loop during Test 330201 only. During Test 330201, the CFT isolation valves were opened at 386 minutes and remained opened until test termination at 480 minutes. During Tests 3301BB and 330302, the CFT isolation valves were switched from automatic to manual close at 213 and 219 minutes, respectively. The criteria for manually closing the CFT isolation valves were satisfied when the core exit subcooling had been at least 50F for 30 minutes, the primary system was less than 715 psia, and the primary system was not repressurizing. During Test 330499, the isolation valves remained closed in automatic control through the entire test.

Pressurizer Main Heaters

For each test in this group, the pressurizer main heaters were deenergized to initiate the transient.

Core Power

The core power control performed satisfactorily during each test. The decay power ramp was specified to activate following the PORV actuation for tests 3301BB, 330201, and 330302, and 15 seconds after the auxiliary feedwater to the steam generators was stopped for Test 330499. The core power decay ramp was initiated as required during each test. Throughout the test transients, core power was maintained within 2.5 kW (1.6%) of the intended core power decay curve.

During Test 330499, the core power was transferred to manual control at about 15.5 minutes when the core outlet subcooling was -1.9F instead of the specified 0F, which occurred at 14.5 minutes. This difference did not impact test performance. Between 15.5 and 145 minutes, the core power was manually adjusted to stabilize primary pressure as the hot leg level decreased to the surge line elevation. To ensure hot leg level decrease below the surge line elevation, the primary pressure was raised by increasing the core power at about 115 minutes. The decay ramp was resumed at about 145 minutes, 15 minutes after surge line drain was verified. The core power remained in automatic control until test termination.

4.1.4. Termination

Test termination activities were acceptable for all the tests in this group. Test 3301BB was terminated on the basis of a maximum elapsed time of 10 hours. Tests 330201 and 330302 were terminated based on a maximum elapsed time of 8 hours. Test 330499 was terminated based on a testing time of 3 hours, primary pressure of less than 1500 psia, and increasing reactor vessel water level. In all cases, the loop was refilled and the reactor vessel upper head void was removed prior to the termination of saving data.

4.2. Instruments

With the exception of Test 330499, each of the four tests used a common set of instrumentation. During Test 330499, an additional set of instruments was used to support reactor coolant pump operation. The critical instruments for the tests in Group 33 are given 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 were performed at steady-state, pre-test initial conditions, during the test transient, and after test termination as summarized below:

Check	Purpose	Time of Performance 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	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 measurements associated with 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. For the 18 conductivity probes identified by Note 4, the measurement system error was not identified until after the test series was completed (except Test 330499). For these tests, the void fraction obtained from neighboring differential pressure measurements provided sufficient backup except for the reactor vessel probes, RVCP01-04. The absence of these measurements did not warrant repeating the test.

During Test 330499, as expected, a number of the primary differential pressure measurements were overranged during the time of pump operation. Many of these transmitters were taken out of service and were not returned to service until pump coastdown was completed as specified in the test procedure. The differential pressure measurement for the HPI supply tank water level (HPDP01) was erroneously left in a "zero" mode during Test 330499, and was not returned to service until after test termination. The absence of this measurement did not impact test performance. Prior to the performance of Test 330499, three differential temperature thermocouples, used for guard heater control in the cold leg A1 and B2 suction pipes and cold leg B2 discharge pipe, failed. The three metal temperatures associated with the differential pairs were used in place of the failed differential temperatures. Approval from the Project Management Group (PMG) for this control method was received per PMG letters 566 and 606.

Prior to and after completion of the tests, a "zero" reading was obtained for all differential pressure and pressure transmitters, mass flowmeters, 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.

RVVV Performance

The behavior of the RVVVs was reviewed using limit switch data. The RVVVs performed symmetrically in Group 33 Tests 2 and 4; RVVV B2 was less active than the other RVVVs, and open more often in Tests 1 (Nominal) and 3 (Delayed HPI). The characteristics of the RVVV differential pressure (DP) transmitters have been examined for each of the Group 33 tests. The responses to the initial DP change were compared among the transmitters using high-speed data. The DP transmitters performed satisfactorily in all the tests except for RVDP08 (associated with RVVV A2) in Test 4. In this instance, the DP transmitted by RVDP08 apparently amplified an abrupt increase of the actual DP, and responded relatively slowly to DP changes. This anomaly appears to have had little impact on the performance of the RVVVs in Test 4.

Table 4.1 Test Initial Conditions

(Underlined entries lie outside the specified band. These deviations are discussed in the text.)

System	Parameter	VTAB	Units	Desired	Tolerance	3301BB	330201	330302	330499
Primary									
	Pressure	RVGP01	psia	1750 (for Test 330499, 2250 psia)	*	1734	1728	1735	2265
	Hot leg subcooling	**	F	22.0	±2.0	23.7	23.3	23.3	***
	Core power	RVWM20	kW	128.7 (for Test 330499 at 330.0)	±1.65	128.5	127.9	128.4	335.7
	Pump speed	C1TA20 C2TA20 C3TA20 C4TA20	rpm	3534 3493 3556 3521	±15.7 ±13.9 ±16.8 ±17.6	***	***	***	3528 3485 3539 3504
	Pressurizer level	PZLV20	ft	20.5 (for Test 330499 at 23.0) and varying less than ±0.6 ft/h.	±0.2	20.6 and steady	20.5 and steady	20.7 and steady	22.8 and steady
	T_{cold}	P1RT02 P2RT02	F	577	±2	***	***	***	576.6 576.6
	Pressurizer surge line fluid temperature	PZTC01	F	Match H1TC11	±5	H1TC11 -4.9	H1TC11 -5.0	H1TC11 +0.4	H1TC11 -4.5
	Fluid/metal temperatures	****	F	Varying less than 3F/h for fluid and 10F/h for metal during a 30-minute interval.		accept-able	accept-able	accept-able	accept-able

Table 4.1 Test Initial Conditions (Cont'd)

System	Parameter	VTAB	Units	Desired	Tolerance	3301BB	330201	330302	330499
Secondary									
	Pressure	S1GP01	psia	1010 (for Test	*****	1012	1014	1015	1247
		S2GP01		330499 at 1275)		1012	1015	1015	1247
	Level	S1LV20	ft	5.0	±1.0	5.4	5.2	4.5	4.9
		S2LV20				5.4	4.7	4.3	5.1
	Feedwater	SFRT01	F	110	±20	112.2	110.0	114.8	110.7
	temperature	SFRT02				113.2	111.0	115.7	110.6
Core flood tank									
	Pressure	CFGP01	psia	600	±10	608.3	599.3	613.5	603.0
	Level	CFLV20	ft	42.8	±0.3	42.9	42.8	42.8	43.1

*For Tests 3301BB, 330201, and 330302, pressure was adjusted to give a hot leg subcooling of 22 ± 2F. For Test 330499, this value was ± 25 psi.

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

***Not applicable.

****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: P1MT01, P2MT01, C1MT04, C2MT04, C3MT04, C4MT04, RVMT24, RVMT25.

*****For Tests 3301BB, 330201, and 330302, this value is ± 10 psi. For Test 330499, secondary pressures were adjusted (not to exceed 1300 psia) to achieve P1RT02, P2RT02 equal to 577 ± 2F.

Table 4.2 Critical Instruments for the Group 33 Test Series

Component	Instrument Type	Critical Instruments	Additional for 3301BB	Additional for 330499*
Reactor vessel	Ammeter	RVAM01		
	Conductivity probe	RVCP01-04		
	Differential pressure transmitter	RVDP01, RVDP03-09	RVDP02	
	Differential temperature	RVDT01-04,-23		
	Pressure transmitter	RVGP01		
	Limit switch	RVLS01-04		
	Metal thermocouple	RVMT01-04,-23 RVMT05-22 (12 of 18)	RVMT24,-25	
	Fluid thermocouple	RVTC01,-02, 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) H2CP01-10 (5 of 10)		
	Differential pressure transmitter	H1DP01,-04,-09-12,-14 H2DP01,-04,-09-12,-14,-16	H1DP02,-03,-05-08,-13,-15 H2DP02,-03,-05-08,-13,-15	
	Differential temperature	H1DT01-04 H2DT01-04		
	Limit switch	H1LS01,H2LS01		
	Metal thermocouple	H1MT01-04 H2MT01-04		
	Resistance temperature 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,H2WM01-04	
	Gamma densitometer		H1GD01,-02, H2GD01,-02	

Table 4.2 Critical Instruments for the Group 33 Test Series (Cont'd)

Component	Instrument Type	Critical Instruments	Additional for 3301BB	Additional for 330499*
Steam generator A	Differential pressure transmitter	P1DP04, S1DP01, S1DP03	S1DP02	
	Differential temperature	S1DT01-05		
	Pressure transmitter	P1GP01, S1GP01		
	Metal thermocouple	S1MT01-05	P1MT01	
	Resistance temperature detector	P1RT01, -02		
	Fluid thermocouple	P1TC01-03, -13-16, -23-26, -33, -34, -35, -36 (10 of 15) P1TC18, -27, -28, -37, -38 (3 of 5) 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		P1TC01-03
	Power controller		S1WM01-05	
Steam generator B	Conductivity probe	S2CP01-12 (6 of 12)		
	Differential pressure transmitter	P2DP06, S2DP01, S2DP12 S2DP02-11 (5 of 10)		
	Differential temperature	S2DT01-05		
	Pressure transmitter	P2GP01, S2GP01		
	Metal thermocouple	S2MT01-05	P2MT01	
	Resistance temperature 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 (13 of 20)		

Table 4.2 Critical Instruments for the Group 33 Test Series (Cont'd)

Component	Instrument Type	Critical Instruments	Additional for 3301BB	Additional for 330499*
	Power controller		S2WM01-05	
Cold legs (n=1,2,3,4)	Differential pressure transmitter**	C1DP01,C2DP01,C2DP09		CnDP01,-02,-07,-08
		CnDP02,-03,-04,-06,-07,-08		
	Differential temperature	CnDT01-03		
	Gamma densitometer		CnGD03,-04	
	Metal thermocouple	CnMT01-03	CnMT04	
	Resistance temperature detector	CnRT01,-02		
	Fluid thermocouple	CnTC02		
		CnTC03-06 (3 of 4)		
		CnTC07-10 (3 of 4)		
		CnTC11-14 (3 of 4)		
	Power controller		CnWM01-03	CnWM04
	Turbine meter			CnTM01
	Tachometer			CnTA20
	Ammeter			CnAM01,C1AM20
	Limit switch			CnLS01
Reactor vessel downcomer	Differential pressure transmitter	DCDP01,-02,-05-08		DCDP03
	Cooled thermocouple		DCCT02-04	
	Differential temperature	DCDT01-03		
	Metal thermocouple	DCMT01-03	DCMT04	
	Resistance temperature 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	

Table 4.2 Critical Instruments for the Group 33 Test Series (Cont'd)

Component	Instrument Type	Critical Instruments	Additional for 3301BB	Additional for 330499*
Pressurizer	Differential pressure transmitter	PZDP01,-02		
	Differential temperature	PZDT01,-02		
	Pressure transmitter	PZGP01		
	Metal thermocouple	PZMT01,-02	PZMT03	
	Resistance temperature detector	PZRT01 or PZTC09		
	Fluid thermocouple	PZTC01,-02 PZTC04-08 (4 of 5)		PZTC10
	Power controller	PZWM04	PZWM01-03	
	Limit switch			PZLS01
HPI	Differential pressure transmitter	HPDP01		
	Flowmeter	HPMM01-05		
	Fluid thermocouple	HPTC01		
Two-phase vent system	Load cell	V2LC01-04		
	Limit switch	V2LS03-06		
	Flowmeter	V2MM01-03		
	Fluid thermocouple	V2TC01-04		
Core flood tank	Differential pressure transmitter	CFDP01		
	Pressure transmitter	CFGP01		
	Limit switch	CFLS01,-02 (1 of 2)		
	Fluid thermocouple	CFTC01	CFTC02,-03	
Gas addition	Fluid thermocouple	GATC02-04 (1 of 3)		
Feedwater circuit	Differential pressure transmitter	SFDP01-06		
	Resistance temperature detector	SFRT01,-02		

Table 4.2 Critical Instruments for the Group 33 Test Series (Cont'd)

Component	Instrument Type	Critical Instruments	Additional for 3301BB	Additional for 330499*
Steam circuit	Differential pressure transmitter	SSDP01-06		
	Resistance temperature detector	SSRT01,-02		
	Fluid temperature	SSTC01-03 (1 of 2) SSTC02,-04 (1 of 2)		
Miscellaneous	Resistance temperature Detector shunt	MSRF01		
	Reference oven temperature	MSTC01-07		

*For Test 330499, the differential pressure transmitters listed as "Critical Instruments" that were out of service when the reactor coolant pumps were running were critical after pump stop.

**The cold leg venturi differential pressure measurements, CnDP03, -04, -05, and -06, were not installed for Test 330499 (n=1,2,3,4).

Table 4.3 Critical Instruments Not Available for the Group 33 Test Series

Instrument	Description	3301BB	330201	330302	330499	Backup Available
CFLS01	Limit switch on loop A header isolation valve	x	x	x	x	yes
C1TC04	Pump suction fluid temperature at 2.36 ft	x	x	x		yes
C3GD04	Beam 2 loop A2 cold leg density at 21.25 ft	x				no
H1GD01	Beam 1 loop A hot leg density at 21.25 ft	x				no
H2CP09	Hot leg fluid conductivity probe at 66.78 ft	x	x	x		yes
P1TC30	Generator A primary fluid temperature at 50.58 ft	x	x	x	x	yes
P1TC35	Generator A primary fluid temperature at 39.08 ft	x	x	x	x	yes
P2TC12	Generator B primary fluid temperature at 49.50 ft	x	x	x	x	yes
RVTC07	Core fluid temperature (mid bundle) at 13.15 ft	x	x	x	x	yes
S1TC04	Generator A secondary fluid temperature at 11.07 ft	x	x	x	x	yes
S1TC16	Generator A secondary fluid temperature at 38.19 ft	x	x	x	x	yes
S1TC19	Generator A secondary fluid temperature at 41.28 ft	x	x	x		yes
S2TC12	Generator B secondary fluid temperature at 14.27 ft	x	x	x		yes

Table 4.3 Critical Instruments Not Available for the Group 33 Test Series (Cont'd)

Instrument	Description	3301BB	330201	330302	330499	Backup Available
S2TC13	Generator B secondary fluid temperature at 20.19 ft	x	x	x		yes
S2TC14	Generator B secondary fluid temperature at 26.27 ft	x	x	x		yes
S2TC16	Generator B secondary fluid temperature at 26.27 ft	x	x	x		yes
S2TC24	Generator B secondary fluid temperature at 38.19 ft	x	x	x		yes
C1DT01	Loop A1 guard heater zone 28 control at 2.60 or 2.57 ft				*	yes
C4DT01	Loop B2 guard heater zone 37 control at 2.59 ft				*	yes
C4DT03	Loop B2 guard heater zone 39 control at 23.47 ft				*	yes
P2TC01	Generator B primary fluid temperature at 50.50 ft				x	yes
P2TC30	Generator B primary fluid temperature at 29.25 ft				x	yes
P2TC40	Generator B primary fluid temperature at 14.25 ft				x	yes
H1CP06	Hot leg fluid conductivity probe at 59.72 ft				x	yes
H2CP04	Hot leg fluid conductivity probe at 43.41 ft				x	yes

Table 4.3 Critical Instruments Not Available for the Group 33 Test Series (Cont'd)

Instrument	Description	3301BB	330201	330302	330499	Backup Available
H2CP05	Hot leg fluid conductivity probe at 50.68 ft				x	yes
H2CP06	Hot leg fluid conductivity probe at 59.69 ft				x	yes
H2CP07	Hot leg fluid conductivity probe at 63.56 ft				x	yes
H2CP08	Hot leg fluid conductivity probe at 65.65 ft				x	yes
C2TC06	Loop B1 pump suction fluid temperature at 17.09 ft				x	yes
HPDP01	Elliot tank differential pressure				**	no
H1RT01	Hot leg fluid temperature at 23.32 ft				***	yes
H2RT01	Hot leg fluid temperature at 23.31 ft				***	yes
P1RT01	Generator A inlet fluid temperature at 53.10 ft				***	no
P1RT02	Generator A outlet fluid temperature at -3.15 ft				***	no
P2RT01	Generator B inlet fluid temperature at 53.09 ft				***	no
P2RT02	Generator B outlet fluid temperature at -3.14 ft				***	no
RVCP01-04	Reactor vessel fluid conductivity probes	****	****	****		no
S2CP01-12	Generator B secondary conductivity probes	****	****	****		no
H1CP01,-02	Hot leg fluid conductivity probes	****	****	****		yes

*Metal temperature used for guard heater control in place of the differential temperature.

**Unavailable from 0 to 227 minutes.

***Unavailable from 93 to 98 minutes.

****Raw data obtained with these conductivity probes can not be processed due to a measurement problem observed after completing these tests.

5. OBSERVATIONS

The four Group 33 tests are described separately in sections 5.2 through 5.5 and compared in section 5.6. A summary of observations is provided in section 5.7.

5.1. Introduction

Three of the four tests of Group 33 were based on the same conditions, as described in section 5.1.1. These three tests were initialized and begun virtually identically, as described in section 5.1.2.

5.1.1. Description of the Group 33 Tests

The four tests of Group 33 fall into two distinct subgroups. Three tests, Tests 1 through 3, were conducted similarly and were based on the same nominal conditions, those of Test 1. Test 4, although it dealt with HPI-PORV cooling, was initialized in forced flow rather than natural circulation and was conducted quite unlike the other tests. The Group 33 tests are listed in Table 5.1.

The Group 33 tests were each initiated with an interruption of feed to the steam generators followed by steam generator isolation. The steam generators were subsequently pressurized with nitrogen to conform to the maximum primary-to-secondary differential pressure facility limit while minimizing steam generator heat removal. In Test 1, the Nominal HPI-PORV Cooling Test, full-capacity HPI was activated immediately upon PORV actuation. Half-capacity HPI was used in Test 2. Full-capacity HPI was used in Test 3, but the activation of HPI was delayed until 20 minutes after PORV actuation. As mentioned earlier, Test 4 was unlike the other three. The PORV was allowed to actuate on overpressure for 12 minutes, rather than maintaining it open after it first actuated. The reactor coolant pumps were stopped upon the loss of subcooling margin (SCM) with the continuous PORV discharge. Then, the core power level was manipulated to adjust primary system pressure and to observe the effects of surge line uncovery.

5.1.2. Initial Conditions and Early Events

The initial conditions of Group 33 Tests 1 through 3 were virtually identical. In each of these tests, the total cold leg flow rates averaged near 4.15% of scaled full flow whereas the downcomer flow rate indicated 3.94%; the flow rate in cold leg A2 registered lowest, 4.05%, and that in B1 indicated highest by a similar amount. The feed and steam flow rates to both steam generators were each approximately 2.3% of scaled full steam generator secondary flow, although certain flow rates were more variable than others during initialization.

The test-initiating events were virtually indistinguishable among the three tests. The following events occurred between 0 and 0.1 minutes:

- Cessation of feed flow rate and the beginning of steam generator secondary level reduction.
- The onset of primary system pressurization and secondary system depressurization.
- The actuation of the RVVVs.

Also in all three tests, the steam generator steam flow rate began to decrease near 0.2 minutes.

Table 5.1 Group 33 Tests

Number	Identifier	Description	Date Tested
1	3301BB	Nominal	8/3/86
2	330201	Reduced HPI	8/1/86
3	330302	Delayed HPI	8/2/86
4	330499	Surge Line Uncovery	3/16/87

5.2. Nominal HPI-PORV Cooling, Test 1

Group 33 Test 1 (3301BB) was the Nominal Feed-and-Bleed (HPI-PORV) Cooling Test. Full-capacity HPI characteristics and no delay of HPI after PORV actuation were used. The test transient exhibited two distinct phases, with the transition between phases at approximately 2 hours. During most of the first phase, the hot legs remained nearly full, and the PORV and HPI flow rates were approximately balanced using full capacity, unthrottled HPI. The transition to the second phase was precipitated when the SCM reached 100F and HPI was interrupted. The hot legs voided extensively and the surge line was uncovered, with the core exit still remaining subcooled. The second phase was characterized by pronounced fluid temperature differences in the loop A hot leg. The core remained covered and cooled throughout the test. HPI control anomalies were encountered early in the test.

Initiation, PORV Actuation, and Primary Saturation

Feed-and-bleed Test 1 was initiated by isolating the steam generators, transferring the RVVV controls to automatic/independent, and deenergizing the pressurizer fluid heaters. The RVVVs opened immediately. Steam generator feeding was stopped at test initiation, and the steam generators were completely isolated (and pressurized with nitrogen) by 30 minutes. The steam generators were thus of minimal consequence to the primary system transient, as had been intended.

With the deletion of the steam generator heat sink, the primary system fluid began a general heatup (Figure 5.2.1), the primary system pressure increased (Figure 5.2.2), and the pressurizer level increased (Figure 5.2.3). The initial rate of primary system pressurization was 25 psi/min. This pressurization rate increased beyond 10 minutes in response to the isolation of the steam generators and to the increase of the expansion coefficient of water with temperature. The increase of the fluid temperatures throughout the primary system almost paralleled the increase of primary system saturation temperature. The pressurizer level rose from approximately 20 ft initially to 26 ft at 16.2 minutes. The pressurizer fluid temperatures subcooled as the pressurizer level increased (Figure 5.2.4) -- the 23.5-ft measurement subcooled at 3.5 minutes, and the 24.5-ft thermocouple indicated subcooling at 13.2 minutes. The primary system pressure reached 2325 psia at 16.3 minutes (Figure 5.2.2) and the PORV actuated.

PORV actuation triggered the second set of test-initiating actions. The PORV controller was placed in the manual-open position, full-capacity HPI was activated, and the core power decay ramp was initiated. The PORV limit switch actuated at 16.3 minutes, but PORV flow was not recorded until slightly later. The HPI (loop isolation valve) limit switches actuated at 16.5 minutes and HPI flow was recorded at 17 minutes. The initial HPI flow rate was unresponsive to primary system pressure (Figure 5.2.5), as discussed in section 4 herein. The initial PORV discharge flow rate reflected saturated vapor flow. The pressurizer filled quickly. Beyond 18 minutes, the pressurizer level indicated full (Figure 5.2.3) and the discharge rate jumped to 700 lbm/h (Figure 5.2.5), indicating subcooled liquid at the PORV (Figure 5.2.6). The PORV discharge rate was now nearly twice that of the HPI flow rate.

The primary system depressurized at 750 psi/min upon PORV actuation. The primary system pressure then stabilized near 1770 psia as the loop fluid saturated (Figure 5.2.2). Saturation occurred at the core outlet and throughout the hot legs (Figures 5.2.1 and 5.2.7). The primary fluid temperature drop through the steam generators had decreased to less than 20F (as steam generator isolation took effect), therefore the lower-elevation primary fluid temperatures were within 30F of saturation. The hot legs and reactor vessel began to void (Figures 5.2.8 and 5.2.9) and loop flow abruptly stagnated; inter-cold leg flow began at 23 minutes. The core-region collapsed liquid level descended to the vent valve elevation at 25 minutes, then the downcomer began to void. At 28 minutes, the downcomer level reached the nozzle elevation and stabilized, and the hot leg levels began to descend more rapidly than before. The RVVVs closed from 28 to 30 minutes, but RVVV A2 was less responsive than the others, apparently due to differences among the valve actuation setpoints. The pressurizer vessel fluid had evidenced thermal inversion, particularly following PORV actuation (Figure 5.2.4). The hot leg fluid supplying the insurge had been continually heating. Thus, the liquid introduced earlier into the pressurizer, which now resided toward the top of the vessel, was some 10F cooler than that entering at the bottom. The pressurizer fluid saturated from the bottom up, beginning at 23 minutes. The uppermost fluid thermocouple at 27.6 ft finally indicated saturation at 30 minutes.

The PORV discharge rate abruptly decreased to about 400 lbm/h at 31 minutes (Figure 5.2.5), indicating saturated conditions at the PORV (Figure 5.2.6). (The pressurizer level decrease was insufficient to indicate on the pressurizer level measurement.) The decreased PORV discharge rate was just less than the current HPI flow rate. The primary system began to depressurize gradually (Figure 5.2.2) at 4 psi/min, apparently in response to the increased volumetric discharge rate with two-phase fluid at the PORV. The core-region collapsed liquid level began to increase slowly, although the hot leg riser levels in both loops continued to decrease. The lower-elevation primary fluid began to cool, and the temperature rise across the core began to increase (after 36 minutes) at 1.7F/min. At 43 minutes, the HPI flow rate abruptly increased by approximately 40 lbm/h (as discussed in section 4 herein), thus augmenting the rate of increase of primary system fluid mass (Figure 5.2.5).

The core-region collapsed liquid level gradually exceeded the hot leg nozzle elevation and, at 118 minutes, the core exit fluid subcooled (Figure 5.2.10). The reactor vessel outlet plenum and hot leg A inlet fluid temperatures subcooled within a few minutes, reflecting the continuing HPI-cooled flow up hot leg A, through the surge line to the pressurizer, and out the PORV. The lowest pressurizer vessel fluid temperature measurement, at 19 ft, subcooled at 126 minutes and the higher-elevations temperatures responded sequentially (Figure 5.2.11).

HPI Throttling, Surge Line Uncovery, and Venting

The core exit SCM exceeded 100F at 135 minutes, thus HPI was manually interrupted (Figure 5.2.12) as specified. The hot leg levels then began to descend relatively rapidly (Figure 5.2.13). The rate of primary system depressurization increased from a primary pressure of 1310 psia (Figure 5.2.14). Also, the temperature rise through the core began to decrease from a maximum of 210F.

The SCM decreased to 50F at 146 minutes and HPI was restored as specified (Figure 5.2.12). Thereafter, the SCM was maintained near the control point of 75F using automatic HPI throttling. At 153 minutes, the PORV site fluid subcooled (Figures 5.2.11 and 5.2.15) in response to the cooling of the pressurizer fluid. The PORV flow rate again increased (Figure 5.2.12) to about 650 lbm/h in response to this subcooling. With a relatively high PORV flow rate and HPI throttling, the hot leg levels decreased quite rapidly. At 171 minutes, the hot leg A riser level reached the surge line connection and stabilized there (Figure 5.2.13). The primary system depressurized relatively rapidly (Figure 5.2.14) from 1020 psia as the surge line was uncovered. The core exit fluid remained approximately 75F subcooled (Figure 5.2.10), therefore the vapor flowing through the surge line originated in hot leg A. The pressurizer fluid temperatures began to rise at 171 minutes. At this time, the hot leg B riser voided completely. Beyond this time, almost full HPI capacity was used to maintain the SCM. Thus, the PORV and HPI flow rates were similar and the system conditions became relatively stable.

The operator opened both hot leg high-point vents at 496 minutes, as specified. The levels in the hot leg risers and steam generator primaries, which had remained quite constant for 5 hours, began to increase (Figure 5.2.16). The loop B hot leg inlet and the loop A hot leg riser beyond the surge abruptly subcooled as HPI-cooled fluid moved upward in the hot legs. The primary system depressurization rate increased almost imperceptibly upon high-point vent actuation (Figure 5.2.17). The test was terminated at 616 minutes based on maximum test duration. Upon termination, the primary system pressure was 315 psia, the core exit remained 75F subcooled, and the hot leg levels were between 31 and 38 feet and rising slowly. The PORV discharge fluid remained subcooled (Figure 5.2.18).

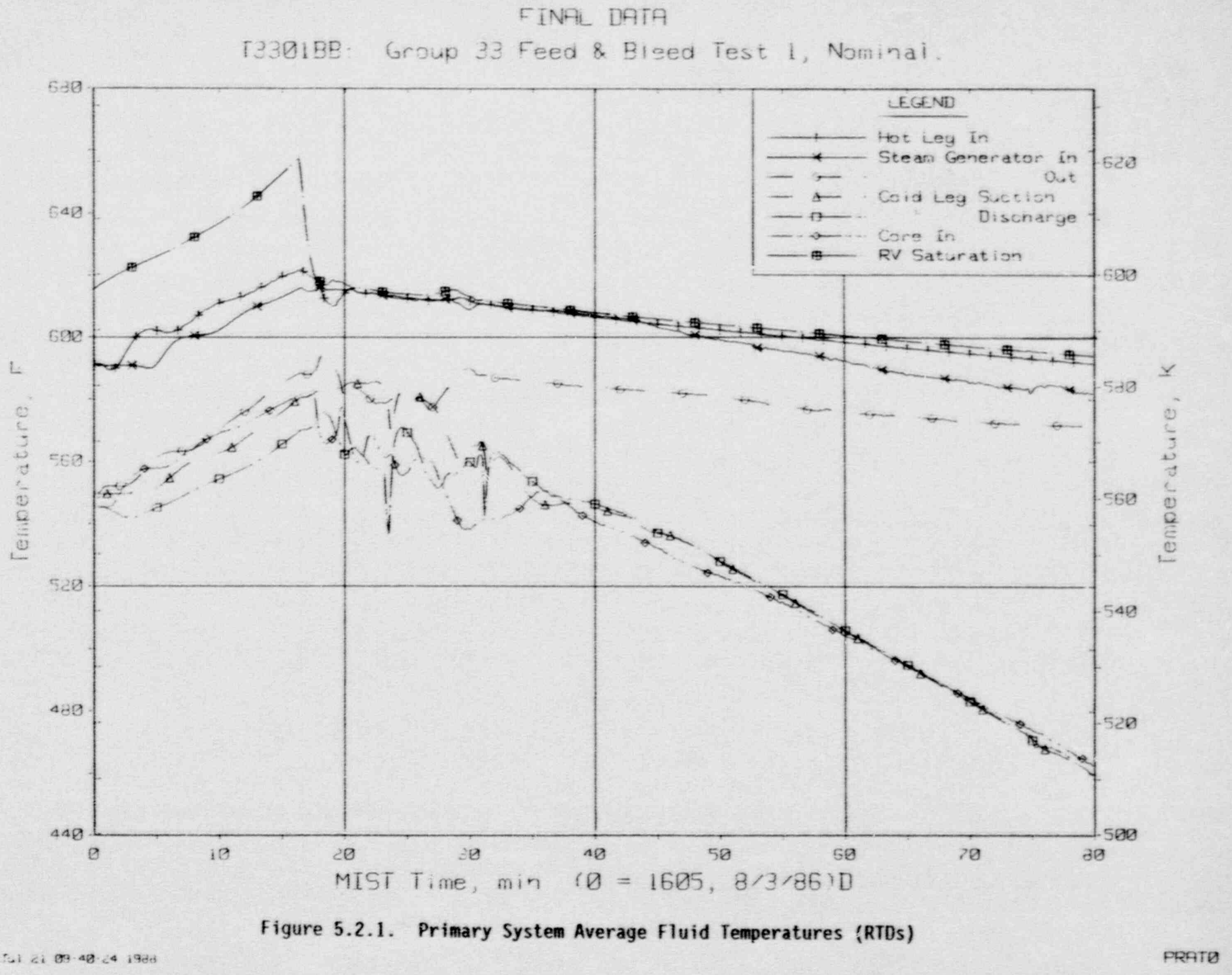


Figure 5.2.1. Primary System Average Fluid Temperatures (RTDs)

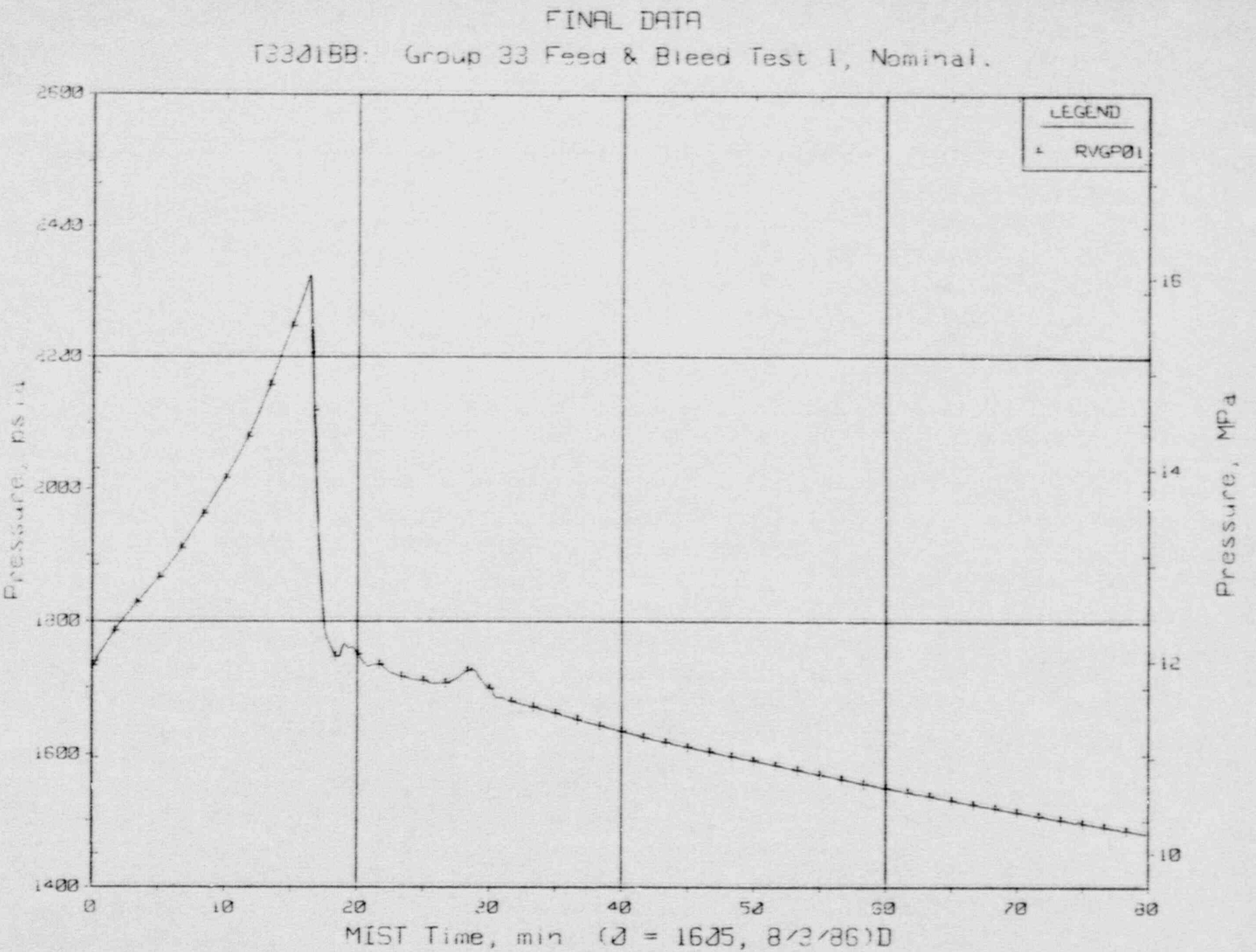


Figure 5.2.2. Reactor Vessel Pressure

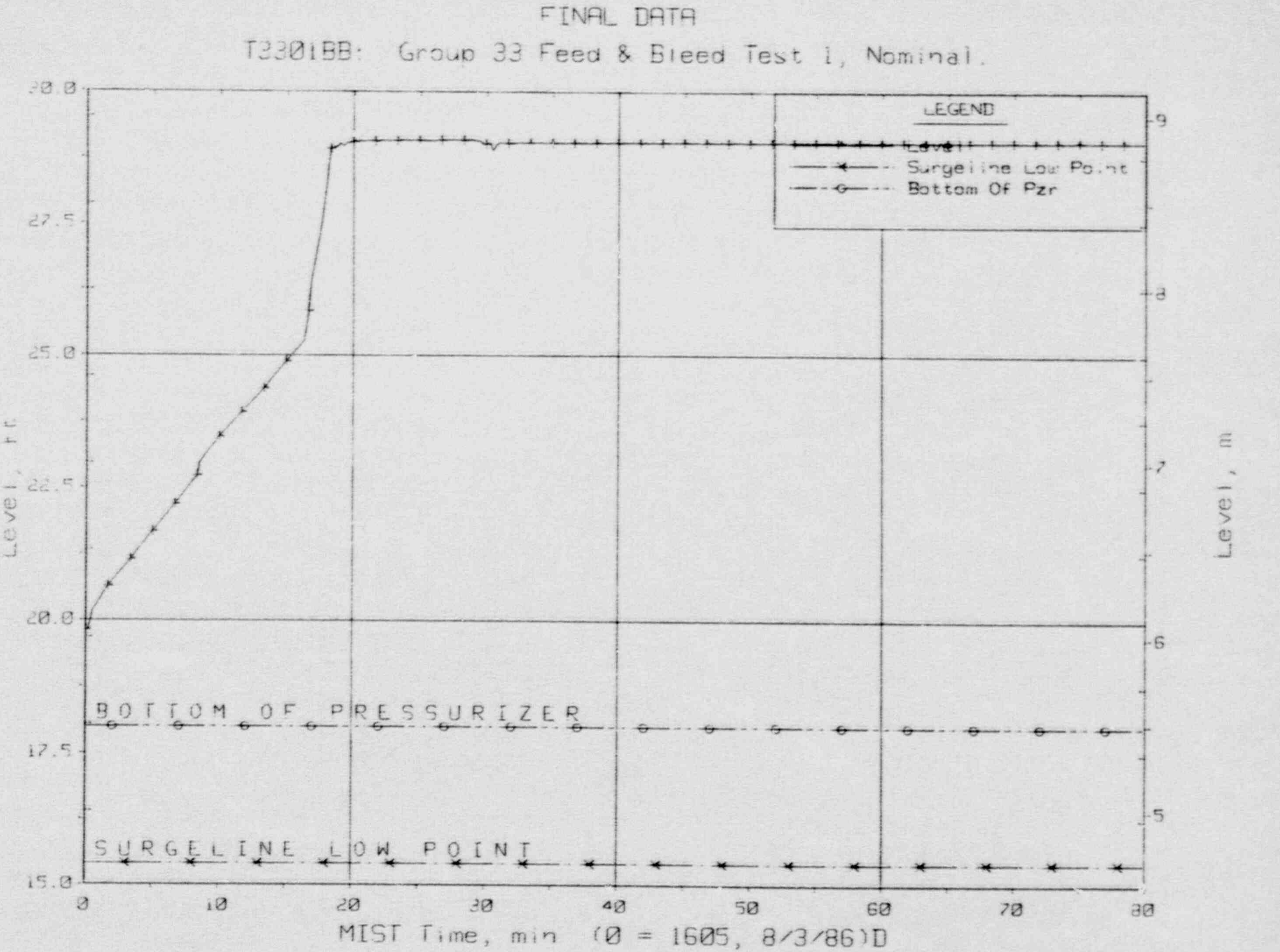


Figure 5.2.3. Pressurizer Collapsed Liquid Level (PZLV20)

Thu Jul 21 09:44:56 1988

PZLV1

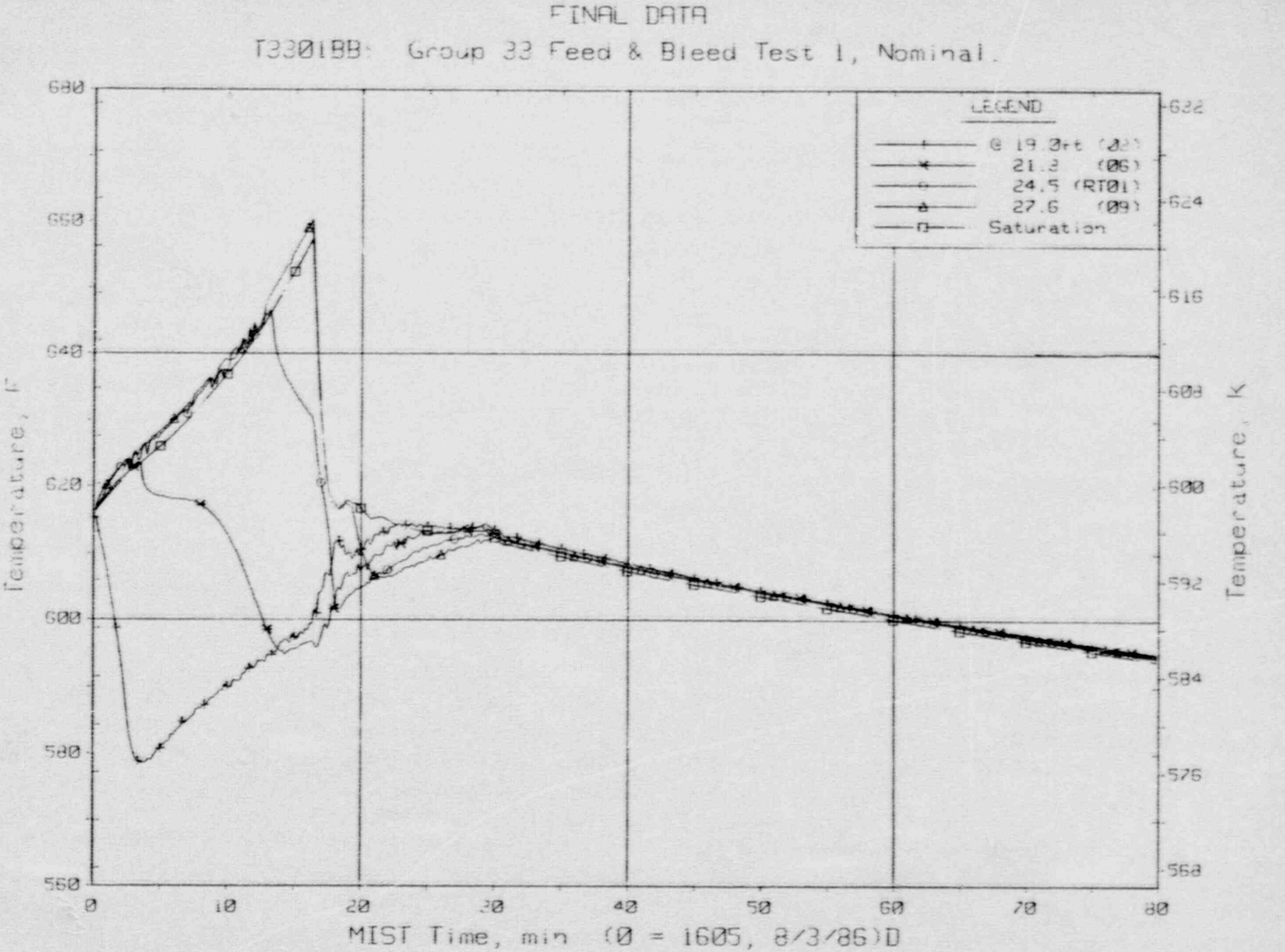


Figure 5.2.4. Pressurizer Vessel Fluid Temperatures (PZTCs)

PZTC2

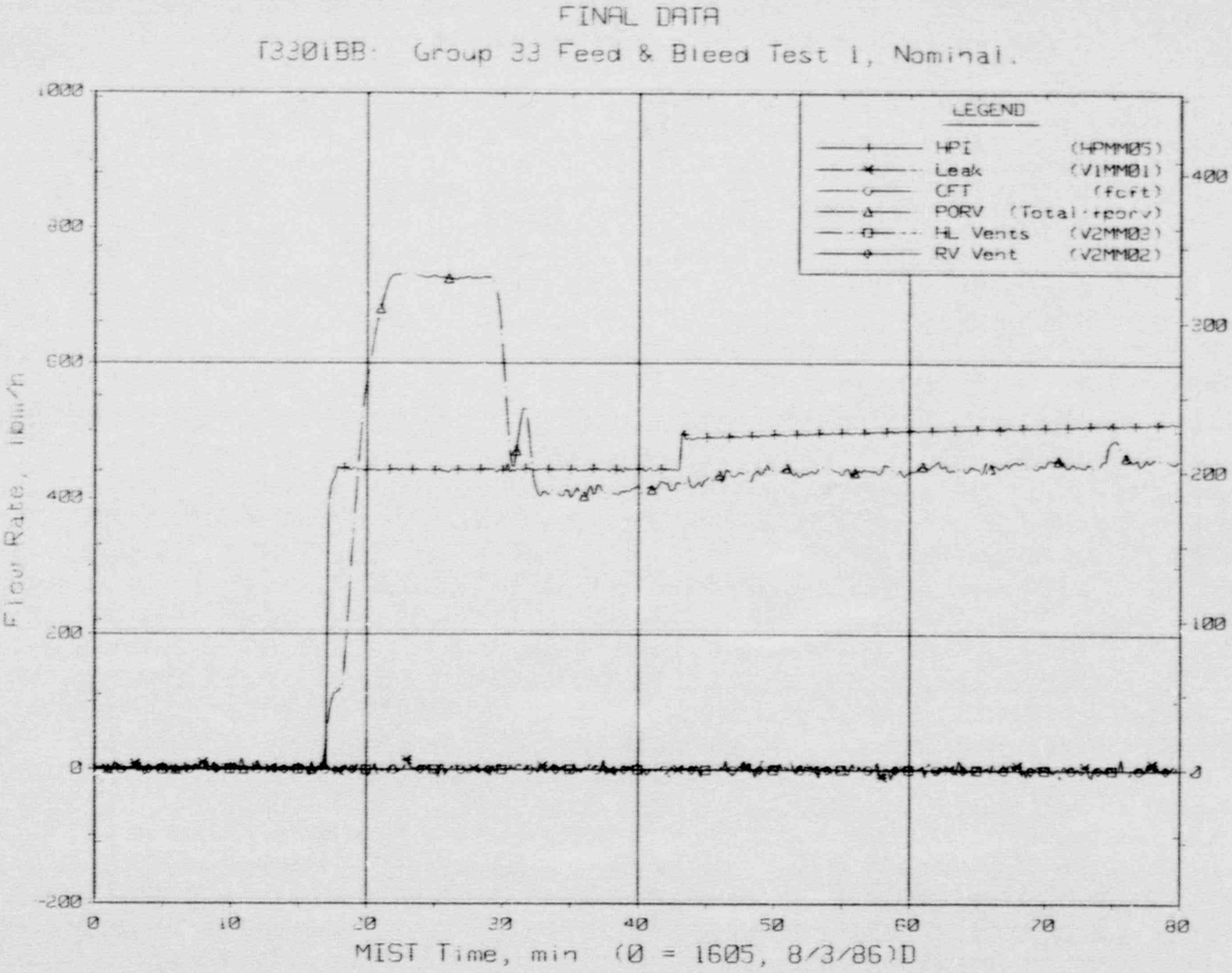


Figure 5.2.5. Primary System Boundary Flow Rates

Thu Jul 21 09:51:28 1988

PRFL2p

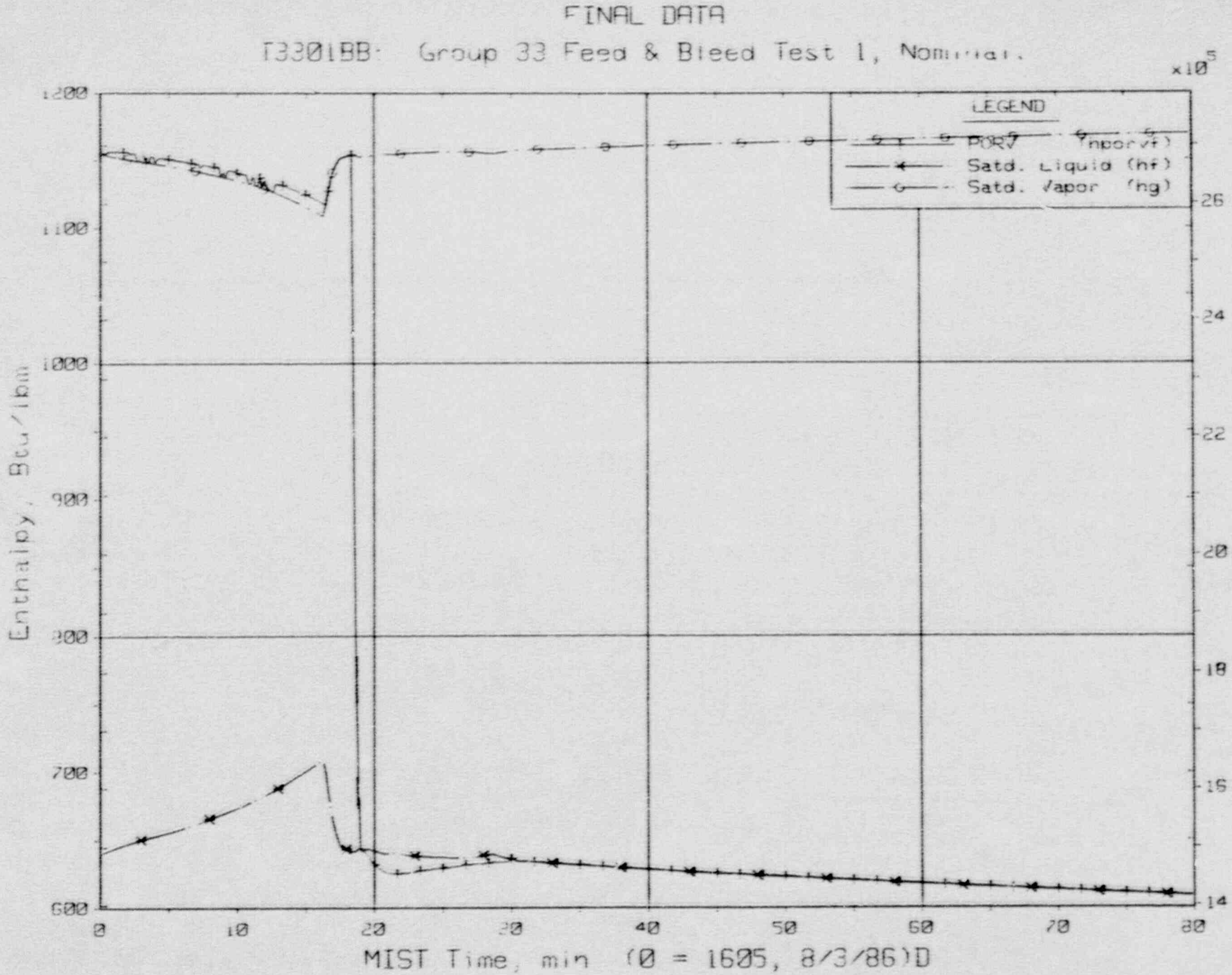


Figure 5.2.6. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

PZEN1

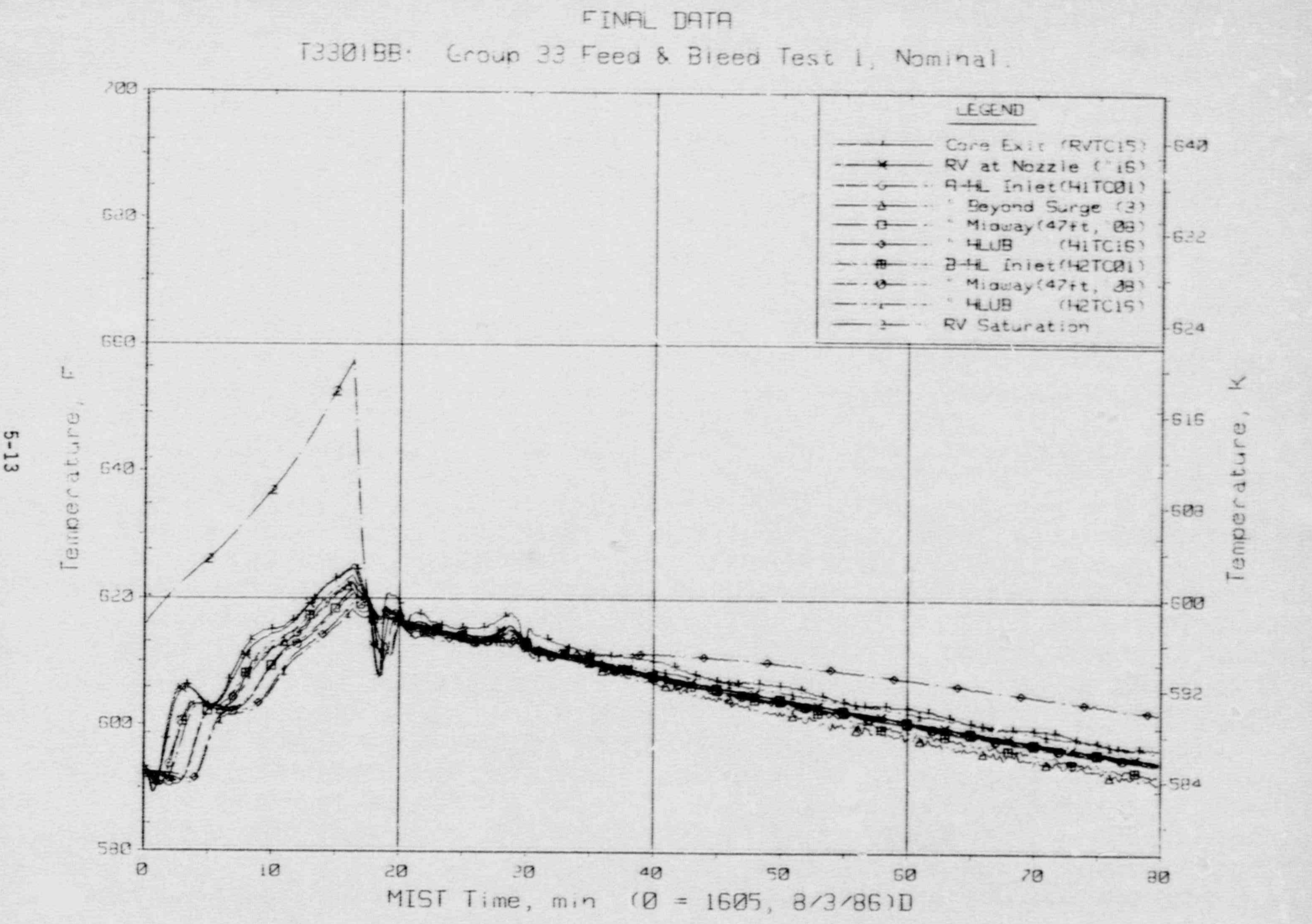


Figure 5.2.7. Composite Core Exit and Hot Leg Fluid Temperatures

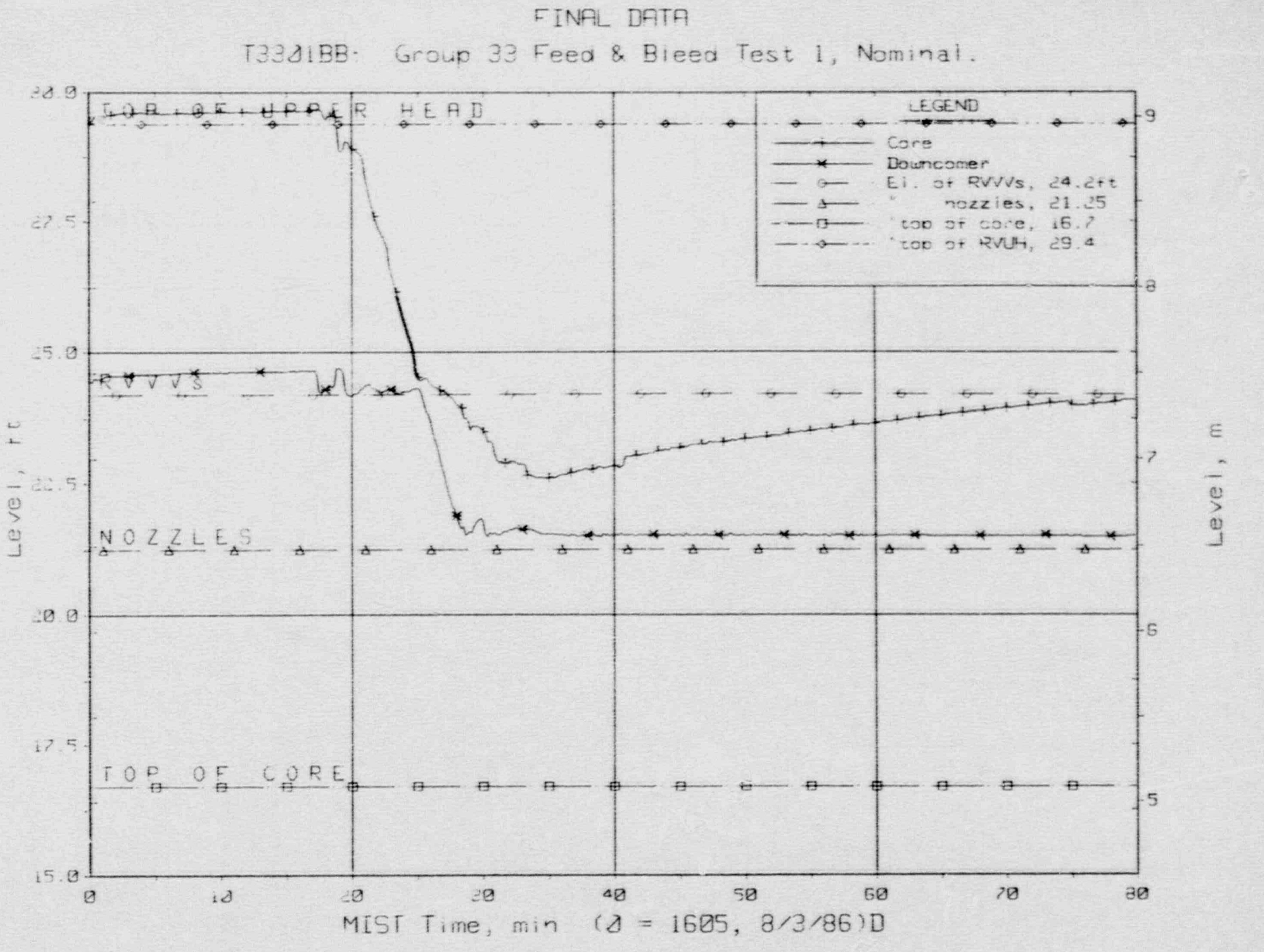


Figure 5.2.8. Core Region Collapsed Liquid Levels

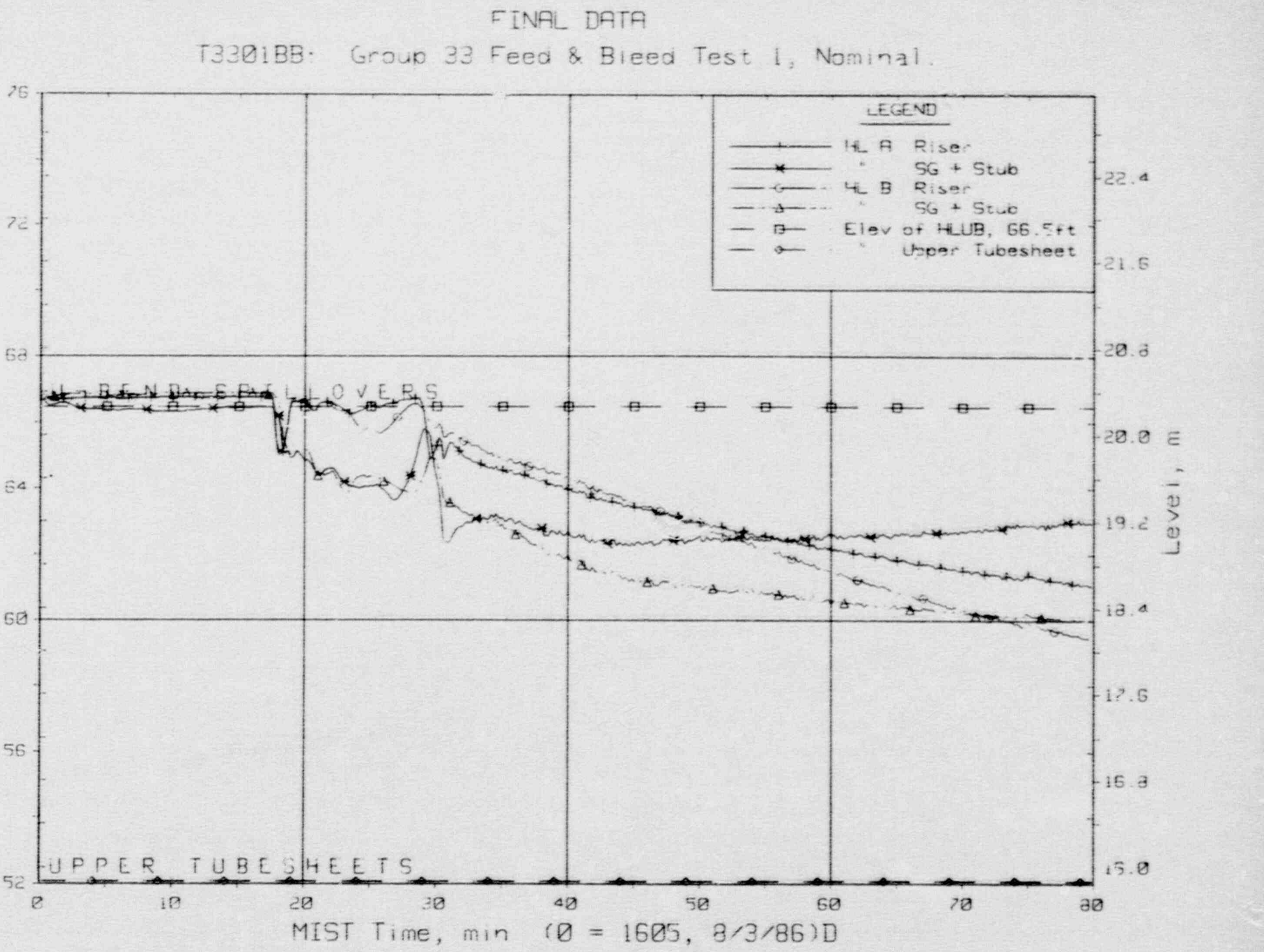


Figure 5.2.9. Hot Leg Riser and Stub Collapsed Liquid Levels

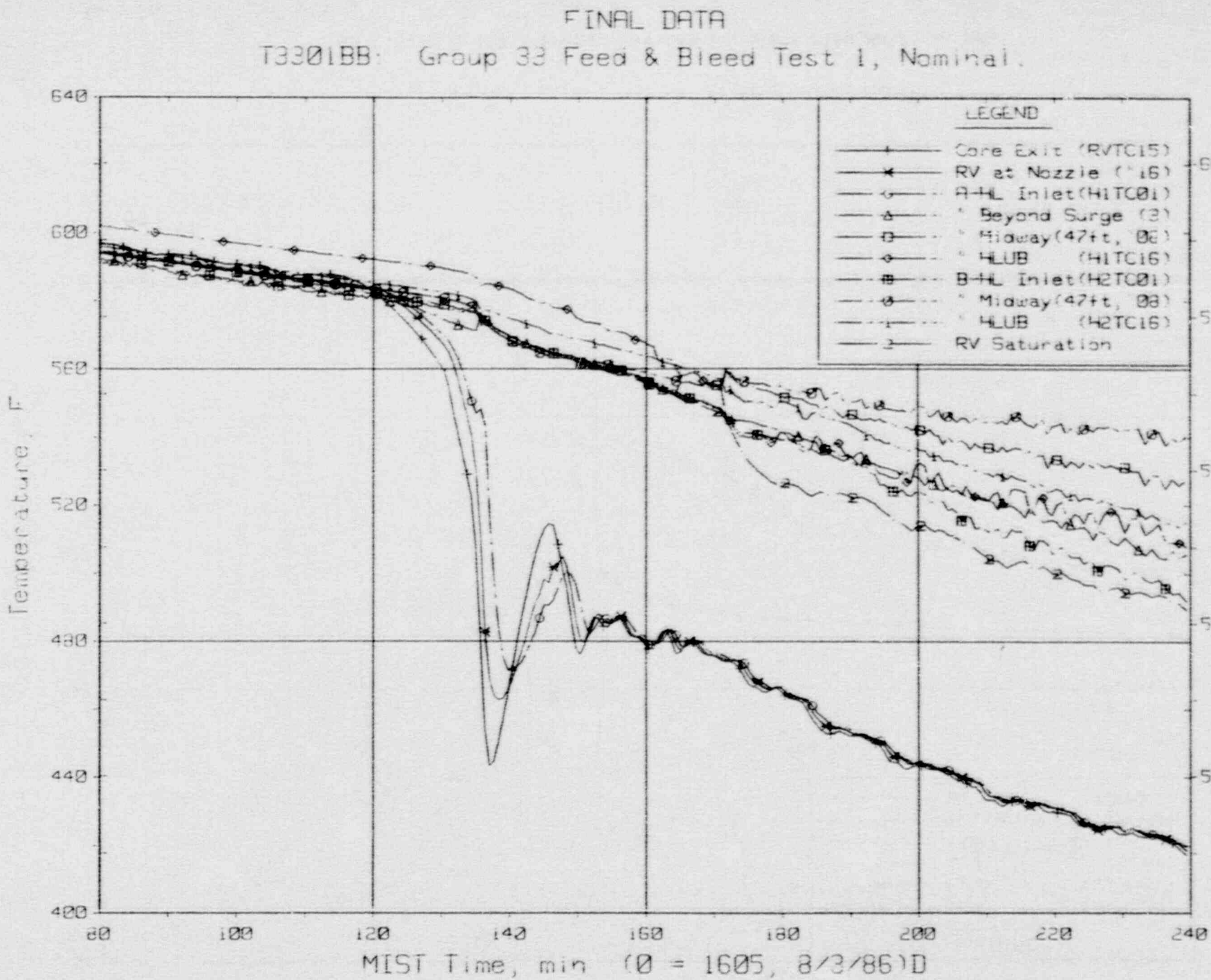


Figure 5.2.10. Composite Core Exit and Hot Leg Fluid Temperatures

Thu Jul 21 11:42:28 1988

PRKT1

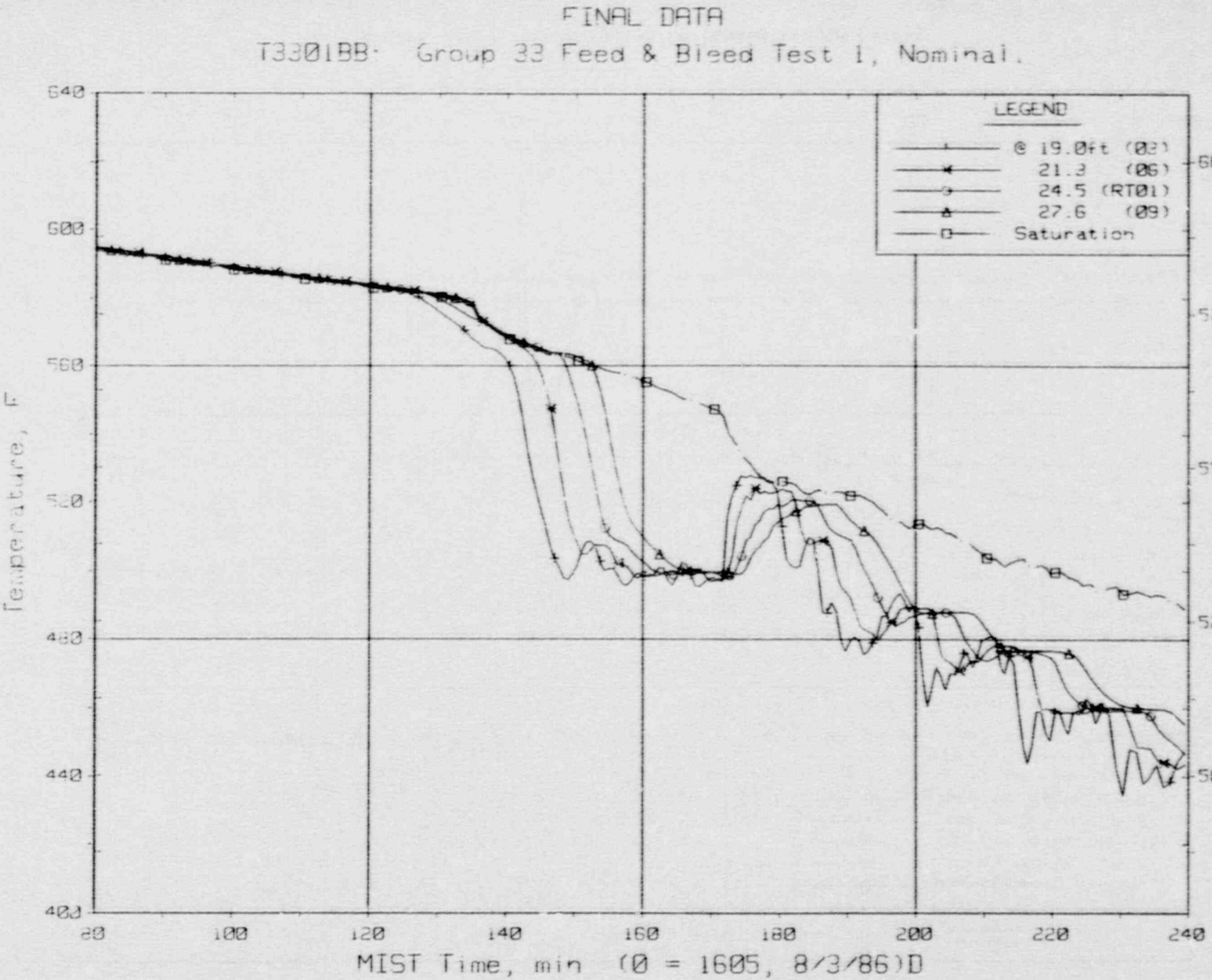


Figure 5.2.11. Pressurizer Vessel Fluid Temperatures (PZTCs)

Thu Jul 21 11:50:24 1988

PZTC2

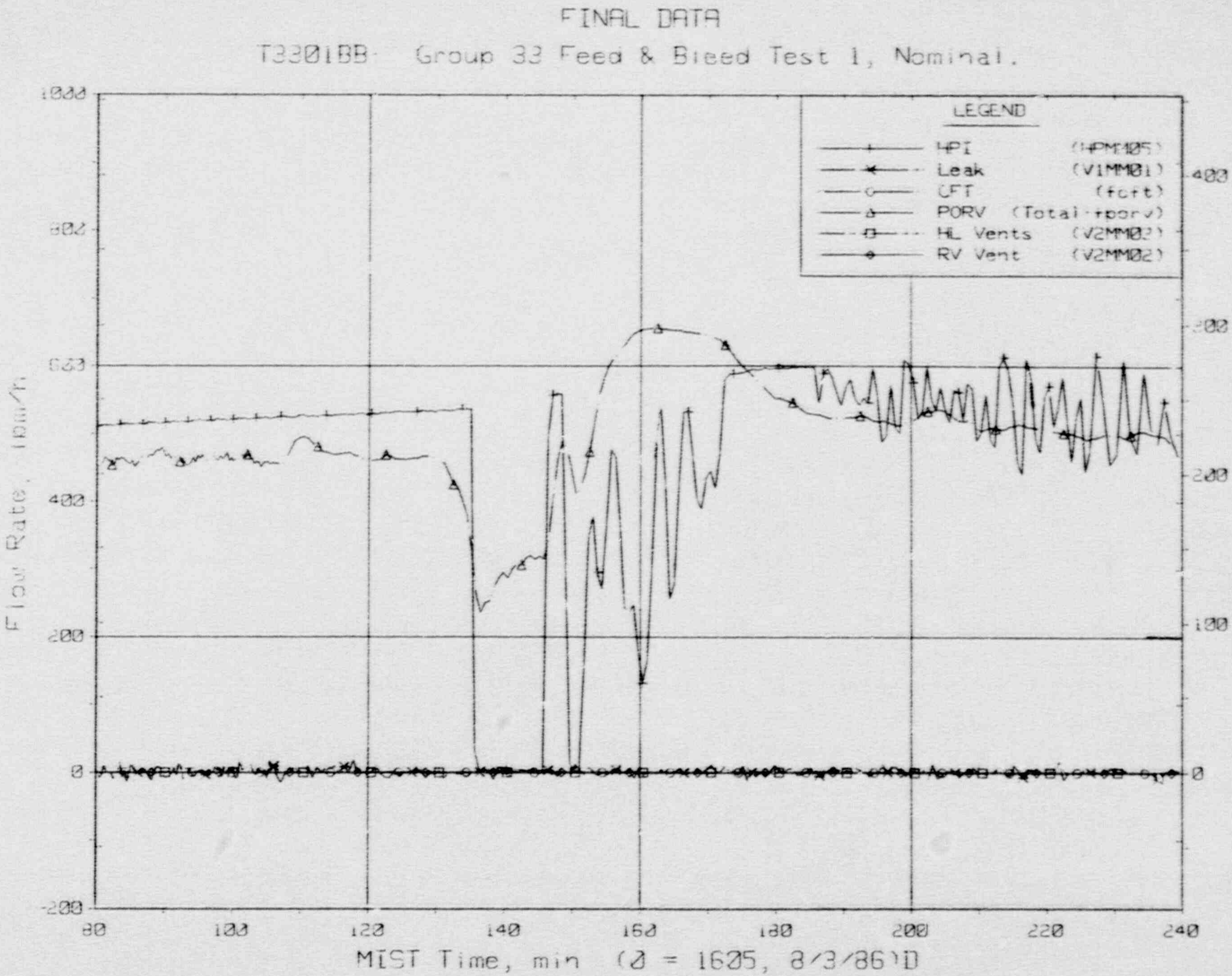


Figure 5.2.12. Primary System Boundary Flow Rates

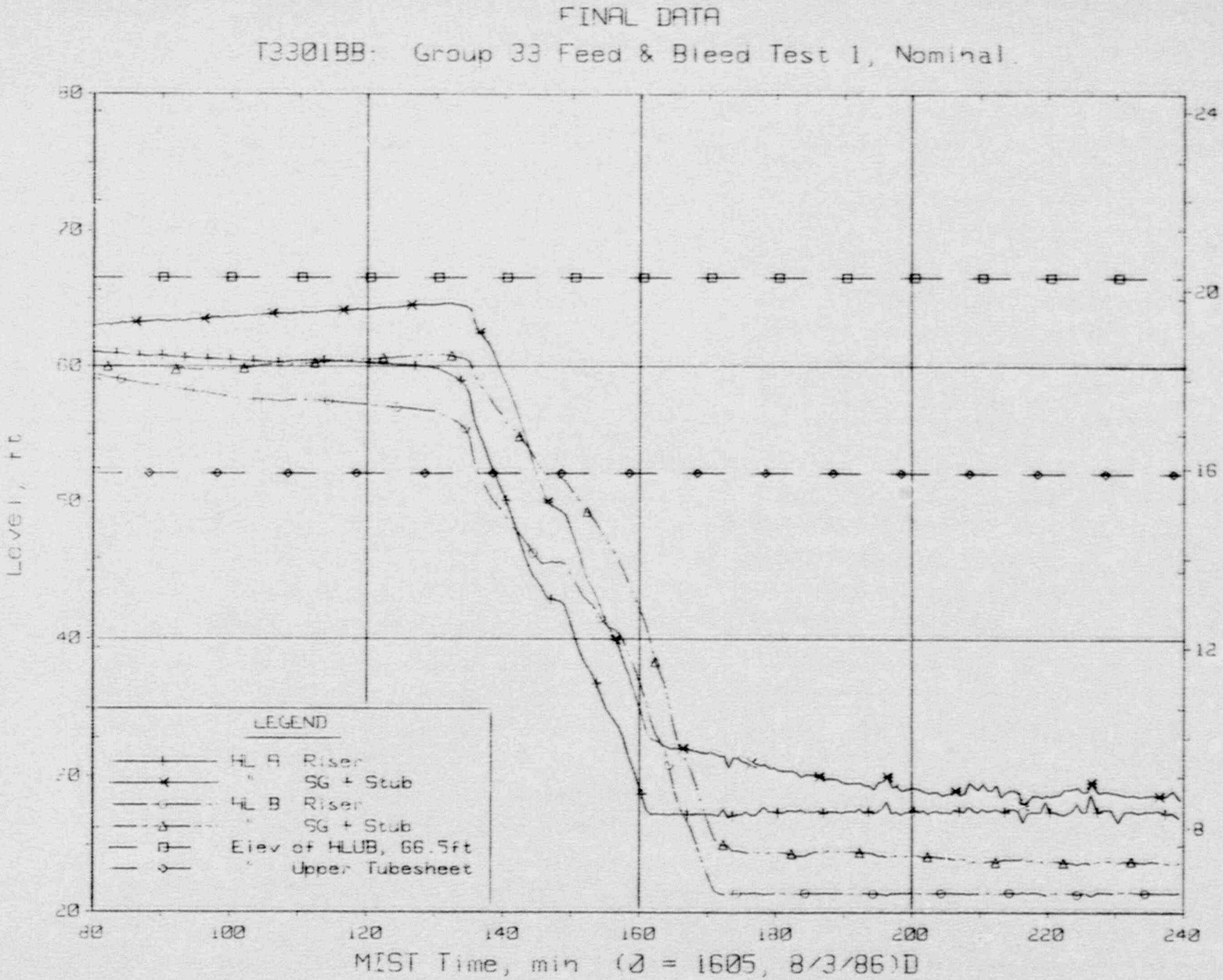


Figure 5.2.13. Hot Leg Riser and Stub Collapsed Liquid Levels

Thu Jul 21 11:56:40 1988

HLLV1

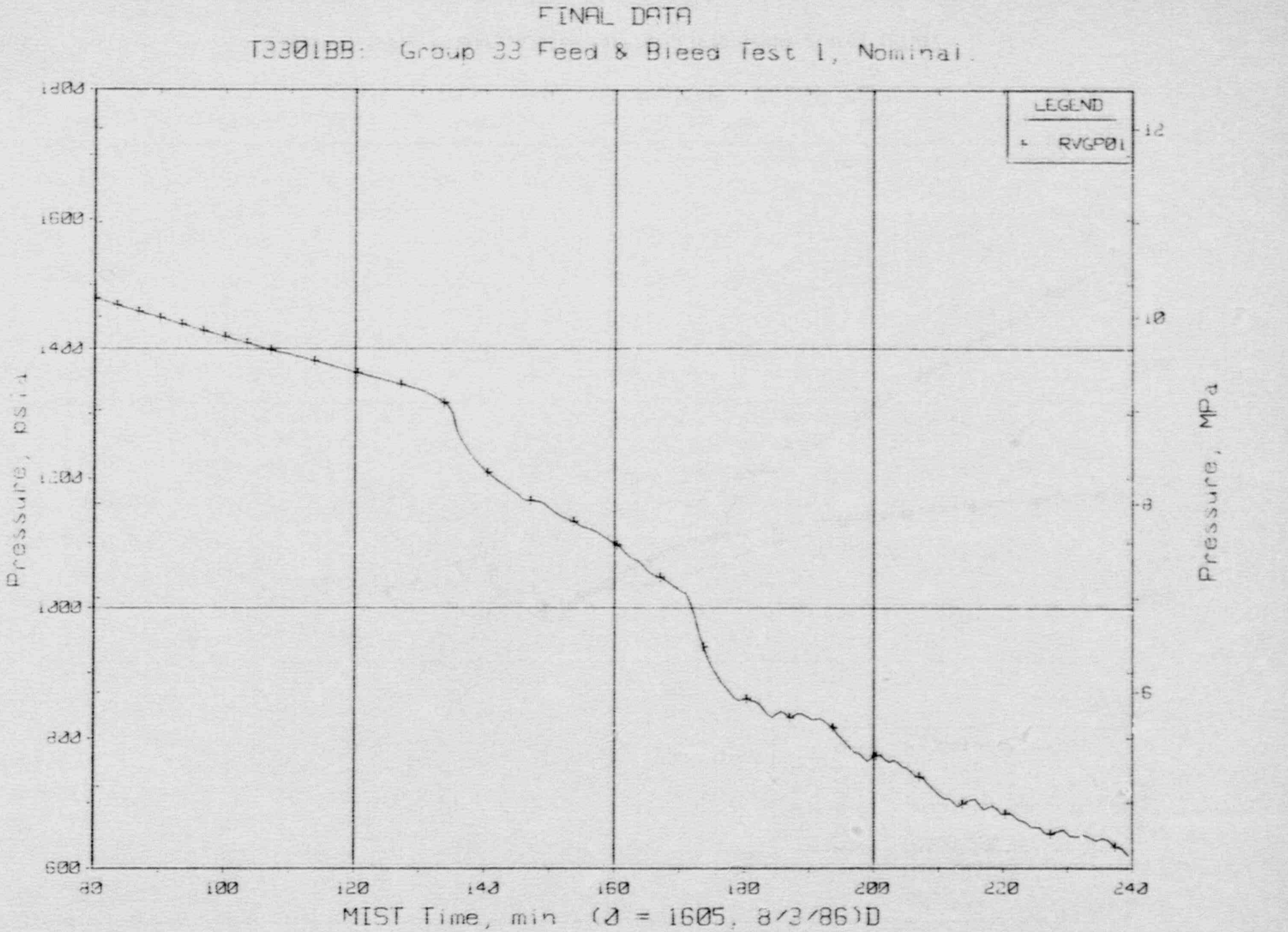


Figure 5.2.14. Reactor Vessel Pressure

RVGP1

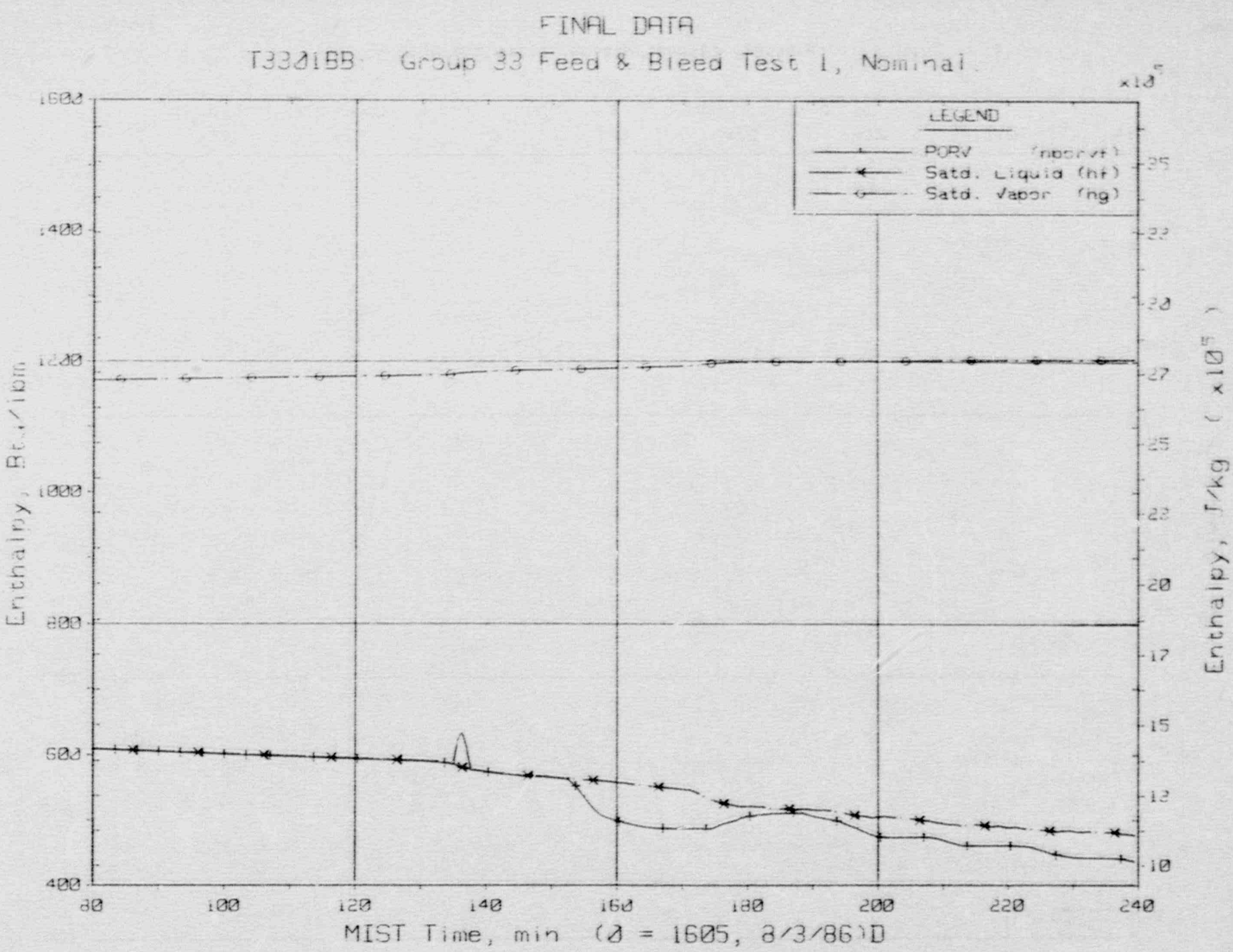


Figure 5.2.15. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 12:00:25 1988

PZEN1

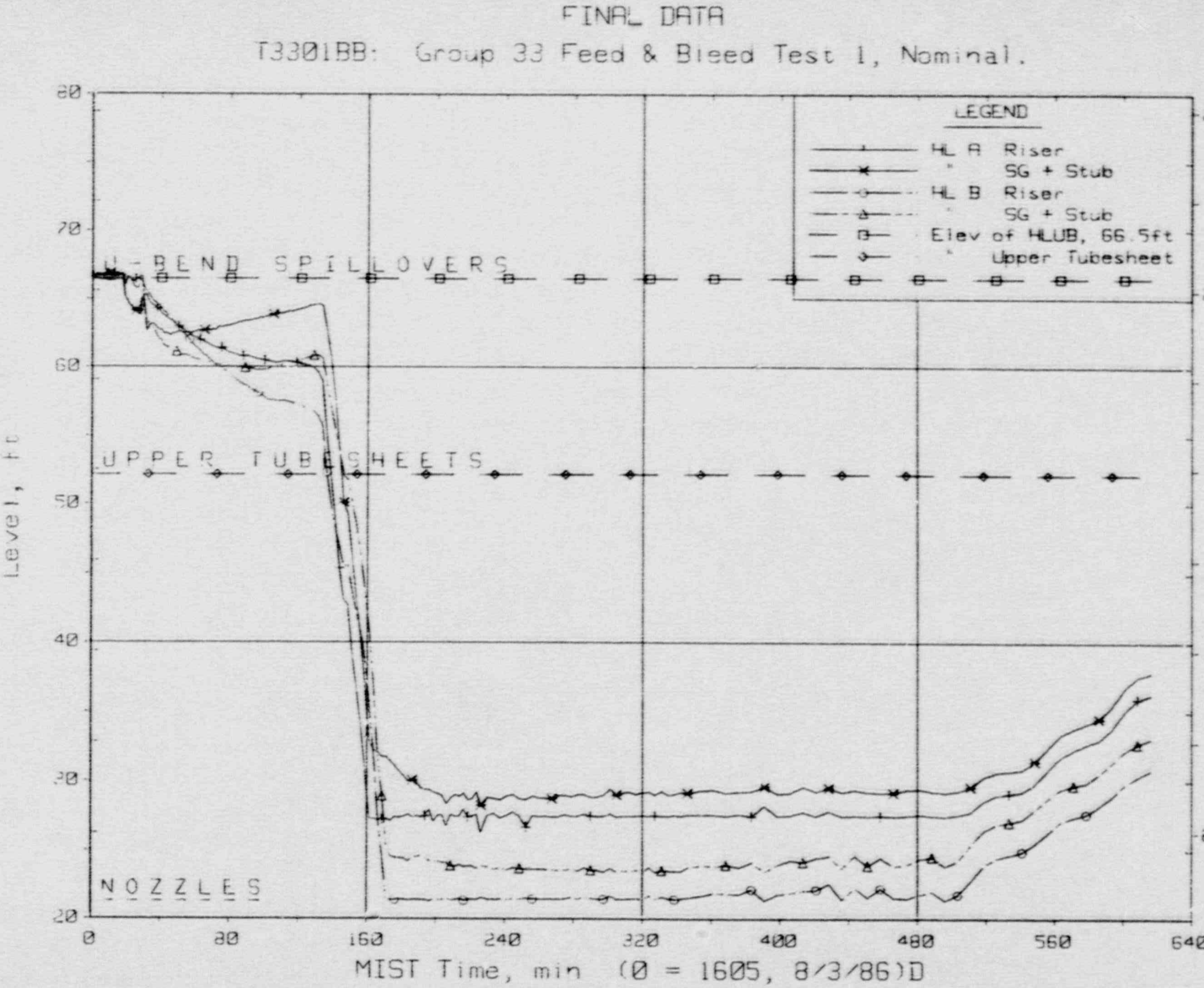


Figure 5.2.16. Hot Leg Riser and Stub Collapsed Liquid Levels

HLLV1

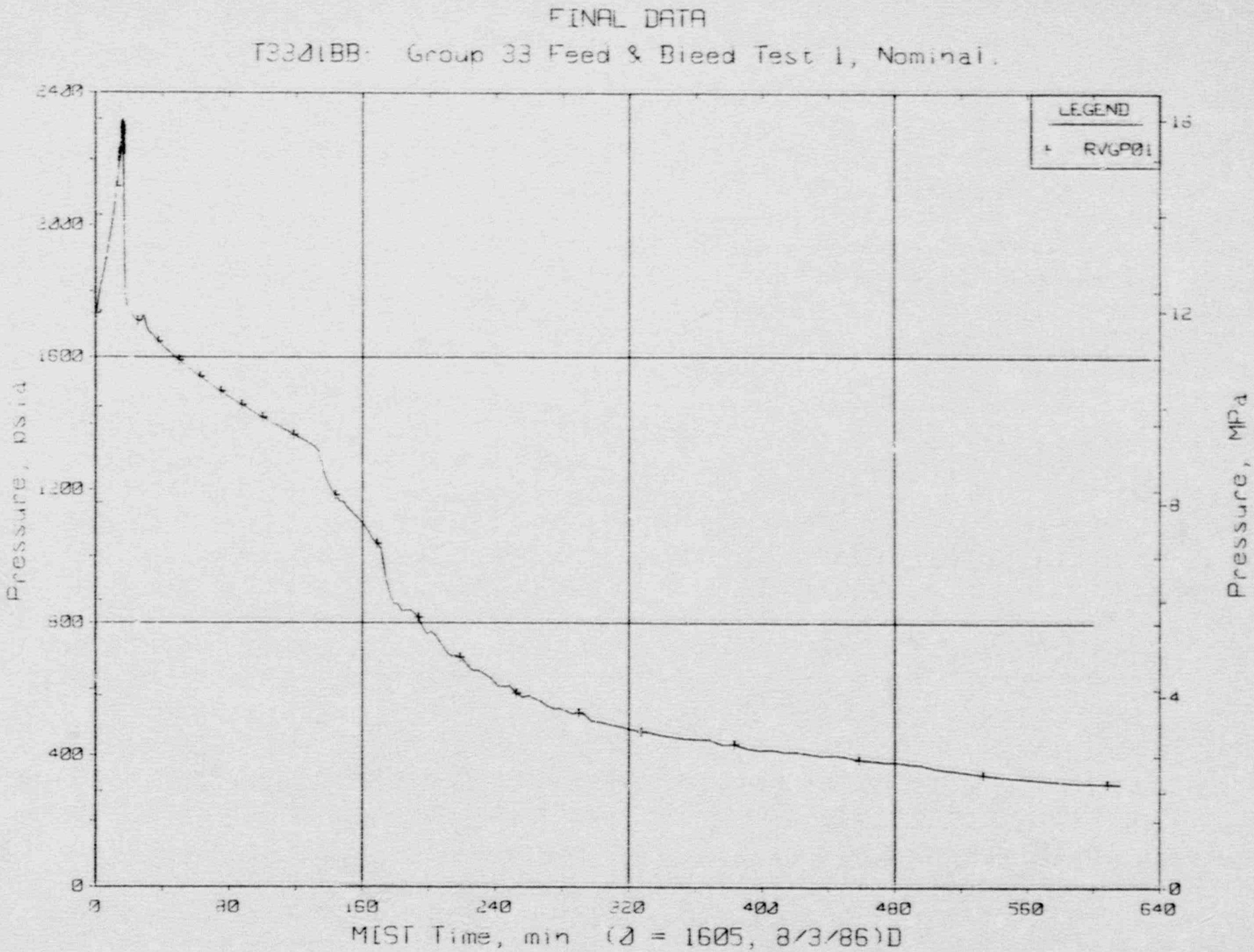


Figure 5.2.17. Reactor Vessel Pressure

Thu Jul 21 12:13:25 1988

RVGP1

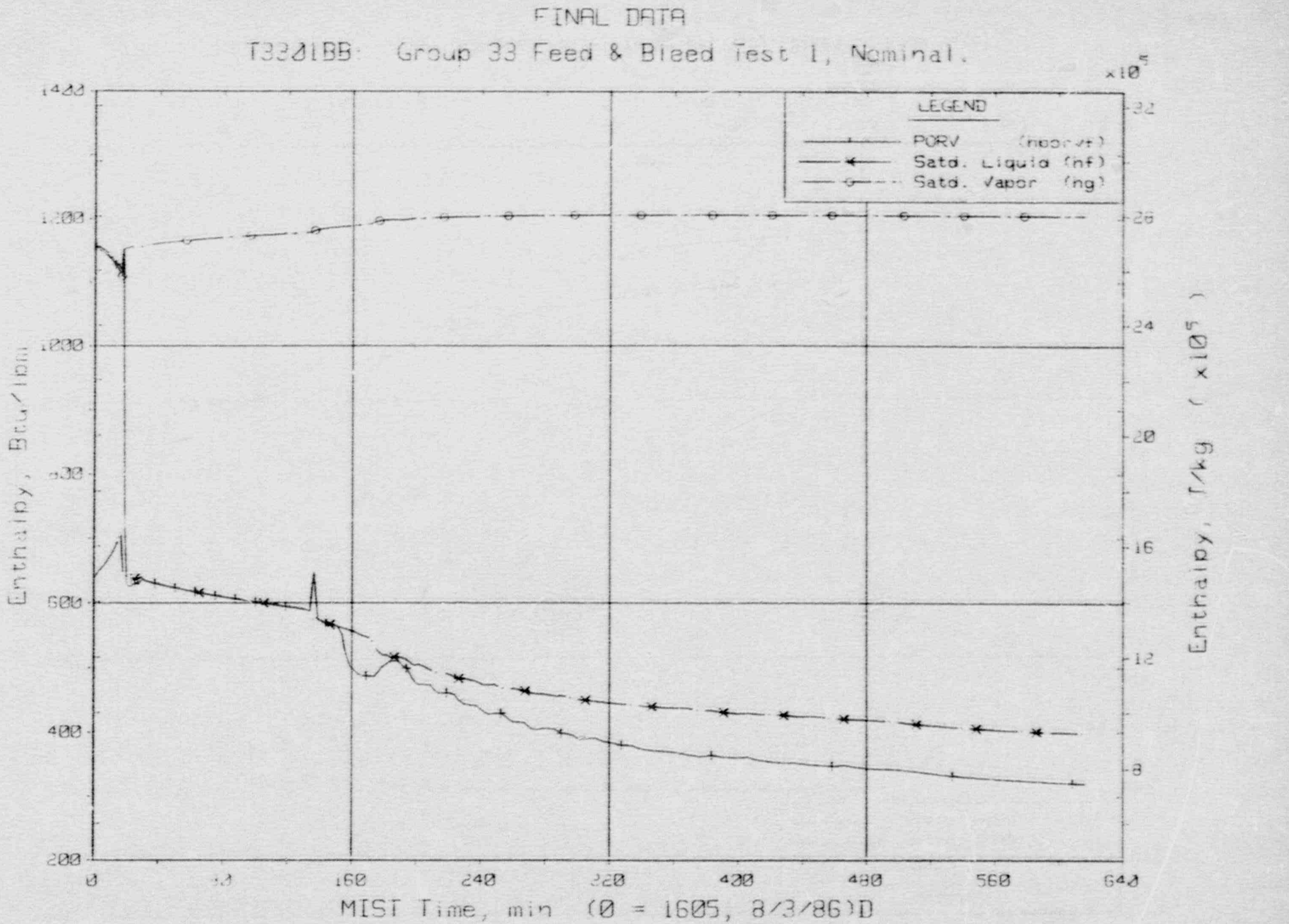


Figure 5.2.18. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

PZEN1

5.3. Reduced Capacity HPI, Test 2

Test 2 (330201) used Evaluation Model HPI characteristics that obtained approximately one-half the injection rate versus pressure compared with the full characteristics. The relatively large imbalance between the PORV discharge rate and the injection rate caused tne primary system to void extensively. The level of the loop A hot leg riser descended to the elevation of the surge line, the PORV discharge state reverted from liquid to two-phase, and the rate of the PORV discharge dropped toward the HPI flow rate, all at approximately 1 hour into the transient. The primary system depressurized continually as core-generated vapor was able to flow out hot leg A, through the surge line, and out the PORV. These conditions predominated during most of the transient.

At test initiation, feed was secured, the RVVV controls were transferred to automatic/independent, and the pressurizer fluid heaters were deenergized. The RVVVs opened immediately and remained open for most of the test. The steam generator steaming rates dropped from 2.2% to approximately 0.5% of the scaled full steam flow rate within the first minute, then lingered in this range until 19 minutes. The steam generators were apparently completely isolated and pressurized with nitrogen beyond approximately 30 minutes. The steam generators thus had little impact on the test transient, as intended.

The deletion of steam generator heat transfer caused a general primary system heatup and pressurization. The rate of primary system pressurization gradually increased from 26 psi/min at test initiation to 50 psi/min beyond 10 minutes (Figure 5.3.1). The general primary system fluid temperatures increased in parallel with the primary saturation temperature (Figure 5.3.2). During this period, the pressurizer level gradually rose from 20 ft at test initiation to 26 ft at PORV lift (Figure 5.3.3). The pressurizer rake fluid reflected the insurge of colder fluid, differing by almost 10F. The pressurizer vessel fluid thermocouples subcooled as the pressurizer filled (Figure 5.3.4); the temperature measurement at 21.3 ft subcooled at 3.7 minutes, while that at 24.5 ft subcooled at 13.3 minutes.

The primary system pressure attained 2325 psia at 16.5 minutes. The PORV lift was recorded at 16.5 minutes by limit switch indications, but the PORV discharge did not begin to register until slightly later due to the deadband of the two-phase metering system. The PORV lifted and was manually maintained open. Also, HPI was actuated (Figure 5.3.5) and the core power decay ramp was activated. The primary system depressurized at a rate of 600 psi/min, stabilizing at and below 1800 psia at 18 minutes (Figure 5.3.1). The upper-elevation primary system fluid as well as the core exit fluid saturated. The loop flow rates briefly increased, stagnated, and then sporadically circulated between adjacent cold legs. The hot leg U-bends and reactor vessel began to evidence voiding. The HPI flow rate varied widely ($\pm$50%) and continued to do so until 28 minutes (Figure 5.3.5), apparently due to the control system anomalies.

The PORV discharge rate had risen initially at 16.5 minutes and the pressurizer filled at approximately 19 minutes. As the PORV fluid approached saturation (Figure 5.3.6) the PORV rate of discharge stabilized at 500 lbm/h, 2-1/2 times the (average) HPI rate using the Evaluation Model HPI characteristics (Figure 5.3.5). The excess of the PORV discharge rate versus the HPI rate caused extensive primary system voiding. The core region level descended from 30 ft at 19 minutes to 24 ft, the elevation of the RVVVs, at 22 minutes (Figure 5.3.7). The core region and downcomer levels then descended to the nozzle elevation, 21 ft, at 25 minutes. The hot leg levels descended several feet (Figure 5.3.8), then the cold legs began to void (Figure 5.3.9). The cold leg discharge piping was completely voided by 38 minutes, and the cold leg A1 and A2 suction piping voided several feet at the same time. Cold leg flow activity ceased. Beyond 38 minutes, the core region and downcomer levels resumed their descent, stabilizing 2 ft above the core at 43 minutes (Figure 5.3.7). As the core region and downcomer levels stabilized, the hot leg levels began to decrease from 63 ft (Figure 5.3.8). The hot leg A riser level dropped to the elevation of the surge line connection at 69.5 minutes and remained there. The loop B hot leg levels descended more slowly than the loop A; they lagged by some 20 ft as the loop A level reached the surge line.

The pressurizer surge line uncovery reversed the mass-depletion trend. The pressurizer began to void at approximately 70 minutes (Figure 5.3.3), the PORV began to discharge two-phase flow (Figure 5.3.6), and the rate of PORV discharge dropped from 500 to about 250 lbm/h (Figure 5.3.5), some 50 lbm/h greater than the rate of HPI flow. The primary system pressure, which had remained near 1650 psia, began to decrease at 8 psi/min (Figure 5.3.1). As the primary system gradually depressurized, the leak and HPI flow rates came into closer balance (Figure 5.3.10). The loop B hot leg drained completely at 160 minutes, at which time the HPI flow rate had begun to exceed the PORV discharge rate. Beyond 240 minutes, the core region and downcomer levels began a gradual ascent towards the nozzle elevation whereas the steam generator primary levels descended. The hot leg and cold leg nozzles were recovered at 310 minutes. The reactor vessel outlet plenum void fraction (between the hot leg nozzles and the RVVVs) had diminished to zero, but the upper 2 feet of the core still indicated a 20% void fraction. The steam generator primary levels abruptly decreased, whereas the cold leg discharge legs refilled. The lower downcomer and reactor vessel inlet fluid began to subcool (Figure 5.3.11). Also, inter-cold leg flow became active beyond 320 minutes.

The hot leg high-point vents were opened at 420 minutes as specified. The rate of primary system depressurization, which had dwindled to 1 psi/min, increased to nearly twice that value (Figure 5.3.12). Shortly after high-point vent actuation, the primary system depressurization progressed sufficiently to activate the CFT. The test was terminated at 480 minutes, based on maximum test duration. At termination, the loop A hot leg riser collapsed liquid level remained at the surge line elevation (Figure 5.3.8), whereas the loop B riser was slowly refilling. The core region and downcomer levels remained at the nozzle elevation (Figure 5.3.7). The primary system pressure was 510 psia and decreasing (Figure 5.3.12). The core exit fluid remained saturated, as did the PORV discharge fluid (Figure 5.3.13).

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.

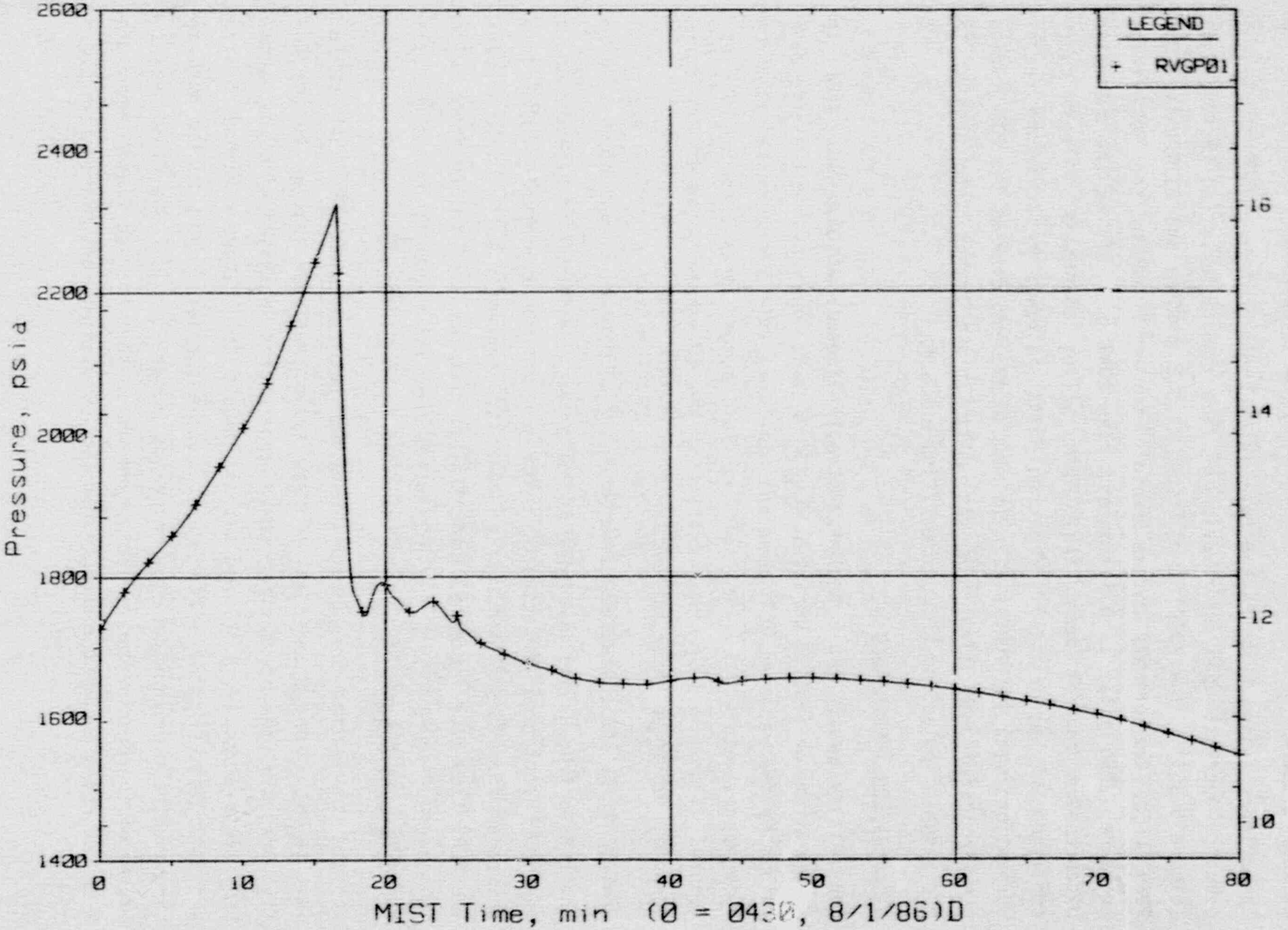


Figure 5.3.1. Reactor Vessel Pressure

Thu Jul 21 12:47:31 1988

RVGP1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.

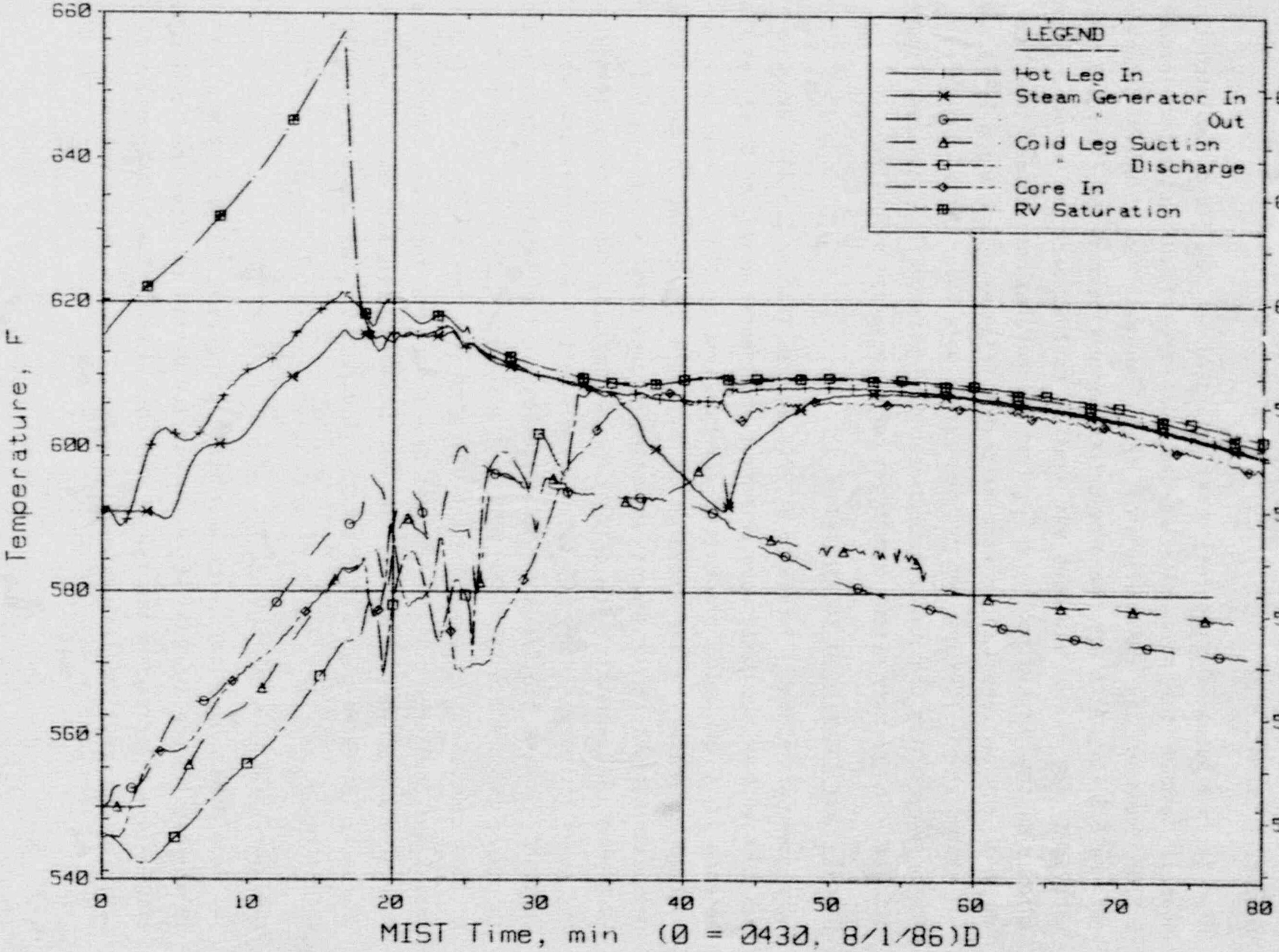
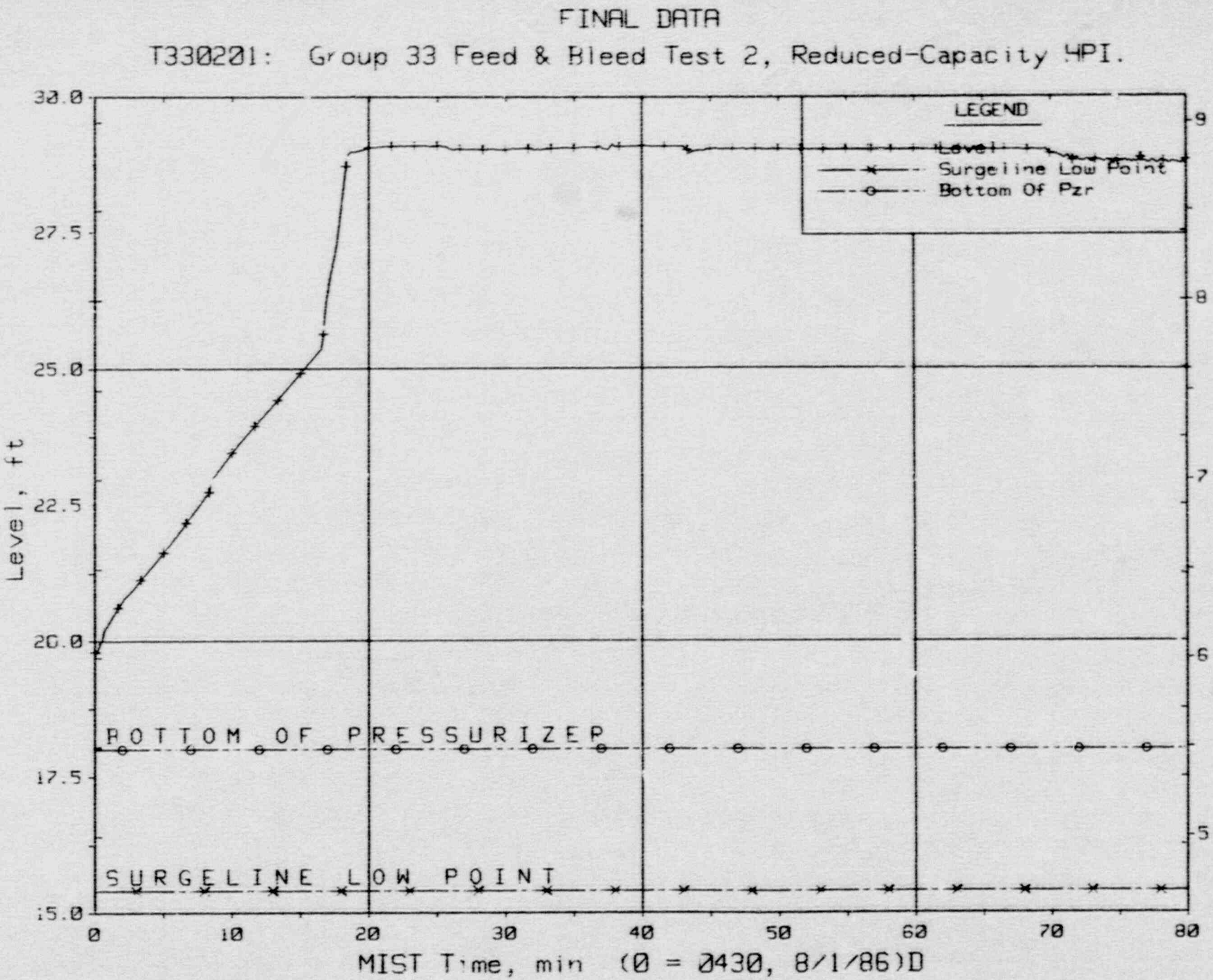


Figure 5.3.2. Primary System Average Fluid Temperatures (RTDs)

Thu Jul 21 12:51:00 1998

PRNT0



5-30

Figure 5.3.3. Pressurizer Collapsed Liquid Level (PZLV20)

Thu Jul 21 12:53:56 1988

PZLV1

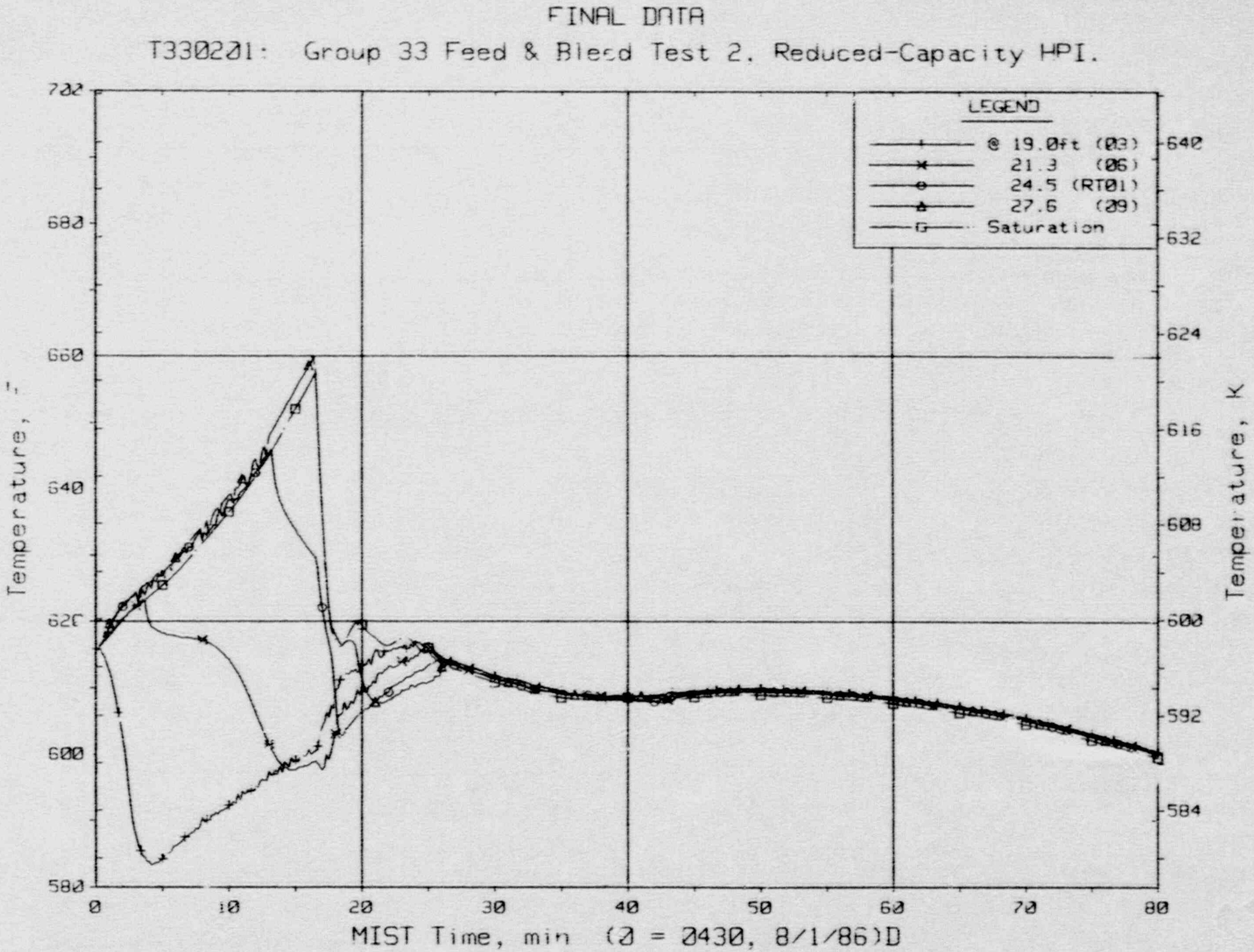


Figure 5.3.4. Pressurizer Vessel Fluid Temperatures (PZTCs)

Thu Jul 21 12:56:53 1988

PZTC2

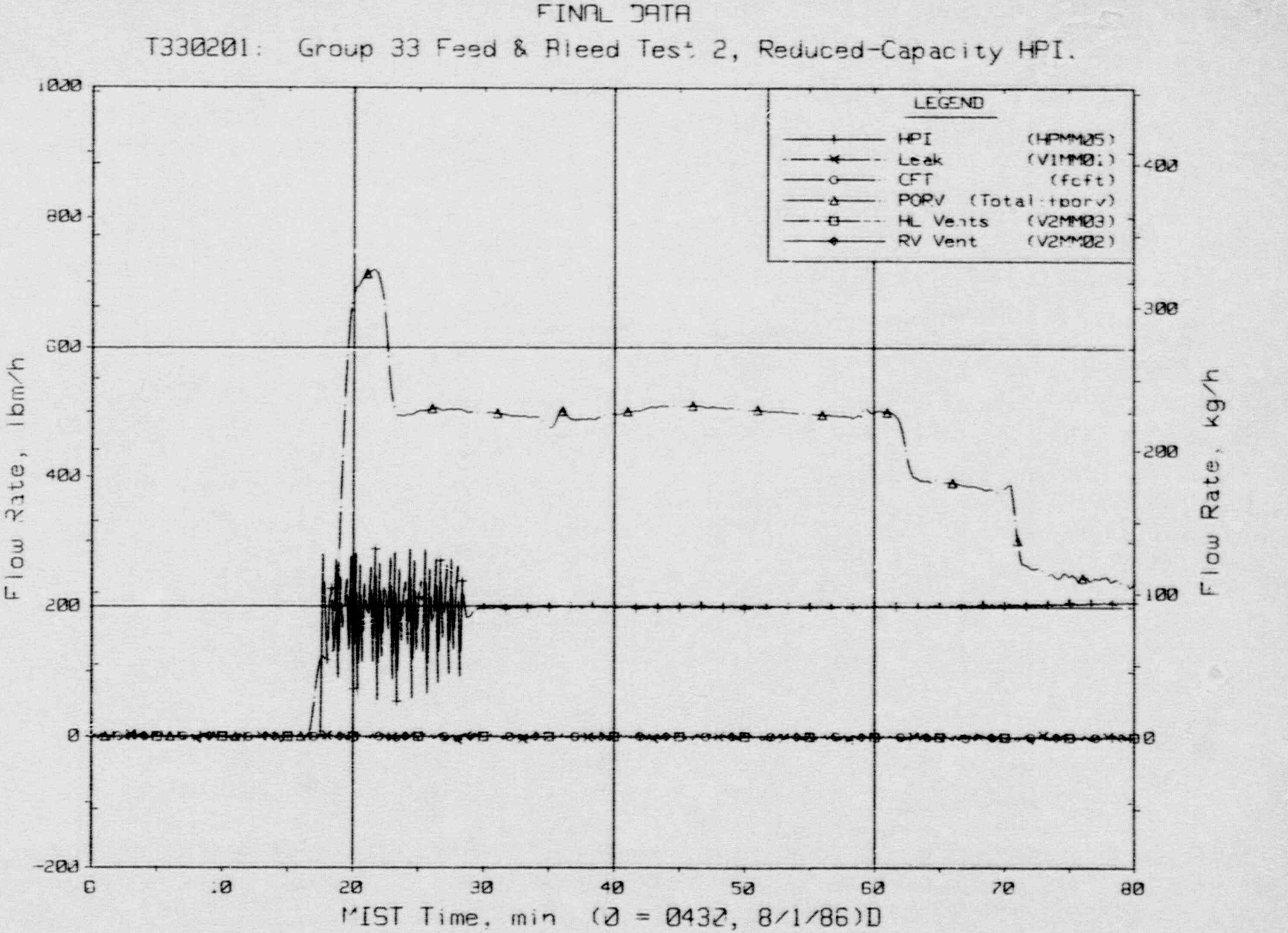


Figure 5.3.5. Primary System Boundary Flow Rates

Thu Jul 21 13:00:24 1988

PRFL3p

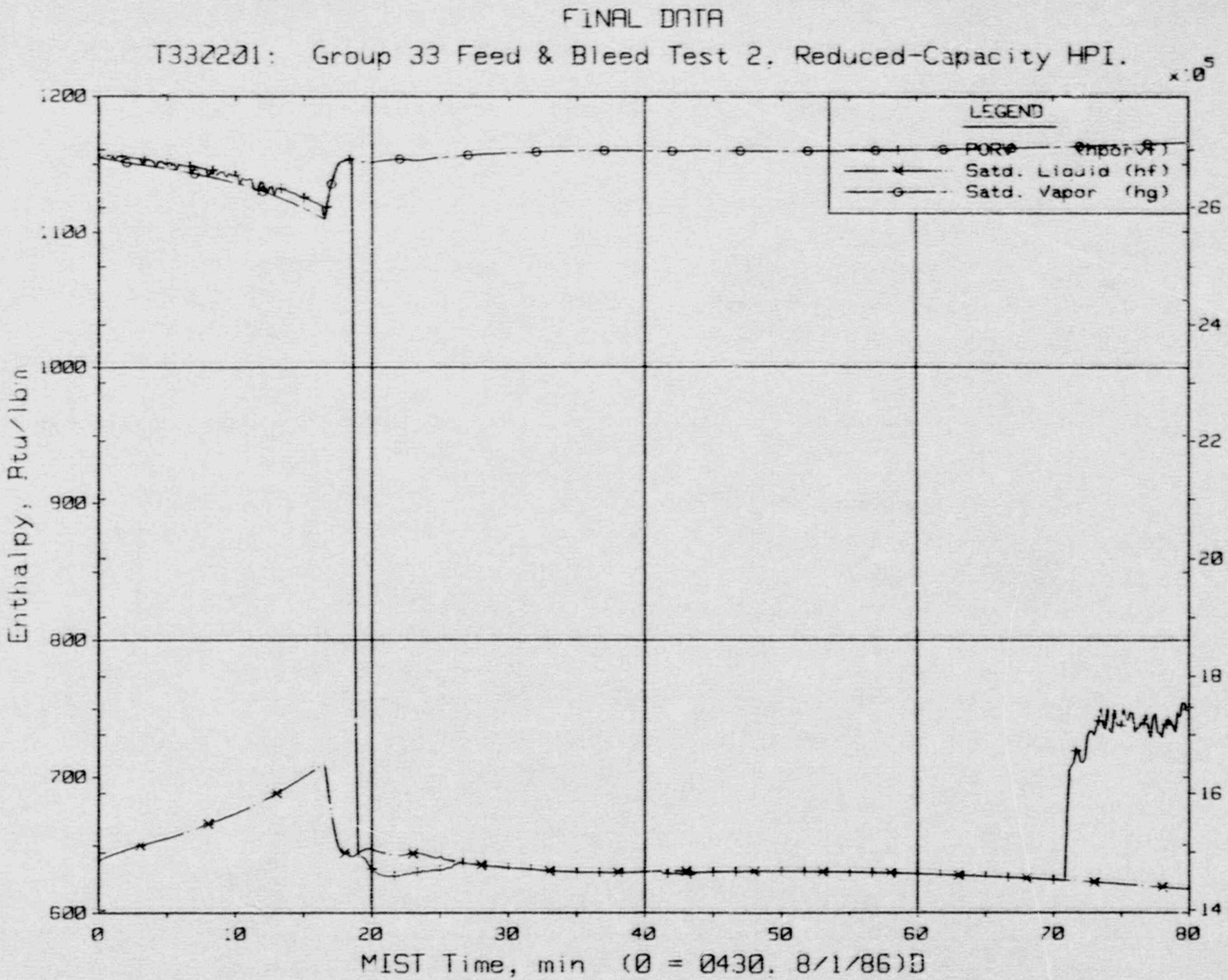


Figure 5.3.6. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 13:03:02 1988

PZEN1

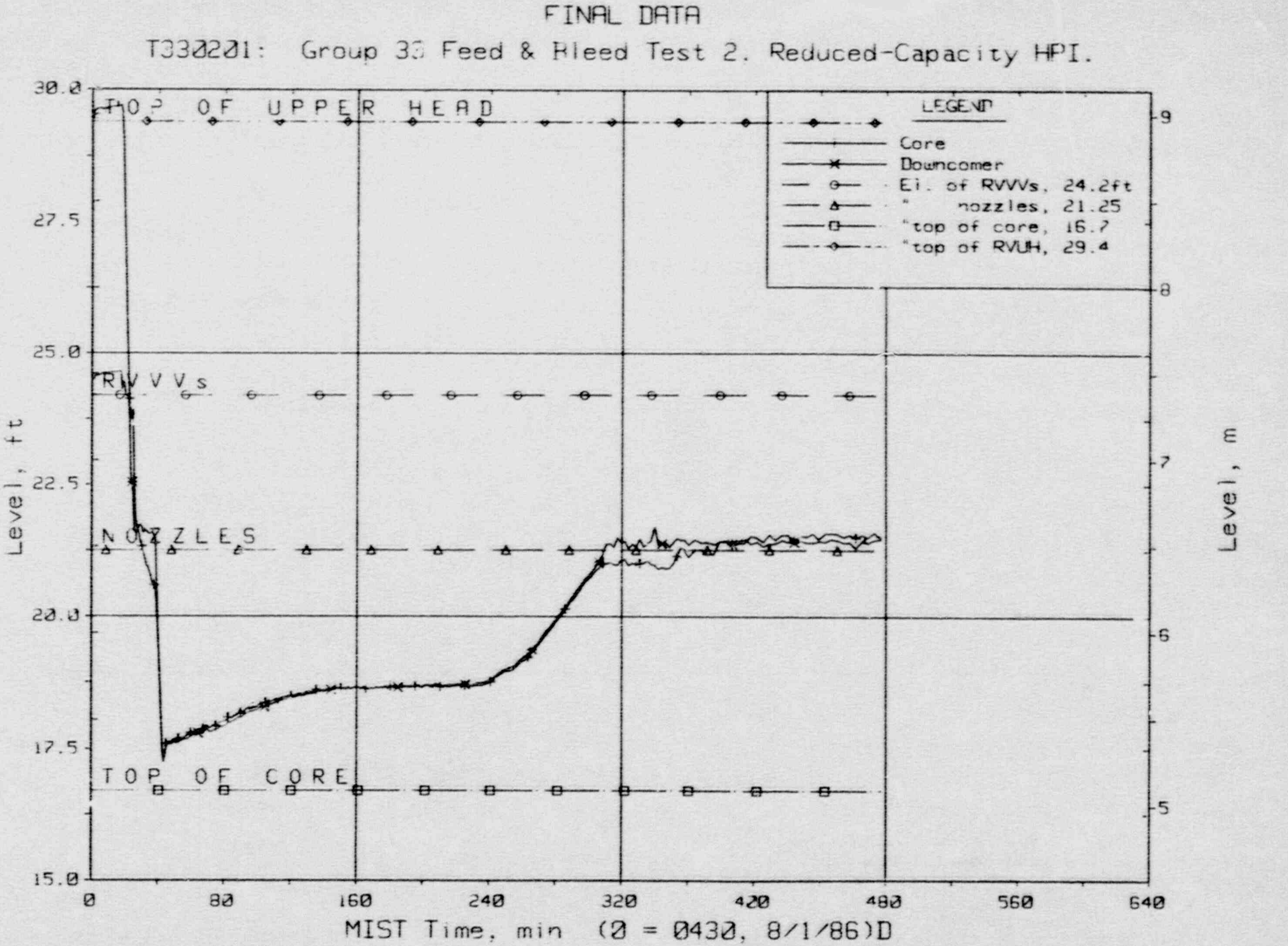


Figure 5.3.7. Core Region Collapsed Liquid Levels

Thu Jul 21 13:09:07 1988

COLV1

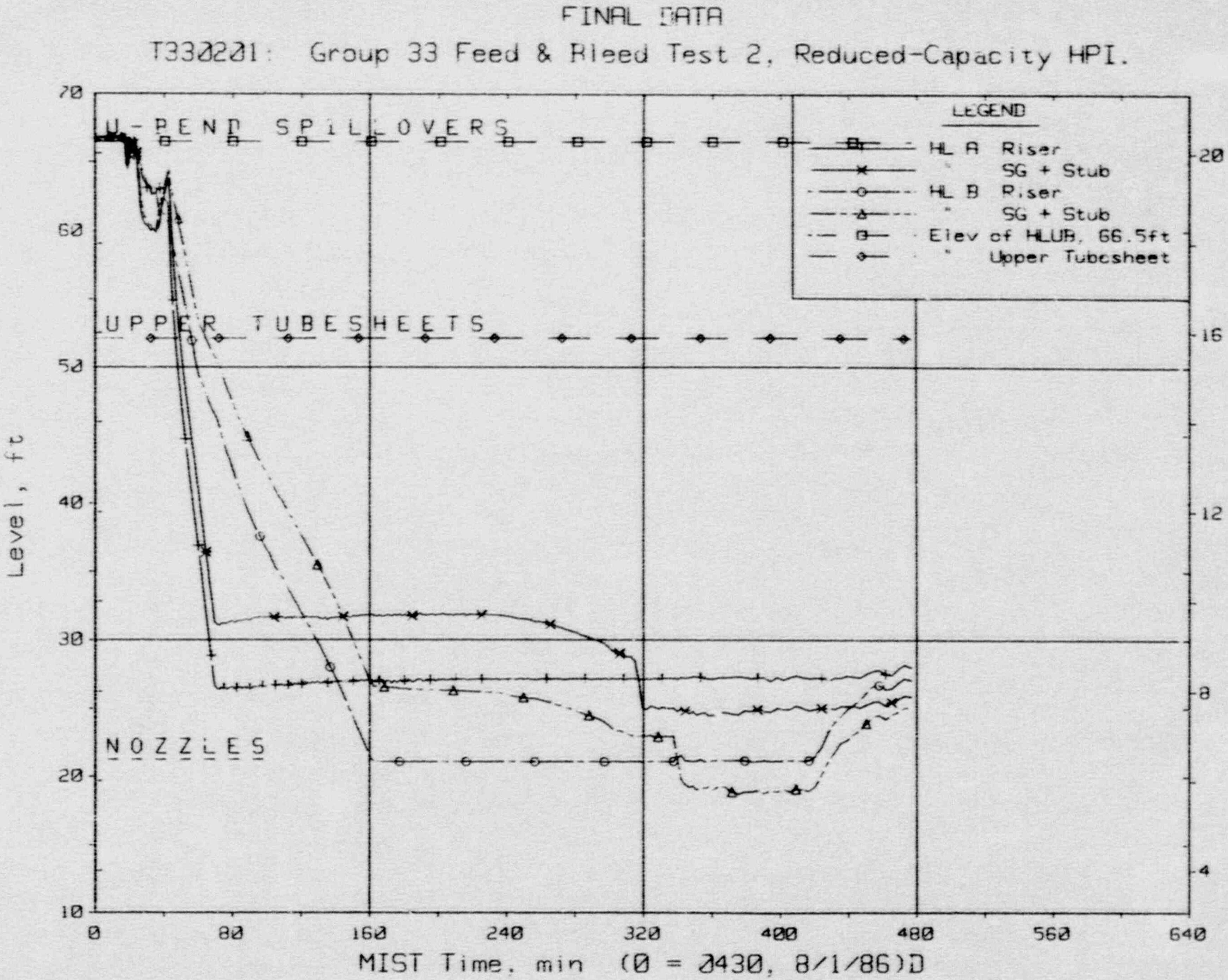


Figure 5.3.8. Hot Leg Riser and Stub Collapsed Liquid Levels

Thu Jul 21 13:12:17 1988

HLLV1

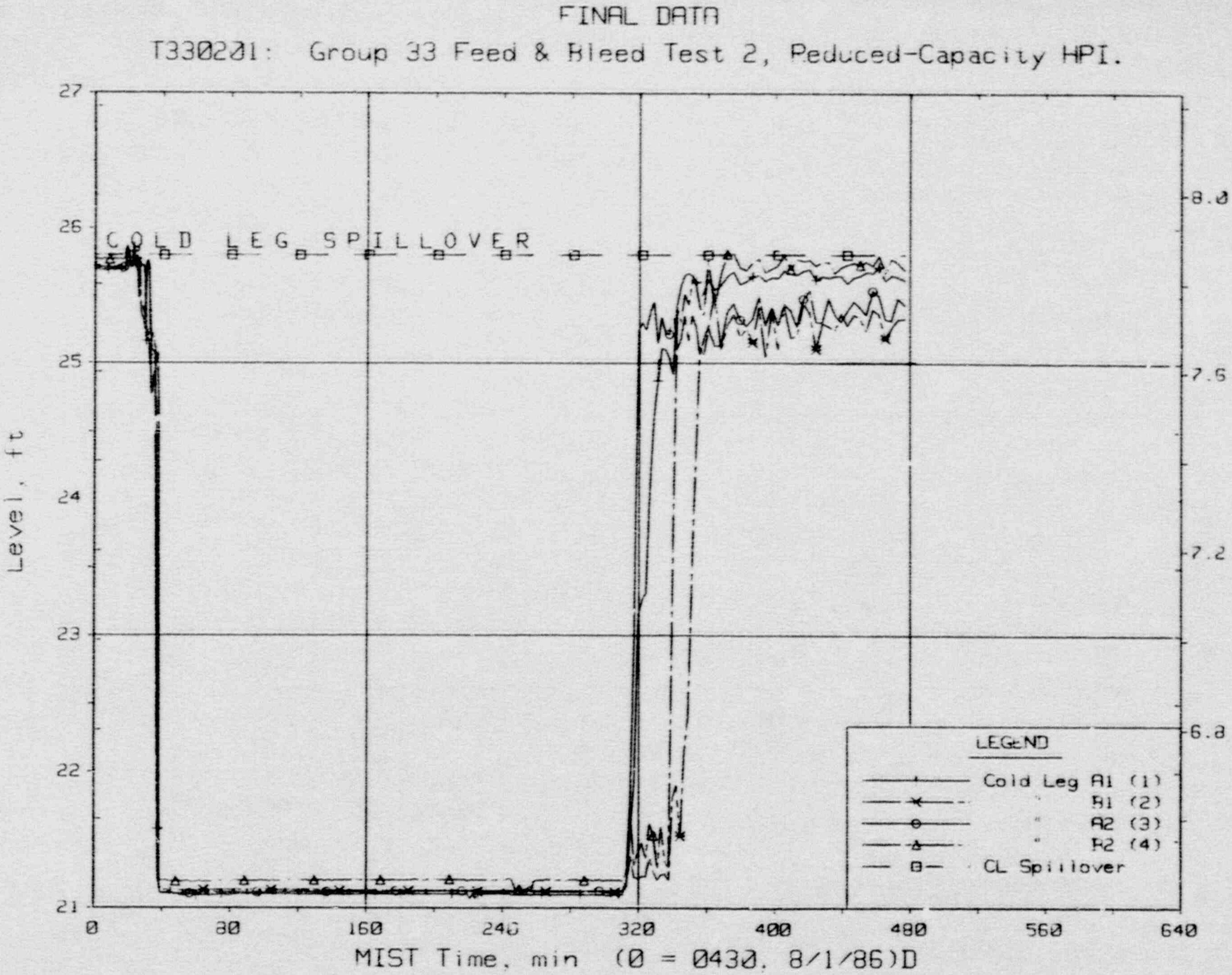


Figure 5.3.9. Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Thu Jul 21 12:15:23 1988

CLLV5

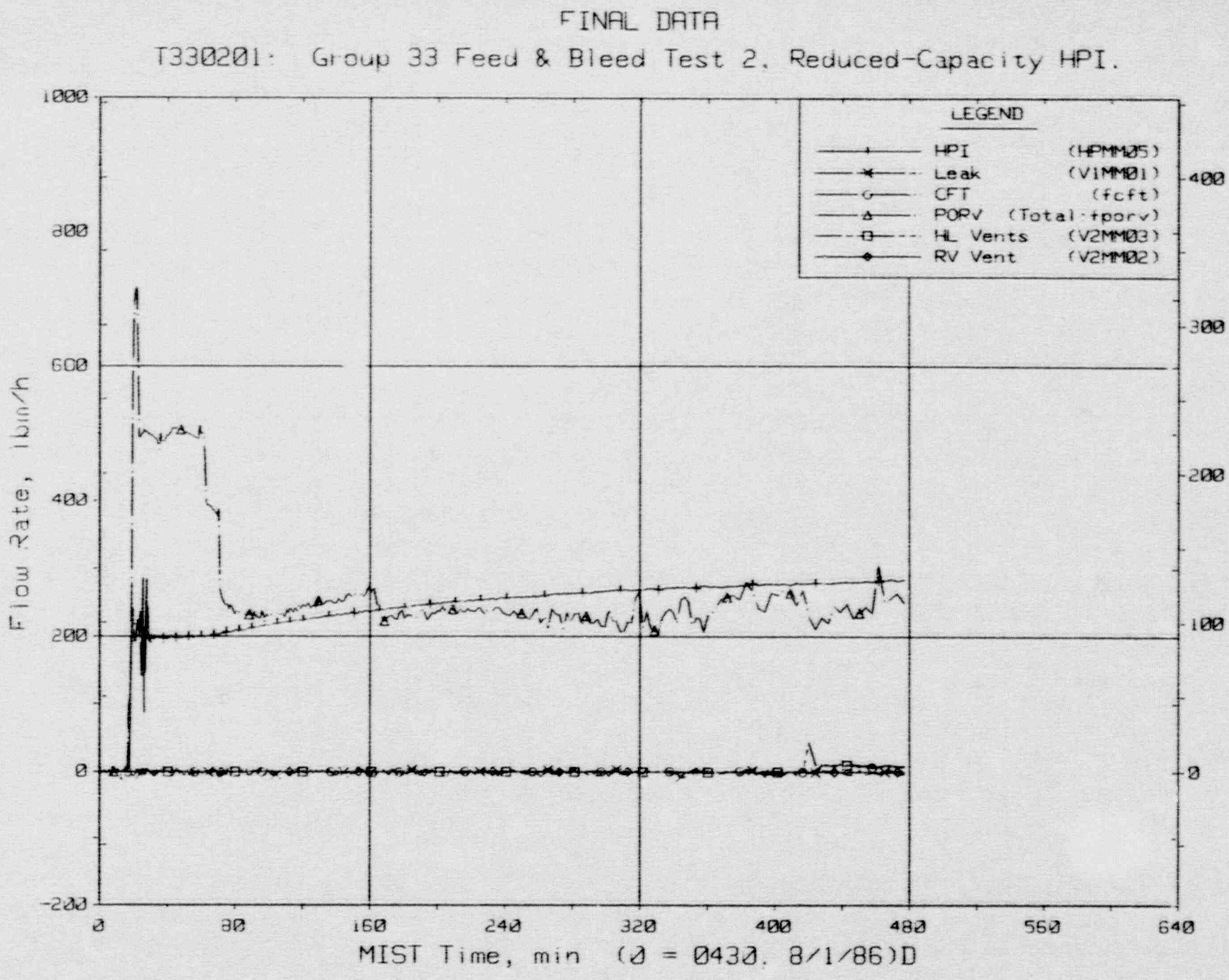


Figure 5.3.10. Primary System Boundary Flow Rates

Thu Jul 21 13:18:25 1988

PPFL3p

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.

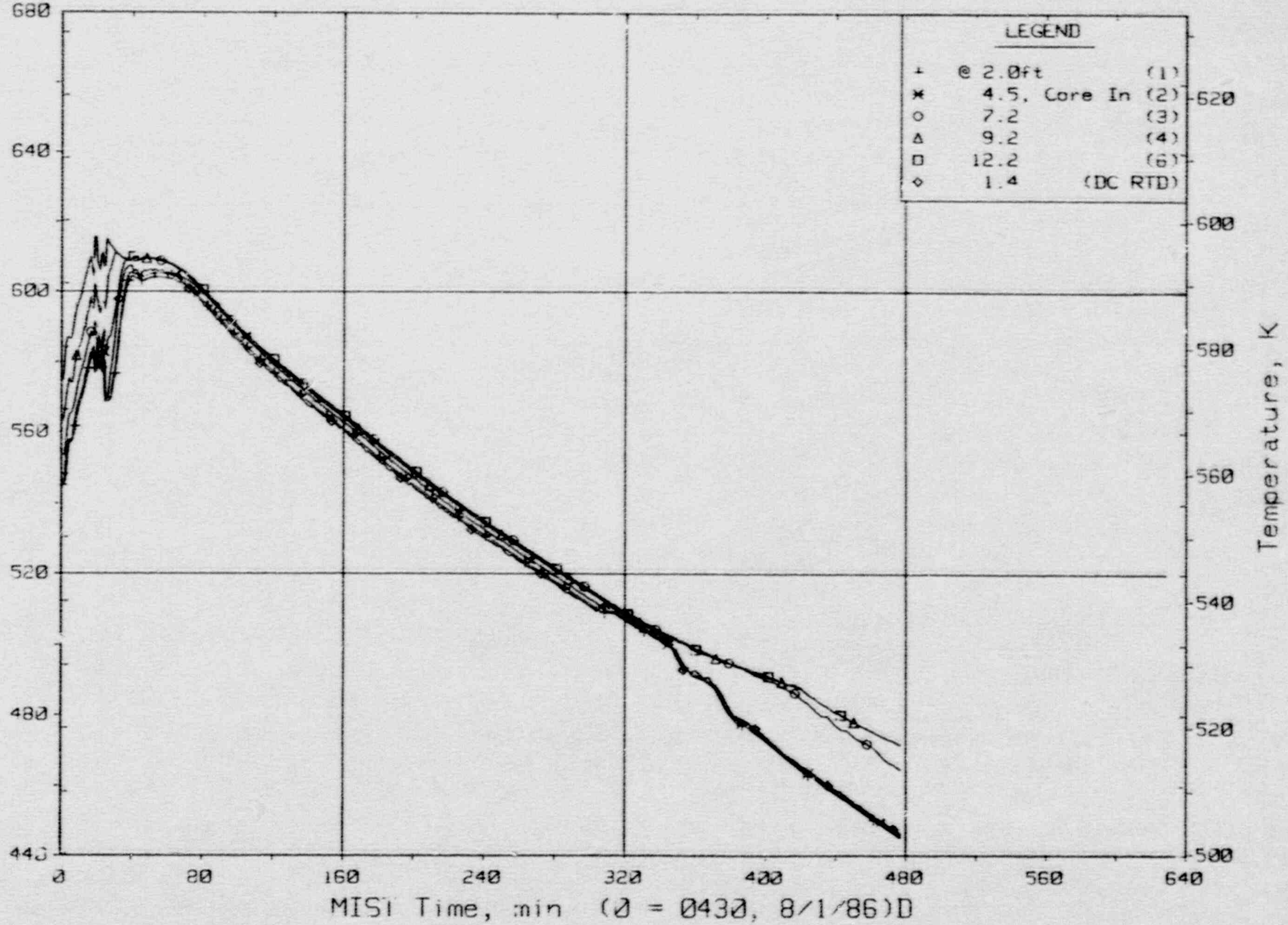


Figure 5.3.11. Reactor Vessel Lower-Elevation Fluid Temperatures (RVTCs)

Thu Jul 21 13:21:13 1988

RVTC1

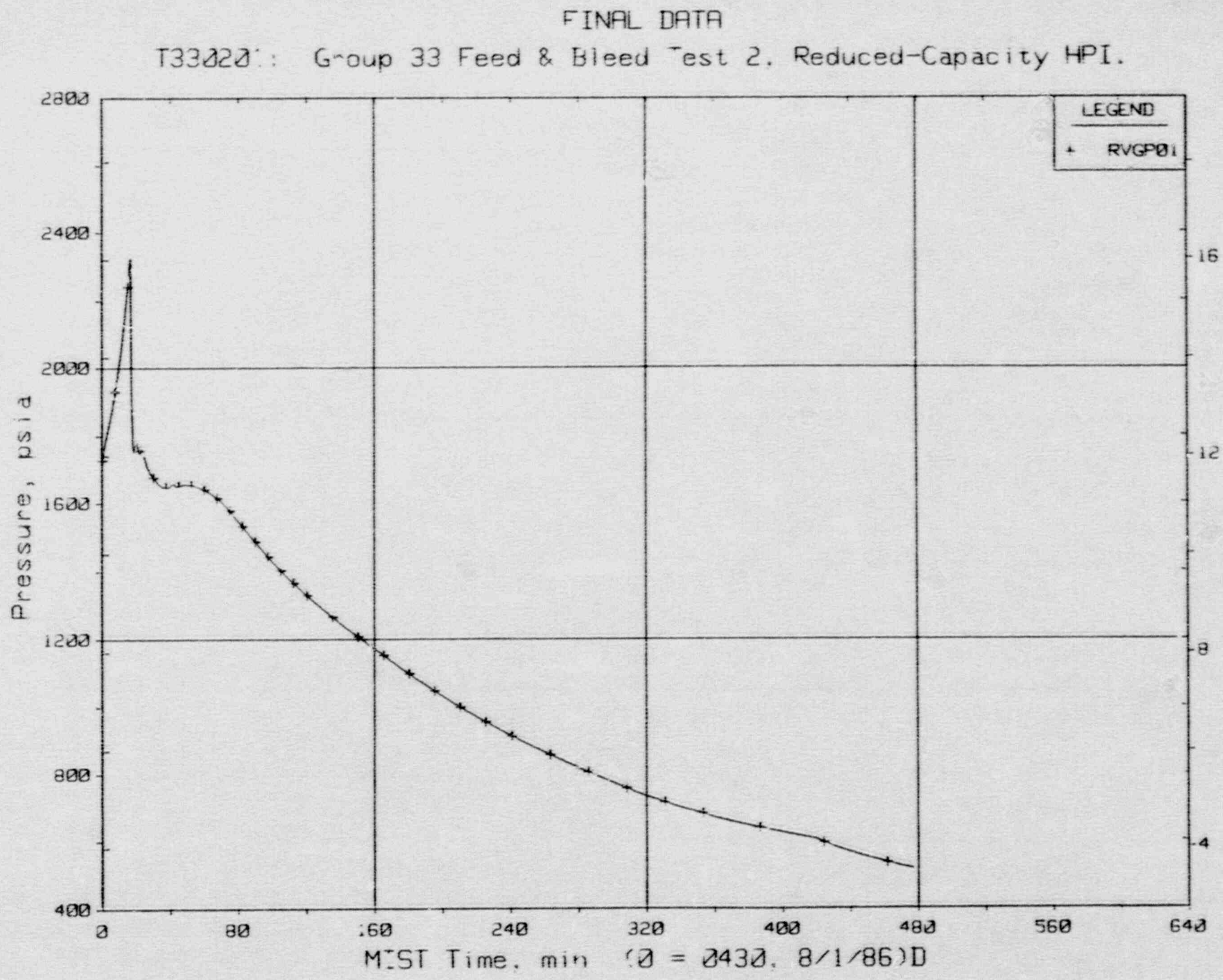


Figure 5.3.12. Reactor Vessel Pressure

Thu Jul 21 13:23:08 1988

RVGP1

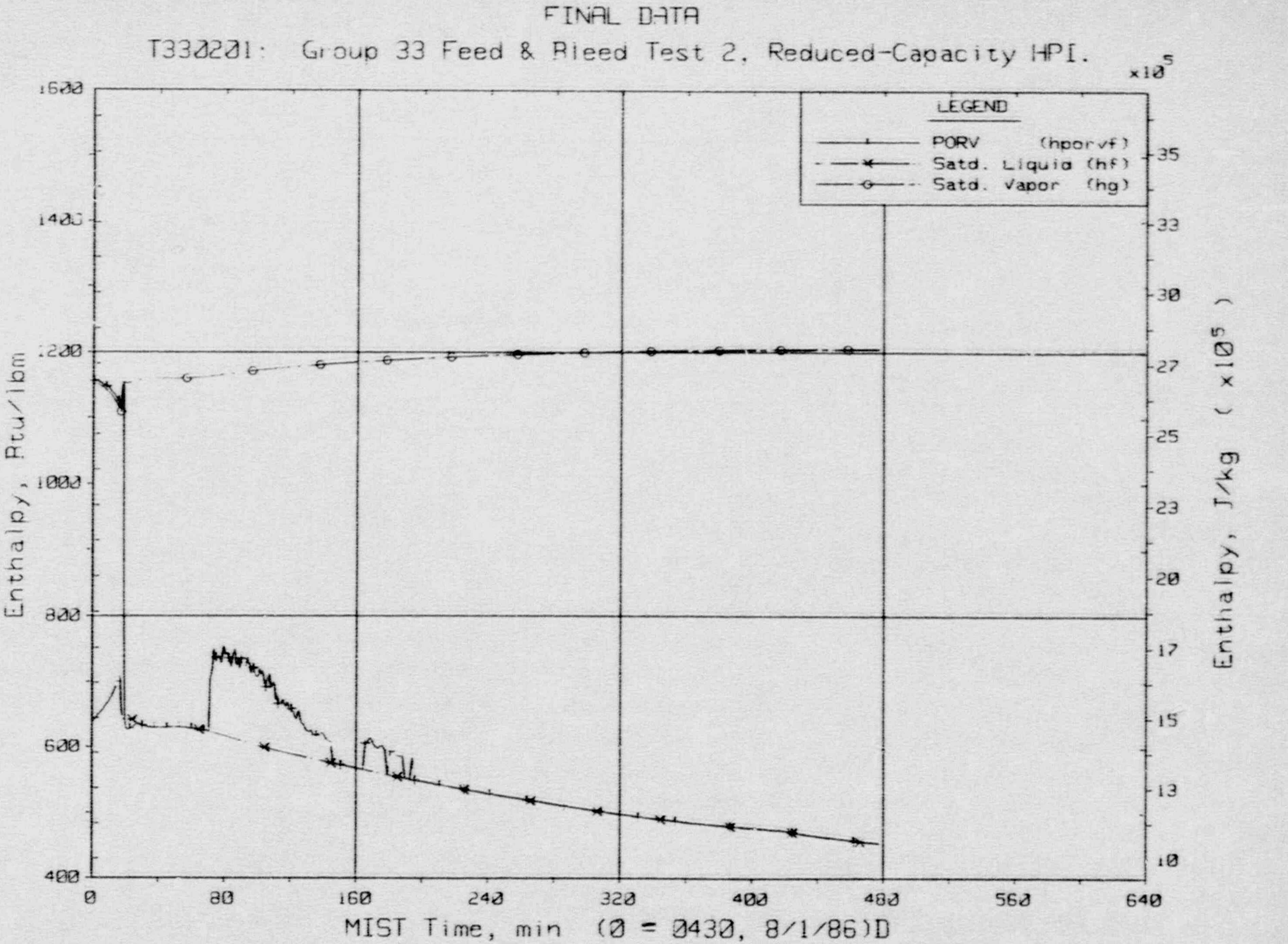


Figure 5.3.13. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 13:25:09 1988

PZEN1

5.4. Delayed HPI, Test 3

Test 3 (330302) invoked delayed HPI. HPI was withheld until 20 minutes after PORV actuation. During the interval between PORV actuation and the introduction of HPI, the entire primary system fluid inventory was approaching saturation. The core region level approached the top of the core and the downcomer level briefly descended a few feet below the top of the core. However, the primary system pressure remained in the range of 1750 to 1900 psia until HPI was activated. Thus, the system conditions were not as challenging as had been expected. The loops intermittently reactivated, which offset core void production by transporting subcooled liquid to the reactor vessel.

The test was initiated by stopping feed to both steam generators, deenergizing the pressurizer heaters, and transferring the RVVV controls to automatic/independent (the RVVVs opened). The indicated feed flow rate immediately dropped to zero, but the steam generator steaming rate, which had been 2.3% (of the scaled full steam flow rate), lingered at 0.5% until 18 minutes and then at 0.2% until 28 minutes. The steam generators were completely isolated (and pressurized with nitrogen) beyond 28 minutes and thus were no longer of significance to the primary system interactions.

The primary system pressure gradually rose from 1740 psia at time 0 to 2350 psia at 15.7 minutes (Figure 5.4.1). The PORV then lifted and was maintained open for the duration of the test. Although the PORV lift was recorded at 15.7 minutes by limit switch indications, the PORV discharge rate did not begin to register until slightly later, reflecting the deadband of the two-phase metering system. Coinciding with the PORV lift, the core power decay ramp was activated. The pressurizer level had been slowly increasing with the attenuation of secondary heat transfer, from approximately 20 ft at test initiation to 25 ft at PORV lift. The level then increased more rapidly and indicated that it was full at 18 minutes (Figure 5.4.2). During this 2-minute period, the loop flow rate abruptly stagnated, the primary system depressurized to 1800 psia at 500 psi/min, the core exit SCM dropped from 30 to 0F, and the hot leg levels began to indicate voiding (Figure 5.4.3). The PORV discharge rate hovered near 250 lbm/h from 16 to 17.5 minutes (Figure

5.4.4), reflecting two-phase flow (Figure 5.4.5), then quickly rose to approximately 700 lbm/h.

The cold leg discharge piping voided completely after 22.8 minutes (Figure 5.4.6) and, except for the spillover event near 31 minutes, remained voided until 41.3 minutes. Also, the RVVVs closed intermittently during this period of PORV discharge without HPI. Each of the RVVVs behaved similarly, except that valve A2 closed less frequently and for shorter periods, apparently reflecting differences among the valve actuation setpoints. The hot leg riser levels again achieved the spillover elevation near 20 minutes and also at 30 minutes (Figure 5.4.3). Both occurrences were preceded by relatively rapid voiding in the core and downcomer regions (Figure 5.4.7). Prior to the first spillover, the core region level decreased to the elevation of the RVVVs; prior to the second spillover, the core region and downcomer levels descended toward the top of the core. (The downcomer level briefly descended to 13 ft, nearly 4 ft below the top of the core.) The cold leg flow rates reactivated during both spillover events.

HPI was activated at 35.7 minutes, 20 minutes after PORV lift, as specified (Figure 5.4.4). The primary system pressure, which had varied between 1750 and 1900 psia with the PORV open, began to decrease gradually (Figure 5.4.1). The core region and downcomer began to refill from 17 ft. Within 1 minute of HPI activation, the PORV flow rate abruptly decreased from 700 to between 200 and 400 lbm/h, indicating two-phase flow. The HPI flow rate then exceeded the PORV discharge rate. The downcomer level approached the nozzle elevation at 41 minutes (Figure 5.4.7), and the cold leg discharge piping began to refill (Figure 5.4.6). However, the hot leg levels continued to gradually decline. The upper-elevation primary fluid temperatures had saturated upon PORV actuation, and the primary system had been approaching saturation generally as the PORV discharge continued. However, shortly after HPI activation, the cold leg discharge and core inlet fluid subcooled and continued to cool (Figure 5.4.8).

The core region level gradually rose beyond 50 minutes, approaching the elevation of the RVVVs at 100 minutes. Beyond 150 minutes, the downcomer began to fill from the nozzle elevation (Figure 5.4.9). At 160 minutes, the downcomer level reached the elevation of the RVVVs and the downcomer flow was reactivated. The core exit SCM increased beyond the setpoint of 100F rather quickly, and HPI was thereby interrupted. Upon interruption of HPI, the hot leg levels, which had been rising slowly, dropped abruptly (Figure 5.4.10). The loop A hot leg levels stabilized near the elevation of the surge line connection, but the loop B hot leg riser voided almost completely. The primary system depressurized relatively rapidly from 1200 psia (Figure 5.4.11). HPI was restored at 173 minutes, when the SCM had diminished to the setpoint of 50F. HPI throttling was then sufficient to maintain the SCM near 75F, and the hot leg levels stabilized.

The CFT was isolated at 218 minutes based on an SCM of 50F or more for 30 minutes. (The CFT had not been active.) The PORV site fluid subcooled at approximately 225 minutes (Figure 5.4.12), causing the PORV mass flow rate to increase somewhat (Figure 5.4.13). The hot leg high-point vents were opened at 240 minutes, as specified. They had little apparent impact on the system conditions. The primary system continued to depressurize, but at a progressively slower rate (Figure 5.4.11). The throttled HPI continued to approximately equal the rate of PORV discharge (Figure 5.4.13). The core exit SCM was maintained near 75F. The test was terminated at 480 minutes based on maximum test duration.

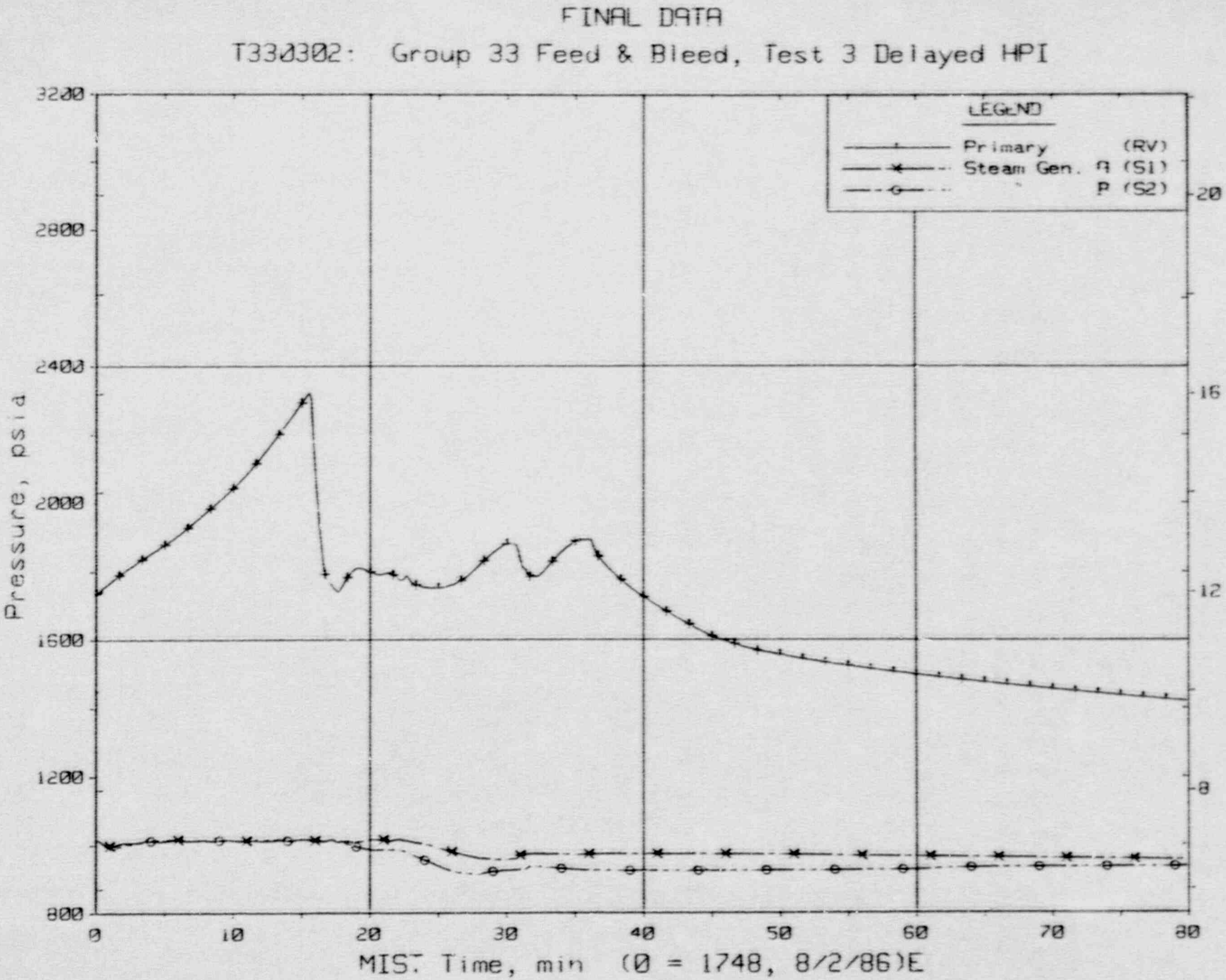


Figure 5.4.1. Primary and Secondary System Pressures (GPOls)

Thu Jul 21 14:49:35 1988

PSGP1

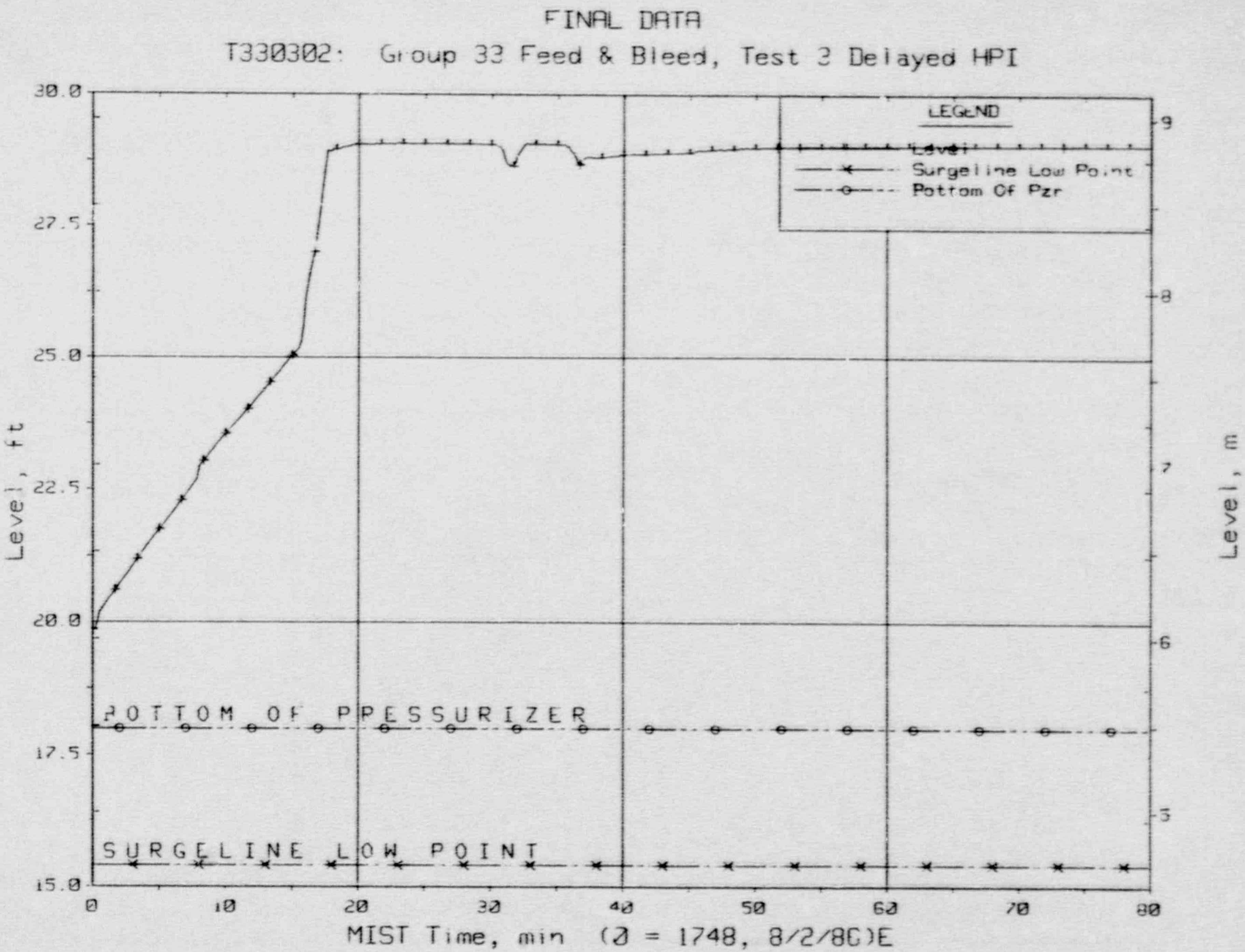


Figure 5.4.2. Pressurizer Collapsed Liquid Level (PZLV20)

Thu Jul 21 14:52:07 1988

PZLV1

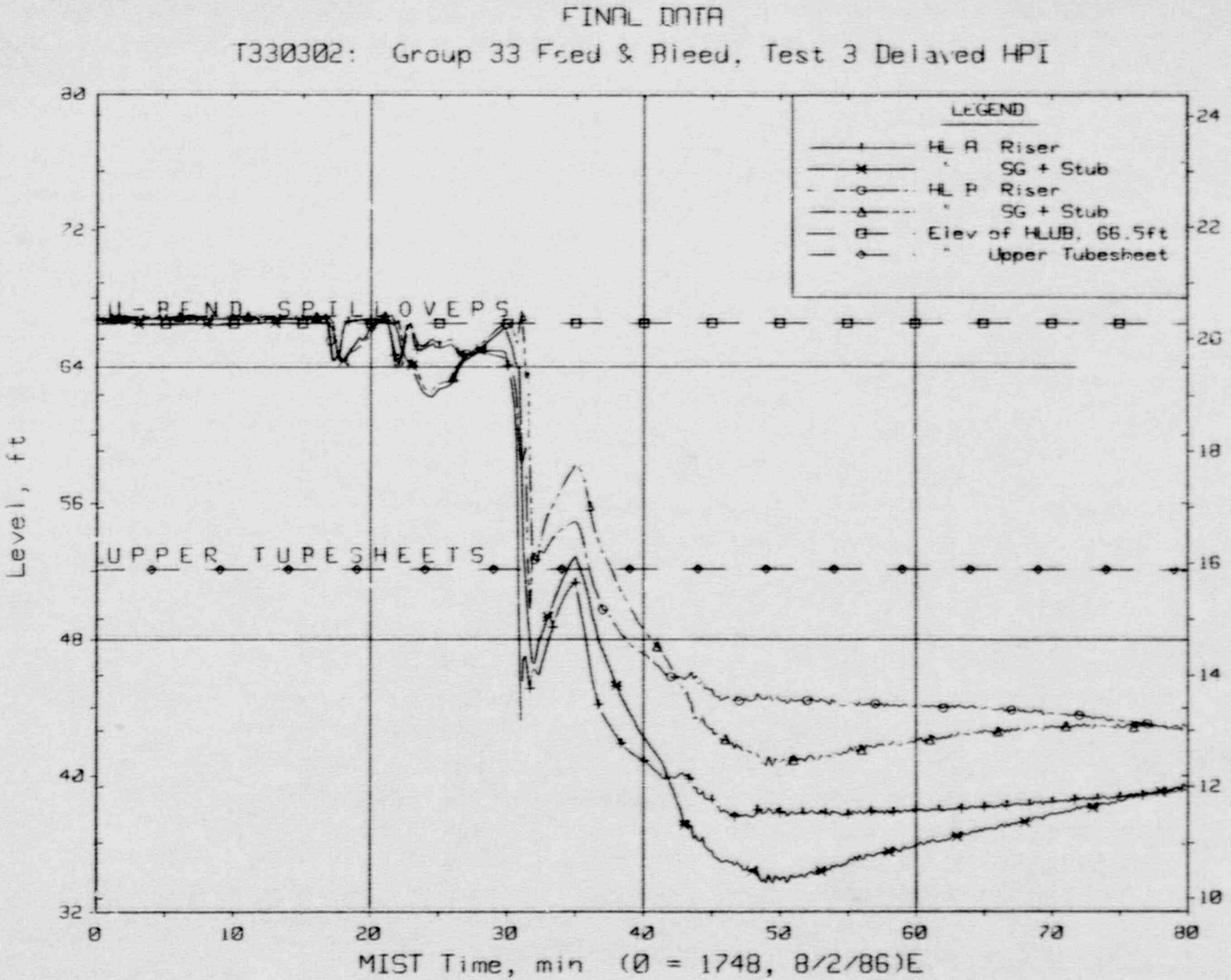


Figure 5.4.3. Hot Leg Riser and Stub Collapsed Liquid Levels

Thu Jul 21 14:55:40 1988

HLLV1

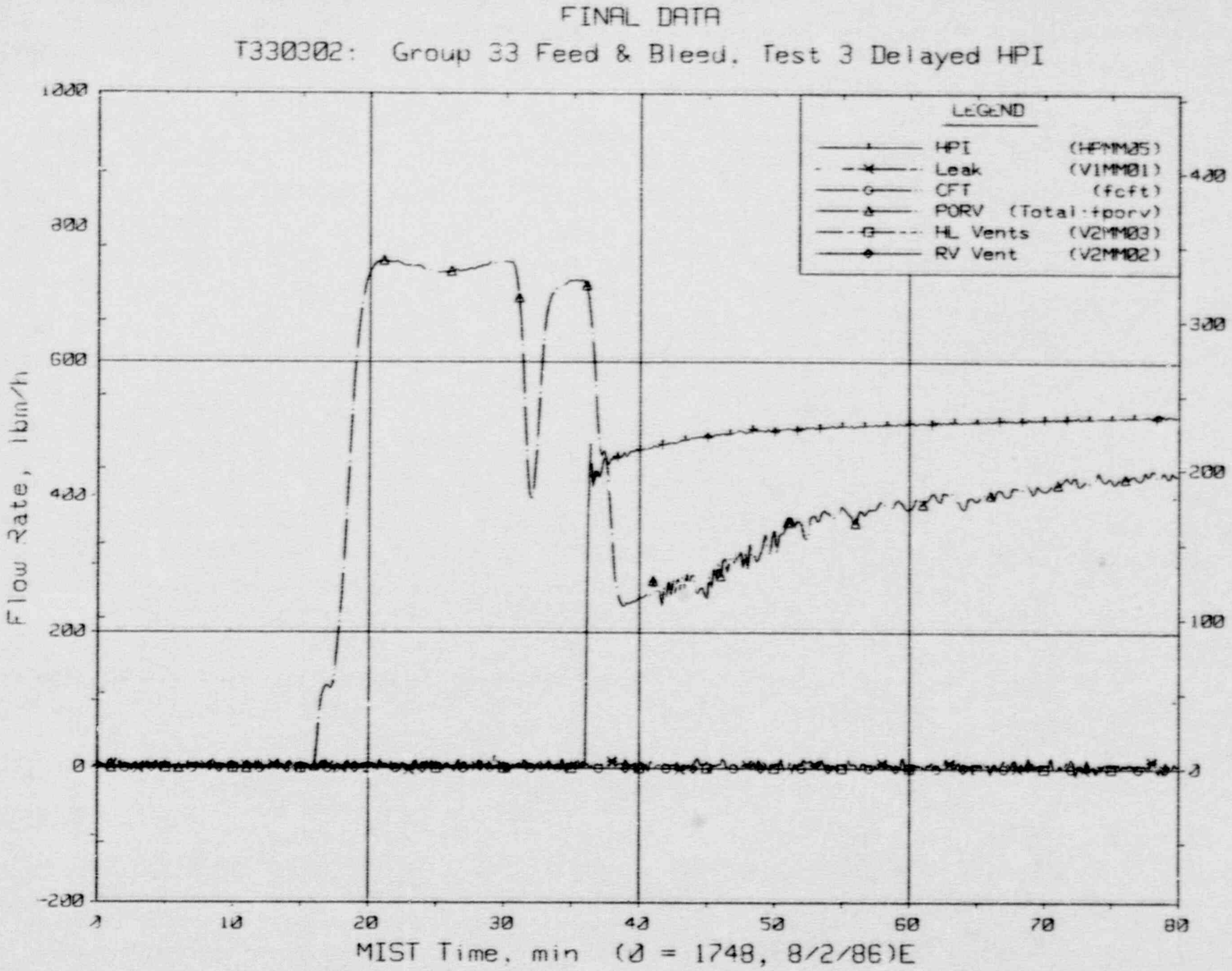


Figure 5.4.4. Primary System Boundary Flow Rates

Thu Jul 21 14:59:25 1988

PRFL3p

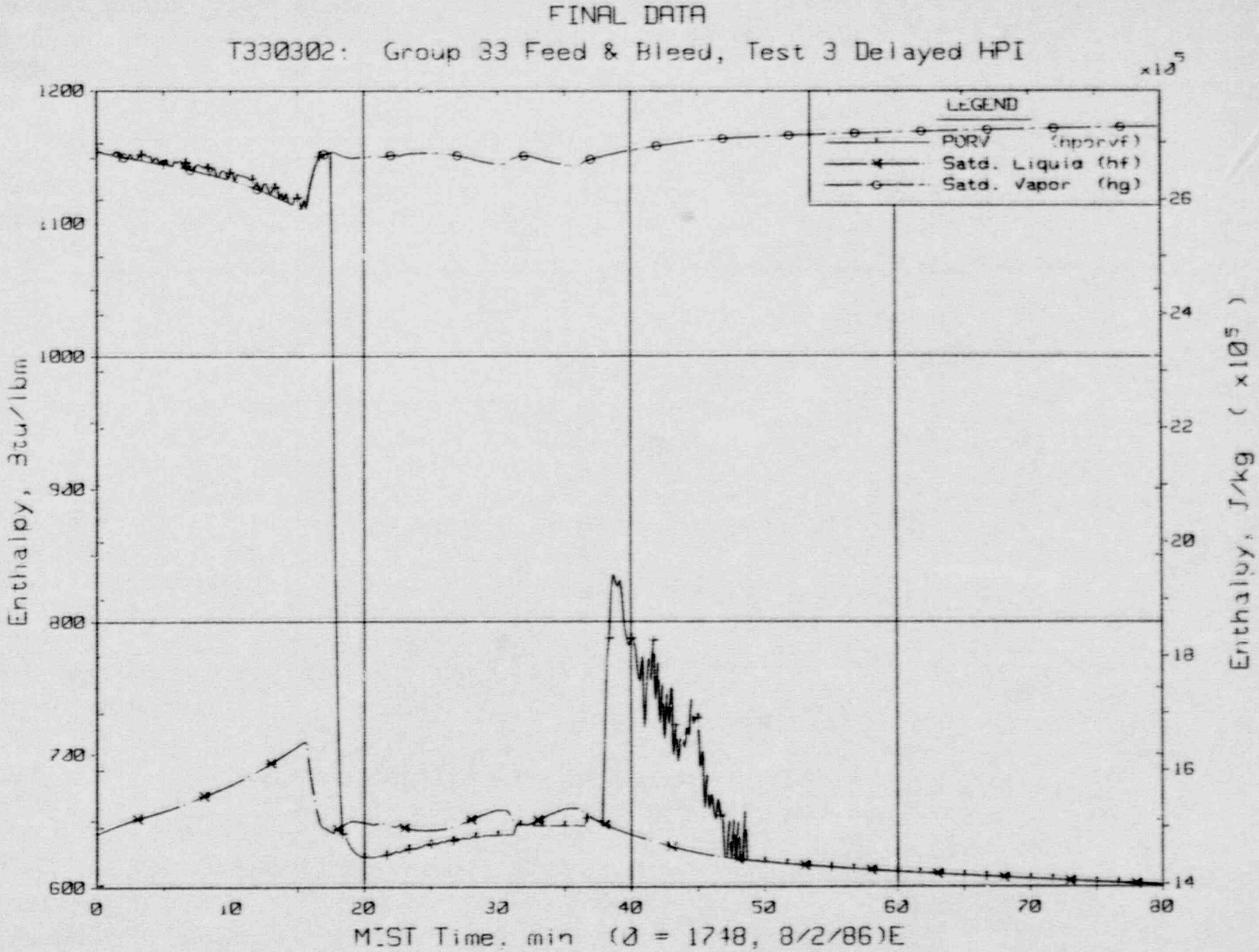


Figure 5.4.5. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 15:02:02 1988

PZEN1

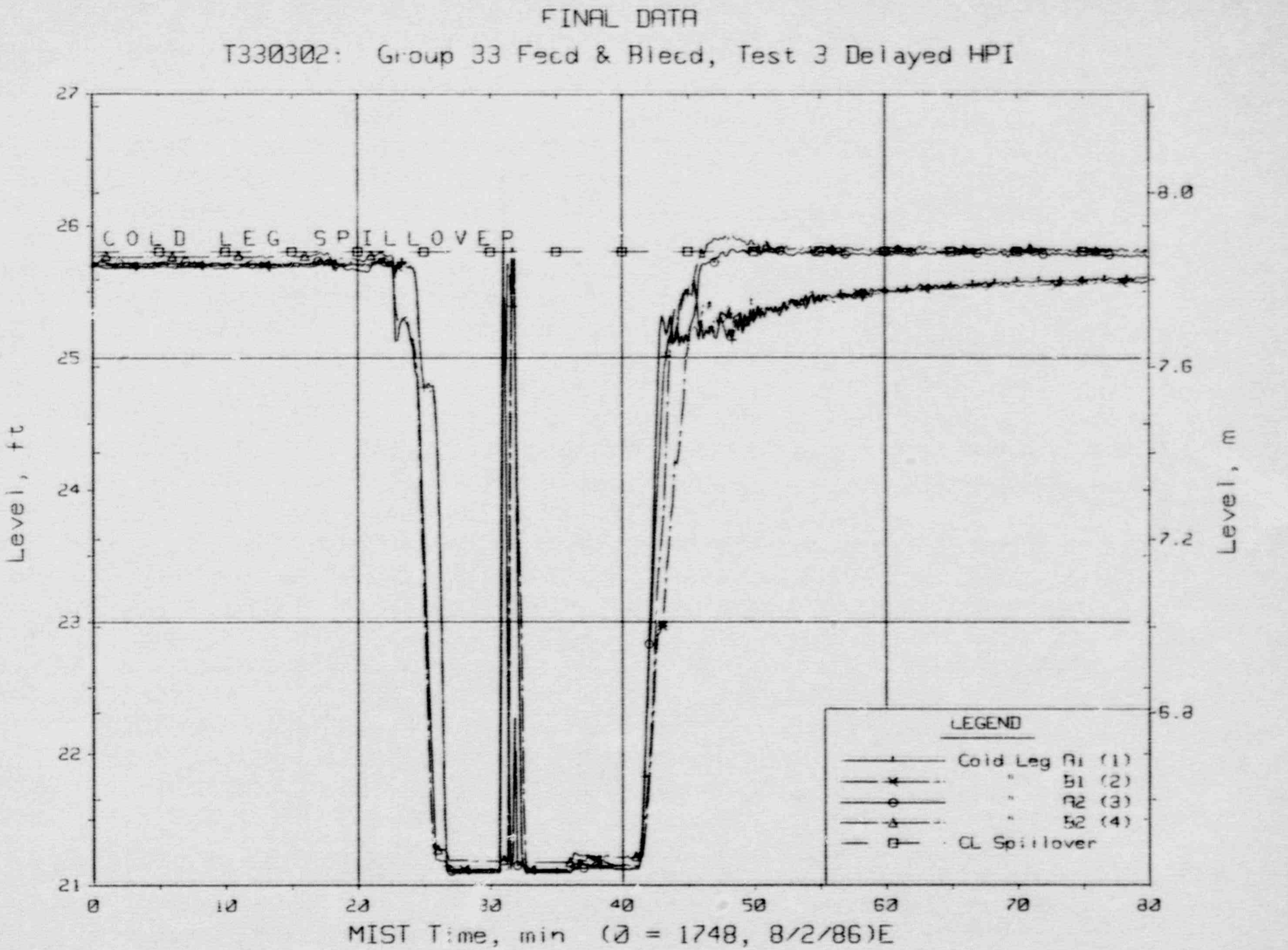


Figure 5.4.6. Cold Leg Discharge Collapsed Liquid Levels (CnLV23s)

Thu Jul 21 15:05:22 1988

CLLV5

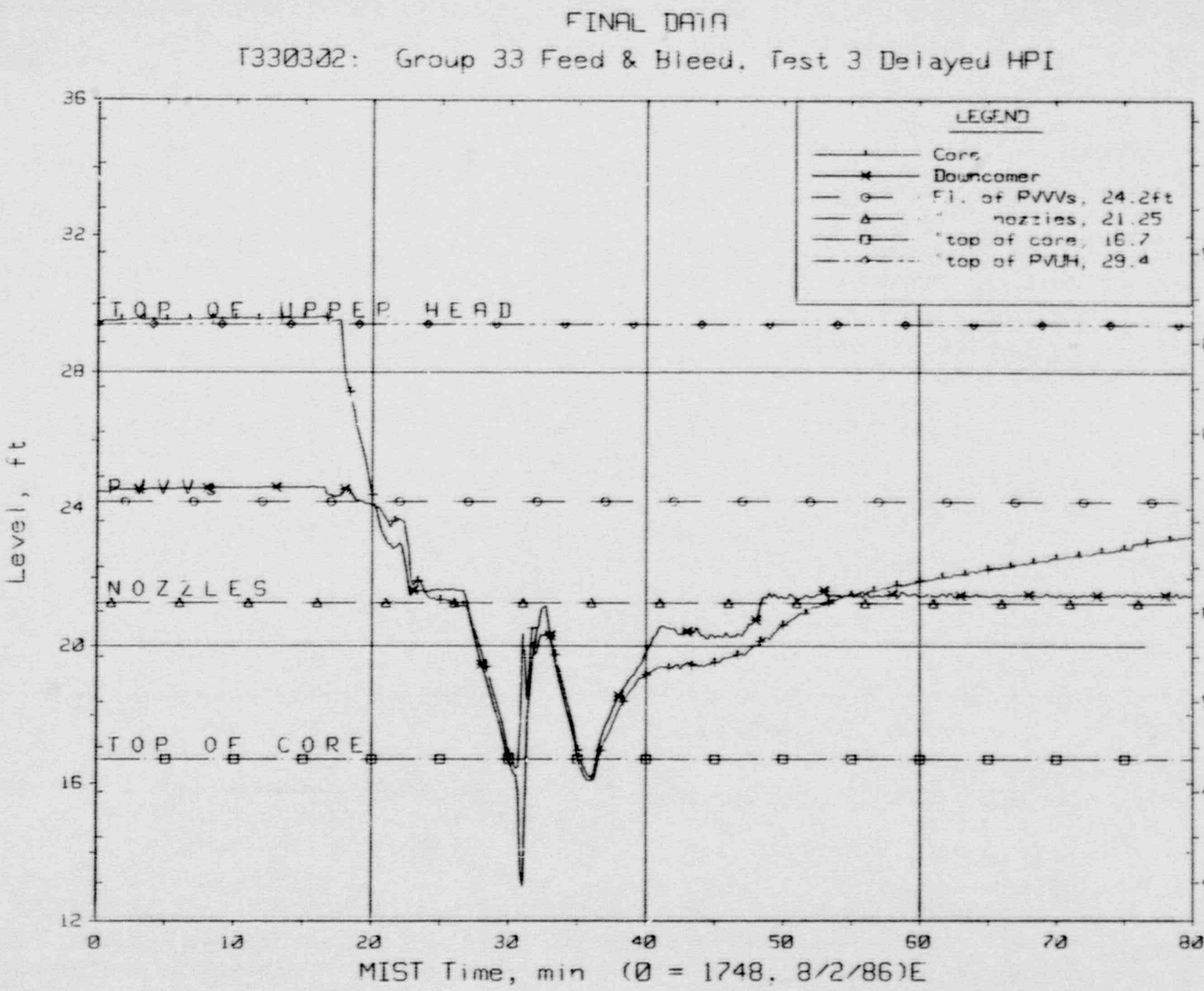


Figure 5.4.7. Core Region Collapsed Liquid Levels

Thu Jul 21 15:08:38 1988

COLV1

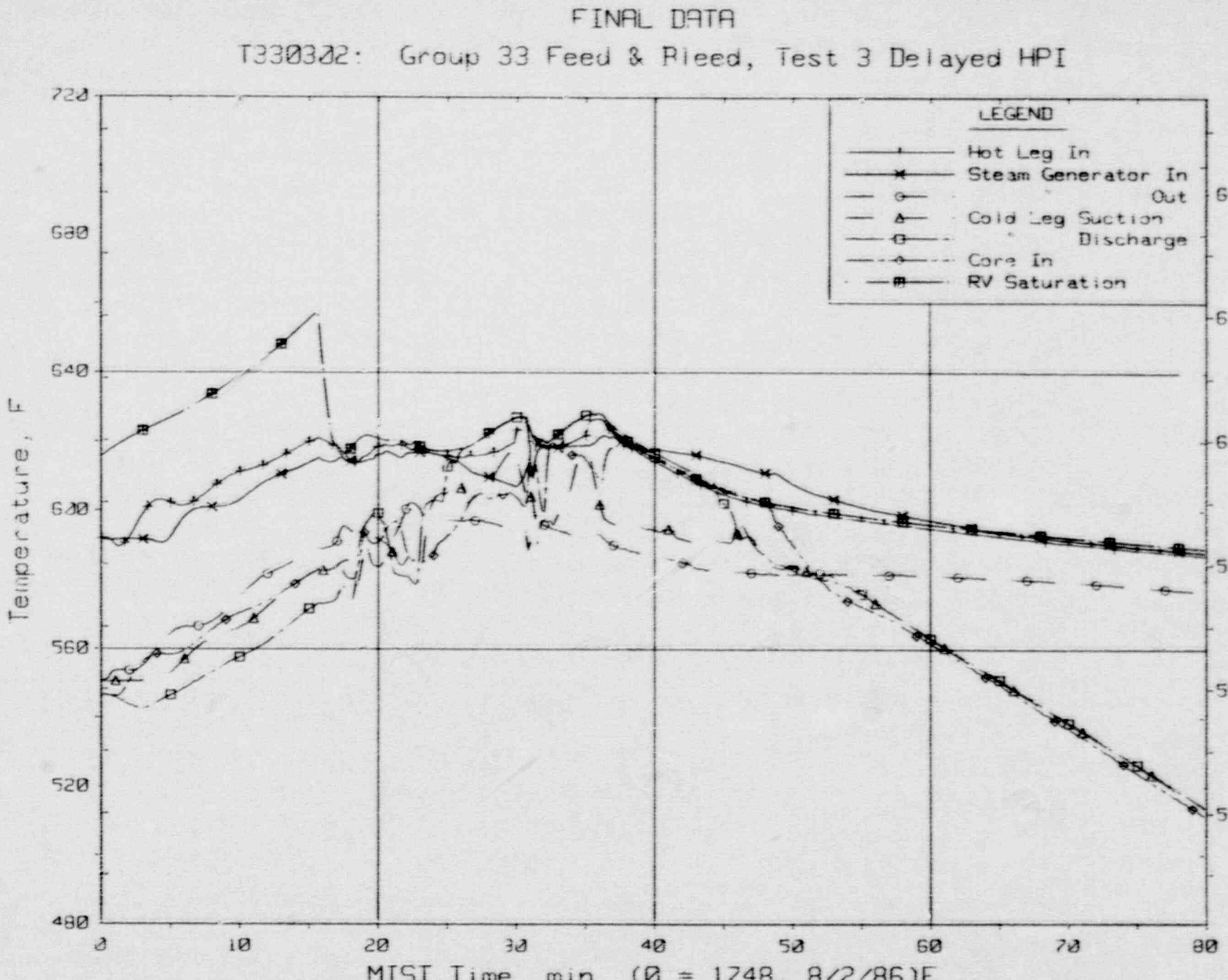


Figure 5.4.8. Primary System Average Fluid Temperatures (RTDs)

Thu Jul 21 15:13:21 1988

PRAT0

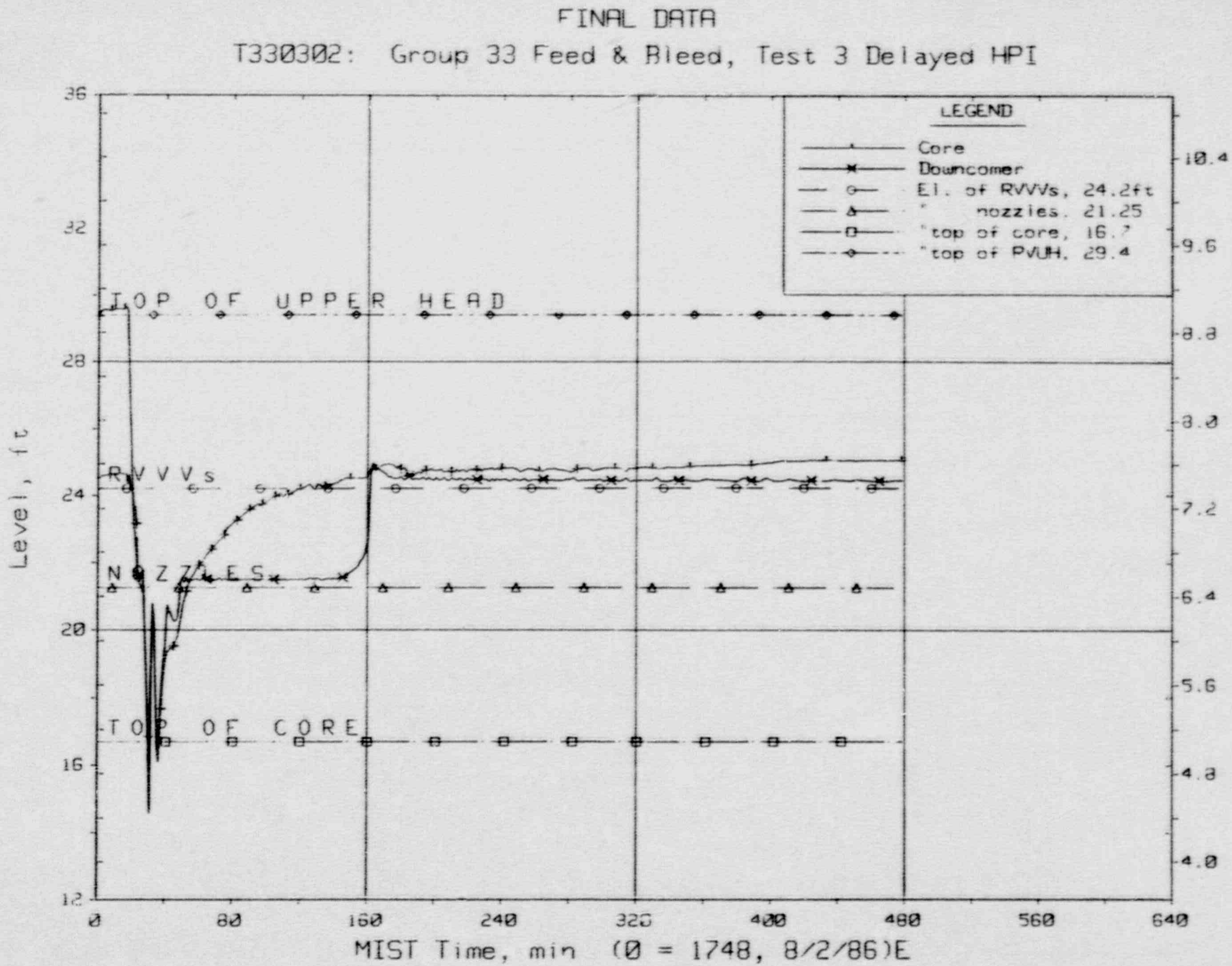


Figure 5.4.9. Core Region Collapsed Liquid Levels

Thu Jul 21 14:22:22 1988

COLV1

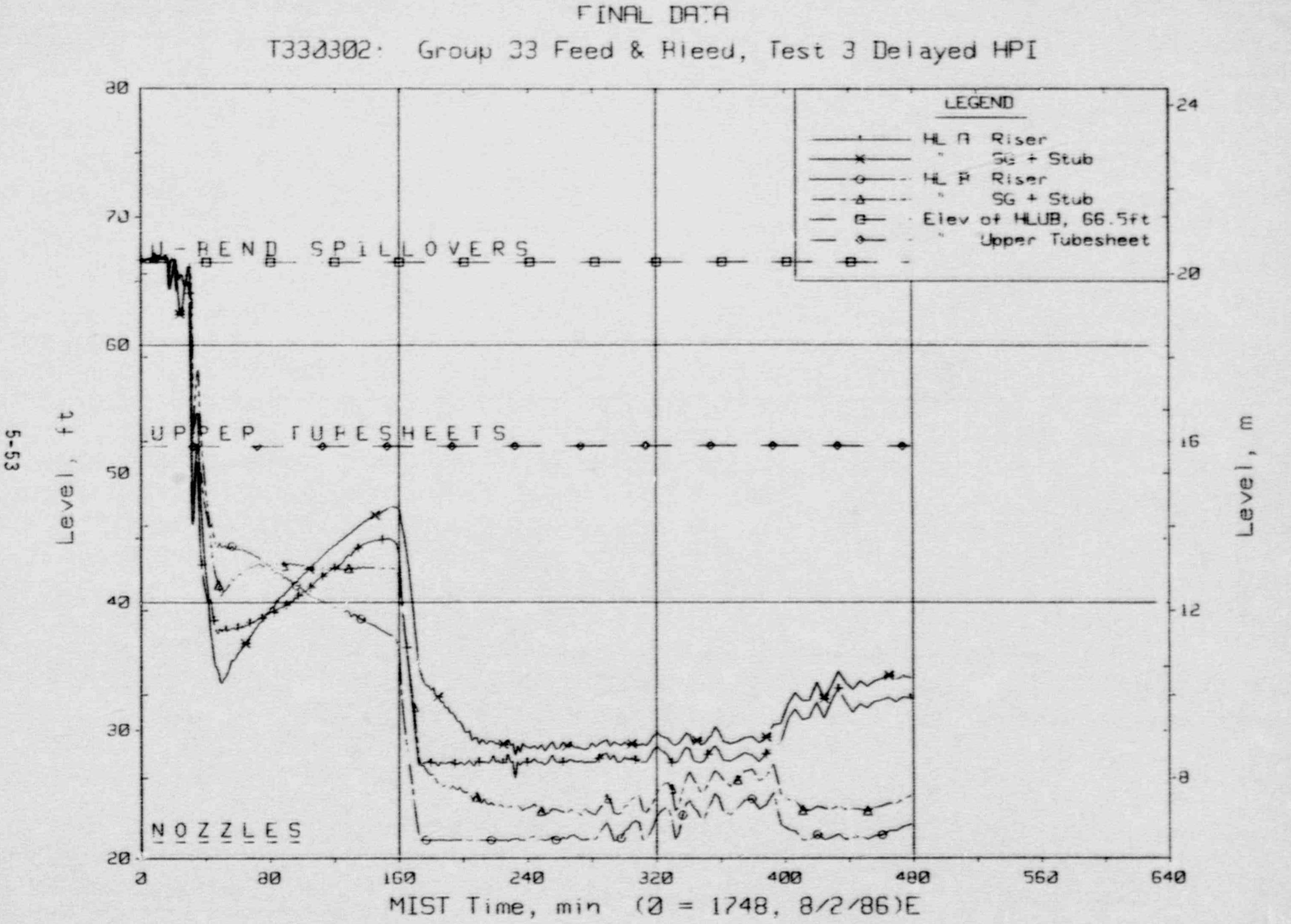


Figure 5.4.10. Hot Leg Riser and Stub Collapsed Liquid Levels

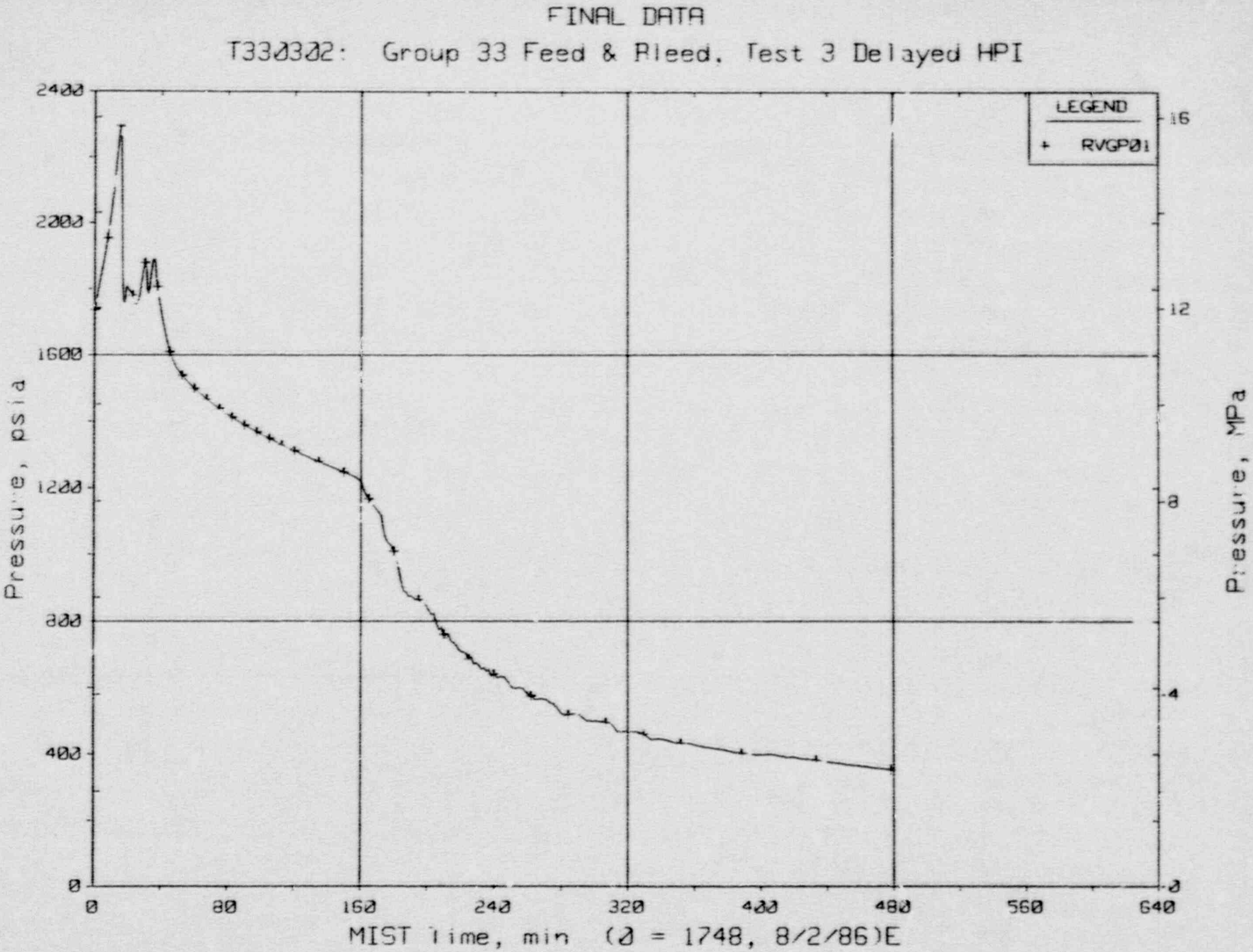


Figure 5.4.11. Reactor Vessel Pressure

Thu Jul 21 14:38:55 1988

RVGP1

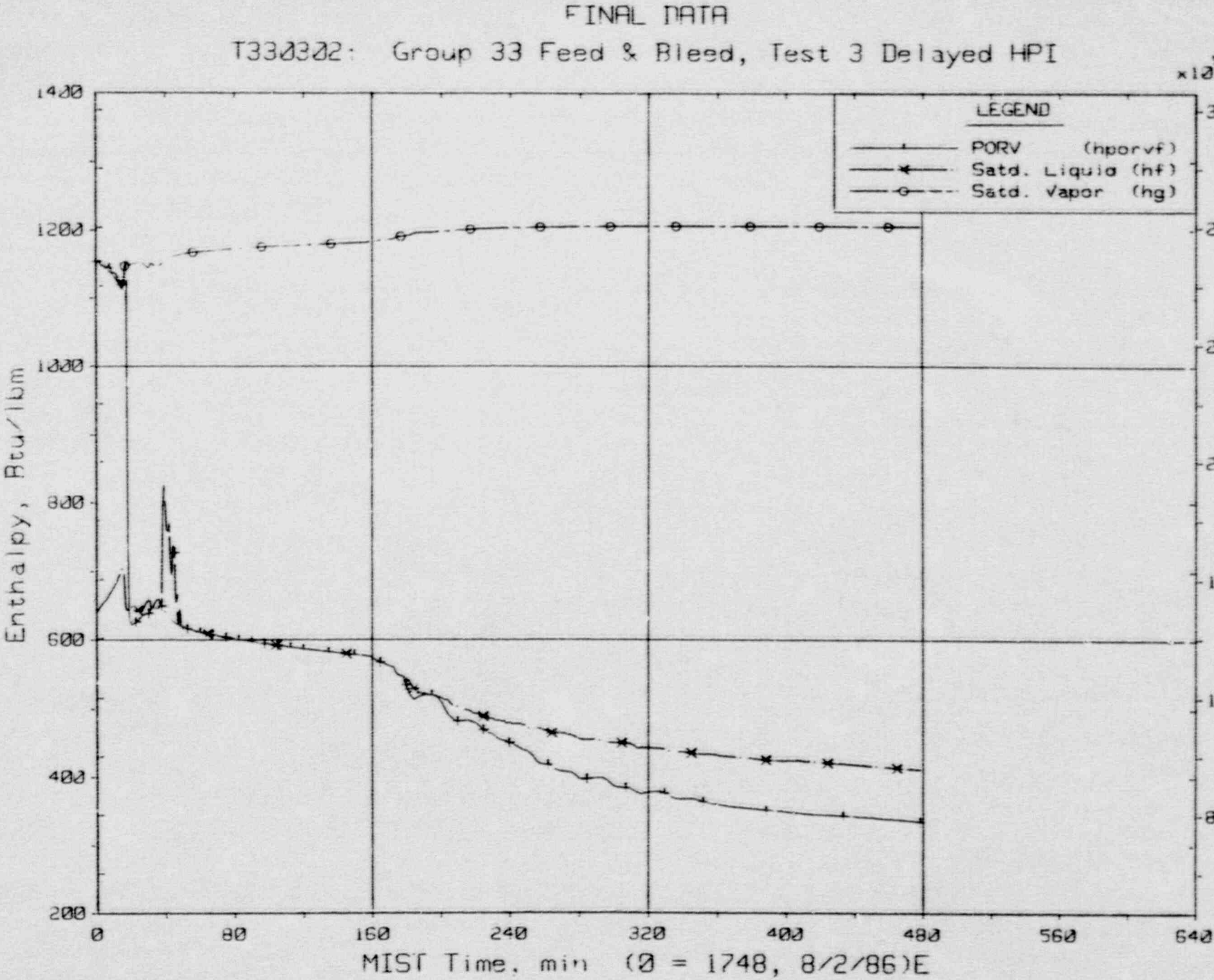


Figure 5.4.12. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 14:40:56 1988

PZEN1

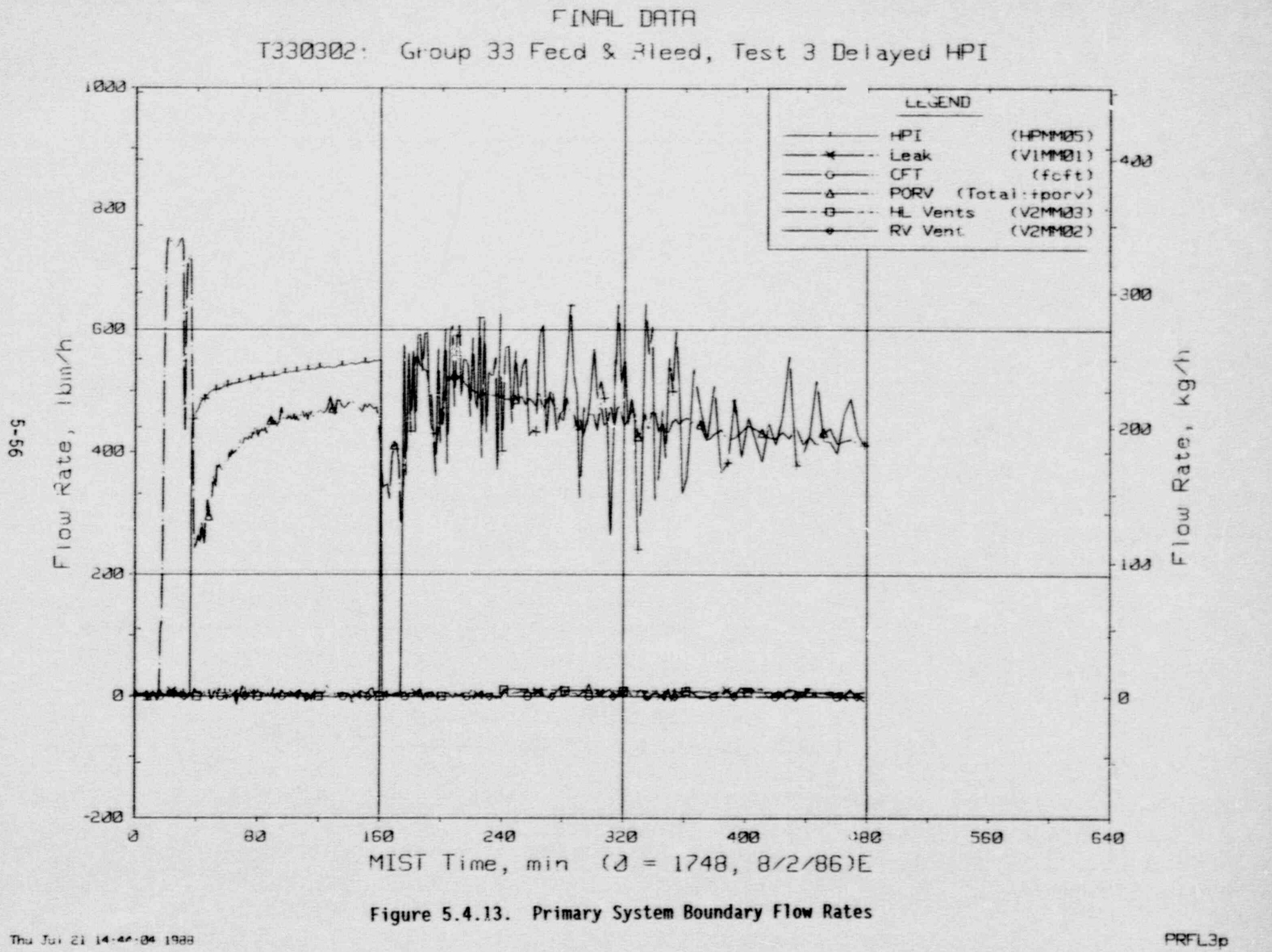


Figure 5.4.13. Primary System Boundary Flow Rates

5.5. Surge Line Uncovery, Test 4

Test 4 (330499) addressed the primary system depressurization upon uncovery of the pressurizer surge line. The test was initiated as planned. The primary system pressurized and heated, causing repeated PORV actuations beginning shortly after the interruption of feed. The pressurizer fluid subcooled due to the combined effects of an increased primary system saturation temperature and the insurge of hot leg fluid. The hot leg fluid temperatures exceeded 590F at 2 minutes, precipitating several operator actions at 12 minutes.

The PORV was manually opened at 12 minutes, as specified. Also, both hot leg high-point vents were opened, and the simulated makeup injection was activated. The primary rapidly depressurized until the loop fluid saturated, causing the operator to deenergize the RCPs at an SCM of 20F, as specified. The primary system then depressurized very gradually as the loop fluid approached general saturation. Core power had been manually held constant at 77 kW after the primary system pressure first stabilized, as specified. At 28 minutes, the operator increased core power to halt the continuing gradual depressurization. The primary system then began to repressurize between periods of intermittent loop B flow. The operator reduced core power at 53 minutes to halt the continuing repressurization.

The surge line uncovered beyond 57 minutes and the primary system began to depressurize. The observed depressurization rate of nearly 50 psi/h was obtained at 77 kW (2.33% of scaled full power), almost 1-1/2 times the current augmented decay power. This trend continued until 80 minutes, when core power was again increased. Primary system pressure now stabilized, quantifying the volumetric capacity of PORV flow (plus vents and makeup condensation) with the surge line uncovered at approximately 85 kW (2.2% of scaled full power plus 0.4% augmentation). Further core power increases beyond 115 minutes led to partial core uncovery and superheating of the core region fluid. The core power decay ramp was subsequently actuated, leading to test termination at 186 minutes.

Test 4 is described using the following four tests phases:

- Test initiation and early events (section 5.5.1).

- Operator actions based on 590F and primary system repressurizations, 12 to 53 minutes (section 5.5.2).

- Surge line uncovery (section 5.5.3).

- Core power adjustments through test termination (section 5.5.4).

The core power levels are discussed in section 5.5.5.

5.5.1. Test Initiation and Early Events

Initialization

The system was initialized in forced flow at 10.2% power, 336 kW. The fluid temperature rise through the core was approximately 5F, and the rise through the model reactor coolant pumps was about 2F. The (steam and feed) flow rates of steam generators A and B were 9.1 and 7.7% of scaled full steam generator secondary flow rates. This imbalance between steam generator secondary heat removal rates was not apparent in the steam generator primary fluid temperature decreases or the primary loop flow rates.

Initiation

The test was initiated by interrupting AFW. At time zero, the steam generator feed rates dropped abruptly from approximately 9 (A) and 7.5% (B) of scaled steam generator secondary flow (Figure 5.5.1), the steam generator secondary levels began to decline from 5 ft, and the steam generator secondaries repressurized slightly. The remaining test-initiating actions were completed in rapid succession.

The core power decay ramp was activated at 0.3 minutes, core power began to decrease gradually from 336 kW (Figure 5.5.2). Also, the pressurizer heaters were manually deenergized and the RVVV controls were transferred to automatic/independent. The RVVVs remained closed with the continuing forced flow. The steam generator secondary steam flow rates increased to counter the secondary pressurization, then decreased as the steam generator secondaries approached dryout (Figure 5.5.1). The steam generator secondaries were subsequently isolated and pressurized with nitrogen (to decrease the primary-to-secondary differential pressures). The steam generators were thus deactivated; except for changes in metal stored energy, the generators had only a negligible impact on subsequent interactions.

PORV Actuations

The primary system pressure had been initialized at 2270 psia. The primary pressure increase upon interruption of feed thus quickly led to PORV lifts (Figure 5.5.3). The PORV first lifted at 0.3 minutes and 2320 psia. Upon PORV lift, the primary system rapidly depressurized to the PORV reseat pressure (2290 psia) at 0.5 minutes. The PORV was left in the automatic, overpressure control mode, thus PORV cycling continued. These cycles consisted of approximately 10-second lifts followed by 20-second repressurizations with the PORV shut. Because of the rapidity of the PORV cycles, the indicated PORV flow rate was quite smooth rather than showing the individual flow and no-flow cycles (Figure 5.5.4).

590F Hot Leg Temperature

The primary system fluid heated virtually linearly at 3F/minute after the interruption of feed (Figure 5.5.5). With the primary system pressure maintained by the repeated PORV openings, the core exit SCM decreased at 3F/min from approximately 71F. The hot leg fluid temperatures exceeded 590F at 2 minutes (Figure 5.5.6), thus initiating the 10-minute count to the corresponding set of operator actions.

Subcooling of the Pressurizer Fluid

The pressurizer gained inventory as the primary system fluid expanded and as the PORV continued to actuate. The pressurizer collapsed liquid level increased from 23 ft initially to 29.2 ft, apparently full, at 10 minutes. The PORV flow rate increased dramatically, from about 50 to 300 lbm/h beyond 10 minutes (Figure 5.5.7), reflecting the decreasing quality of the PORV site fluid (Figure 5.5.8).

All but the bottom pressurizer fluid had been saturated at 654F at test initiation. Upon the initial primary system repressurization to the PORV lift pressure, the pressurizer vapor temperatures increased with the saturation temperature increase, whereas the liquid temperature remained constant and therefore slightly subcooled. The pressurizer liquid cooled markedly throughout the pressurizer-insurge period (Figure 5.5.9). The fluid near the bottom of the pressurizer cooled toward the current hot leg fluid temperature, 585F, starting just after test initiation. The mid-height pressurizer fluid, at 21 and 24 feet, cooled similarly beginning at 3 and at 8 minutes. The uppermost pressurizer fluid, at 27.6 feet, remained near saturation during this period. The pressurizer rake fluid temperatures indicated a maximum vertical temperature gradient of 2.5F/inch during the insurge (Figure 5.5.10).

5.5.2. Operator Actions Based on 590F and Primary System Repressurizations, 12 to 53 Minutes

Operator Actions Based on 590F

The specified set of actions based on a hot leg fluid temperature of 590F plus 10 minutes was initiated at 12 minutes. These actions included manually opening the PORV and hot leg high-point vents as well as activating makeup/ HPI -- the simulation of makeup injected through the cold leg A1 HPI nozzle at higher pressures, followed by HPI through all four nozzles at lower pressures. With the PORV manually kept open rather than allowed to cycle, the primary system depressurized at 188 psi/min beyond 12 minutes (Figure 5.5.11). The hot leg high-point vent flow rate (the sum of the flow rates from vents A and B) began to register approximately 150 lbm/h (Figure 5.5.7). Makeup flow was delayed until 13.2 minutes, reflecting the time required to pressurize the MIST HPI system accumulators; the makeup flow stabilized near 200 lbm/h (Figure 5.5.7). The SCM dropped rapidly, at about 15F/min, as the primary system depressurized. The SCM dropped below 20F at 13.2 minutes, causing the operator to deenergize the RCPs as specified.

Pump Coastdown, Primary Saturation

The input power, rotational speed, and head and flow rate associated with each reactor coolant pump began a gradual decrease beyond approximately 13.4 minutes and persisting to 15 minutes, simulating a four-pump coastdown (Figures 5.5.12 through 5.5.15). Midway through this coastdown, at 14.4 minutes, the primary system fluid saturated generally, halting the primary system depressurization at 1840 psia (Figure 5.5.11). The operator noted the primary pressure stabilization and, as specified, deactivated the core power reduction simulating decay. Core power was manually held constant at 77 kW (2.33%) beyond approximately 15 minutes (Figure 5.5.16).

Liquid at the PORV

The concurrent transition from forced to natural circulation and primary fluid saturation (due primarily to primary depressurization) triggered a wide range of system interactions. In addition to these two major events, the fluid at the PORV subcooled at 16 minutes (Figure 5.5.8) as the hot leg fluid (displaced into the pressurizer earlier in the transient, and at a lower hot leg fluid temperature, Figure 5.5.9) reached the top of the pressurizer. The PORV discharge rate increased correspondingly (Figure 5.5.7), attaining nearly 800 lbm/h. The transition from vapor to liquid at the PORV site had no marked effect on primary system pressure, which continued a slow decrease toward 1750 psia (Figure 5.5.11).

Core Region Voiding

The primary system fluid temperatures diverged as the loop flow slowed. The primary fluid temperatures downstream of the steam generators gradually decreased, whereas those beyond the core generally remained saturated (Figure 5.5.17). The discharge fluid temperatures for cold leg A1 dropped more than the rest because of the injection of makeup to that cold leg (Figure 5.5.18). The RVVVs opened at 15 minutes (Figure 5.5.19), as loop flow decayed. Whereas the lower downcomer fluid temperatures gradually decreased, the downcomer fluid above the nozzles heated towards saturation. The reactor vessel began to void at approximately 15.5 minutes (Figure 5.5.20). The reactor vessel collapsed liquid level descended to the RVVVs at 19 minutes, then both the reactor vessel and the downcomer began to void. The RVVV differential pressures became variable during this period (Figure 5.5.21), causing three of the valves to close, whereas RVVV B2 continued to actuate intermittently (Figure 5.5.19). The zone of saturated fluid extended farther down into the core, reaching the 14-foot elevation at approximately 20 minutes, and 12 ft at 22.5 minutes. The lower downcomer and core inlet fluid, however, remained as much as 20F subcooled (Figure 5.5.5).

Loop Voiding

The reactor vessel and downcomer (collapsed liquid) levels approached the hot leg and cold leg nozzle elevations at 25 minutes (Figure 5.5.20). The RVVVs opened, the cold leg discharge piping voided, and both hot leg U-bend regions voided. The upper core and core-to-nozzle void fractions increased beyond 25%, whereas the void fraction decreased in the annular region above the nozzles (Figure 5.5.22).

Also at 25 minutes, the progression of saturated hot leg fluid completed its transit through the pressurizer. The PORV site fluid saturated (Figure 5.5.8), causing the PORV discharge mass flow rate to abruptly decrease (Figure 5.5.7). Although the pressurizer surge line had not literally been uncovered, the fluid transport was similar to that expected to occur upon uncovering the surge line. The fluid at the hot leg nozzles was two-phase, the hot legs and pressurizer were saturated (Figures 5.5.6 and 5.5.9), and the states at the PORV and hot leg vent sites were vapor or two-phase fluid. The primary system pressure remained near 1785 psia until 27 minutes (Figure 5.5.11). The primary system then began to depressurize slightly.

Manual Power Increase at 28 Minutes

Core power was manually increased at 27.8 minutes (Figure 5.5.16). Core power was to have been decreased upon primary system repressurization to offset the absence of a simulated plant code safety valve in MIST. Core power was instead increased by the operator to halt the continuing primary system depressurization. After several adjustments, core power was maintained at 99 kW beyond 29.3 minutes. The primary system began to repressurize following the power increase (Figure 5.5.11). The PORV site fluid temperature remained constant (Figure 5.5.9), thus it subcooled as the saturation temperature increased (Figure 5.5.8). The PORV mass discharge rate again increased due to this subcooling to approximately 700 lbm/h (Figure 5.5.7). The reactor vessel and downcomer collapsed liquid levels declined regularly, whereas the U-bend void fractions decreased. The hot leg high-point vent mass flow rates gradually increased beyond 31.5 minutes (Figure 5.5.7) as the U-bend quality decreased.

Loop B Activity (32 Minutes)

The loop B hot leg riser level approached the U-bend spillover elevation at 32 minutes (Figure 5.5.23), while the reactor vessel and downcomer collapsed liquid levels approached the top of the core. Loop flow became momentarily active (Figure 5.5.24), saturated liquid from the core was propelled through the hot legs (Figure 5.5.25 and 5.5.26), the primary system depressurized (Figure 5.5.27), and the loops voided extensively (Figures 5.5.28 and 5.5.29). The accumulation of these voids quickly reinterrupted loop flow. The RVVVs closed momentarily; the downcomer fluid generally heated, however, due to the displacement loop fluid. The reduction of the primary saturation temperature plus the displacement of hot leg voids into the pressurizer (suggested by the relatively rapid propagation of the increased fluid temperature indications through the pressurizer, Figure 5.5.30) caused the PORV site fluid to saturate (Figure 5.5.31). The PORV discharge mass flow rate dipped correspondingly at 34.4 minutes (Figure 5.5.32). The primary system immediately began to repressurize (Figure 5.5.27), again subcooling the PORV site fluid (Figure 5.5.31).

Second Primary Repressurization (34 Minutes)

The primary system had repressurized at 29 psi/min to 1860 psia, ending at 33 minutes. Beyond 34 minutes, the primary system repressurized at a slightly lower rate, 25 psi/min, but from a higher initial pressure, 1805 psia (Figure 5.5.27). This pressure excursion was interrupted at 38 minutes and 1910 psia in a manner similar to the previous interruption. The primary system fluid remained closer to saturation with successive repressurizations. That is, the pressurizer fluid subcooled less than before simply because it remained at successively higher temperatures (Figure 5.5.30). The displacement of loop fluid during the brief flow reactivation had a smaller effect, primarily because the flow pulses were less robust (Figure 5.5.24).

Suppression of Repressurization

A third repressurization began from 1890 psia at 40 4 minutes (Figure 5.5.27). Unlike the previous repressurizations the pressurizer fluid saturated during the pressure increase at approximately 44 minutes (Figure 5.5.30), rather than after the repressurization had been interrupted. As the PORV site fluid saturated, the PORV mass flow rate was reduced (Figure 5.3.32) as was the primary system repressurization rate. The primary system had begun to repressurize at 28 psi/min from 1890 psia. After 42.5 minutes, the rate became approximately 16 psi/min (Figure 5.5.27). The reactor vessel and downcomer collapsed liquid levels remained at or slightly below the top of the core (Figure 5.5.33). The core, hot leg, surge line, and pressurizer fluid, as well as the cold leg discharge and upper downcomer fluid, were at least saturated -- the core exit fluid temperatures indicated slight superheating (Figure 5.5.34). Both hot leg risers evidenced extensive and similar voiding. The upper risers were completely voided, the lower hot leg riser elevations from the inlet to 30 feet indicated 20 to 30% voiding (Figures 5.5.28 and 5.5.29). The elevation of the hot leg A-to-pressurizer surge line connection was 27 feet; thus, complete uncovery of the surge line was imminent.

5.5.3. Surge Line Uncovery

Pressure Stabilization by Core Power Reduction (53 Minutes)

Core power had been manually held at 99 kW since 30 minutes. As the primary system pressure reached 2070 psia at 51.2 minutes, the operator manually reduced core power to halt the repressurization. Core power was reduced from 99 to 30 kW, immediately increased to 55 kW (which was about the current augmented decay heat power), and finally increased to 77 kW at 52.8 minutes (Figure 5.5.35). This power adjustment approximately stabilized primary system pressure near 2035 psia (Figure 5.5.27). The power manipulations perturbed system conditions, notably the fluid state at the PORV (Figure 5.5.31), but these perturbations quickly subsided. The PORV discharge rate remained near 350 lbm/h, indicative of saturated liquid at the PORV, from 53 to 58 minutes (Figure 5.5.32). The reactor vessel and downcomer collapsed liquid levels, which had increased momentarily as the core void generation was reduced by the core power reduction, returned to the elevation of the top of the core (Figure 5.5.33).

Surge Line Uncovery at 57 Minutes

The hot leg A-to-pressurizer surge line connection uncovered completely at 57 minutes. The hot leg A riser local void fraction bracketing the surge line connection increased from 20% at 56 minutes to 100% at 58 minutes (Figure 5.5.28). The indicated hot leg A riser collapsed liquid level stabilized at 29 ft beyond 58.4 minutes (Figure 5.5.23), i.e. near the surge line connection at 27.1 feet.

The PORV mass flow rate gradually declined after 59 minutes (Figure 5.5.32), attesting to the increasing quality of the PORV site fluid (Figure 5.5.31).

At 66 minutes, the PORV discharge mass flow rate decreased further toward the all-vapor value and the primary system began to depressurize at nearly 500 psi/h from 2030 psia (Figure 5.5.27). During this surge line uncovery depressurization, core power was manually maintained at 77 kW or 2.33% of scaled full power (Figure 5.5.35), about twice the current decay value.

5.5.4. Core Power Adjustments Through Test Termination

Core Power Increase At 80 Minutes

The operator manually increased core power from 77 to 89 kW at 77 minutes. Power was subsequently adjusted to 83 kW beyond 80 minutes to stabilize primary system pressure (Figure 5.5.35). The preceding surge line uncovery had not been detected, the observed PORV discharge of steam was attributed to the effects of the pressurizer-hot leg A manometer. Thus, primary pressure was stabilized in anticipation of surge line uncovery, but it had already occurred.

The primary system repressurized at 89 kW but gradually depressurized at 83 kW (Figure 5.5.27), thus quantifying the power being offset by venting steam through the surge line and out the PORV. The primary system continued to depressurize at about 2 psi/min with 83 kW core power. The PORV discharge mass flow rate remained near 150 lbm/h (Figure 5.5.32), indicating vapor at the PORV. The reactor vessel and downcomer collapsed liquid levels decreased about 1/2 ft below the top of the core during the core power adjustment at 80 minutes, then remained just below the top of the core (Figure 5.5.33). The hot leg B riser had voided completely at 63 minutes (Figure 5.5.29). The hot leg A riser, on the other hand, apparently retained some liquid in the piping between the hot leg inlet at 21.2 feet and the surge line connection at 27.1 feet. The 23- to 27-foot zone finally voided completely at 9[illegible] minutes while the void fraction over the lower 2 feet gradually increased beyond 30% (Figure 5.5.28).

Core Power Adjustments, Core Uncovery, and Superheating

At 104 minutes, the operator noted the difficulty in defining surge line uncovery. The hot leg level appeared to be low enough, but no pronounced depressurization had been observed. A depressurization was not expected until the bottom of the surge line was uncovered. Therefore, core power was to be elevated further to obtain a net mass outflow, and thus to completely drain the pressurizer and allow for a primary depressurization. Core power was therefore manually and incrementally increased, from 83 kW at 115 minutes to 122 kW at 122 minutes, then incrementally reduced to 83 kW at 135 minutes (Figure 5.5.36). The primary system had generally been saturated and extensively voided before the power increase. As power was increased, the system pressurized further, approaching 2100 psia at 130 minutes (Figure 5.5.37). The reactor vessel and downcomer collapsed liquid levels descended almost 4 feet below the top of the core (Figure 5.5.38). The core region fluid superheated, exceeding saturation by more than 30F (Figure 5.5.39). The heater metal upper temperatures increased 80F (Figure 5.5.40). These conditions subsided as core power was returned to its previous value of 83 kW.

Test Termination

The automated core power reduction ramp was activated from 83 kW (2.52% of full power) at 146 minutes (Figure 5.5.36). At 179 minutes, the primary system depressurized to 1700 psia (Figure 5.5.37) and the injection configuration was transferred from makeup (injection to cold leg A1) to HPI (injection to all four cold legs). The test was terminated at 186 minutes, based on primary pressure less than 1500 psia, reactor vessel level increasing, and more than 3 hours of testing.

5.5.5. Power Level

The MIST core power versus time (less uncompensated losses) was 0.3% of scaled full power less than that used in the code prediction of a similar, hypothetical plant transient. There were two approximately equal contributions to this difference. The plant-to-MIST power conversion was based on a plant power of 2700 MW versus 2772 MW of the code-modelled plant. The second source of difference related to the MIST uncompensated heat losses to ambient. The MIST core power was increased by 0.4% of scaled full power to offset these uncompensated losses, but the actual losses were approximately 0.55% of scaled full power.

In addition to these differences in power schedule, there was a power consideration relating to volume. MIST had approximately 30% excess fluid and metal volume compared to a power-to-volume scaled model. Therefore, considering the energy deposition required to heat the total primary inventory, the MIST power-decay schedule should have been prolonged by extending the time base.

As a result of the lower core power (less uncompensated losses) in MIST, MIST tended to depressurize earlier than the plant prediction. Whereas the net volume balance in the plant prediction was slightly positive at 17 minutes, the MIST volume balance with otherwise the same conditions would have been virtually zero because of power differences alone.

Power was held constant in MIST beyond 15 minutes, thus the prediction-to-MIST power difference began to decrease. The MIST power (less losses) exceeded that of the plant beyond 26 minutes. Then, the MIST power was increased manually and MIST began to repressurize.

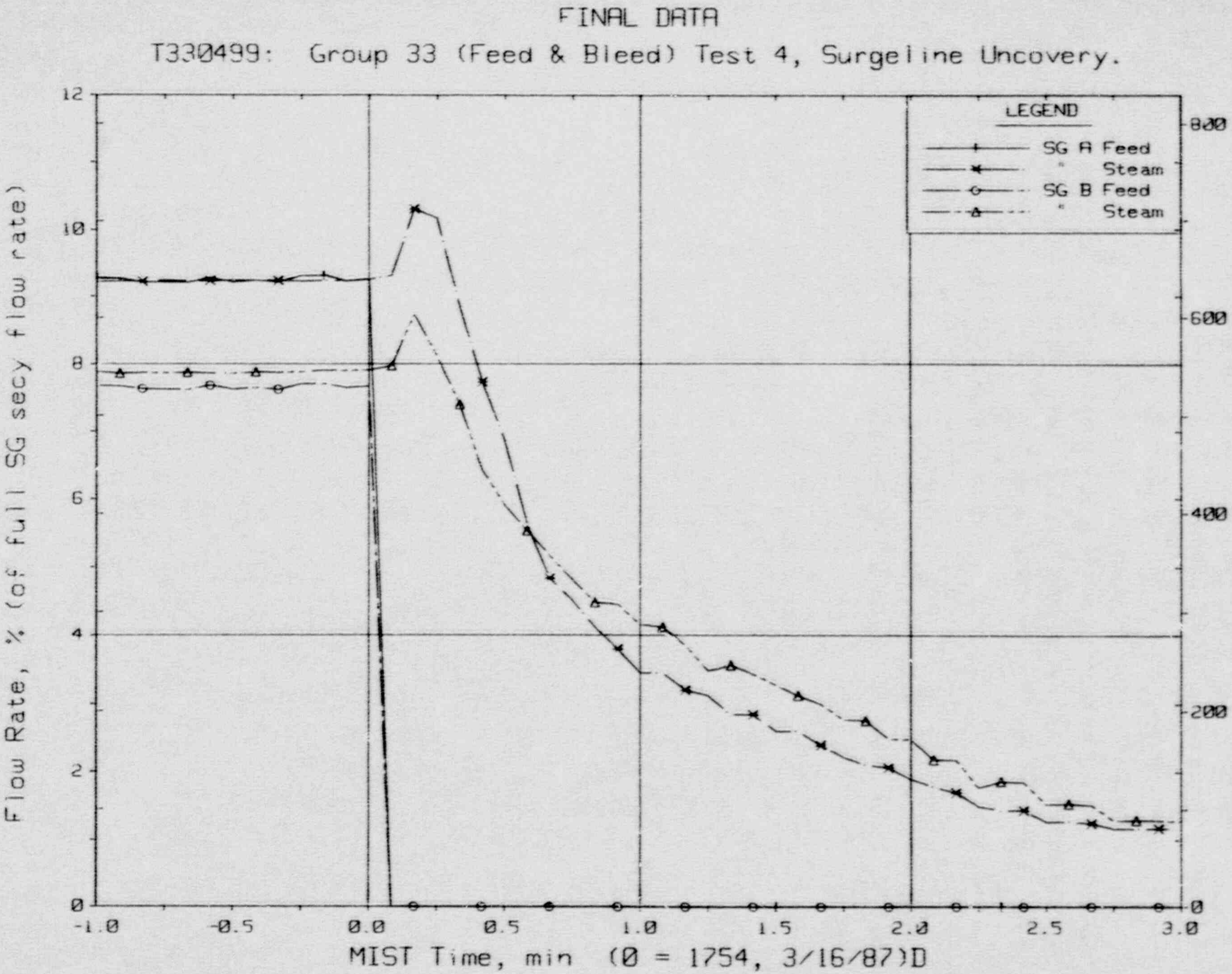


Figure 5.5.1. Secondary System Flow Rates

Mon Jul 18 12:36:27 1988

SGFL2

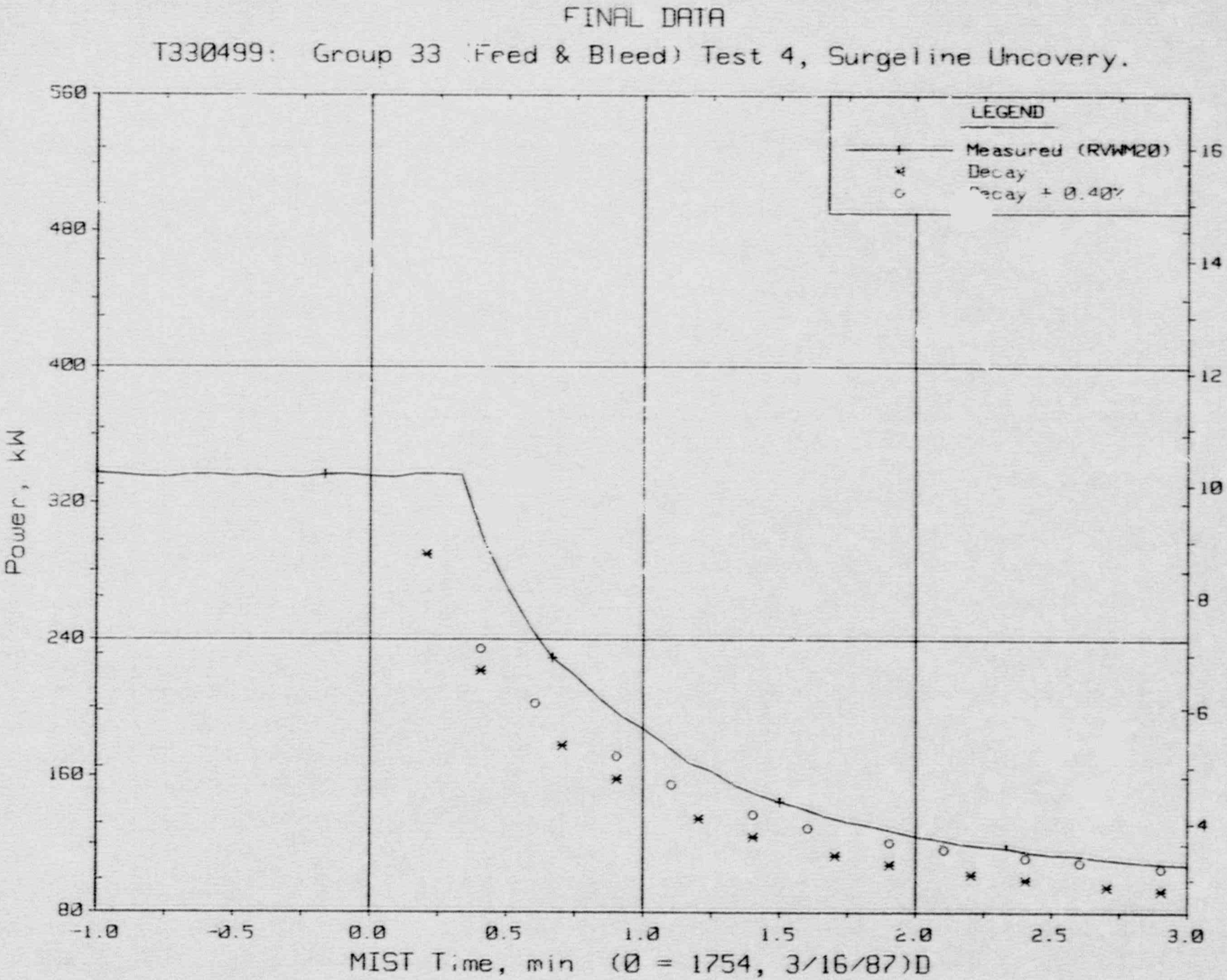


Figure 5.5.2. Core Power

Mon Jul 18 12:29:09 1988

RVKW1

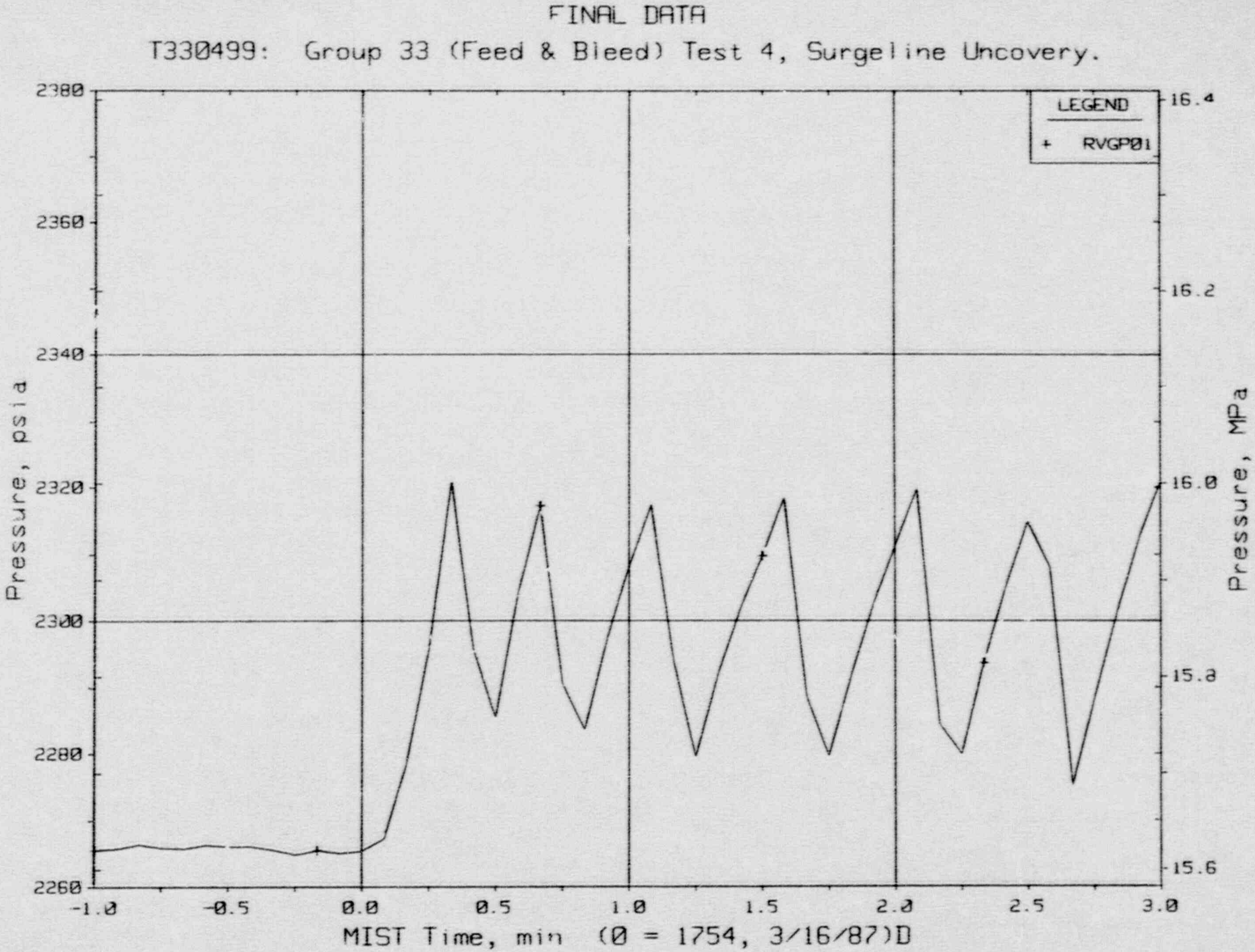


Figure 5.5.3. Reactor Vessel Pressure

Mon Jul 18 12:41:40 1988

RVGP1

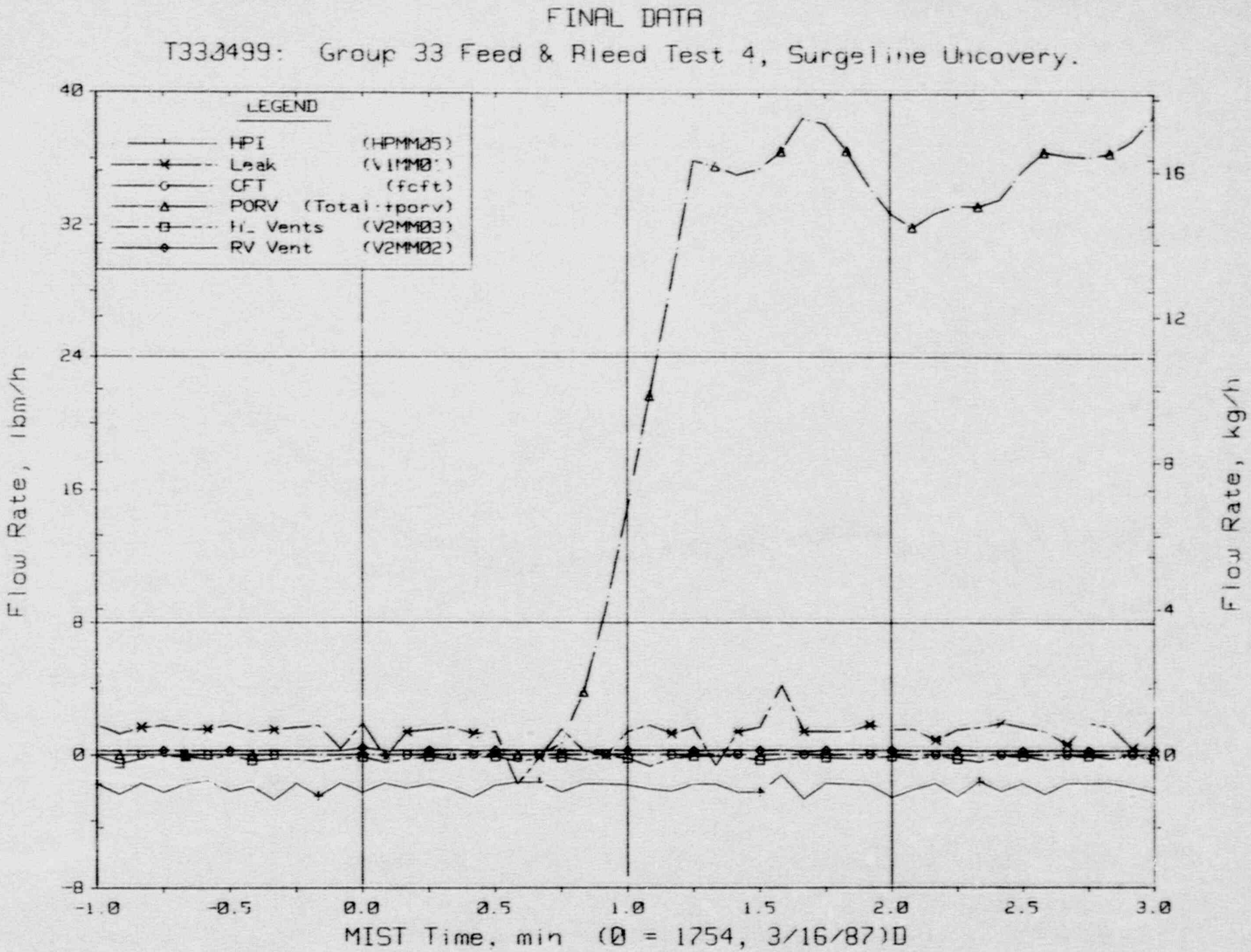


Figure 5.5.4. Primary System Boundary Flow Rates

Tue Nov 1 10:16:51 1988

PPFL3p

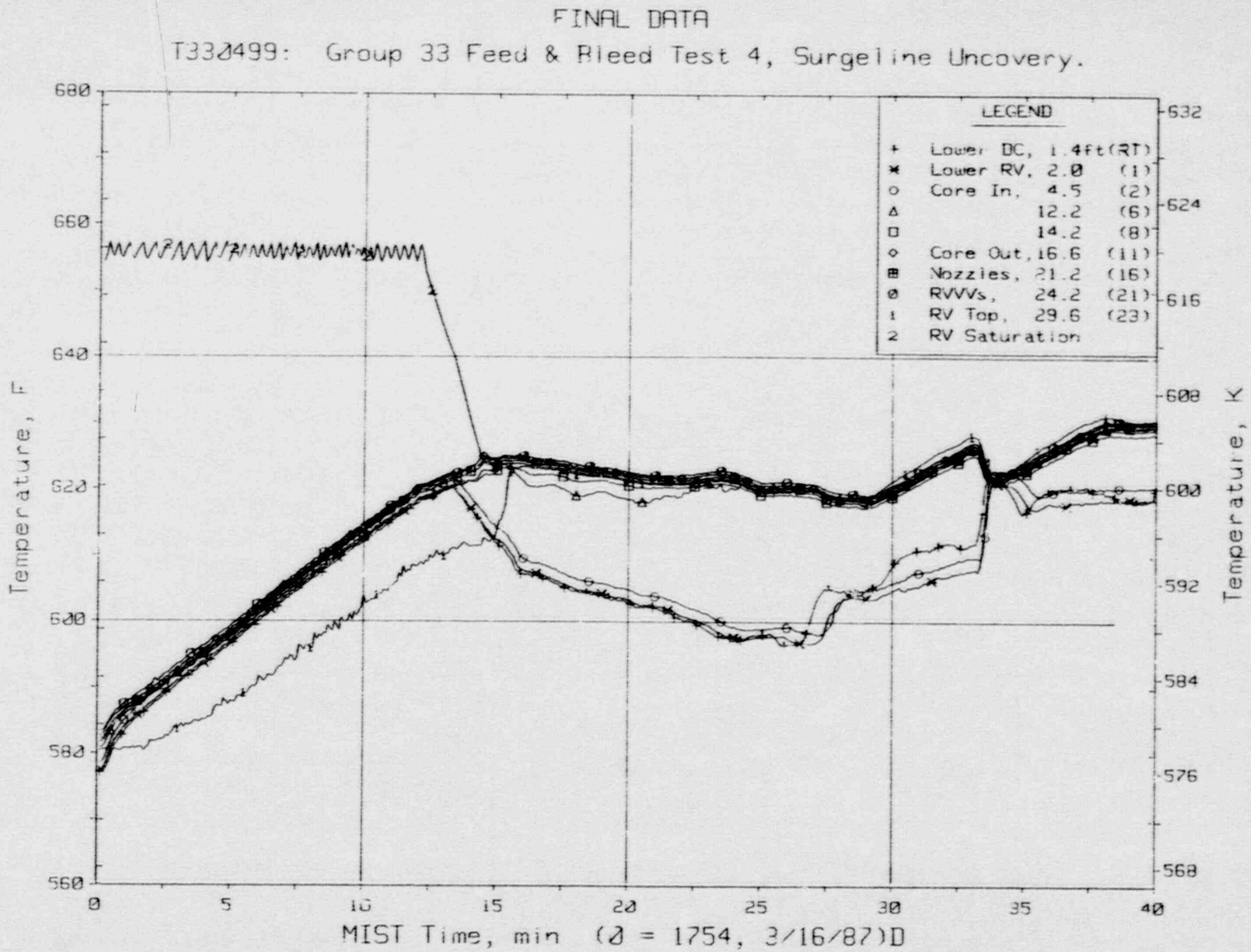


Figure 5.5.5. Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs)

Tue Nov 1 10:22:10 1988

RVTC0

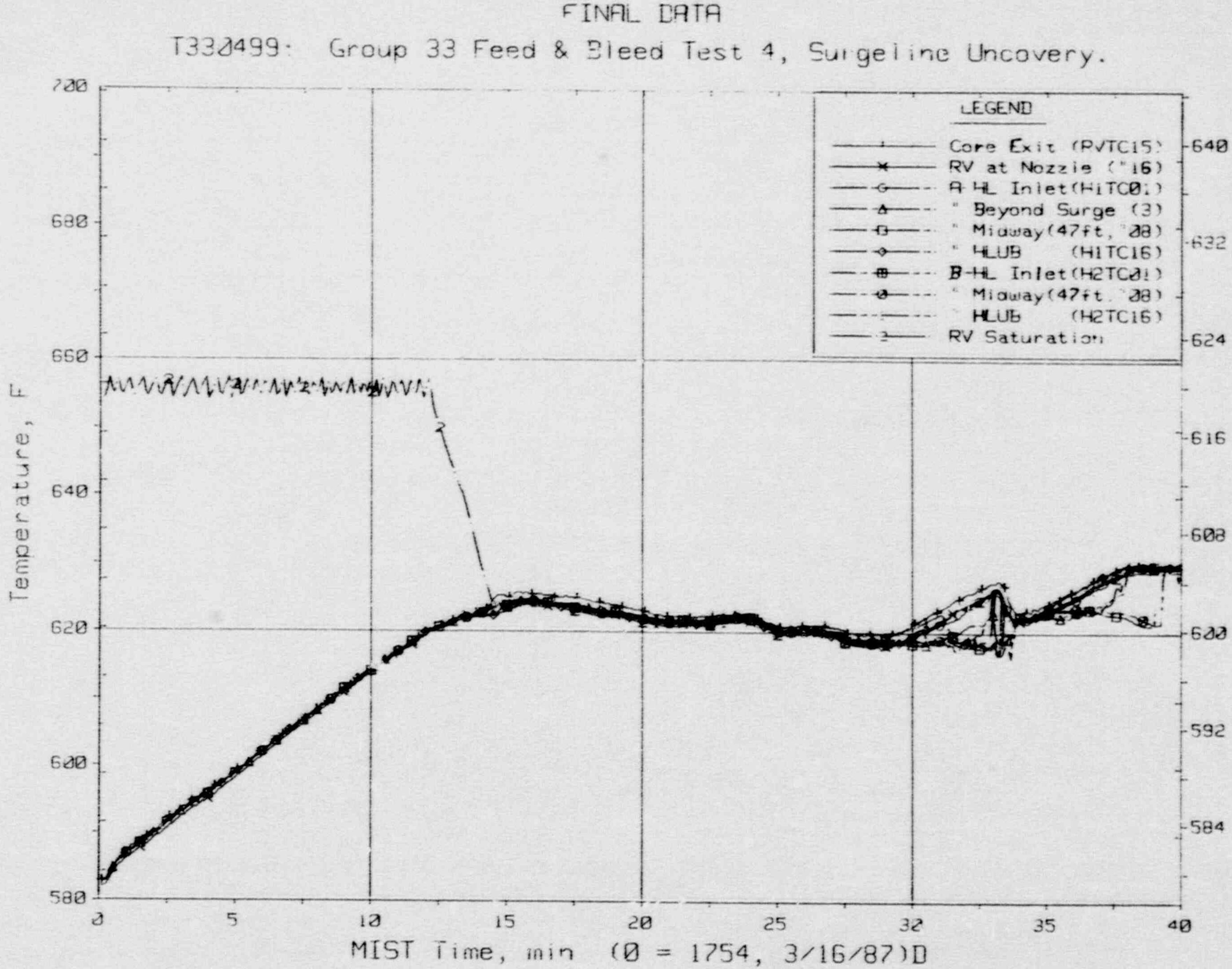


Figure 5.5.6. Composite Core Exit and Hot Leg Fluid Temperatures

Tue Nov 1 10:29:44 1988

PRKT1

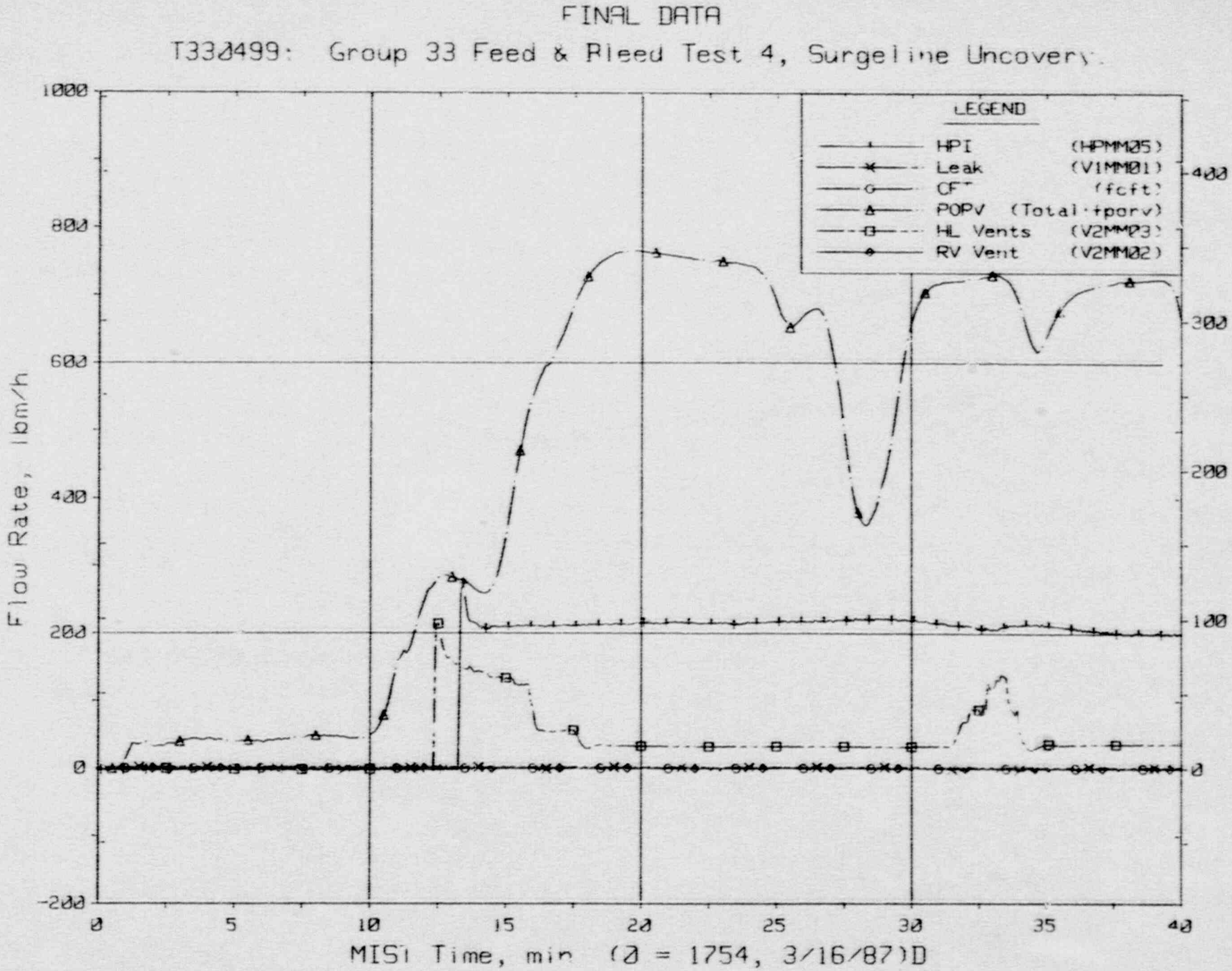


Figure 5.5.7. Primary System Boundary Flow Rates

Tue Nov 1 10:34:04 1988

PRFL3p

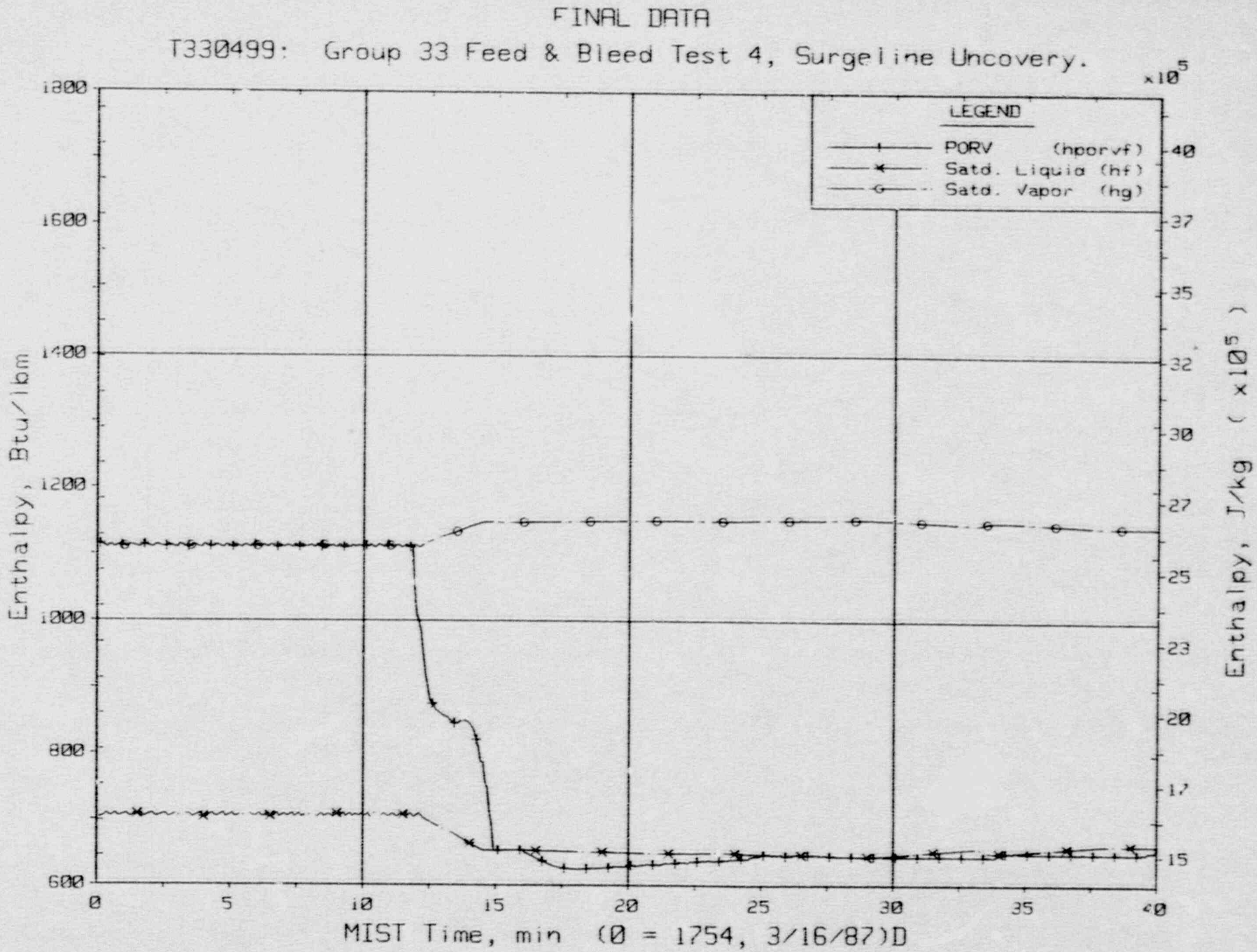


Figure 5.5.8. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Tue Nov 1 17:16:05 1988

PZEN1

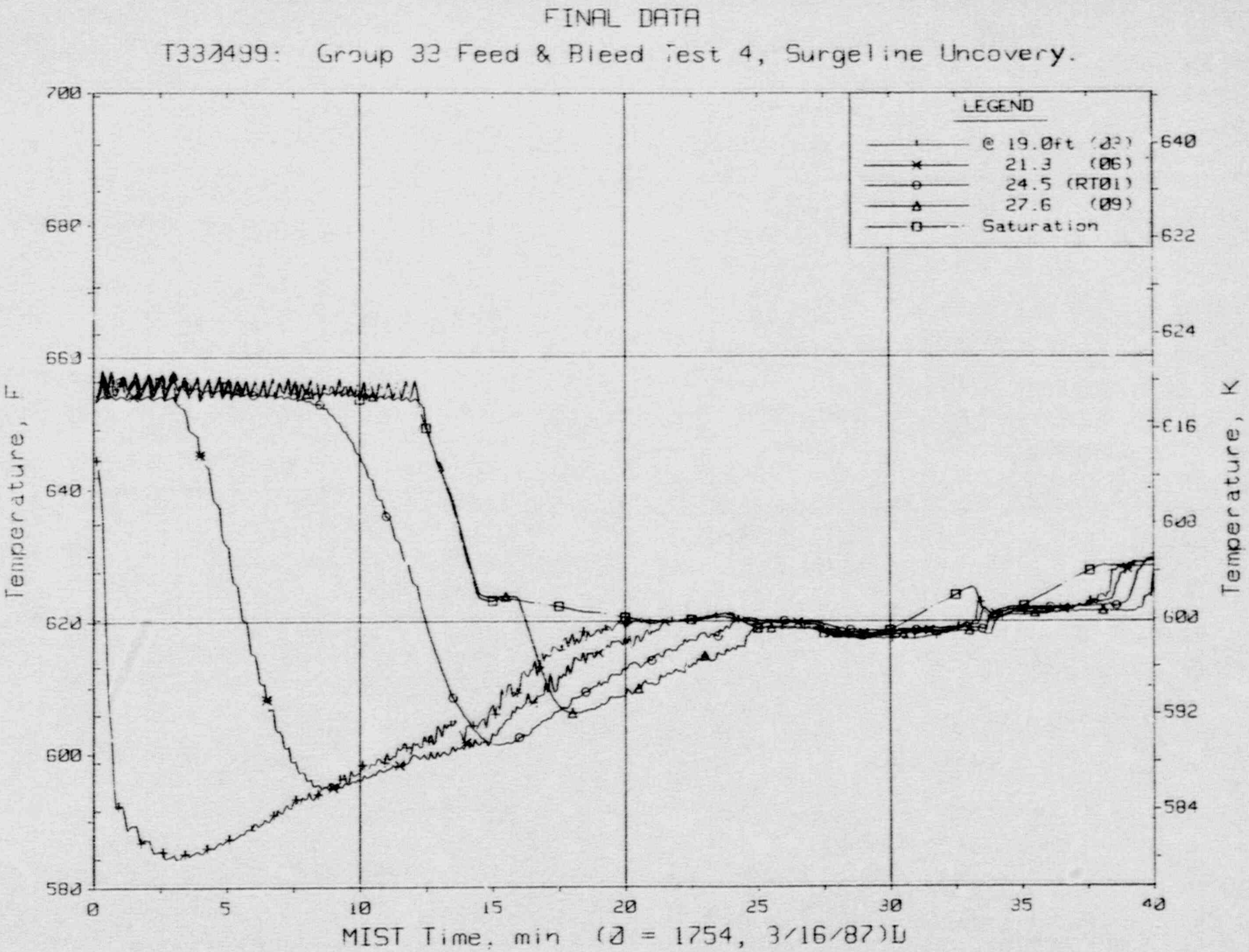
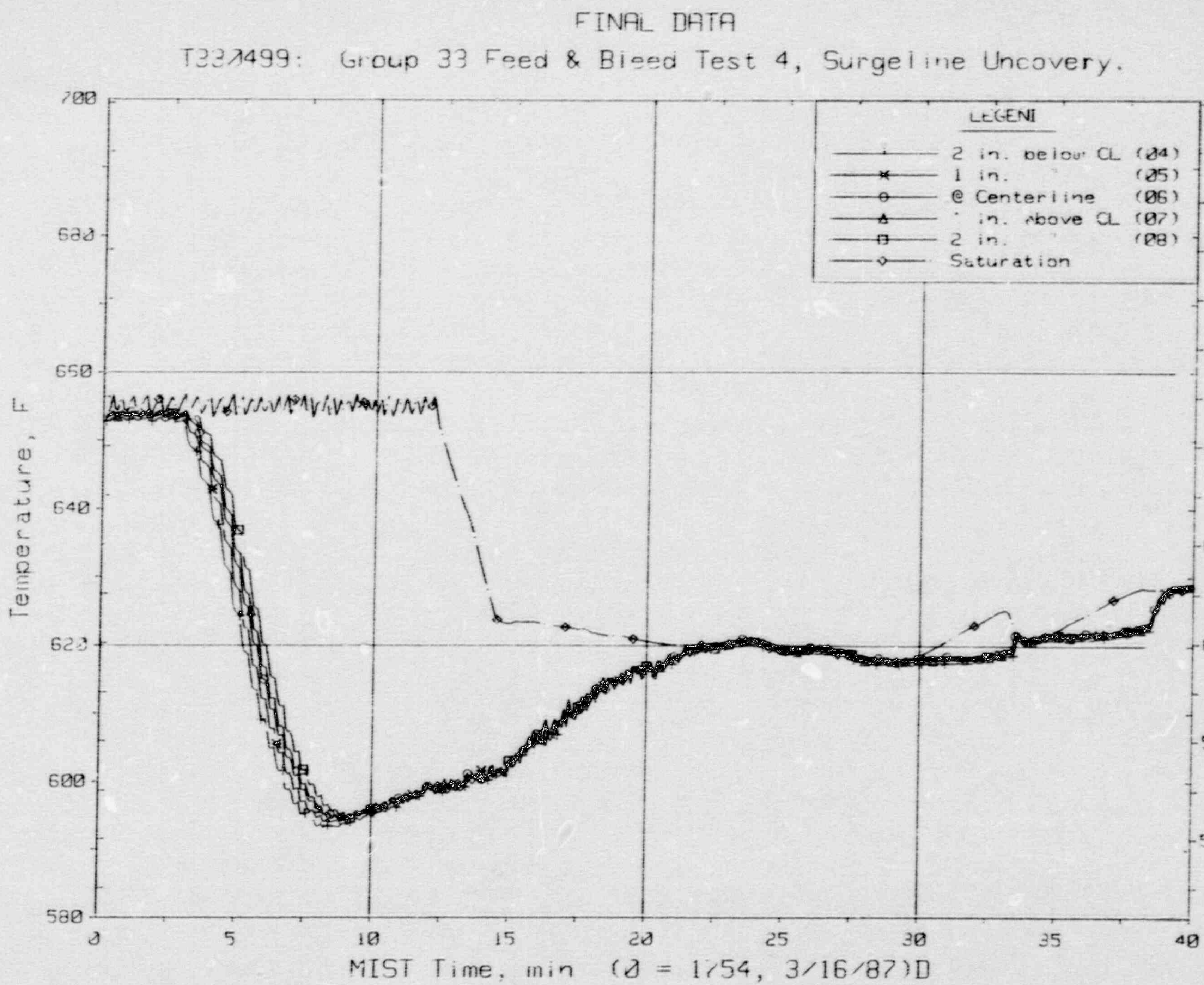


Figure 5.5.9. Pressurizer Vessel Fluid Temperatures (PZTCs)

Tue Nov 1 11:04:56 1988

PZTC2



5-77

Figure 5.5.10. Pressurizer Rake Fluid Temperatures (Elevation 21.4 ft, PZTCs)

Tue Nov 1 10:45:24 1988

PZTC3

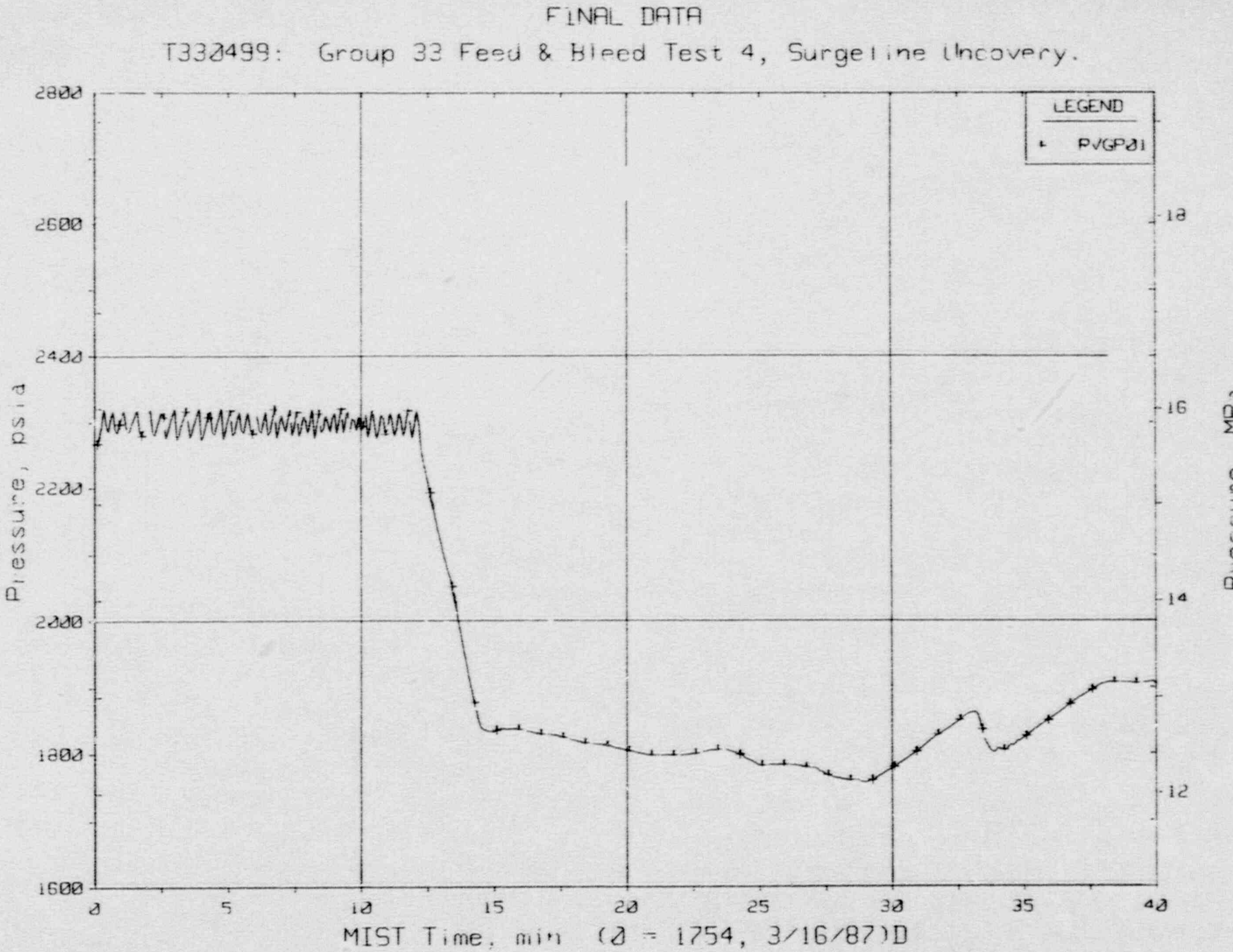


Figure 5.5.11. Reactor Vessel Pressure

Tue Nov 1 10:48:12 1988

PVGP1

FINAL DATA

T33Ø499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.

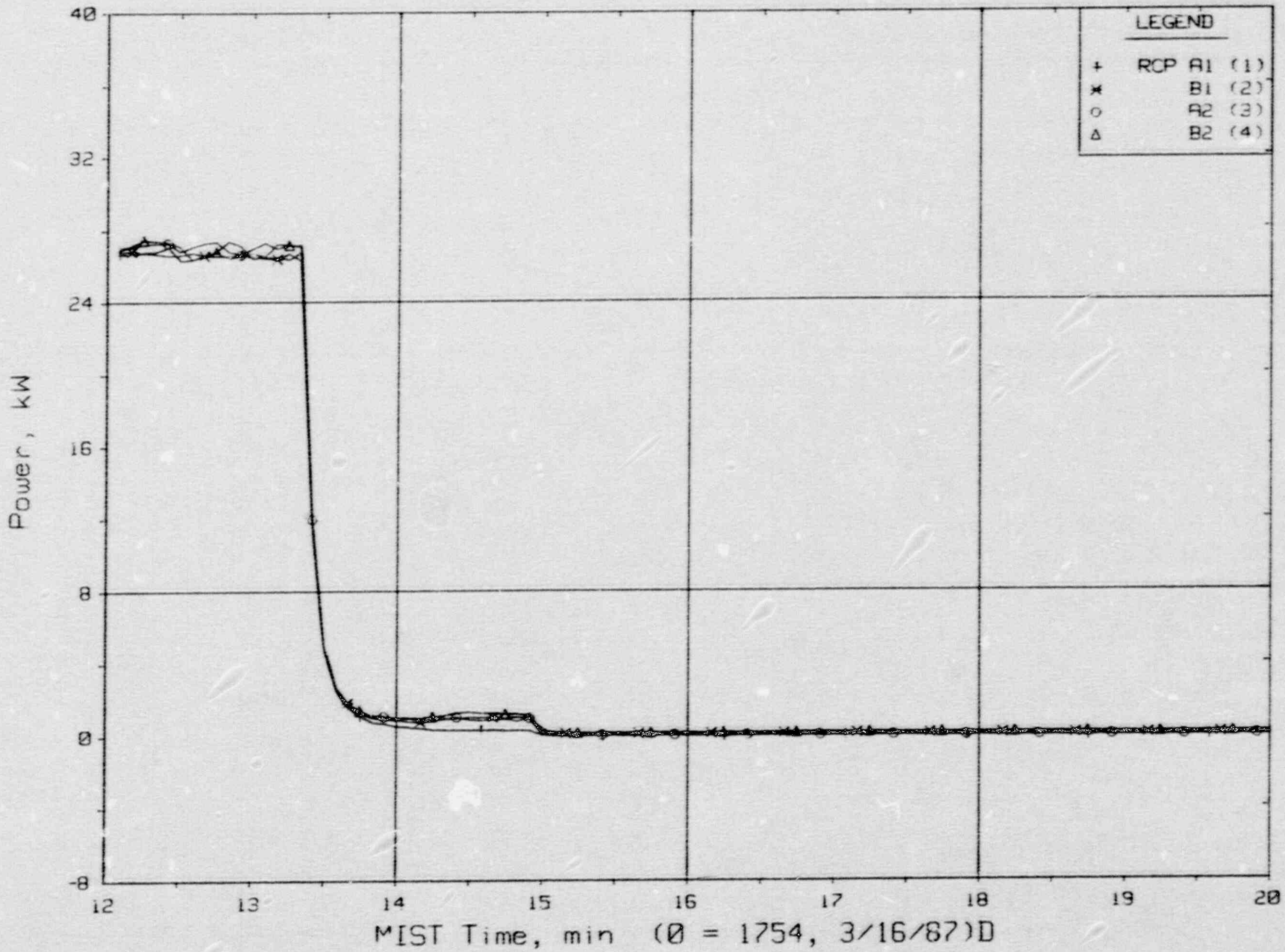


Figure 5.5.12. Reactor Coolant Pump Power (CnWM04s)

Mon Jul 18 12:51:12 1988

PUWM1

FINAL DATA

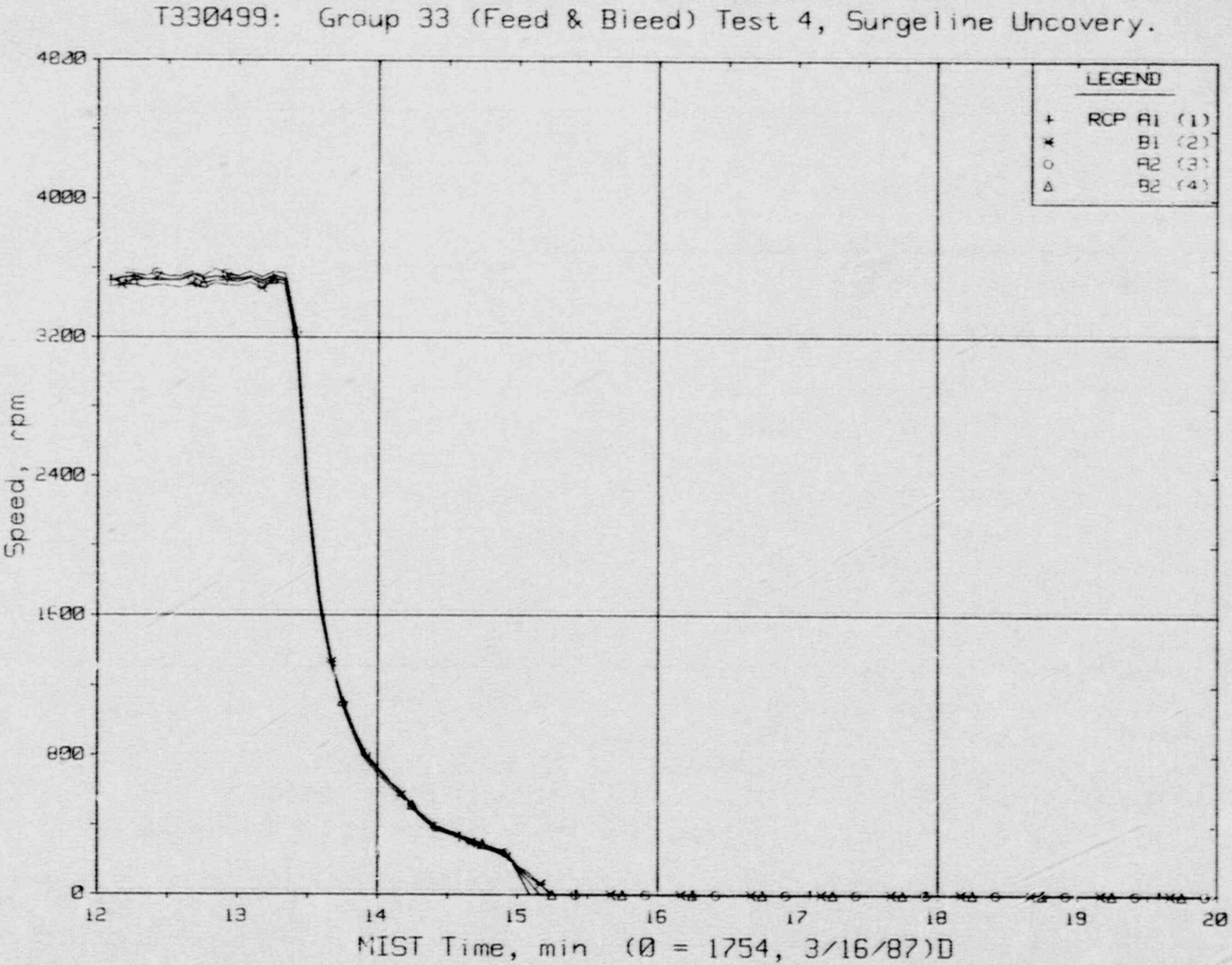


Figure 5.5.13. Reactor Coolant Pump Speed (CnTA20s)

Mon Jul 18 12:52:59 1988

PUTA0

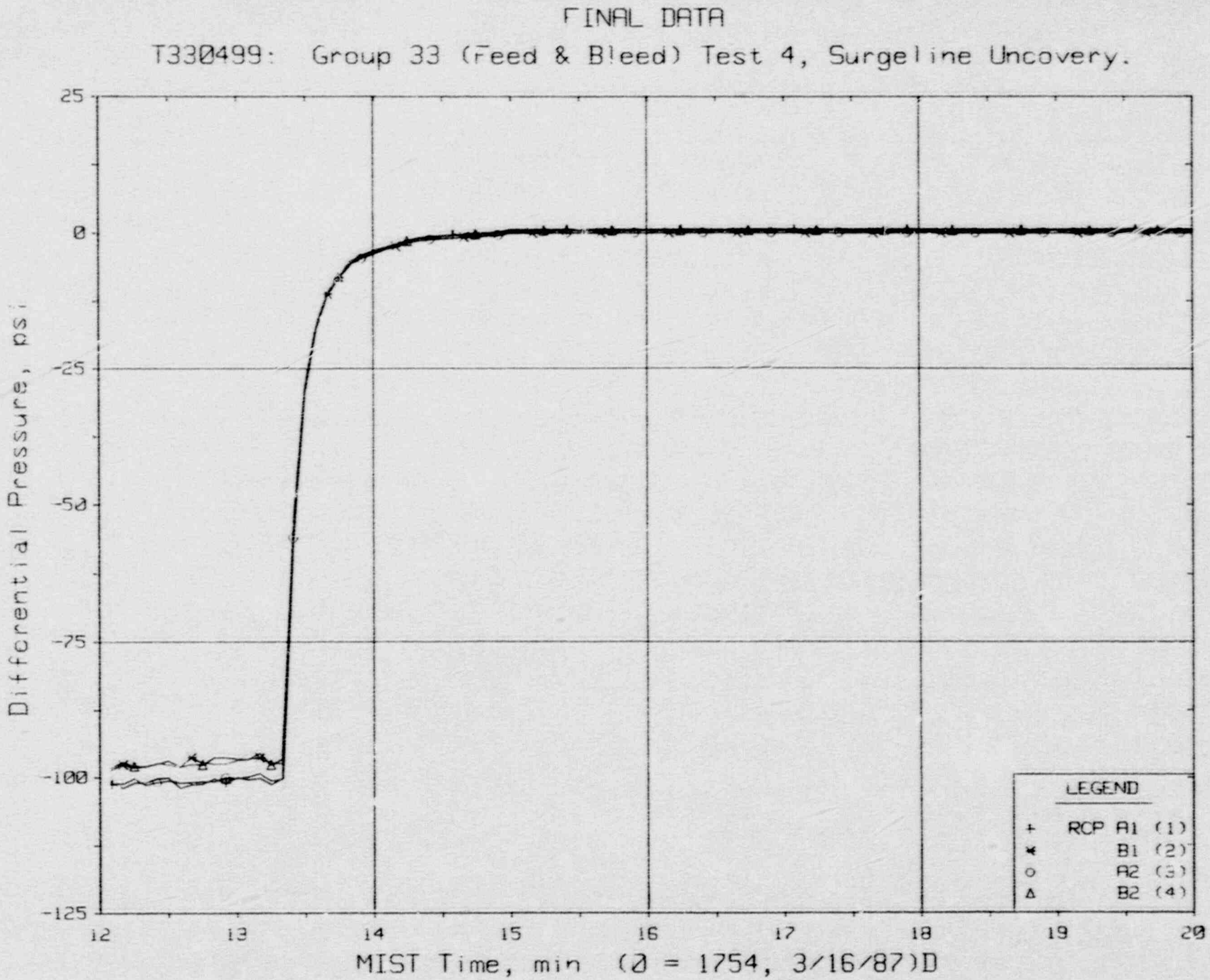


Figure 5.5.14. Reactor Coolant Pump DPs (CnDP07s)

Mon Jul 18 12:54:46 1988

PUDP1

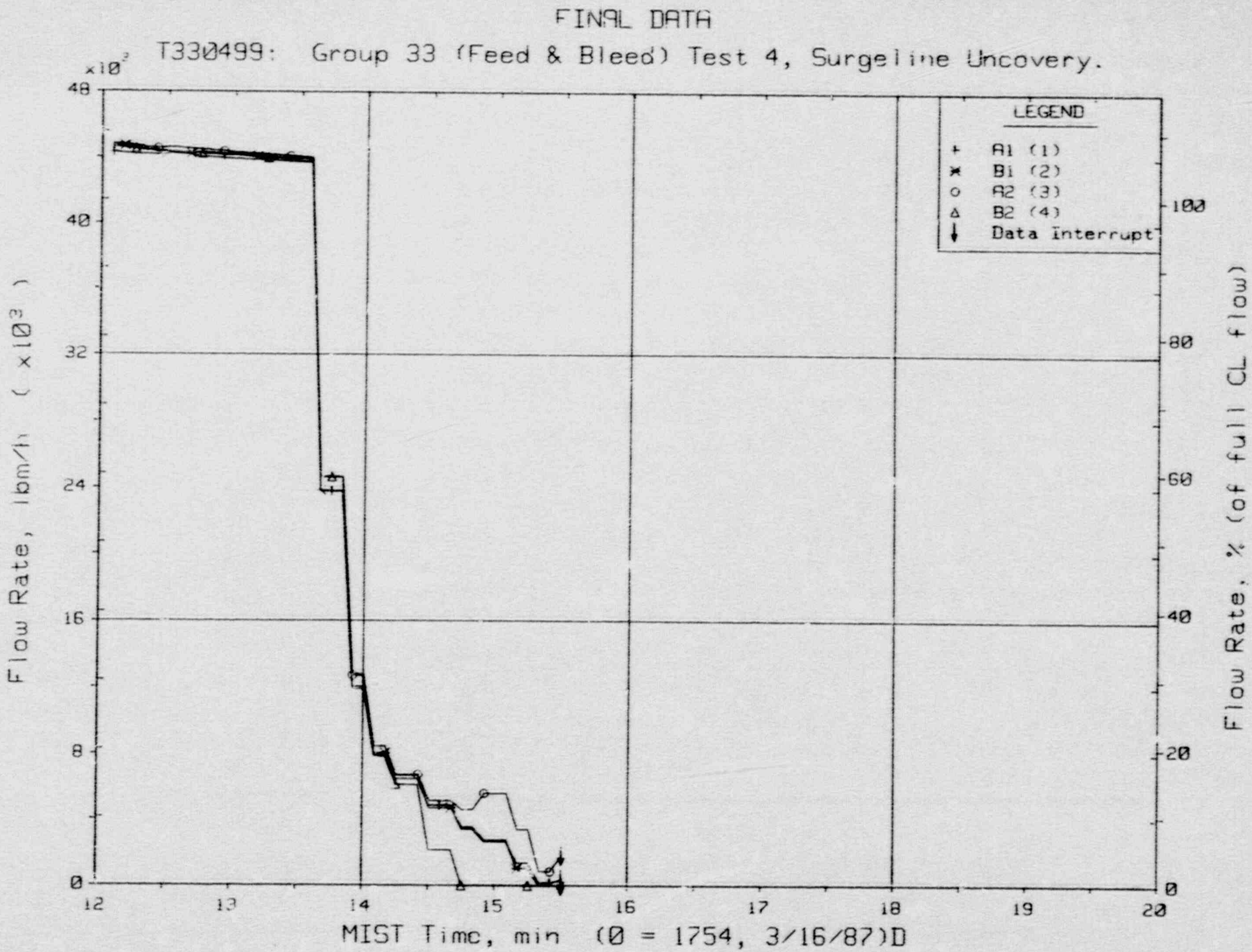


Figure 5.5.15. Cold Leg (Turbine Meter) Flow Rates (CnTM01s)

Mon Jul 16 12:56:20 1988

CLFL3

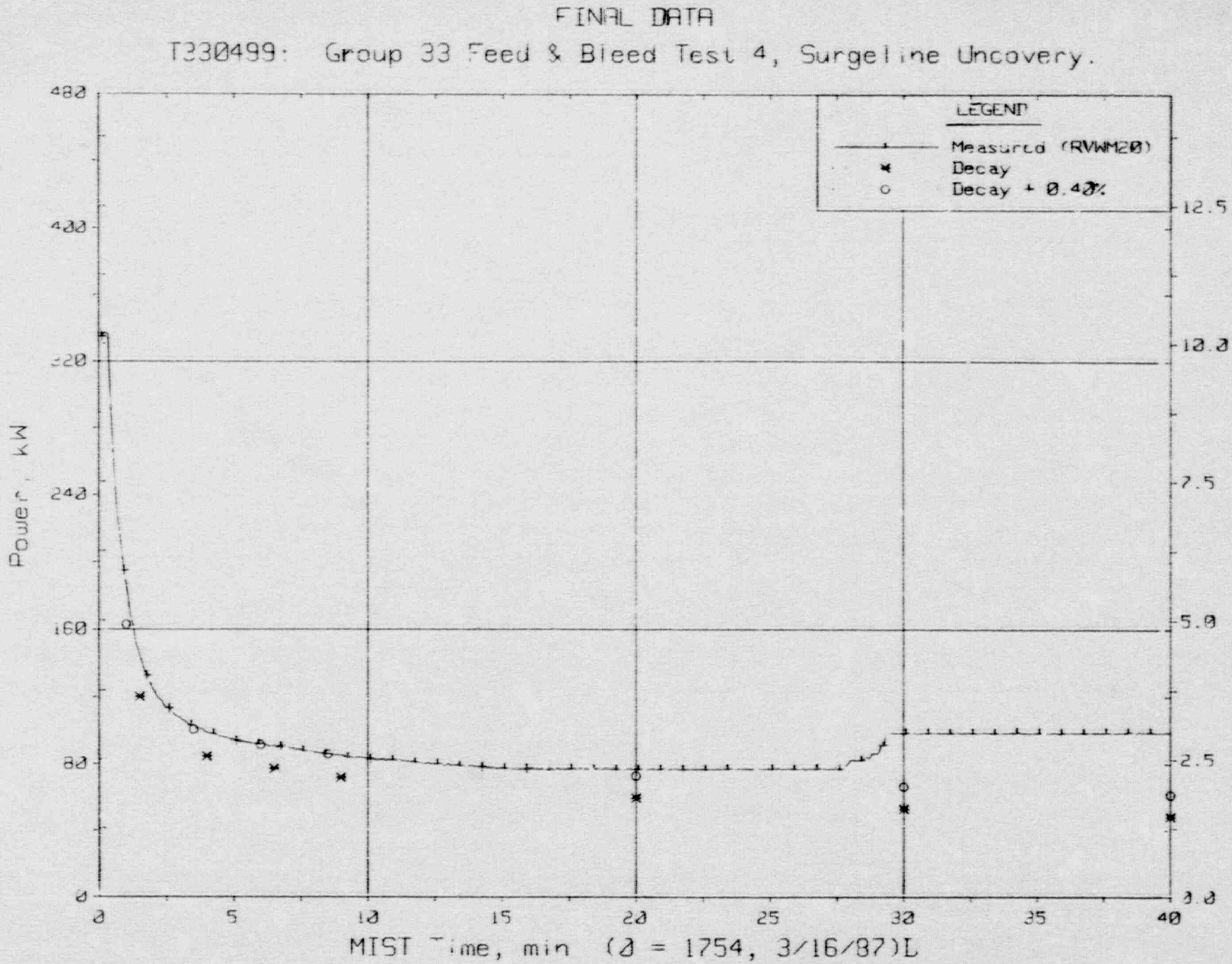


Figure 5.5.16. Core Power

Tue Nov 1 10:50:22 1988

RVKW1

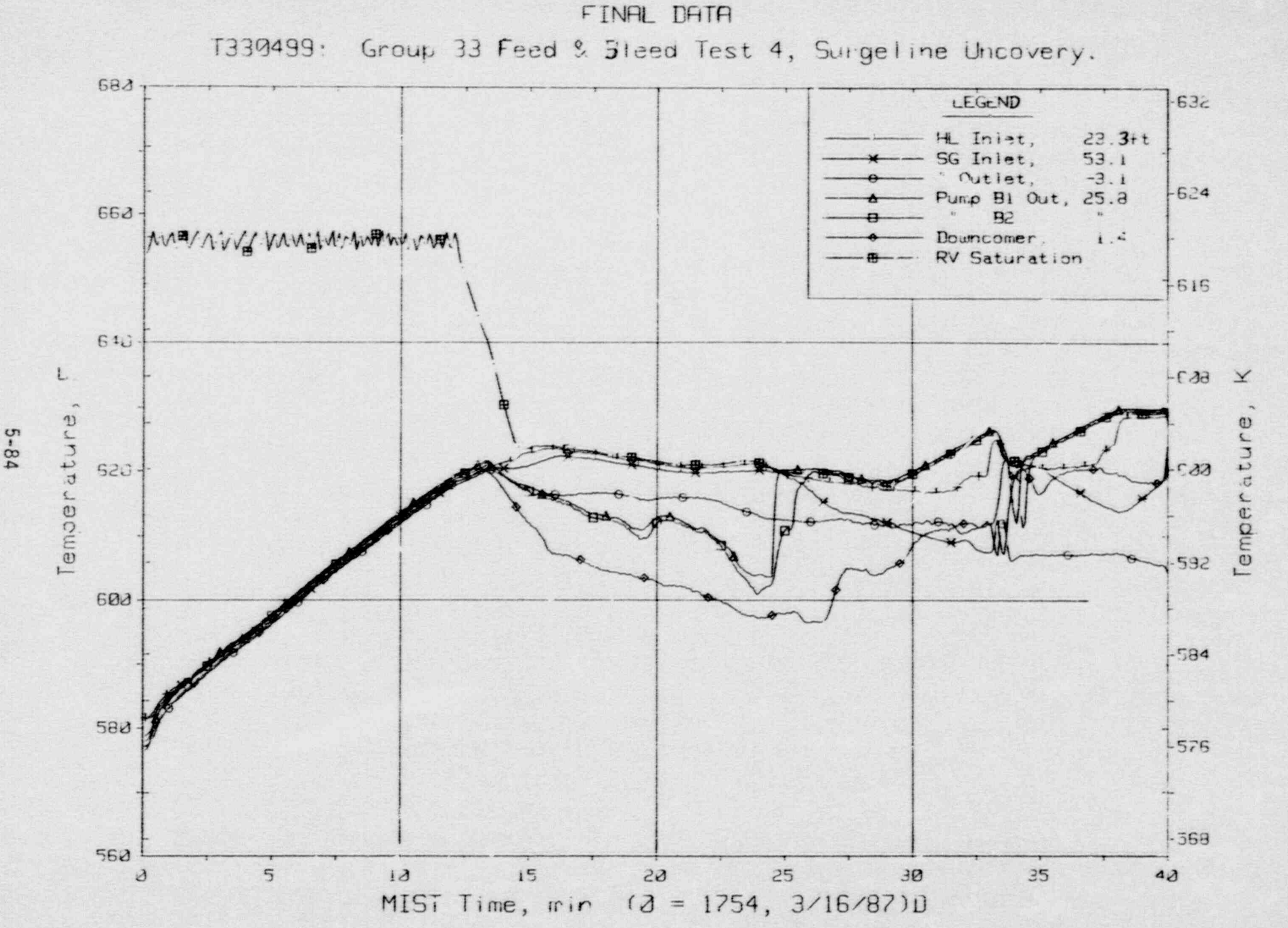


Figure 5.5.17. Loop B Primary Fluid Temperatures (RTDs)

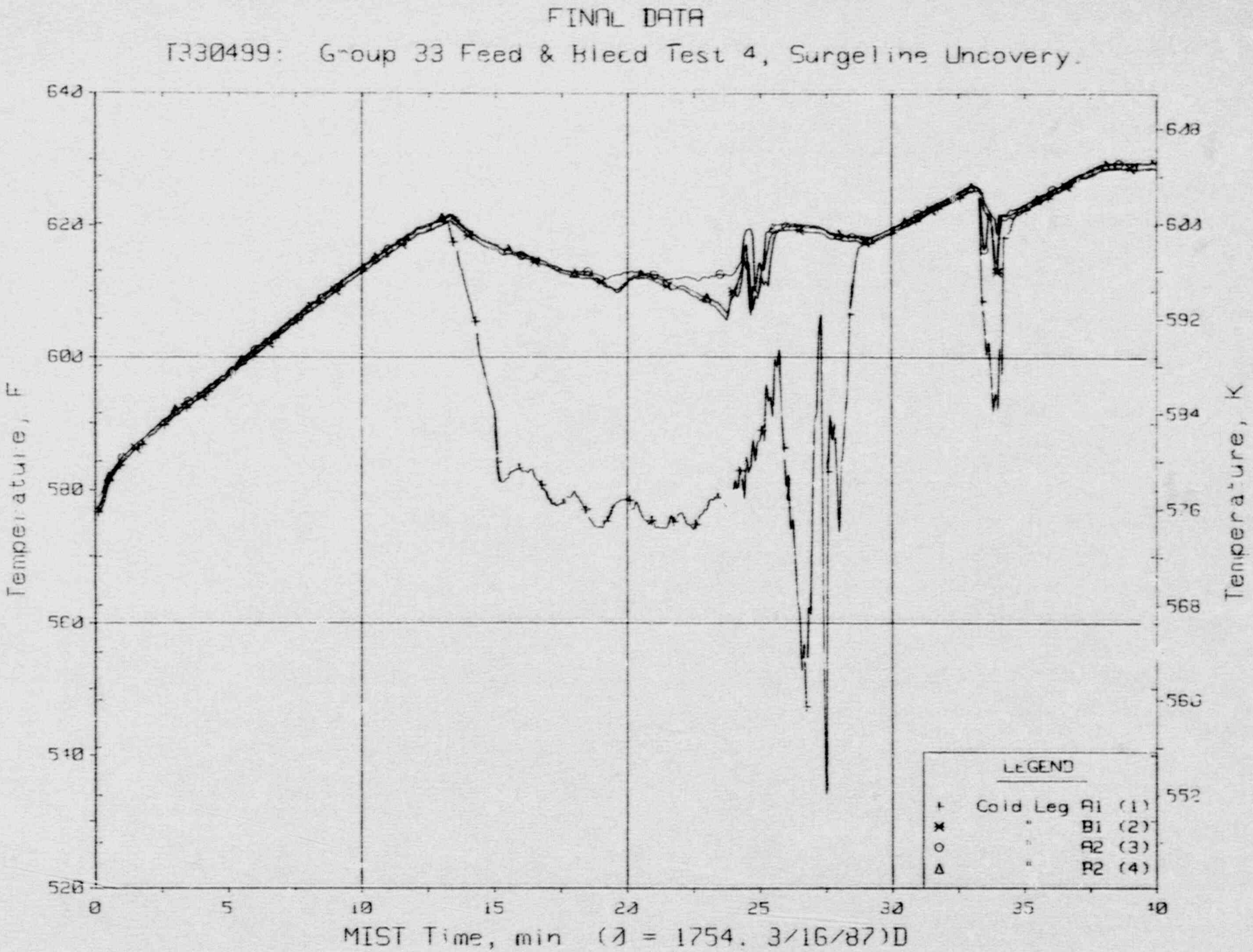
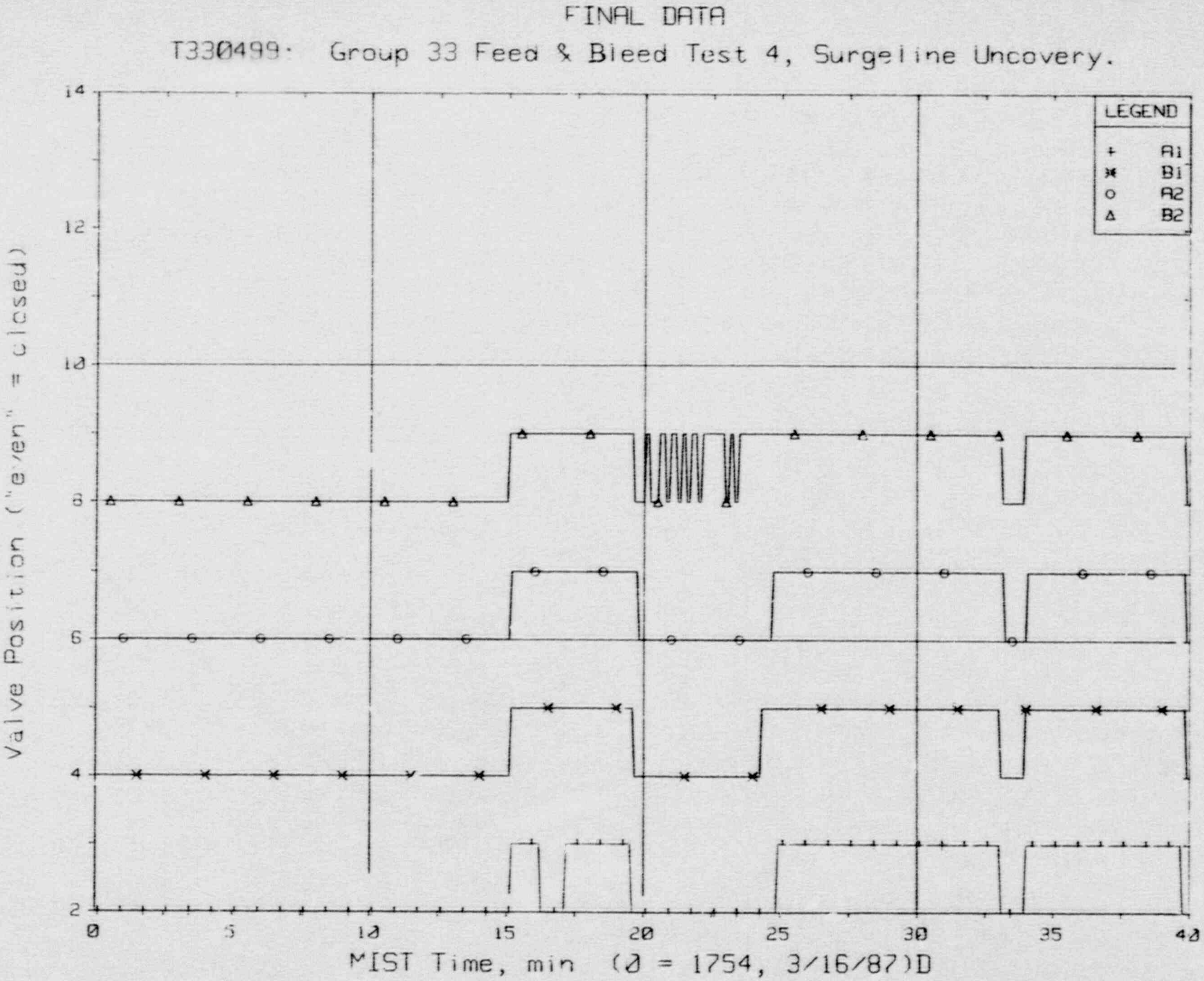


Figure 5.5.18. Cold Leg Nozzle Fluid Temperatures, Bottom of Rake (21.2 ft, CnTC14s)

Tue Nov 1 10:57 27 1988

CLTC2



5-86

Figure 5.5.19. Reactor Vessel Vent Valve Positions

Tue Nov 1 11:01:21 1988

VVLS1

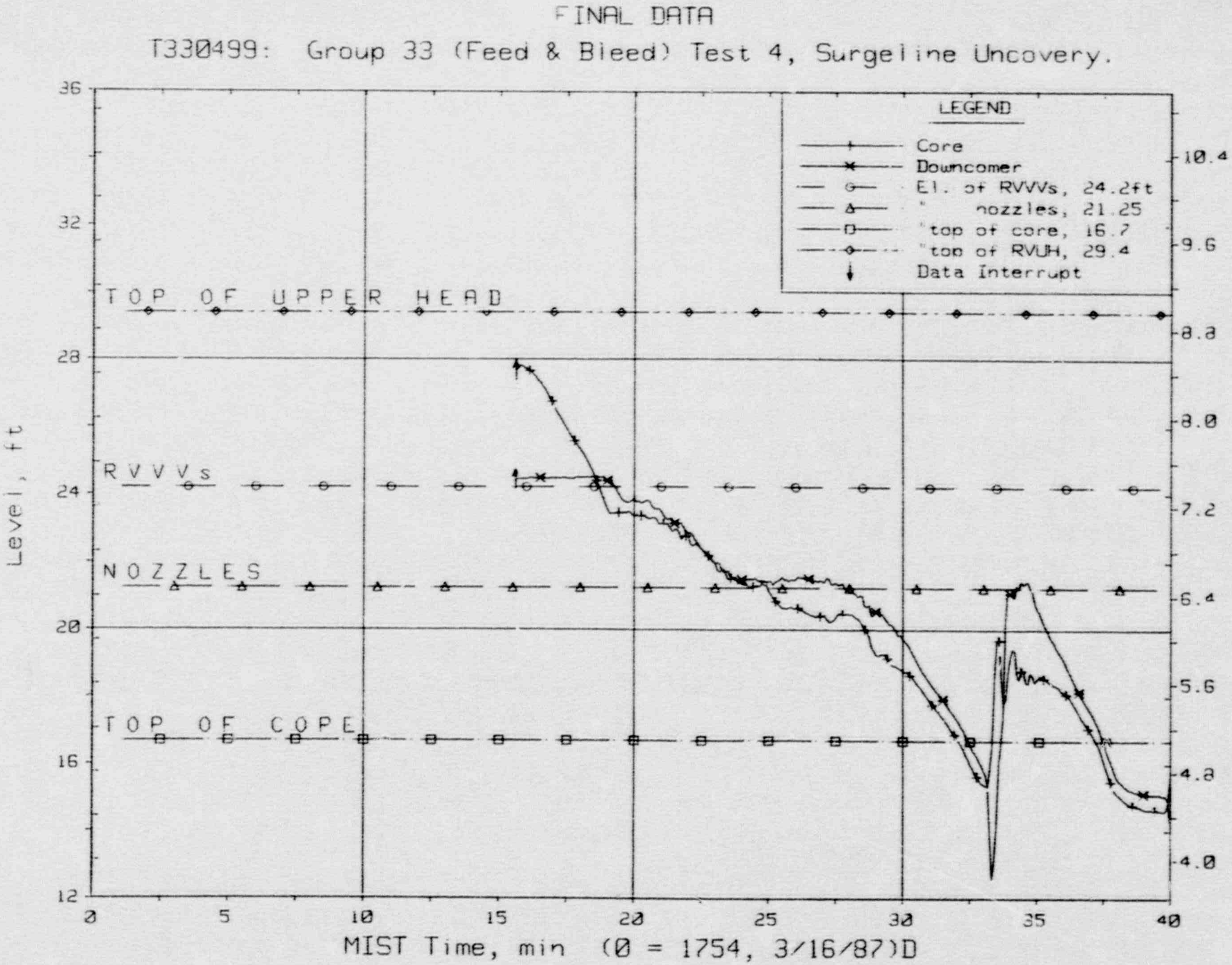
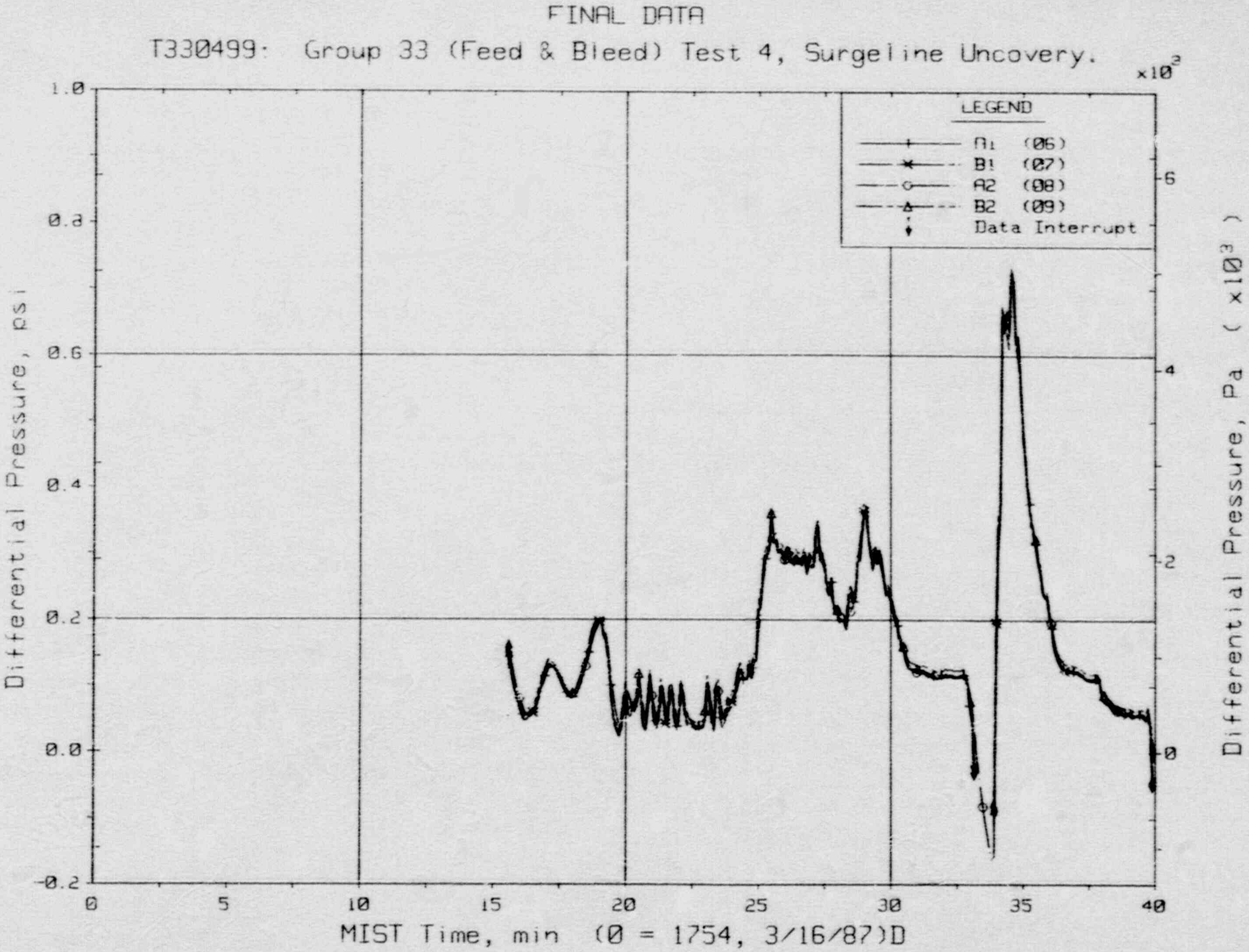


Figure 5.5.20. Core Region Collapsed Liquid Levels

Mon Jul 18 12:41:50 1988

COLV1



5-88

Figure 5.5.21. Reactor Vessel Vent Valve Differential Pressures (RVDPs)

Mon Jul 18 12:44:38 1988

VVDP1

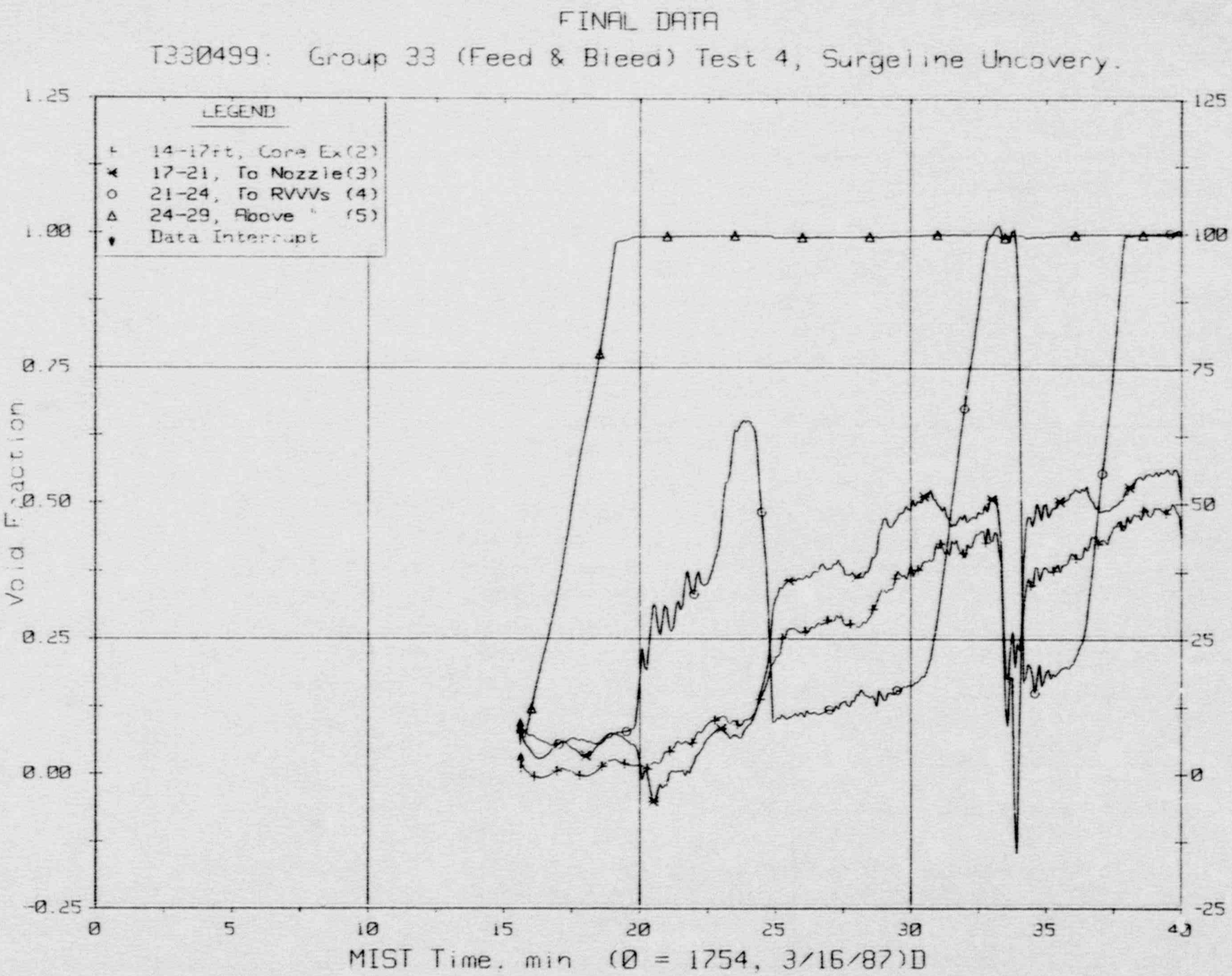


Figure 5.5.22. Reactor Vessel Void Fractions from Differential Pressures (RVVFs)

Mon Jul 18 12:47:17 1988

RVVF1

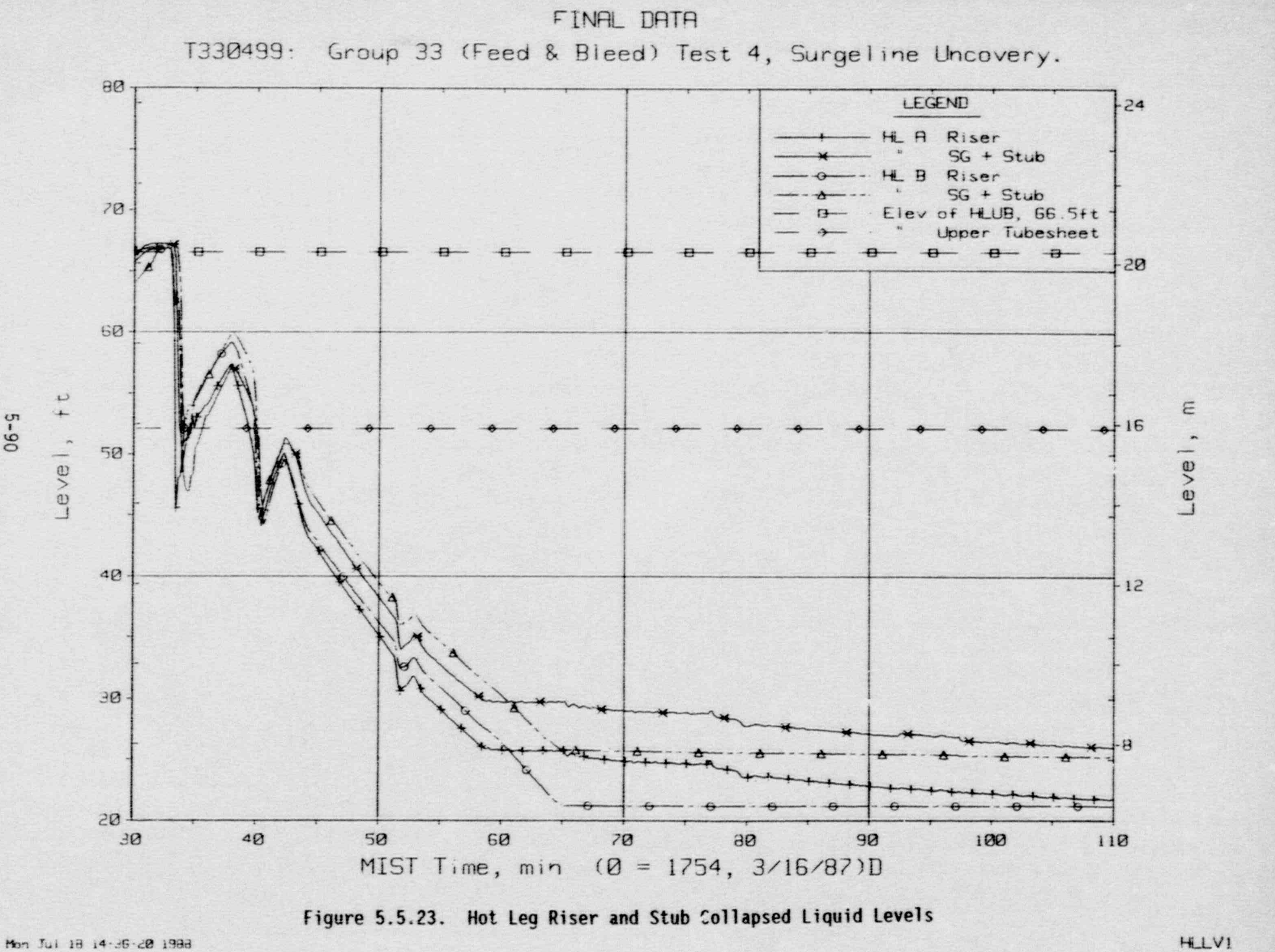


Figure 5.5.23. Hot Leg Riser and Stub Collapsed Liquid Levels

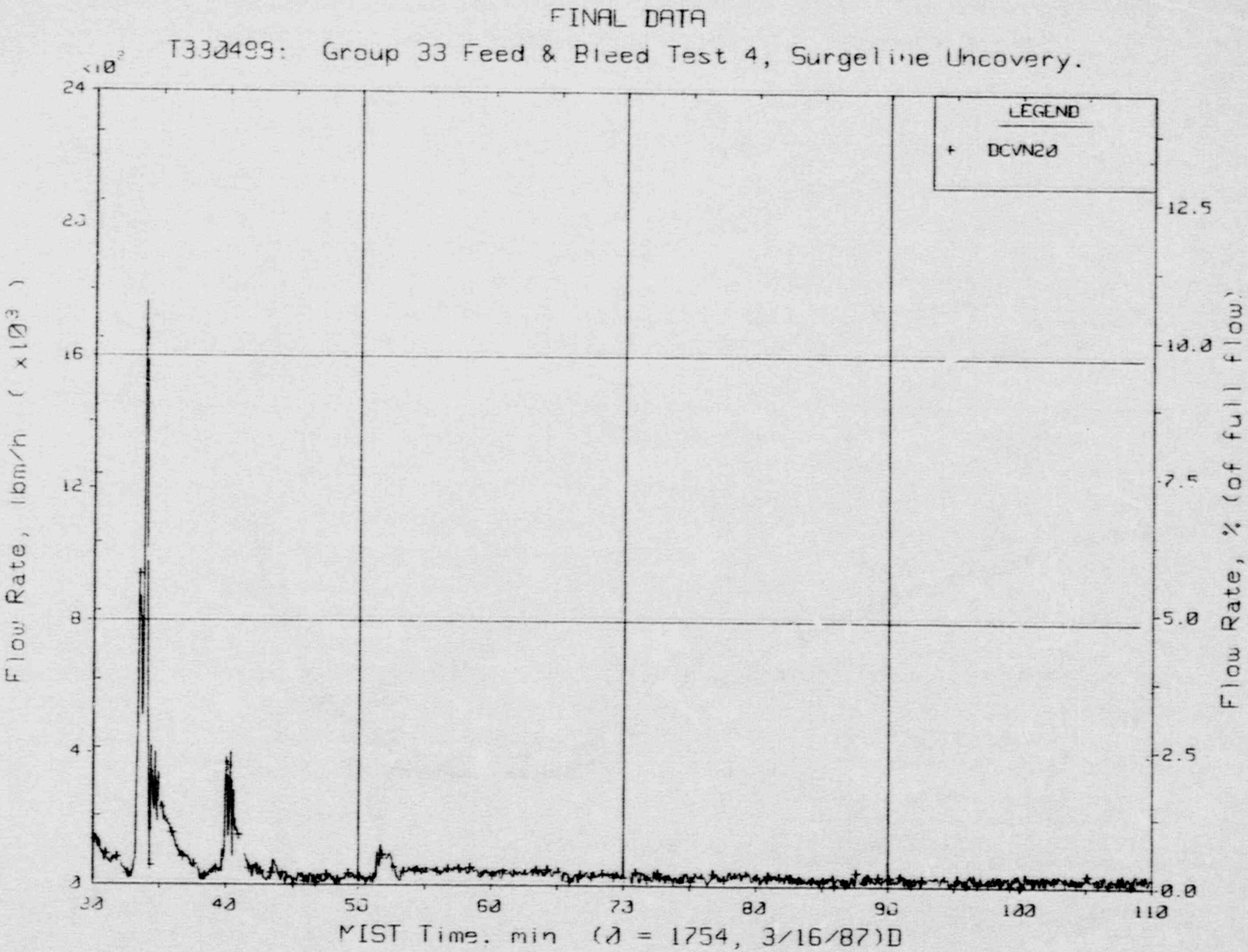


Figure 5.5.24. Primary System Venturi Flow Rates

Tue Nov 1 11:33:10 1988

DCFL1

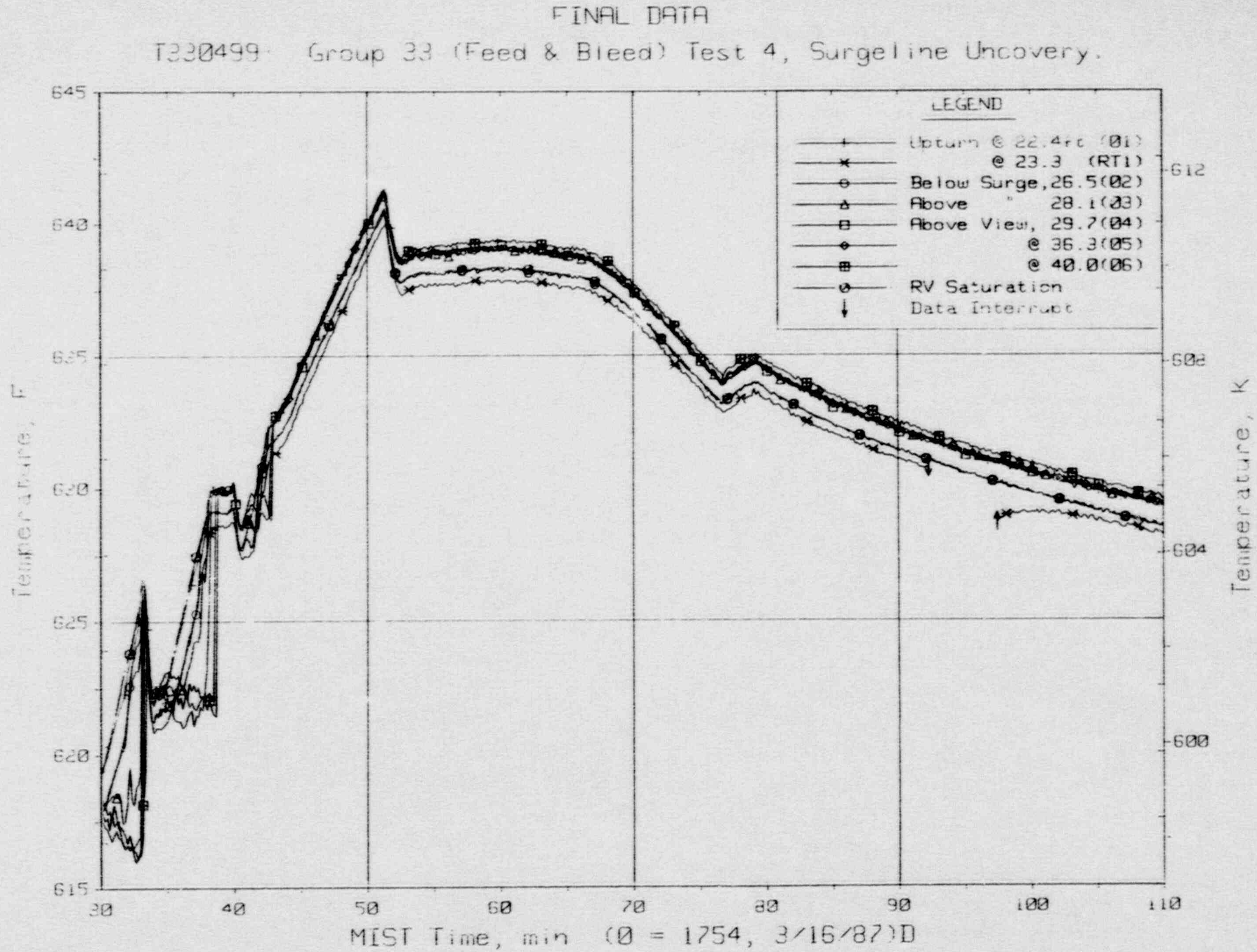


Figure 5.5.25. Hot Leg A Lower-Elevation Riser Fluid Temperatures (H1TCs)

Mon Jul 18 14:01:22 1988

H1TC1

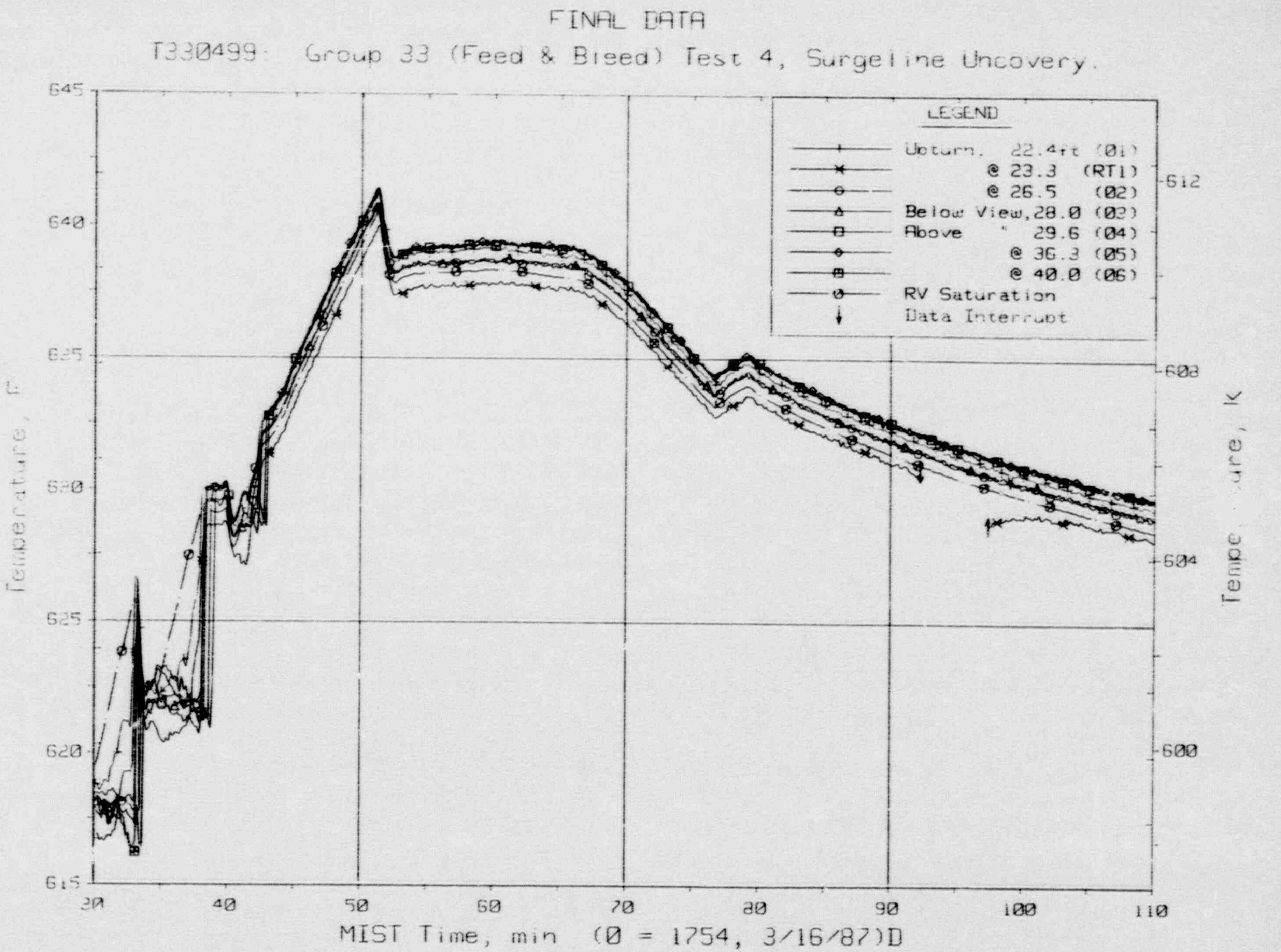


Figure 5.5.26. Hot Leg B Lower-Elevation Riser Fluid Temperatures (H2TCs)

Mon Jul 18 14:05:24 1988

H2TC1

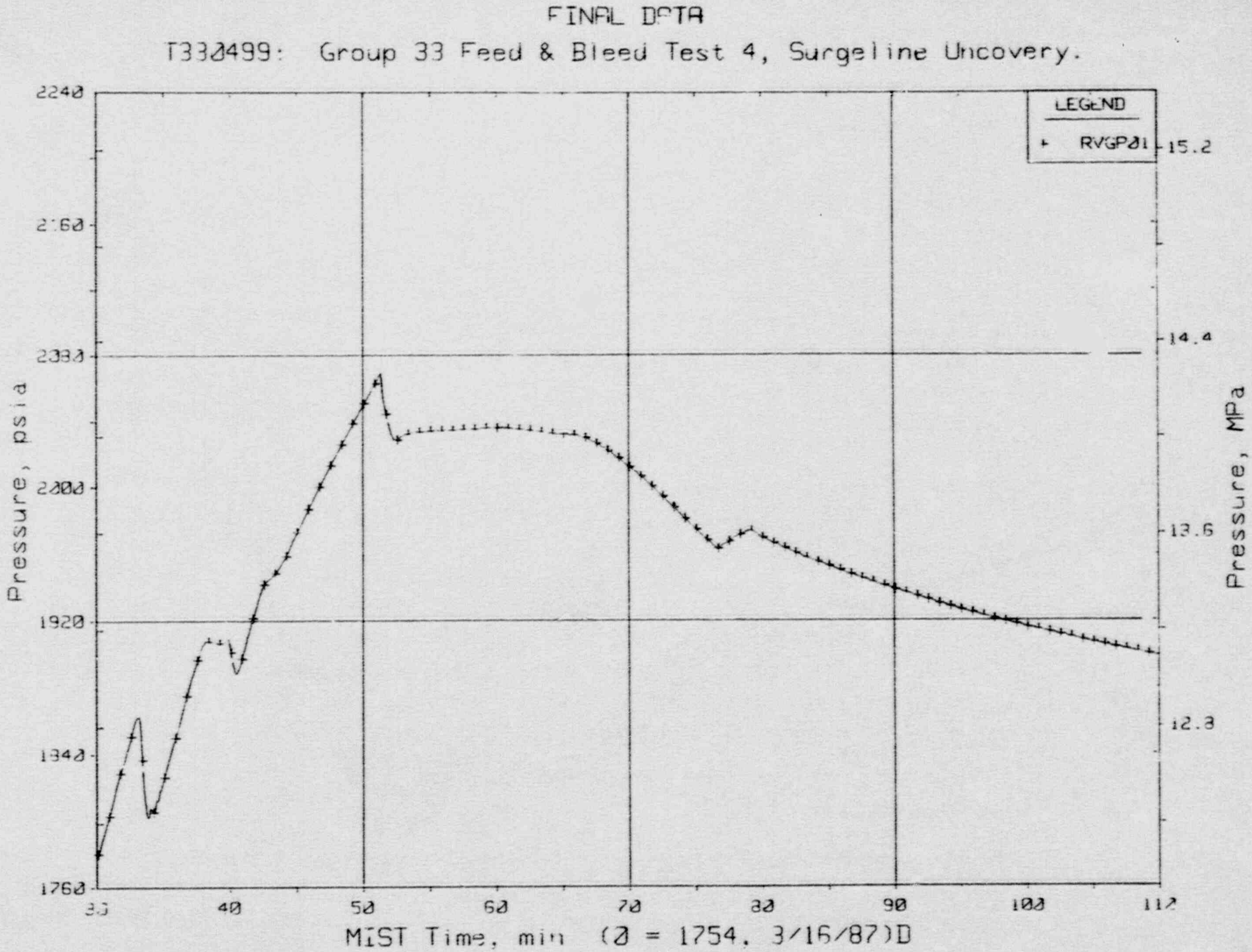


Figure 5.5.27. Reactor Vessel Pressure

Tue Nov 1 11:10:28 1988

RVGP1

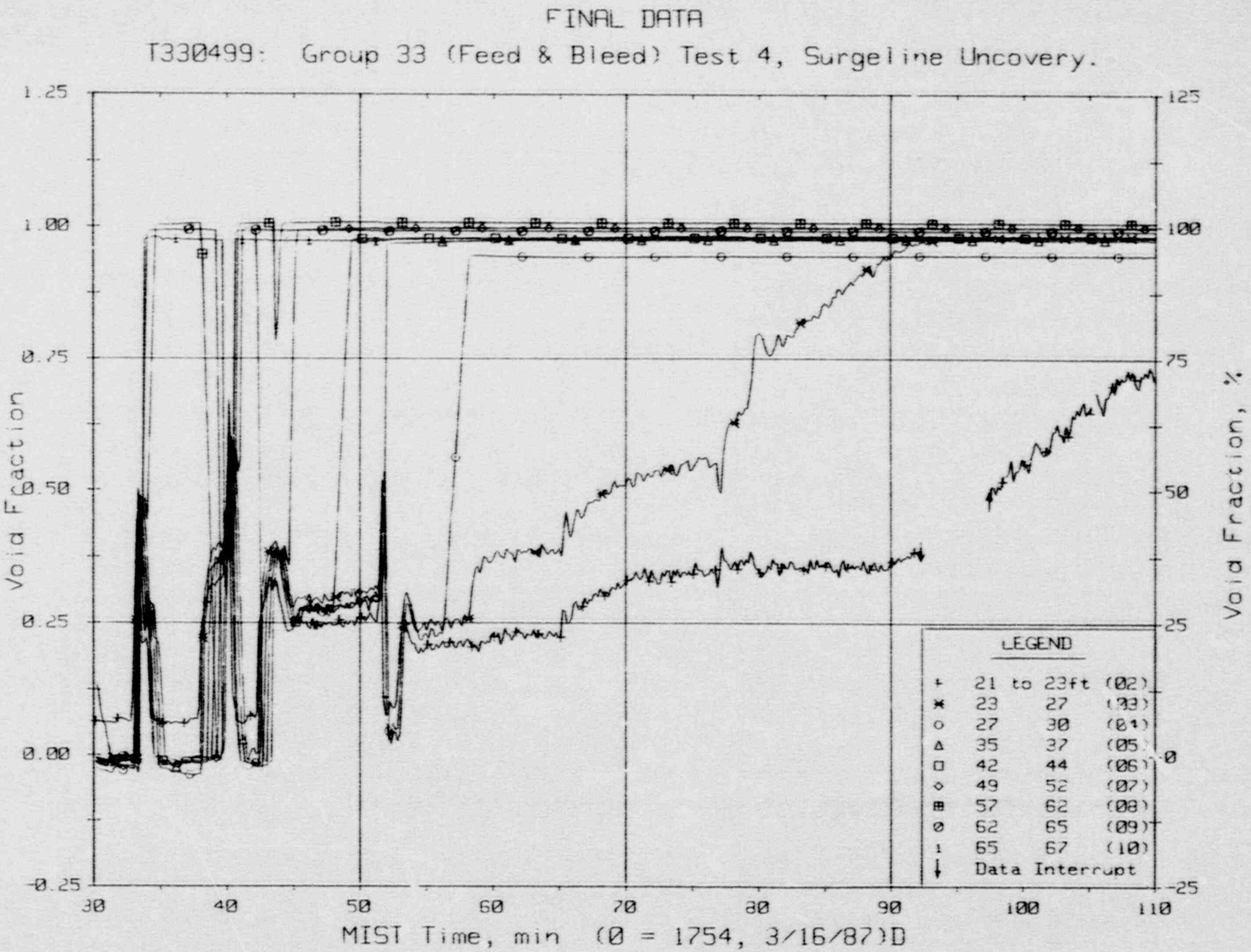


Figure 5.5.28. Hot Leg A Riser Void Fractions from Differential Pressures (H1VFs)

Mon Jul 18 14:40:14 1988

H1VF1

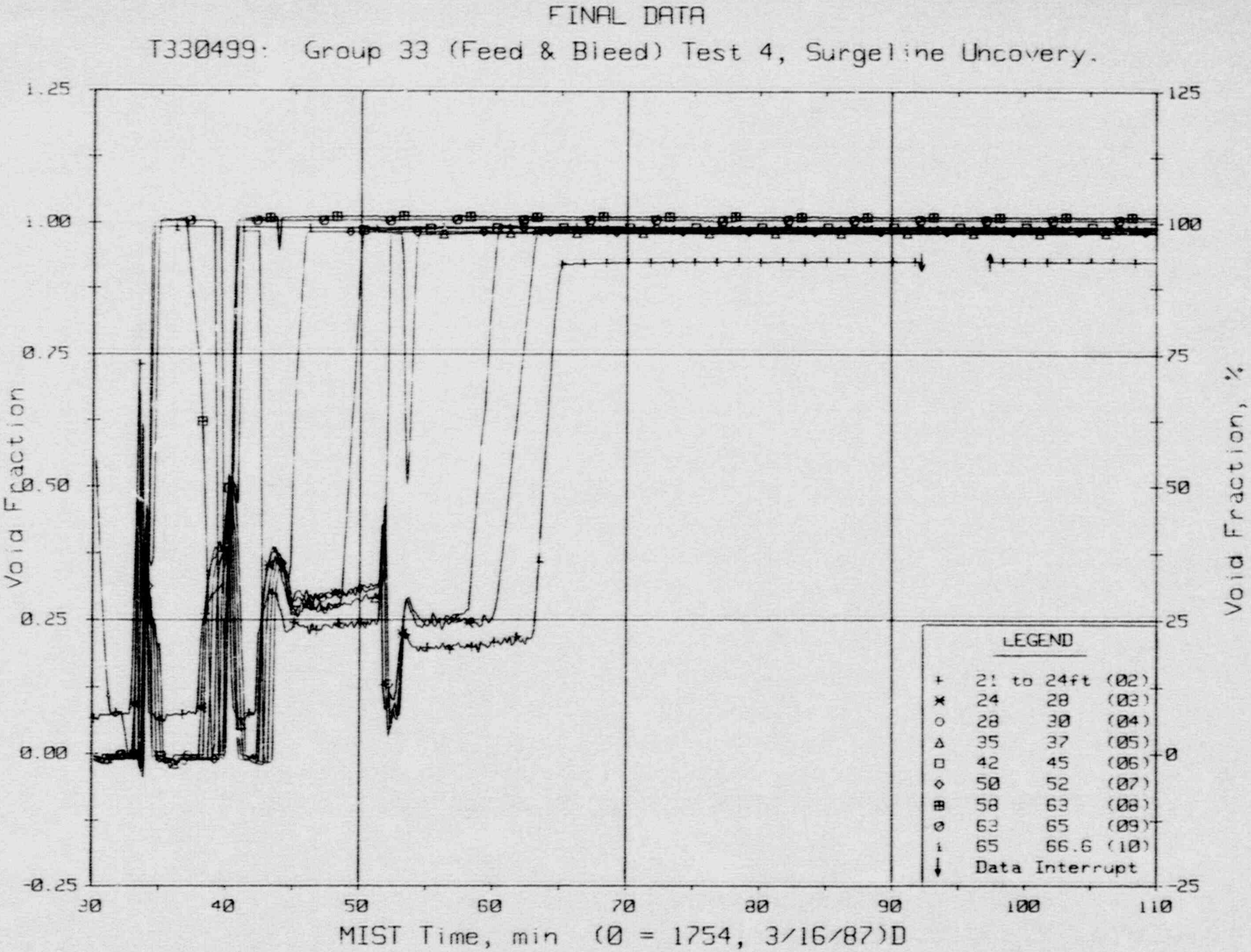


Figure 5.5.29. Hot Leg B Riser Void Fraction from Differential Pressures (H2VFs)

Mon Jul 18 14:44:16 1988

H2VF1

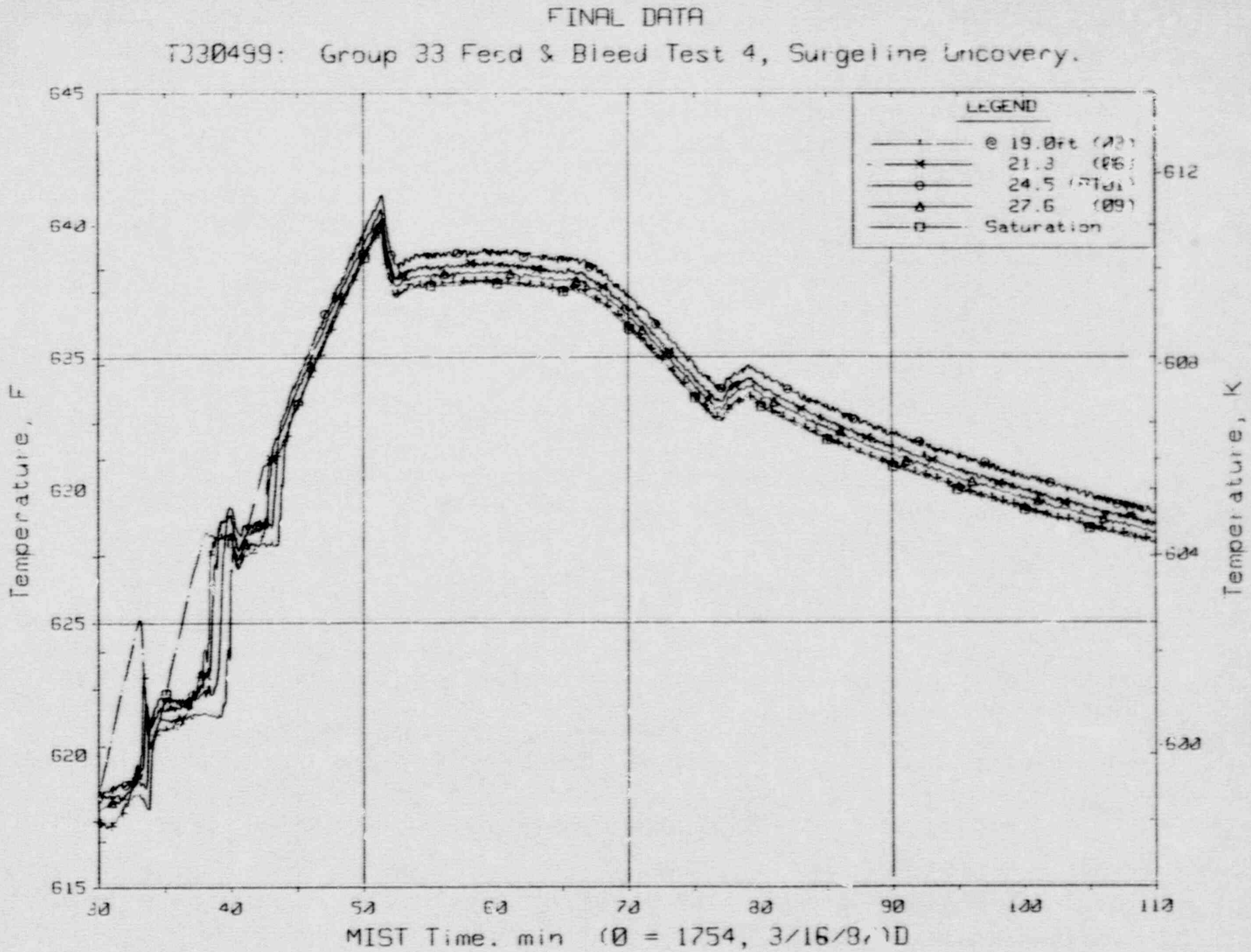


Figure 5.5.30. Pressurizer Vessel Fluid Temperatures (PZTCs)

Tue Nov 1 11:12:54 1988

PZTC2

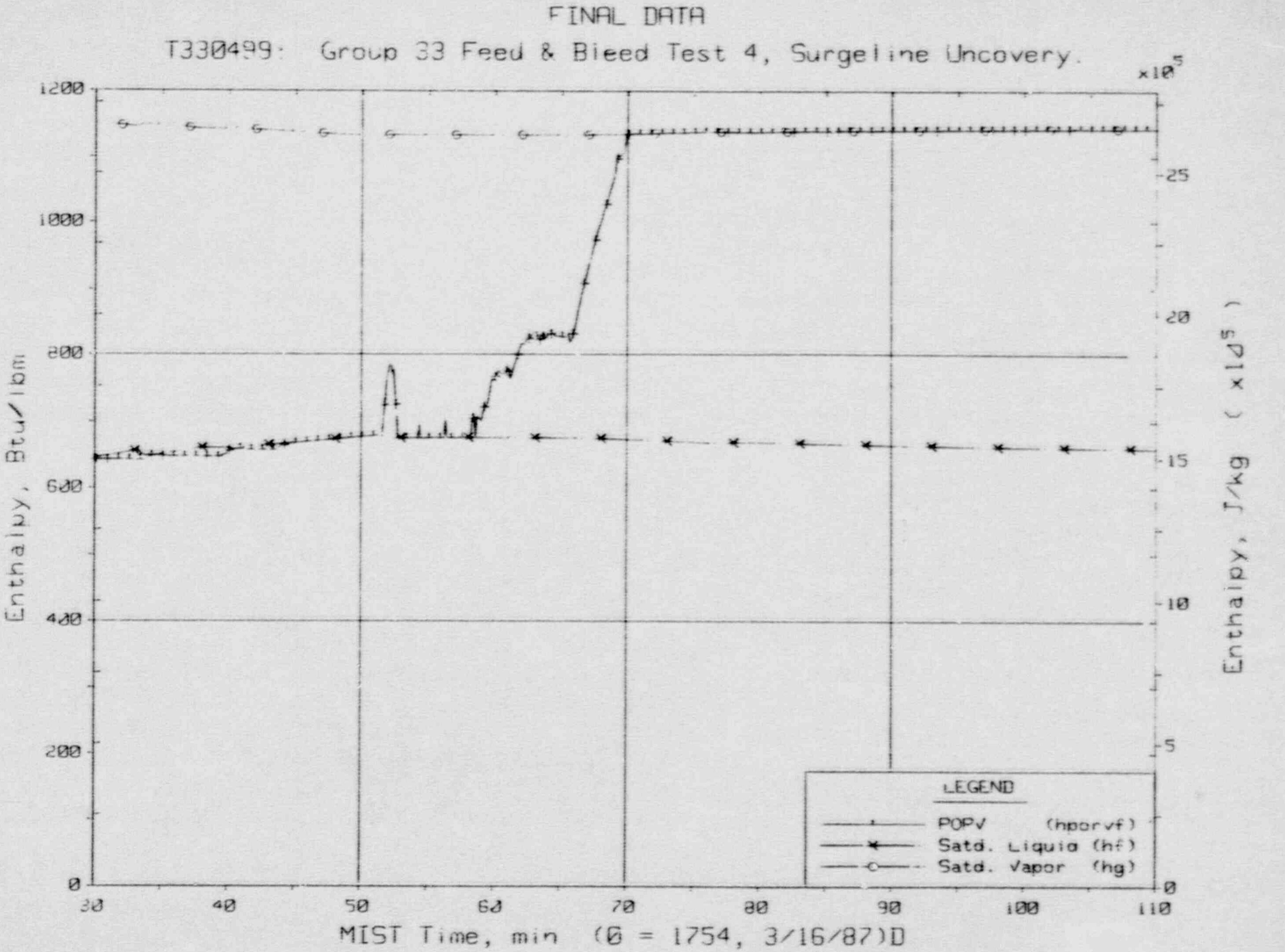


Figure 5.5.31. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Tue Nov 1 11:20:54 1988

PZEN1

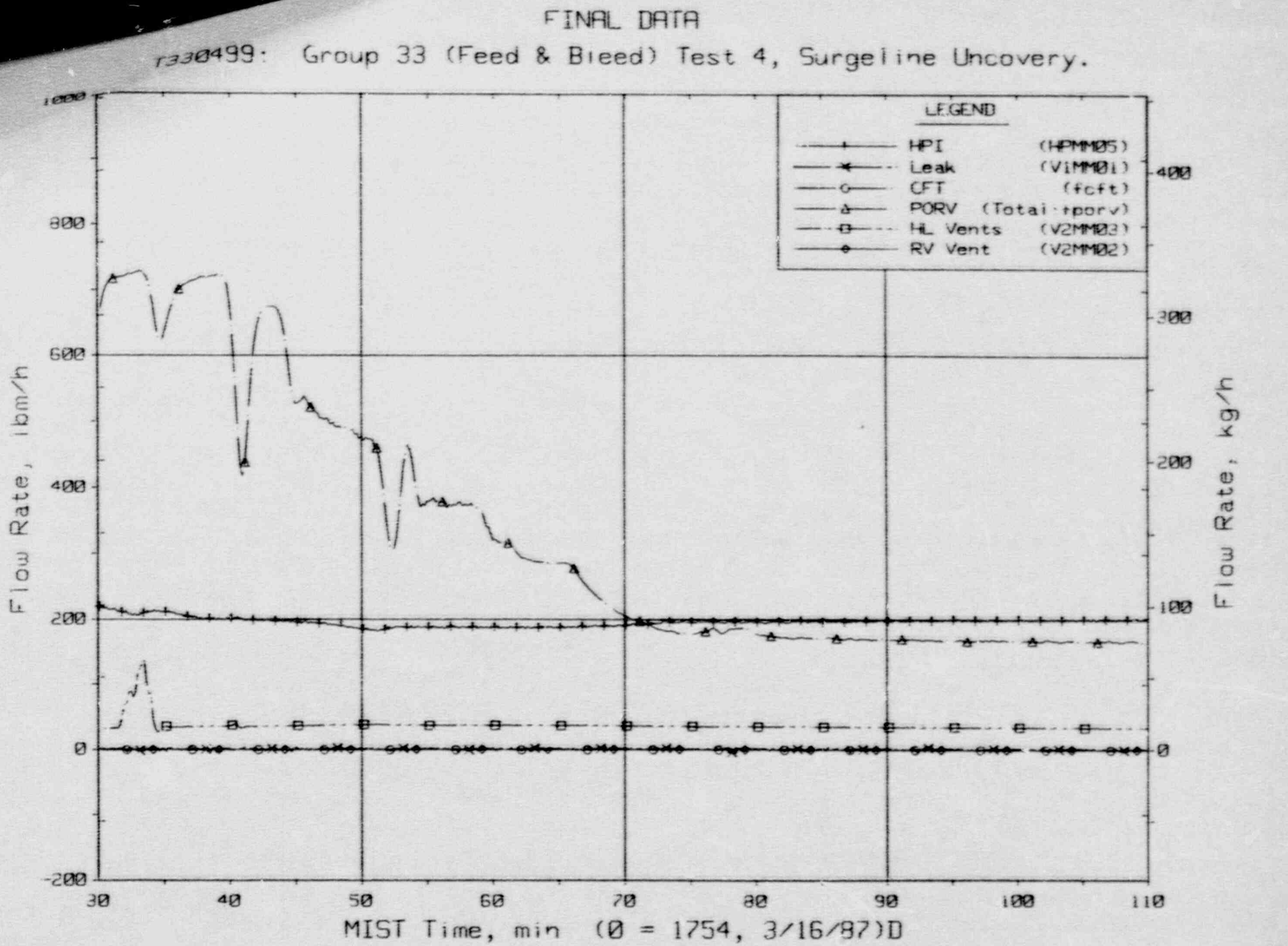


Figure 5.5.32. Primary System Boundary Flow Rates

Mon Jul 18 14:17:25 1988

PRFL3p

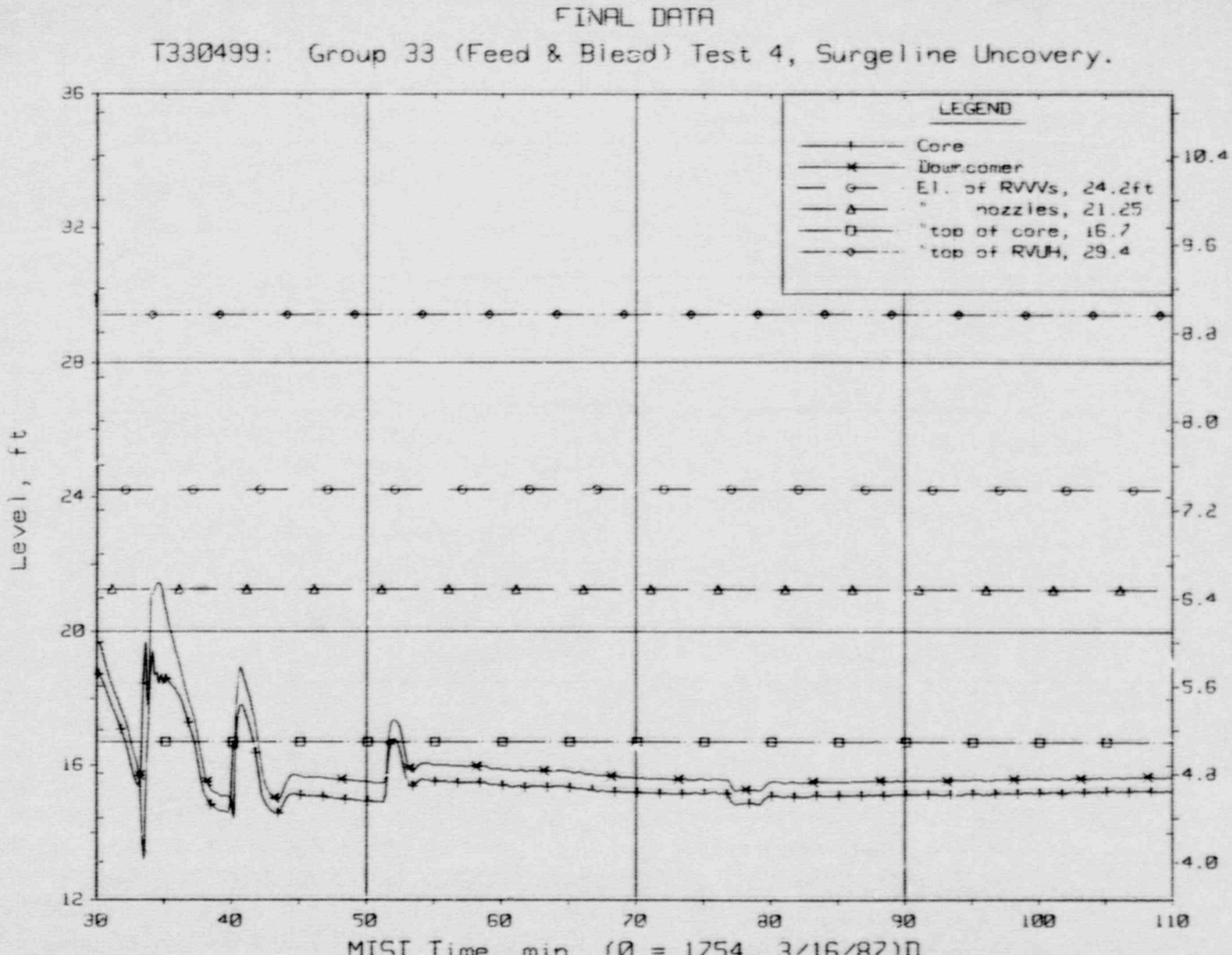
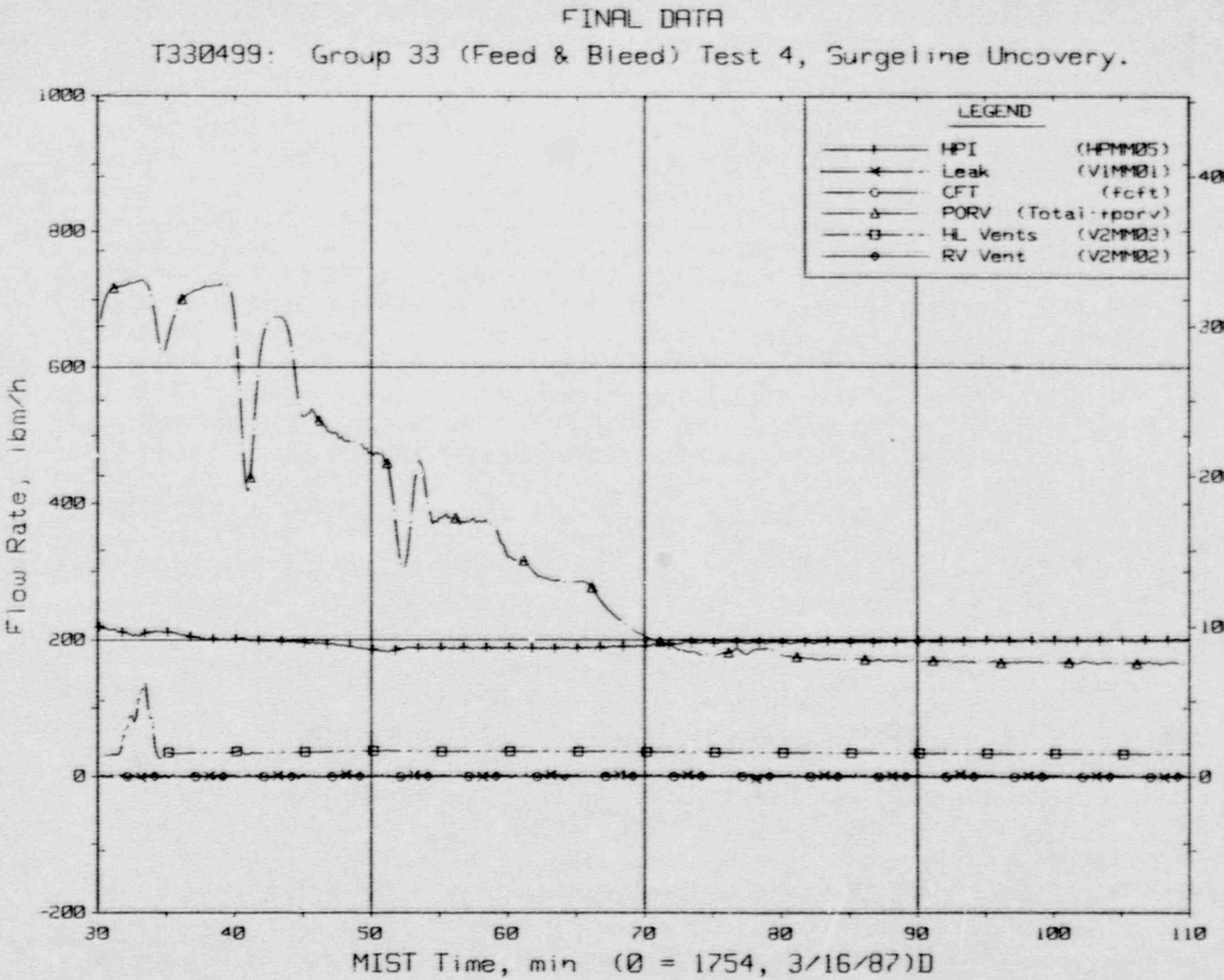


Figure 5.5.33. Core Region Collapsed Liquid Levels

Mon Jul 18 14:20:50 1988

COLV1



6-99

Figure 5.5.32. Primary System Boundary Flow Rates

Mon Jul 18 14:17:25 1988

PRFL3p

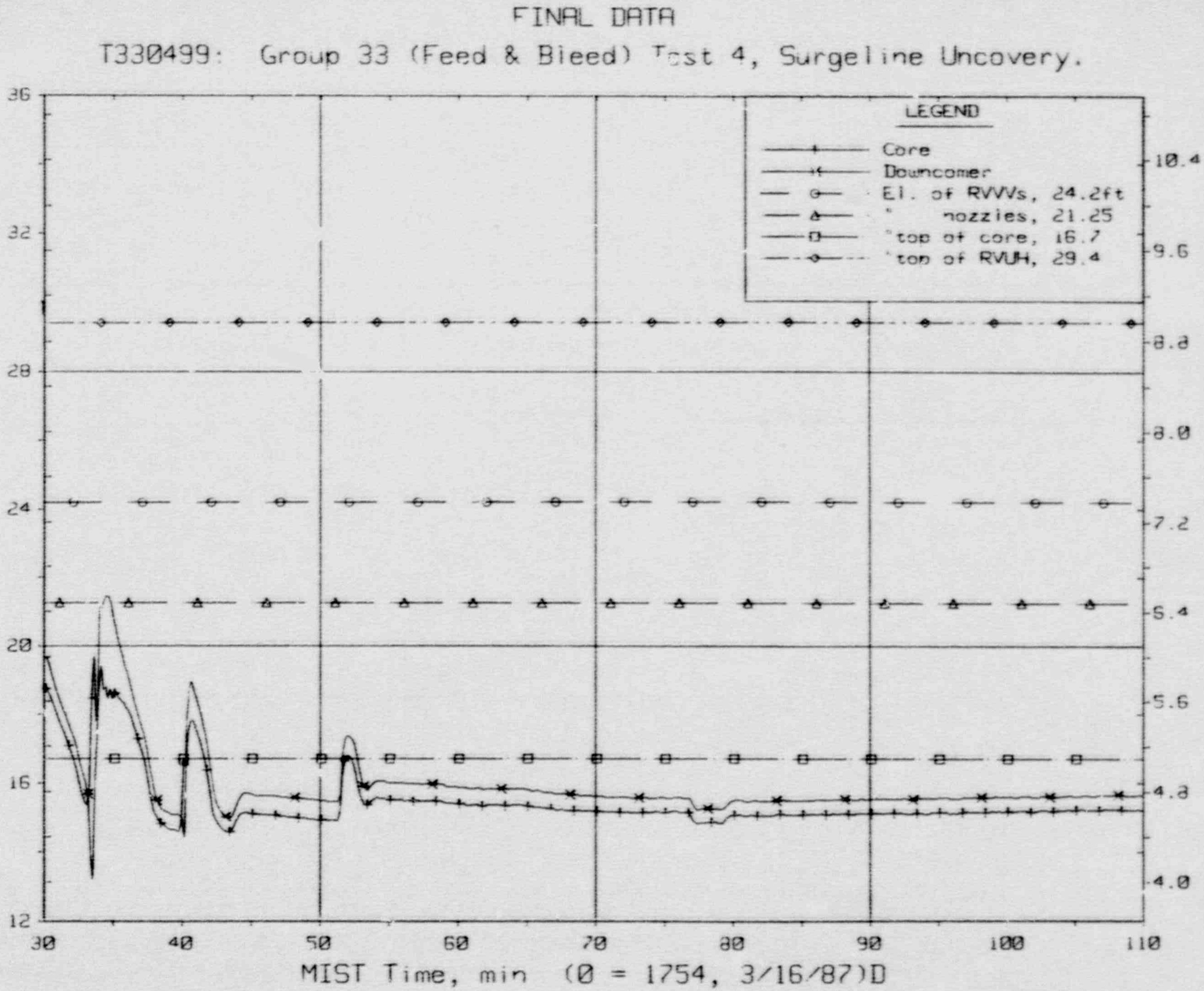


Figure 5.5.33. Core Region Collapsed Liquid Levels

Mon Jul 18 14:20:50 1988

COLV1

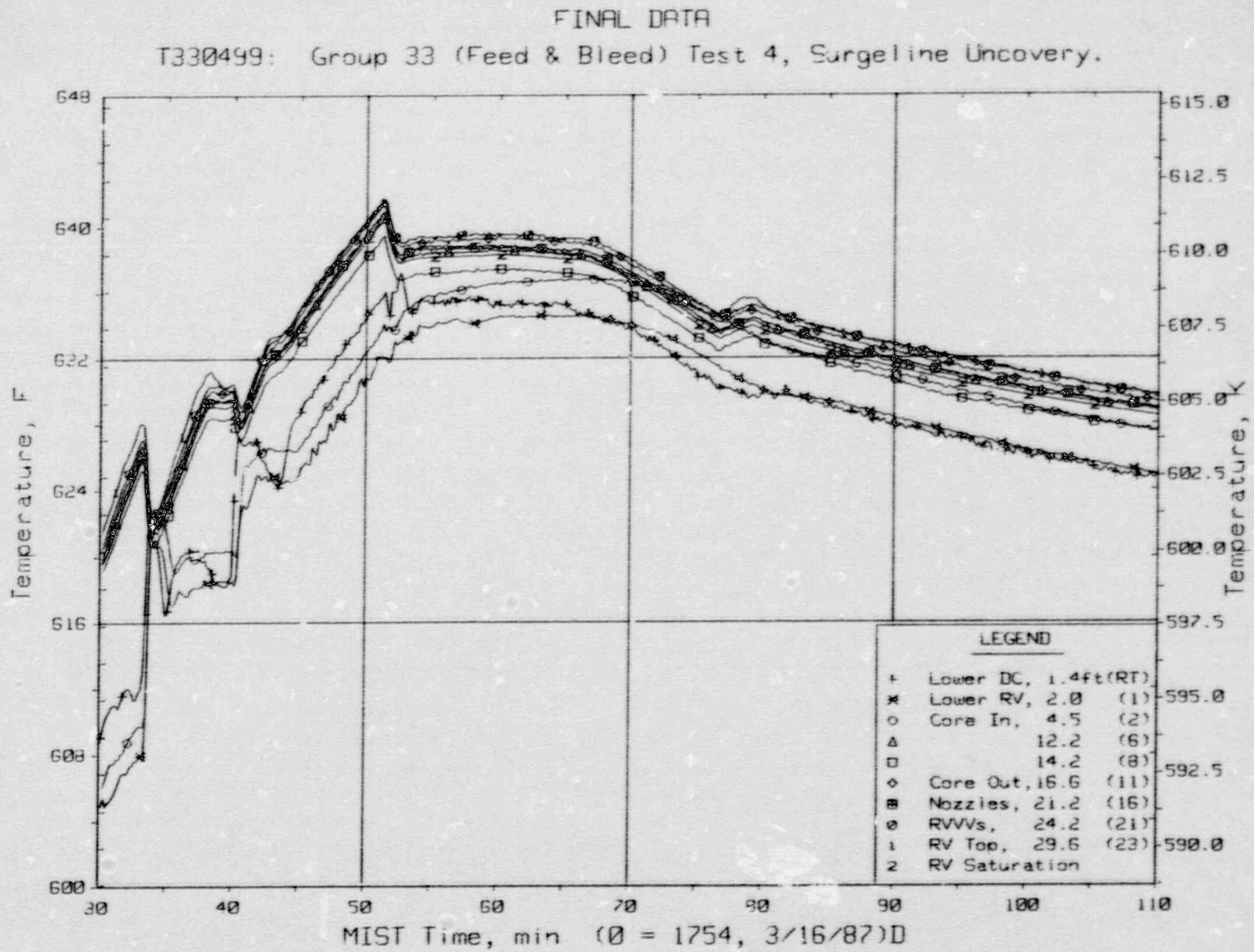


Figure 5.5.34. Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs)

Mon Jul 18 14:24:56 1988

RVTC0

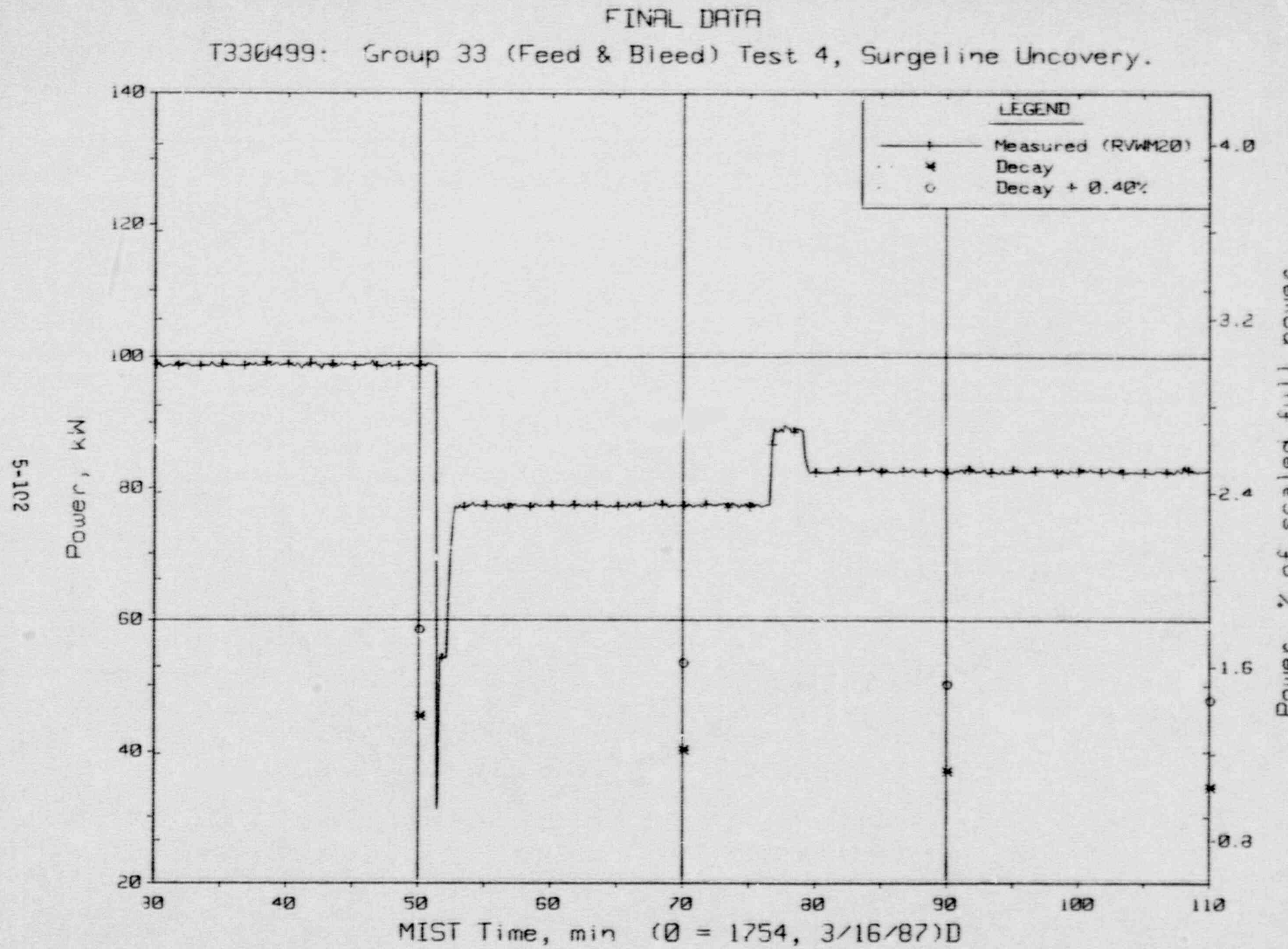


Figure 5.5.35. Core Power

Mon Jul 18 14:27:22 1988

RVKW1

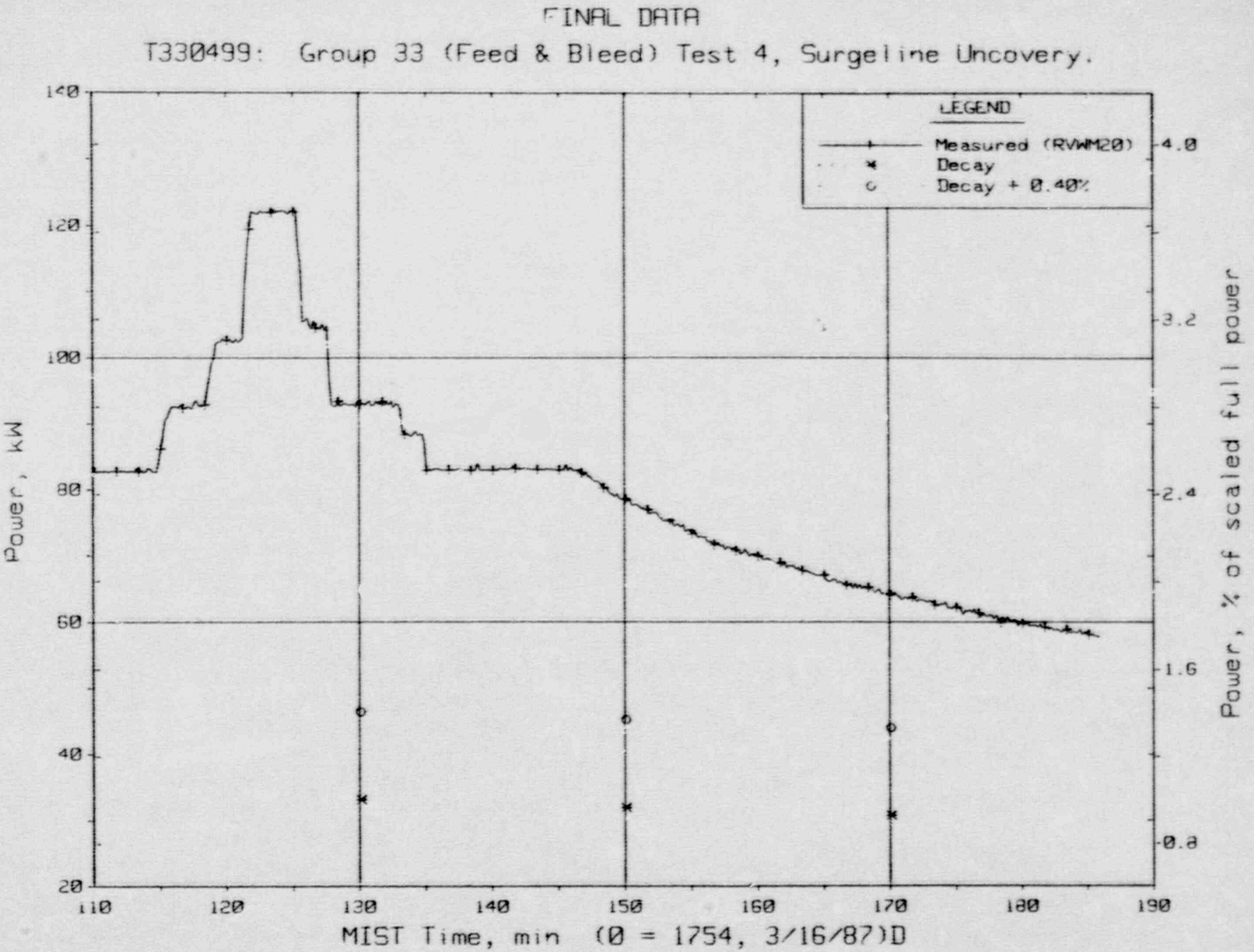


Figure 5.5.36. Core Power

Mon Jul 18 15:04:35 1988

RVKW1

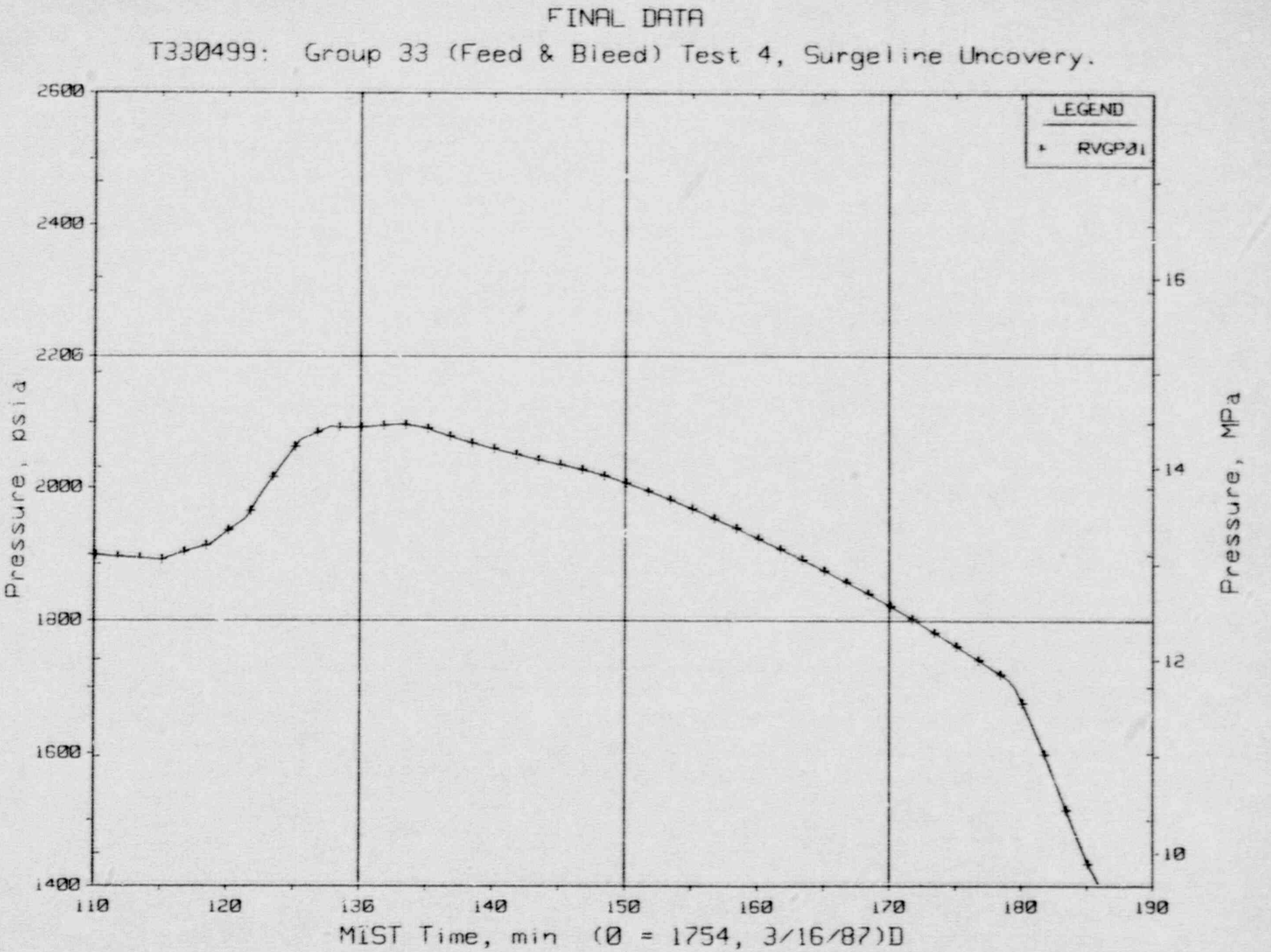


Figure 5.5.37. Reactor Vessel Pressure

Mon Jul 18 15:06:28 1988

RVGP1

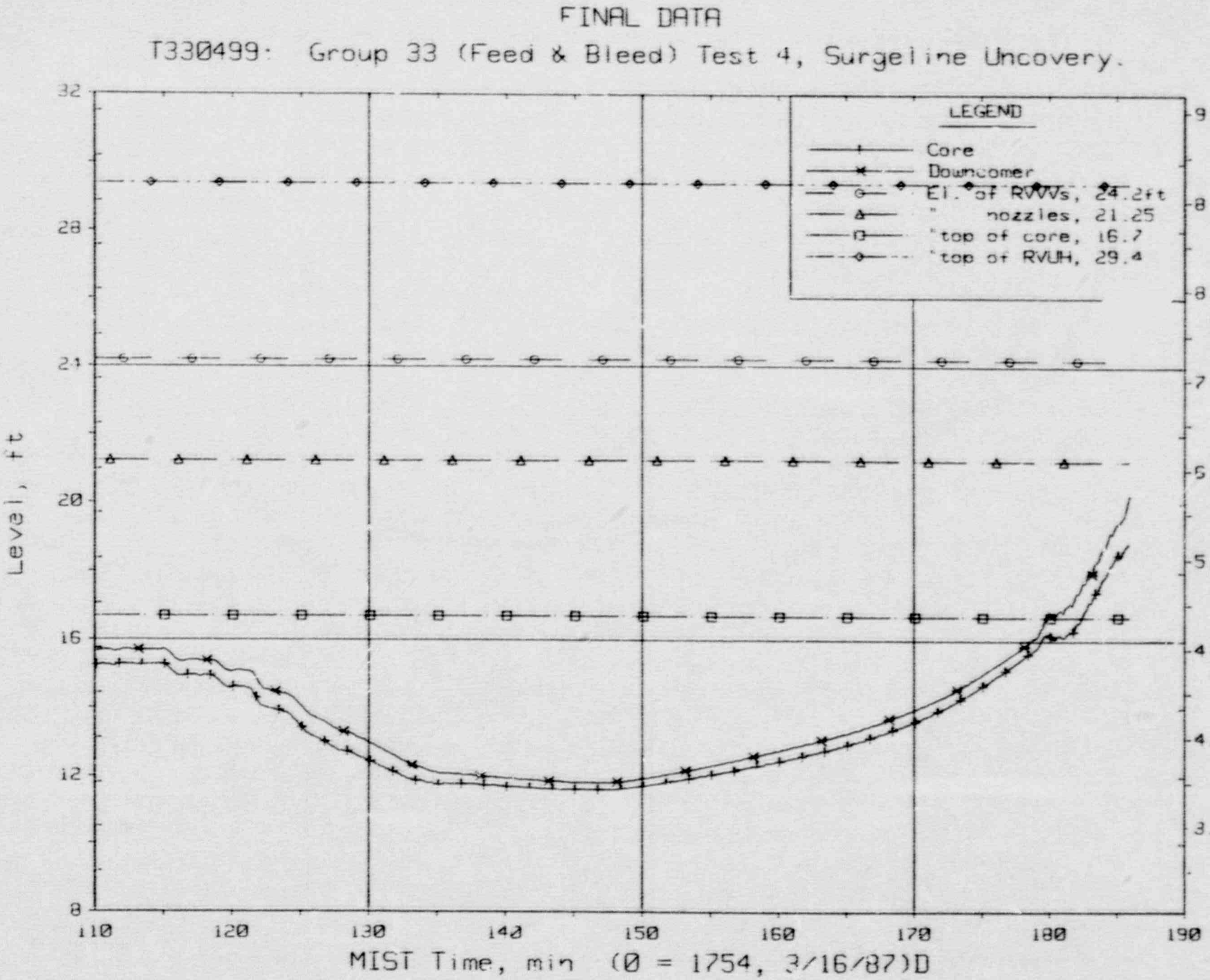
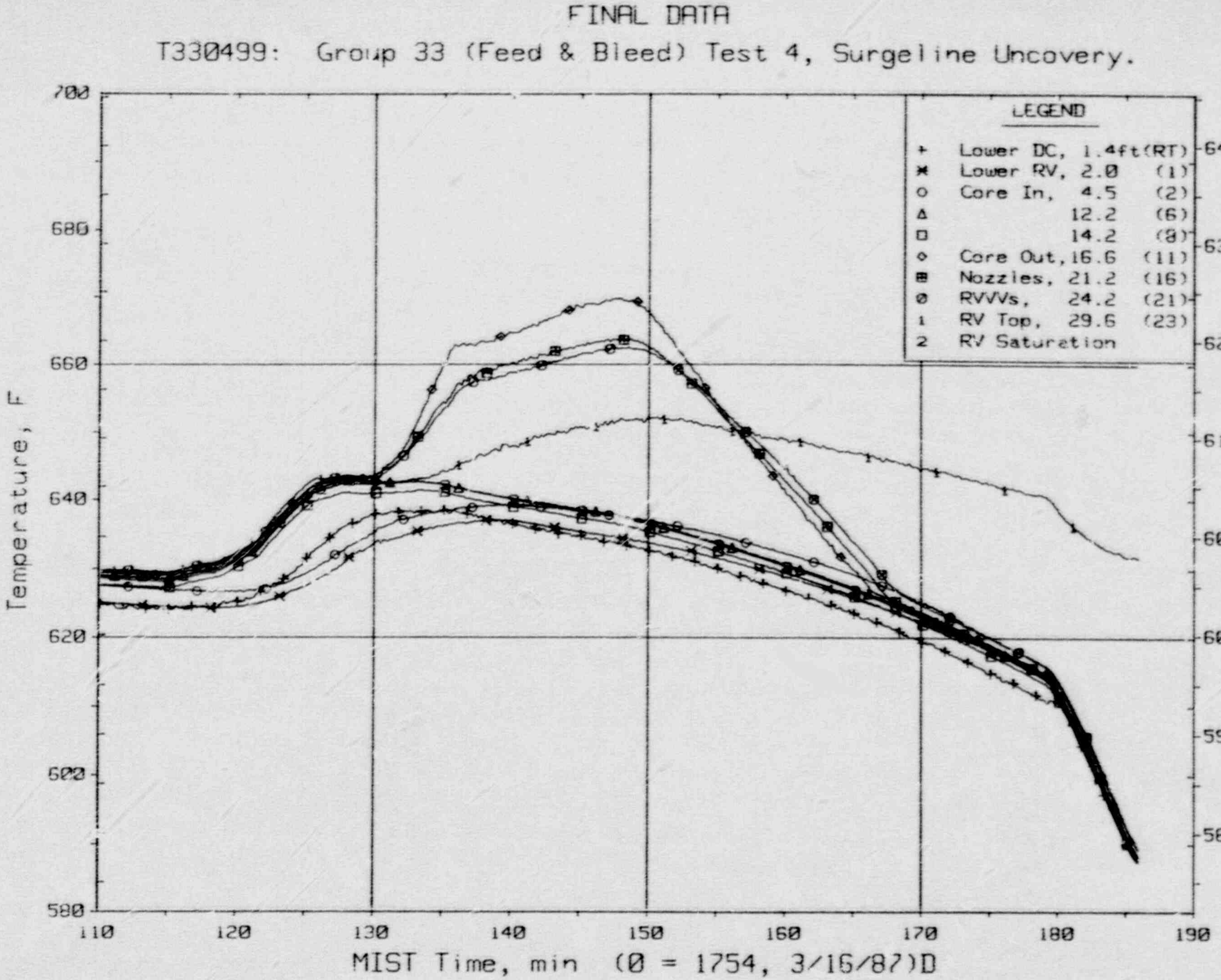


Figure 5.5.38. Core Region Collapsed Liquid Levels

Mon Jul 18 15:09:22 1988

COLV1



5-106

Figure 5.5.39. Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs)

Mon Jul 18 15:12:19 1988

RVTC0

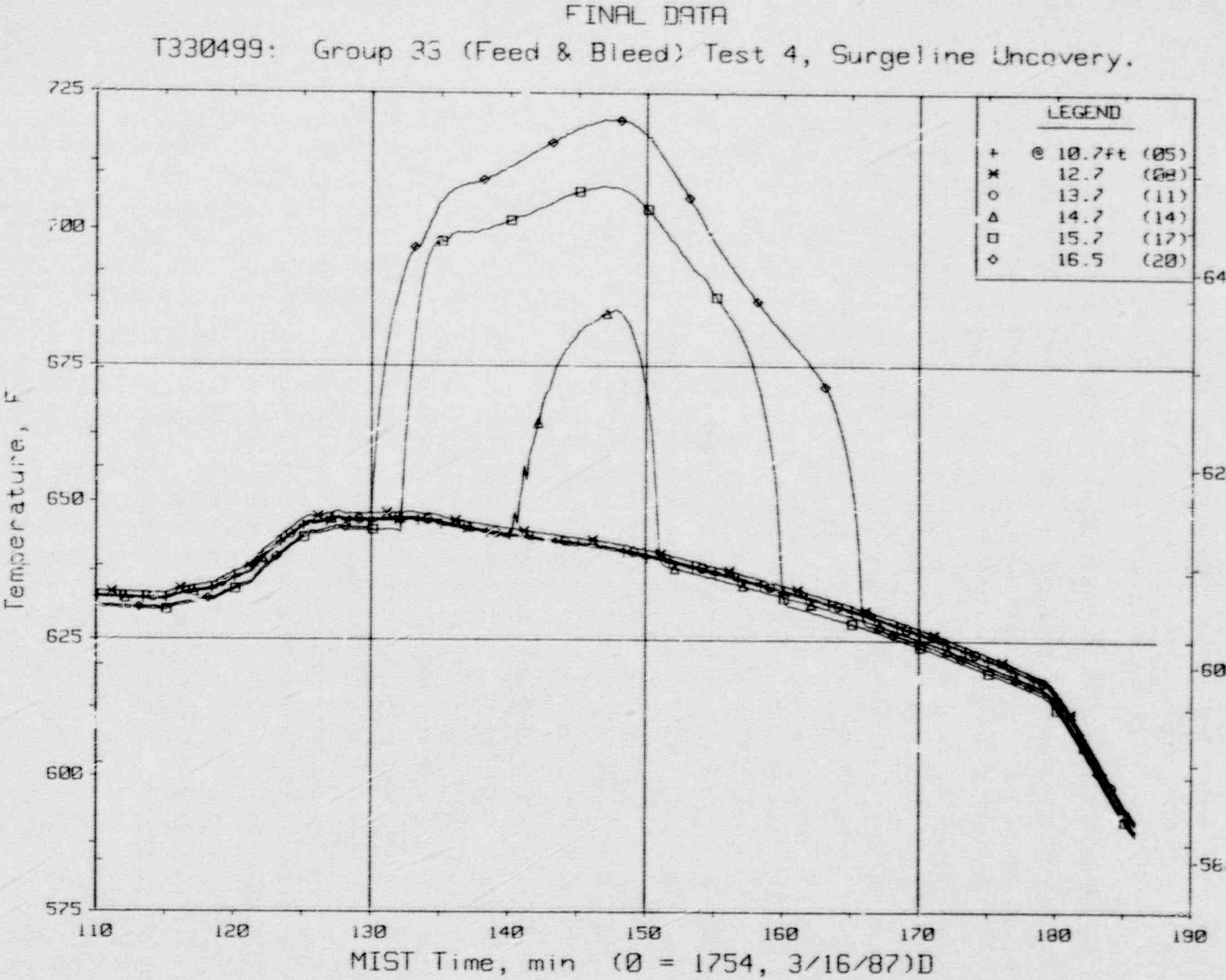


Figure 5.5.40. Core Central Heater Metal Temperatures (RVMTs)

Mon Jul 16 15:16:38 1988

COMT1

5.6. Inter-Test Comparisons

Reduced HPI Test 2 and delayed HPI Test 3 are separately compared to the Nominal HPI-PORV Cooling Test in sections 5.6.1 and 5.6.2. The volume balance of Test 4 is described in section 5.6.3.

5.6.1. Test 2 (Reduced HPI Capacity) Versus Nominal Test 1

The initial transient responses of Tests 1 and 2 were virtually identical. In both tests, the primary system repressurized to approximately 2330 psia at 16.5 minutes (Figure 5.6.1) and the PORV actuated. Also in both tests, the primary system depressurized to primary saturation in approximately 1 minute. The pressurizer quickly filled (Figure 5.6.2), the PORV fluid enthalpy decreased to that of subcooled liquid (Figure 5.6.3), and the PORV mass flow rate increased commensurately (Figure 5.6.4). PORV fluid subcooling persisted longer in Test 1 than in Test 2, therefore the PORV discharge mass flow rate decreased earlier in Test 2, from approximately 700 to 500 lbm/h (Figure 5.6.4). Whereas the lower PORV flow rate approximately equalled the HPI flow rate in Test 1 (Figure 5.6.5), the PORV flow rate remained more than double the HPI flow rate with reduced HPI capacity (Figure 5.6.6). Consequently, the total primary fluid mass and energy declined more rapidly in Test 2 than in Test 1 (Figure 5.6.7), and the core region and hot leg levels began to void earlier (Figures 5.6.8 and 5.6.9).

The PORV mass flow rate remained near 450 lbm/h with full-capacity HPI, but began to decrease beyond one hour with reduced capacity HPI (Figure 5.6.10). Whereas the PORV site fluid remained near saturated liquid in Test 1, the PORV site fluid became two-phase in Test 2 (Figure 5.6.11). The inter-test difference in PORV fluid enthalpy and PORV mass flow rate was caused by the differing rates of primary fluid mass depletion. With reduced capacity HPI, the core region levels descended below the (hot leg and cold leg) nozzle elevations by 40 minutes (Figure 5.6.12) and the hot leg levels began to descend relatively rapidly, uncovering the pressurizer surge line before 70 minutes (Figure 5.6.13). Using the full-capacity HPI of Test 1, these inventory depletion events were deferred until HPI was throttled after regaining SCM, at approximately 140 minutes (Figure 5.6.14).

The total primary system fluid mass stabilized and then began to increase beyond 3 hours in both Tests 1 and 2 (Figure 5.6.15). Whereas the PORV flow rate had decreased to approximately the (reduced capacity) HPI flow rate in Test 2 (Figure 5.6.16), the HPI flow rate was throttled in Test 1 (Figure 5.6.17) to maintain an SCM of 75F. The core exit fluid remained saturated in Test 2 (Figure 5.6.14). The primary system pressure in Tests 1 and 2 remained approximately equal until 3 hours (Figure 5.6.18). Then, the primary system depressurized relatively rapidly in Test 1, as HPI was throttled. The SCM was stabilized at 75F by 3-1/2 hours and the Test 1 depressurization rate slowed below 600 psia.

The major difference between Tests 1 and 2 was the surge line uncovery near 1 hour in Test 2. The PORV site fluid quality increased in Test 2 (Figure 5.6.19), the PORV mass flow rate decreased toward the reduced capacity HPI flow rate (Figure 5.6.20), and the PORV volumetric flow rate approximately doubled (Figure 5.6.21). Whereas the net (imposed) primary fluid volume change had been slightly positive, upon surge line uncovery the fluid volume balance of Test 2 became negative (Figure 5.6.22), thus depressurizing the primary system. The later events of nominal Test 1, beyond approximately 3 hours, were dominated by SCM recovery and HPI throttling. The core exit fluid remained saturated in Test 2.

5.6.2. Test 3 (Delayed HPI) Versus Nominal Test 1

HPI was delayed in Test 3 until almost 36 minutes, 20 minutes after PORV lift. The initial repressurization transient of Test 3, like that of Test 2 with reduced HPI capacity, replicated the controls of nominal Test 1 and experienced similar conditions. The depressurization upon PORV actuation was similar to that of Test 1 (Figure 5.6.23). Also as in Test 1, the PORV site fluid quickly subcooled as the pressurizer filled (Figure 5.6.3), with the cooler fluid from the onset of the insurge residing at the top of the pressurizer. As the pressurizer filled and the PORV site fluid subcooled, the PORV discharge mass flow rate increased accordingly, as it had in Test 1, to nearly 800 lbm/h (Figure 5.6.4).

Whereas the primary system gradually depressurized after saturation in Test 1, the primary system intermittently repressurized in Test 3 (Figure 5.6.23). The PORV discharge mass flow rate decreased as the PORV site liquid approached saturation, in both tests, but then increased beyond 33 minutes in Test 3 (Figure 5.6.4), as the increasing primary system pressure caused the PORV site fluid to again subcool (Figure 5.6.24).

The primary system total fluid mass declined rapidly in Test 3 without HPI, dropping to 75% of its initial value by 36 minutes (Figure 5.6.25). The core region and hot leg levels decreased correspondingly. The core liquid level achieved the elevation of the RVVVs by 21 minutes (Figure 5.6.26). The core and downcomer levels approached the nozzle elevations at 22 minutes and descended to the top of the core at 31 minutes.

The hot leg levels in Test 3 remained similar to those of Test 1 until the core region levels neared the top of the core. Then, the hot leg levels dropped precipitously, achieving 50 feet in 1 minute (Figure 5.6.27) and displacing fluid into the reactor vessel and downcomer. Just before the activation of HPI in Test 3, the core region levels had again stabilized near the top of the core and the hot leg levels had again begun their steep decline.

The system conditions abruptly realigned upon the (delayed) activation of HPI in Test 3. The imposed primary fluid volume balance (due to core voiding, condensation on boundary streams, and boundary system injection and discharge) swung from the equivalent of +1% of scaled full power to -1% (Figure 5.6.28). The major impetus of this change was HPI condensation (Figure 5.6.29), but the PORV discharge also contributed. As the primary system depressurized and as the pressurizer insurge slowed due to the contraction of the primary fluid volume, the PORV site fluid saturated (Figure 5.6.30), thereby increasing the PORV volumetric flow rate (Figure 5.6.31). The primary system depressurization rate thus approached 100 psi/min (Figure 5.6.32).

Following HPI activation, the conditions of Test 3 quickly realigned towards those of Nominal Test 1. Beyond 40 minutes, the primary fluid mass began to increase at a rate similar to that of Test 1, but starting from a lower value (Figure 5.6.33). The core region gained liquid inventory (Figure 5.6.34) whereas the hot leg levels varied only slowly, remaining between 40 and 45 feet (Figure 5.6.35). The core exit fluid began to subcool at 146 minutes in Test 3, some 26 minutes after Nominal Test 1 (Figure 5.6.36). The time delay between Tests 1 and 3 thus approximately equalled the delay of HPI activation in Test 3. The SCM reached the control value of 75F at 160 minutes in Test 3, triggering HPI throttling. Now, the event timing in Test 3 merged with that of Test 1. The hot leg A level descended to the surge line elevation approximately 10 minutes after this had occurred in Test 1 (Figure 5.6.35). The primary system depressurized relatively rapidly so that the Test 1 and Test 3 pressures almost merged by 4 hours (Figure 5.6.32). HPI throttling to control at an SCM of 75F was used for the duration of both tests.

The hot leg high-point vents were opened at 4 hours in Test 3, but not until 8 hours in Test 1. These vent actuations had little impact on system conditions. The subsequent primary system depressurization rate after 4 hours was slightly faster in Test 3 than in Test 1 (Figure 5.6.32), and the hot leg levels increased somewhat in Test 3 whereas they remained almost constant in Test 1 (Figure 5.6.35).

Summary

The differences between Nominal Test 1 and Test 3 with delayed HPI were pronounced before HPI actuation, but were quickly reduced after HPI actuation. Before HPI was introduced in Test 3 the primary system intermittently repressurized, causing the PORV site fluid to subcool. As a consequence, the PORV discharge mass flow rate remained relatively high, thus accentuating the loss of primary system fluid inventory. As the time of HPI activation was approached in Test 3, the core-region collapsed liquid level resided near the top of the core and the hot leg levels were descending through 45 feet. Had the Test 3 phase without HPI been extended, it is speculated that the pressurizer surge line soon would have been uncovered. The subsequent change of state of the PORV site fluid would then have reduced the rate of loss of primary system fluid mass as well as suppressed primary system repressurization.

5.6.3. Volume Balance in Test 4, Surge Line Uncovery

Unlike Tests 1 through 3 of Group 33, Test 4 was initialized in forced flow; also, the PORV was allowed to cycle in automatic before being opened by manual switch actuation. The transient events of Test 4 were thus unlike those of the other three tests. Test 4 did provide supplementary information regarding the effects of the PORV site fluid state and the primary system volume balance, however.

The primary system fluid energy balance was usually performed from time 0, equating the indicated and calculated total fluid energies at the start of the test. Pump operation precluded this procedure because the differential pressures with forced flow overranged many of the level instruments. This obstacle was circumvented by assuming a time-zero total energy for the calculated value, based on the full-loop energy observed in other tests. This assumption precluded meaningful point-to-point comparisons of the calculated and indicated total fluid energies, but did permit comparison of the energy trends after the pumps were stopped. Based on this comparison of trends (Figure 5.6.37), the calculated values, specifically the PORV flow rate and PORV discharge fluid enthalpy based primarily on flow rate, were of the proper magnitudes.

The PORV discharge fluid enthalpy was calculated to be subcooled and saturated through the first 50 minutes, then intermittently two-phase, and finally saturated vapor (Figure 5.6.38). The phase transition beginning at 57 minutes was related to surge line uncovery. The net (imposed) primary system volume balance became negative due to the increased PORV volumetric flow rate (Figure 5.6.39), and the primary system began to depressurize (Figure 5.6.40 until the core power increase at 77 minutes (Figure 5.6.41). Beyond this power increase, the net primary system volume balance was nearly zero and the primary system pressure gradually stabilized (Figure 5.6.40).

Core power was again increased beyond 115 minutes and was decreased using the decay ramp beyond 144 minutes. Both core power changes were sufficient to obtain a detectably nonzero volume balance; the primary system pressure change responded accordingly (Figure 5.6.40). The ratio of the change in primary system pressure to the change in (imposed) primary system volume provides a measure of primary system response. For example, if the primary system fluid volume is reduced, such as by condensation and discharge, then the resulting primary system depressurization is suppressed by the flashing of liquid that was nearly saturated and by the release of metal stored energy. If the primary system fluid volume is increased, such as by core voiding and injection without condensation, then the primary system repressurization is suppressed by vapor compression and condensation and by heat transfer to the vapor region metal. The ratio of the pressure change to the (imposed) volume change thus provides a measure of system stiffness or resiliency, and indicates the effectiveness of the mechanisms that suppress pressure changes. This responsiveness indicator would be expected to be lower in MIST than in a plant or in a power-to-volume scaled facility. The larger pipe cross-sectional areas and metal mass of MIST tended to counter pressure changes.

The ratio of pressure change to imposed fluid volume change is presented in Figure 5.6.42. The plot was interrupted (indicated by plotted arrows) when the net pressure change was less than ± 1 psi/min and when the net fluid volume change was less than the equivalent of ± 0.1% of scaled full power. The calculations were also deactivated during the period of pump operation.

Both positive and negative ratios were obtained between the pump stop at 12 minutes and 40 minutes (Figure 5.6.42). During this period, the primary system periodically depressurized but the calculated net volume balance remained positive. This discrepancy was chiefly attributable to the inability to accurately determine the effects of core inlet subcooling, due to the uncertainties associated with the downcomer flow rate. After 40 minutes, the core inlet subcooling remained small and the log of the response ratio generally remained between 1.2 and 1.5; this corresponded to a primary system pressure rate of change of 15 to 30 psi/min for a primary system fluid volume change rate equivalent to 1% of scaled full power.

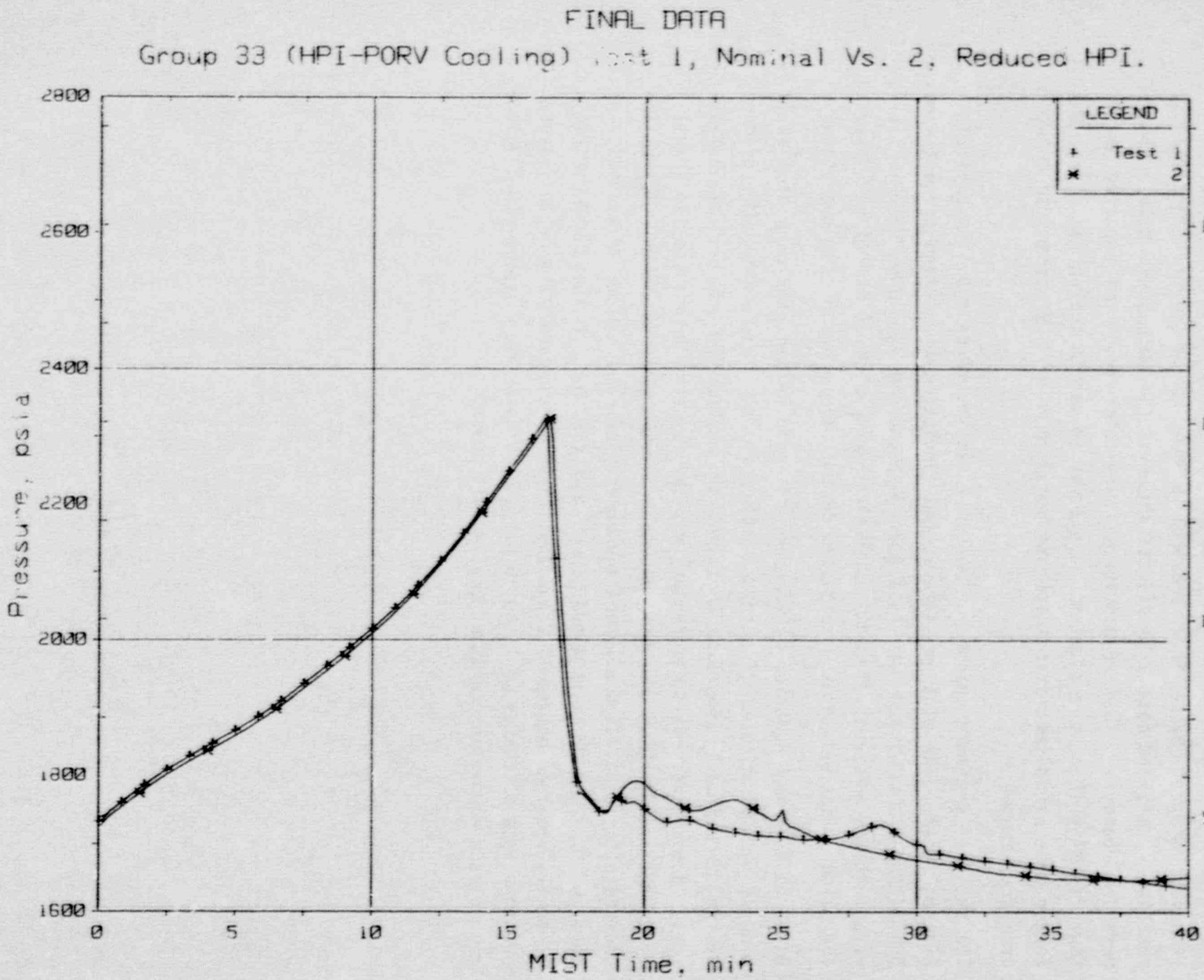


Figure 5.6.J. Reactor Vessel Pressure

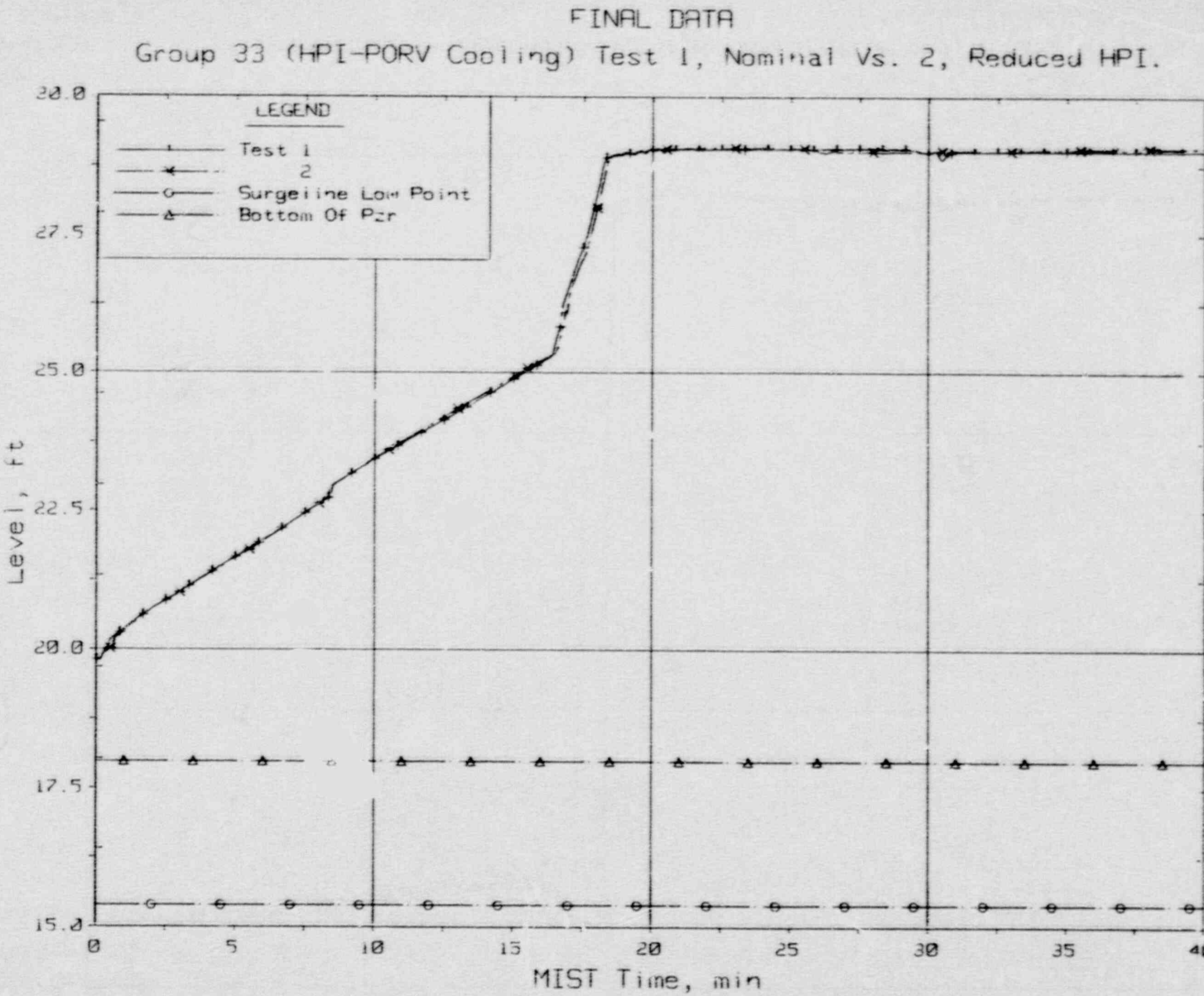


Figure 5.6.2. Pressurizer Collapsed Liquid Level (PZLV20)

Thu Jul 21 15:28:05 1988

12PZLV1

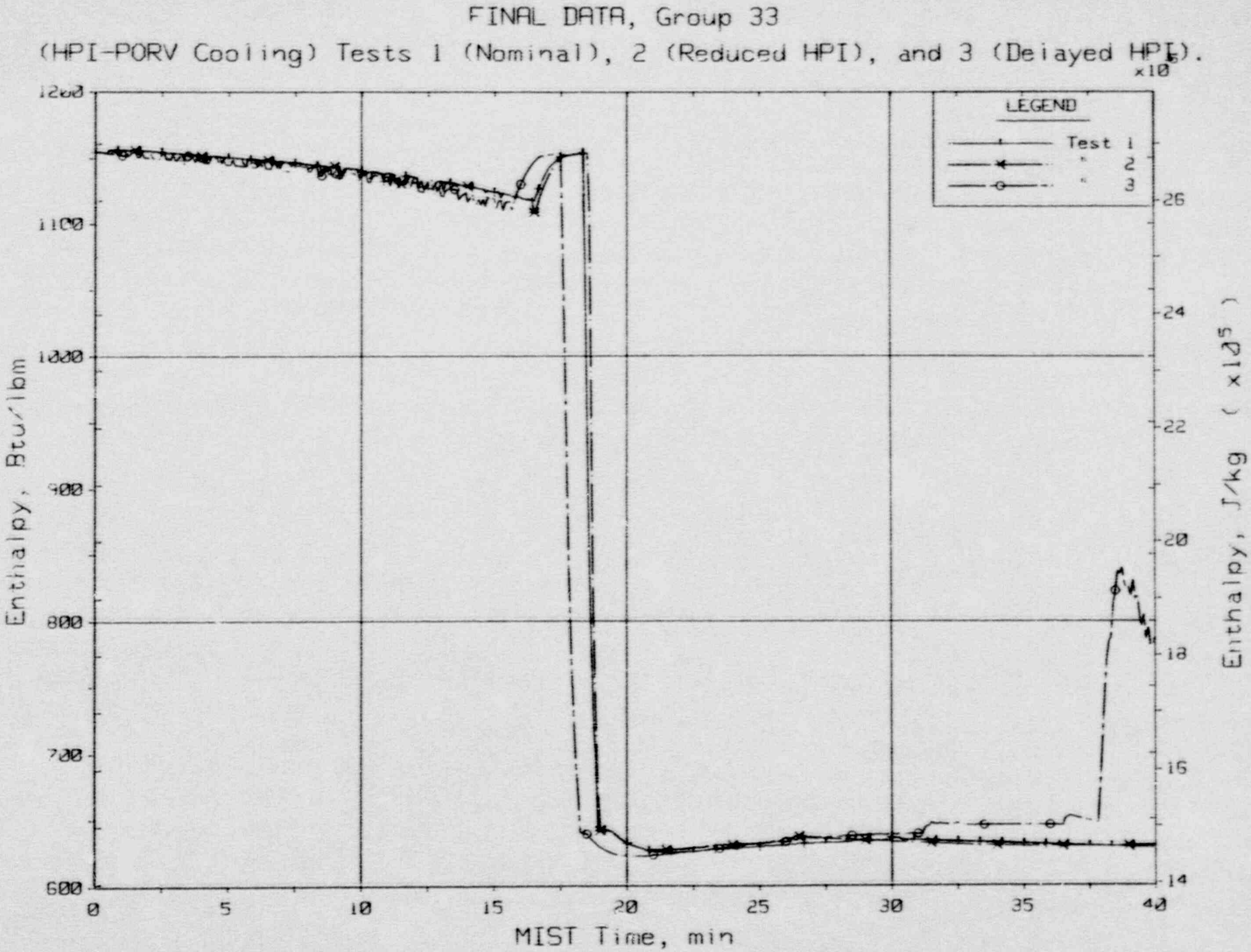


Figure 5.6.3. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 15:49:20 1988

123PZEN1

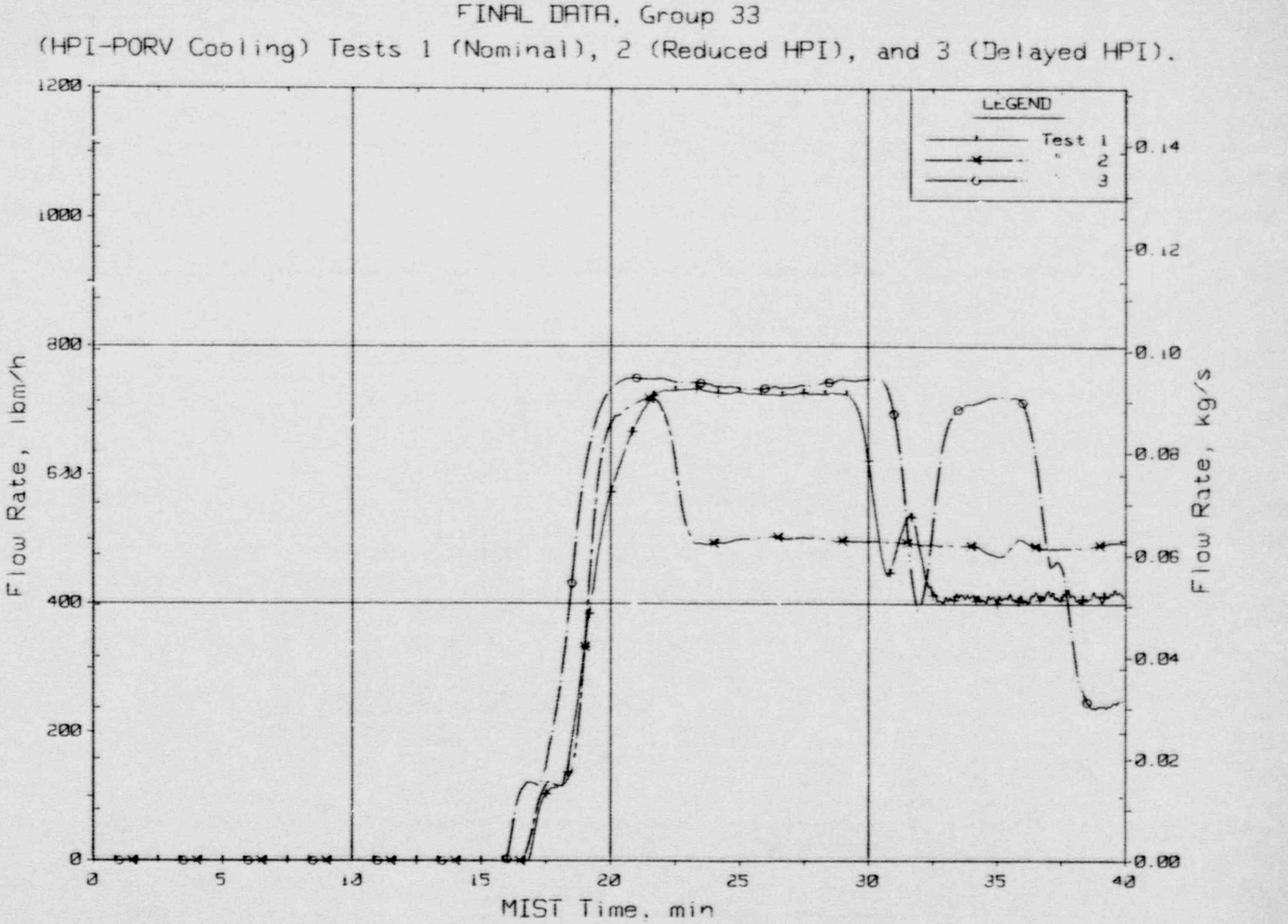


Figure 5.6.4. Power-Operated Relief Valve (Total) Flow Rates

Thu Jul 21 15:52:07 1988

123PPFL3

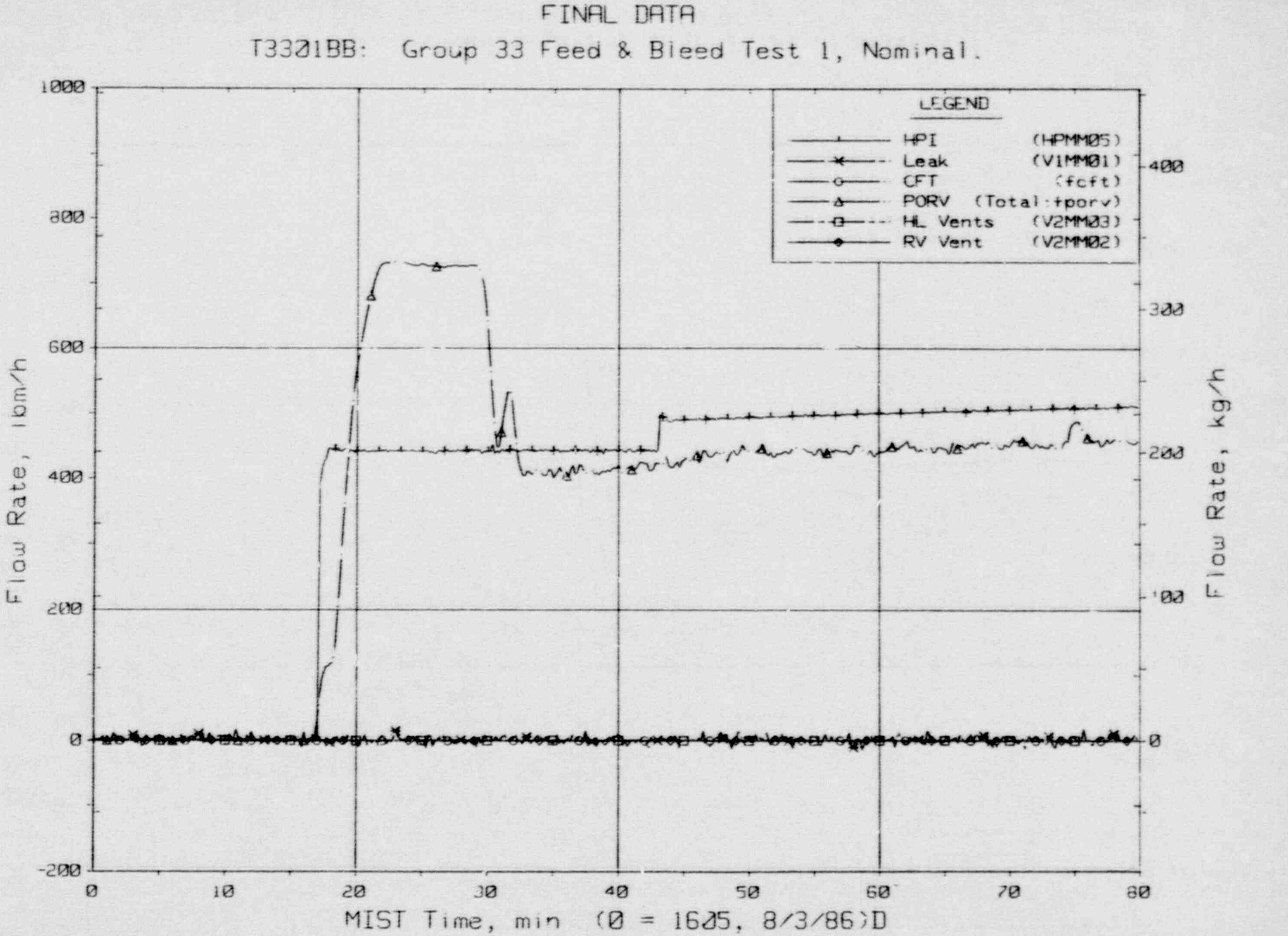


Figure 5.6.5. Primary System Boundary Flow Rates

Tul 22 10:18:24 1988

PRFL3p

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.

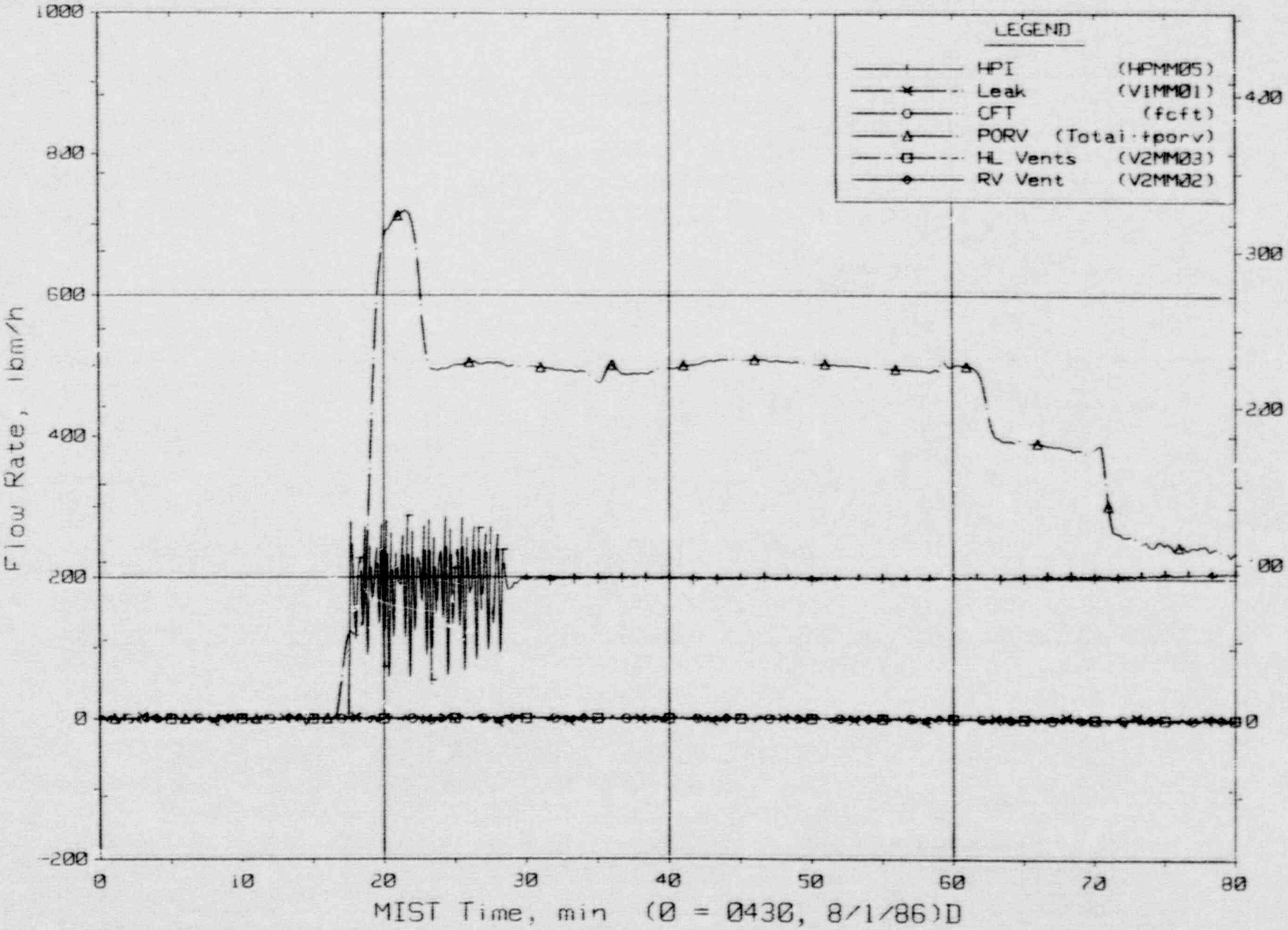


Figure 5.6.6. Primary System Boundary Flow Rates

Fri Jul 22 10:21:52 1988

PRFL3p

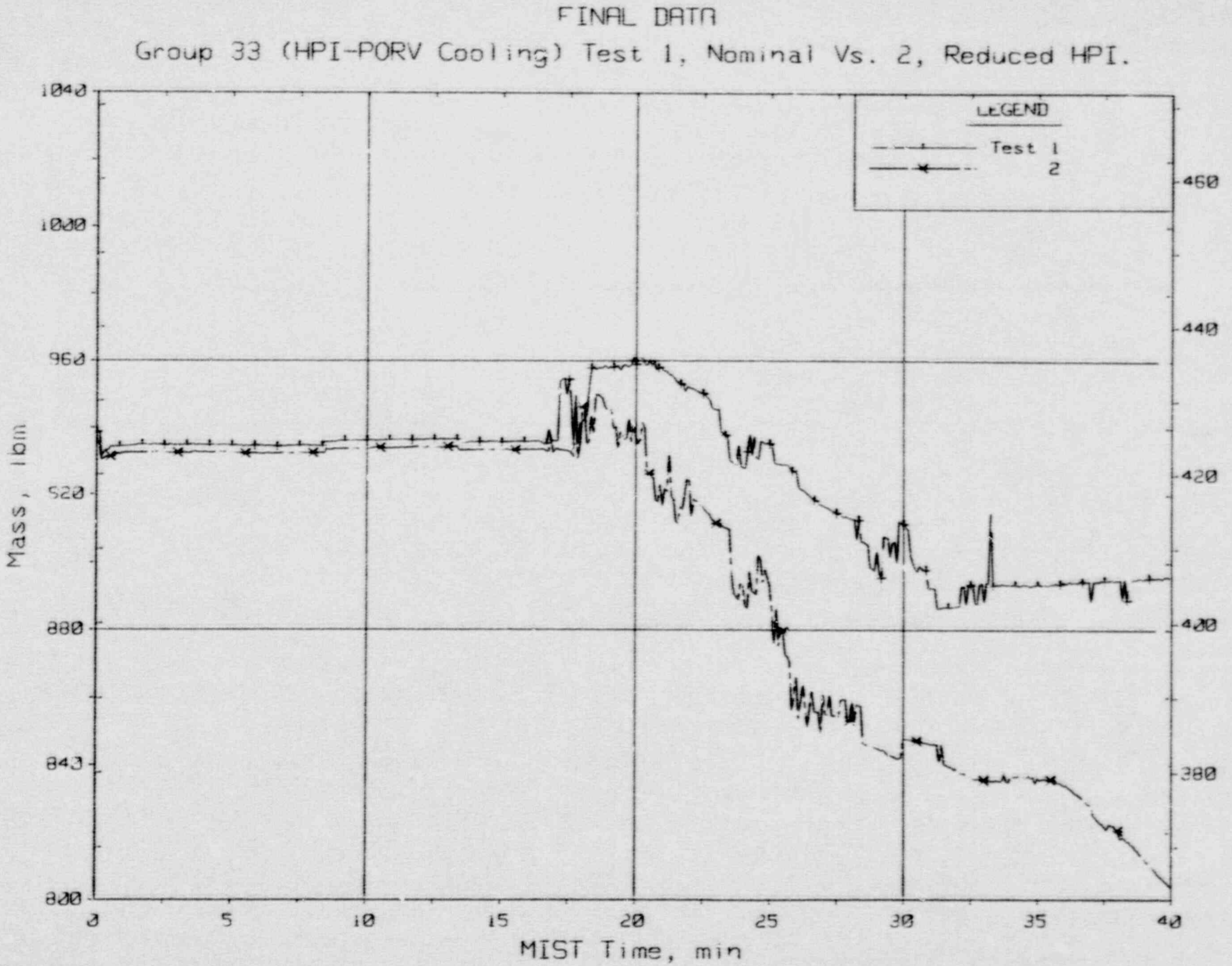


Figure 5.6.7. Indicated Primary System Total Fluid Mass (PLML20s)

Thu Jul 21 15:20:10 1988

12PRML1

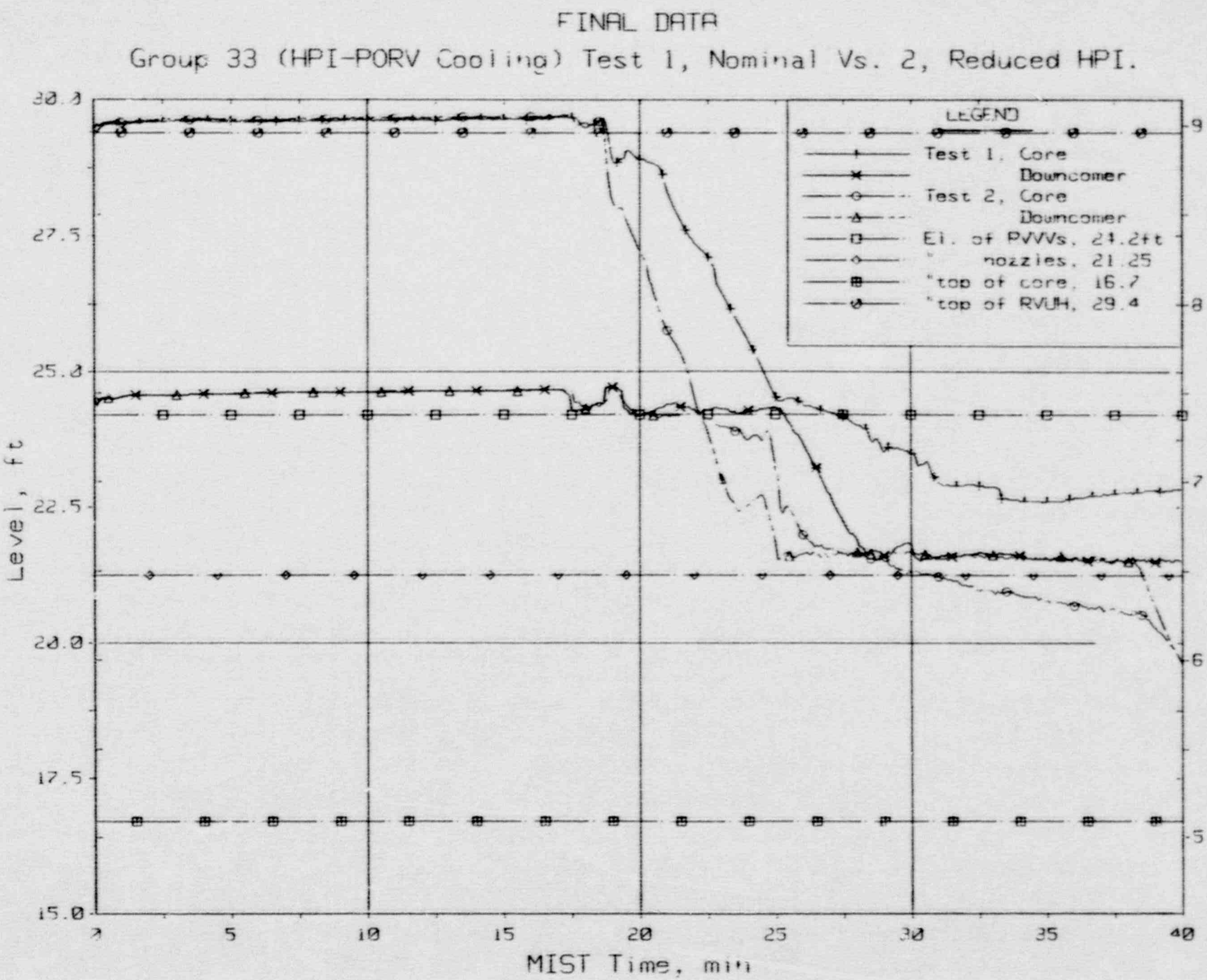


Figure 5.6.8. Core Region Collapsed Liquid Levels

Thu Jul 21 15:34:03 1988

12COL_V1

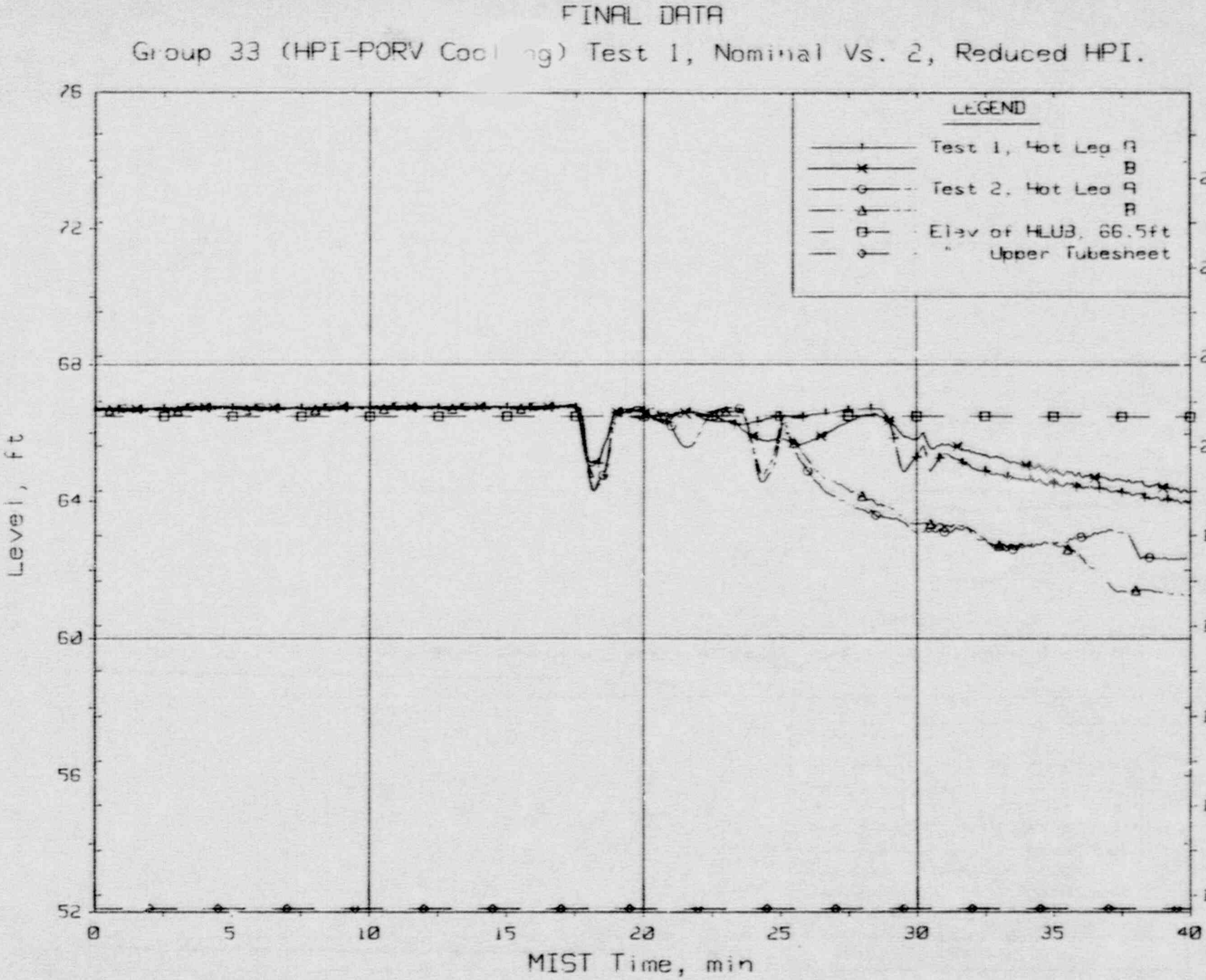


Figure 5.6.9. Hot Leg Riser Collapsed Liquid Levels

Thu Jul 21 15:28:08 1988

12HLLV1

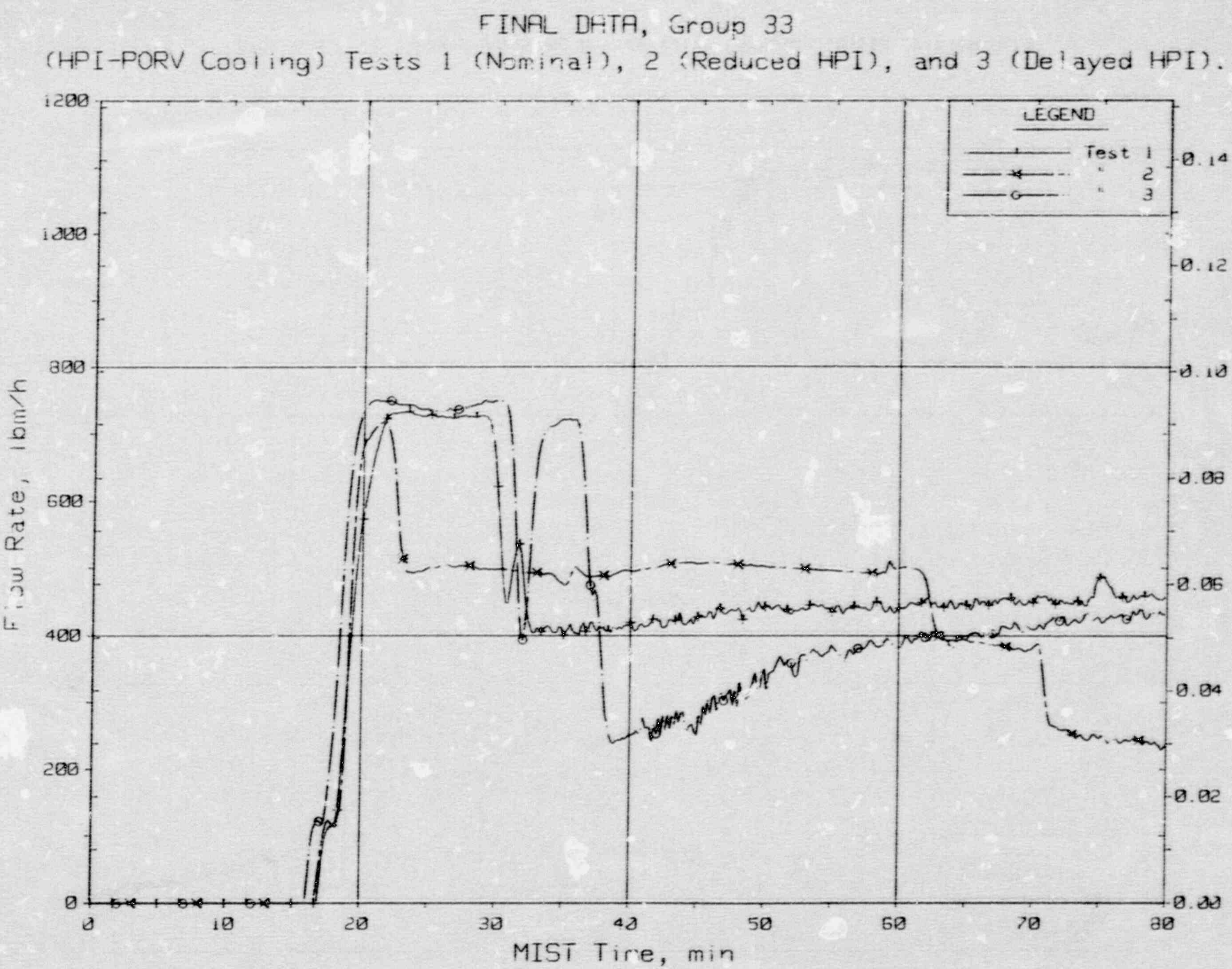


Figure 5.6.10. Power-Operated Relief Valve (Total) Flow Rates

Thu Jul 21 16:48:28 1988

123PRFL3

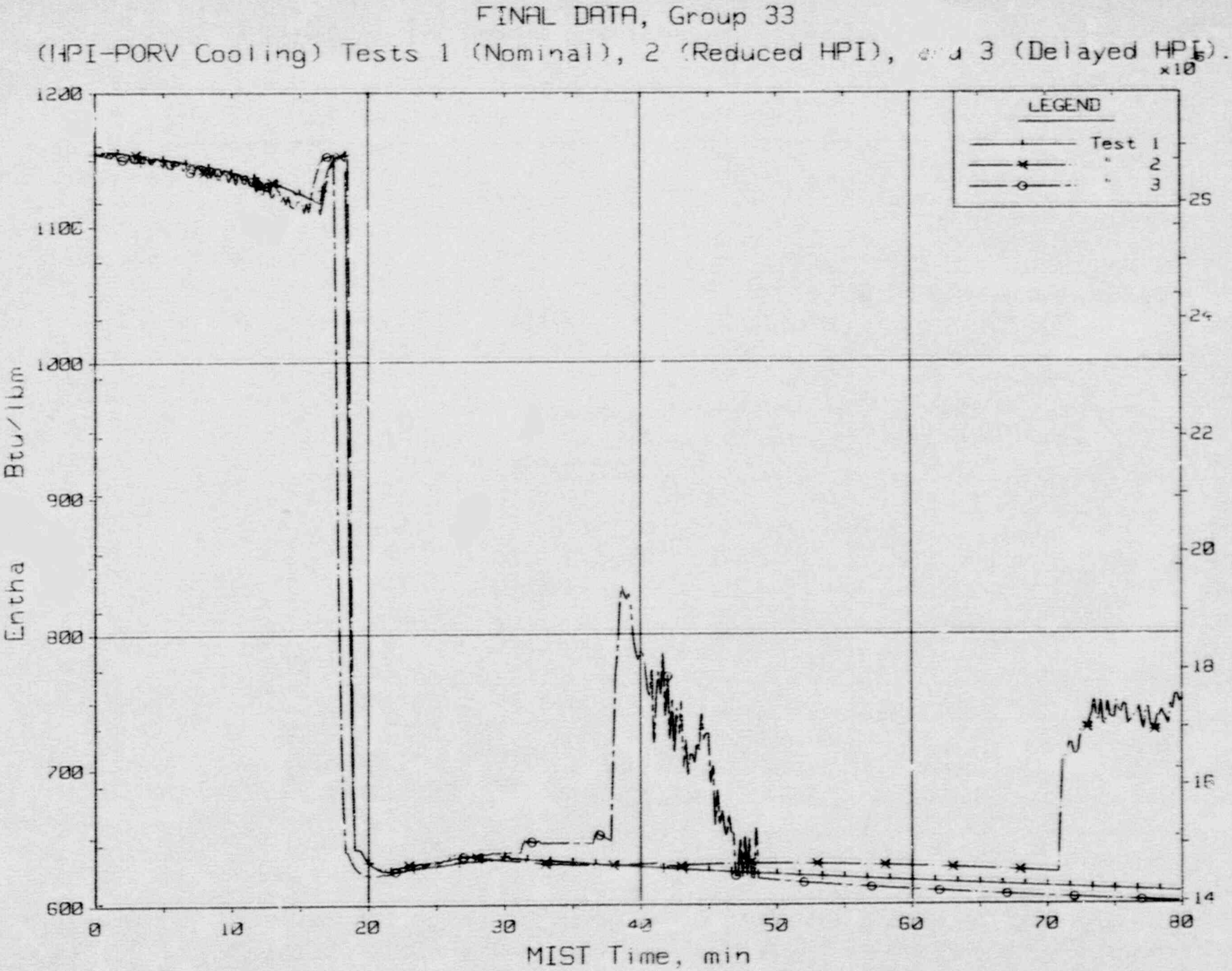


Figure 5.6.11. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 16:51:26 1988

123PZEN1

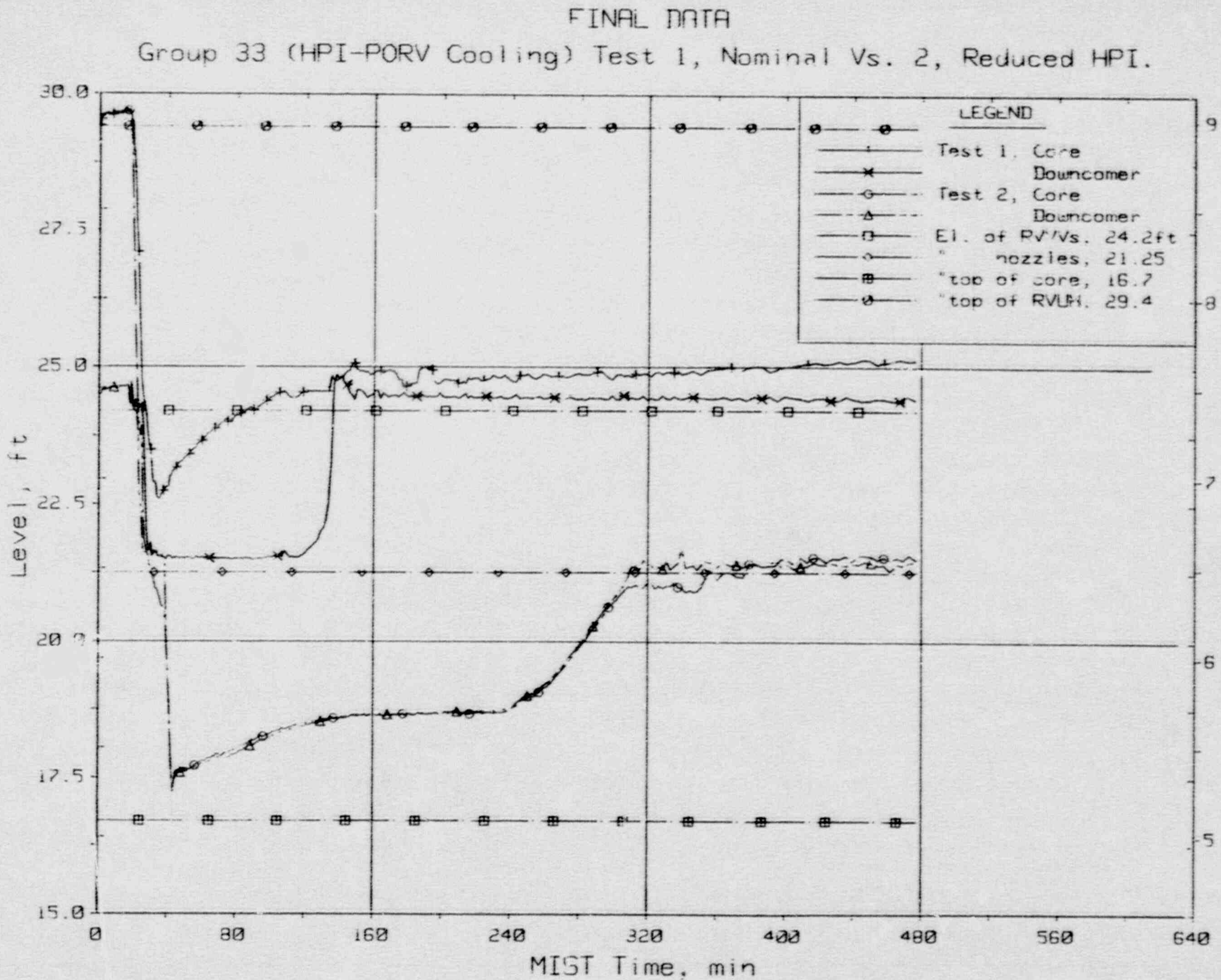


Figure 5.6.12. Core Region Collapsed Liquid Levels

Thu Jul 21 15:57:55 1988

12COLV1

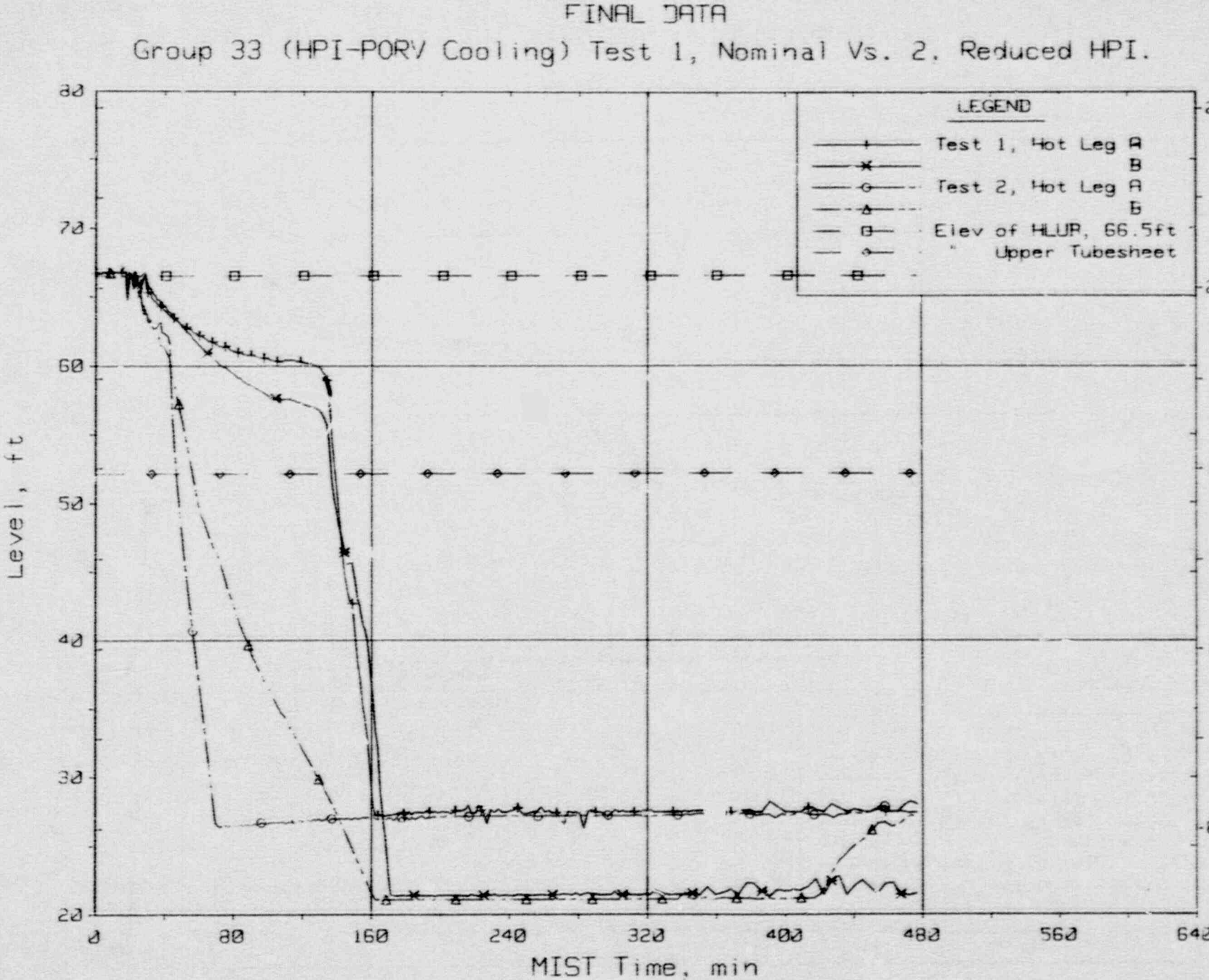


Figure 5.6.13. Hot Leg Riser Collapsed Liquid Levels

Thu Jul 21 16:01:05 1988

12HLLV1

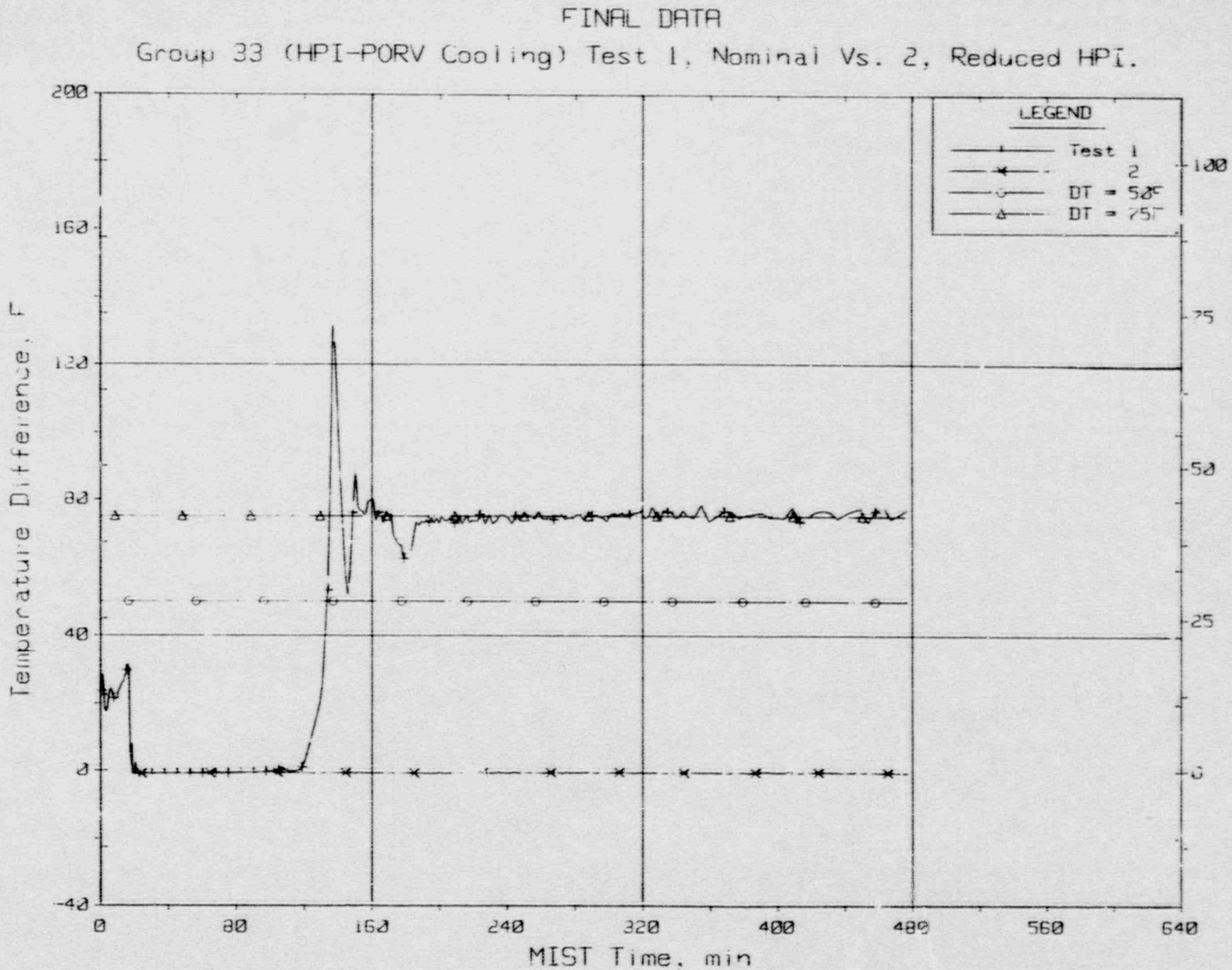


Figure 5.6.14. Subcooling Margin

Thu Jul 21 16:03:23 1988

12PRTD1

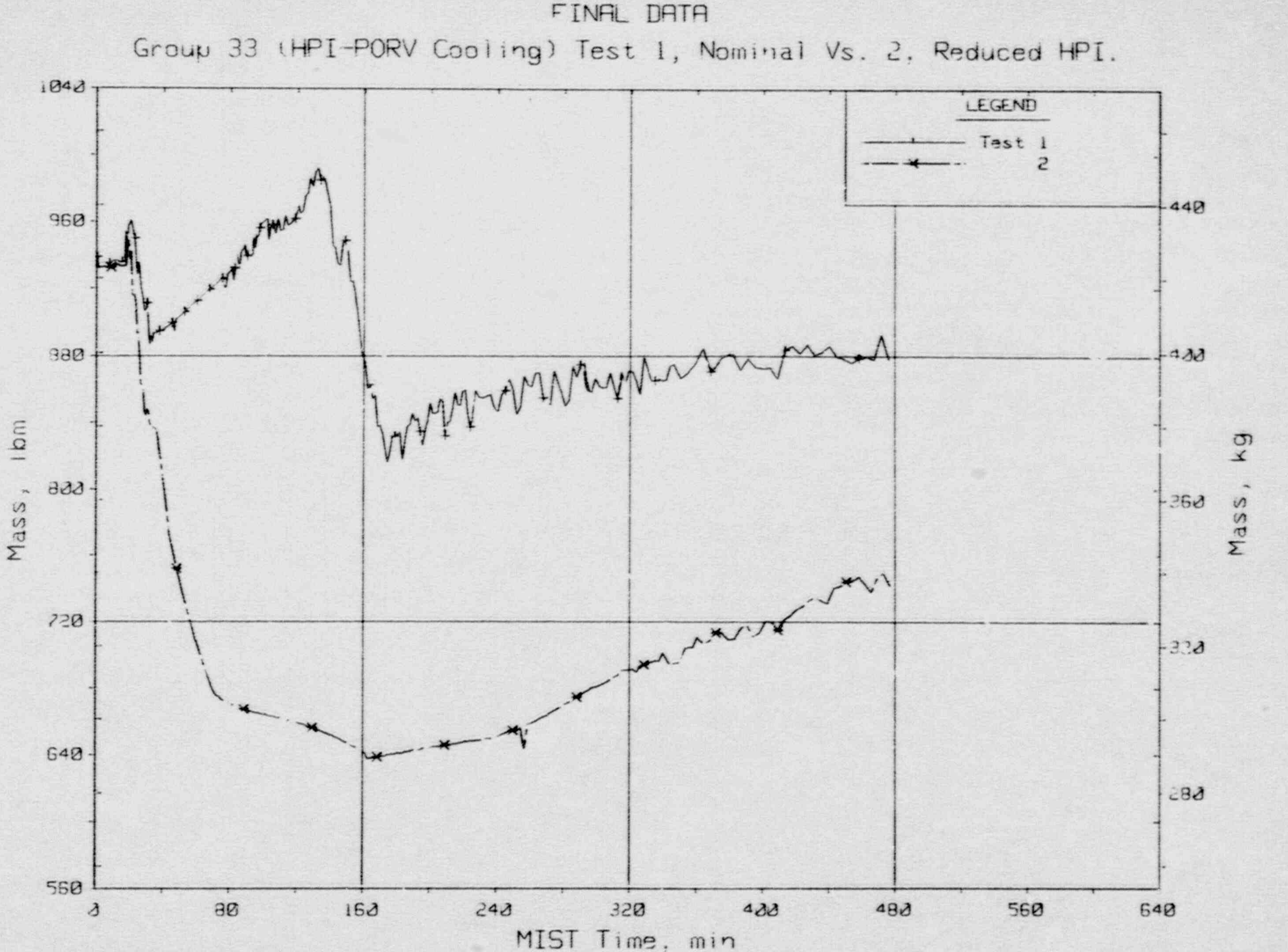


Figure 5.6.15. Indicated Primary System Total Fluid Mass (PLML20s)

Thu Jul 21 16:05:22 1988

12PPM_1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.

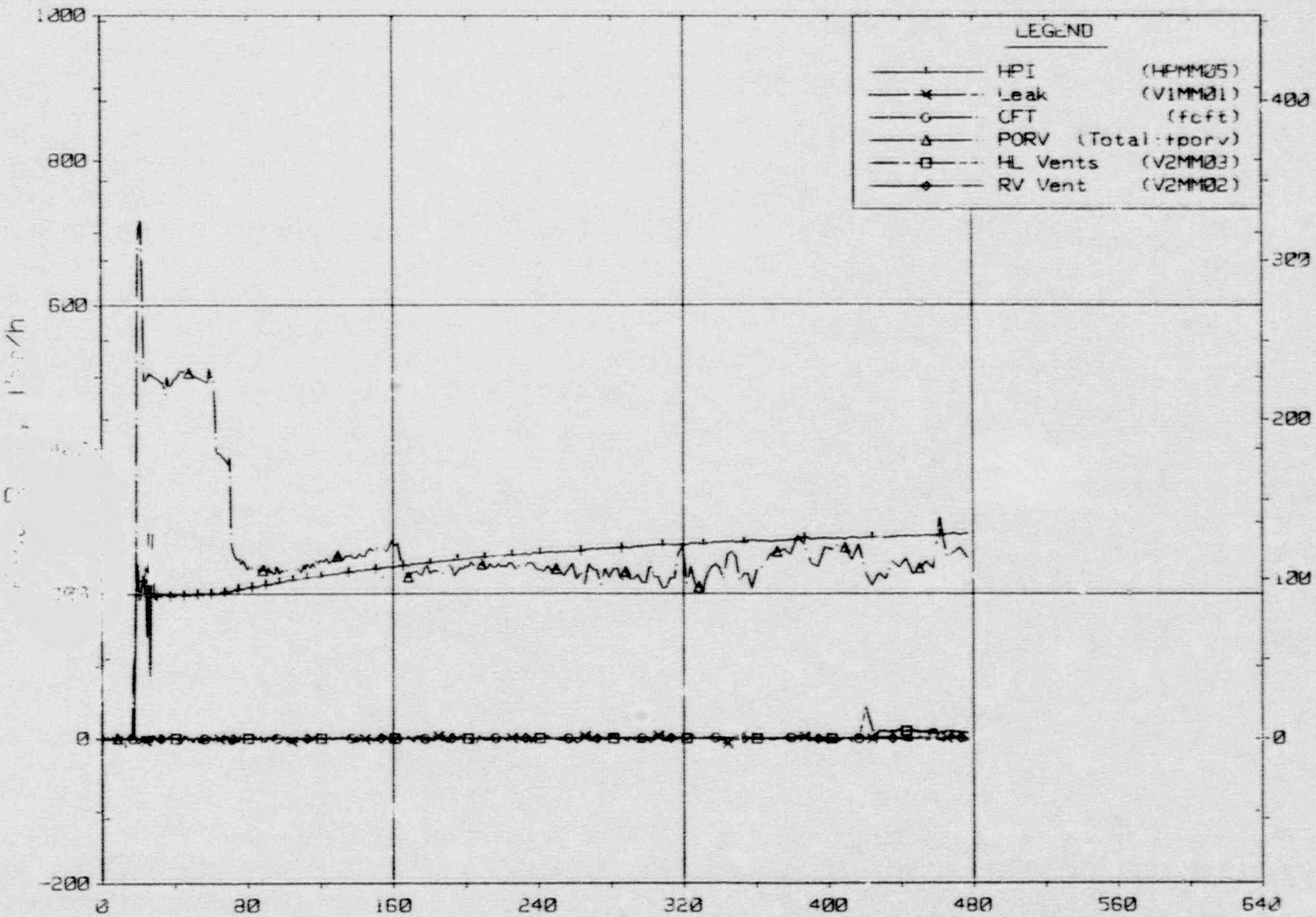


Figure 5.6.16. Primary System Boundary Flow Rates

Fri Jul 22 10:24:52 1988

PRFL3p

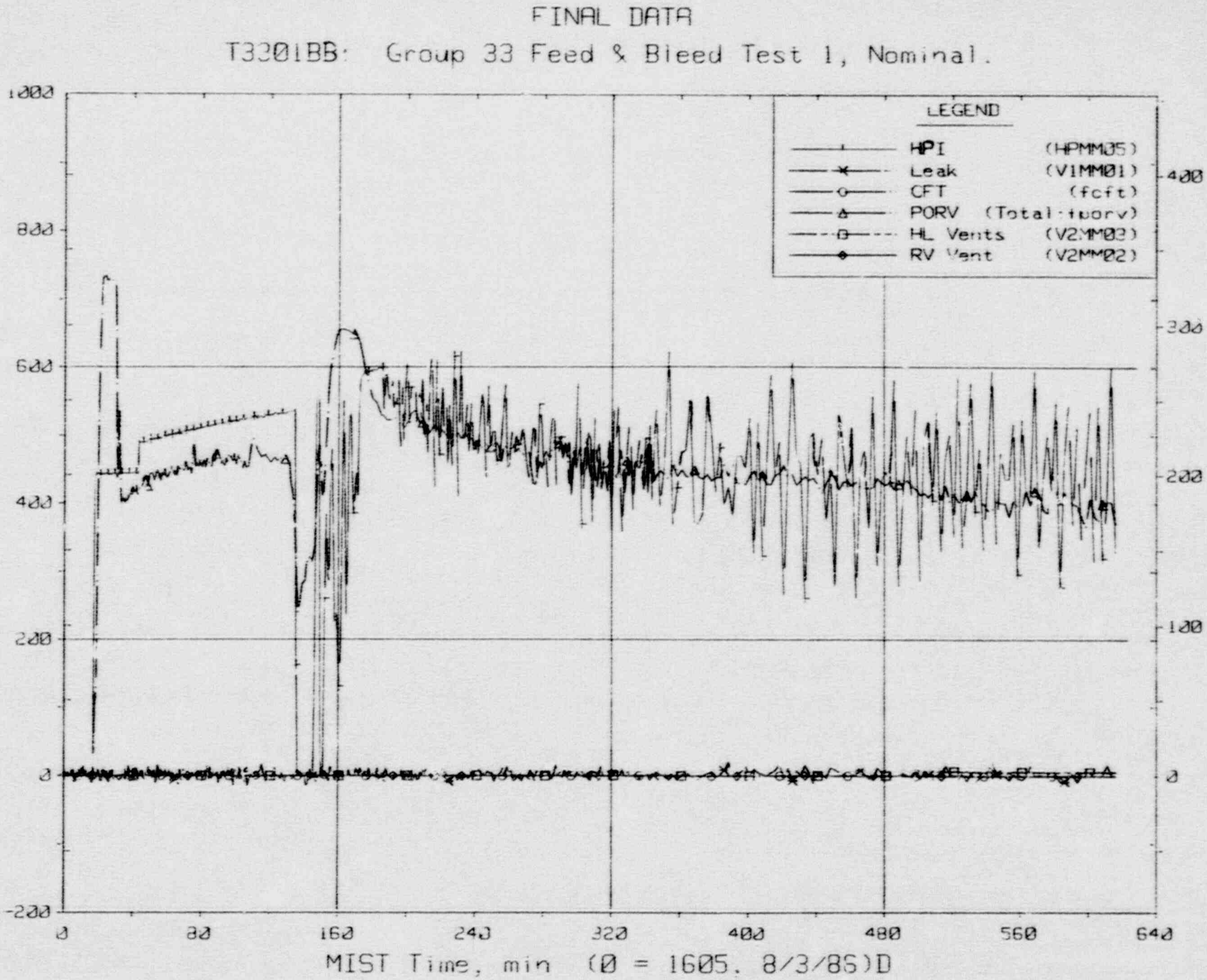


Figure 5.6.17. Primary System Boundary Flow Rates

Tue Nov 1 09:19:41 1988

PRFL3p

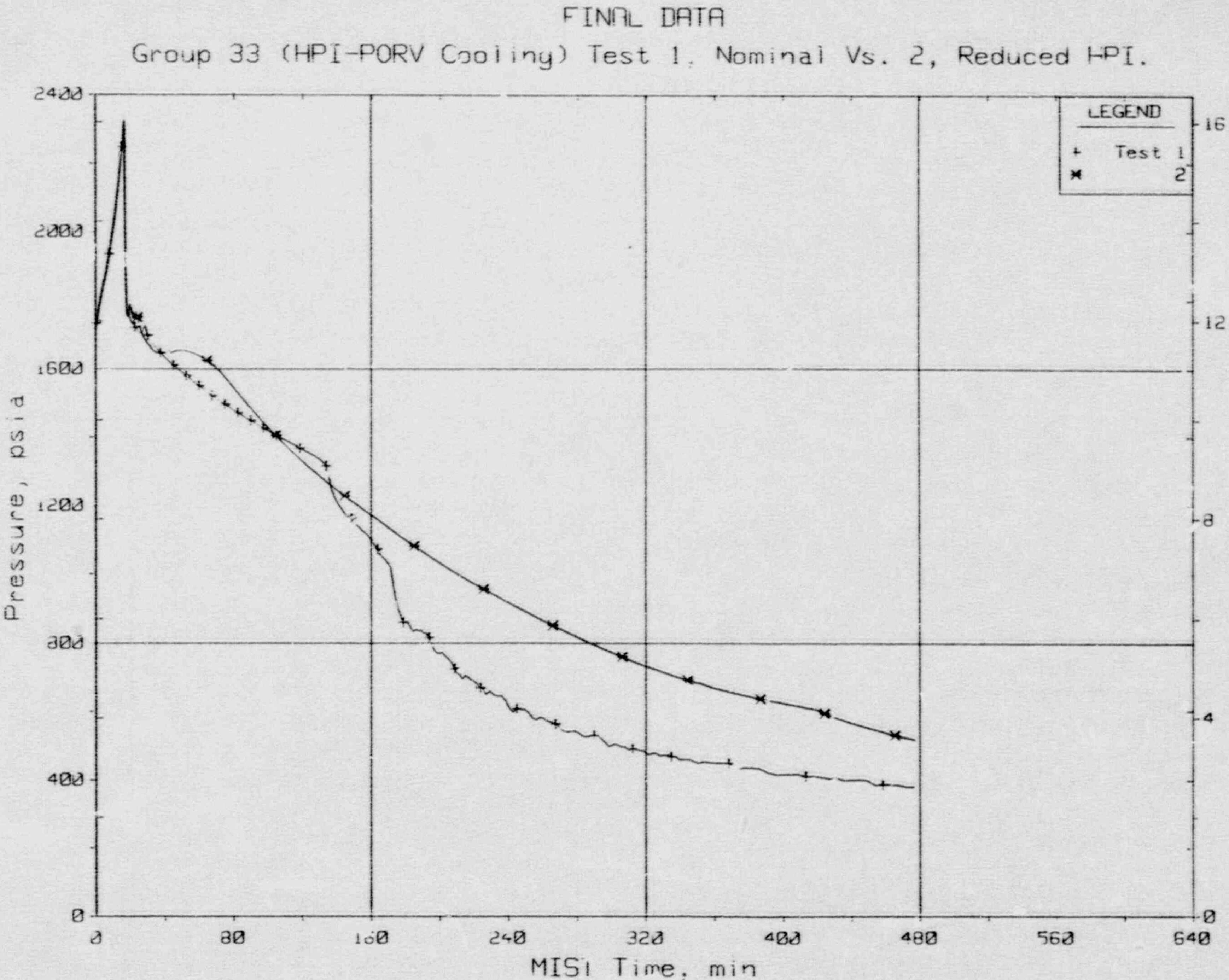


Figure 5.6.18. Reactor Vessel Pressure

Thu Jul 21 16:07:24 1988

12RVGP1

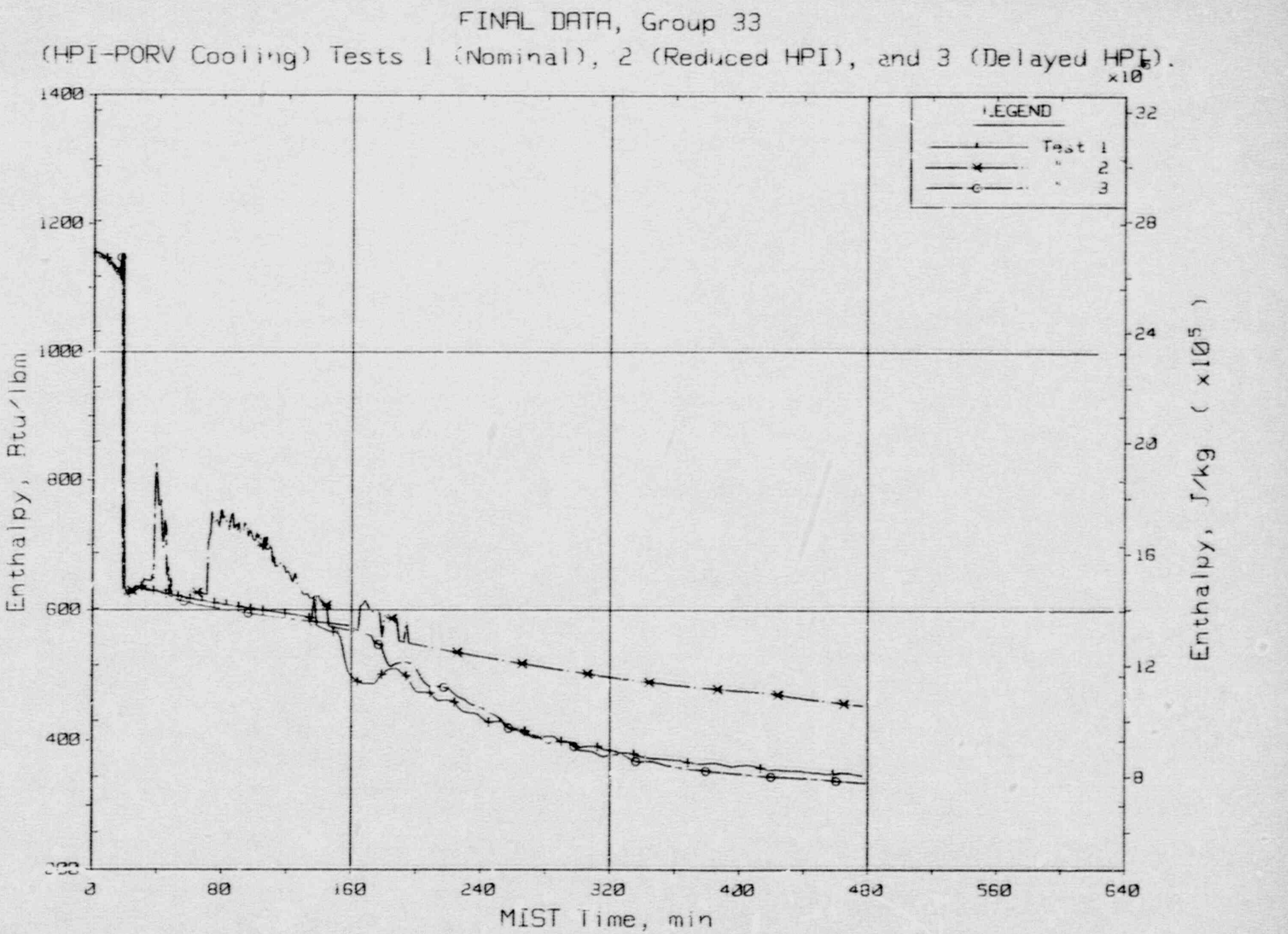


Figure 5.6.19. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Thu Jul 21 16:55:46 1988

123PZEN1

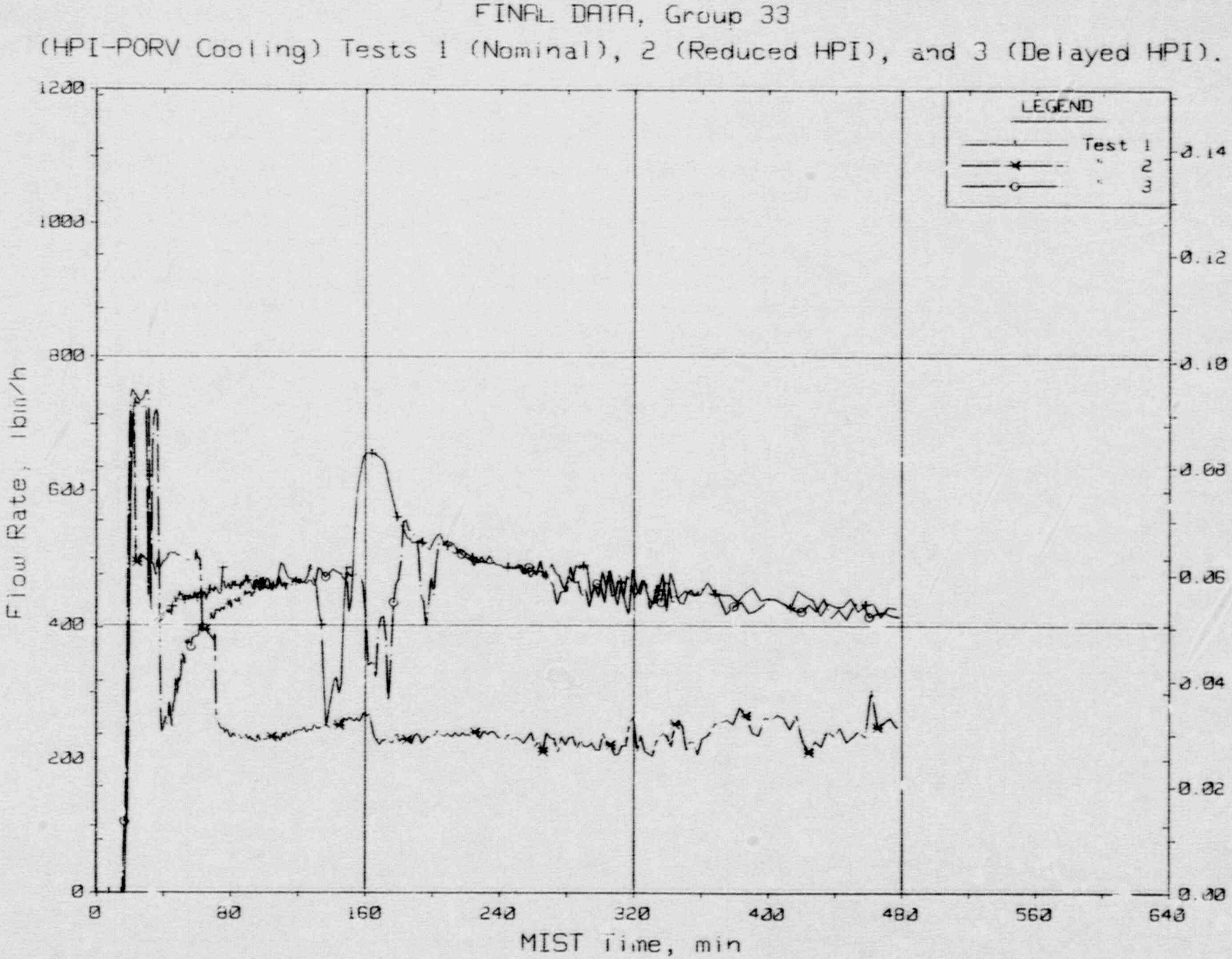


Figure 5.6.20. Power-Operated Relief Valve (Total) Flow Rates

Thu Jul 21 16:58:17 1988

123PRFL3

FINAL DATA, Group 33

(HPI-PORV Cooling) Tests 1 (Nominal), 2 (Reduced HPI), and 3 (Delayed HPI).

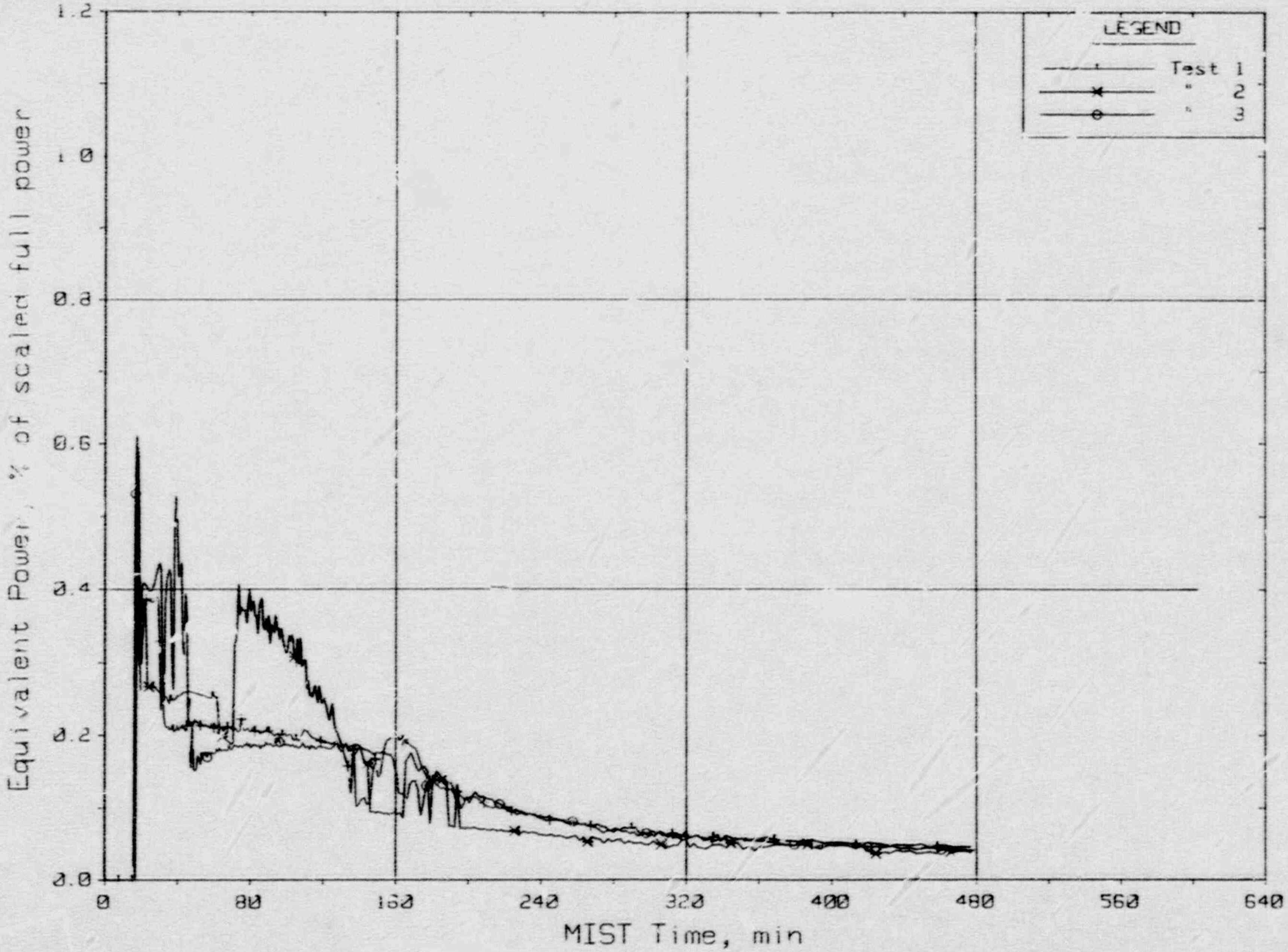


Figure 5.6.21. PORV Fluid Volume Change

Thu Jul 21 17:02:18 1988

123PRPA0

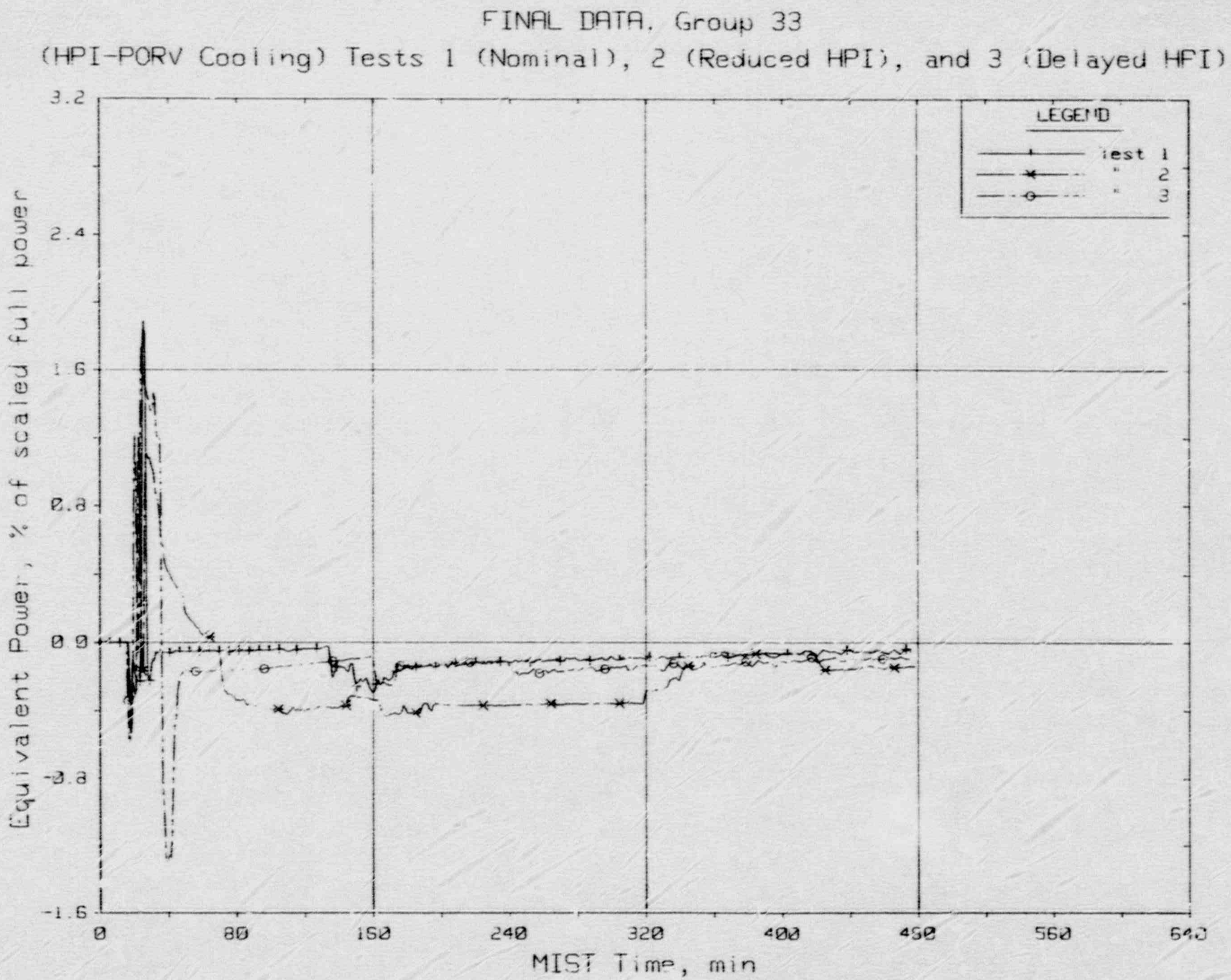


Figure 5.5.22. Net Primary System Fluid Volume Change

Tue Nov 1 12:01:09 1988

123PRPA1

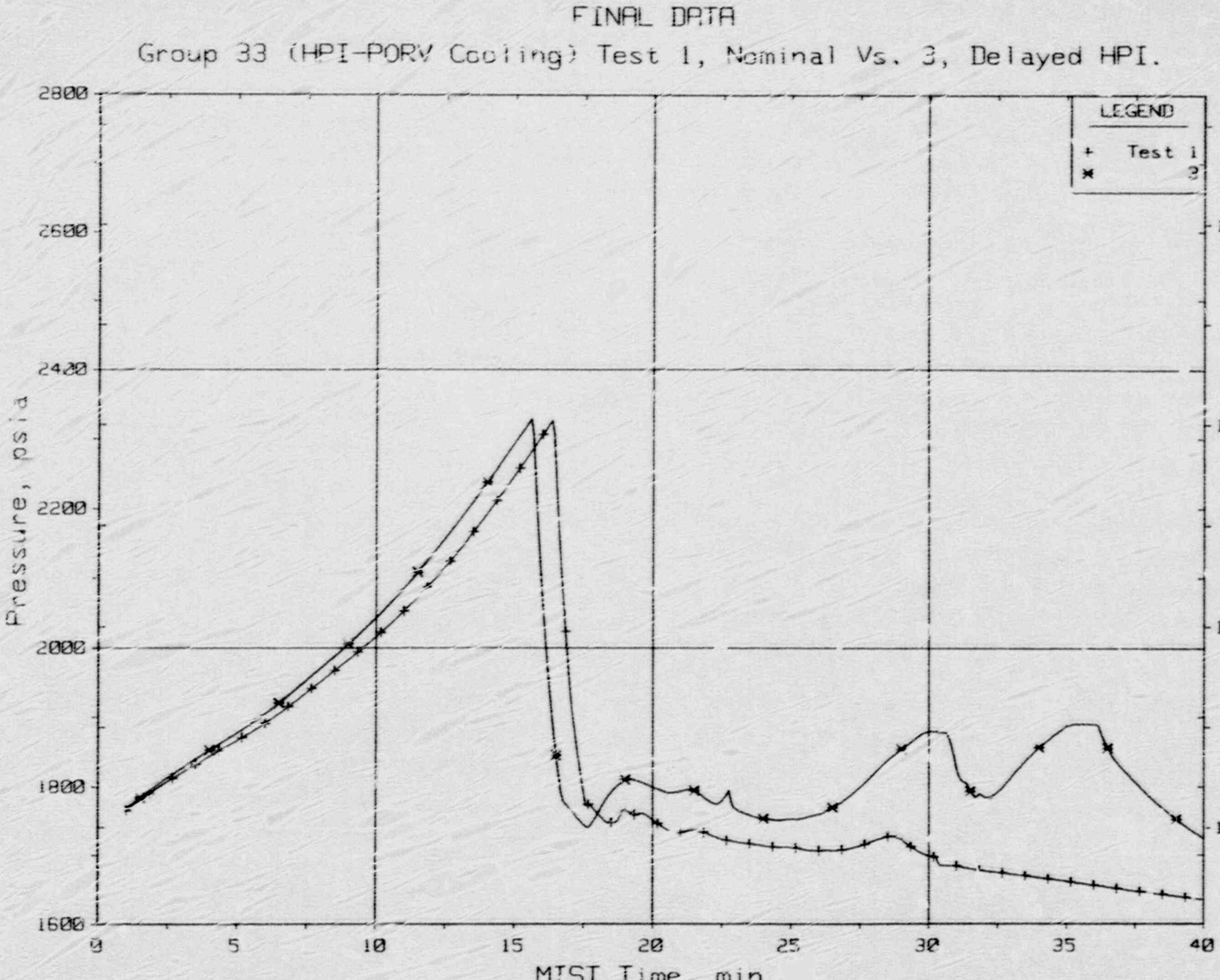


Figure 5.6.23. Reactor Vessel Pressure

Fri Jul 22 09:35:37 1988

13RVGP1

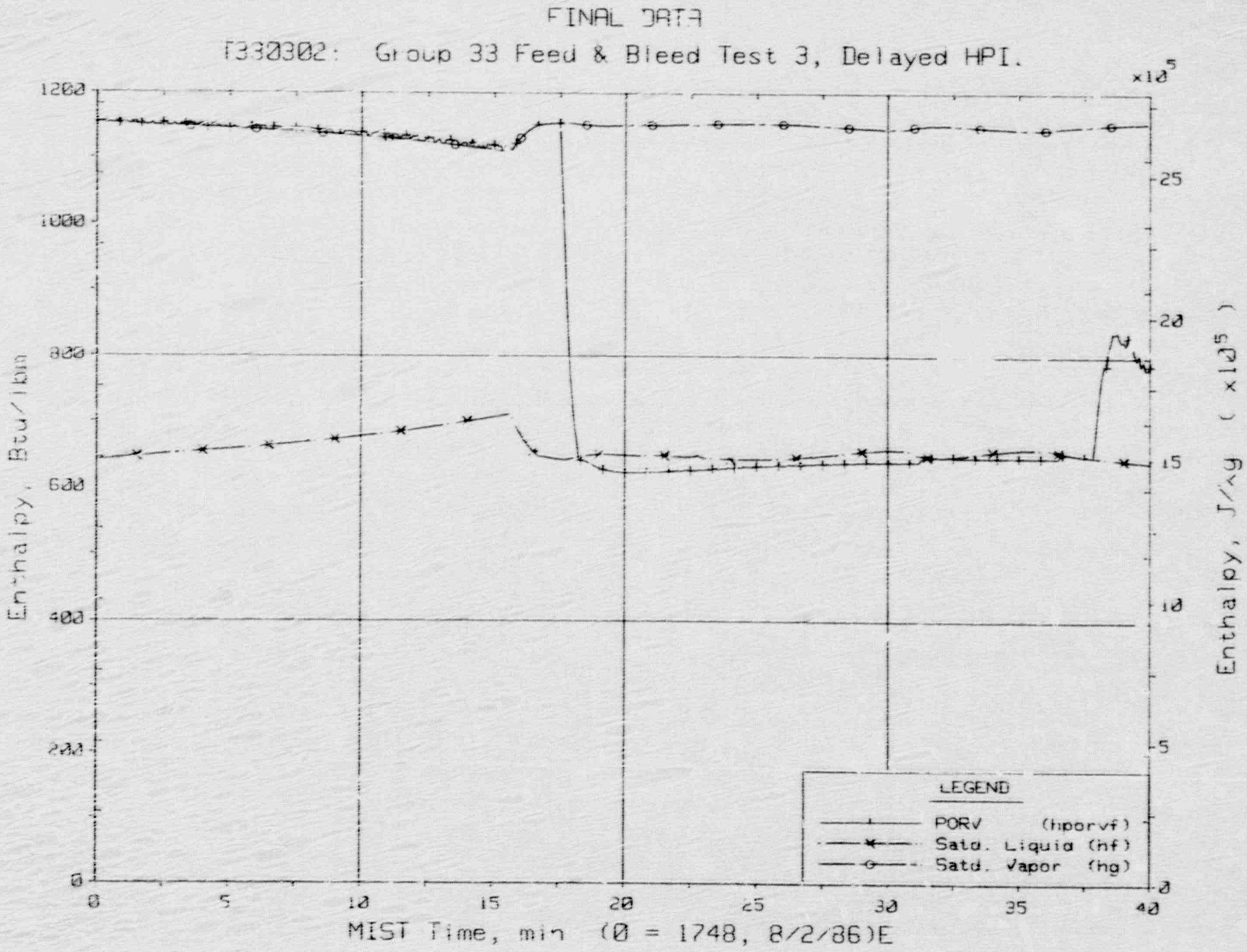


Figure 5.6.24. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Tue May 1 09:41:13 1988 PZEN1

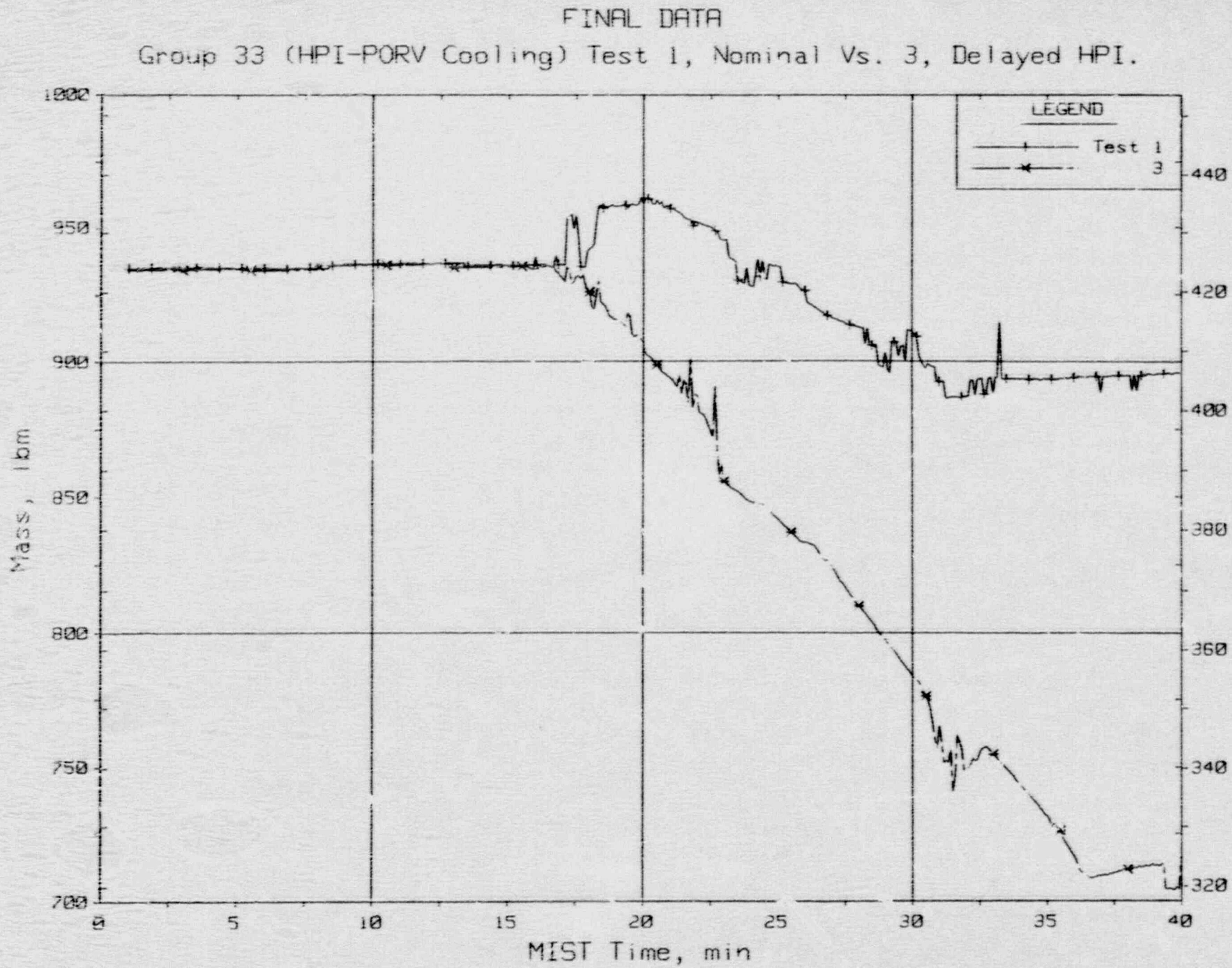


Figure 5.6.25. Indicated Primary System Total Fl'id Mass (PLML20s)

Fri Jul 22 09:27:32 1988

13PRML_i

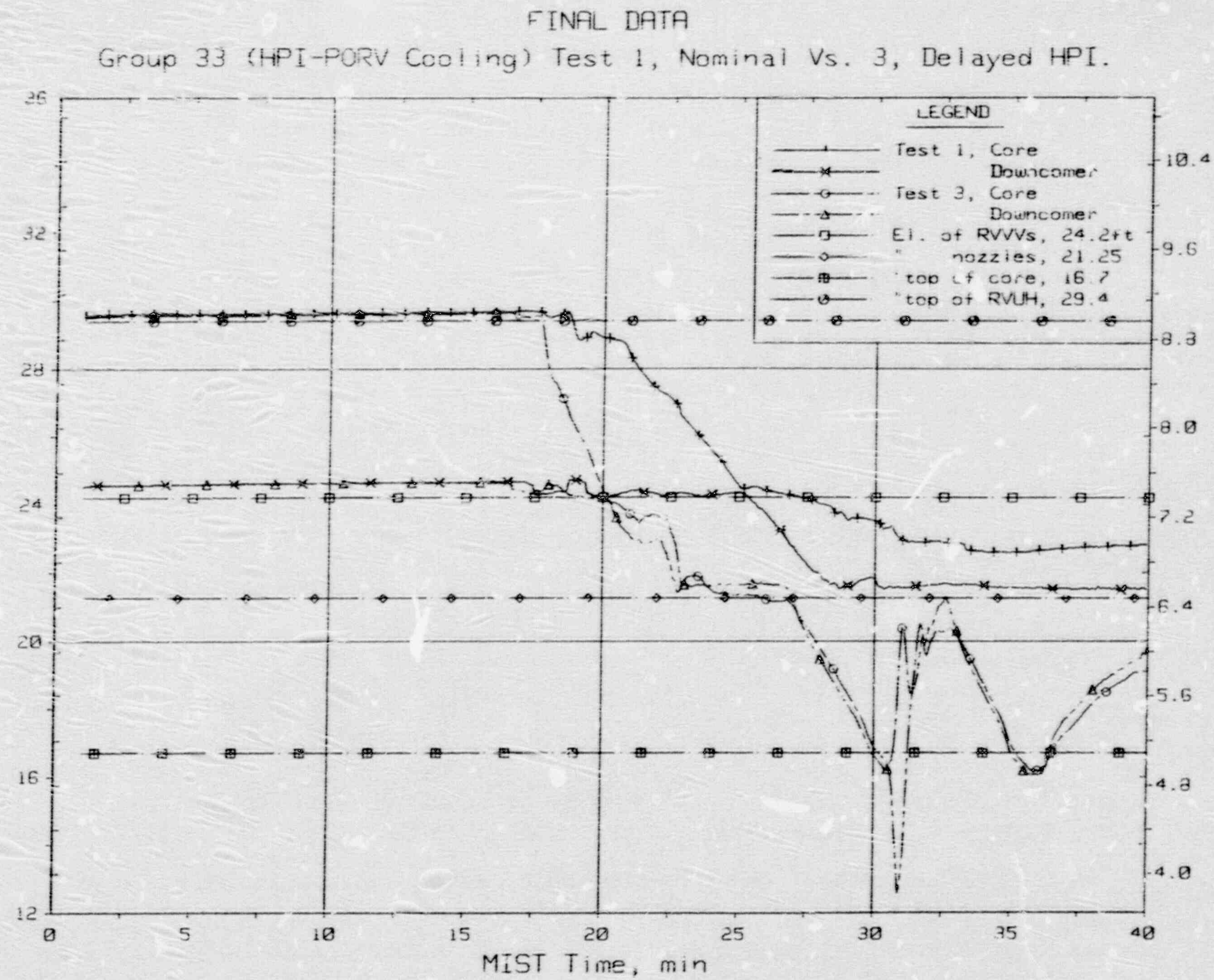
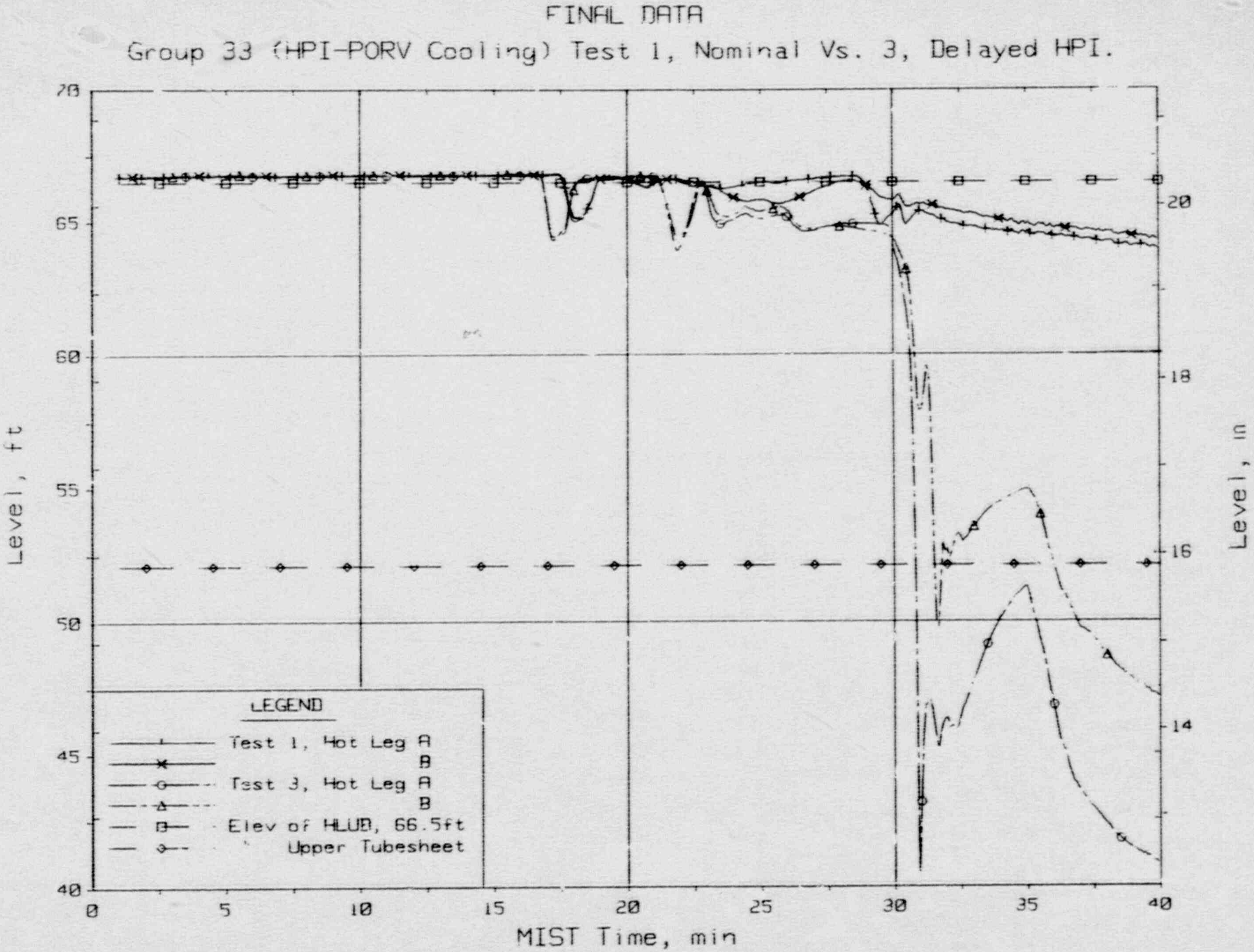


Figure 5.6.26. Core Region Collapsed Liquid Levels

Fri Jul 22 09:41:25 1988

13COLV1



5-140

Figure 5.6.27. Hot Leg Riser Collapsed Liquid Levels

Fri Jul 22 09:44:56 1988

13HLLV1

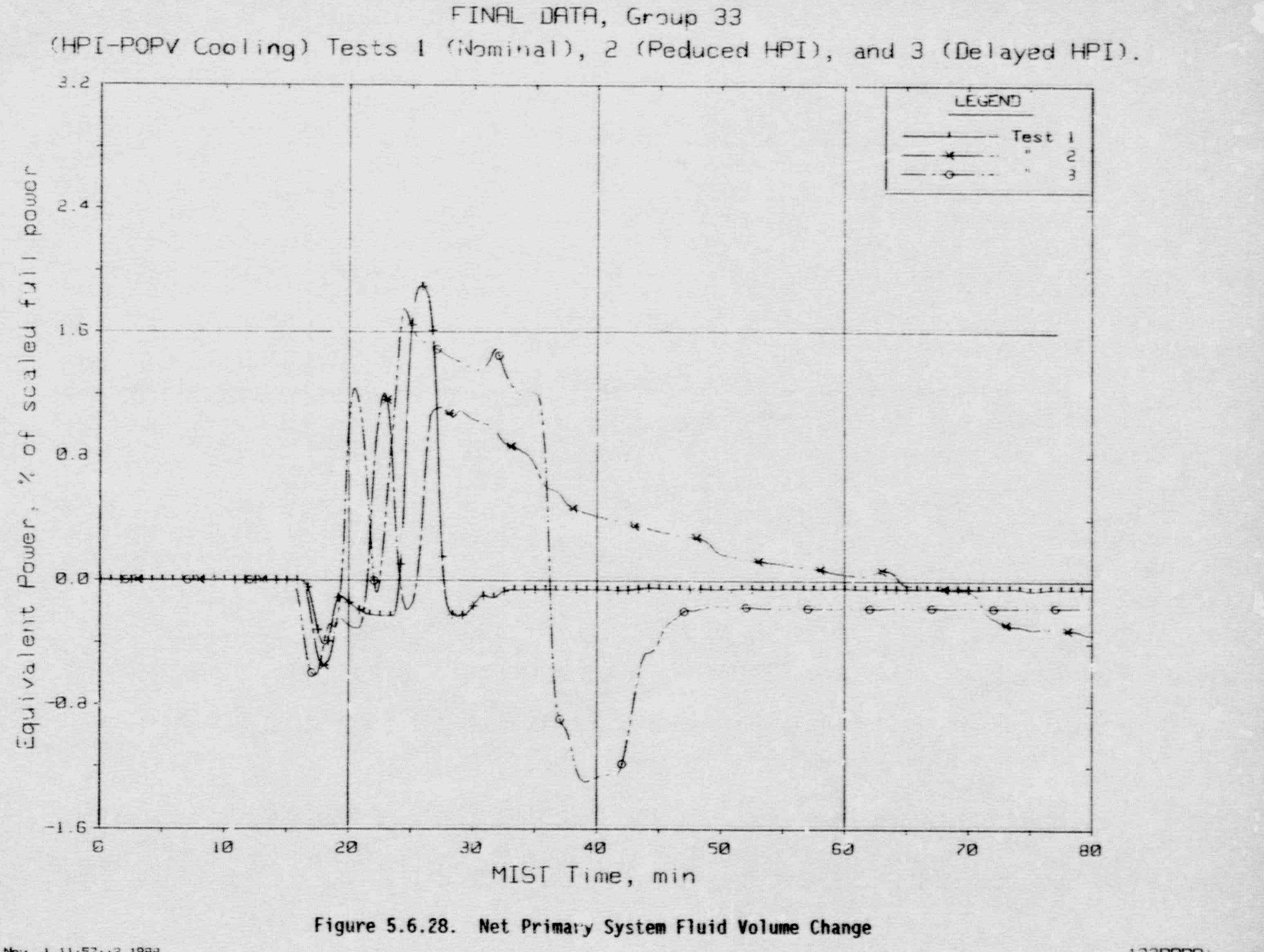


Figure 5.6.28. Net Primary System Fluid Volume Change

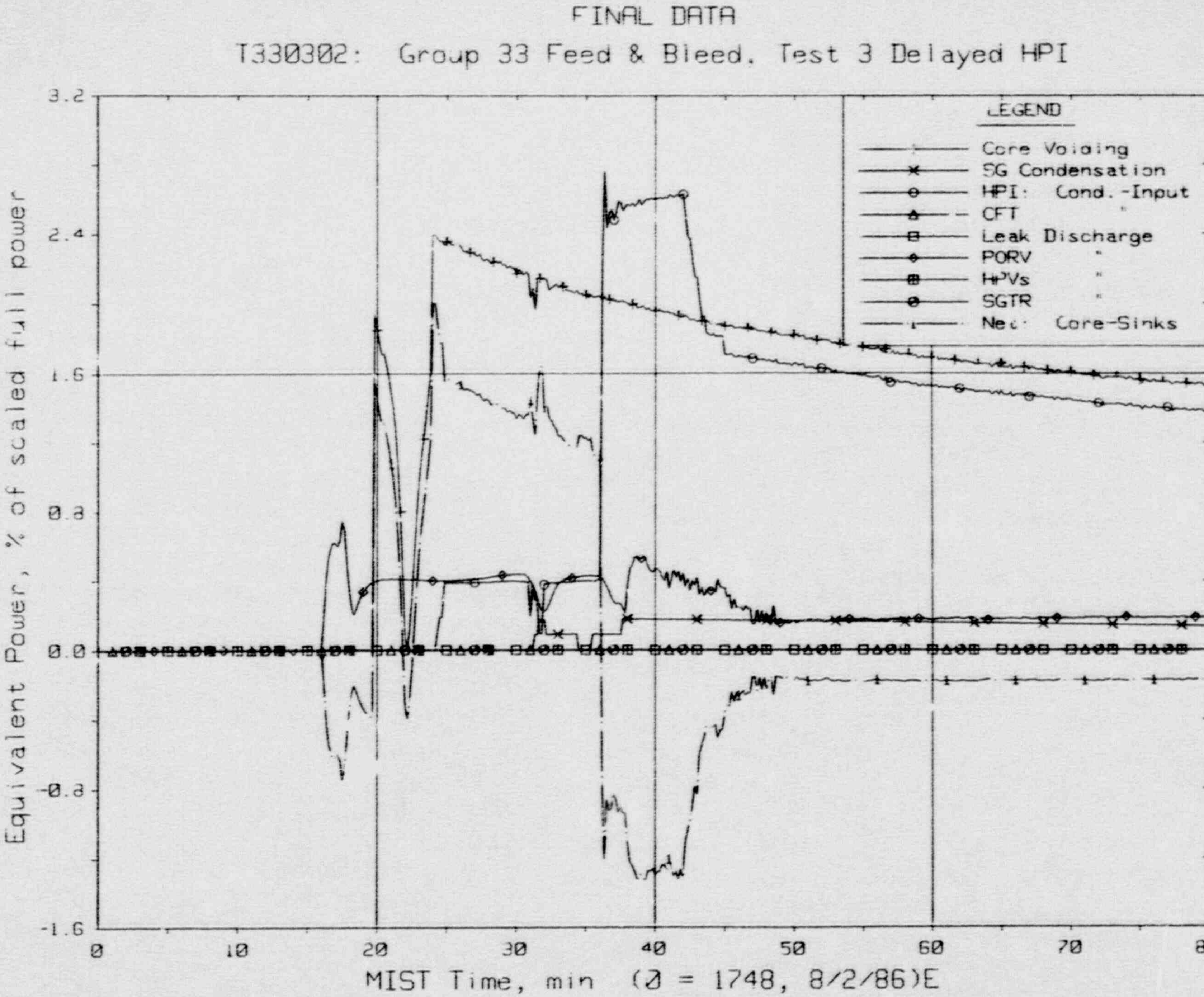


Figure 5.6.29. Primary Fluid Volume Changes by Components

Fri Jul 22 10:02:50 1988

PRP36

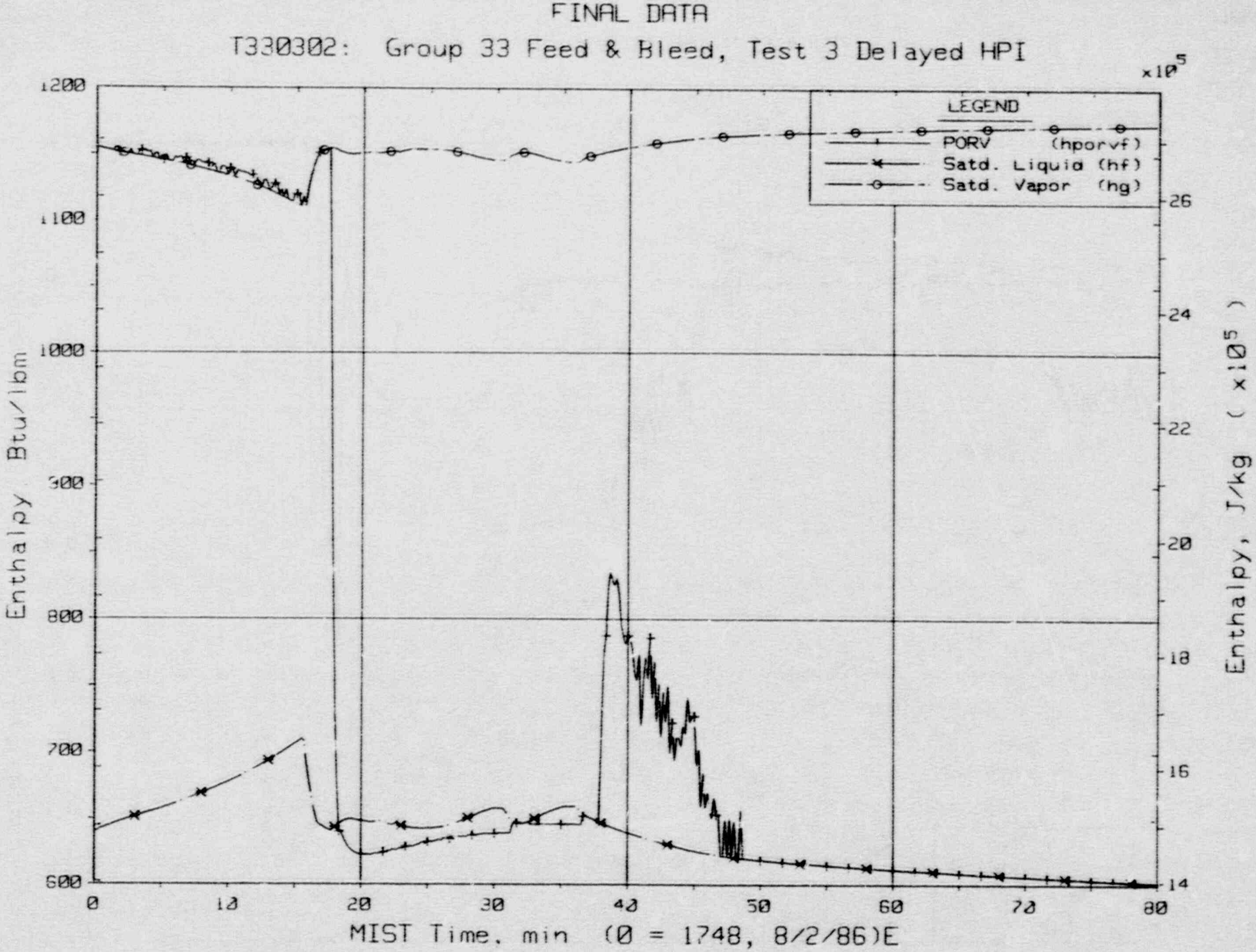


Figure 5.6.30. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Fri Jul 22 10:05:30 1988

PZEN1

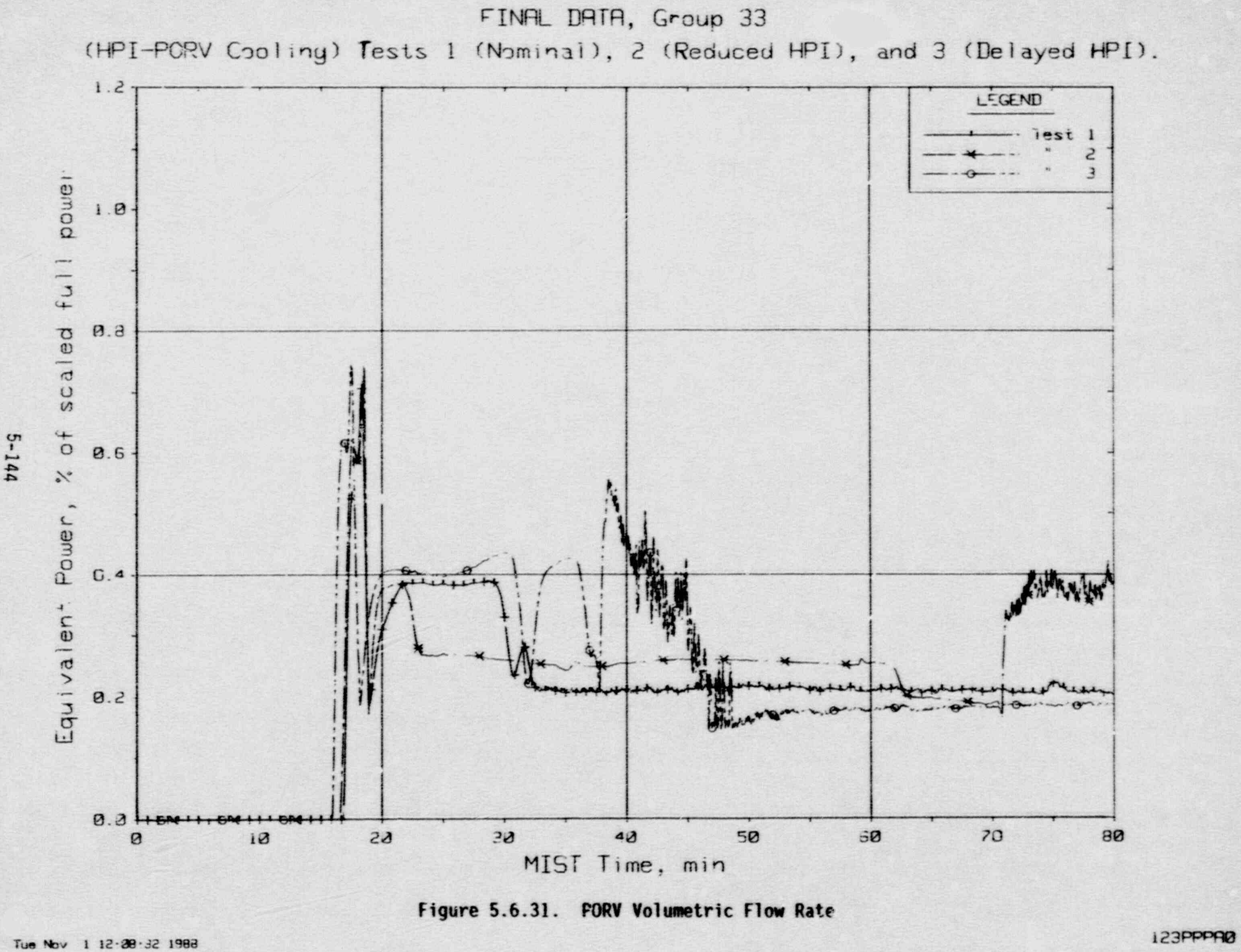


Figure 5.6.31. PORV Volumetric Flow Rate

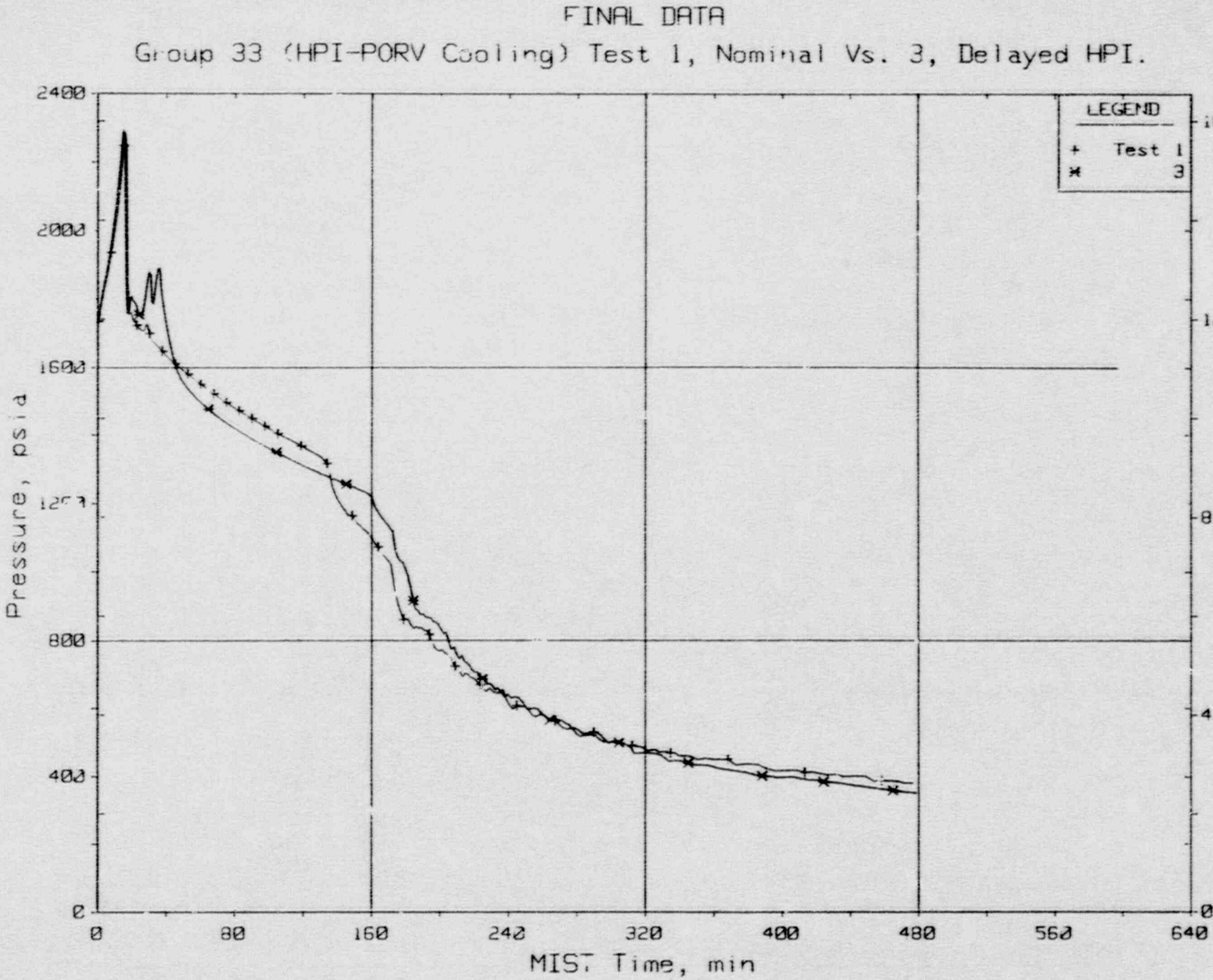


Figure 5.6.32. Reactor Vessel Pressure

Thu Jul 21 16:13:15 1988

13RVGP1

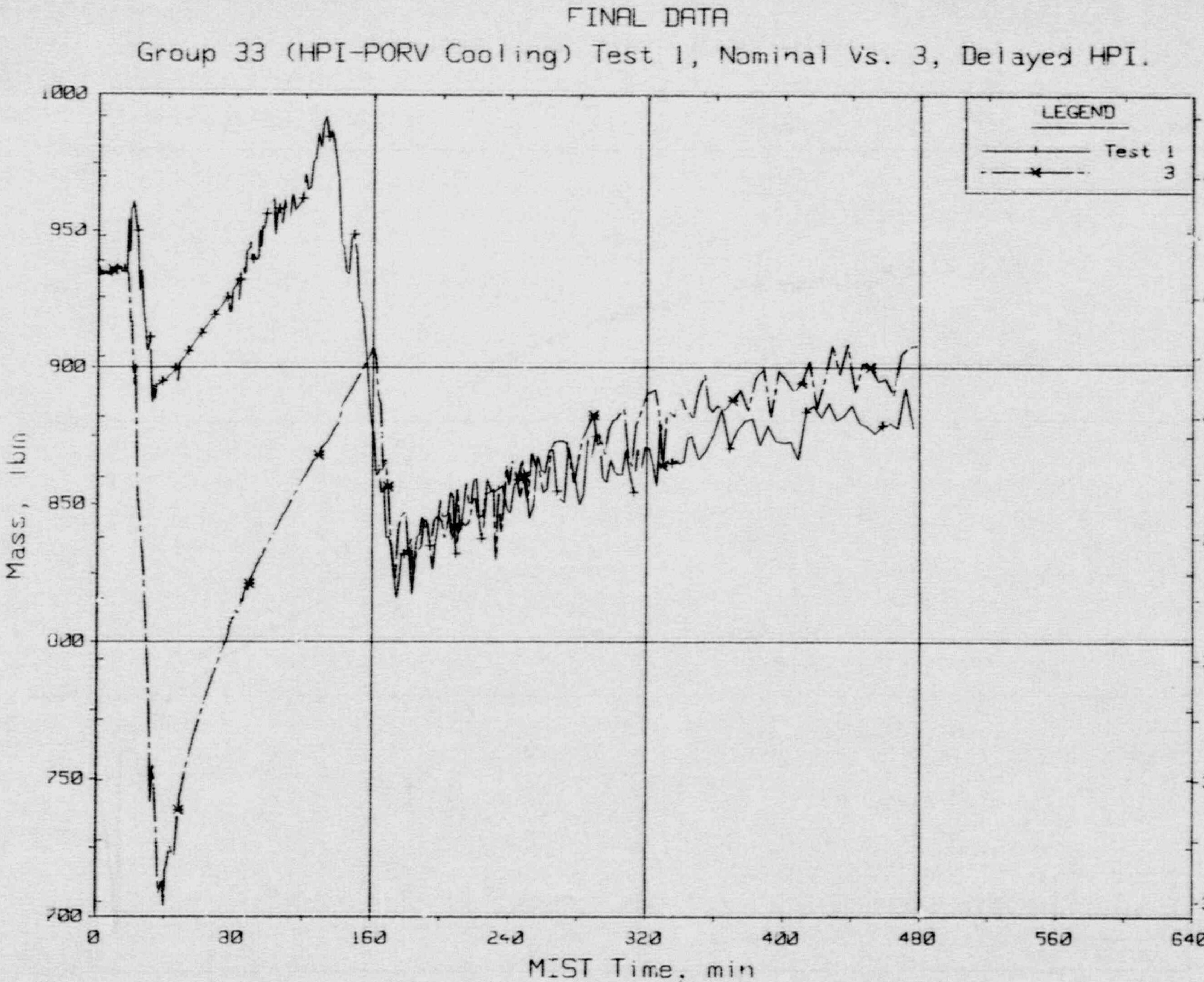


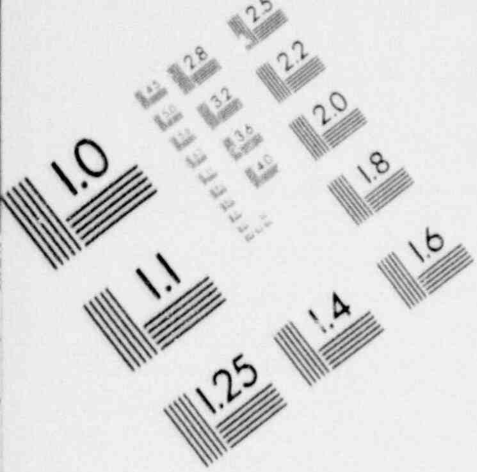
Figure 5.6.33. Indicated Primary System Total Fluid Mass (PLML20s)

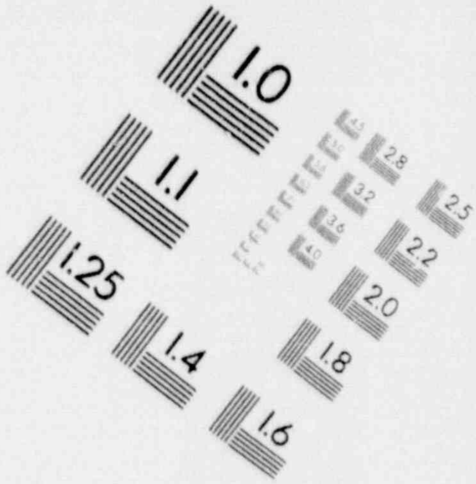
Thu Jul 21 16:15:07 1988

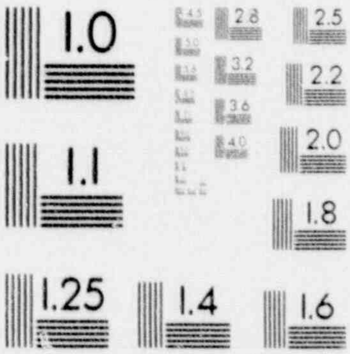
13PPML1

2

IMAGE EVALUATION TEST TARGET (MT-3)

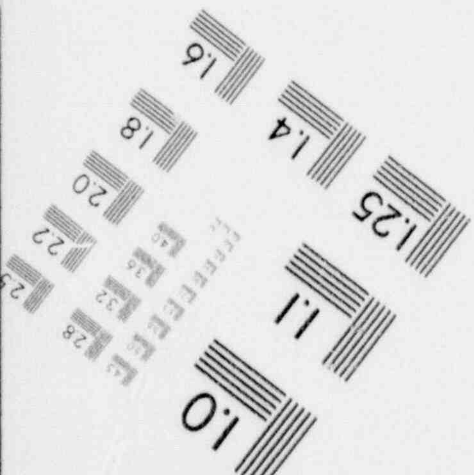


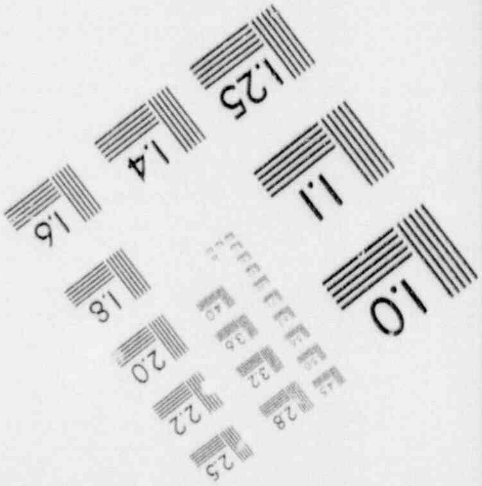




150mm

6″

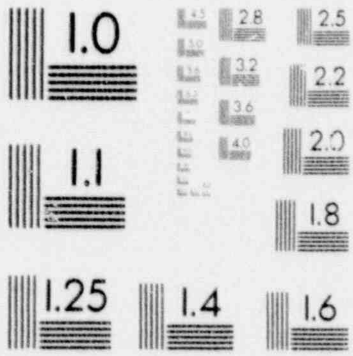




PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

2

IMAGE EVALUATION TEST TARGET (MT-3)



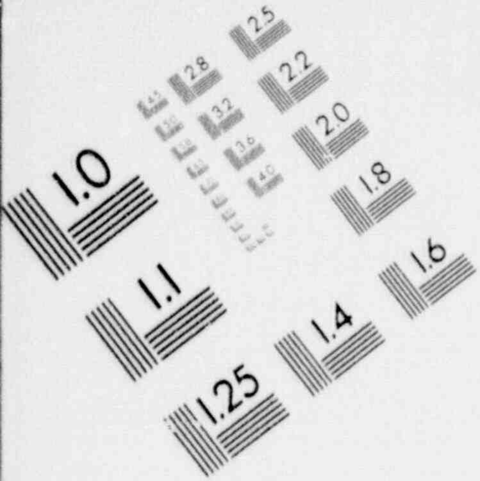
150mm

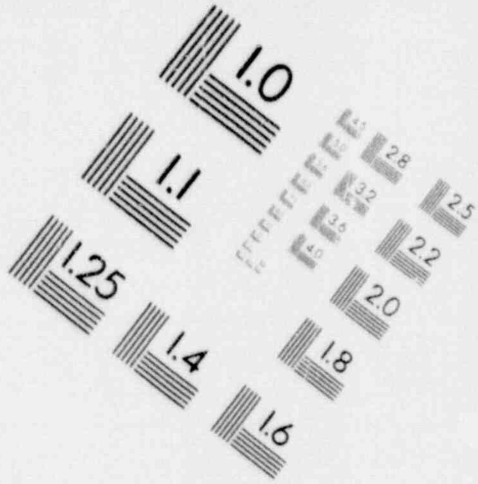
6"

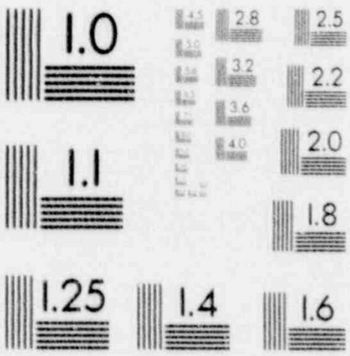
PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

2

IMAGE EVALUATION TEST TARGET (MT-3)

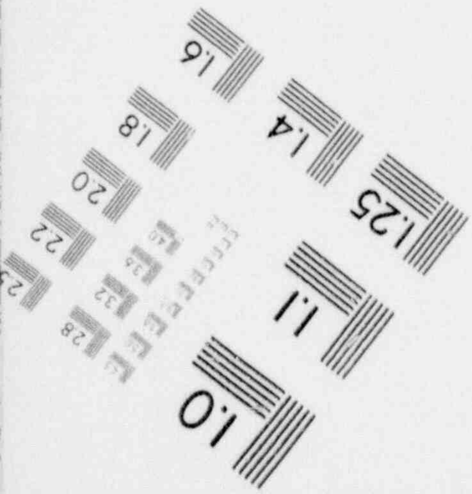


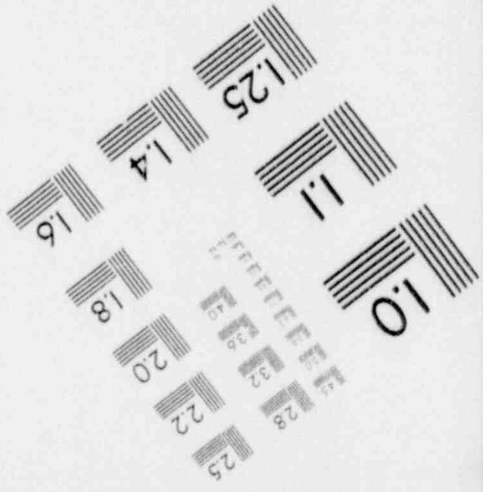




150mm

6"

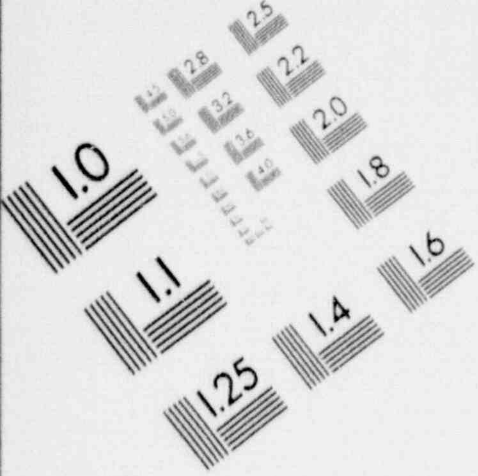
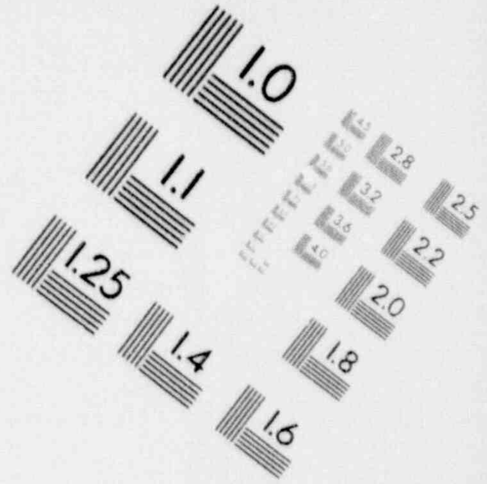
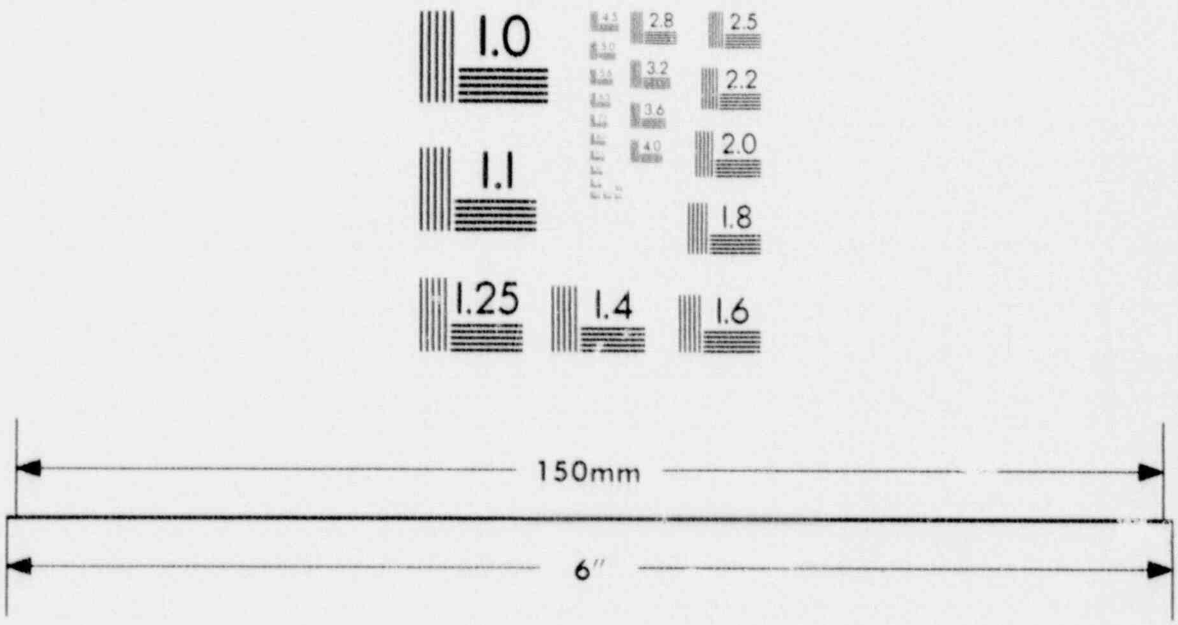


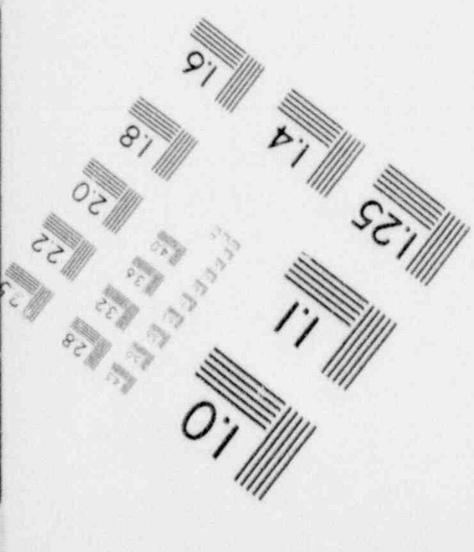
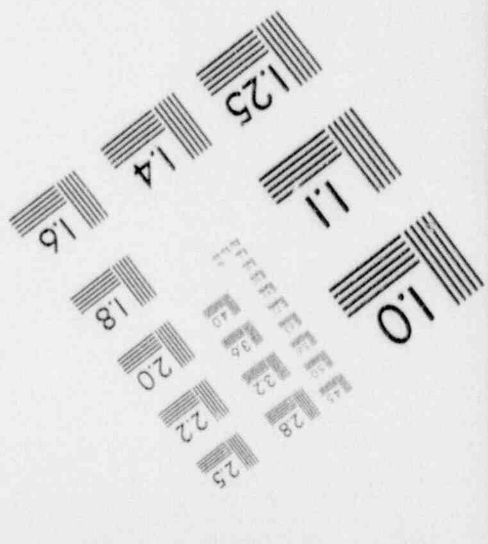


PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

2

IMAGE EVALUATION TEST TARGET (MT-3)

PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

FINAL DATA

Group 33 (HPI-PORV Cooling) Test 1, Nominal Vs. 3. Delayed HPI.

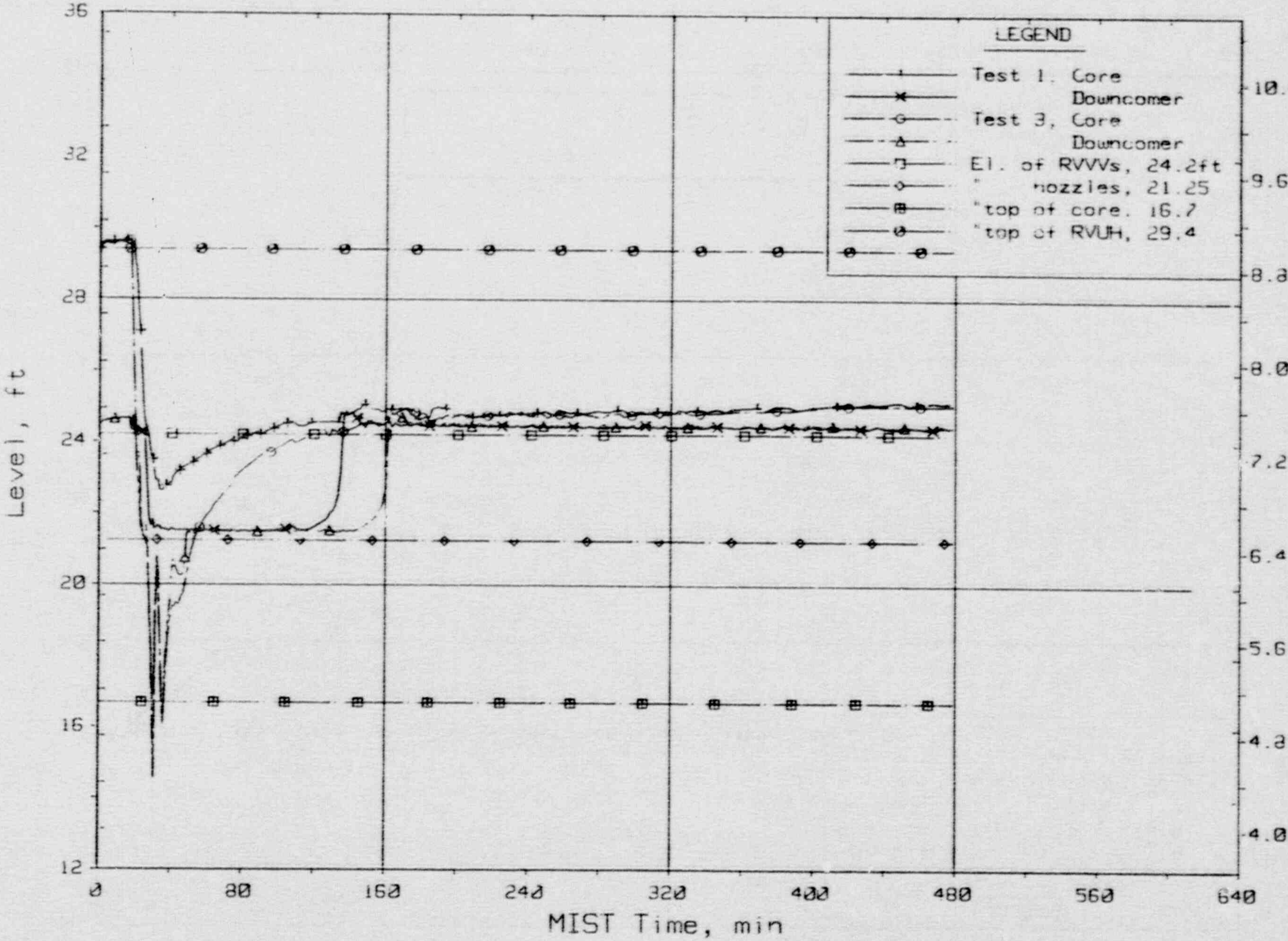


Figure 5.6.34. Core Region Collapsed Liquid Levels

Thu Jul 21 16:18:56 1988

13COLV1

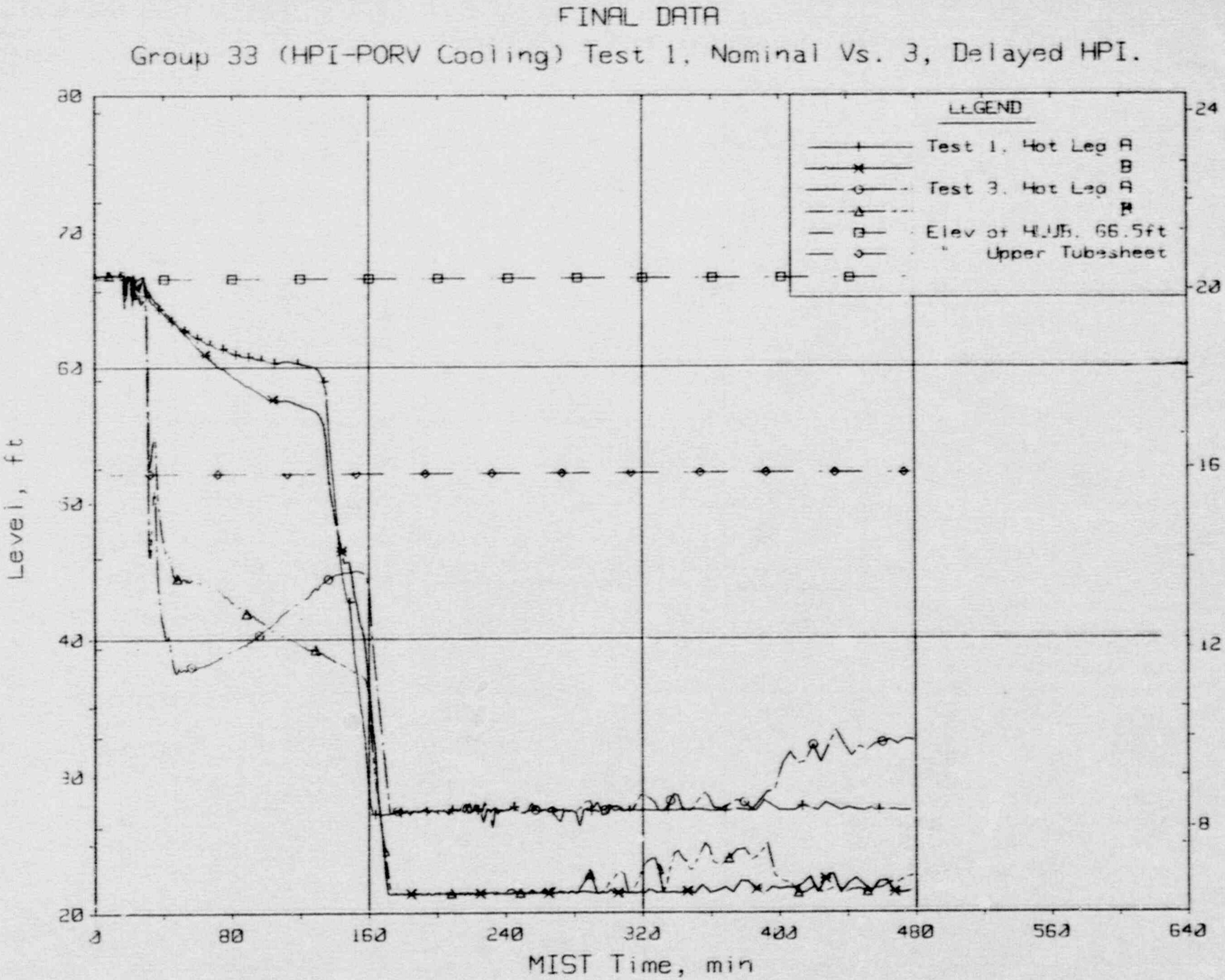


Figure 5.6.35. Hot Leg Riser Collapsed Liquid Levels

Thu Jul 21 15:22:17 1988

13HLLV1

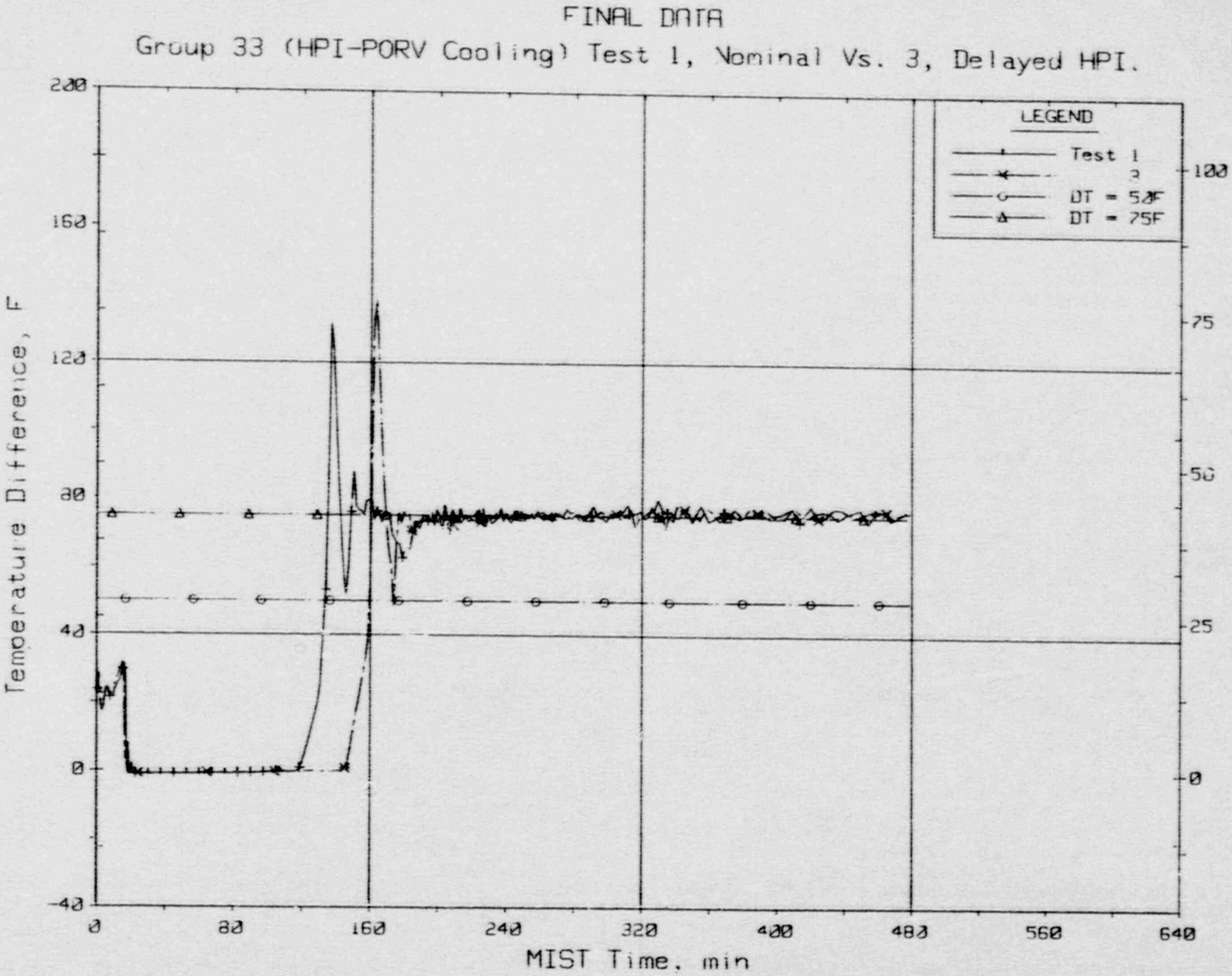


Figure 5.6.36. Subcooling Margin

5-149

Thu Jul 21 16:24:49 1988

13PRTD1

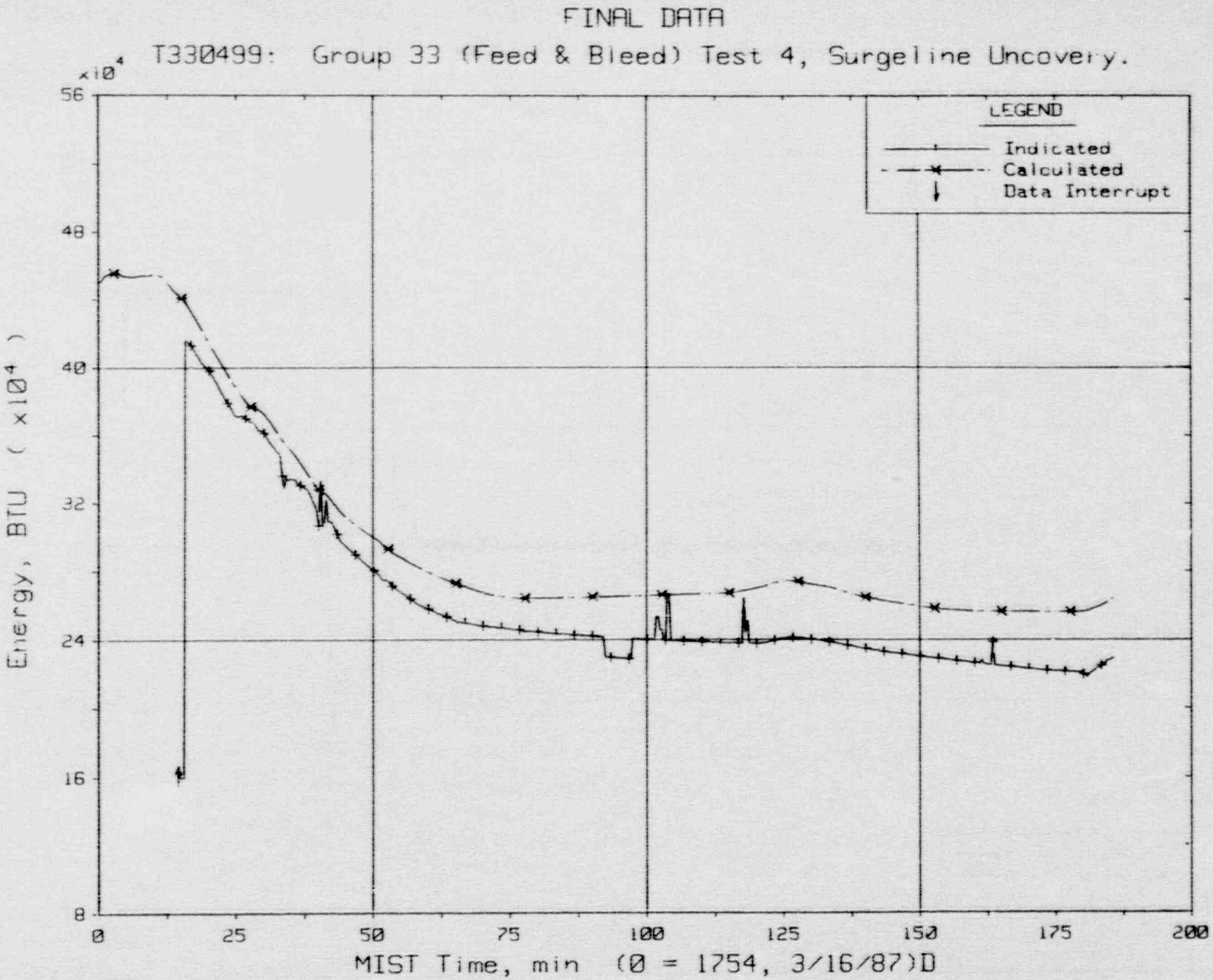


Figure 5.6.37. Primary System Total Fluid Energy

Fri Jul 22 09:50:41 1988

PRTE2

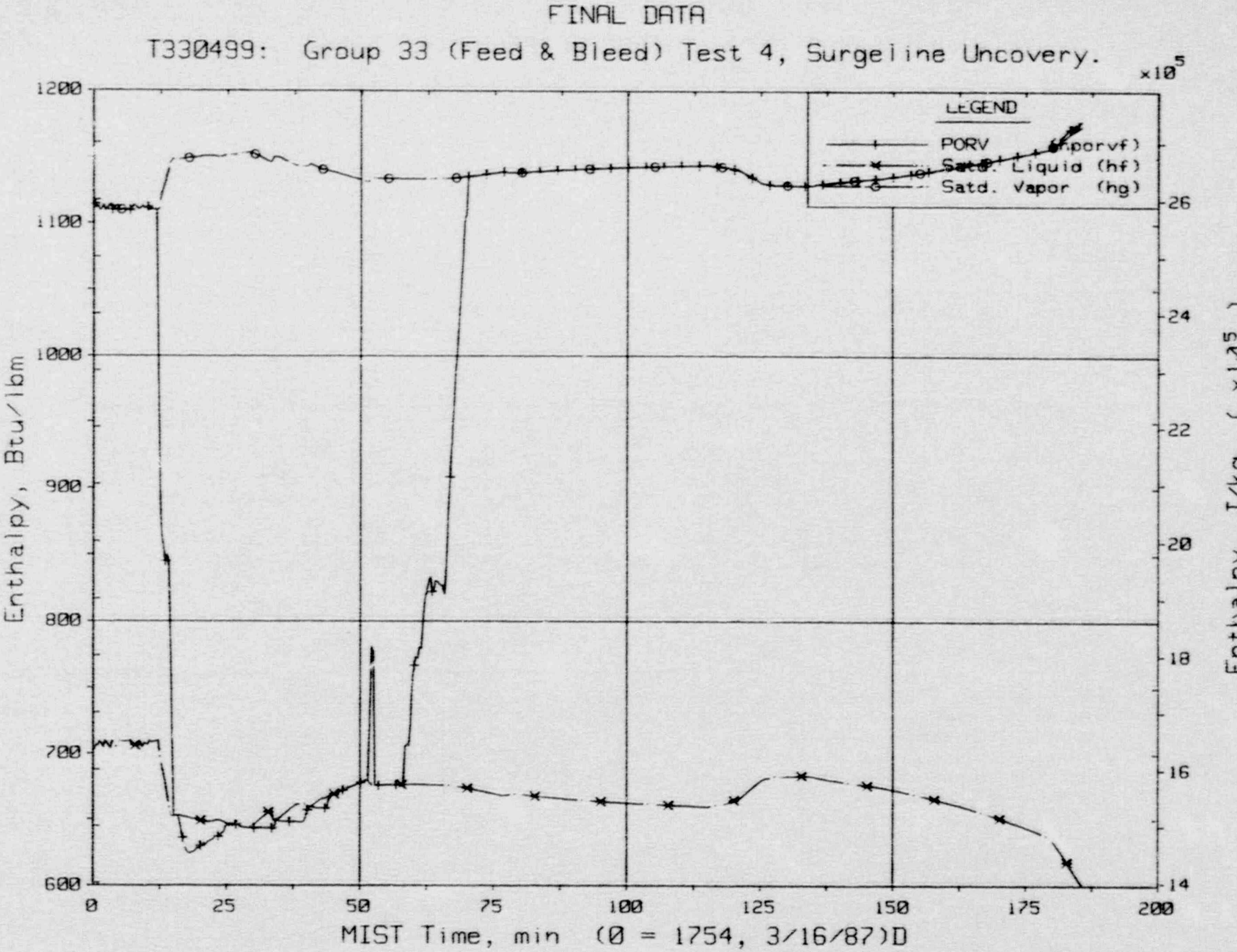


Figure 5.6.38. Power-Operated Relief Valve Enthalpy (Based on Flow Rate)

Fri Jul 22 09:53:14 1988

PZEN1

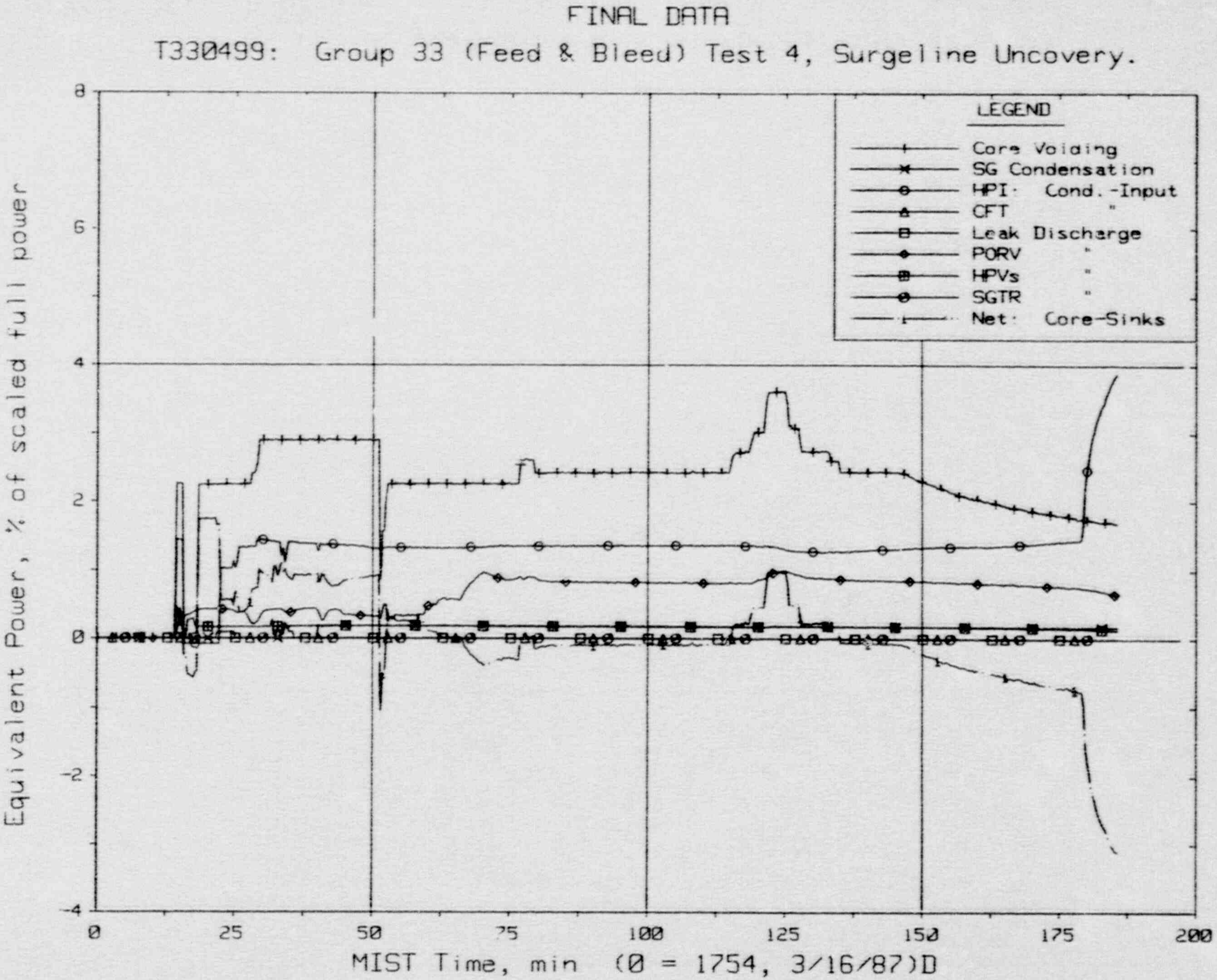


Figure 5.6.39. Primary Fluid Volume Changes by Components

Fri Jul 22 09:57:18 1988

PRPA0

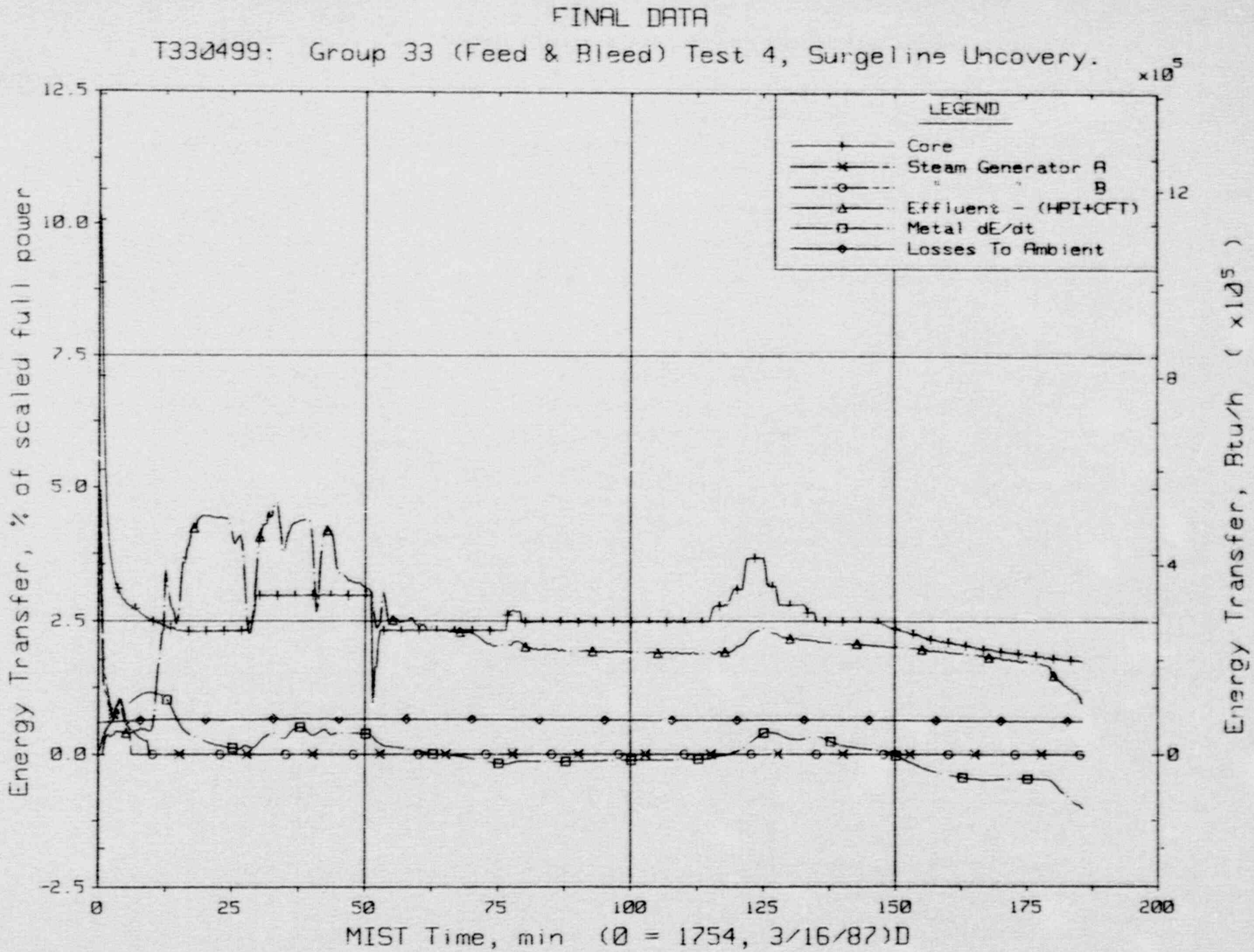


Figure 5.6.41. Primary System Energy Transfer

Fri Jul 22 10:40:02 1988

PROE2

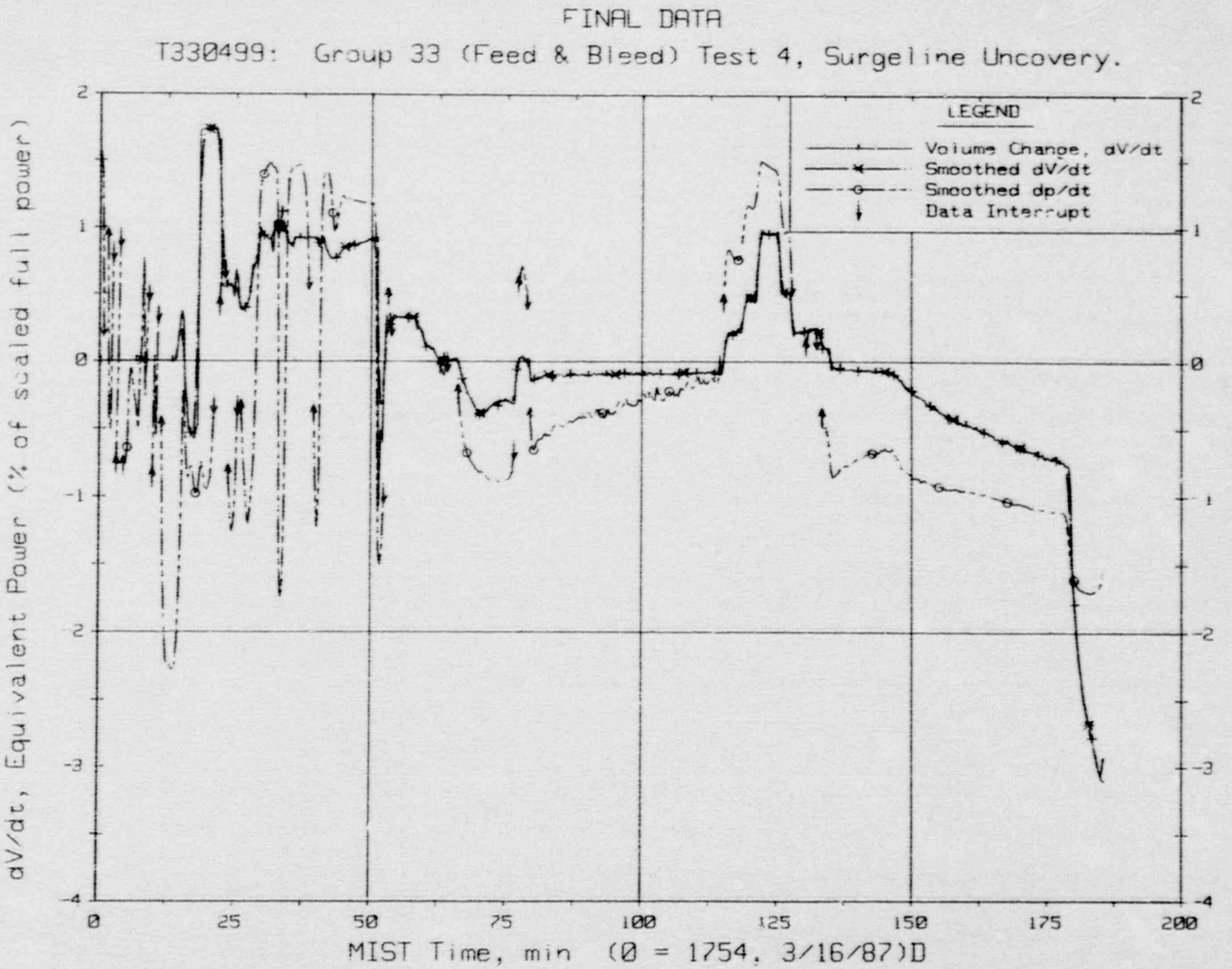


Figure 5.6.40. Primary Fluid Volume and Pressure Changes, dV/dt and dp/dt

Fri Jul 22 10:36:13 1988

PRPA2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.

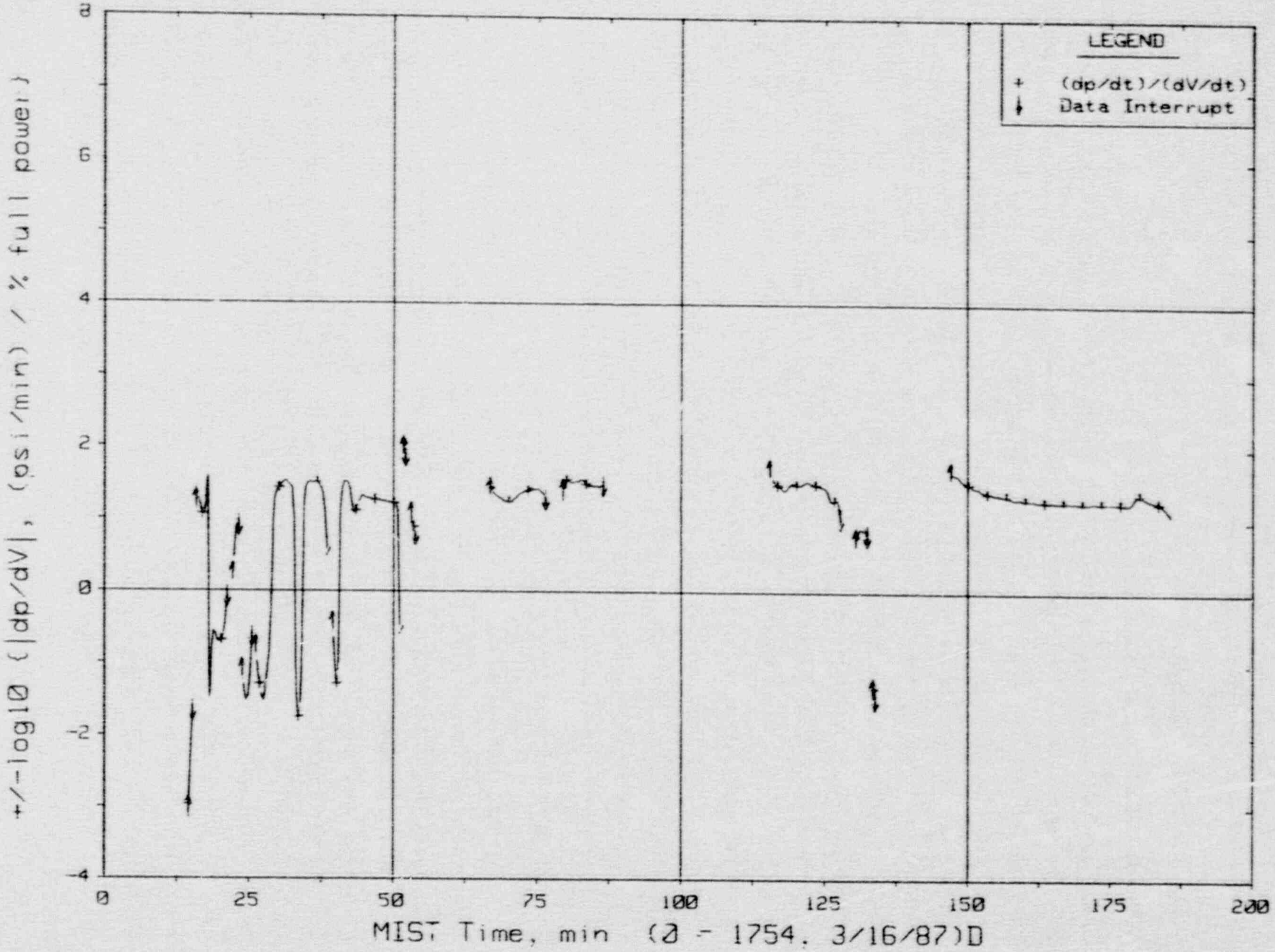


Figure 5.6.42. Primary System Response: dp/dt divided by dV/dt

Fri Jul 22 10:42:05 1988

PRPA3

5.7. Summary of Observations

General observations and the effects of altered boundary conditions are given in section 5.7.1. Noteworthy interactions are addressed in section 5.7.2.

5.7.1. General Observations

Pressure Increase and PORV Lift

Group 33 Tests 1 through 3 used identical control through the activation of HPI following PORV lift. The three tests behaved almost identically through this period of the deactivation of the steam generator secondaries. The primary system pressurized as primary-to-secondary heat transfer was reduced. The pressurizer began to fill as the primary system liquid expanded with heating. As the pressurizer level rose, the ongoing primary system heatup produced a pronounced temperature gradient within the pressurizer. The uppermost liquid had been slightly subcooled at the initial pressure whereas the lower liquid reflected subsequent heating and was warmer. When the primary system pressurized to the PORV lift pressure, the PORV actuated and was kept open by manual switch actuation. The resulting PORV depressurization reduced the primary system pressure to saturation. The upper reactor vessel and hot leg fluid voided, the pressurizer quickly filled, and the PORV site fluid subcooled because of the previously described temperature gradient of the pressurizer liquid. The subsequent events were transient dependent.

Nominal Test

Full capacity HPI was used in Nominal Test 1. As the PORV site liquid approached saturation with the continuing PORV discharge, the PORV mass flow rate decreased accordingly and approximately matched the HPI mass flow rate. The total primary system fluid mass stabilized, the core region levels gradually increased, and the core exit fluid began to subcool at 2 hours. The HPI flow was throttled as the SCM reached 75F, causing the primary system to lose fluid mass. Although the core exit fluid remained subcooled, the hot leg A liquid level descended below the surge line at 160 minutes. The primary system depressurization was enhanced and the subcooling of the PORV site fluid was diminished, therefore the primary system fluid mass again stabilized but with throttled HPI.

Reduced HPI Capacity, Test 2

Reduced capacity HPI was used in Test 2. Whereas the primary system total fluid mass had stabilized in Test 1 (until HPI was throttled to control SCM), it continued to decline in Test 2. In Test 2, the core region liquid levels descended below the nozzle elevation by 40 minutes, then the hot leg levels began to decline relatively rapidly. The hot leg A level reached the surge line elevation near 70 minutes. The PORV site fluid quality increased, causing the PORV mass flow rate to decrease toward the HPI mass flow rate, and augmenting the PORV volumetric flow rate. Thus, the primary system depressurized and the total primary fluid mass approximately stabilized. The PORV site fluid remained a saturated vapor and the core exit fluid remained saturated for the duration of Test 2.

Delayed HPI, Test 3

The activation of HPI was delayed for 20 minutes after PORV actuation in Test 3. During this period without HPI, the primary system intermittently repressurized, the core region levels stabilized near the top of the core, and the hot leg levels descended toward the surge line elevation. Upon HPI activation, the primary system depressurized at almost 100 psi/min due to both HPI condensation and the transition of the PORV site fluid from liquid to saturated vapor. After the HPI activation events subsided, the conditions in Test 3 quickly realigned towards those of Nominal Test 1. As in Test 1, the conditions stabilized with HPI throttled to maintain an SCM of 75F. The actuation of both hot leg high-point vents at 4 hours had little effect on system conditions.

Surge Line Uncovery, Test 4

Test 4, surge line uncovery, was quite dissimilar to the other Group 33 tests. Test 4 was initiated in forced flow. The PORV was allowed to cycle in response to pressure until 10 minutes after the hot leg temperatures exceeded 590F. At this time, the PORV was held open by manual switch actuation, the hot leg high-point vents were opened, and makeup injection was activated. A four-pump coastdown was enacted as the SCM diminished to 20F. Core power was adjusted manually several times during the transient. The resulting changes in core void production obtained a variety of primary fluid volume balances. Of particular interest, a surge line uncovery was obtained with a (constant) core power of 2.33% of scaled full power; this power level, less 0.55% uncompensated losses to ambient, is achieved 20 minutes after reactor trip from prolonged operation at full power. Upon uncovery of the surge line, the state of the PORV site fluid changed from saturated liquid to saturated vapor. The net primary system fluid volume change became negative due to the increased PORV volumetric flow rate, causing the primary system to depressurize. The observed ratio of pressure change to imposed fluid volume change generally ranged from 15 to 30 psi/min per percentage of scaled full power.

Core power was subsequently increased, first to stabilize primary system pressure and later to obtain surge line uncovery (the preceding surge line uncovery had not been detected by the test operators). These core power adjustments provided valuable data. The first power increase obtained the core power offset by PORV discharge with the surge line uncovered. The core exit was saturated, primary system pressure was approximately 2000 psia, and makeup injection was active. The core void production less uncompensated losses to ambient was approximately 2% of scaled full power. This decay power level is achieved 13 minutes after reactor trip from prolonged operation at full power.

The second manual core power increase obtained core uncovery. Core power was increased as high as 3.7% of scaled full power with the primary system fluid saturated and extensively voided. The primary system pressurized toward 2100 psia, the reactor vessel and downcomer collapsed liquid levels descended almost 4 feet below the top of the core, the core exit region fluid superheated by more than 30F, and the upper heater rod metal temperatures increased as much as 80F.

System Compensation

Although the boundary conditions imposed in Tests 1 through 3 differed markedly, the transients were similar in several important aspects. These similarities included the primary system pressure trends and primary system mass balance. For example, the half-capacity HPI of Test 2 was insufficient to condense the vapor being generated by the core. Hence, primary system pressure remained elevated and intermittently increased. The rate of primary system mass loss remained relatively high at elevated pressure and was increased further by the subcooling of the PORV site fluid as pressure increased. The relatively high rate of mass loss hastened surge line uncovery. Then, the state of the PORV site fluid changed to vapor, reducing the rate of mass loss and augmenting the rate of PORV volumetric discharge. The system thus depressurized and the total primary system fluid mass stabilized. In Test 3 with HPI delayed, system compensation was apparent after HPI was activated. Before activation, the hot leg levels were descending but the surge line had not yet been uncovered.

System Responsiveness

MIST evidenced a ratio of pressure change to imposed fluid volume change of 15 to 30 psi/min per equivalent percentage of scaled full power. This ratio represents the pressure change due to an imposed volume change. A small ratio would reflect a compliant fluid system whereas a large ratio would indicate a stiff system. The MIST hot leg diameters and metal mass were almost a factor of four larger than power-to-volume scaled. Both of these MIST characteristics tended to suppress pressure change, that is to lower the aforementioned ratio of pressure change to imposed fluid volume change. This ratio in a power-to-volume scaled facility, and in a plant, would thus be expected to be higher than in MIST. Two observations relate to these ratios: First, code models must account for metal masses and system configuration. Second, certain types of tests may be improved by modifying the timing of their boundary system variations, such as the core power reduction schedule and the simulated operator actions. The types of tests which might benefit are those which involve primarily the heating and flashing of resident fluid, rather than the injection and discharge of fluid streams. For those which depend on fluid heating, the timing of the boundary system changes could be modified to rescale the total energy deposition as the contained fluid volume.

5.7.2. Noteworthy Observations

Upon continual PORV actuation with natural circulation, the primary system depressurization obtained saturation and voiding in the upper reactor vessel and hot legs.

The uppermost pressurizer liquid subcooled during system heatup and pressurizer insurge due to the time required for the insurge fluid to traverse the pressurizer.

As the pressurizer filled upon PORV actuation, the initial PORV discharge mass flow rate was relatively high due to the subcooling of the PORV site fluid.

Primary system repressurization generally increased the rate of primary system mass loss by subcooling the PORV site fluid.

Upon surge line uncovery, the enthalpy of the PORV site fluid increased. The resulting decreased subcooling reduced the PORV discharge mass flow rate. When the PORV site fluid changed state from liquid to vapor, the PORV discharge mass flow rate decreased significantly while the PORV volumetric flow rate increased markedly. These changes tended to stabilize primary system mass while promoting depressurization.

The system generally compensated for imbalanced boundary conditions. For example, with reduced HPI capacity, the system conditions realigned to decrease the PORV discharge mass flow rate and to increase the PORV volumetric flow rate. The realignment thereby aided depressurization while slowing the rate of loss of primary fluid mass.

The MIST ratio of pressure change to imposed fluid volume change was approximately 15 to 30 psi/min per percentage of scaled full power.

6. SUMMARY

MIST Test Group 33 addressed HPI-PORV cooling. Tests 1 through 3 singly varied either HPI capacity or the time of HPI activation. Test 4 was controlled unlike the other three tests and examined surge line uncovery. The conduct of the Group 33 tests was acceptable. The MIST interactions are of intrinsic interest because they may provide insight into expected plant behavior. MIST was necessarily atypical of a plant in certain important respects, however. The MIST interactions therefore are not to be applied directly to a plant.

Steam generator feed was interrupted to initiate the tests. The steam generators were subsequently isolated and pressurized with nitrogen, thus effectively nulling primary-to-secondary heat transfer. Three of the four Group 33 tests were initiated in natural circulation. The PORV was kept open by manual switch actuation after the valve actuated on high pressure. In the nominal HPI-PORV cooling test, full-capacity HPI was activated as the PORV actuated. The PORV activation depressurized the primary system sufficiently to saturate the upper reactor vessel and hot leg fluid. The pressurizer quickly filled with liquid, causing the PORV mass flow rate to increase. The uppermost pressurizer fluid was slightly subcooled due to the finite pressurizer transit time and the preceding primary system heating. Thus, the PORV mass flow rate first increased due to PORV site subcooling, then subsided as the PORV site fluid approached saturation. The reduced PORV mass flow rate approximately matched the HPI flow rate, thus the primary system total fluid mass approximately stabilized. The core region gradually refilled and the core exit fluid subcooled, therefore the HPI was throttled to maintain a core exit SCM of 75F. The primary system lost mass as the HPI flow rate was reduced, but the system conditions realigned to restore the mass balance. The hot leg levels descended to uncover the pressurizer surge line, causing the PORV site fluid subcooling as well as the PORV mass flow rate to diminish. The core exit fluid remained subcooled at 75F.

Reduced capacity HPI was used in the second test. The system responded by uncovering the surge line relatively early, while the core exit remained saturated. The PORV site fluid state became vapor. As a result of this state change, the PORV discharge mass flow rate decreased toward the (reduced) HPI flow rate whereas the PORV volumetric flow rate increased sufficiently to obtain primary system depressurization.

HPI activation was delayed 20 minutes beyond PORV actuation in the third HPI-PORV cooling test. The primary system repressurized intermittently during the period without HPI. The PORV site fluid subcooled upon repressurization, exacerbating the primary system mass loss. Upon HPI reactivation, the core region liquid level resided near the top of the core while the hot leg levels were descending toward the elevation of the surge line. The primary system depressurized relatively rapidly upon HPI activation. The ensuing transient conditions resembled those of the nominal HPI-PORV cooling test.

The fourth HPI-PORV cooling test was unlike the other three. The test was initialized in forced flow, and the PORV was allowed to cycle with pressure rather than being held open. Ten minutes after the hot leg fluid temperature exceeded 590F, the PORV was kept open, the hot leg high-point vents were opened, and makeup injection was activated. Core power was subsequently varied manually, based primarily on primary system pressure. The resulting interactions documented the depressurization upon surge line uncovery and the link between the primary system fluid volume balance and primary system pressure. Core uncovery data were also generated.

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

3. J. R. Gloudemans, "Simulation of Reactor Vessel Vent Valves," ASME Paper 85-WA/HT-29, 106th ASME Winter Annual Meeting, Miami, Florida, November 1985.

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

5. "MIST Test Specifications," BAW-1894, Rev. 1, March 1986.

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC. Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-5395, Vol. 5
EPRI/NP-6480
BAW-2064

2. TITLE AND SUBTITLE

Multiloop Integral System Test (MIST): Final Report
Test Group 33, HPI-PORV Cooling

3. DATE REPORT PUBLISHED

MONTH	YEAR
July	1989

4. FIN OR GRANT NUMBER

B8909 & D1734

5. AUTHOR(S)

J. R. Gloudemans

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

June 1986-March 1988

8. PERFORMING ORGANIZATION – NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

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

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

9. SPONSORING ORGANIZATION – NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Systems Research
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Electric Power 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 5 pertains to Test Group 33, HPI-PORV cooling. The specifications, conduct, observations, and results of these tests are described.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Multiloop Integral System Test (MIST), Babcock and Wilcox
Small break loss-of-coolant accident, transient testing, reactor safety
steam generator (once through), feed and bleed
steam generator tube rupture, station black out
Two-phase flow, SBLOCA without HPI injection, RELAP5/MOD2 calculations

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page) Unclassified

(This Report) Unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

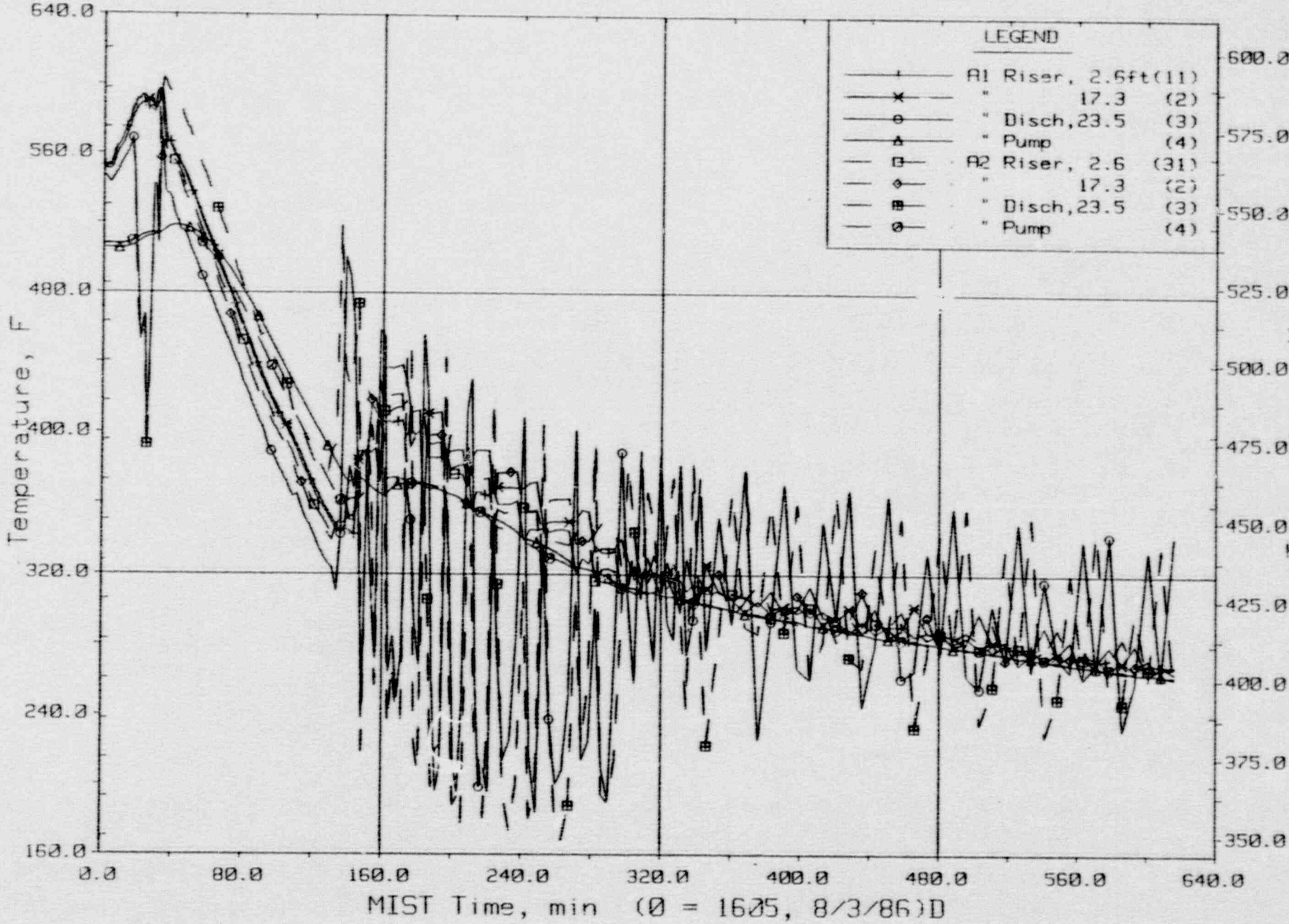
SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
USNRC
PERMIT No. G-67

120555139531 1 1AN1R2
US NRC-OADM
DIV FOIA & PUBLICATIONS SVCS
TPS PDR-NUREG
P-209
WASHINGTON DC 20555

T3301BB

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



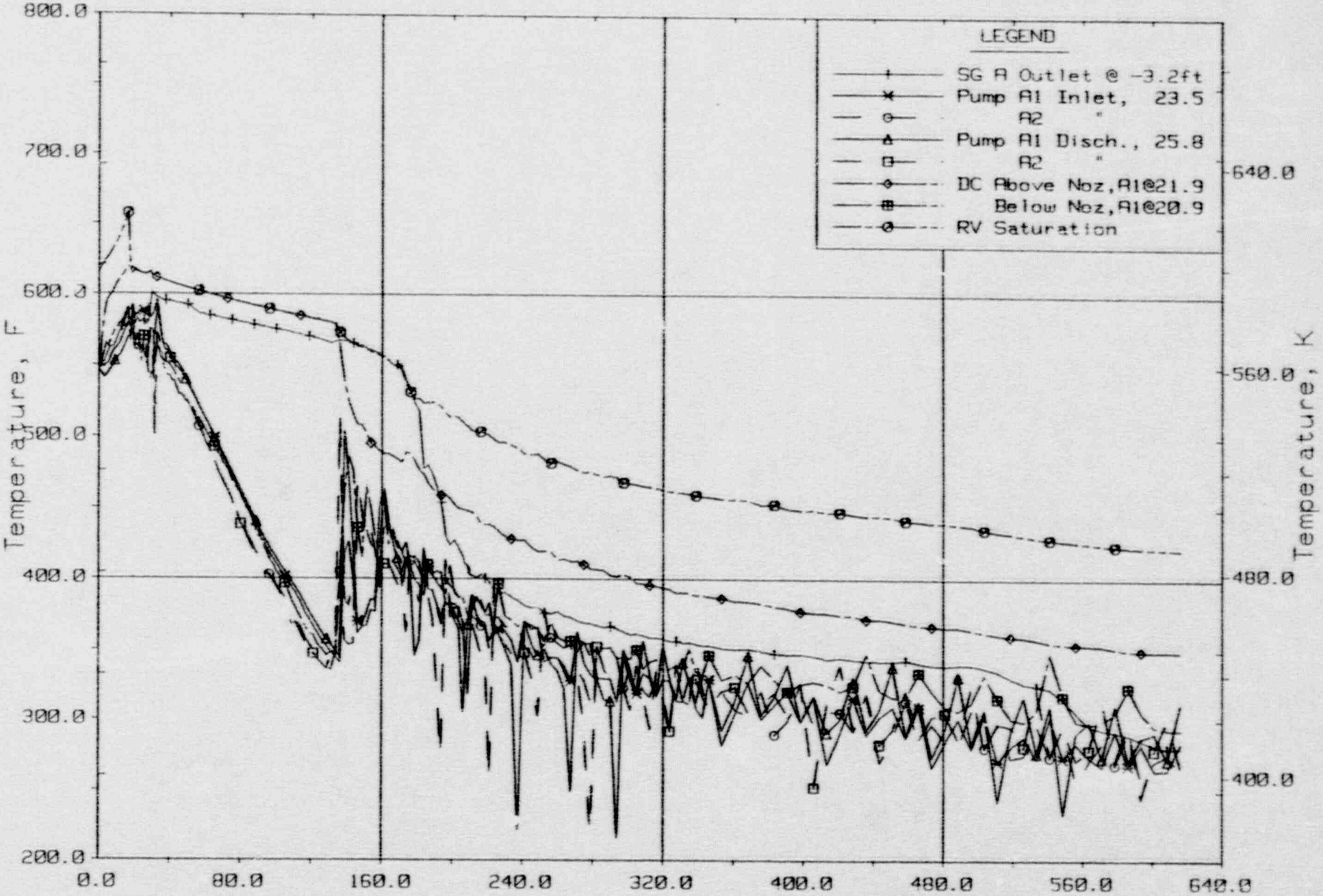
Loop A Cold Leg Metal Temperatures (C1,3MTs).

Tue May 24 10:15:08 1988

C1MT1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



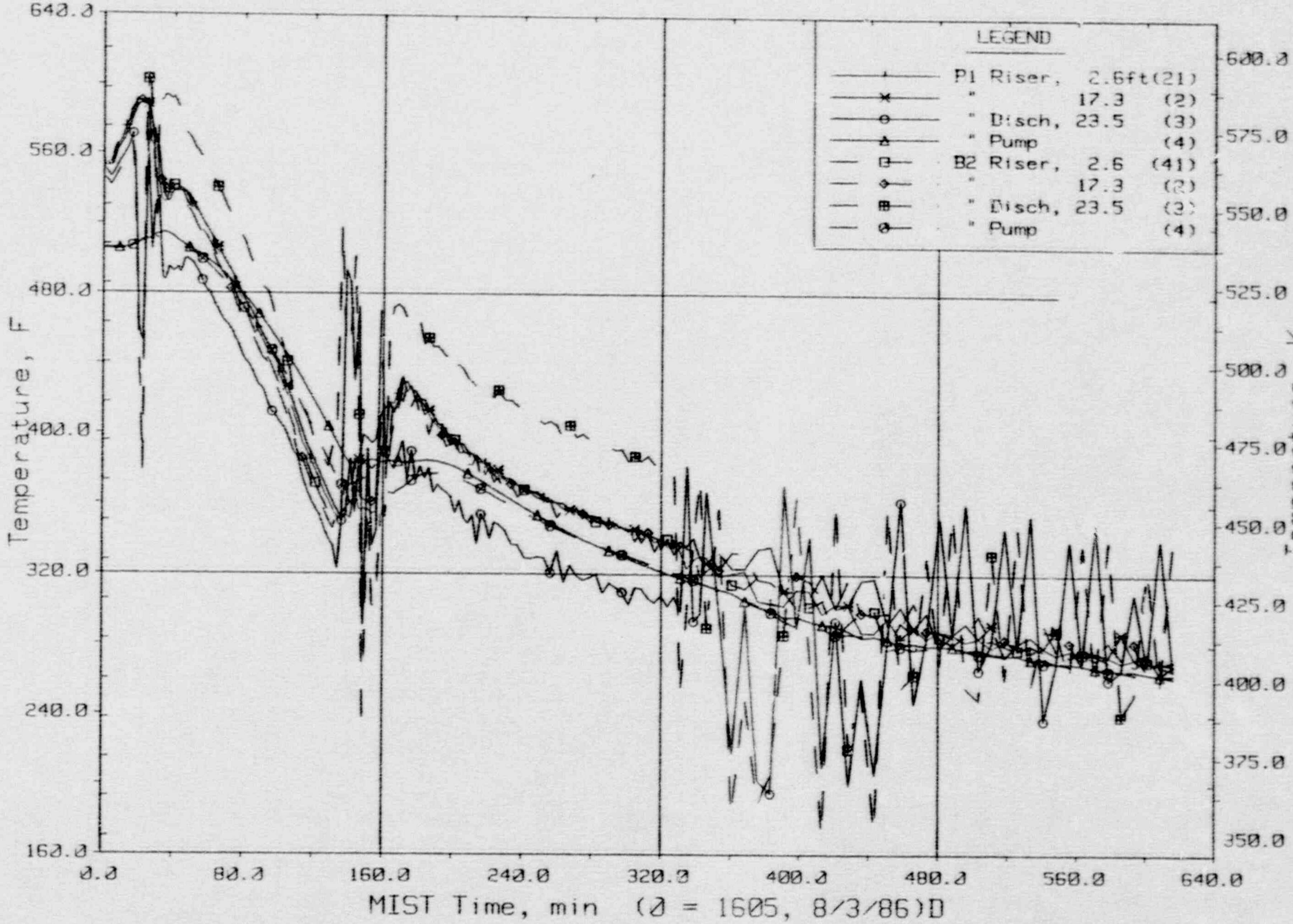
Loop A Cold Leg Fluid Temperatures (RTDs).

Tue May 24 10:19:40 1988

C1RT0

FINAL DATA

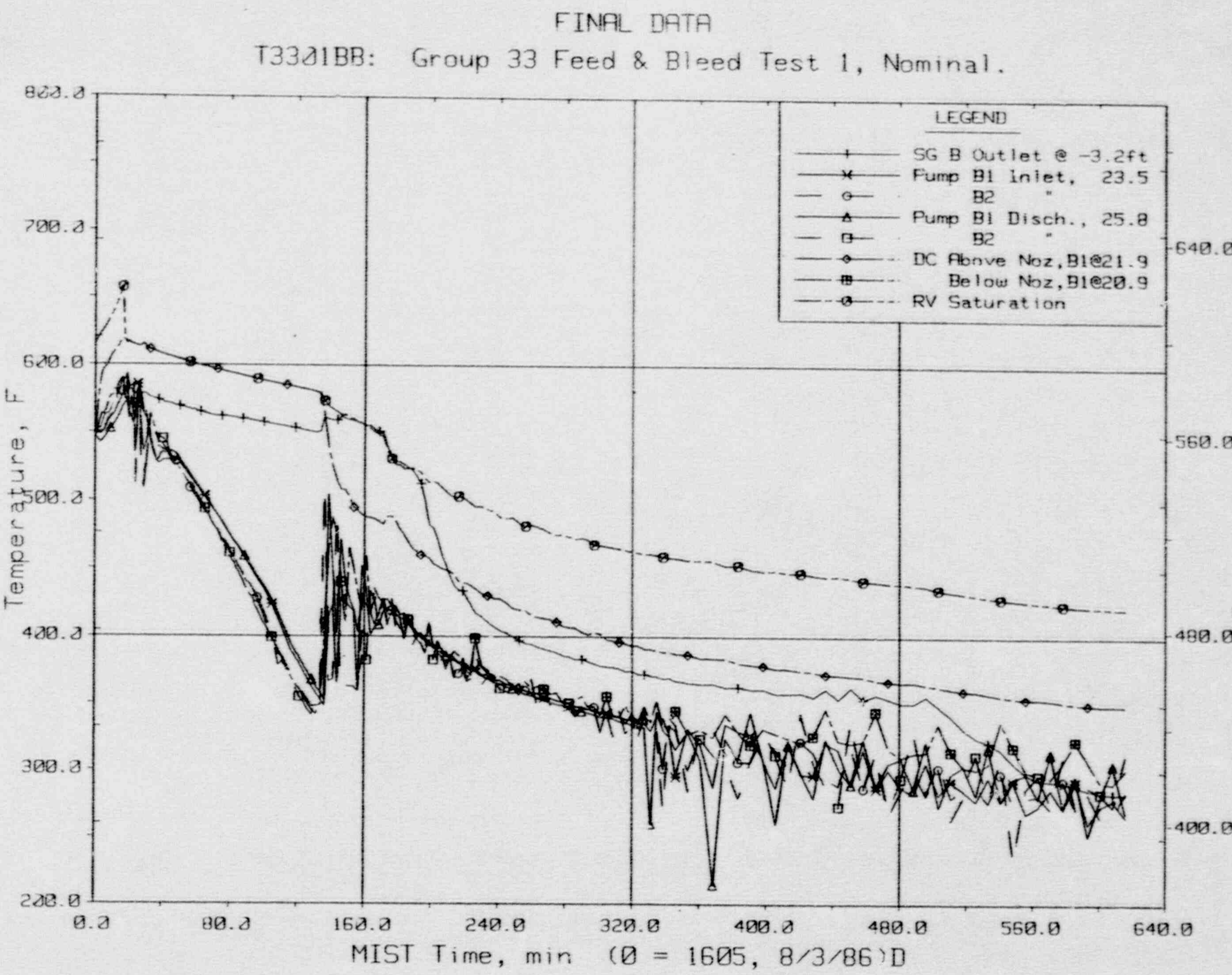
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Loop B Cold Leg Metal Temperatures (C2,4MTs).

Tue May 24 10:25:36 1988

C2MT1



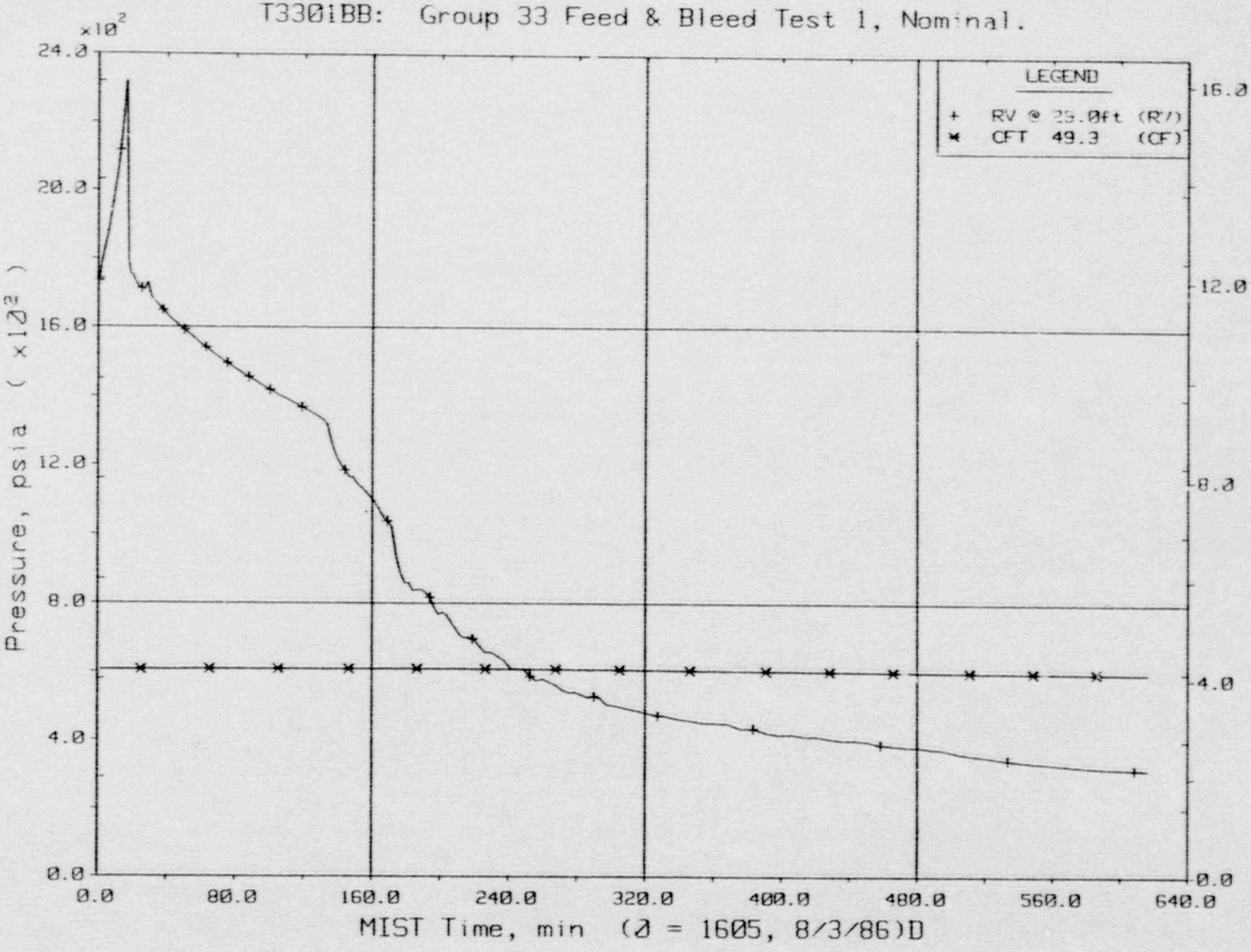
Loop B Cold Leg Fluid Temperatures (RTDs).

Tue May 24 10:34:31 1988

C2RT0

FINAL DATA

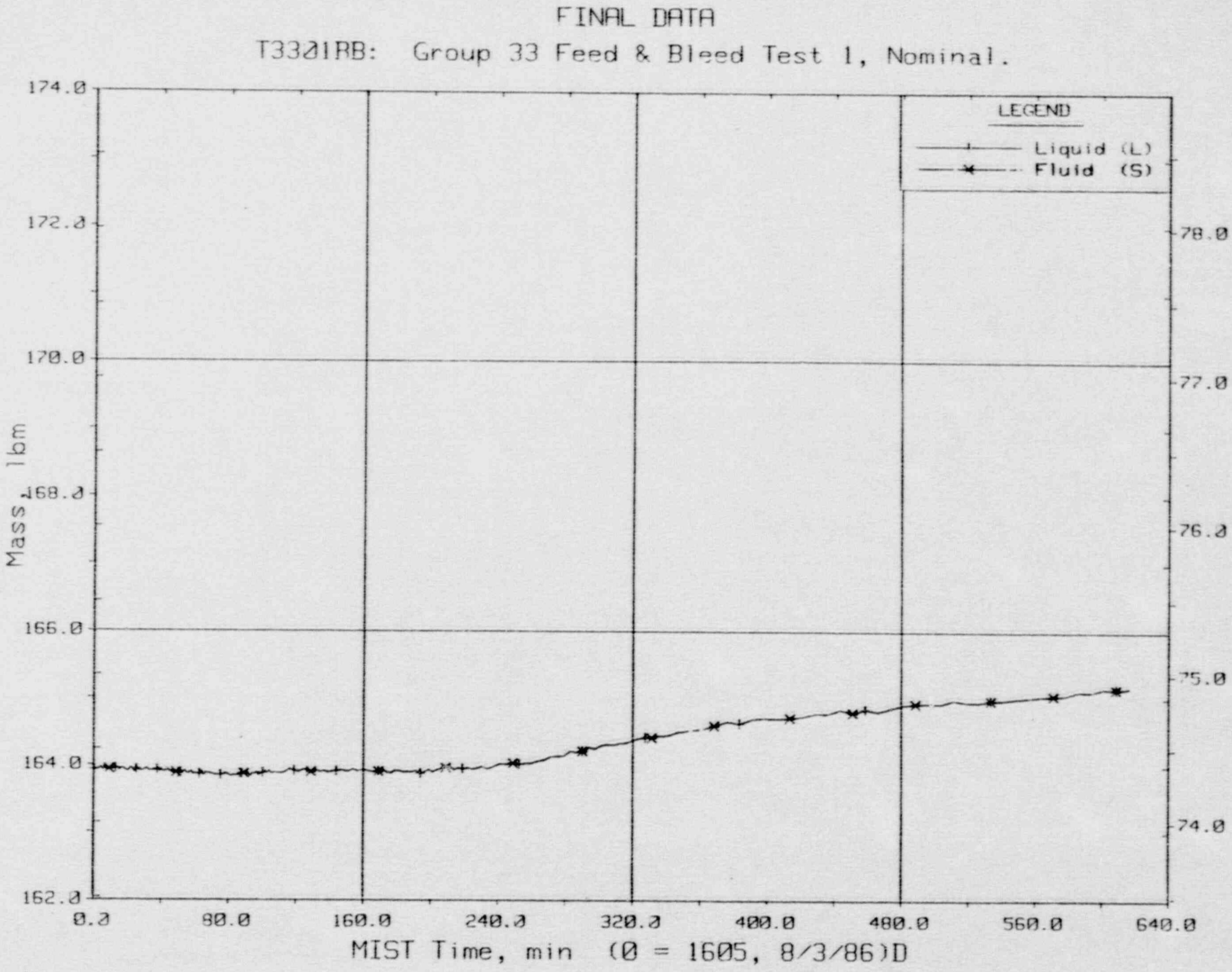
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Primary System and Core Flood Tank Pressures (GP01s).

Tue May 24 11:02:45 1988

CFGP1



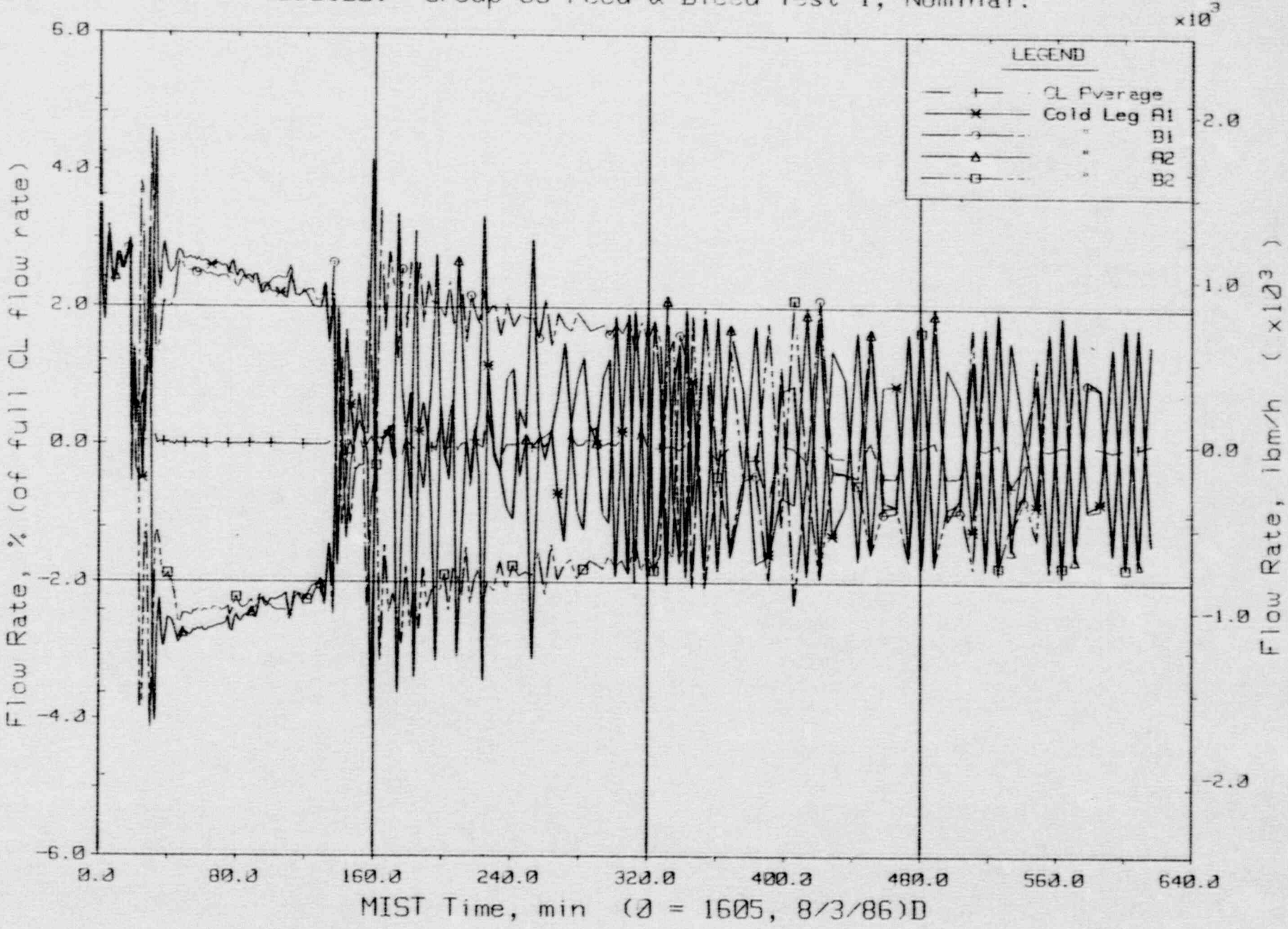
Core Flood Tank Liquid and Fluid Mass (CFMa20s).

Tue May 24 11:06:35 1988

CFML1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



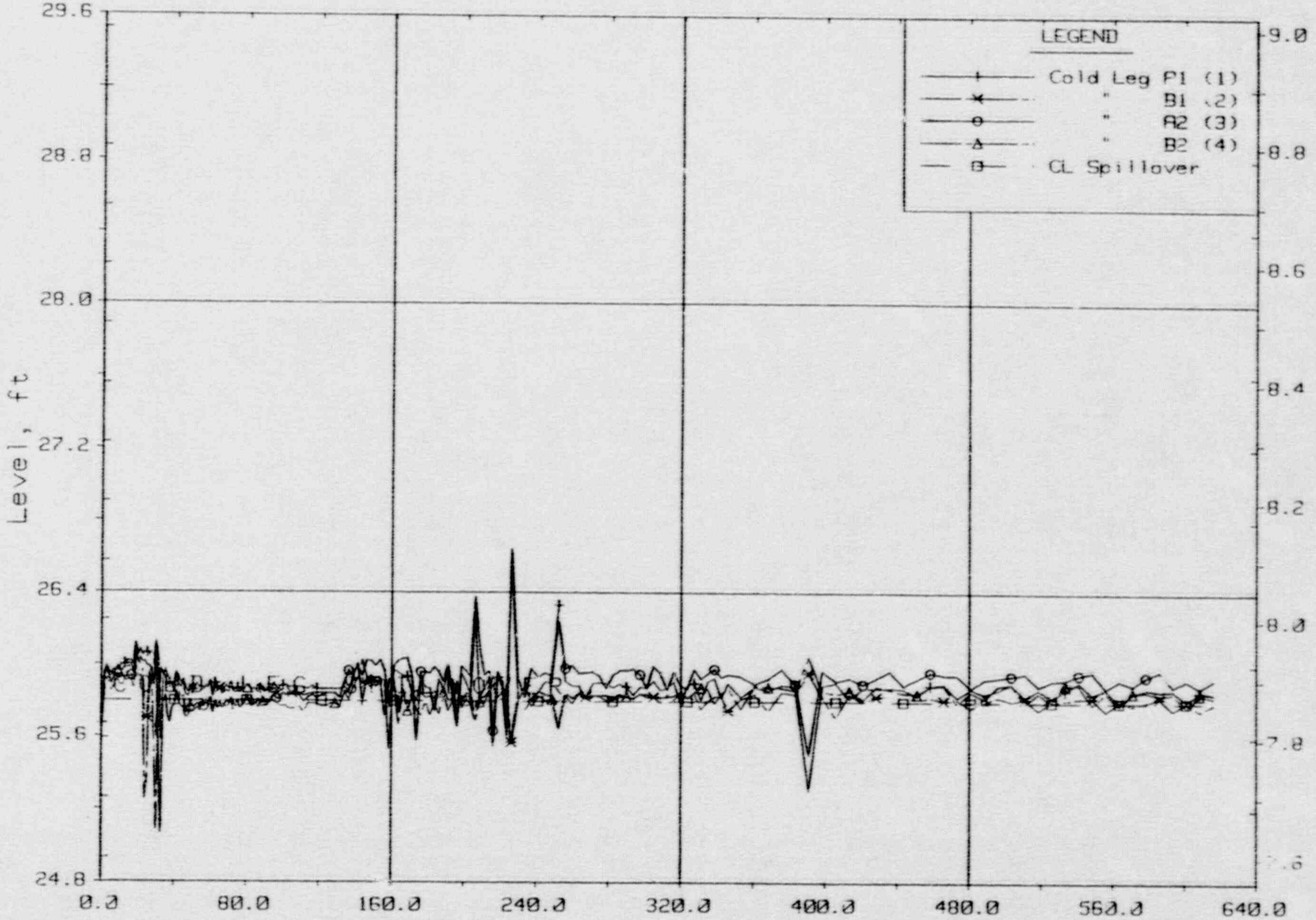
Cold Leg (Venturi) Flow Rates.

Tue May 24 11:14:57 1988

CLFL1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



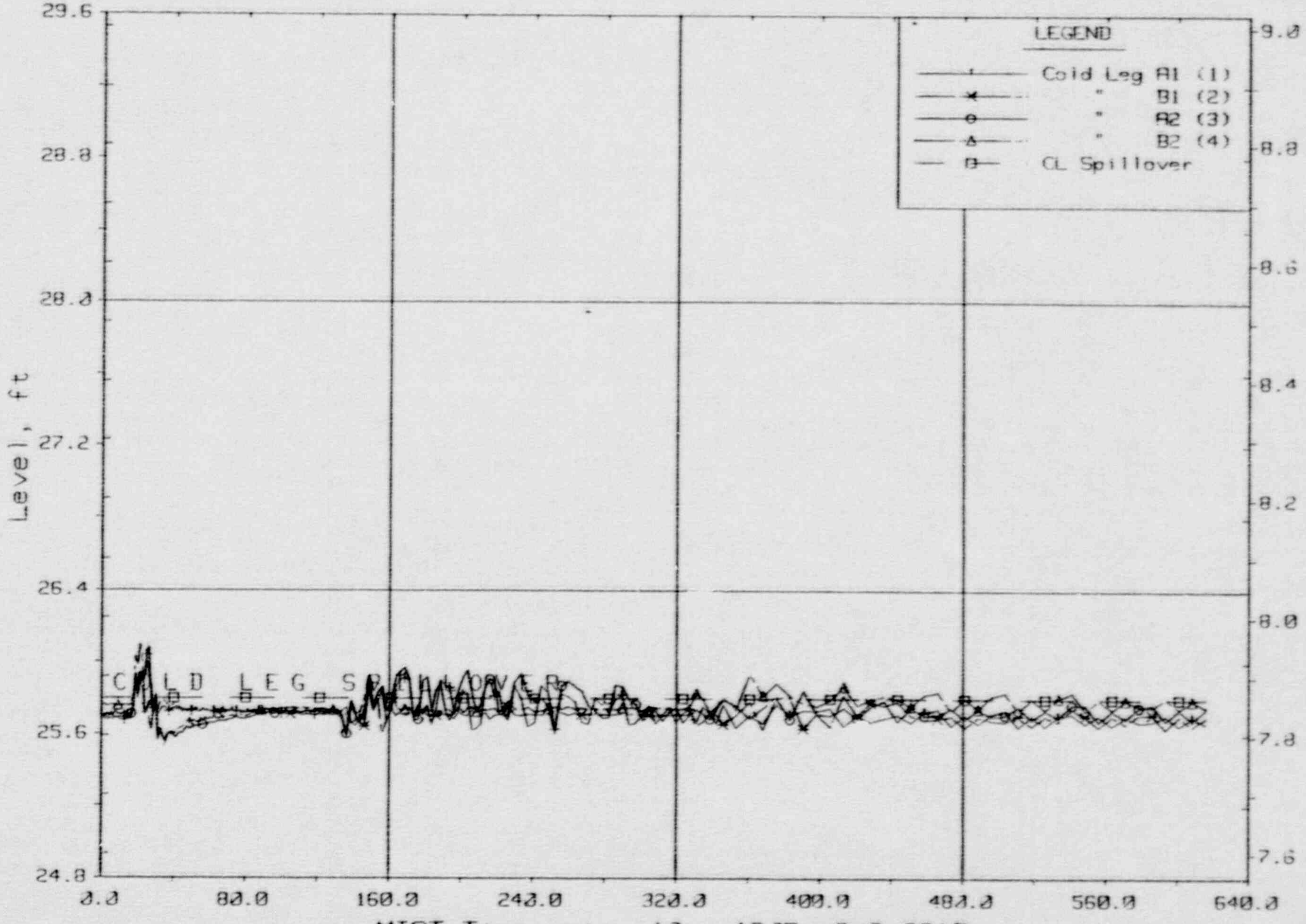
Cold Leg Suction Collapsed Liquid Levels (CnLV22s).

Tue May 24 11:20:05 1988

CLLV4

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



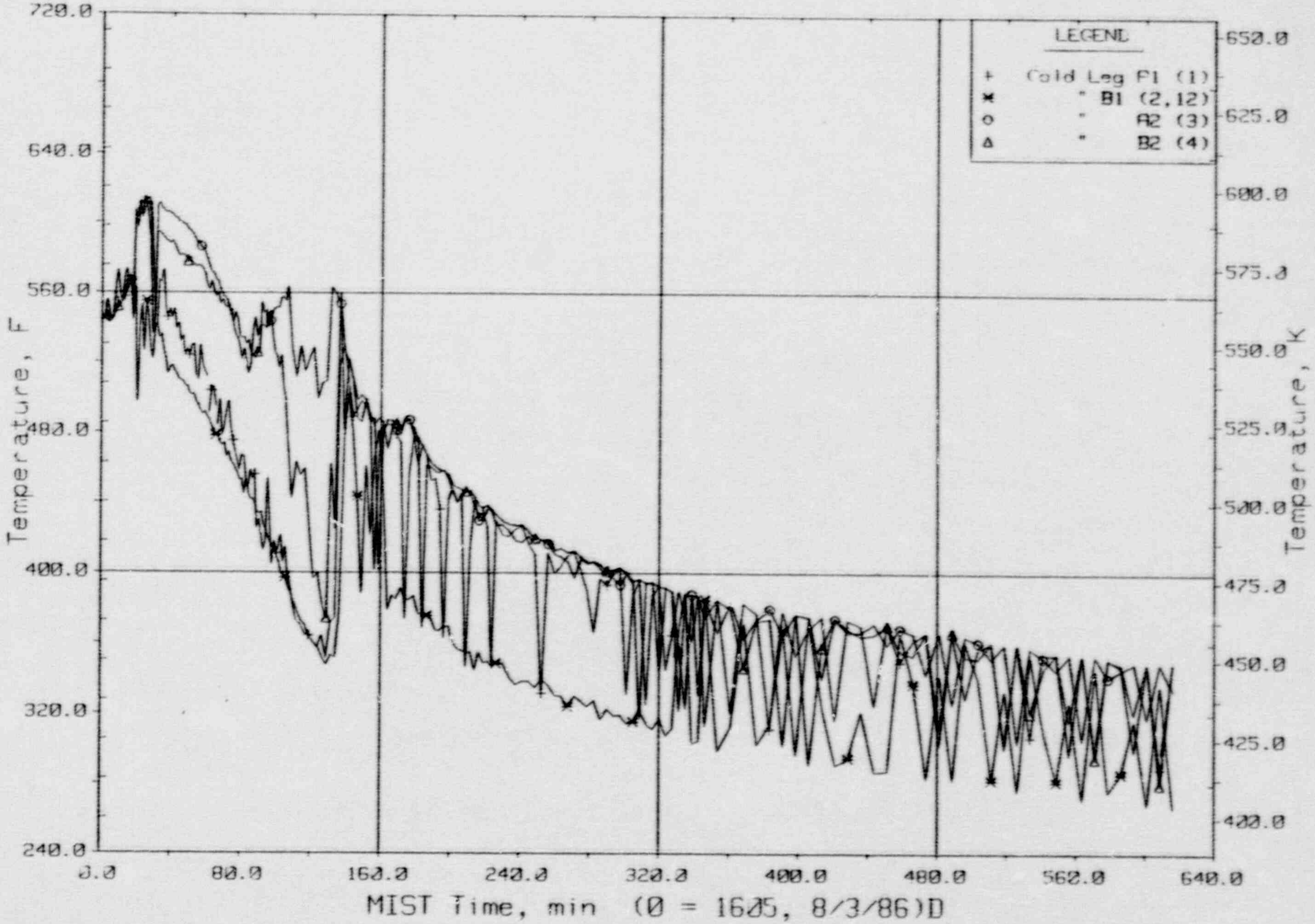
Cold Leg Discharge Collapsed Liquid Levels (CnLV23s).

Tue May 24 11:24:45 1988

C_LV5

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



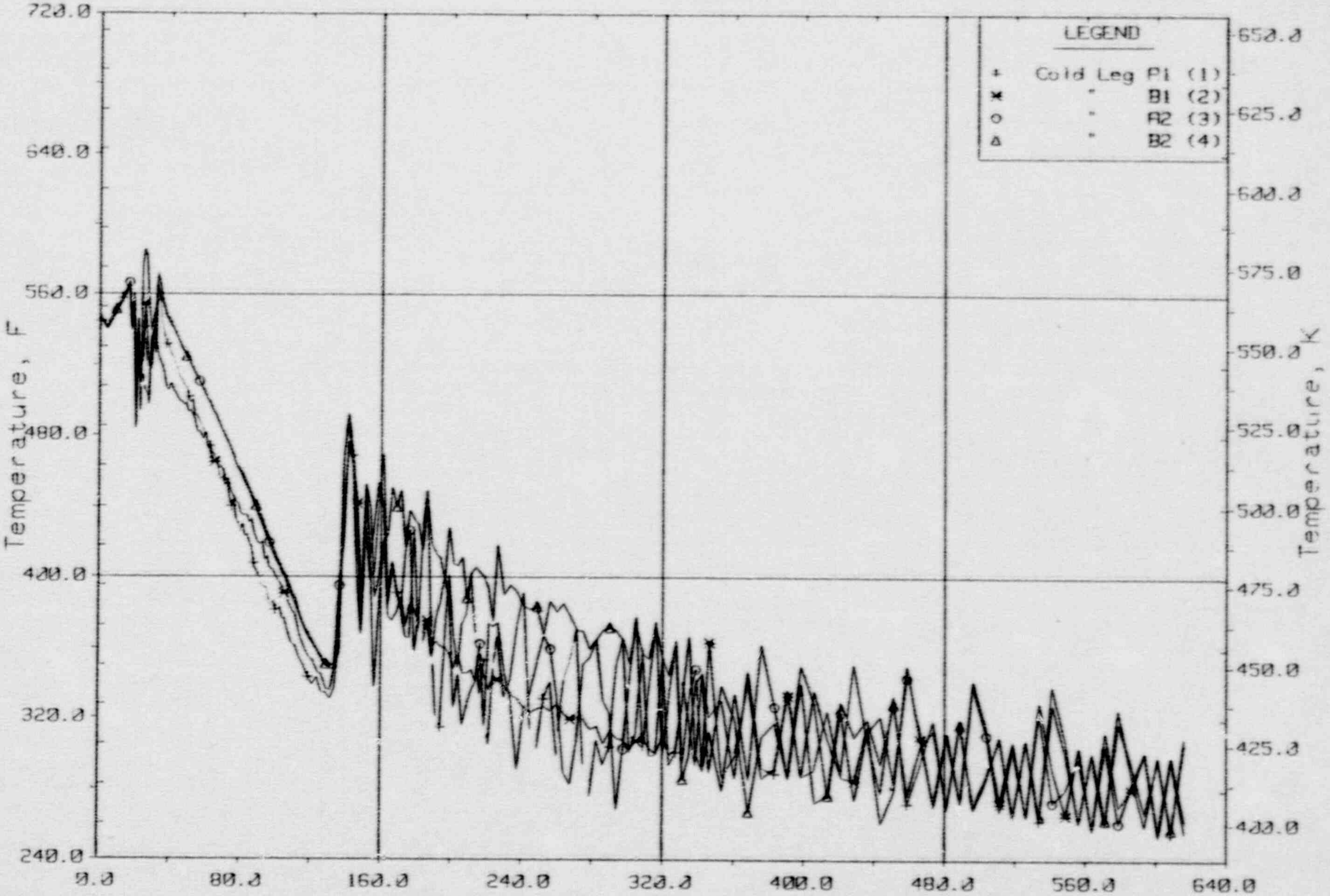
Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3ft, CnTC11s).

Tue May 24 11:20:15 1988

CLTC1

FINAL DATA

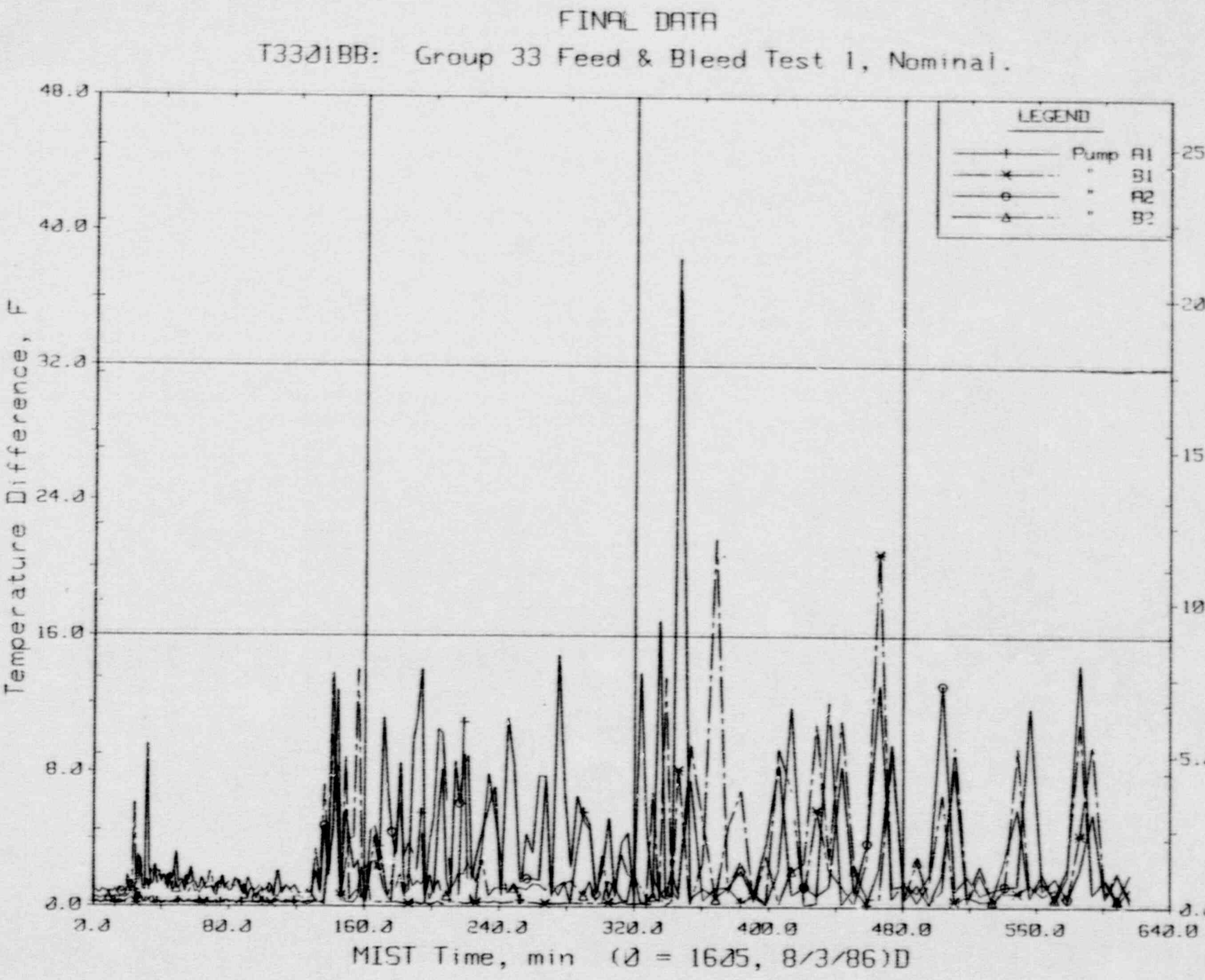
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Cold Leg Nozzle Fluid Temperatures, Bottom of Rake (21.2ft, CnTC14s).

Tue May 24 11:32:59 1988

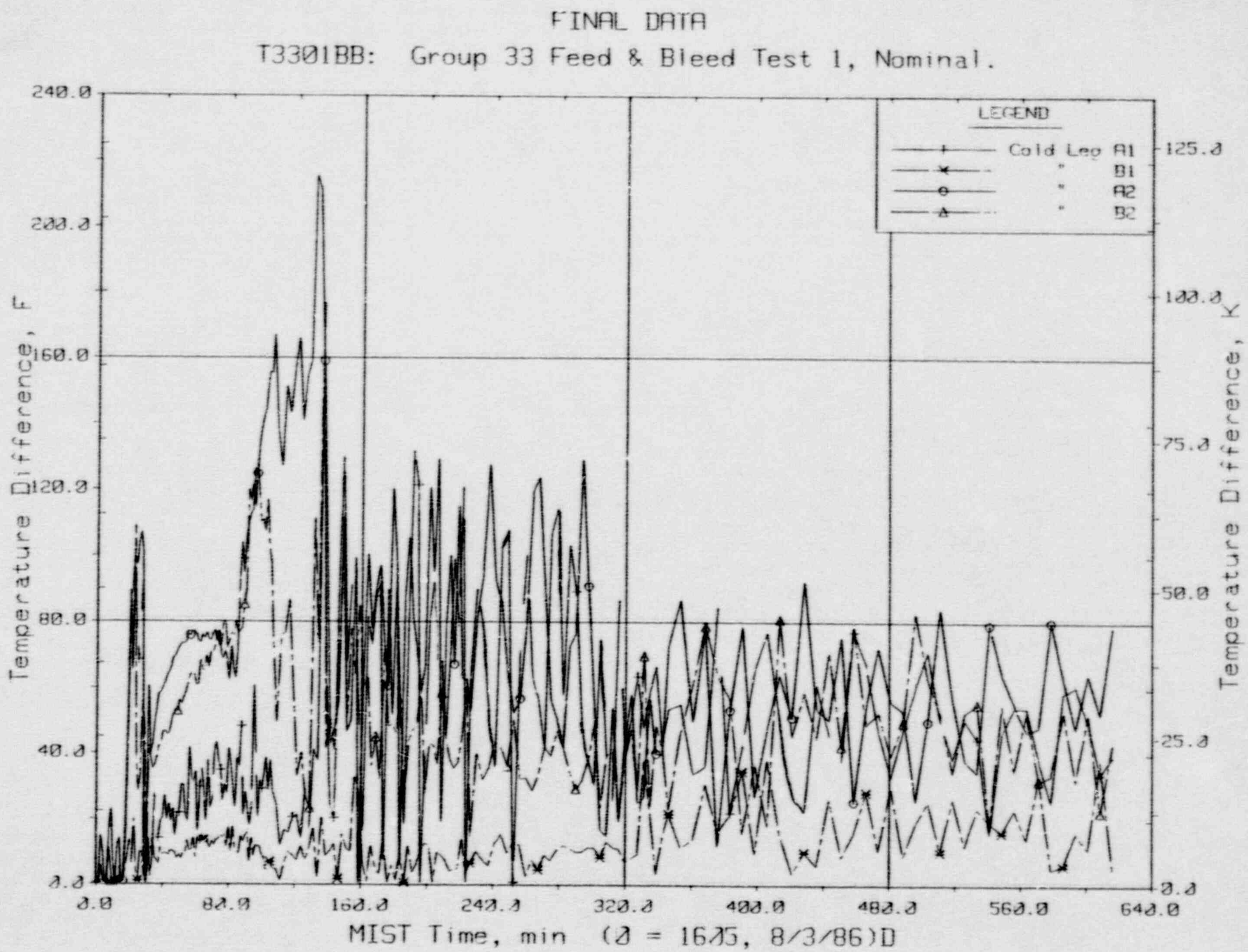
CLTC2



Maximum Differences Among RCP Rake Fluid Temperatures.

Tue May 24 11:35:50 1988

CLTD1



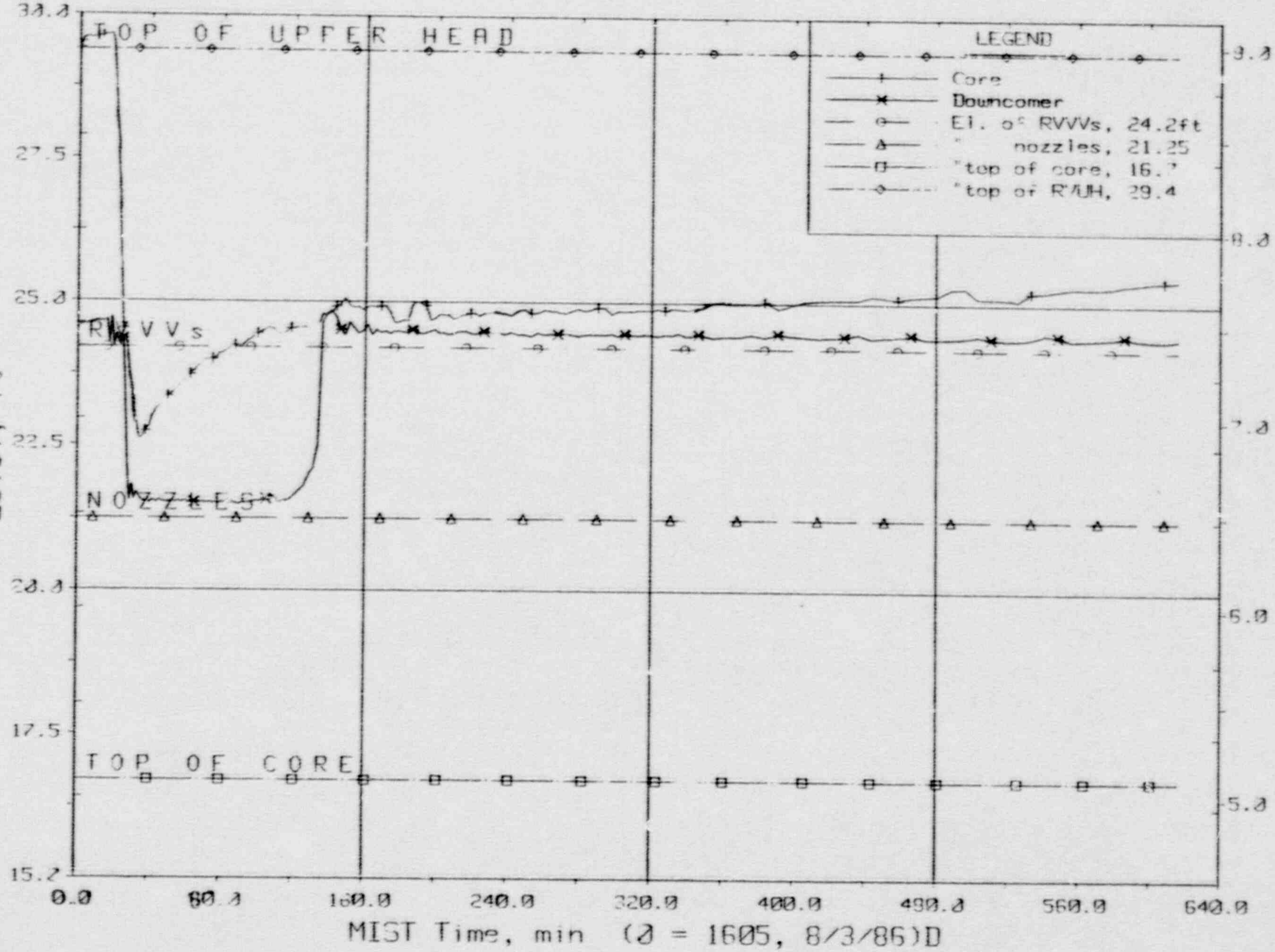
Maximum Differences Among CL Nozzle Rake Fluid Temperatures.

Tue May 24 11:39:31 1988

CLTD2

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



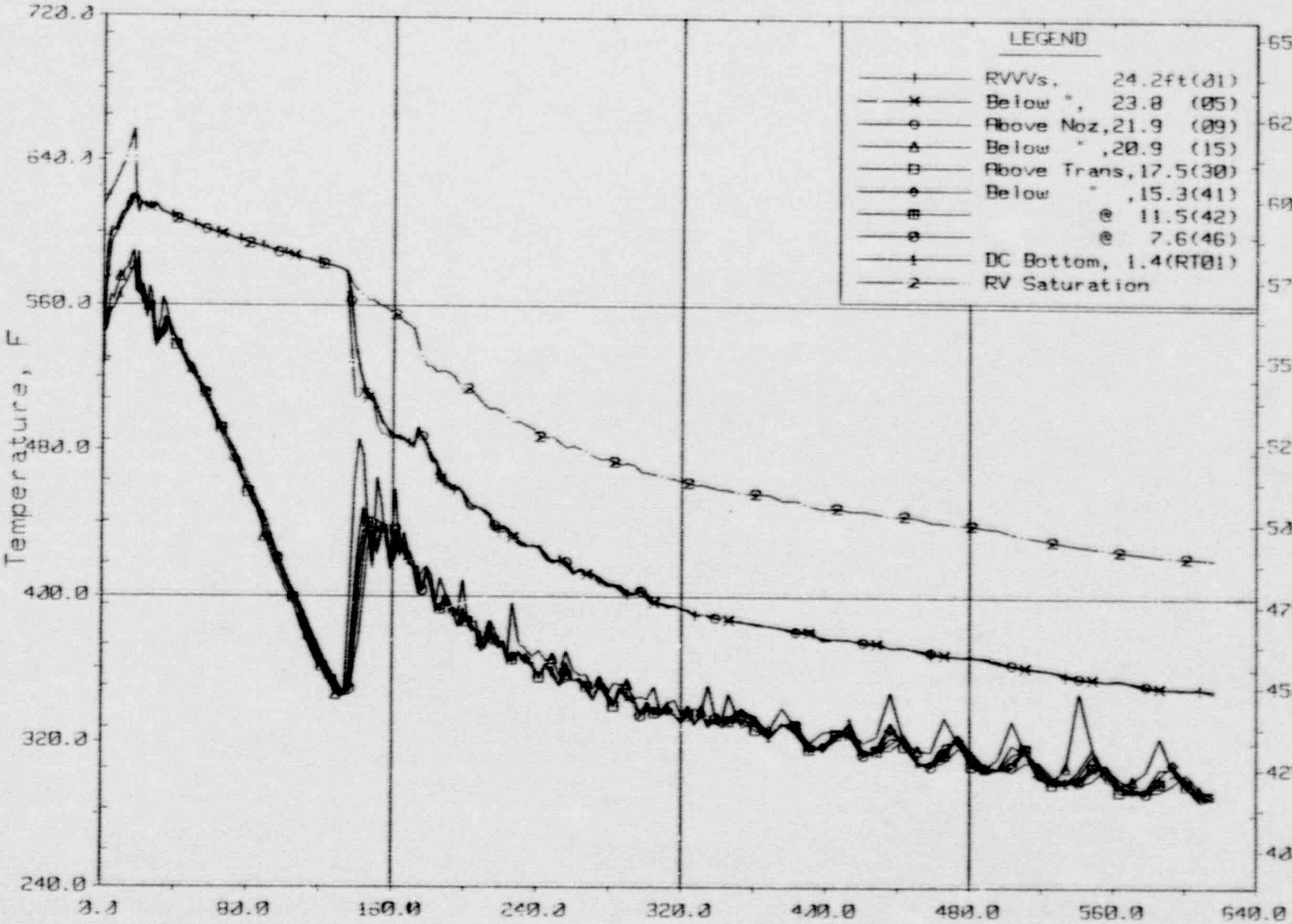
Core Region Collapsed Liquid Levels.

Tue May 24 11:4? :03 1988

CLV1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



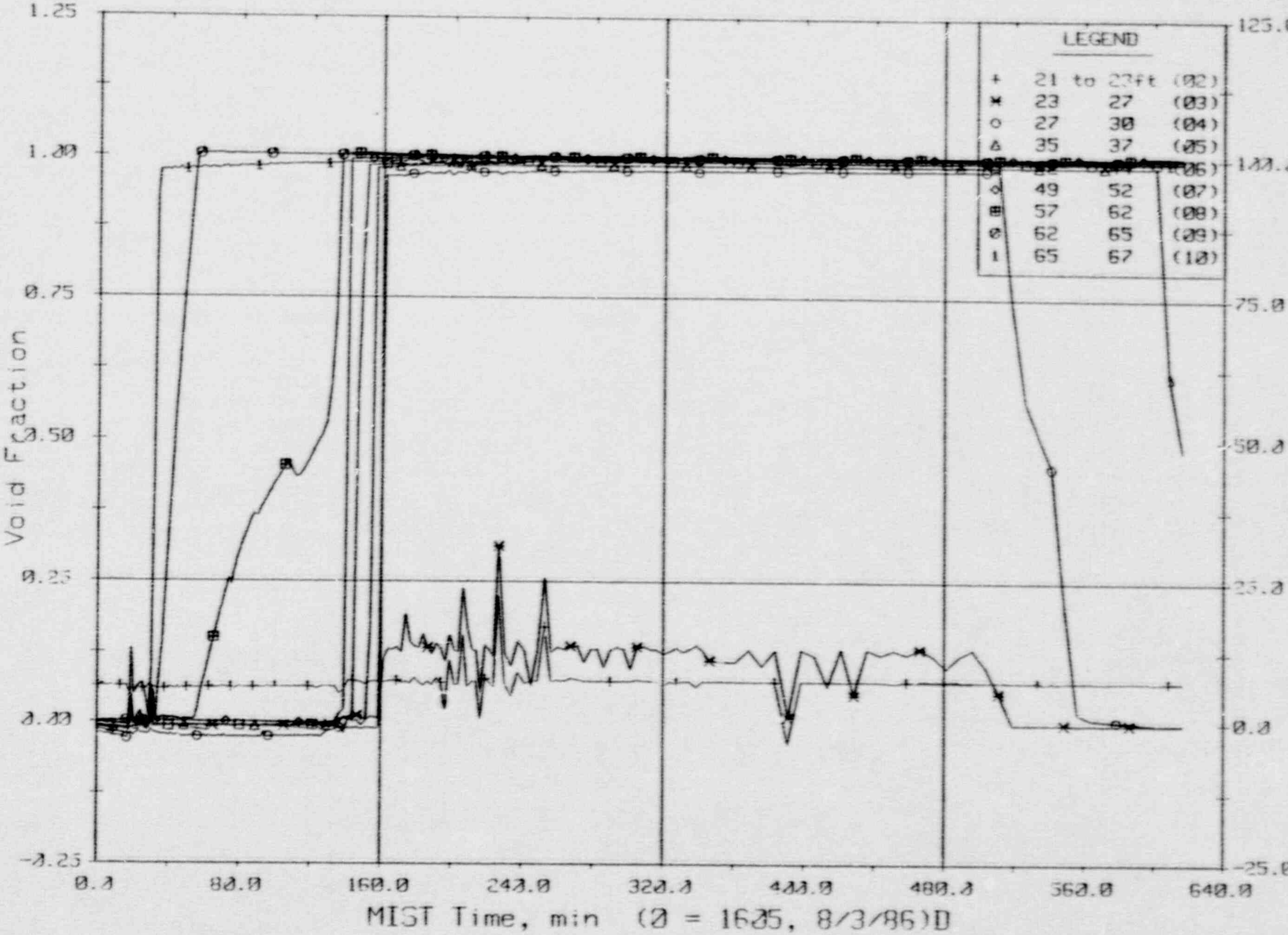
Downcomer Quadrant A1 Fluid Temperatures (DCTCs).

Tue May 24 11:52:44 1988

DCTC6

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



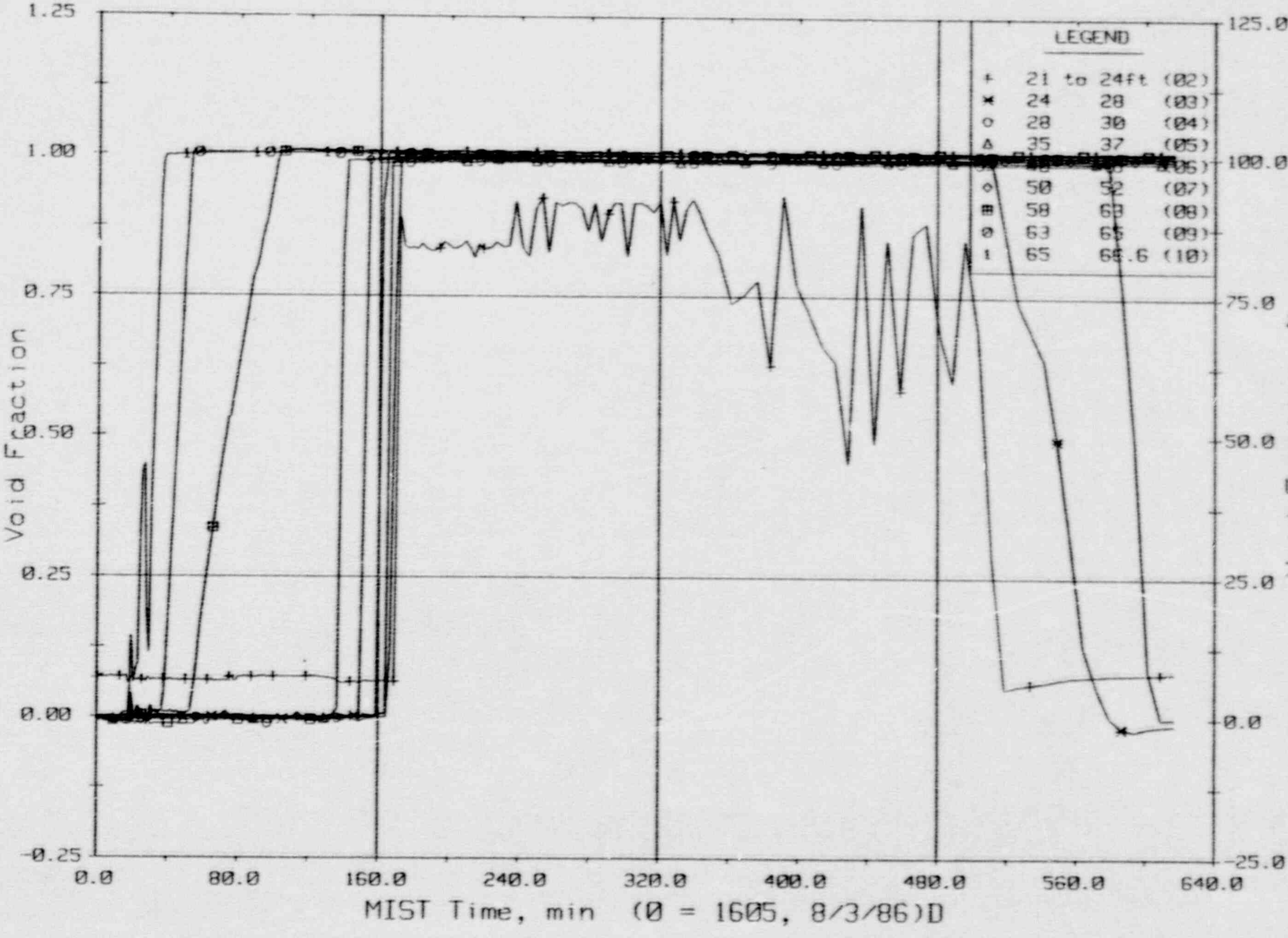
Hot Leg A Riser Void Fractions From Differential Pressures (HIVFs).

Tue May 24 11:56:34 1988

HIVF1

FINAL DATA

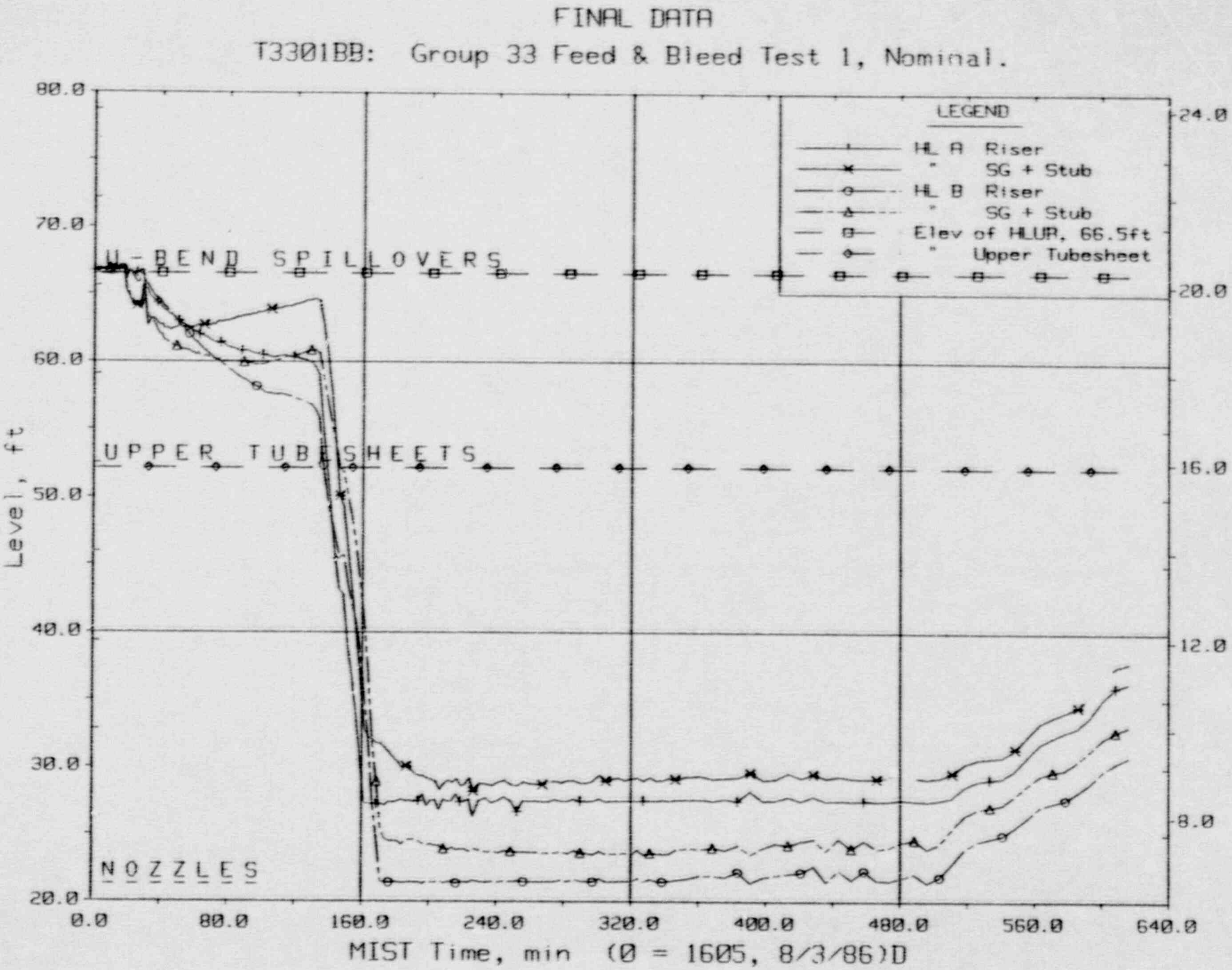
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Hot Leg B Riser Void Fraction From Differential Pressures (H2VFs).

Tue May 24 12:01:16 1988

H2VF1



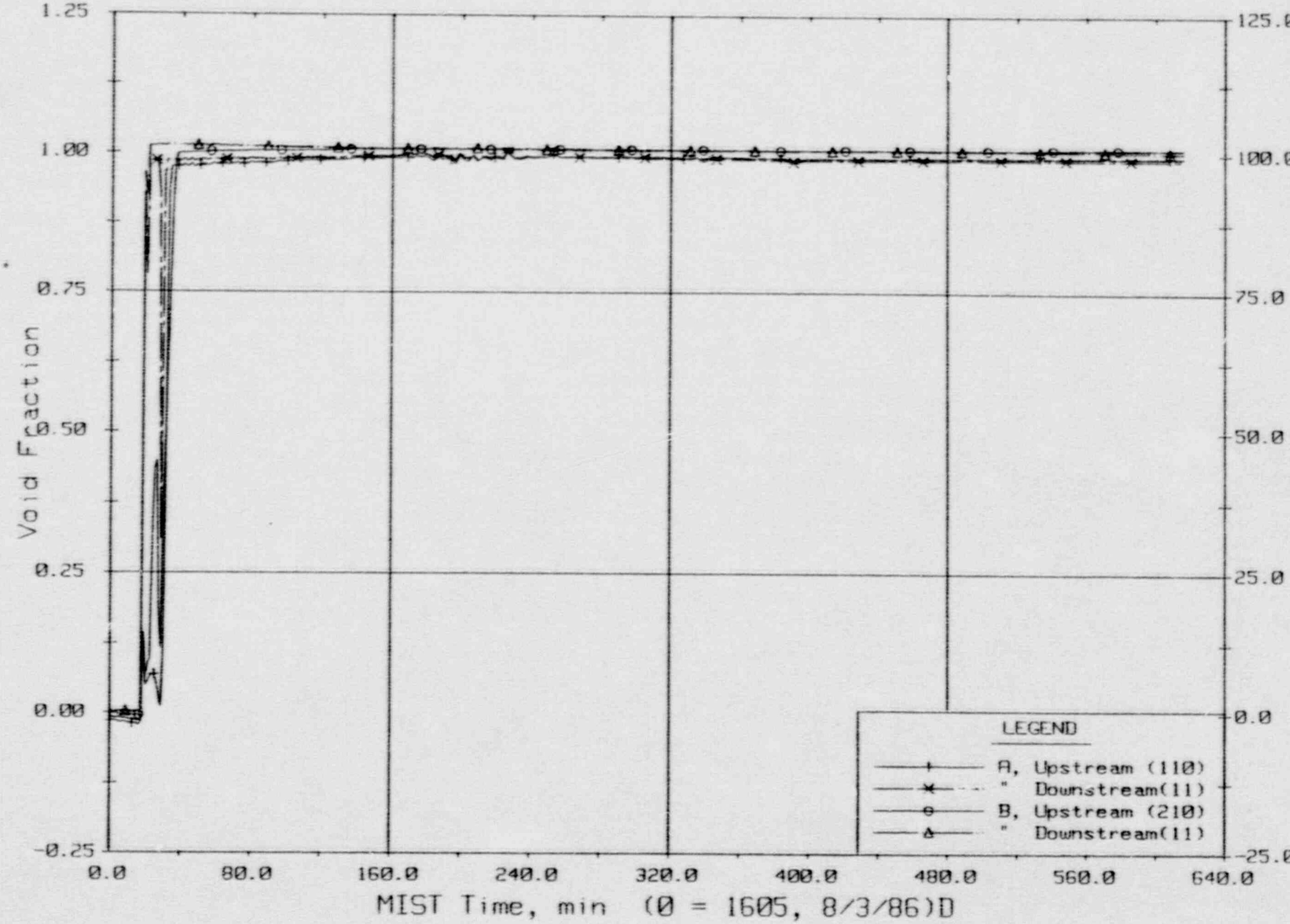
Hot Leg Riser and Stub Collapsed Liquid Levels.

Tue May 24 12:05:08 1988

HLLV1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



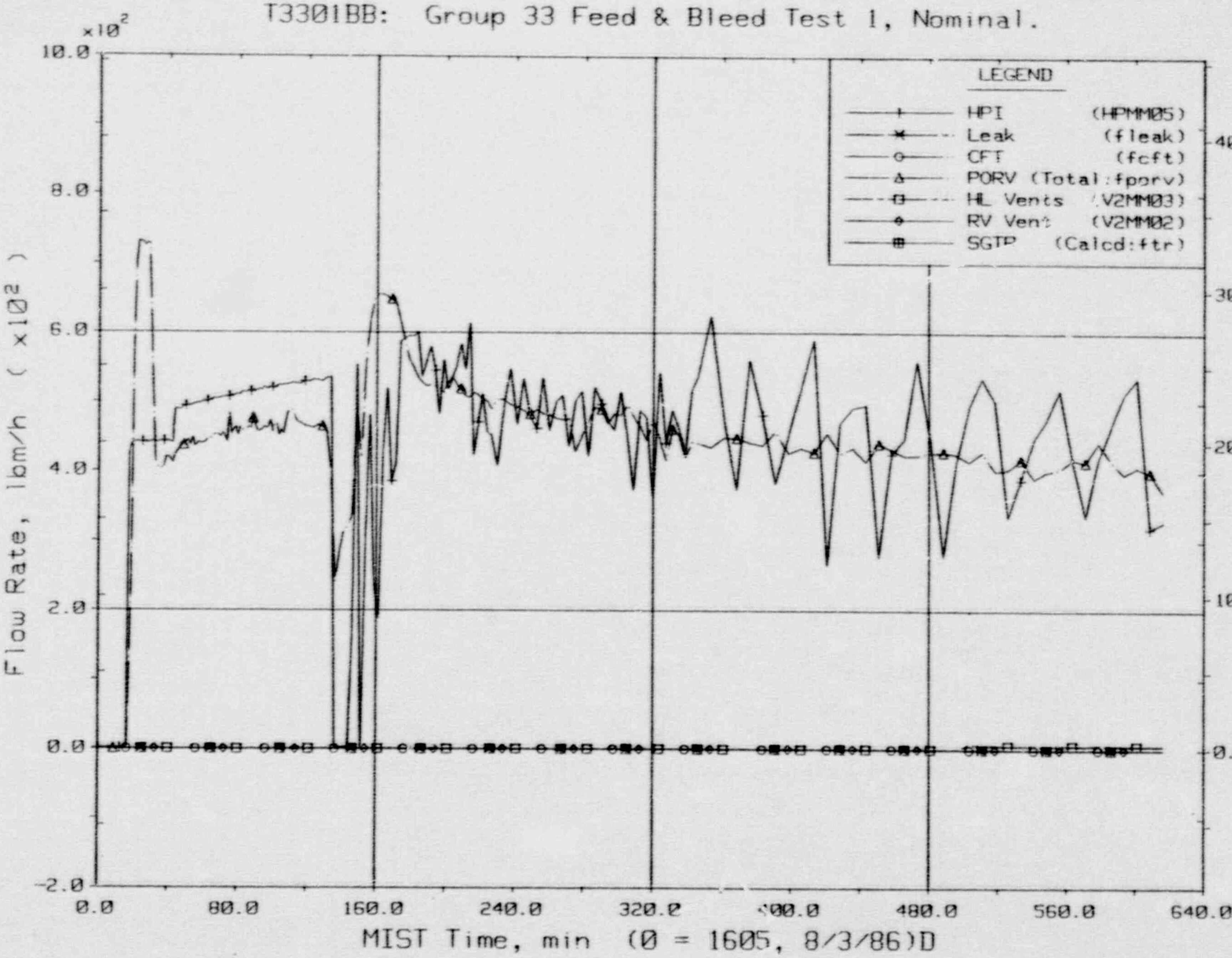
Hot Leg U-Bend Void Fractions From Diffl. Pressures (64.8 to 66.6 ft, HnVFs).

Tue May 24 12:08:21 1988

HLVF1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



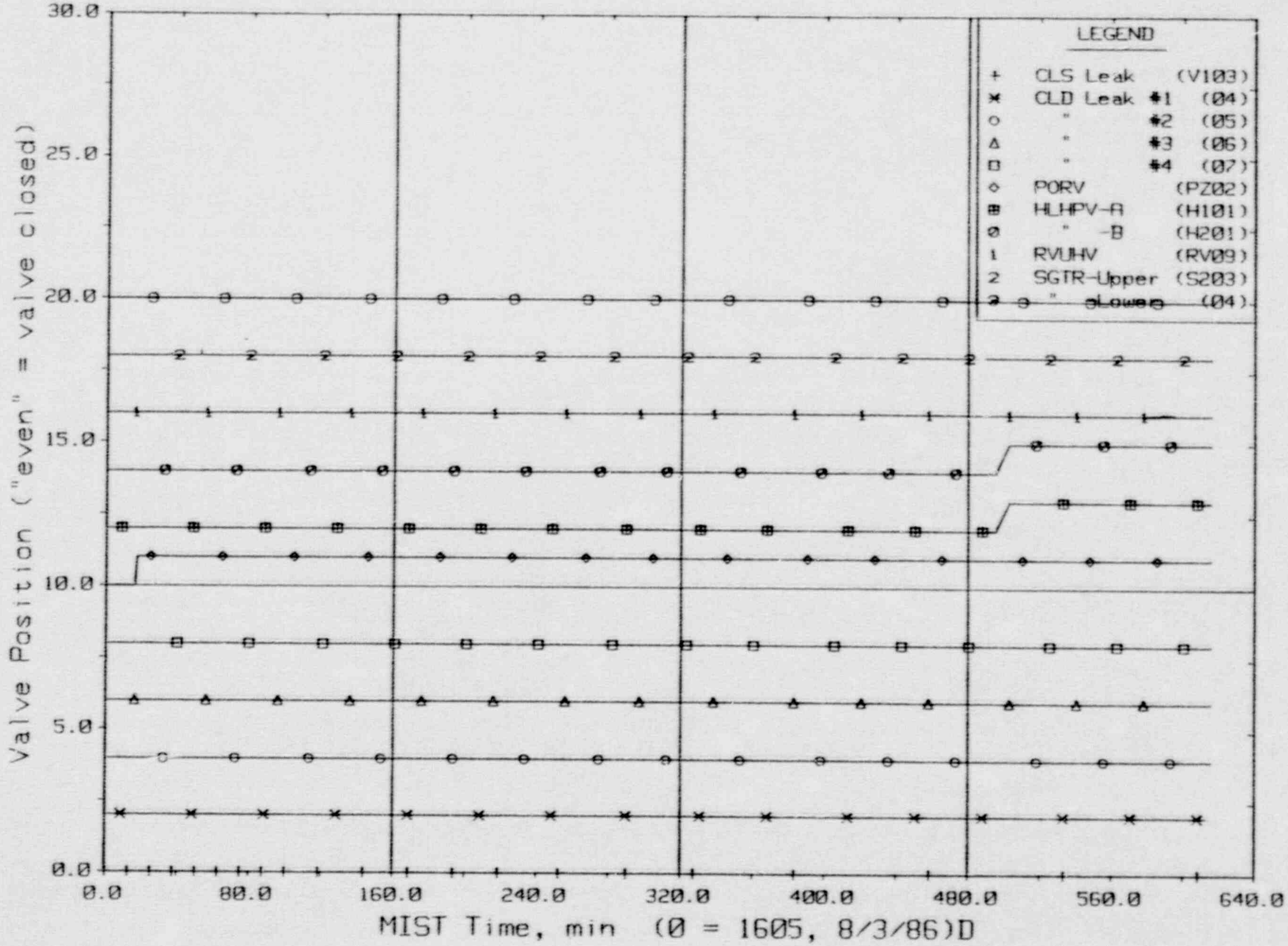
Primary System Boundary Flow Rates.

Tue May 24 12:12:12 1988

PBFL3

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



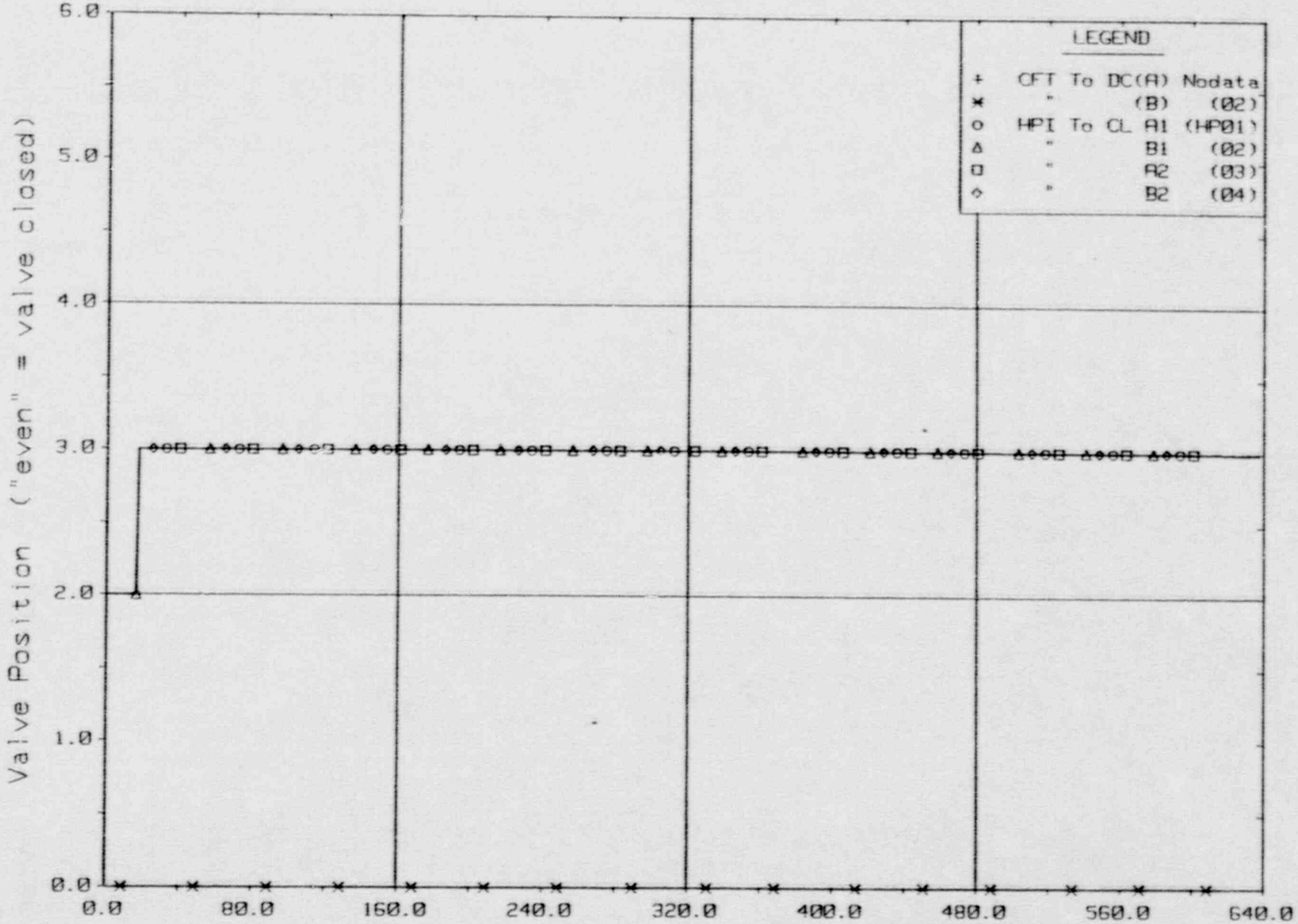
Primary System Discharge Limit Switch Indications (LSs).

Tue May 24 12:17:02 1988

PBLS1

FINAL DATA

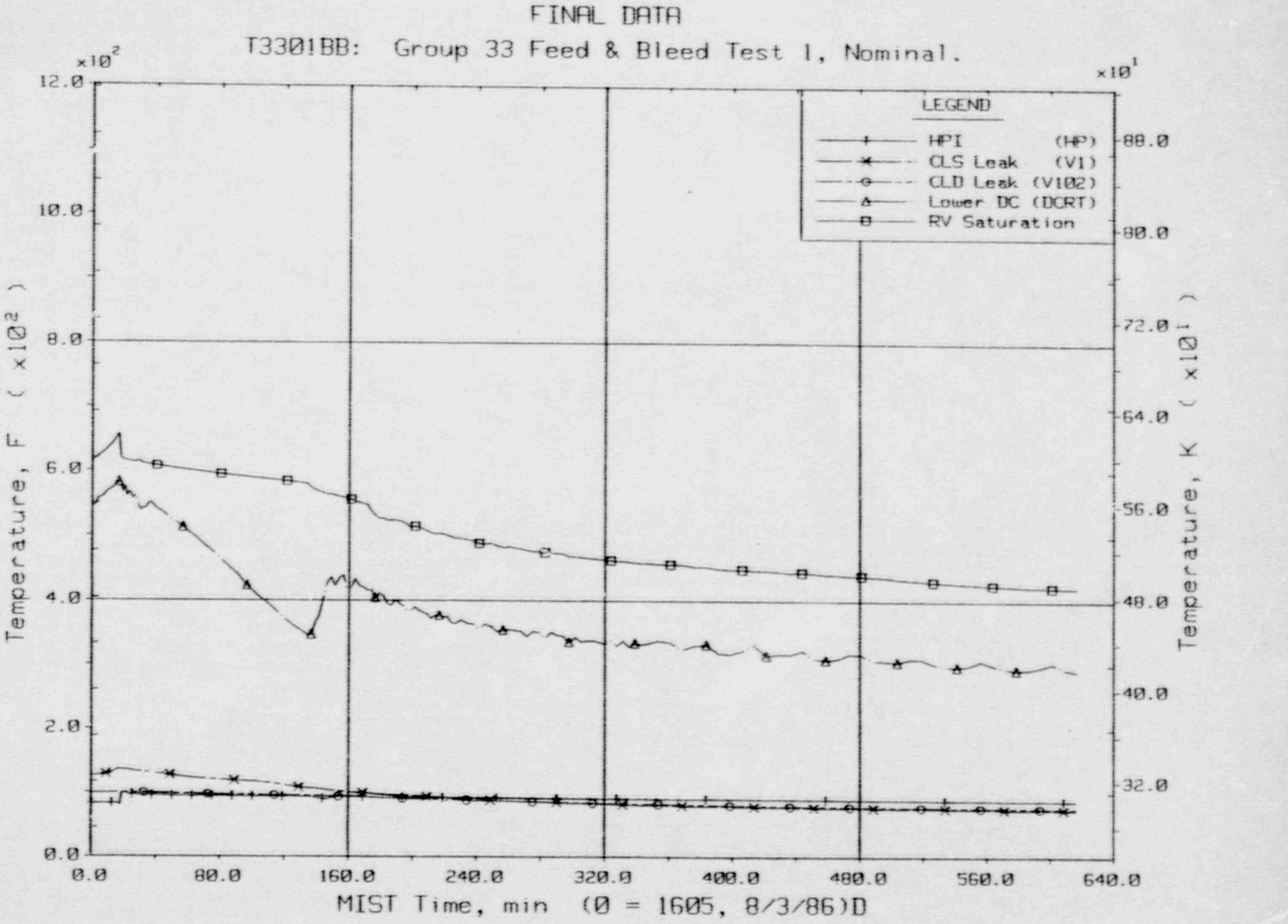
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Primary System Injection Limit Switch Indications (LSs).

Tue May 24 12:20:34 1988

PBLS2



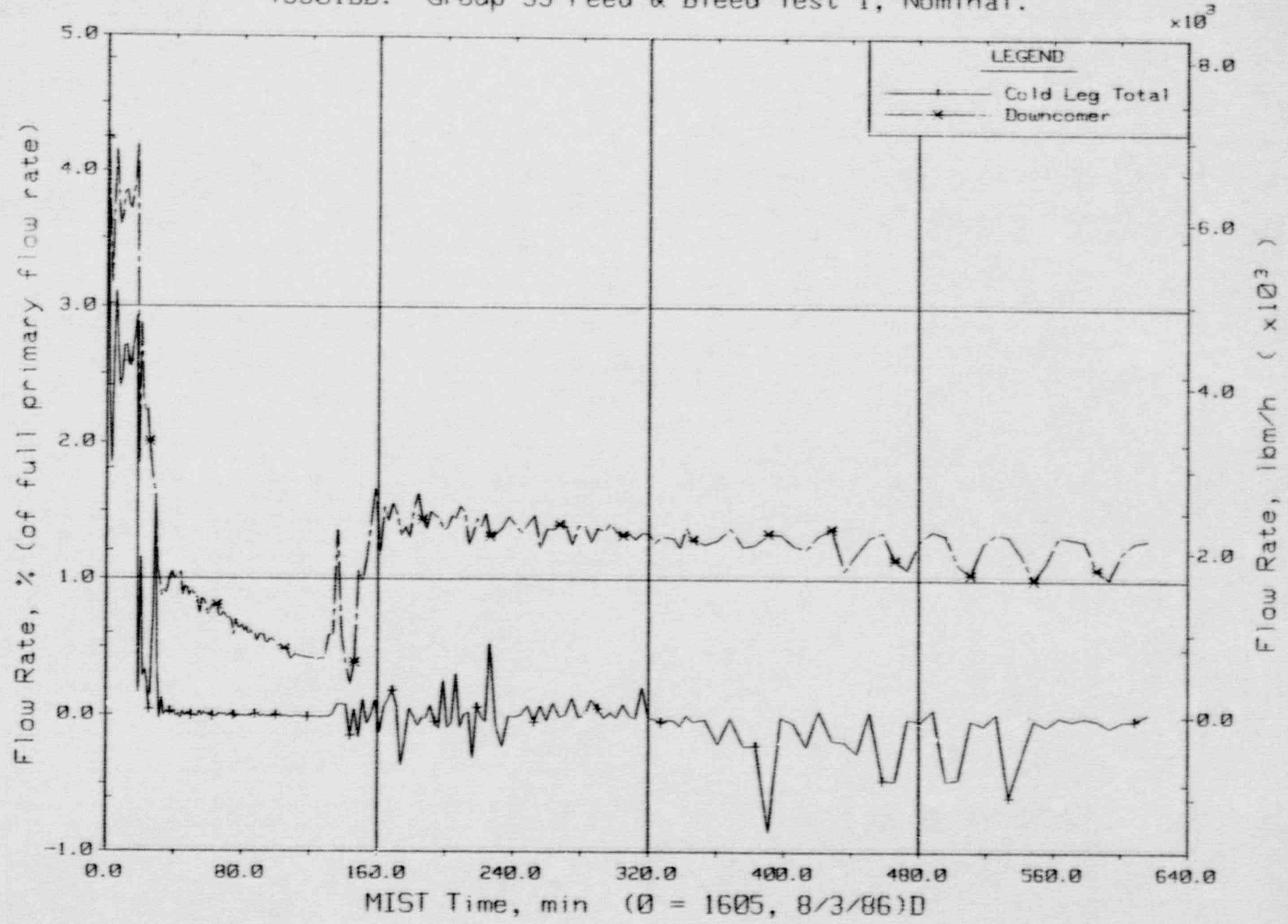
Single-Phase Discharge and HPI Fluid Temperatures (TC01s).

Tue May 24 12:23:05 1988

PBTC1p

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



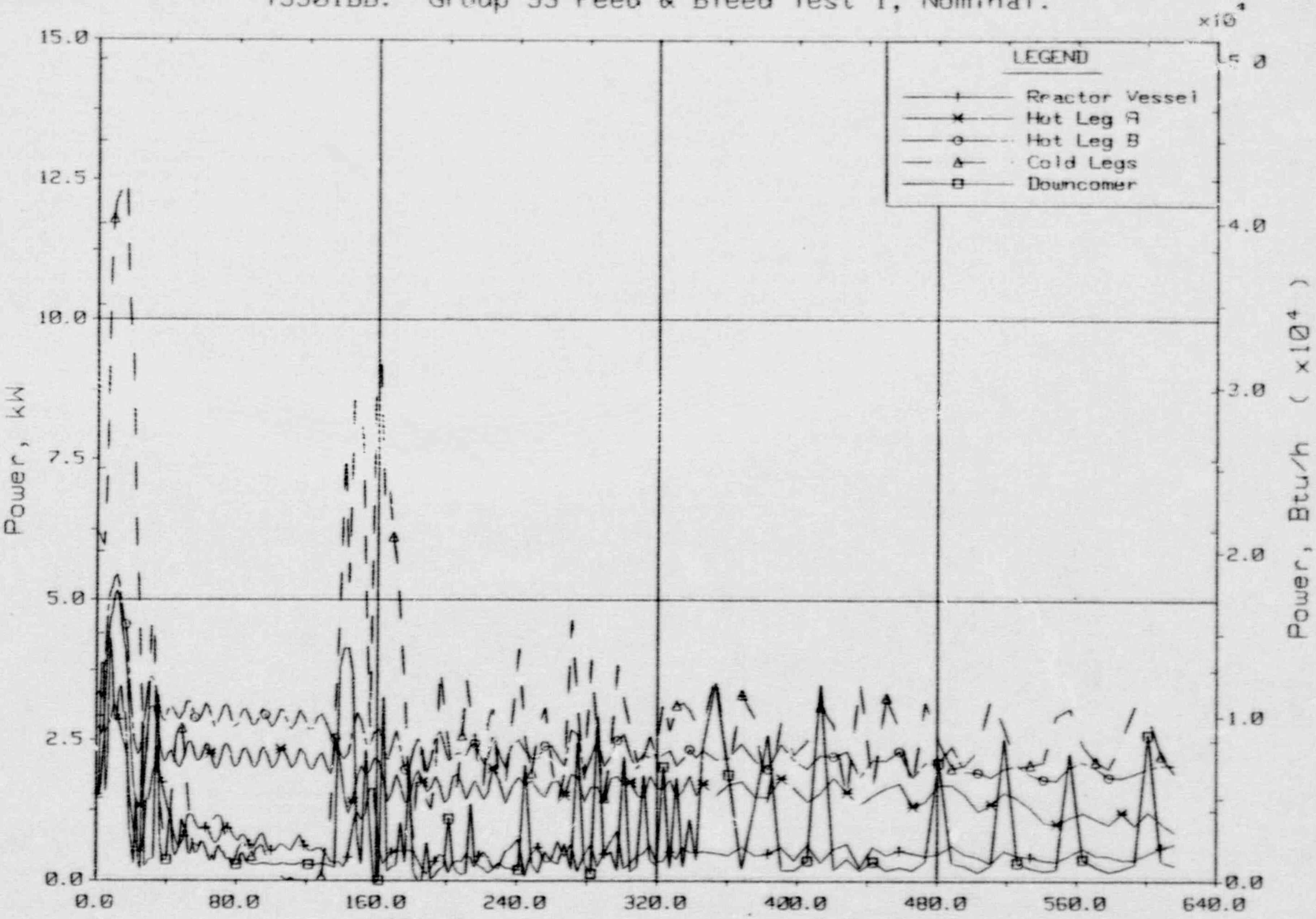
Primary System Venturi Flow Rates.

Tue May 24 12:25:24 1988

PRFL7

FINAL DATA

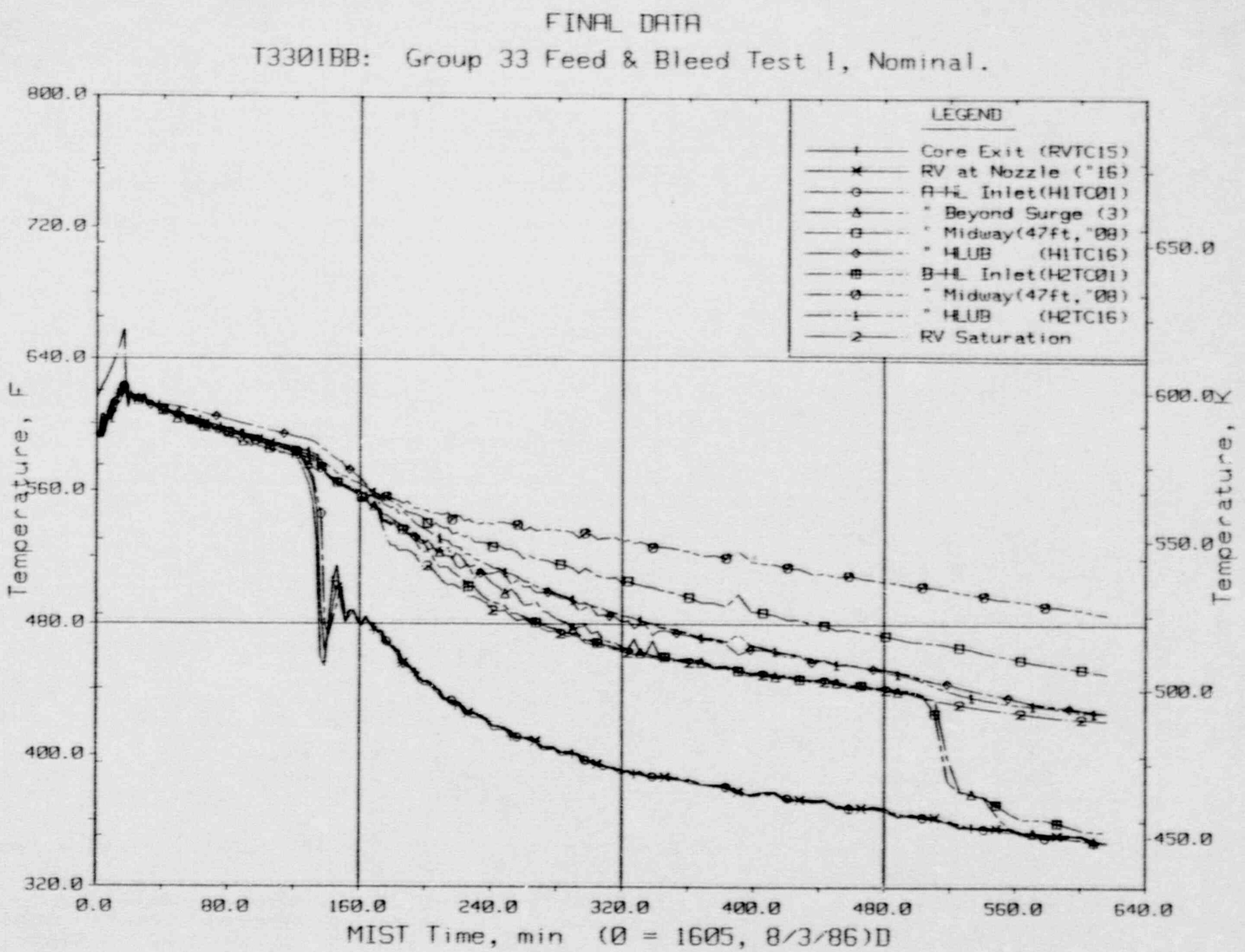
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Guard Heater Specified Power Per Primary Component.

Tue May 24 12:28:30 1988

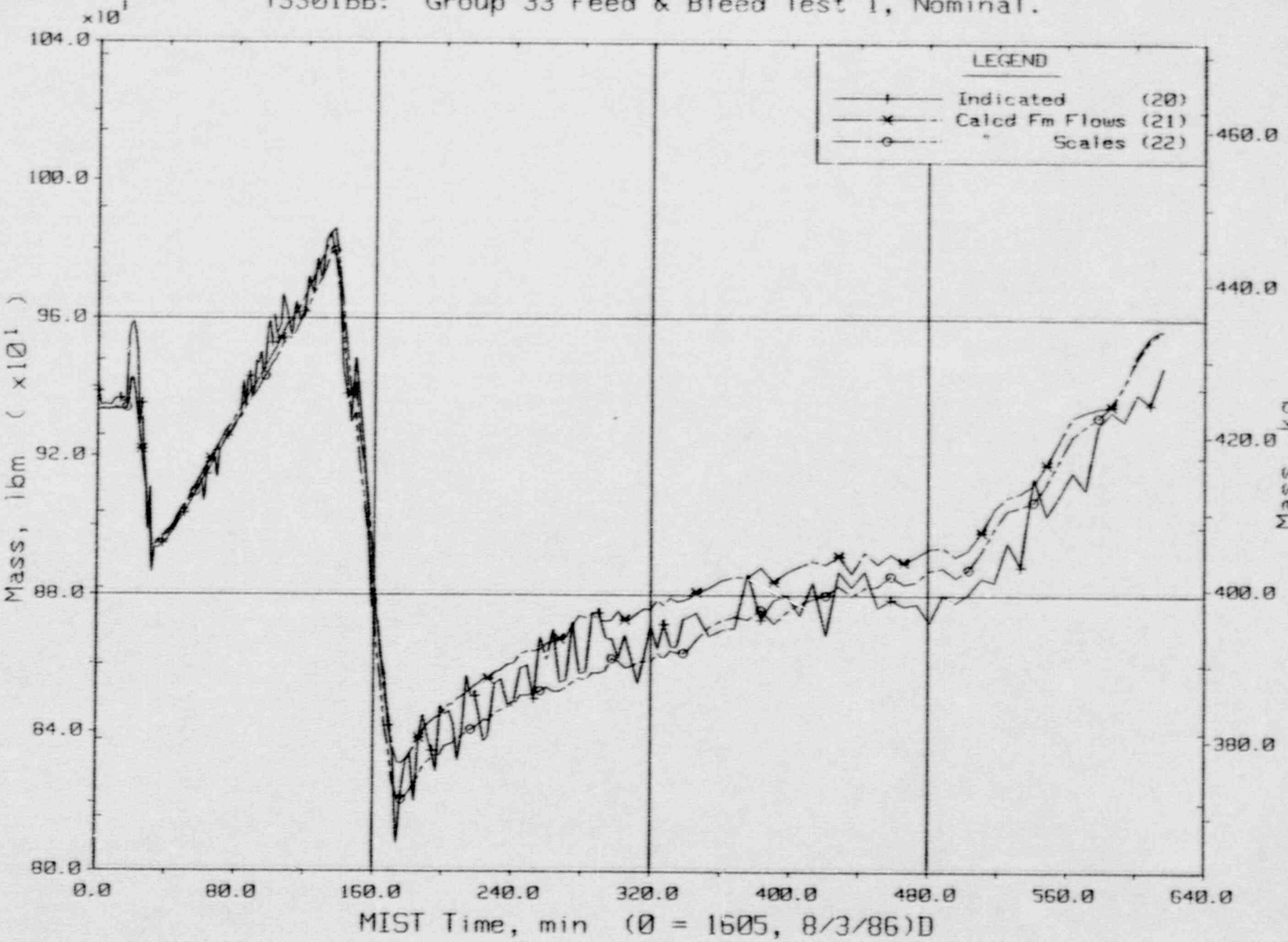
PRGQ1



Composite Core Exit and Hot Leg Fluid Temperatures.

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



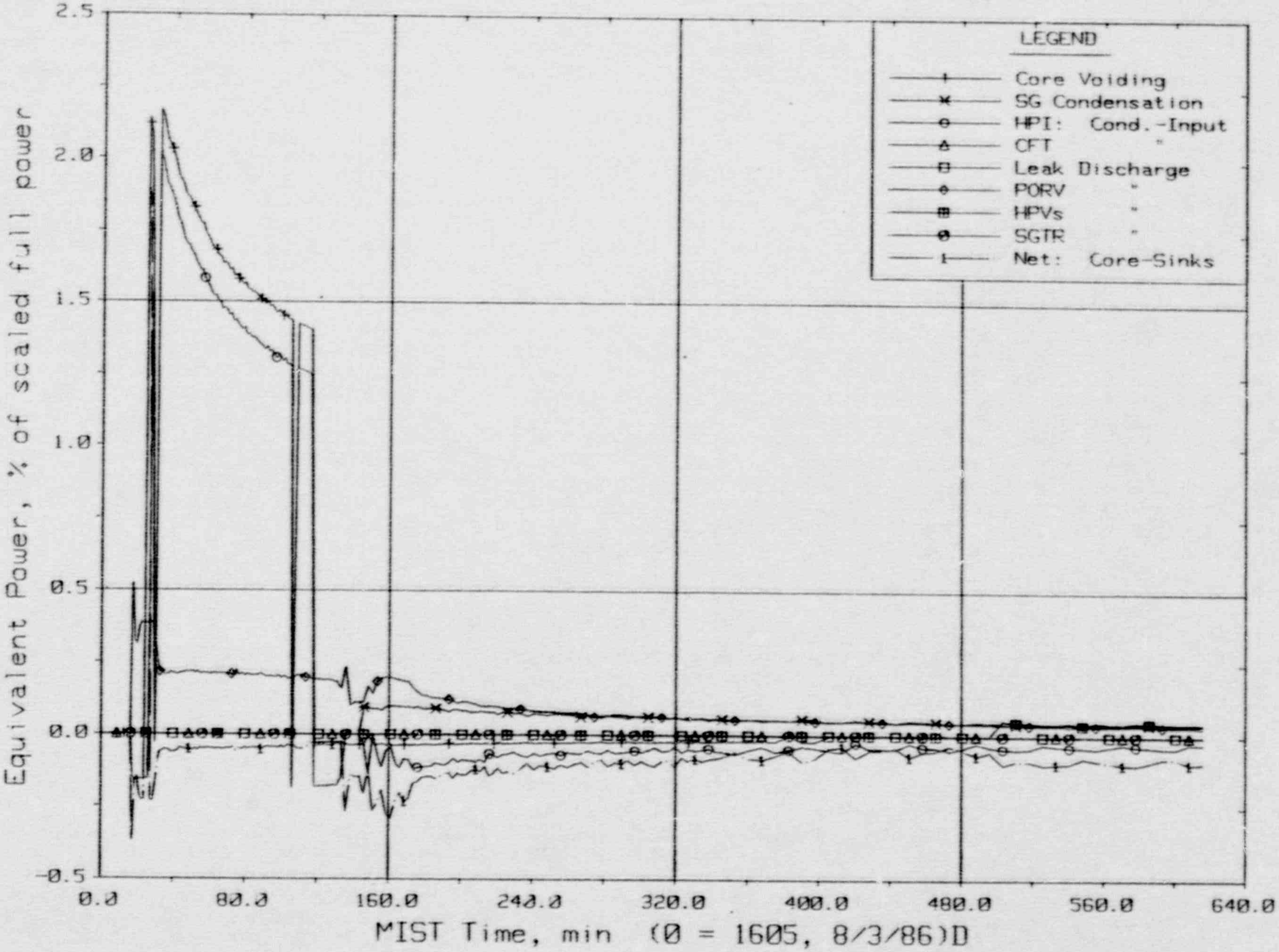
Primary System Total Fluid Mass (PLMLs).

Tue May 24 12:36:27 1988

PRML2

FINAL DATA

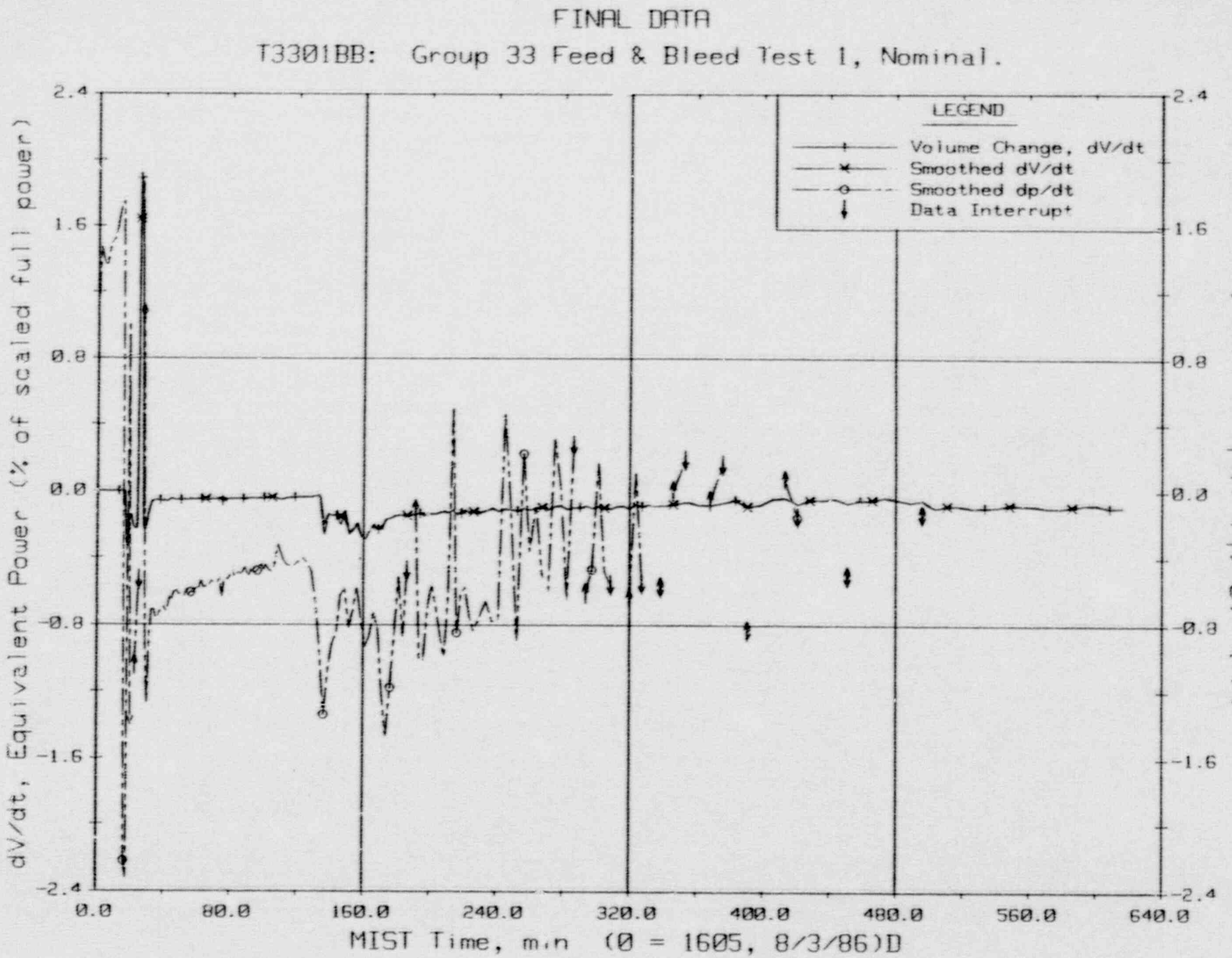
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Primary Fluid Volume Changes By Components.

Tue May 24 12:40:52 1988

PRPA0



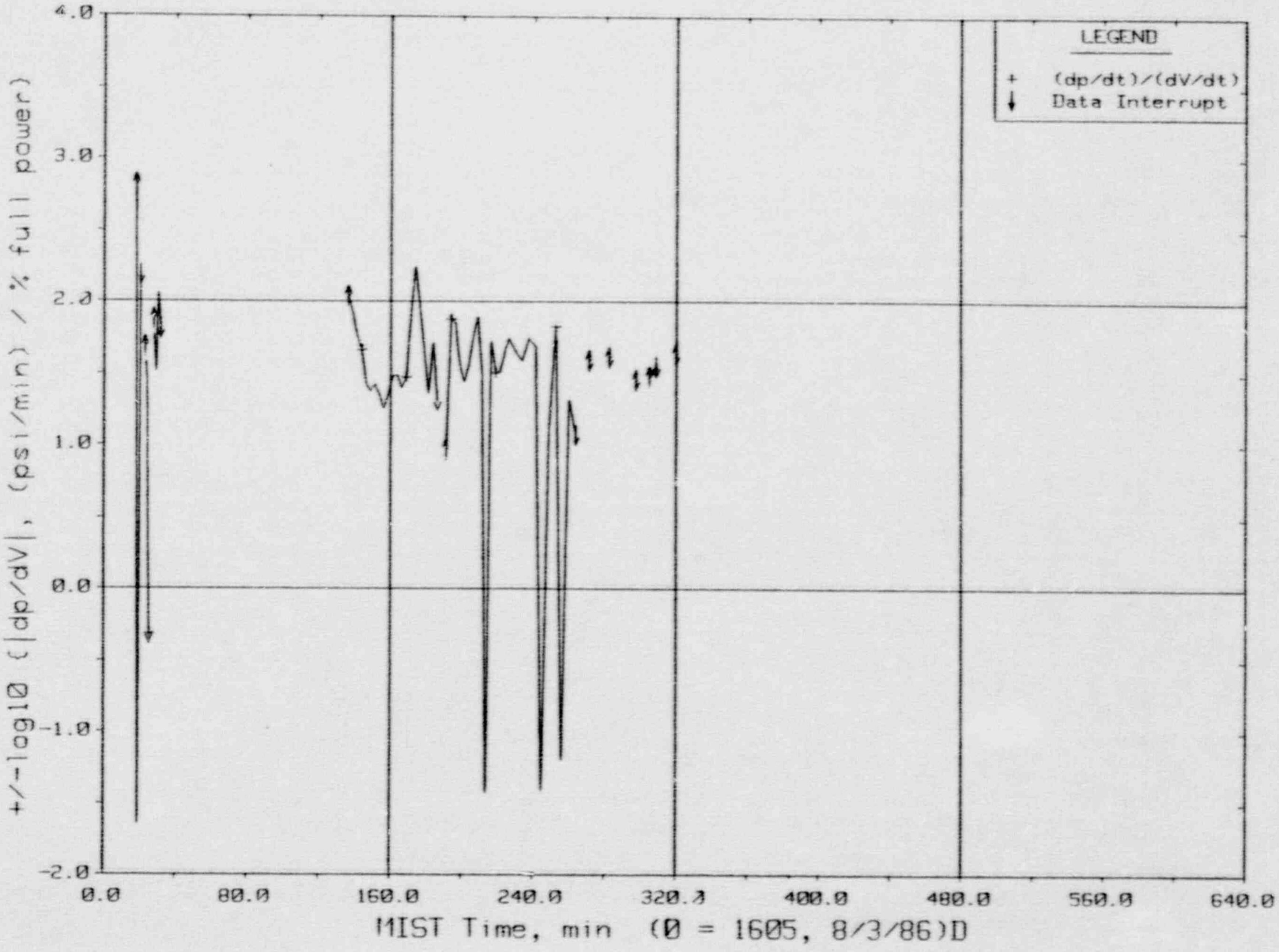
Primary Fluid Volume and Pressure Changes, dV/dt and dp/dt.

Tue May 24 12:44:22 1988

PRPA2

FINAL DATA

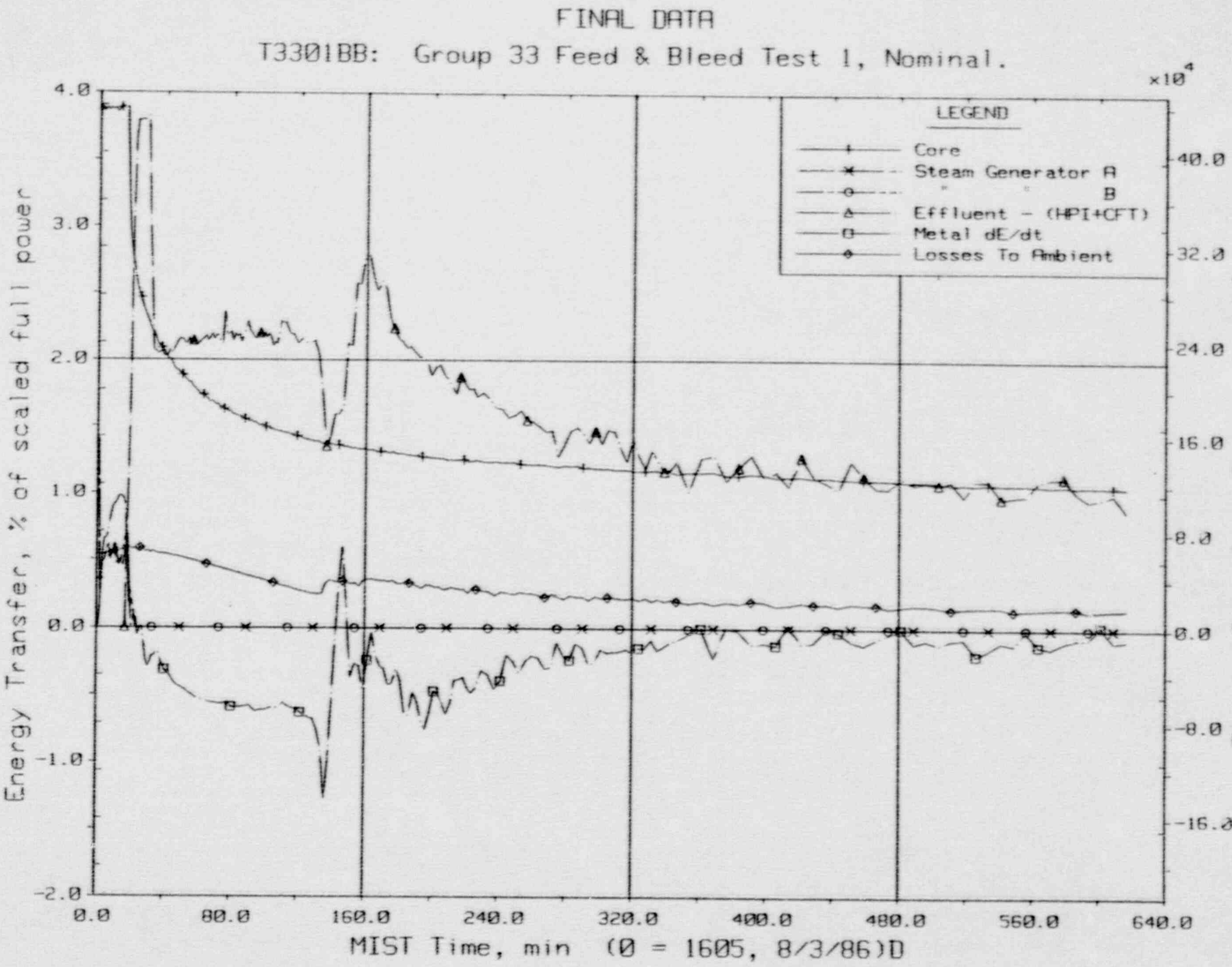
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Primary System Response: dp/dt divided by dV/dt.

Tue May 24 12:47:18 1988

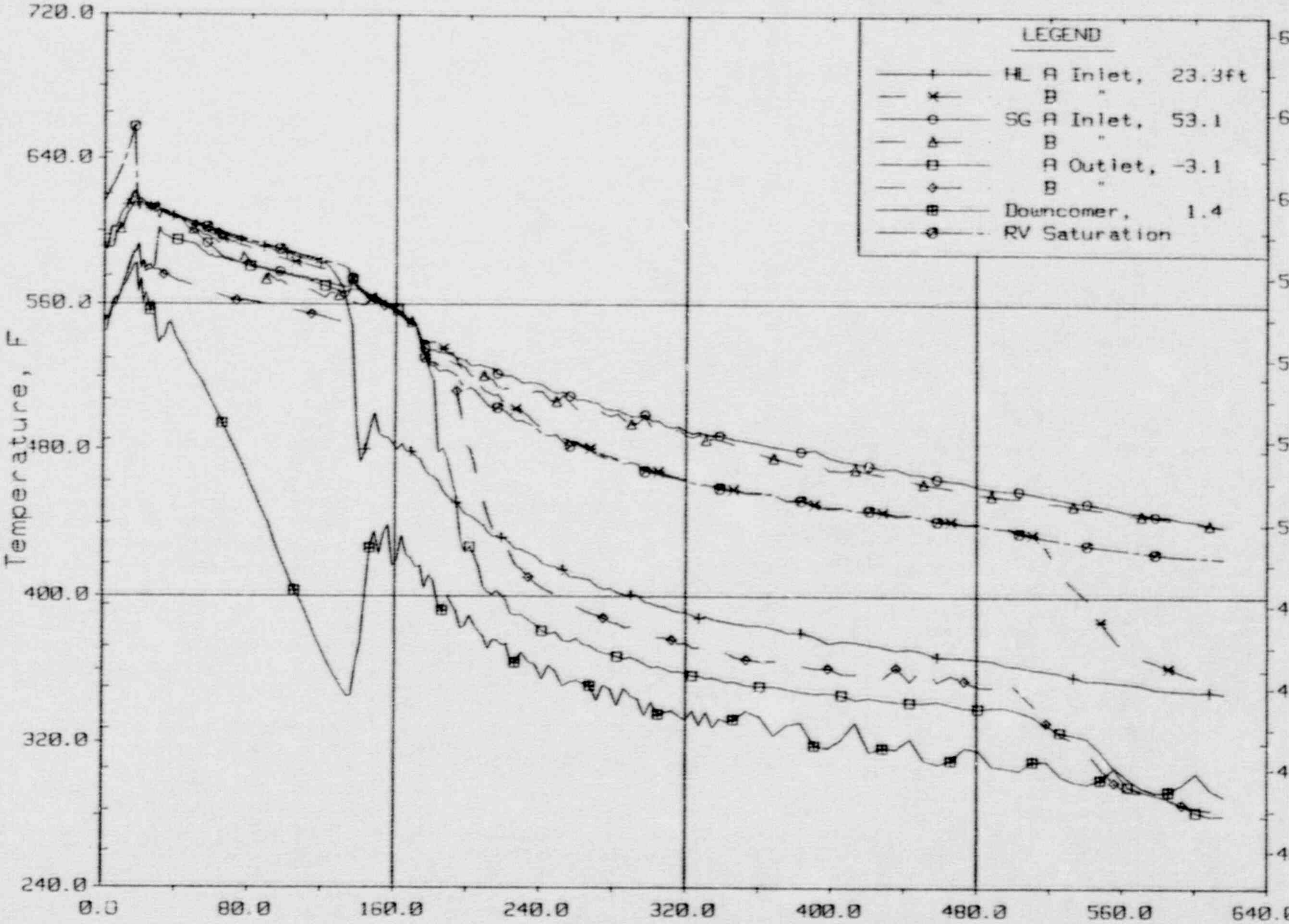
PRPA3



Primary System Energy Transfer.

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



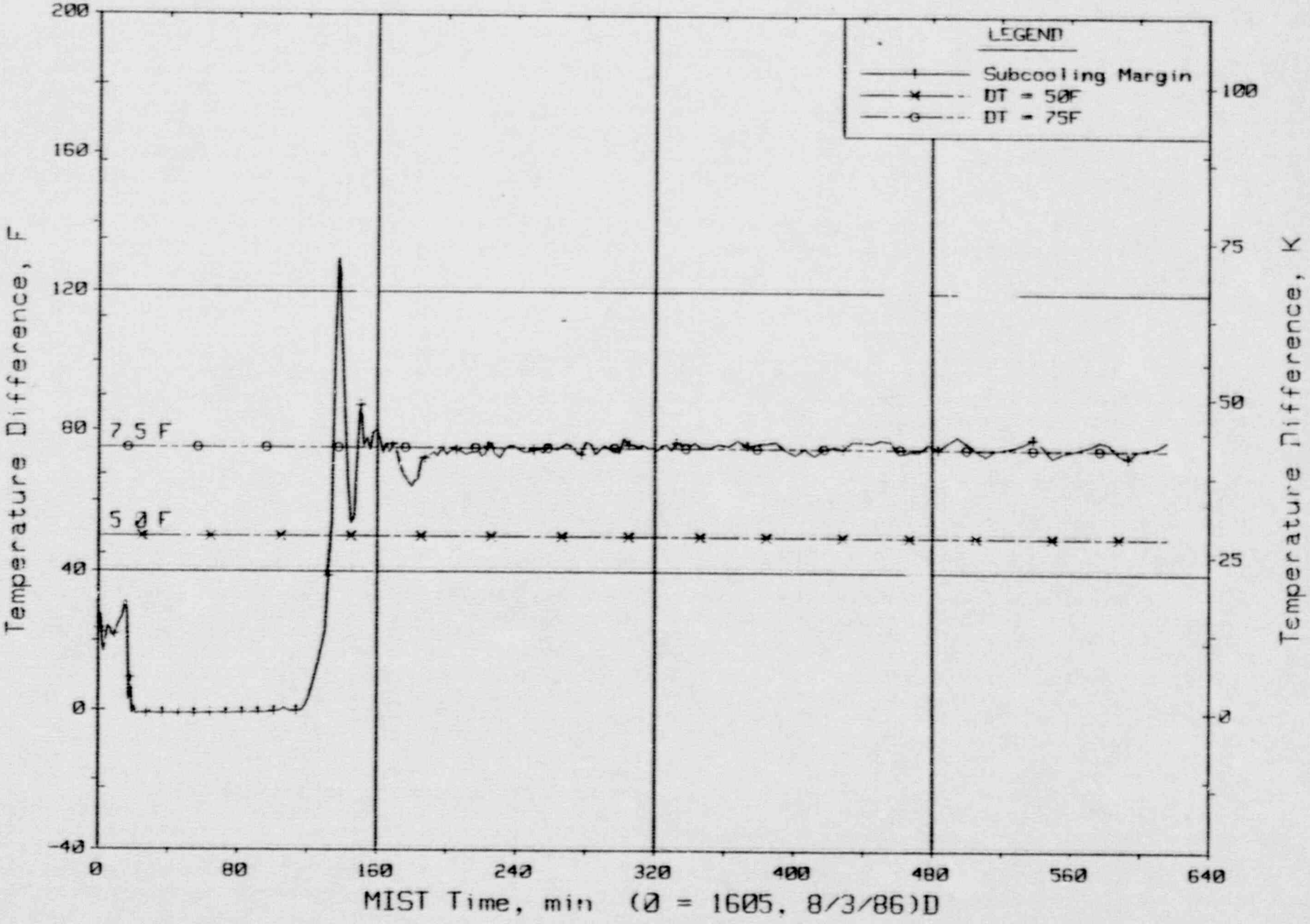
Primary System Fluid Temperatures (RTDs).

Tue May 24 13:00:45 1988

PRRT0

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



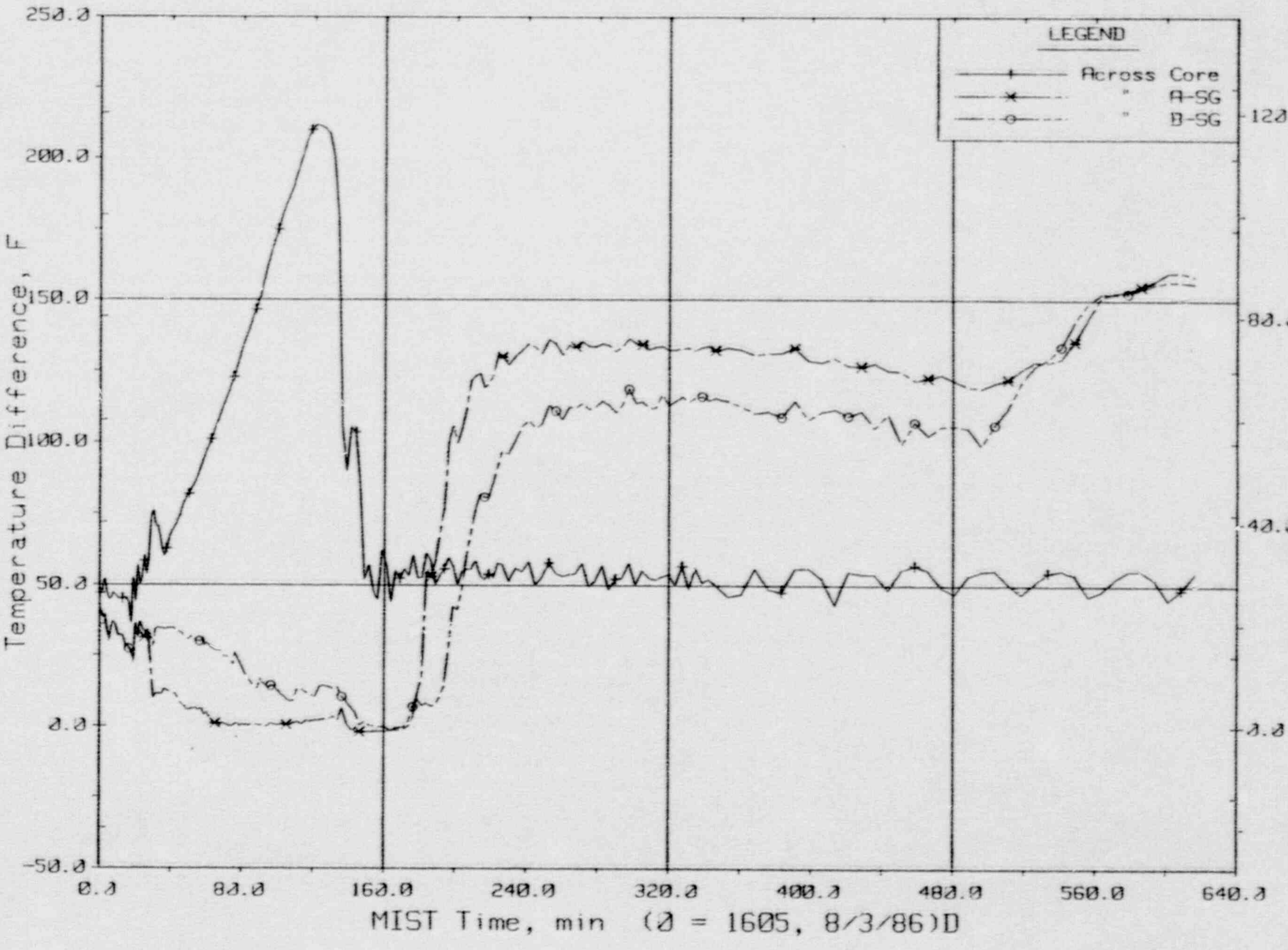
Control Temperature Differences.

Tue Nov 1 09:00:09 1988

PRTD0

FINAL DATA

T33Ø1BB: Group 33 Feed & Bleed Test 1, Nominal.



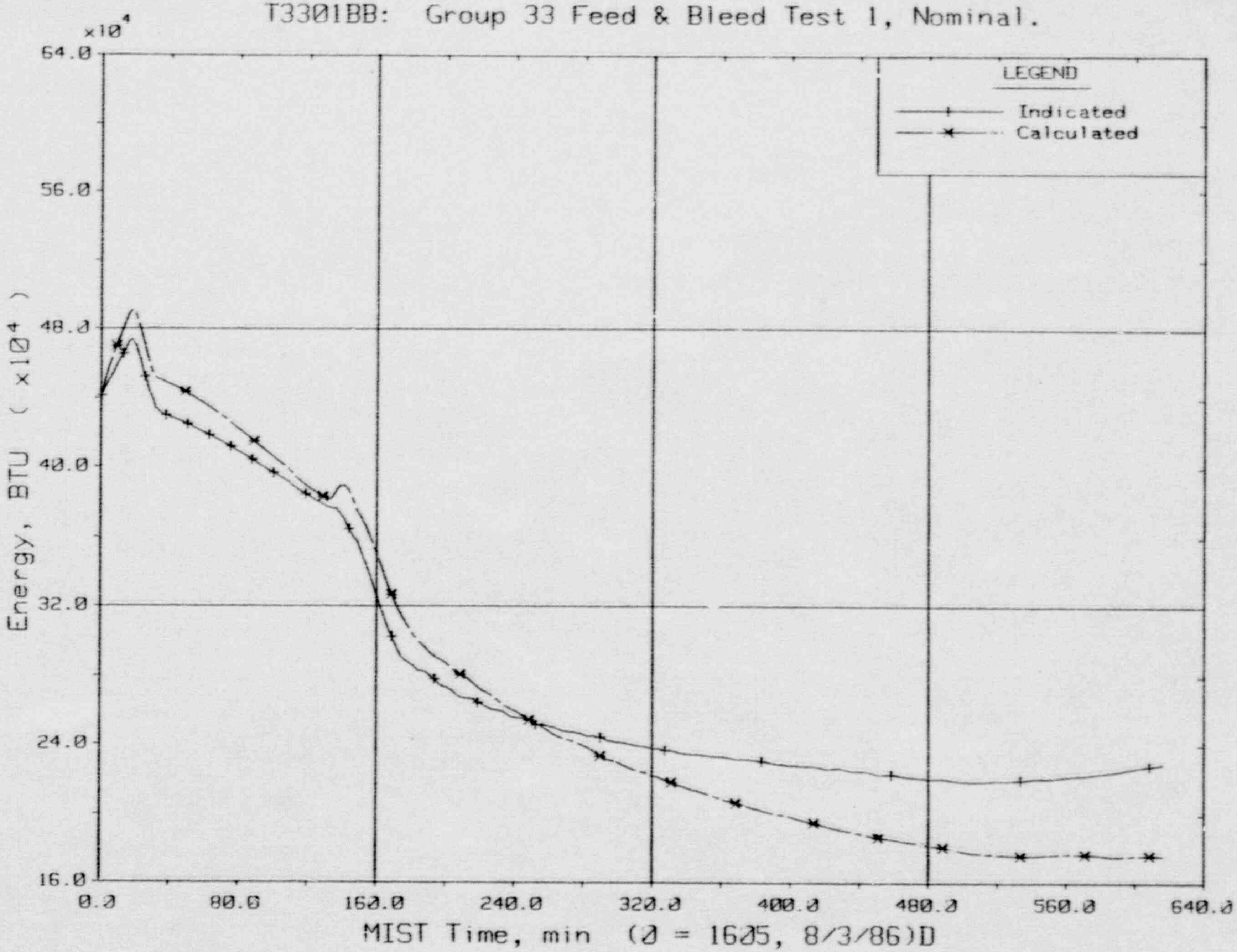
Key Temperature Differences.

Tue May 24 13:26:31 1988

PRTD2

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



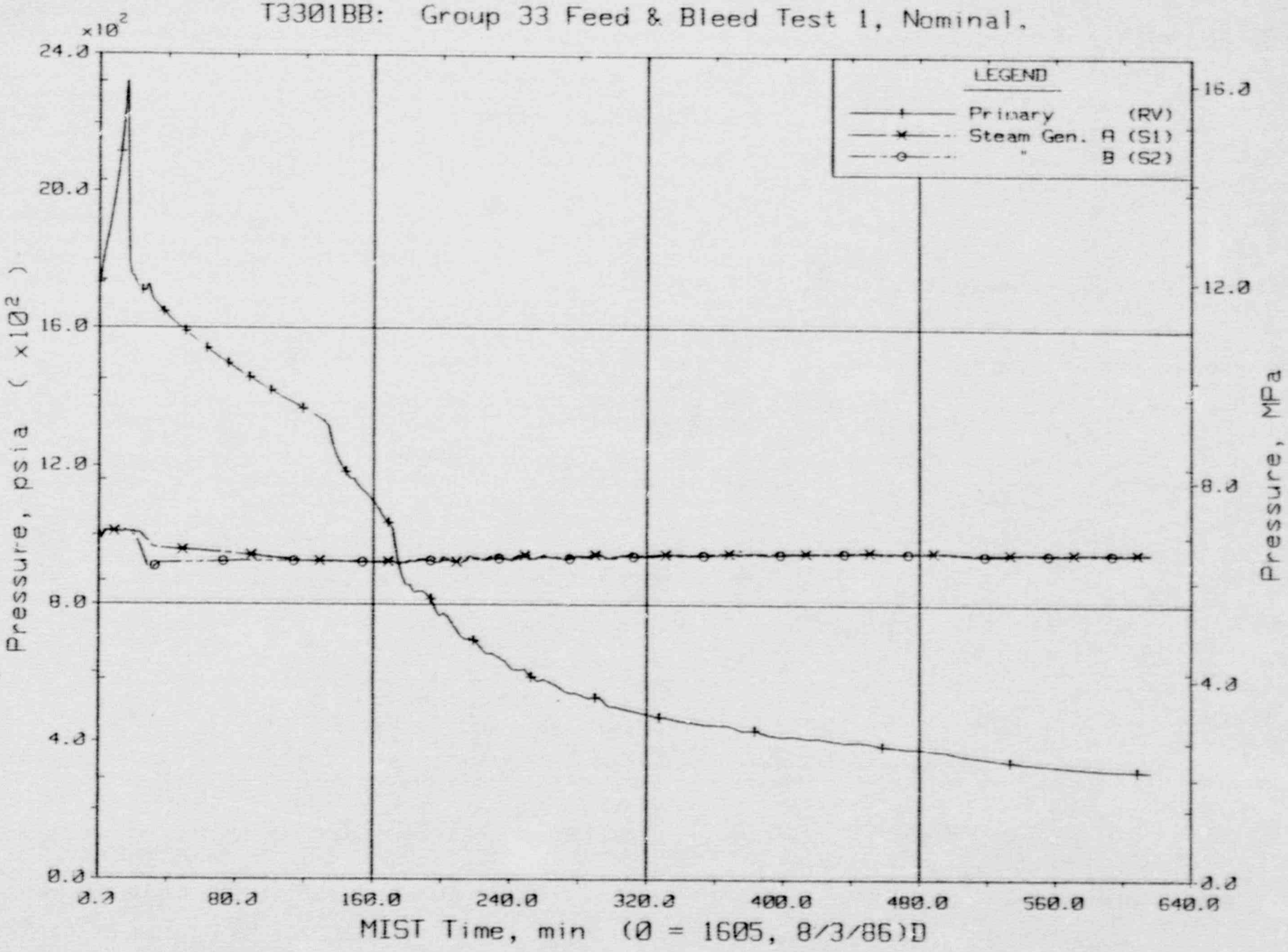
Primary System Total Fluid Energy.

Tue May 24 13:17:35 1988

PRTE2

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



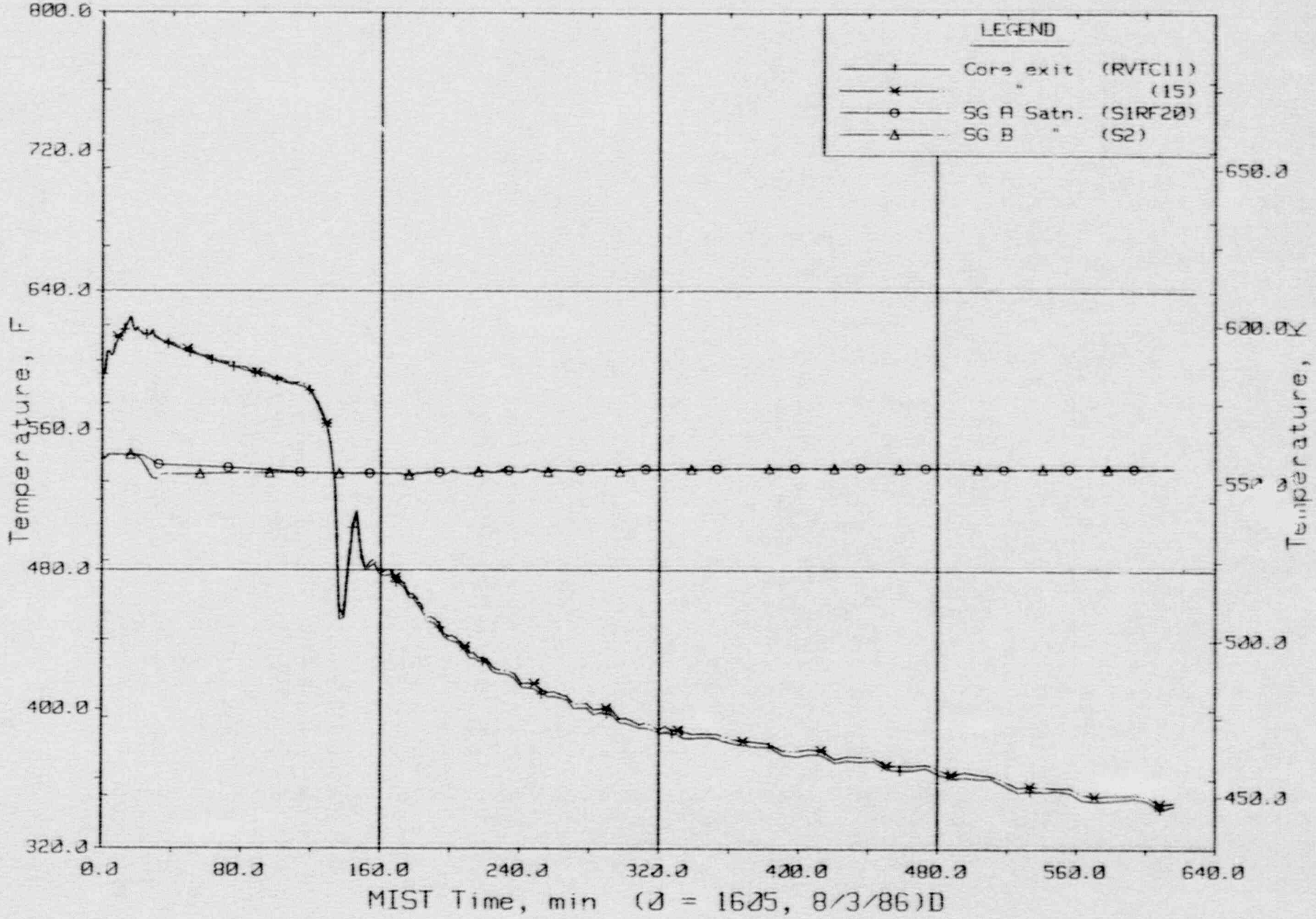
Primary and Secondary System Pressures (GP01s).

Tue May 24 17:20:16 1988

PSGP1

FINAL DATA

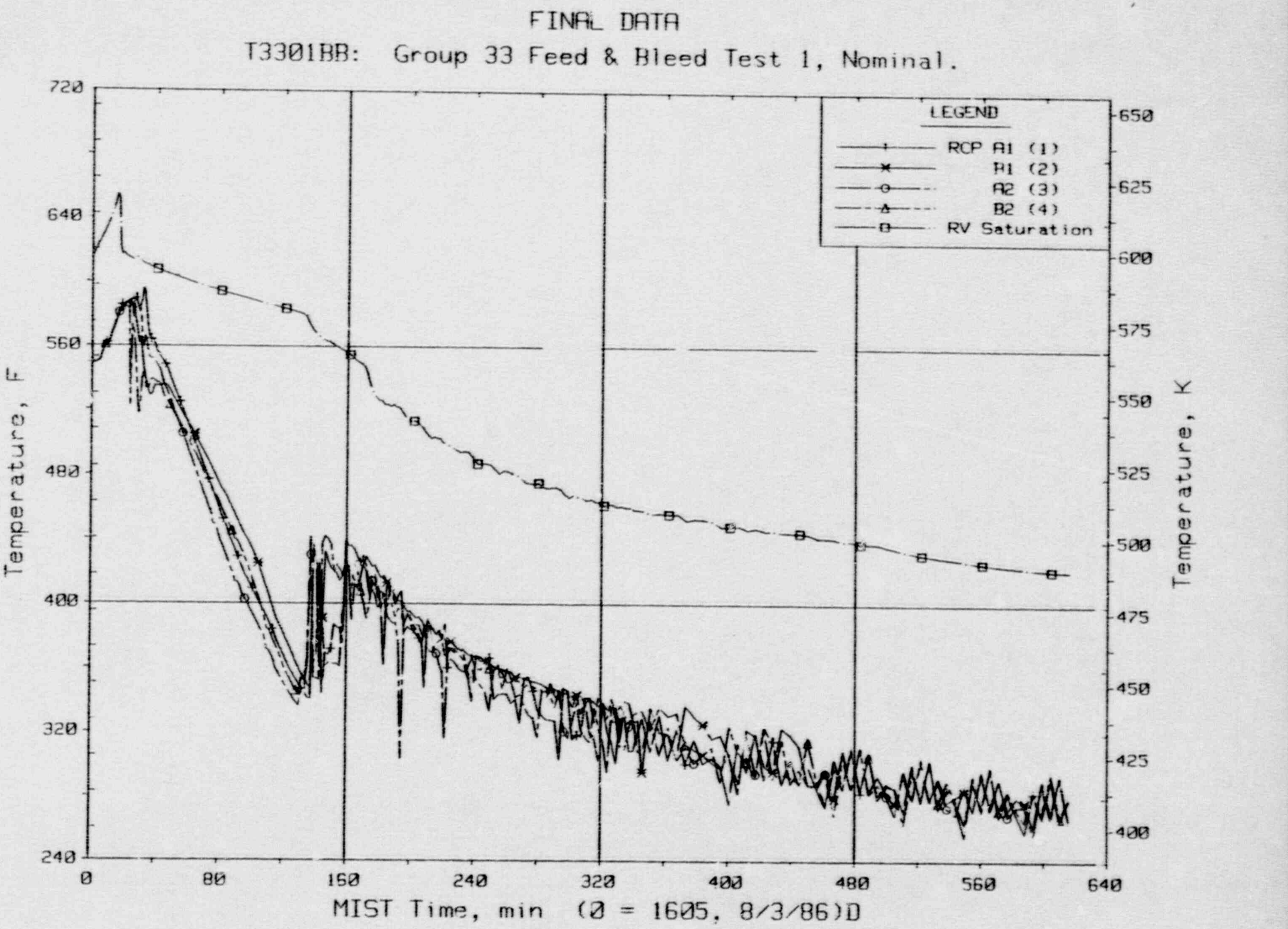
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Core Exit and Steam Generator Secondary Saturation Temperatures.

Tue May 24 13:27:01 1988

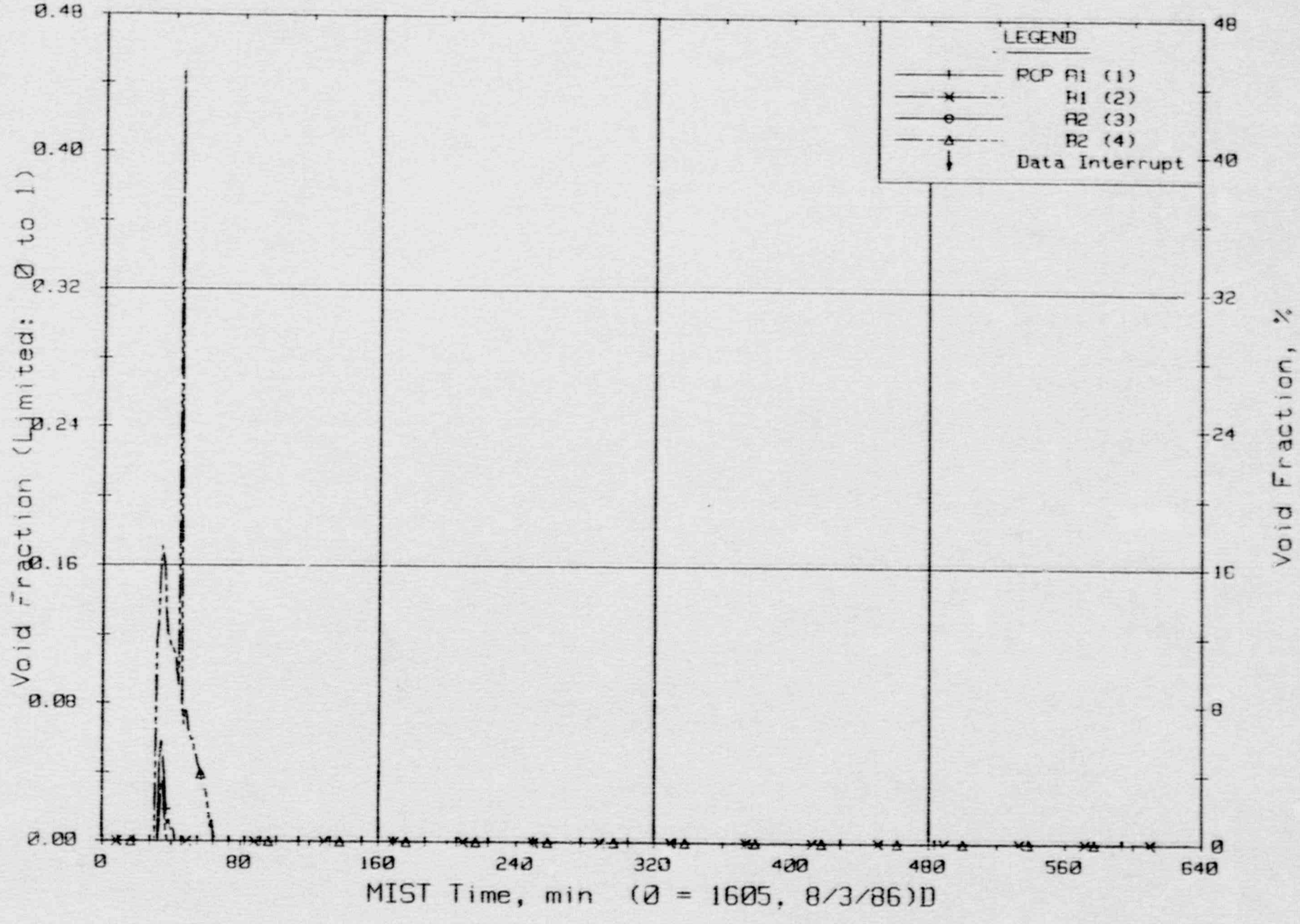
PSTC3p



Pump Suction Fluid Temperature (CnRT21s).

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



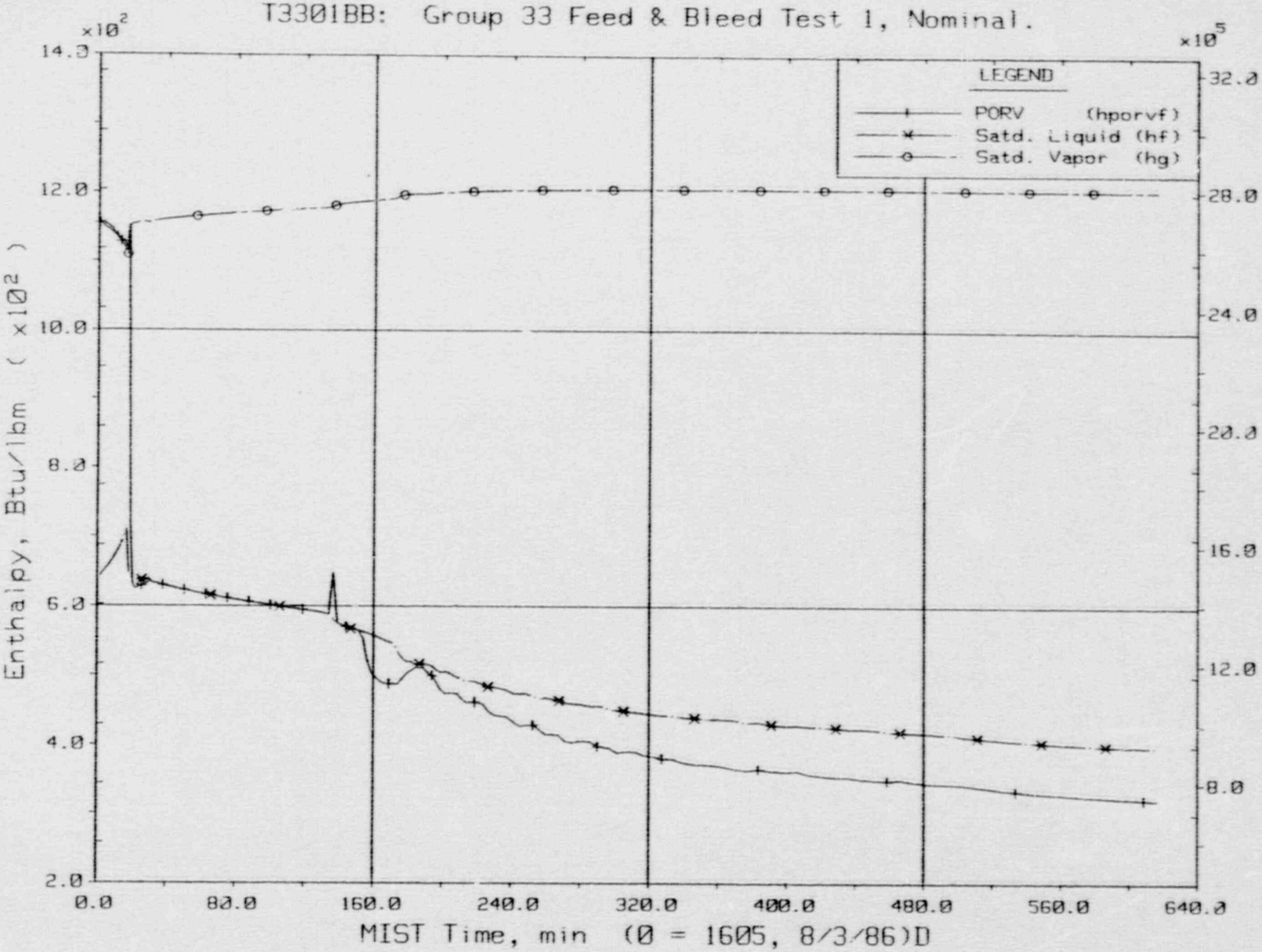
Pump Suction Void Fraction From Gamma Densitometers (CnGM2').

Tue Nov 1 09:06:14 1988

PUVF2

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



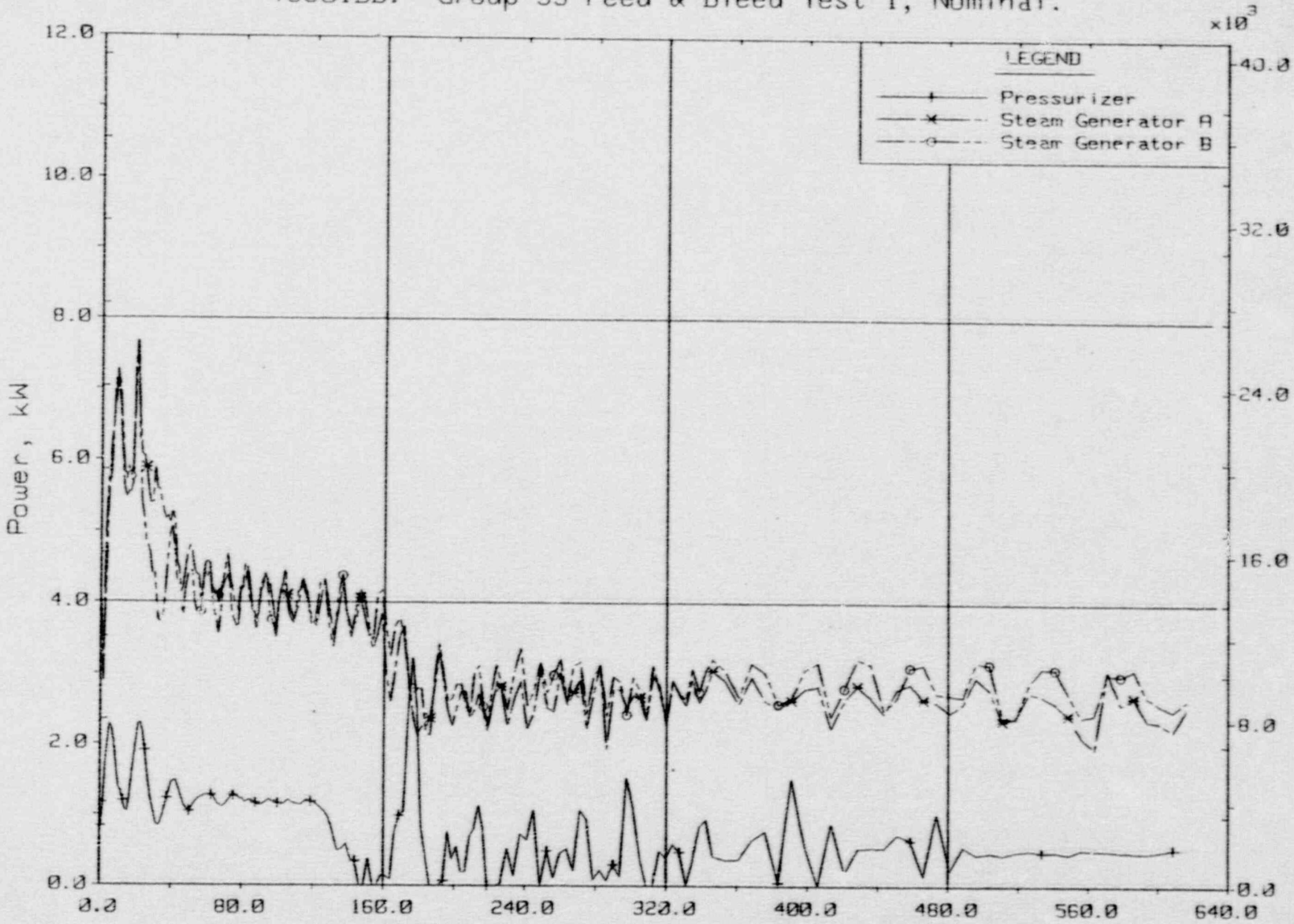
Power-Operated Relief Valve Enthalpy (Based On Flow Rate).

Tue May 24 13:34:30 1988

PZEN1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



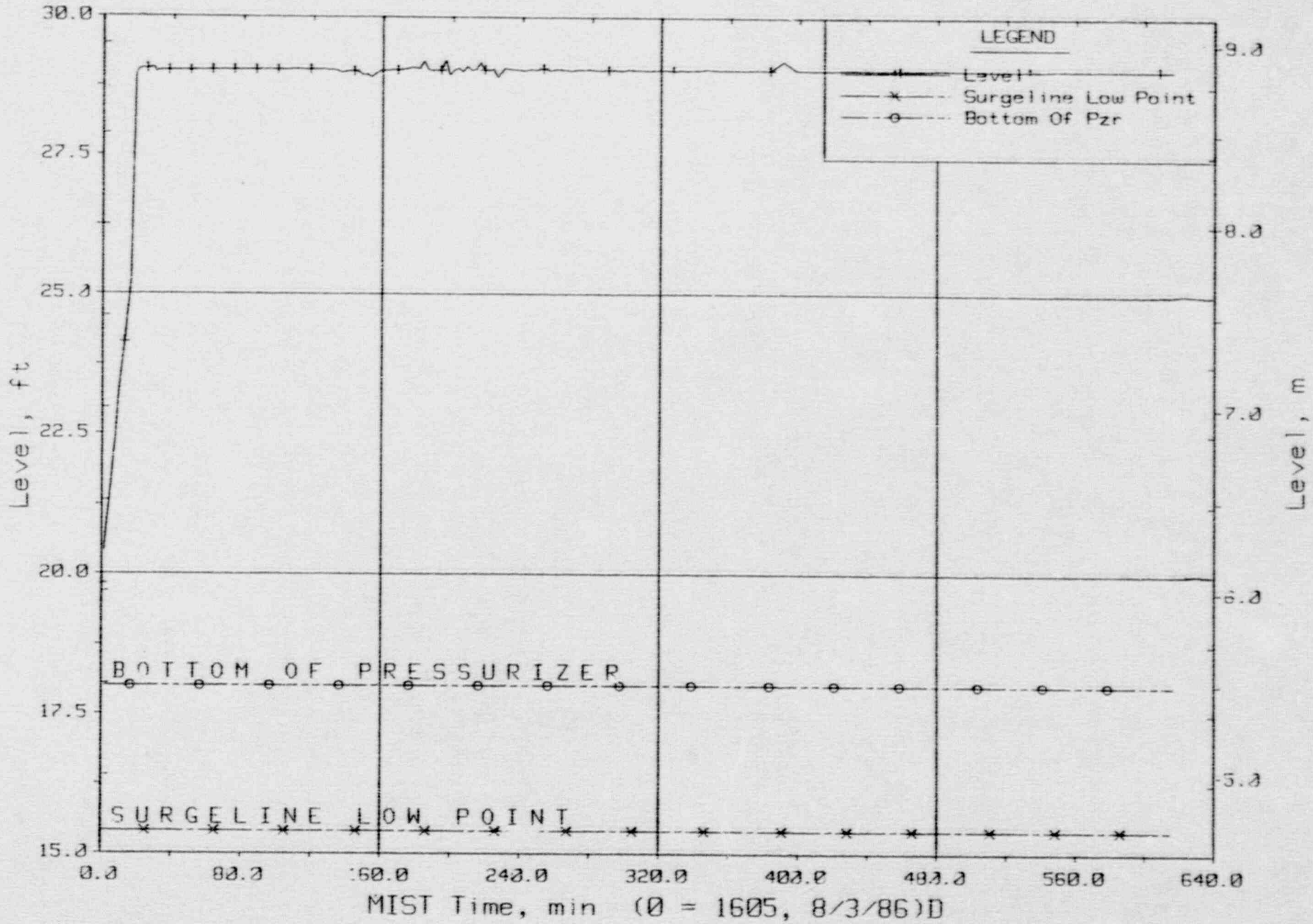
Guard Heater Specified Power. Pressurizer and Steam Generators.

Tue May 24 13:40:19 1988

PZGQ1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



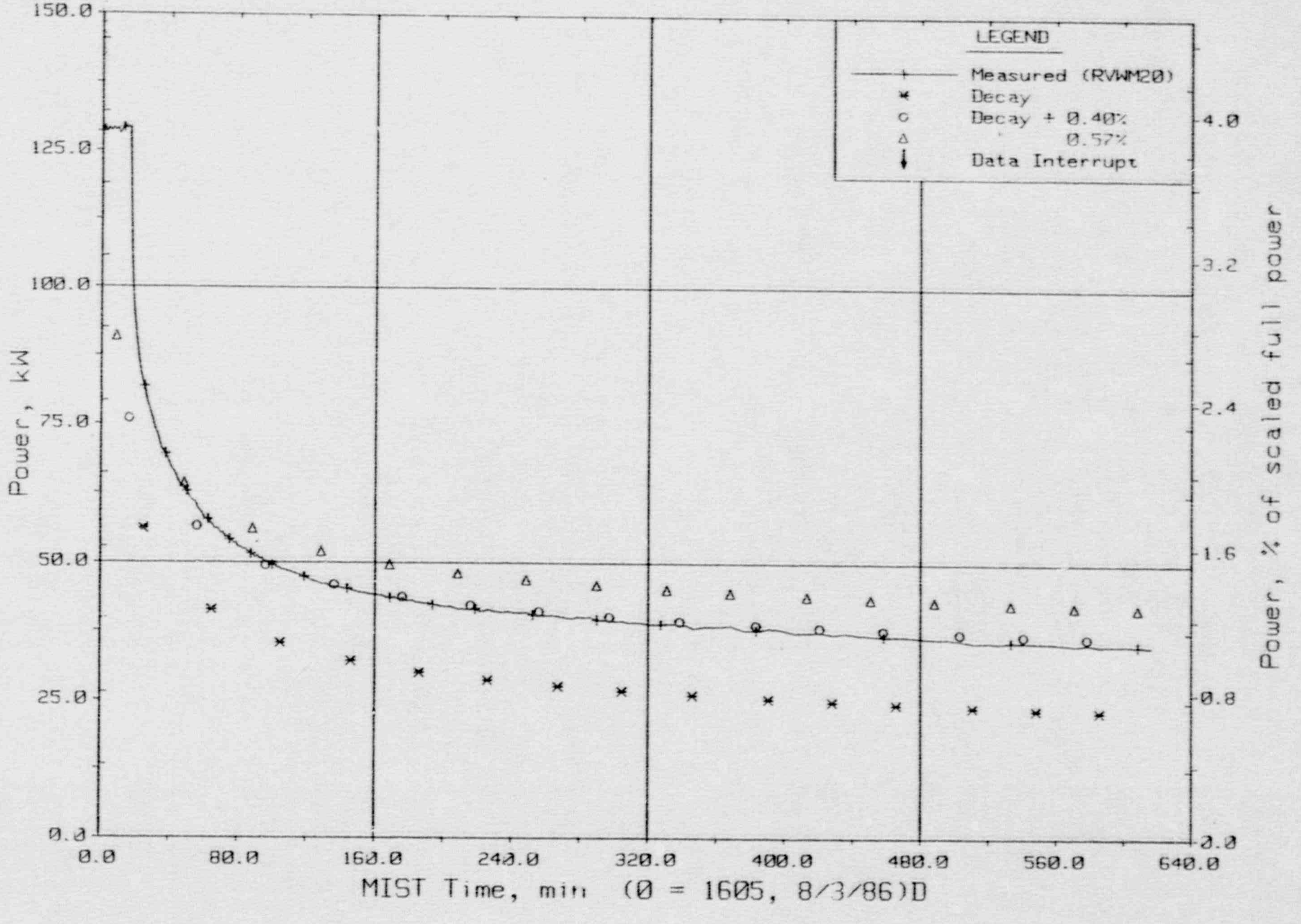
Pressurizer Collapsed Liquid Level (PZLV20).

Tue May 24 13:45:05 1988

PZLV1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



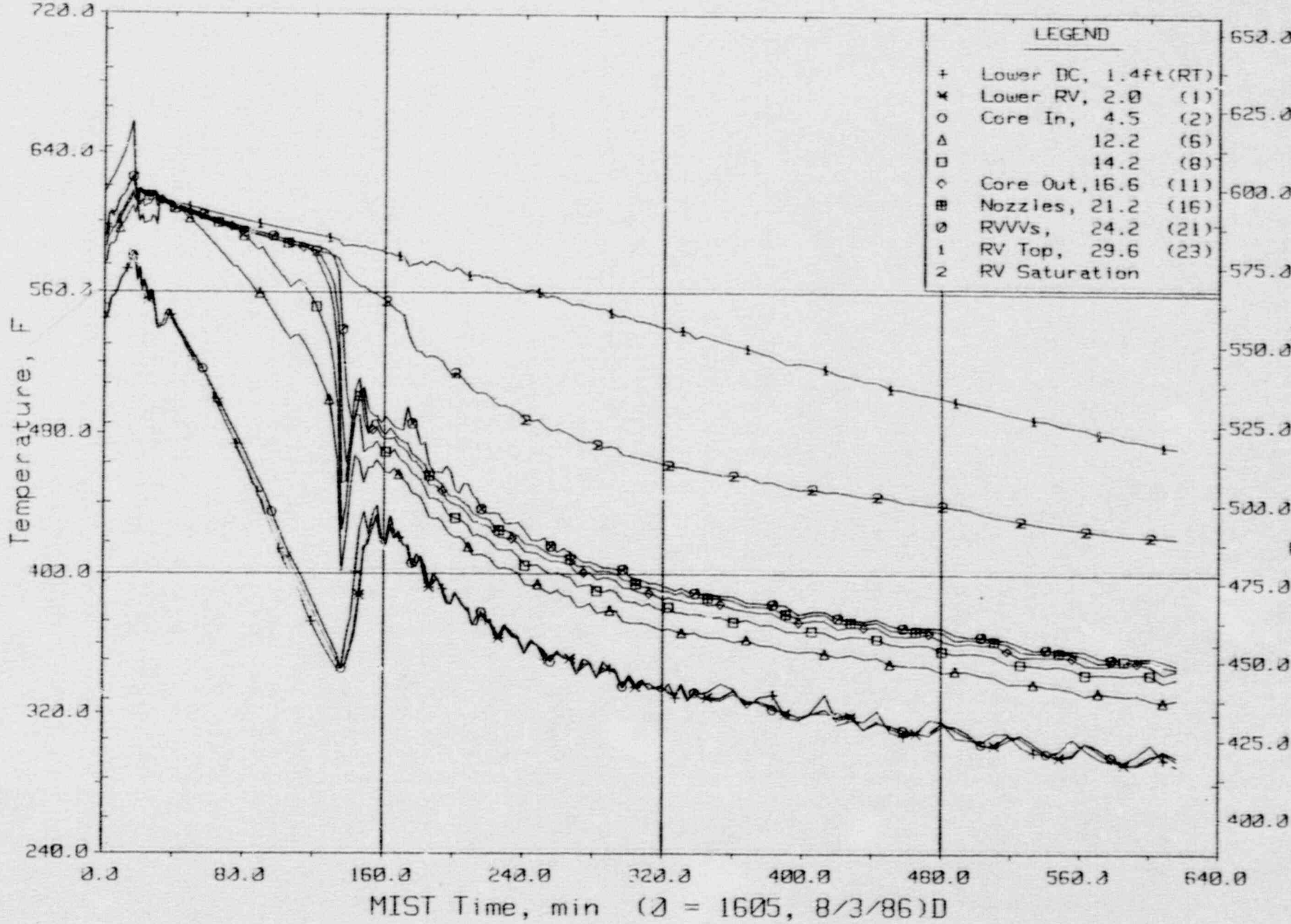
Core Power.

Tue May 24 13:49:34 1988

RVKW0

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



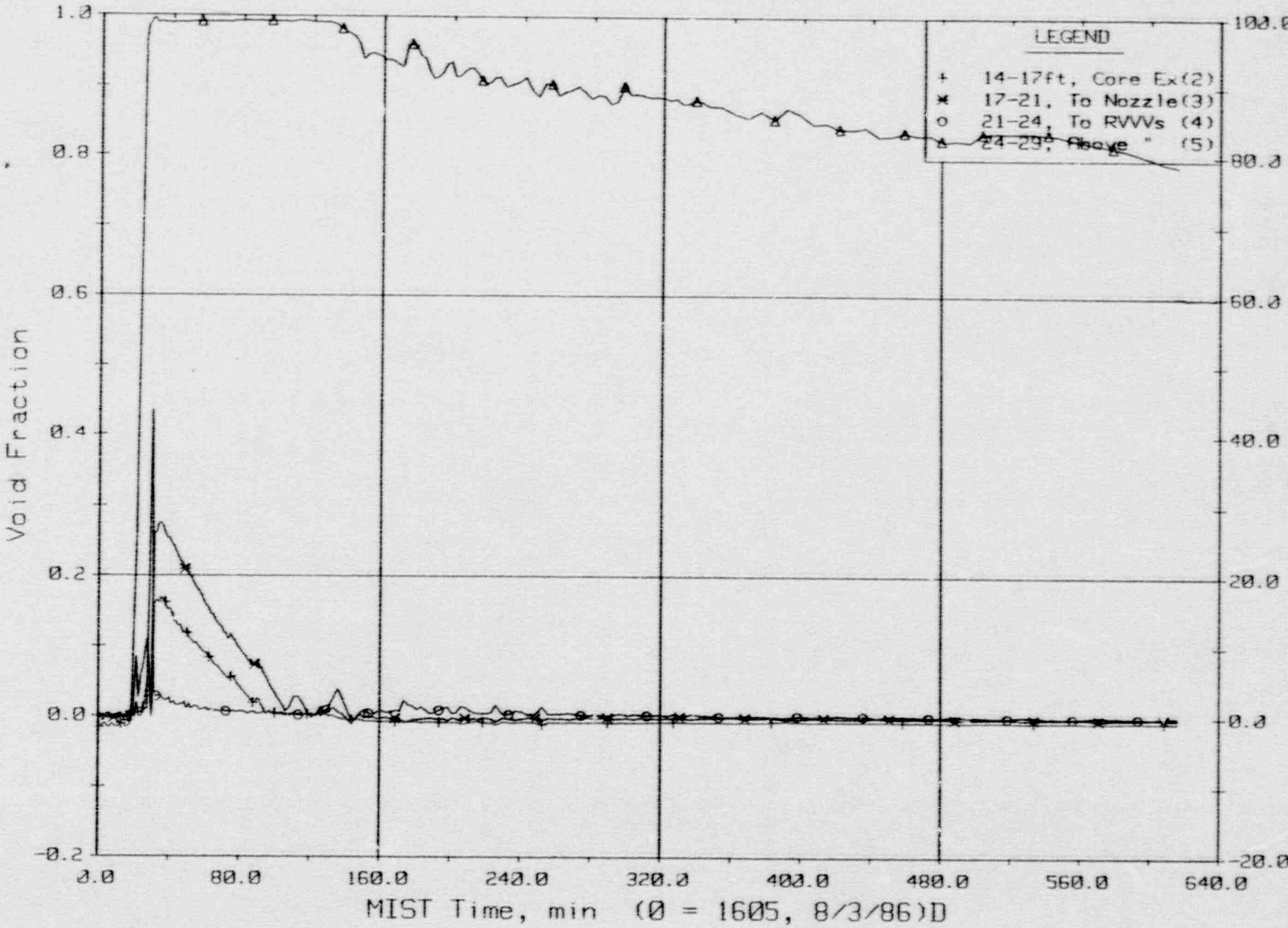
Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs).

Tue May 24 13:55:10 1988

RVTC0

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



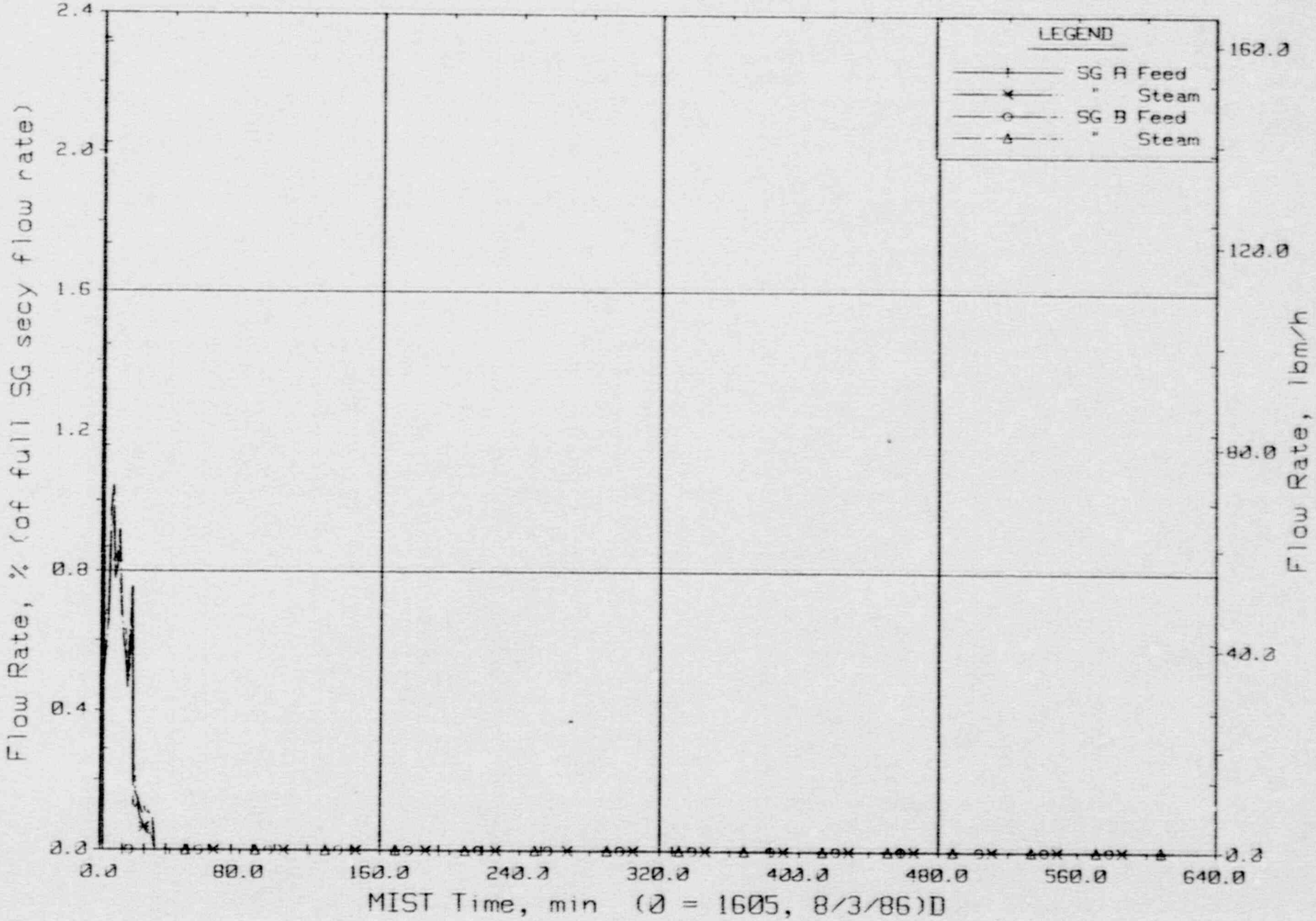
Reactor Vessel Void Fractions From Differential Pressures (RVVFs).

Tue May 24 14:20:27 1988

RVVF1

FINAL DATA

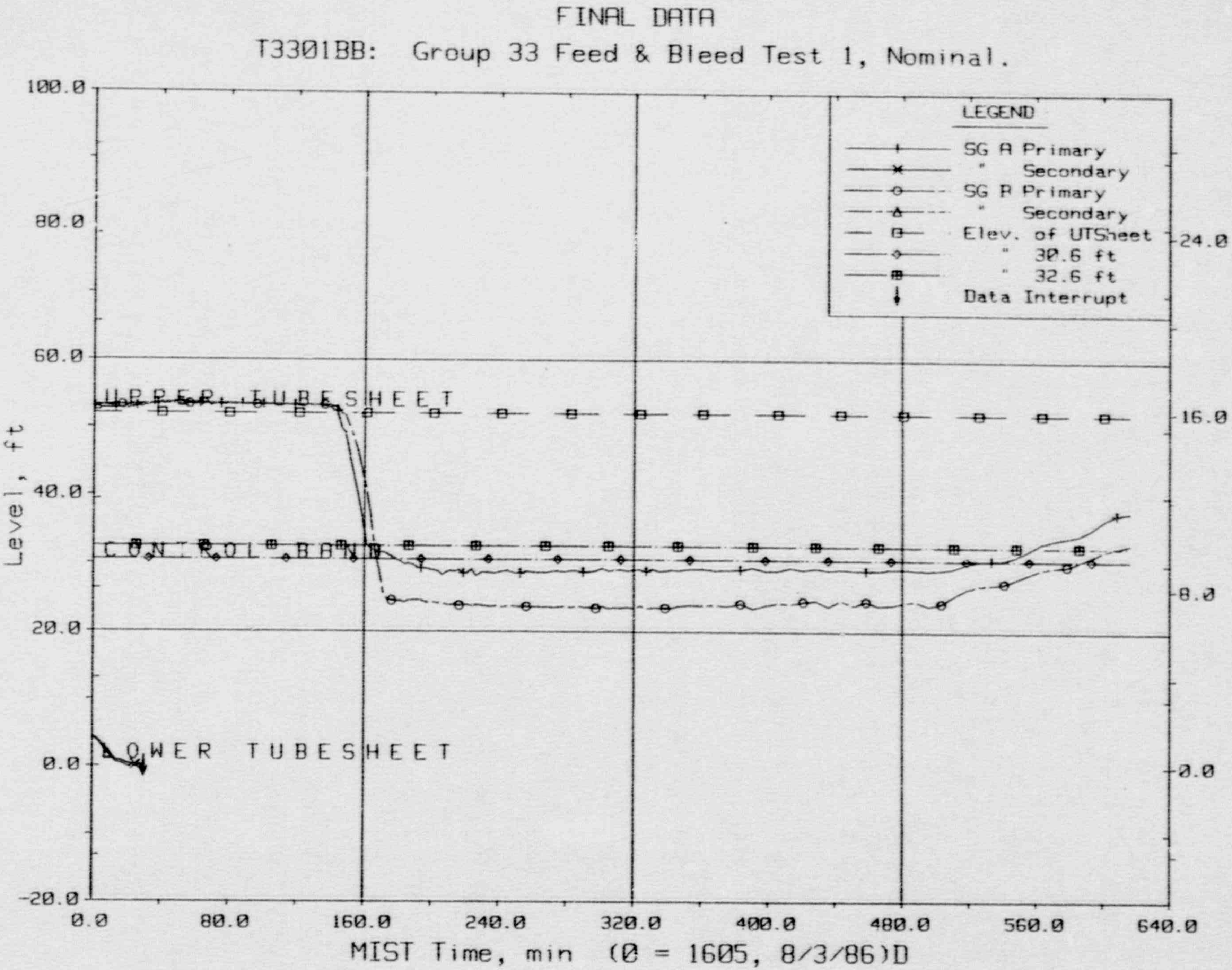
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Steam Generator Secondary System Flow Rates.

Tue May 24 14:04:22 1988

SGFL2



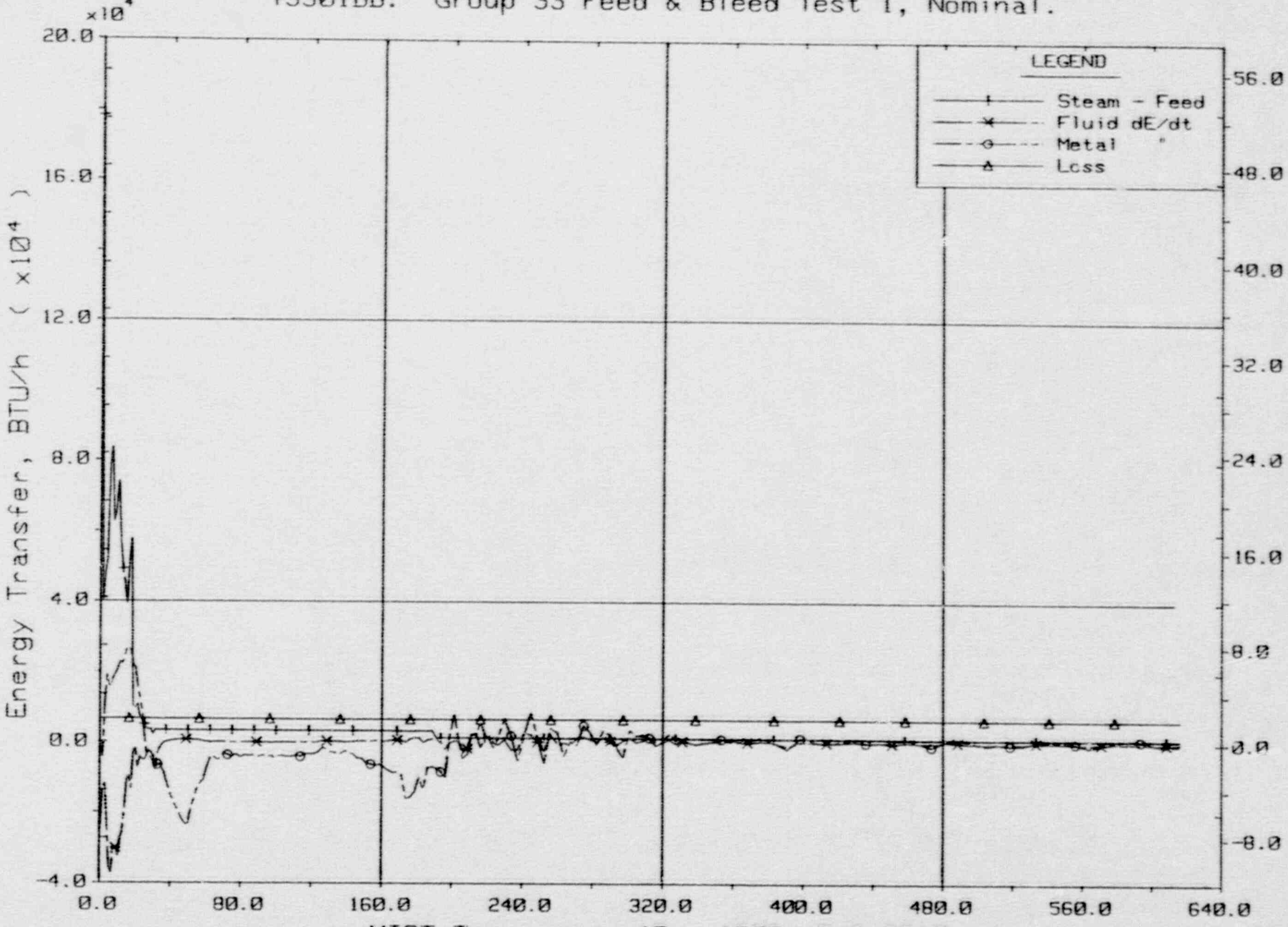
Steam Generator Collapsed Liquid Levels.

Tue May 24 14:52:00 1988

SGLV2

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



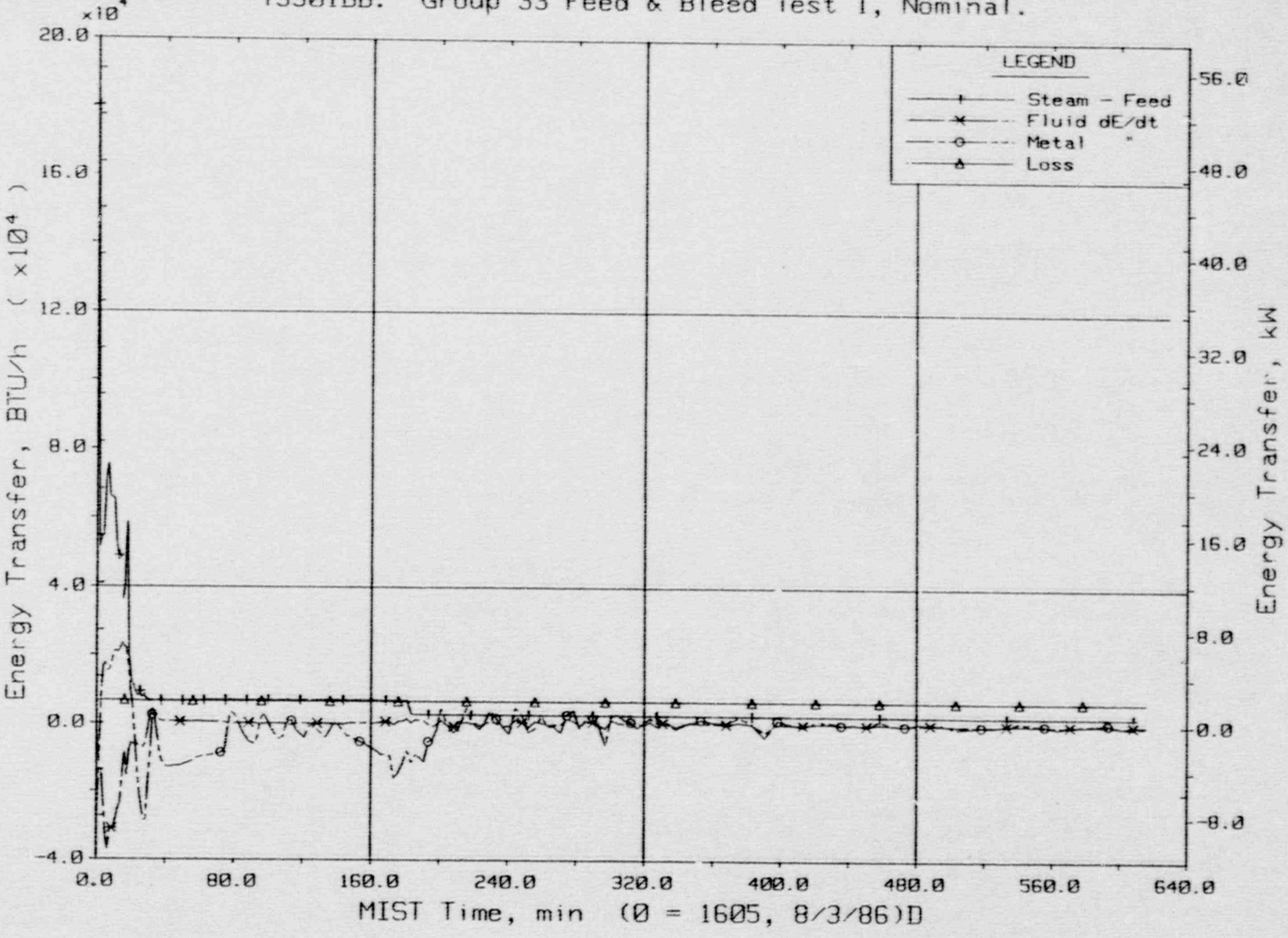
Steam Generator A Energy Transfer.

Tue May 24 15:01:33 1988

SGQE3

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



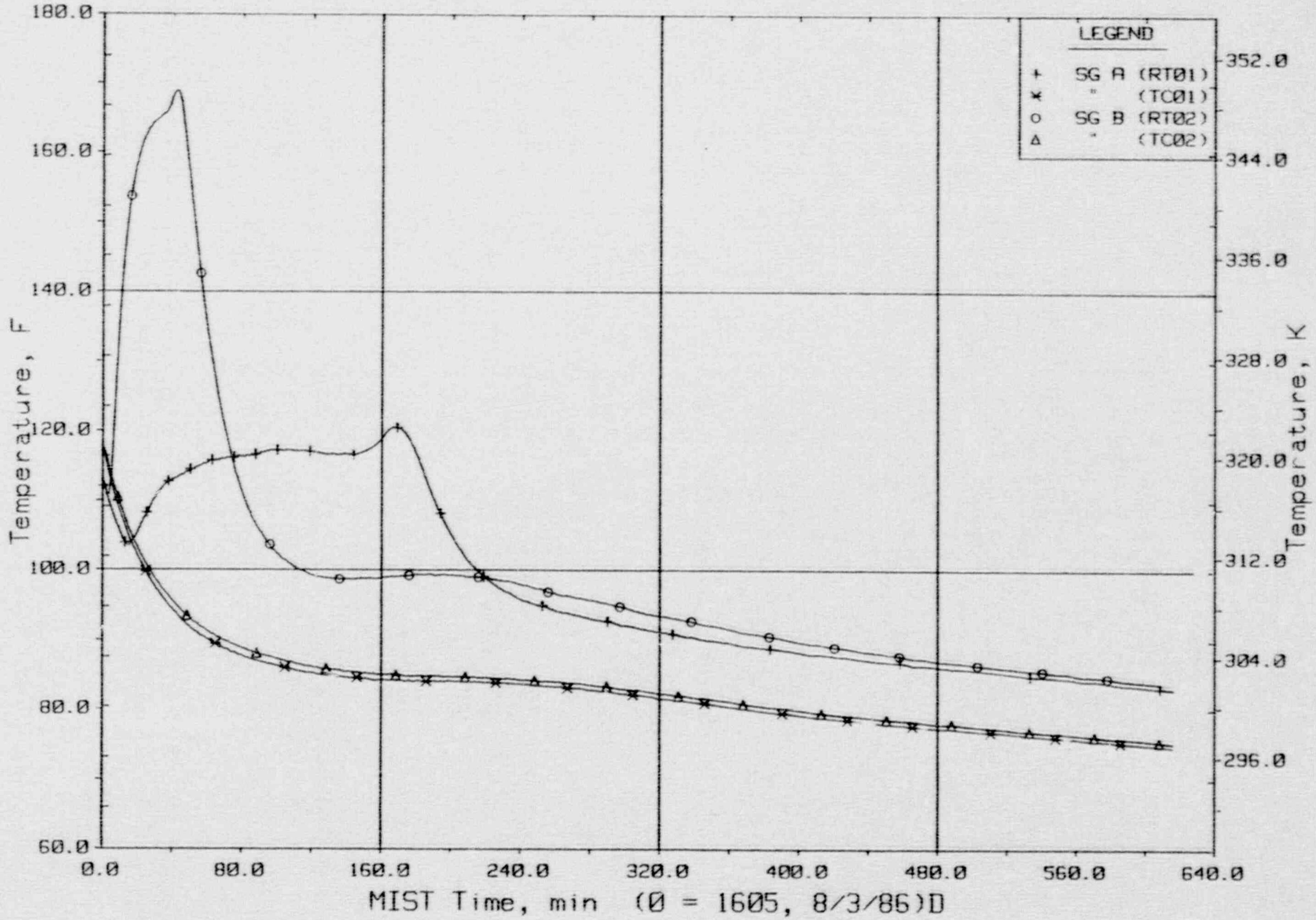
Steam Generator B Energy Transfer.

Tue May 24 15:04:30 1988

SGOE6

FINAL DATA

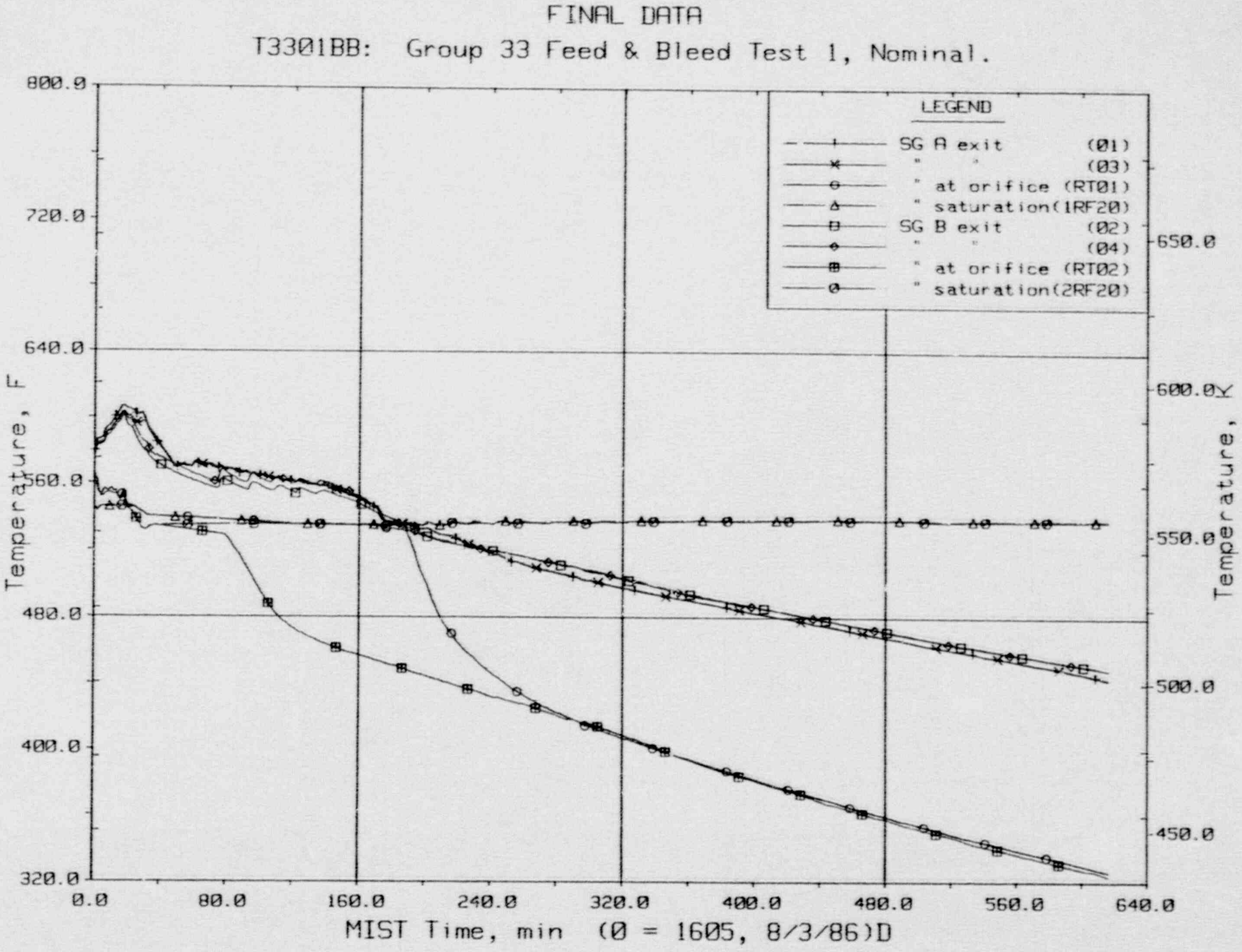
T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



Feedwater Temperatures (SFs).

Tue May 24 15:07:18 1988

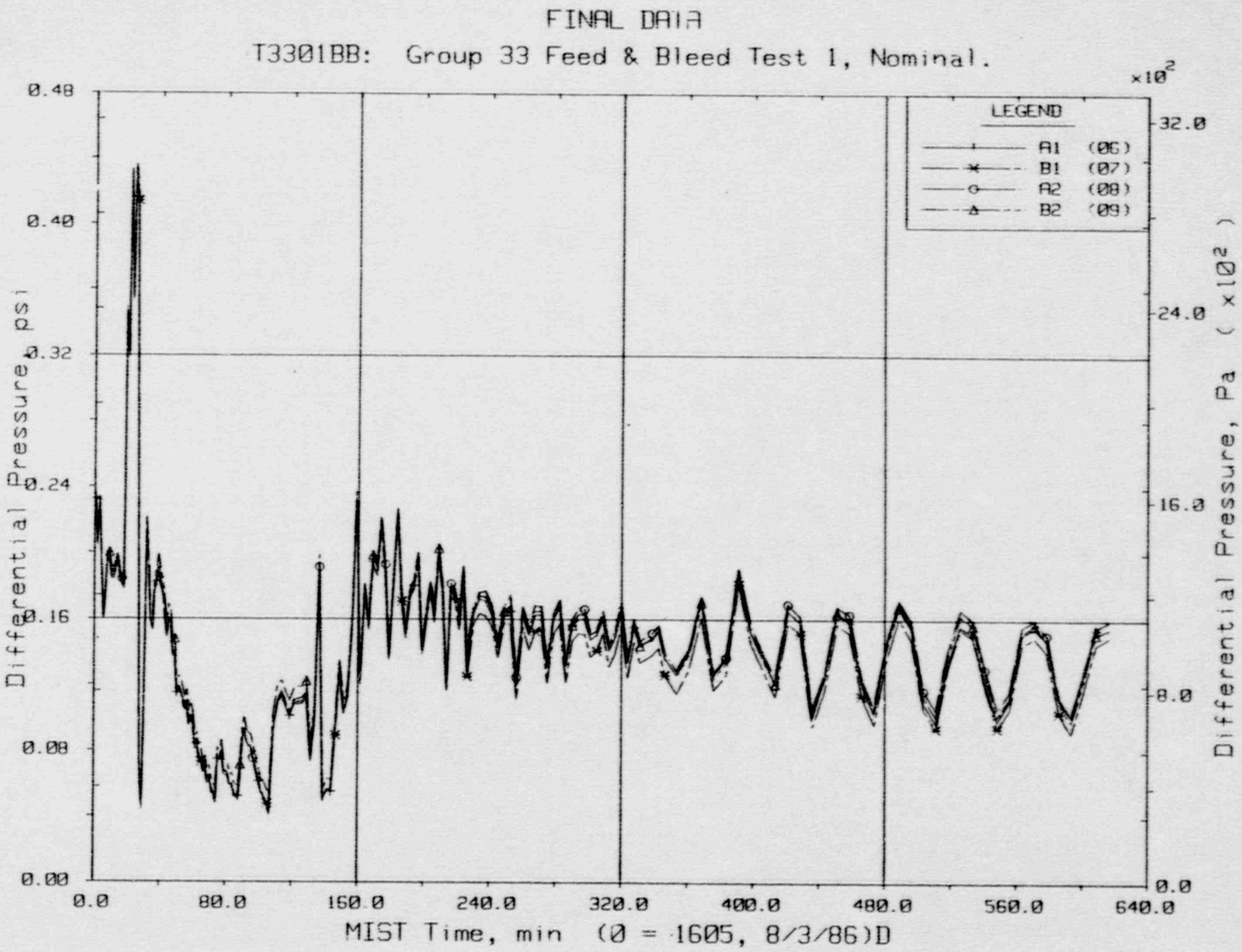
SGRT1



Steam Generator Steam Outlet Temperatures (SSTCs).

Tue May 24 15:10:55 1988

SGRT2



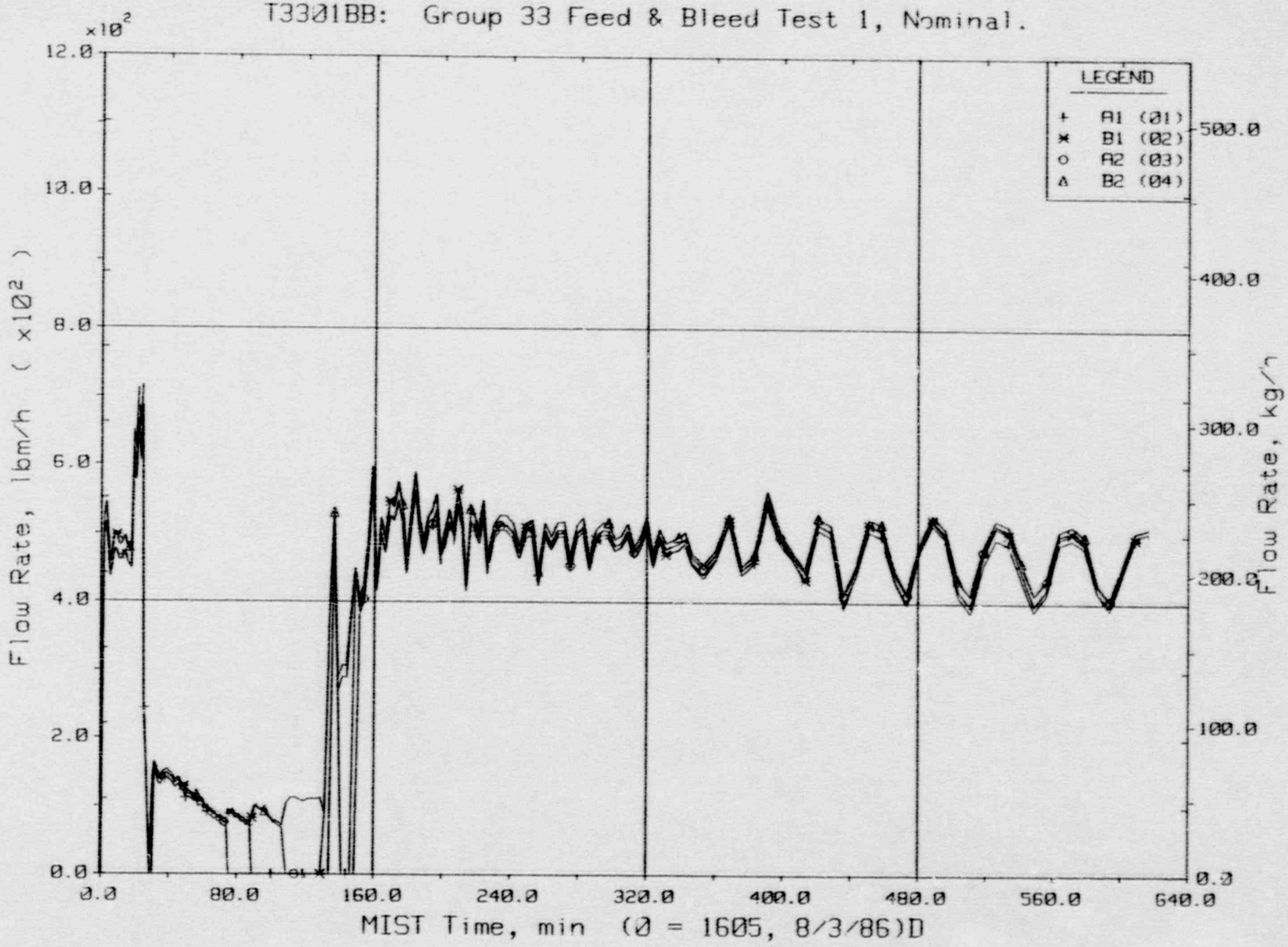
Reactor Vessel Vent Valve Differential Pressures (RVDPs).

Tue May 24 15:15:03 1988

VVDP1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



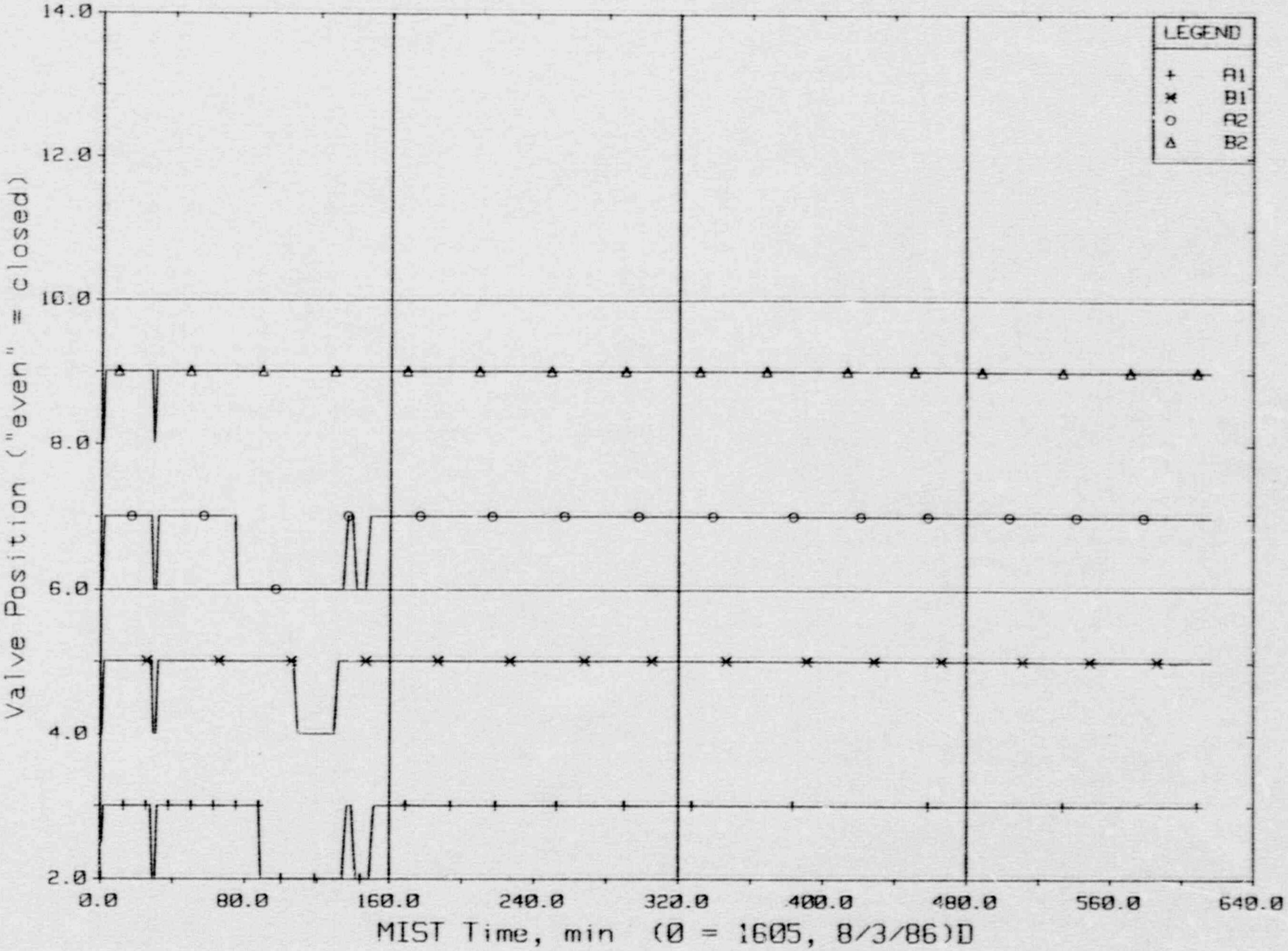
Reactor Vessel Vent Valve Flow Rates (RVORs).

Tue May 24 15:19:08 1988

VVFL1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.



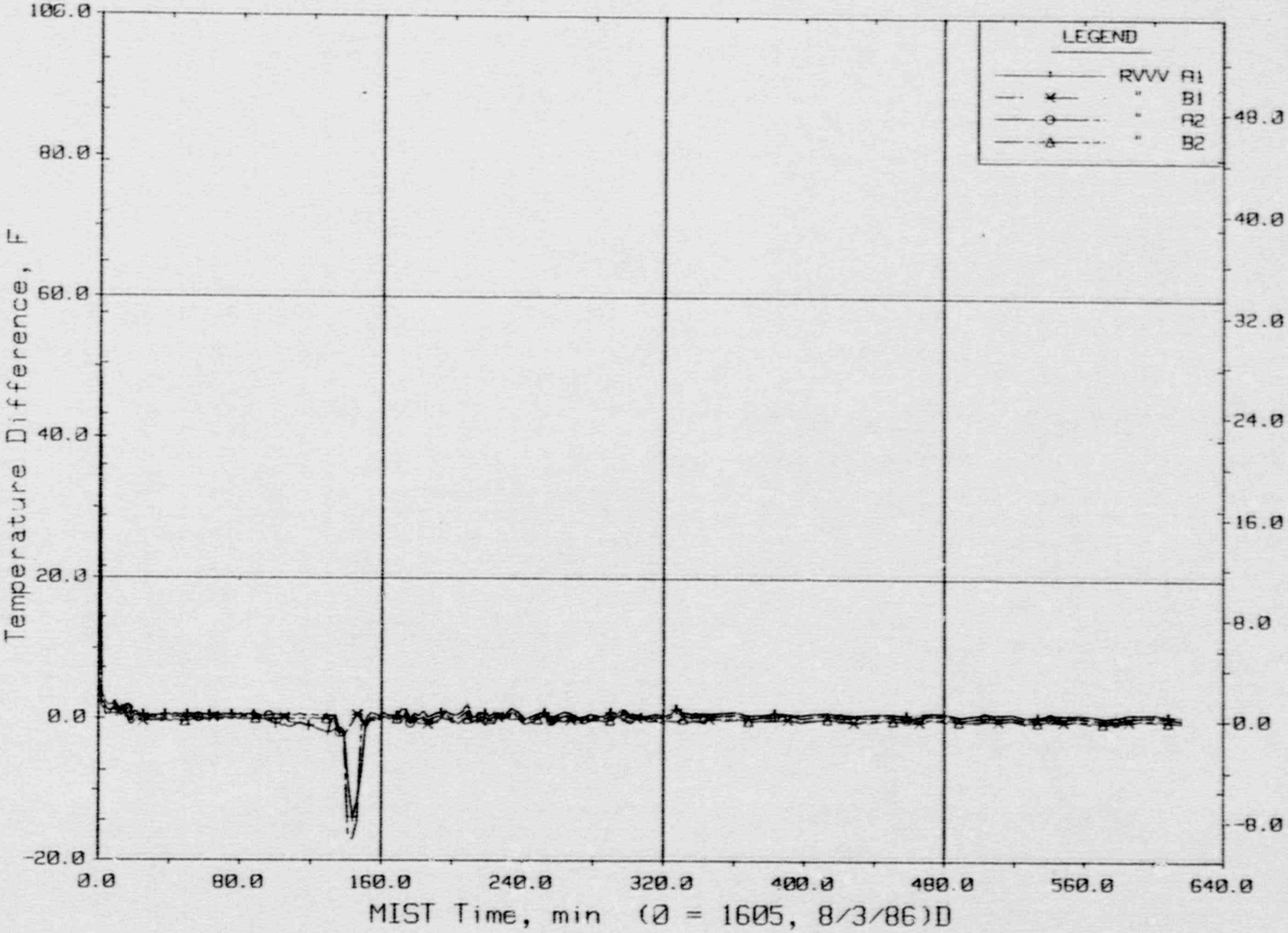
Reactor Vessel Vent Valve Positions.

Tue May 24 15:21:52 1988

VVLS1

FINAL DATA

T3301BB: Group 33 Feed & Bleed Test 1, Nominal.

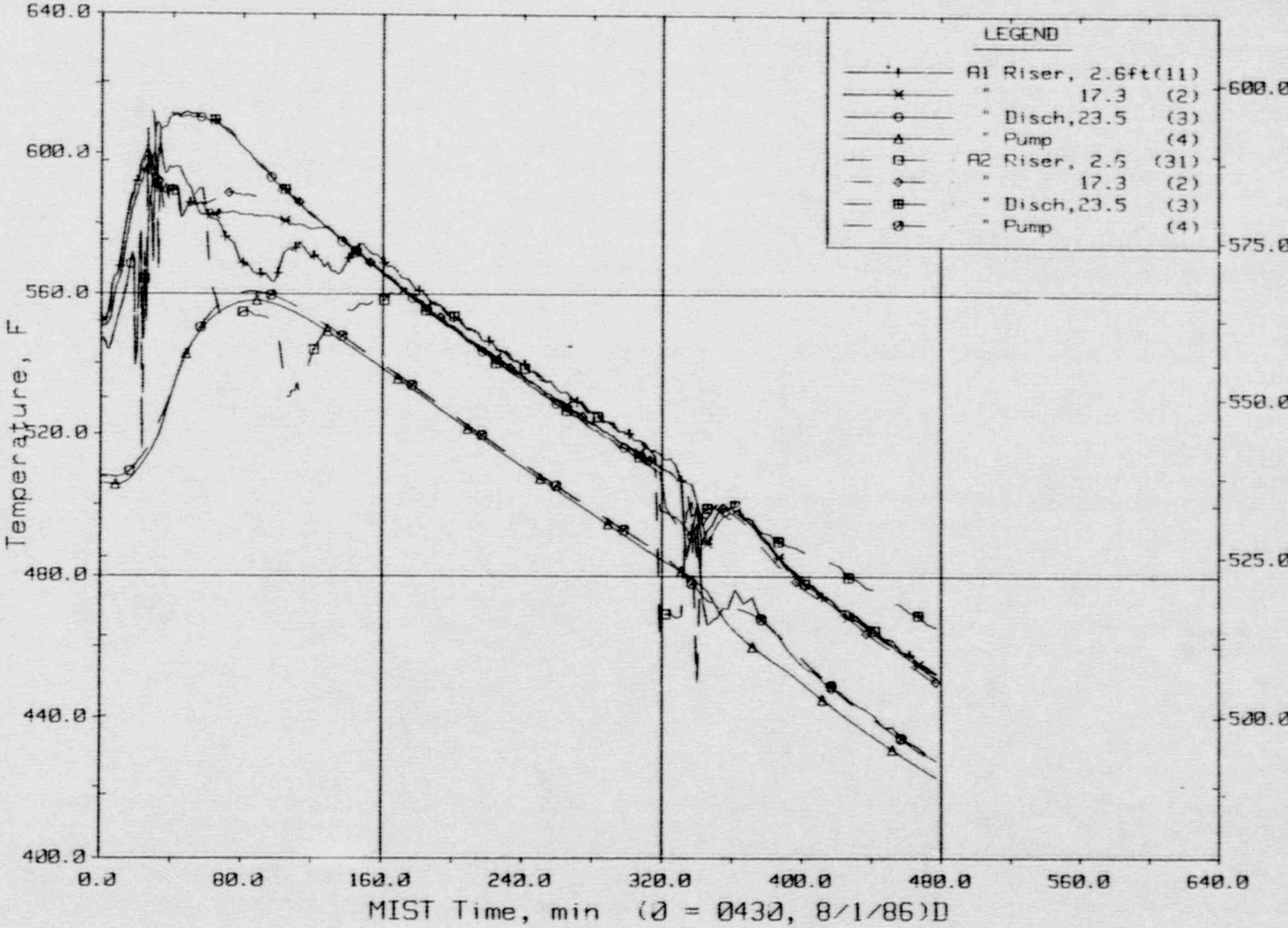


Temperature Differences Across Vent Valves.

T330201

FINAL DATA

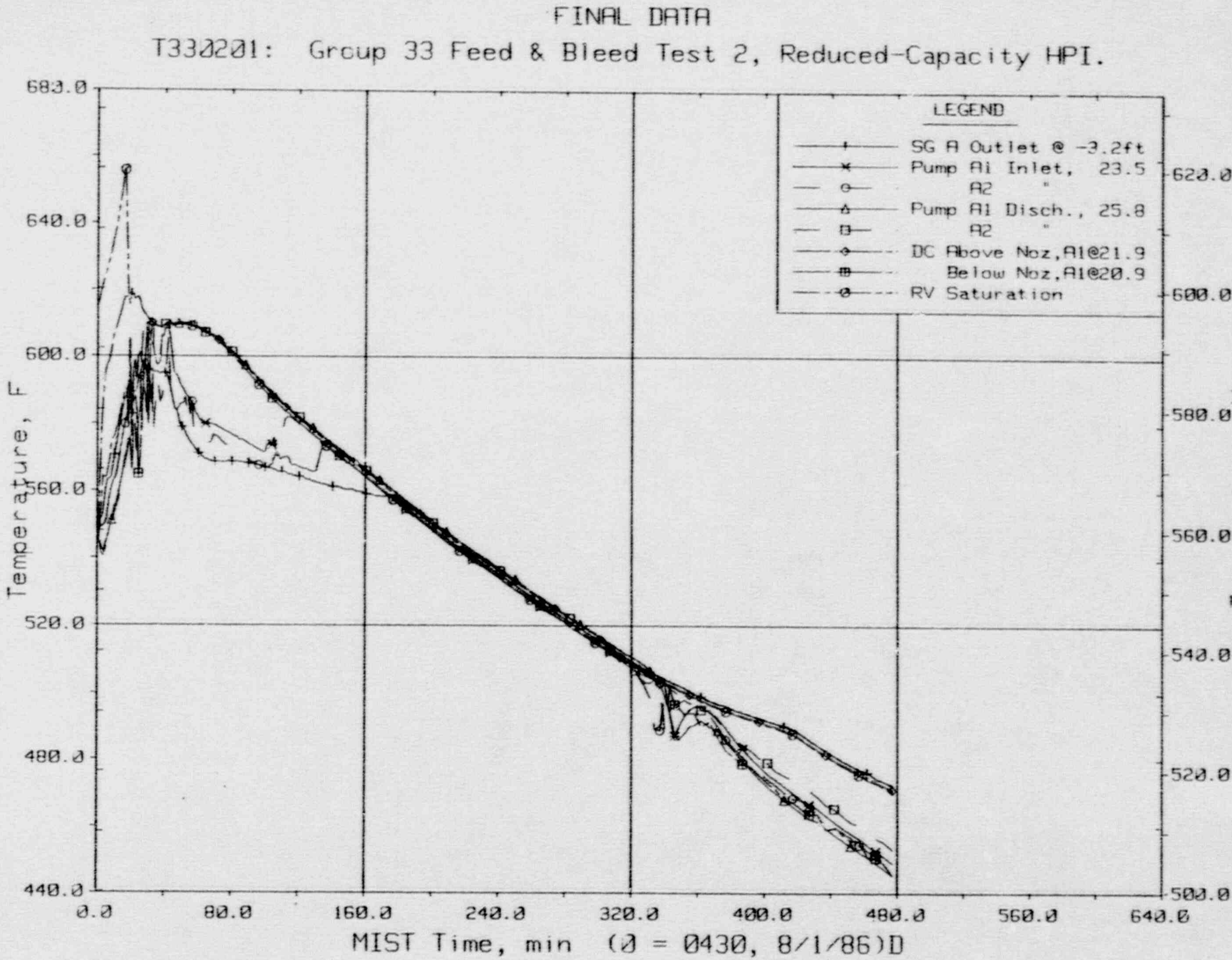
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Loop A Cold Leg Metal Temperatures (C1,3MTs).

Tue May 24 14:52:33 1988

C1MT1



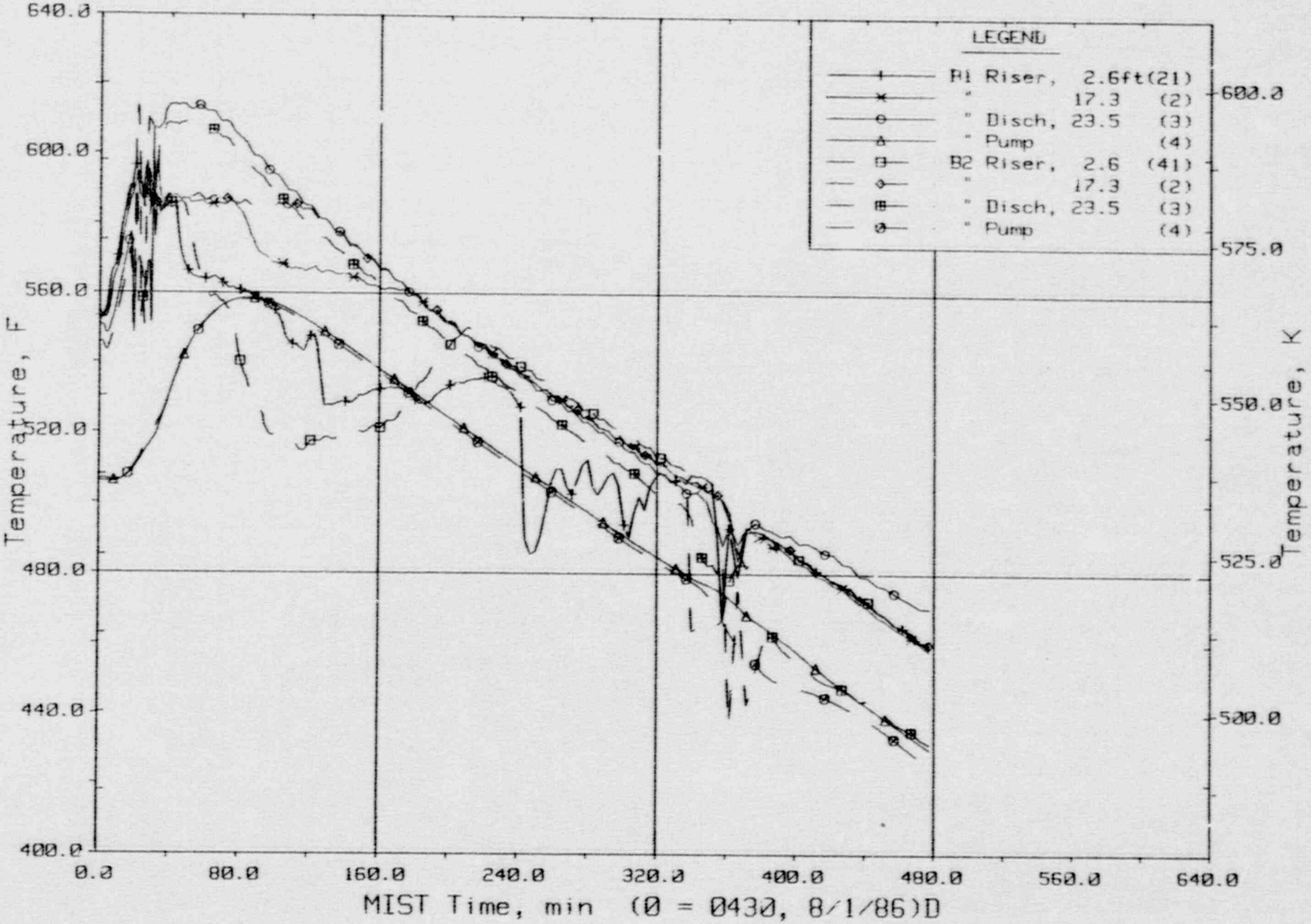
Loop A Cold Leg Fluid Temperatures (RTDs).

Tue May 24 14:59:18 1988

C1RT0

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



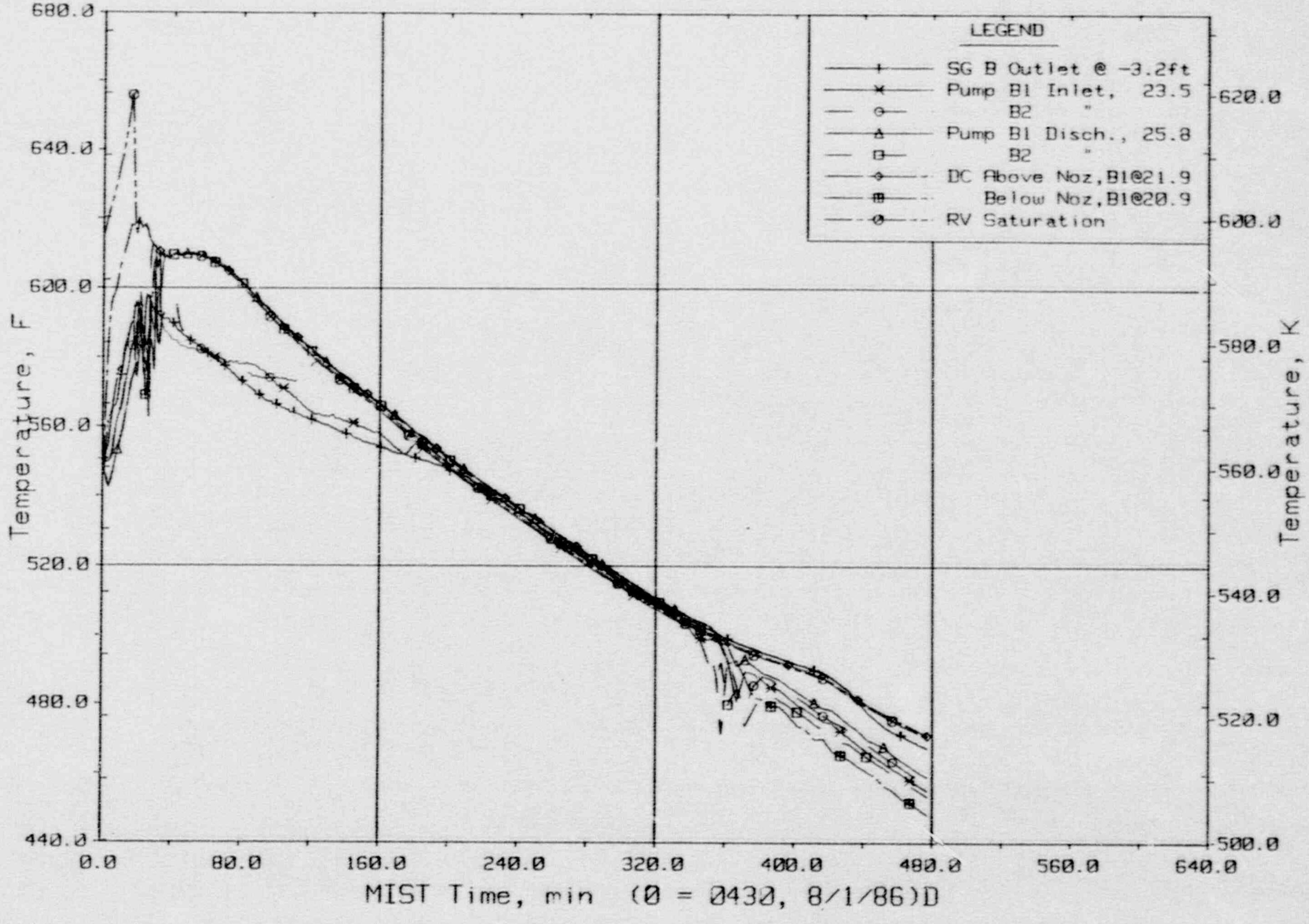
Loop B Cold Leg Metal Temperatures (C2,4MTs).

Tue May 24 15:03:40 1988

C2MT1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



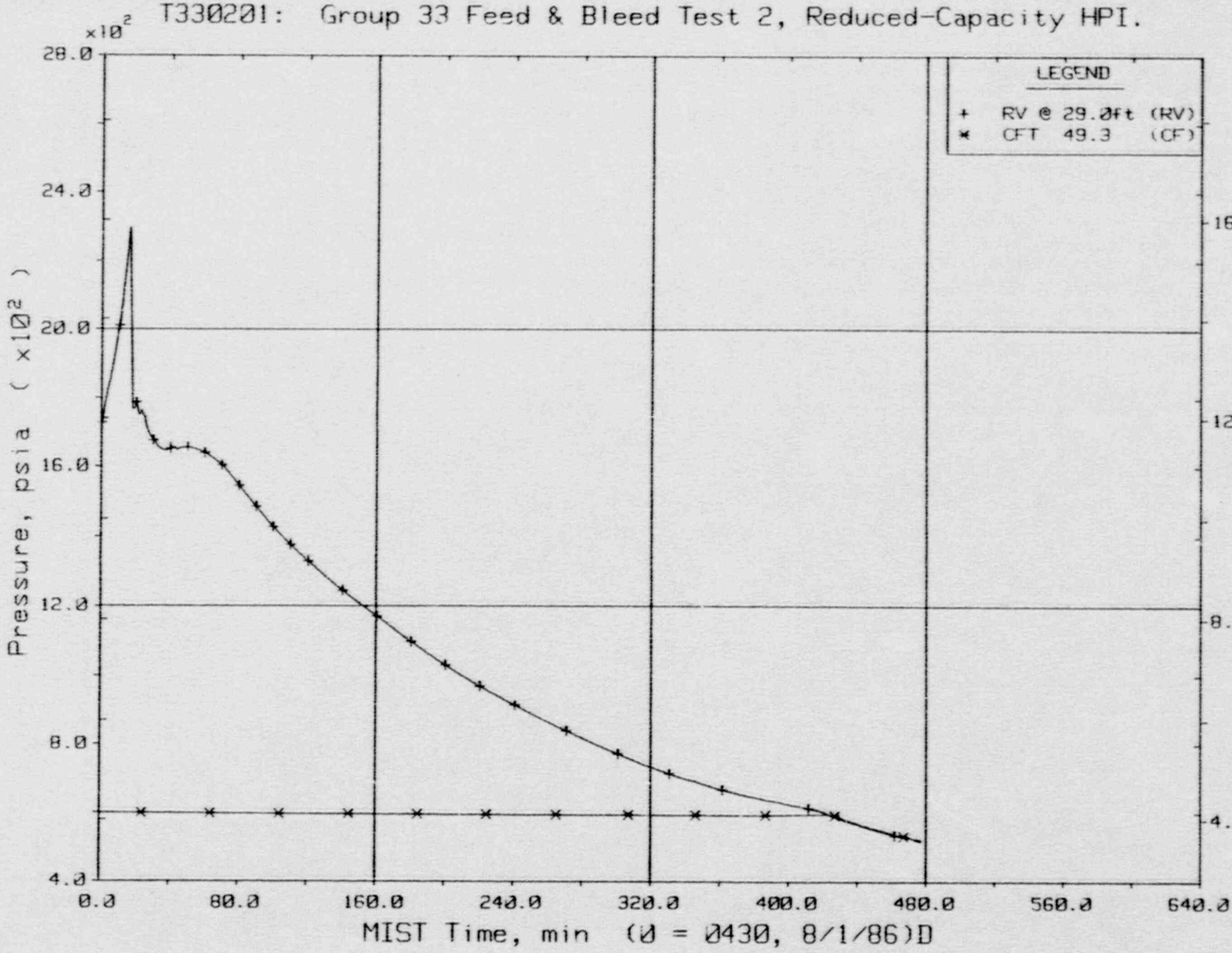
Loop B Cold Leg Fluid Temperatures (RTDs).

Tue May 24 15:07:33 1988

C2RT0

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



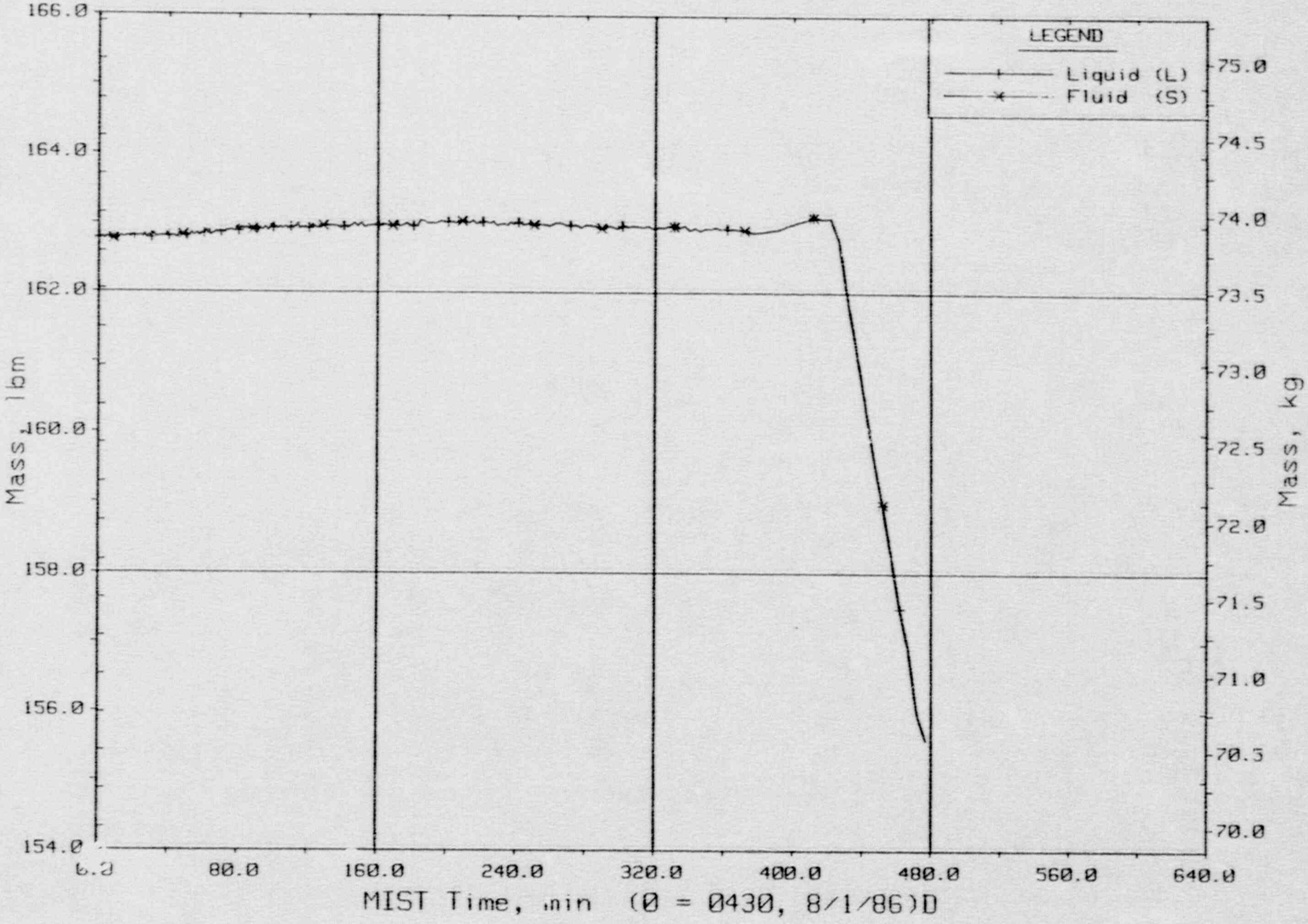
Primary System and Core Flood Tank Pressures (GP01s).

Tue May 24 15:10:20 1988

CFGP1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



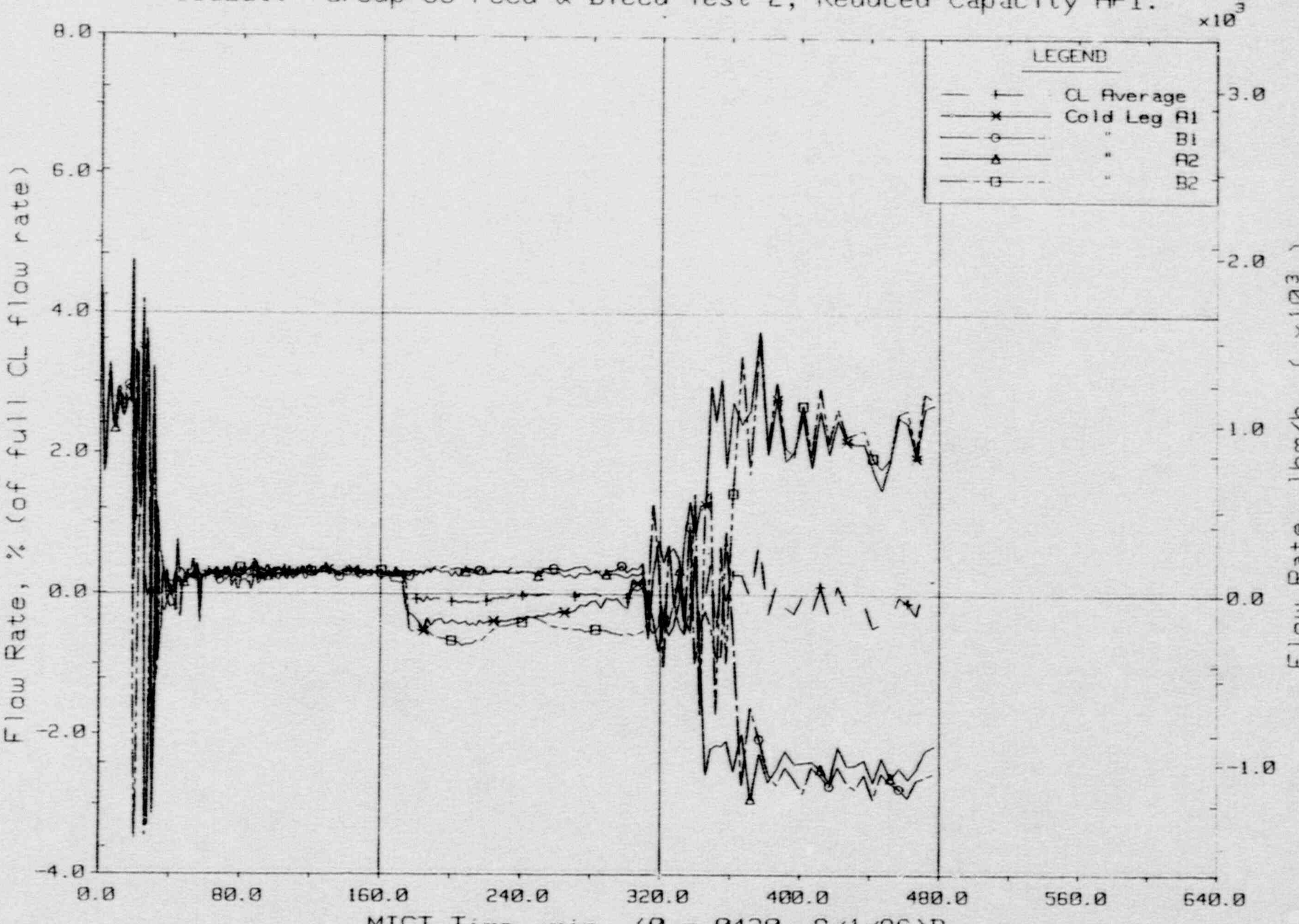
Core Flood Tank Liquid and Fluid Mass (CFMa20s).

Tue May 24 15:13:03 1988

CFML1

FINAL DATA

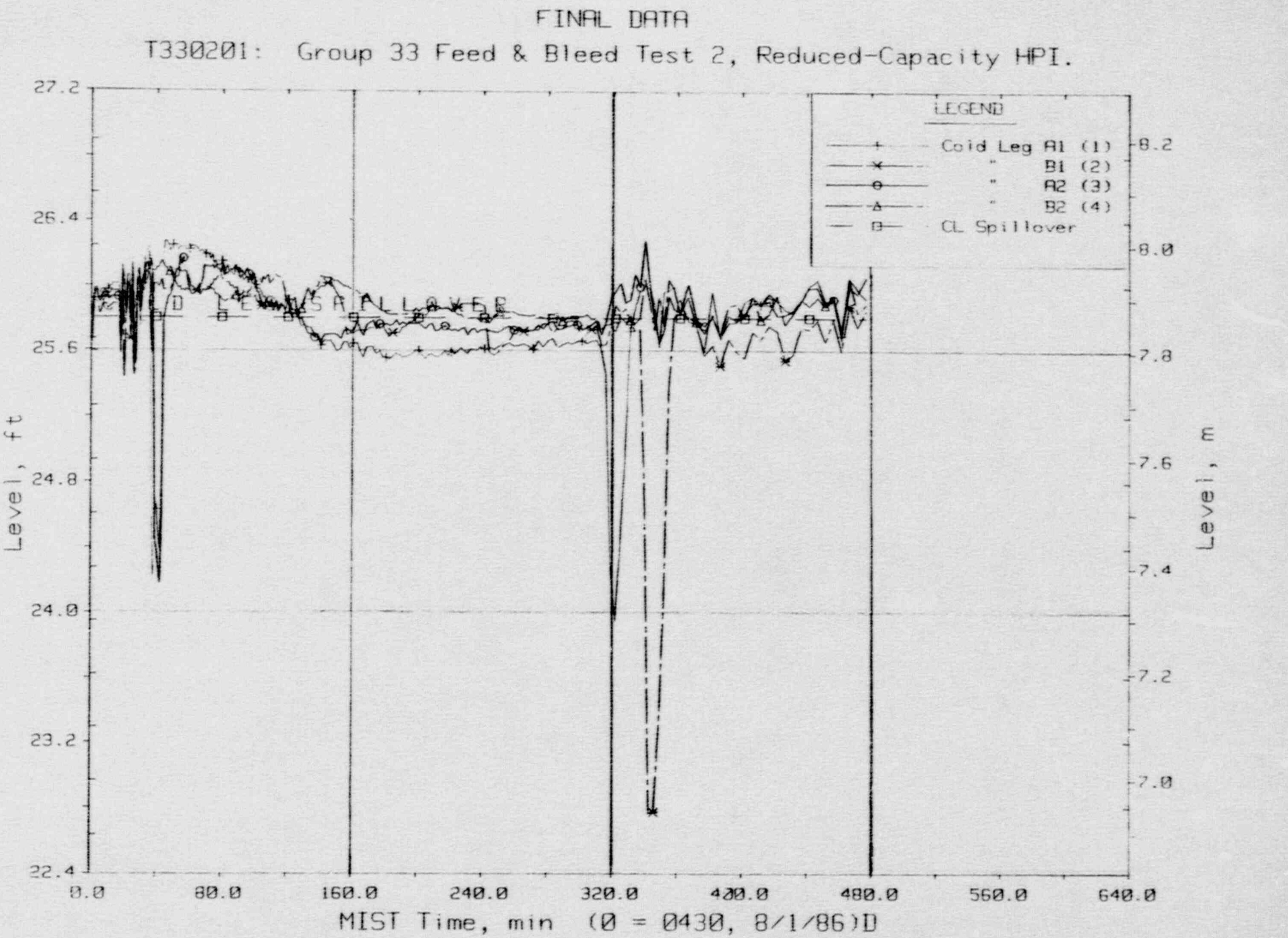
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Cold Leg (Venturi) Flow Rates.

Tue May 24 15:17:17 1988

CLFL1



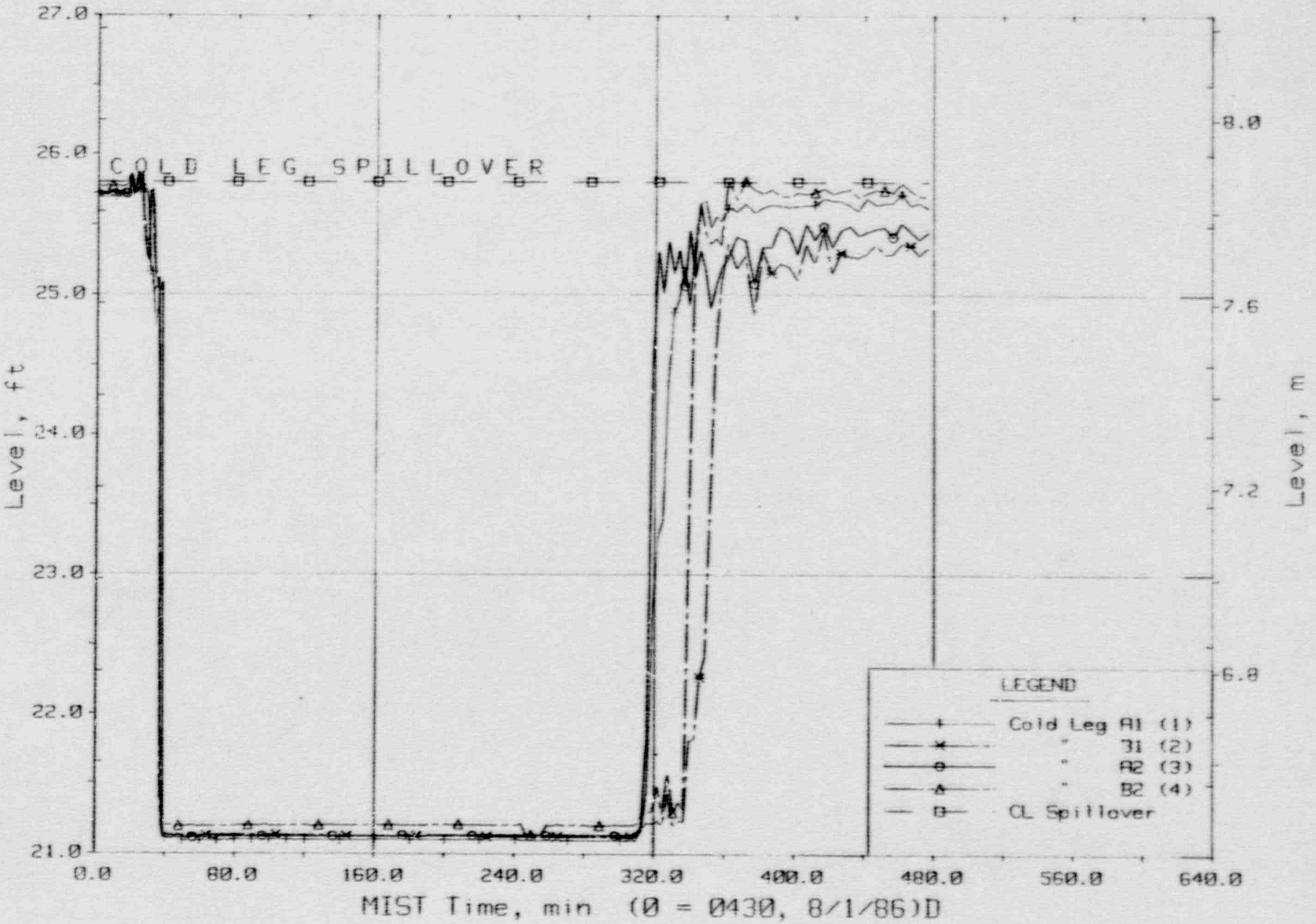
Cold Leg Suction Collapsed Liquid Levels (CnLV22s).

Tue May 24 15:20:53 1988

CLLV4

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



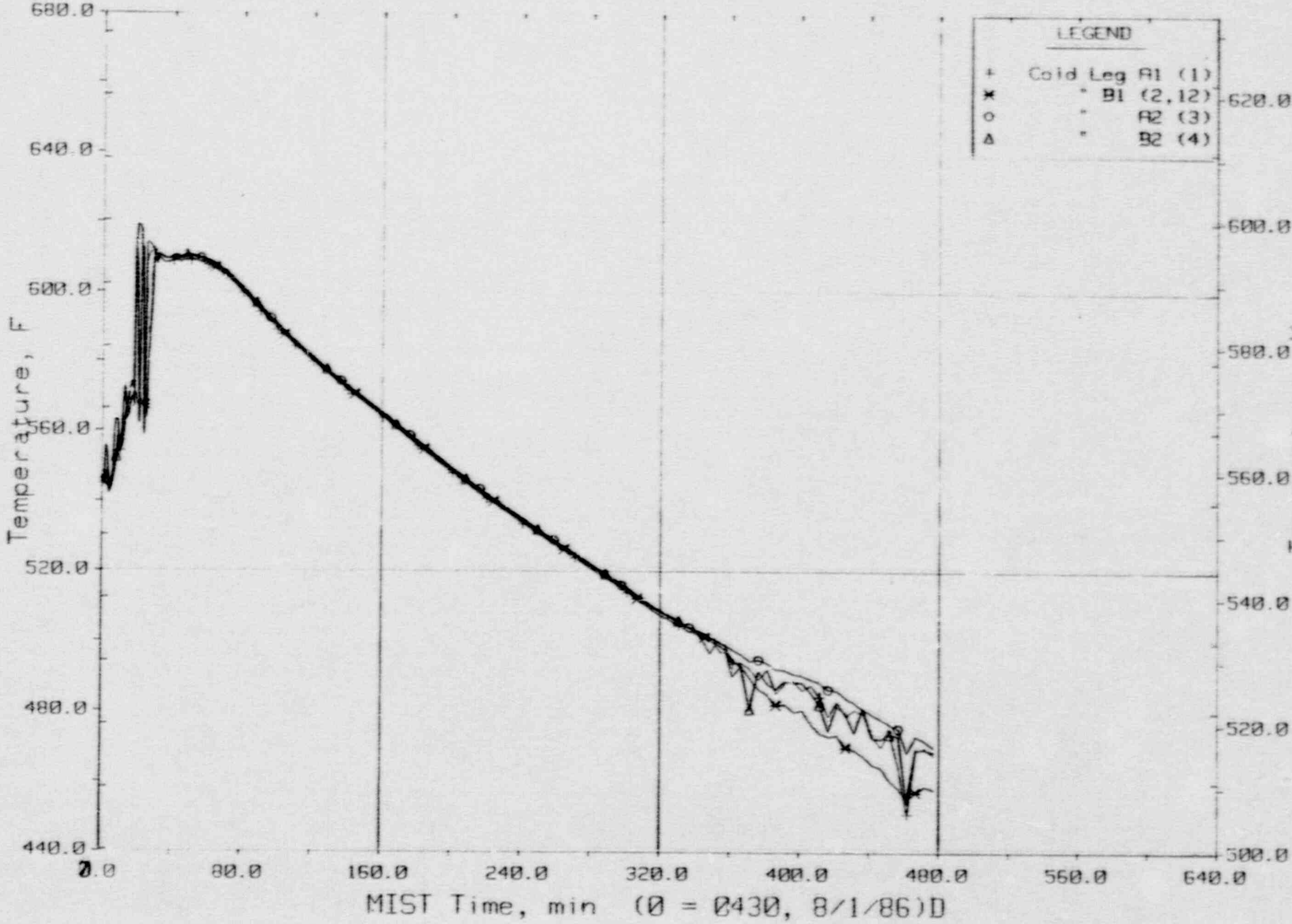
Cold Leg Discharge Collapsed Liquid Levels (CnLV23s).

Tue May 24 15:24:27 1983

CLLV5

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



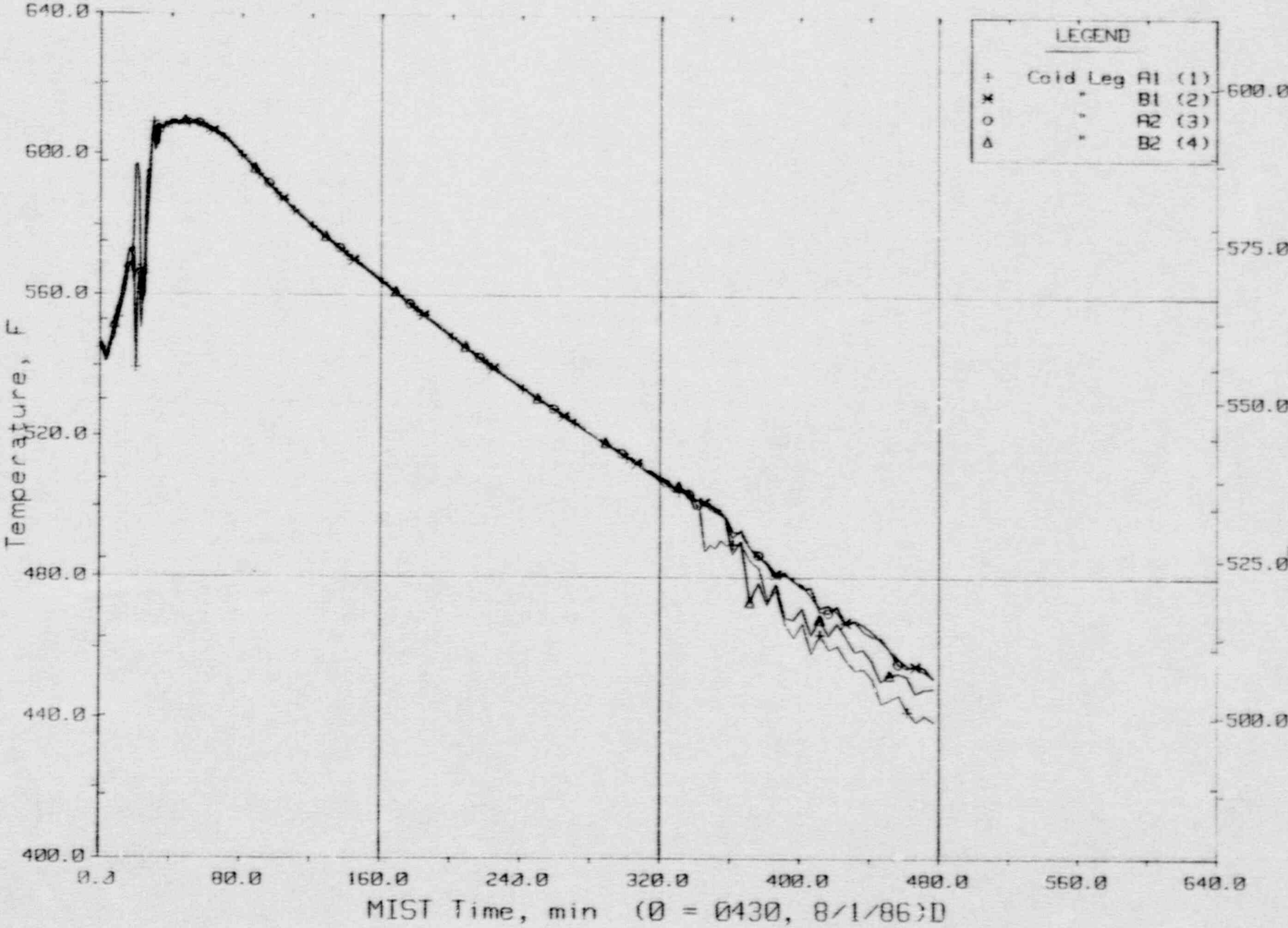
Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3ft, CnTC1ls).

Tue May 24 15:29:15 1988

CLTC1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



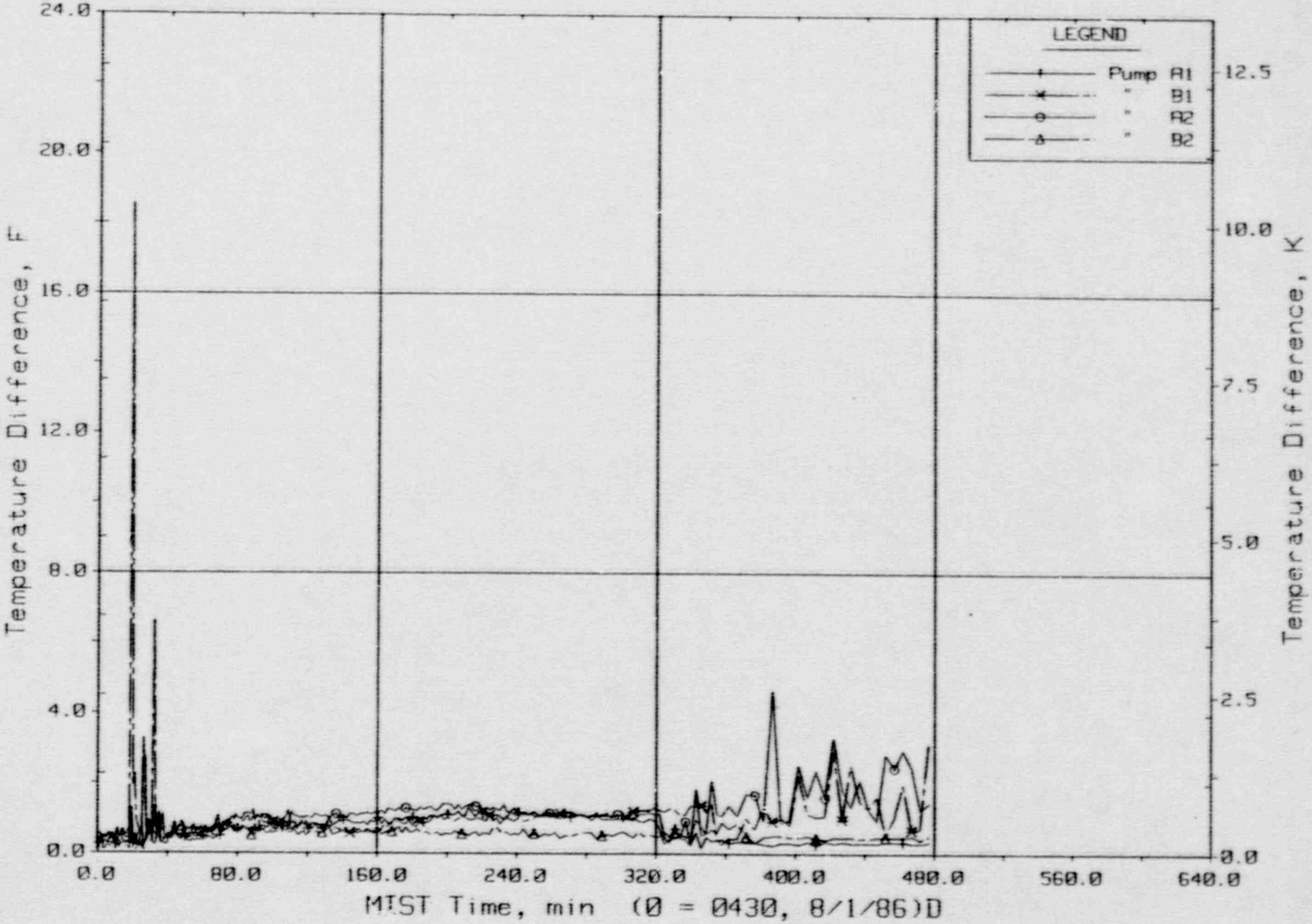
Cold Leg Nozzle Fluid Temperatures, Bottom of Rake (21.2ft, CnTC14s).

Tue May 24 15:31:36 1988

CLTC2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



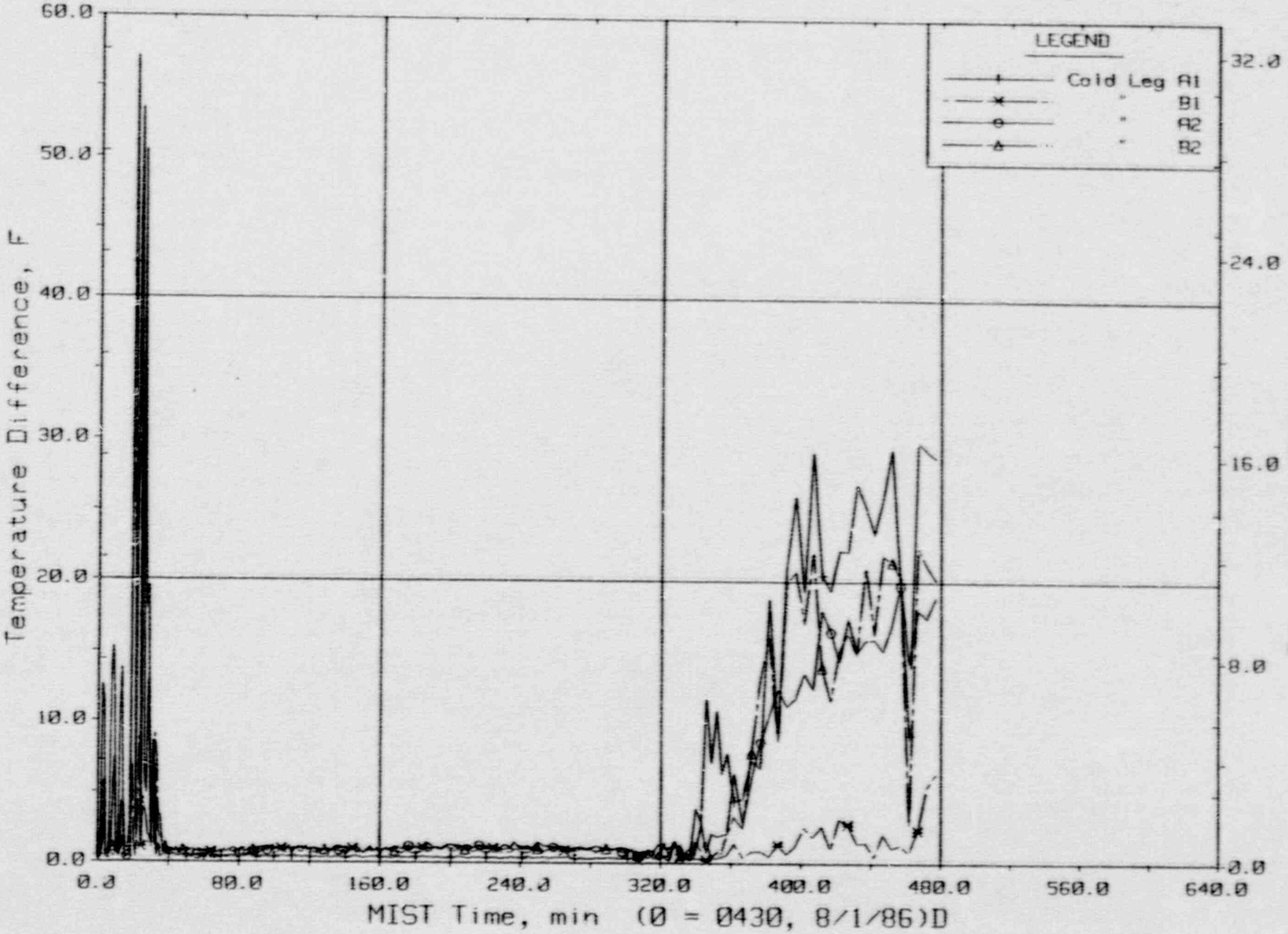
Maximum Differences Among RCP Rake Fluid Temperatures.

Tue May 24 15:35:21 1988

CLTD1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



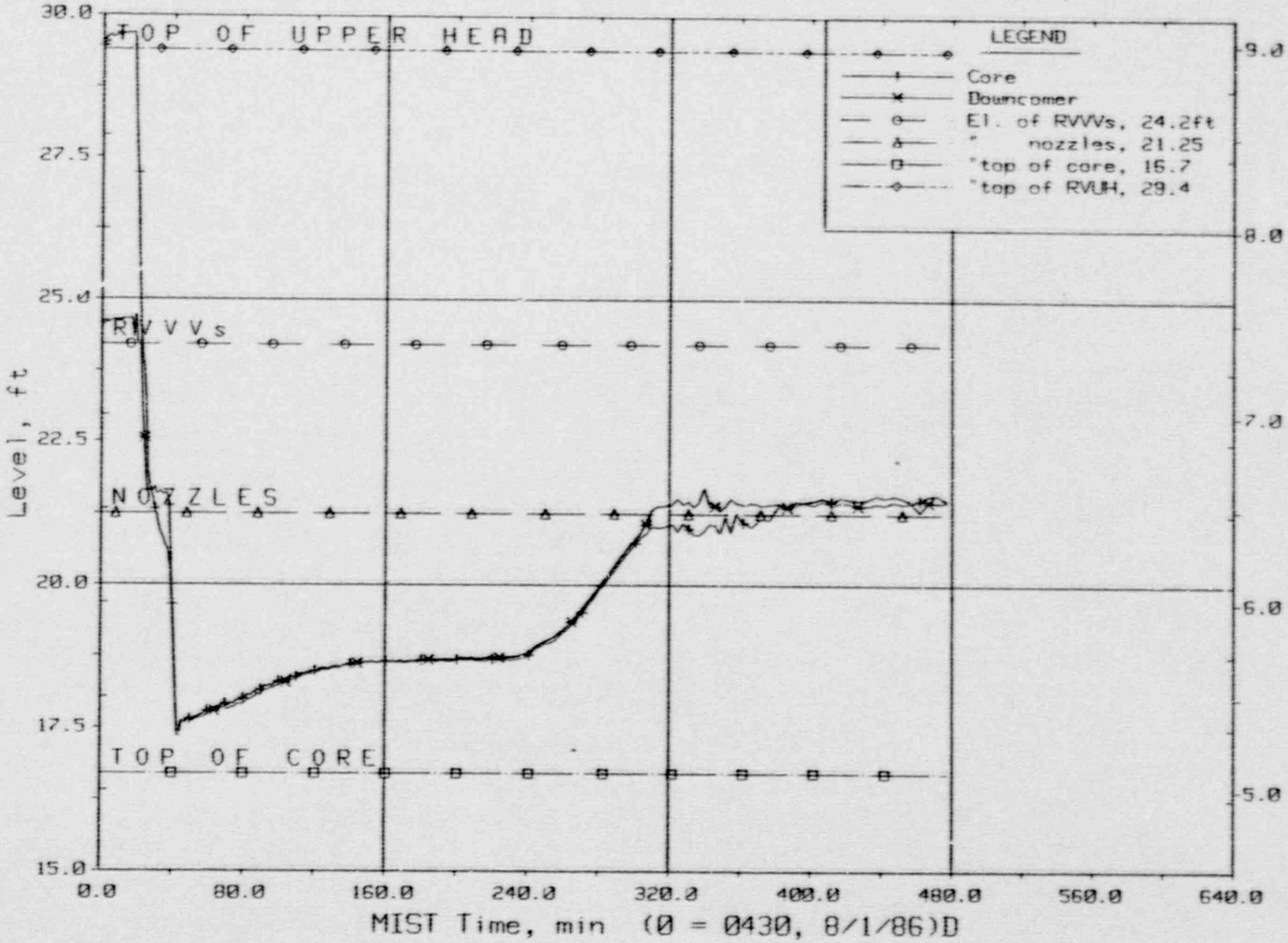
Maximum Differences Among CL Nozzle Rake Fluid Temperatures.

Tue May 24 15:38:02 1988

CLTD2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



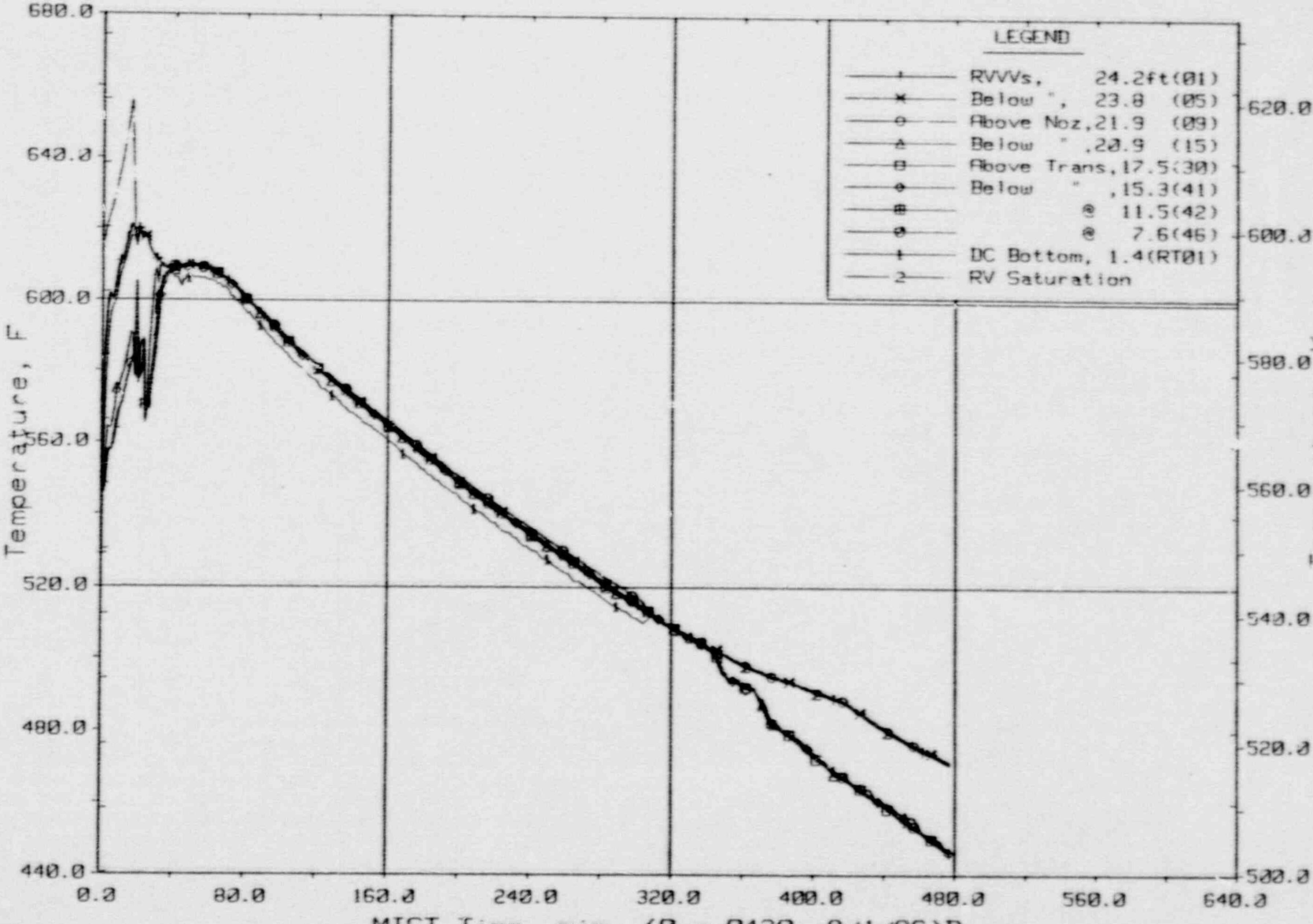
Core Region Collapsed Liquid Levels.

Tue May 24 15:42:06 1988

COLV1

FINAL DATA

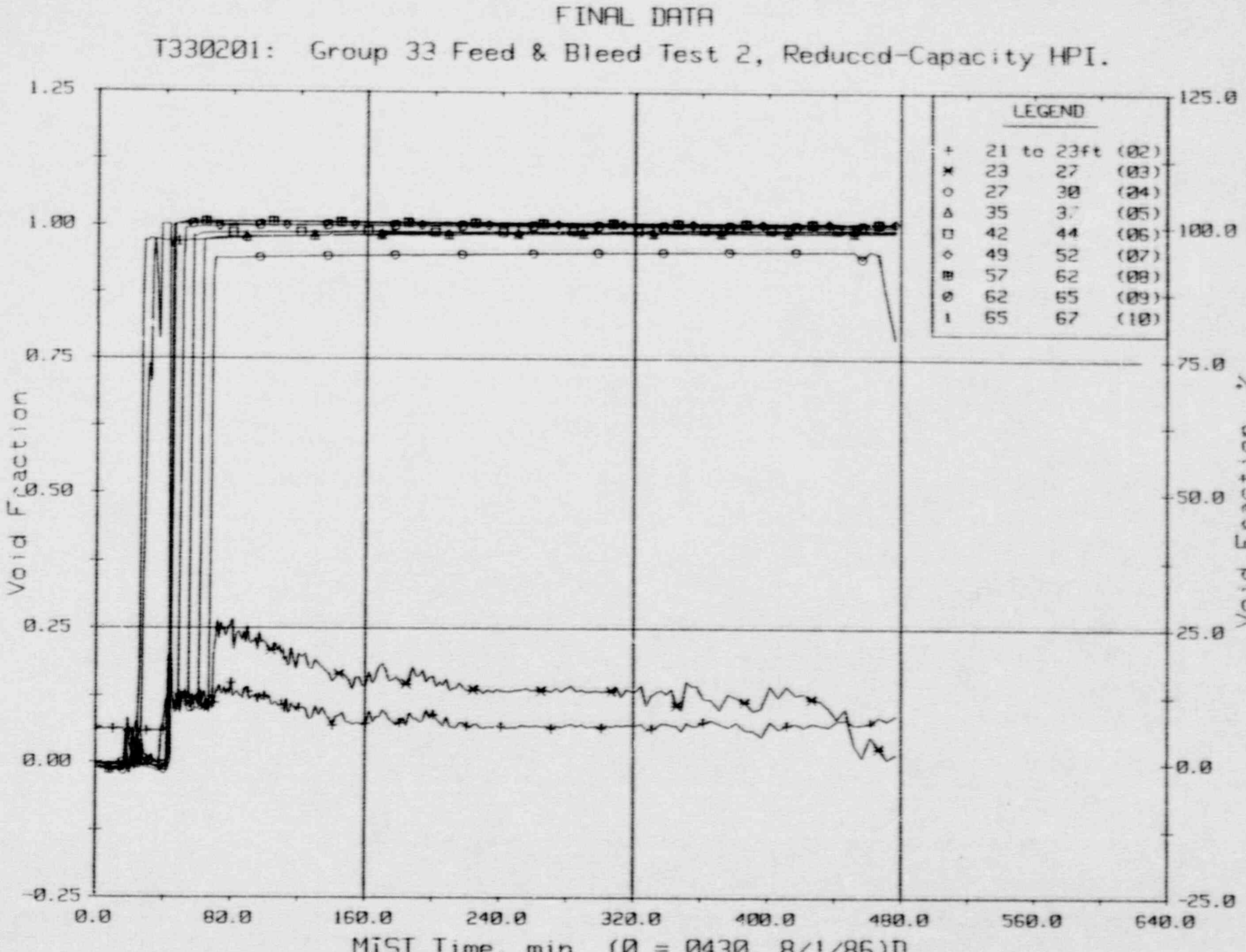
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Downcomer Quadrant A1 Fluid Temperatures (DCTCs).

Tue May 24 15:53:55 1988

DCTC6



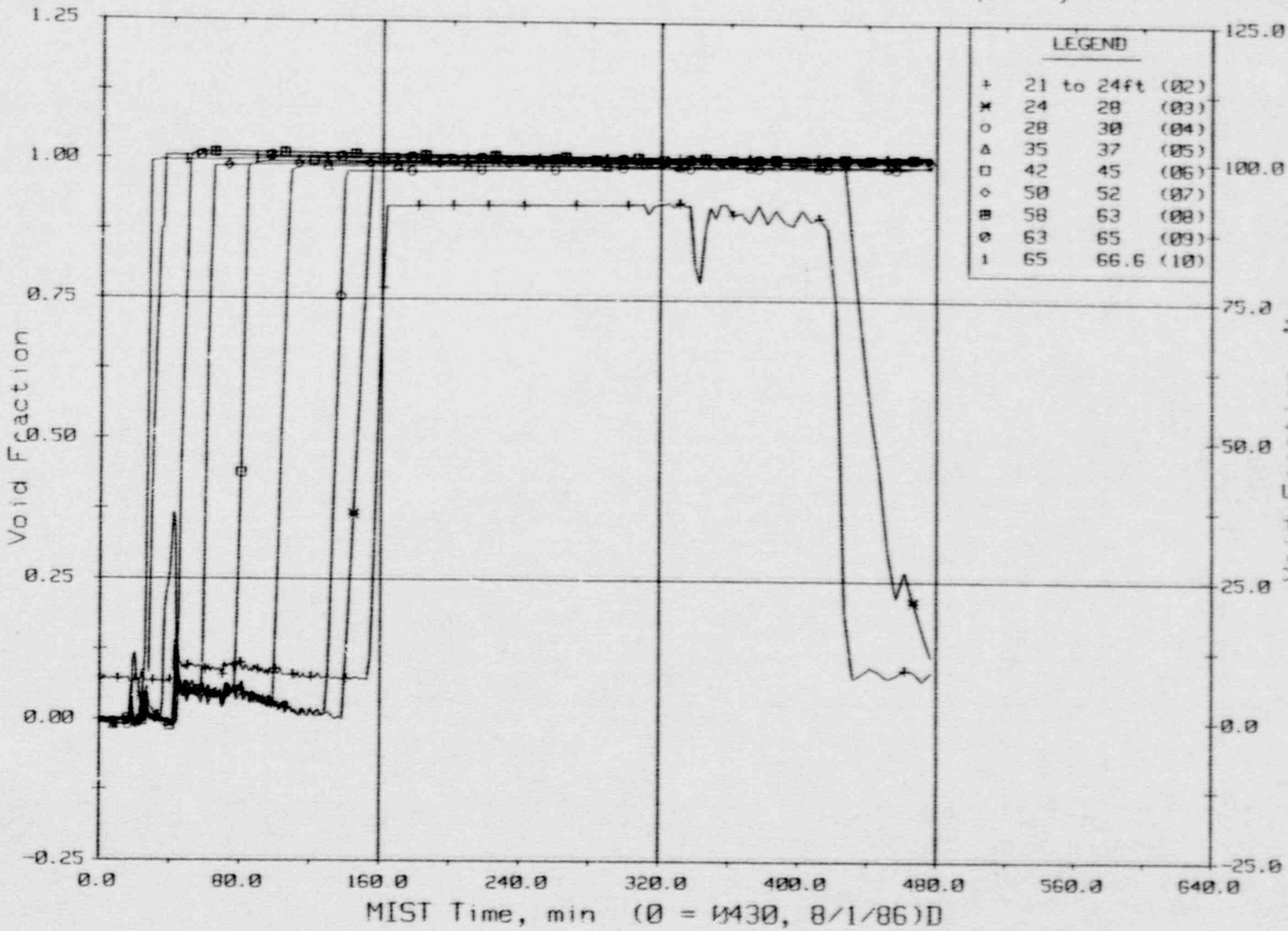
Hot Leg A Riser Void Fractions From Differential Pressures (HIVFs).

Tue May 24 16:05:10 1988

H1VF1

FINAL DATA

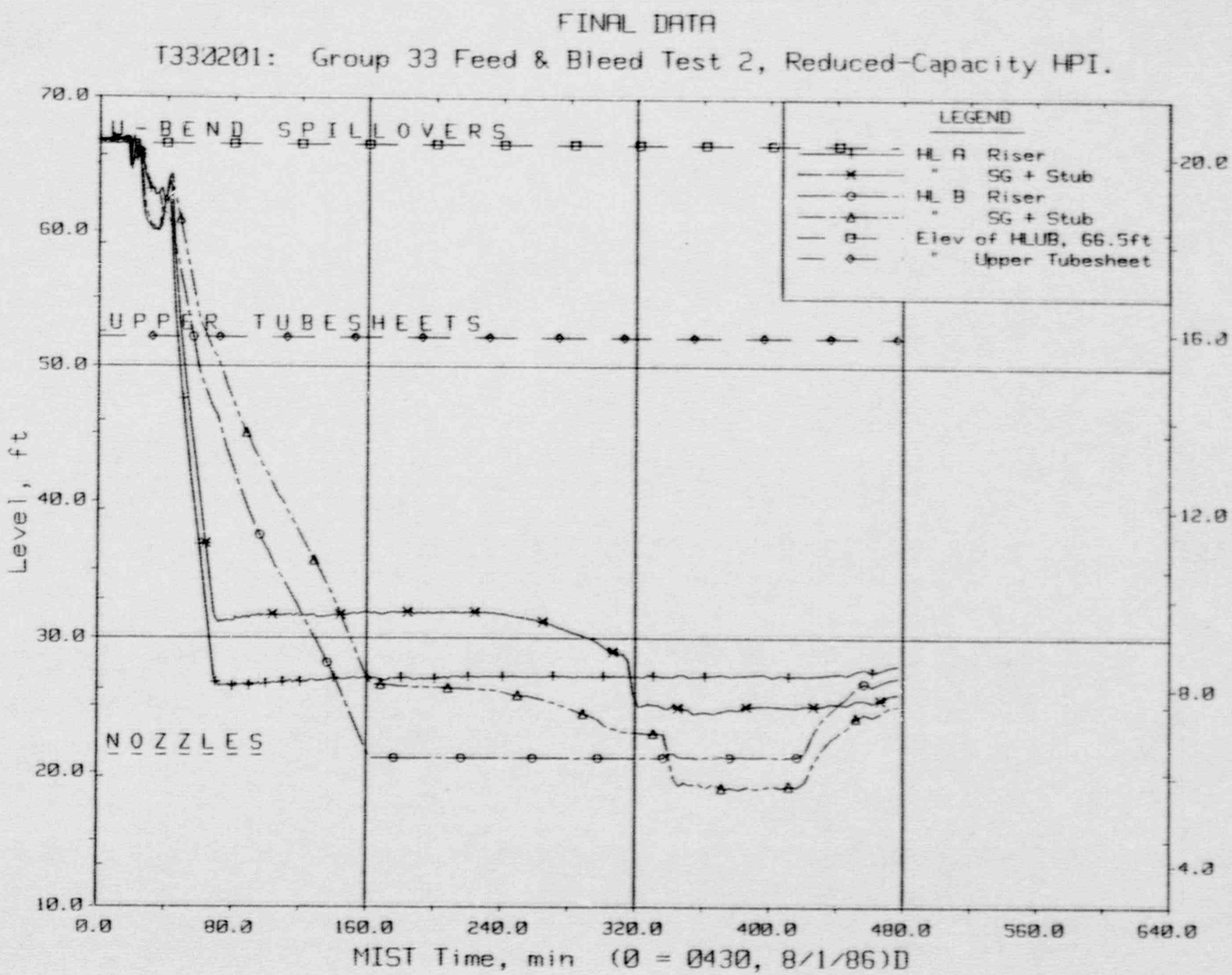
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Hot Leg B Riser Void Fraction From Differential Pressures (H2VFs).

Tue May 24 16:10:43 1988

H2VF1



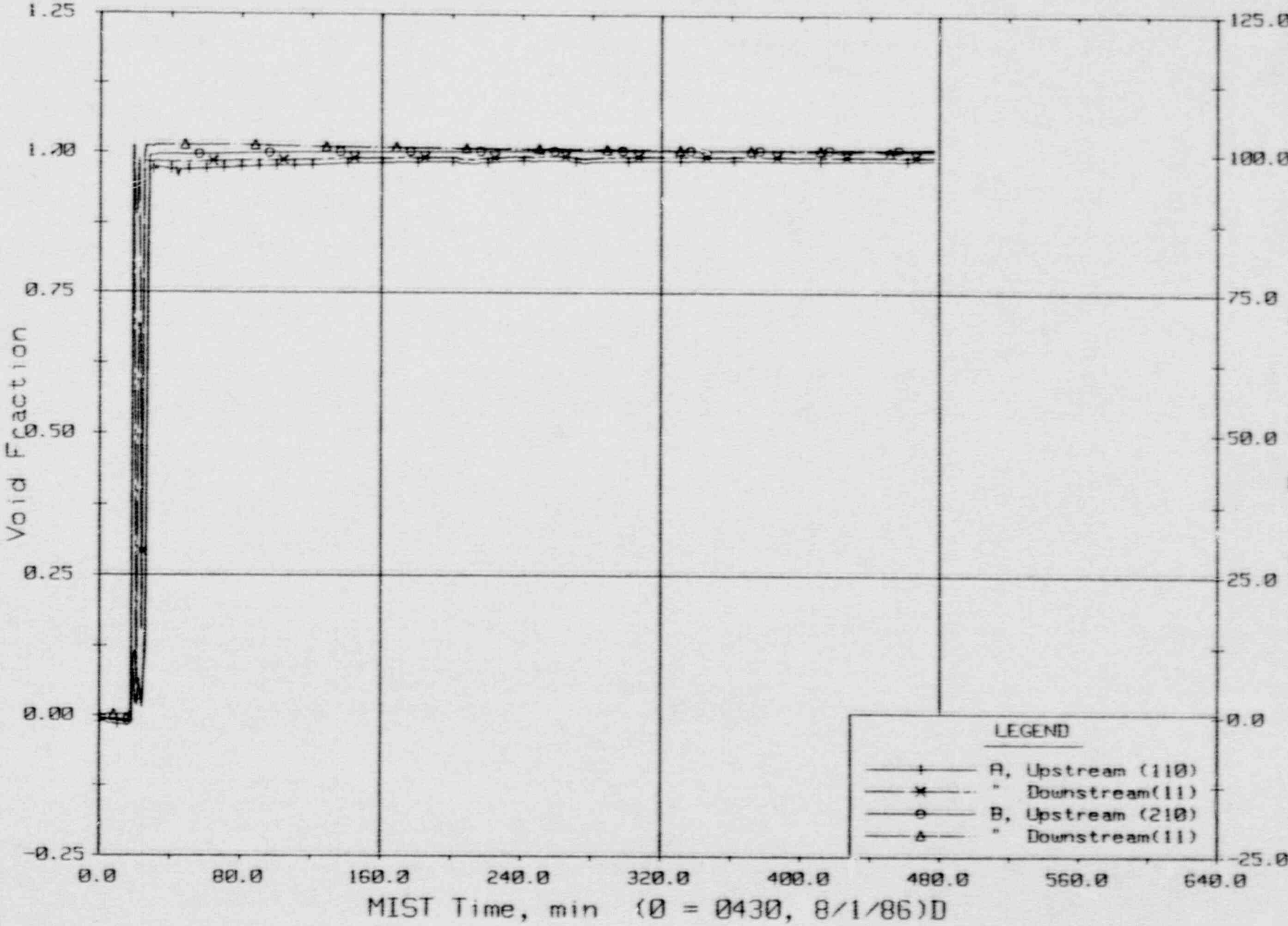
Hot Leg Riser and Stub Collapsed Liquid Levels.

Tue May 24 16:14:35 1988

HLLV1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



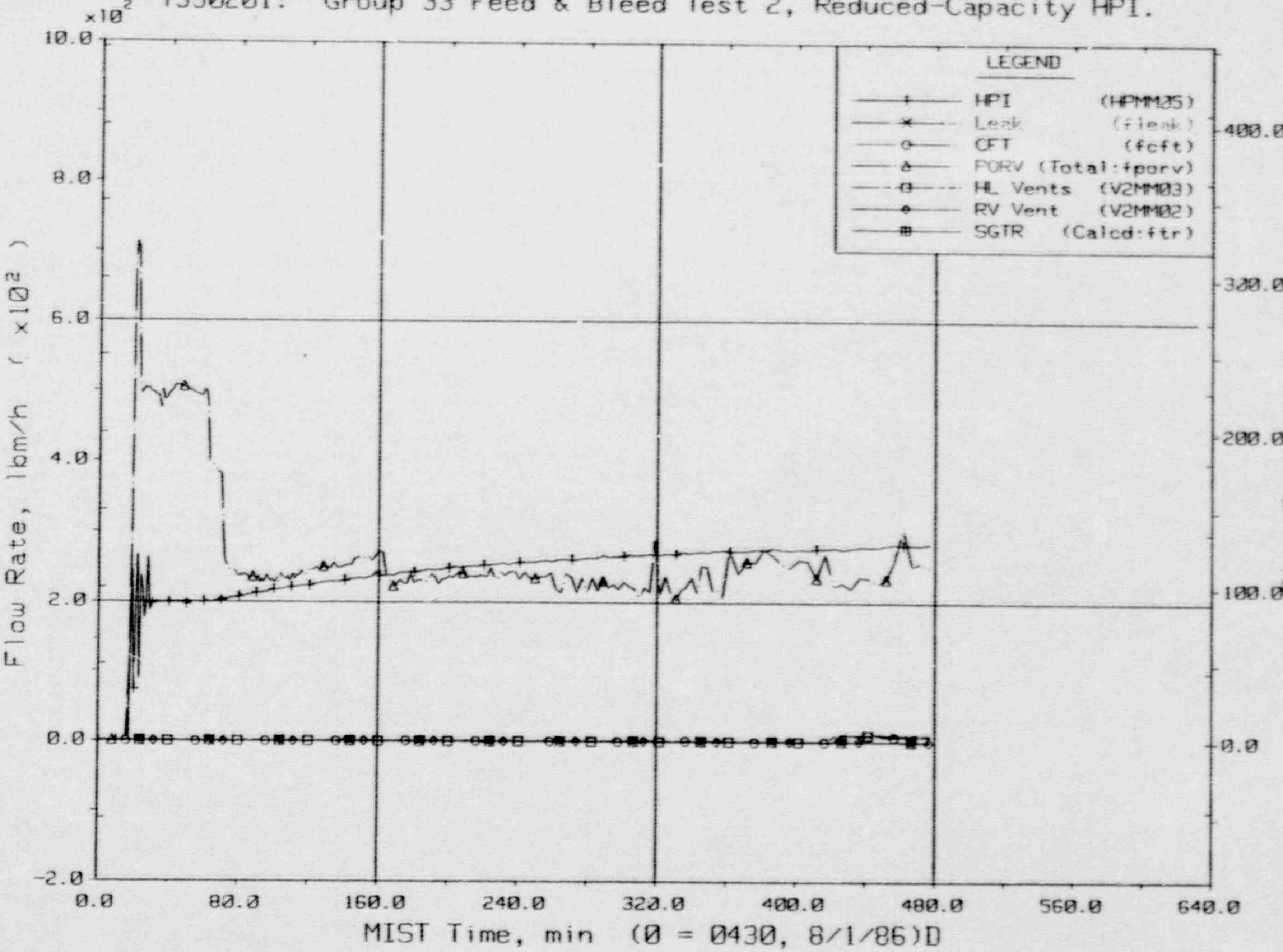
Hot Leg U-Bend Void Fractions From Diffl. Pressures (64.8 to 66.6 ft, HnVFs).

Tue May 24 16:10:04 1988

HLVF1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



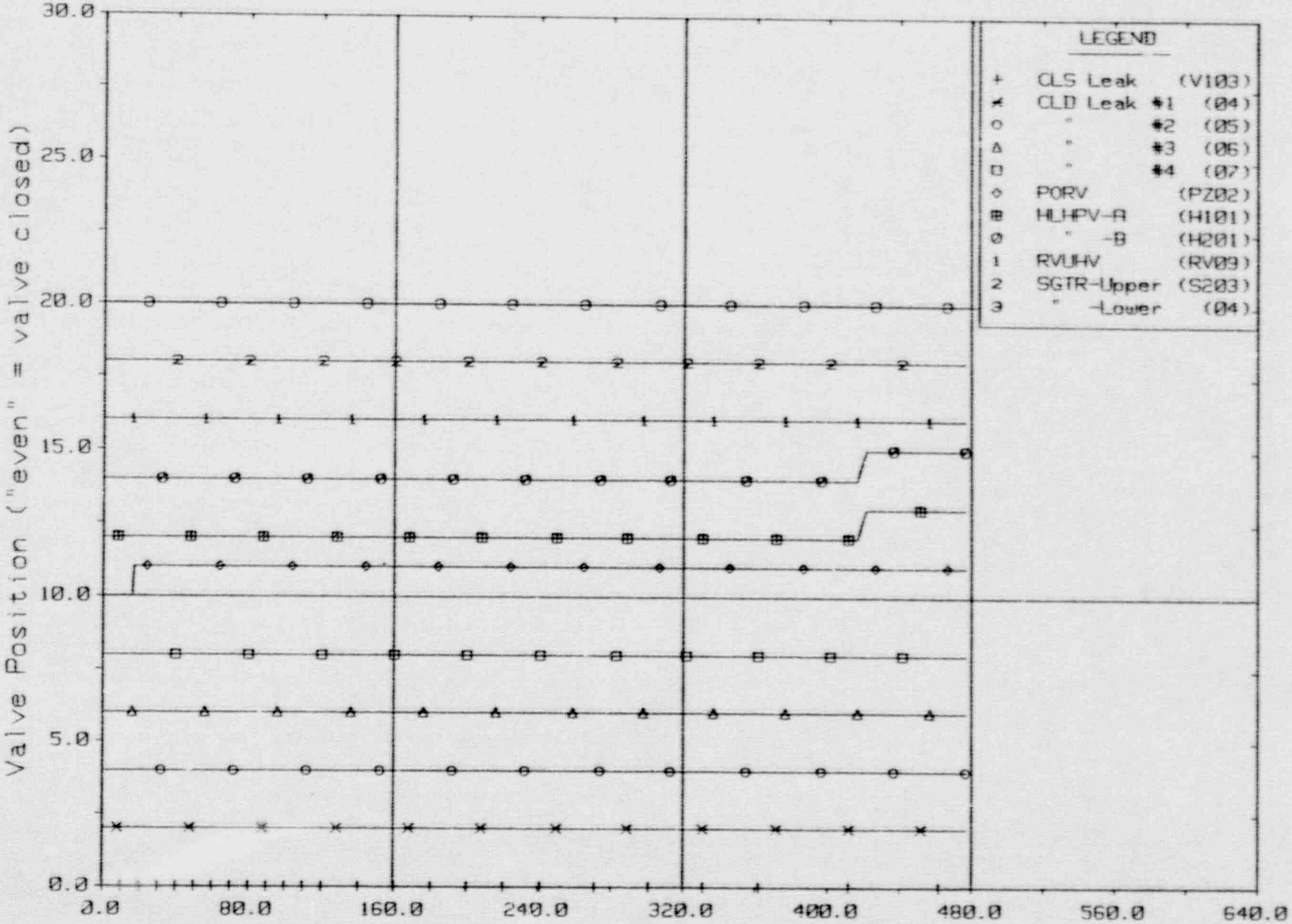
Primary System Boundary Flow Rates.

Tue May 24 16:22:01 1988

PBFL3

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



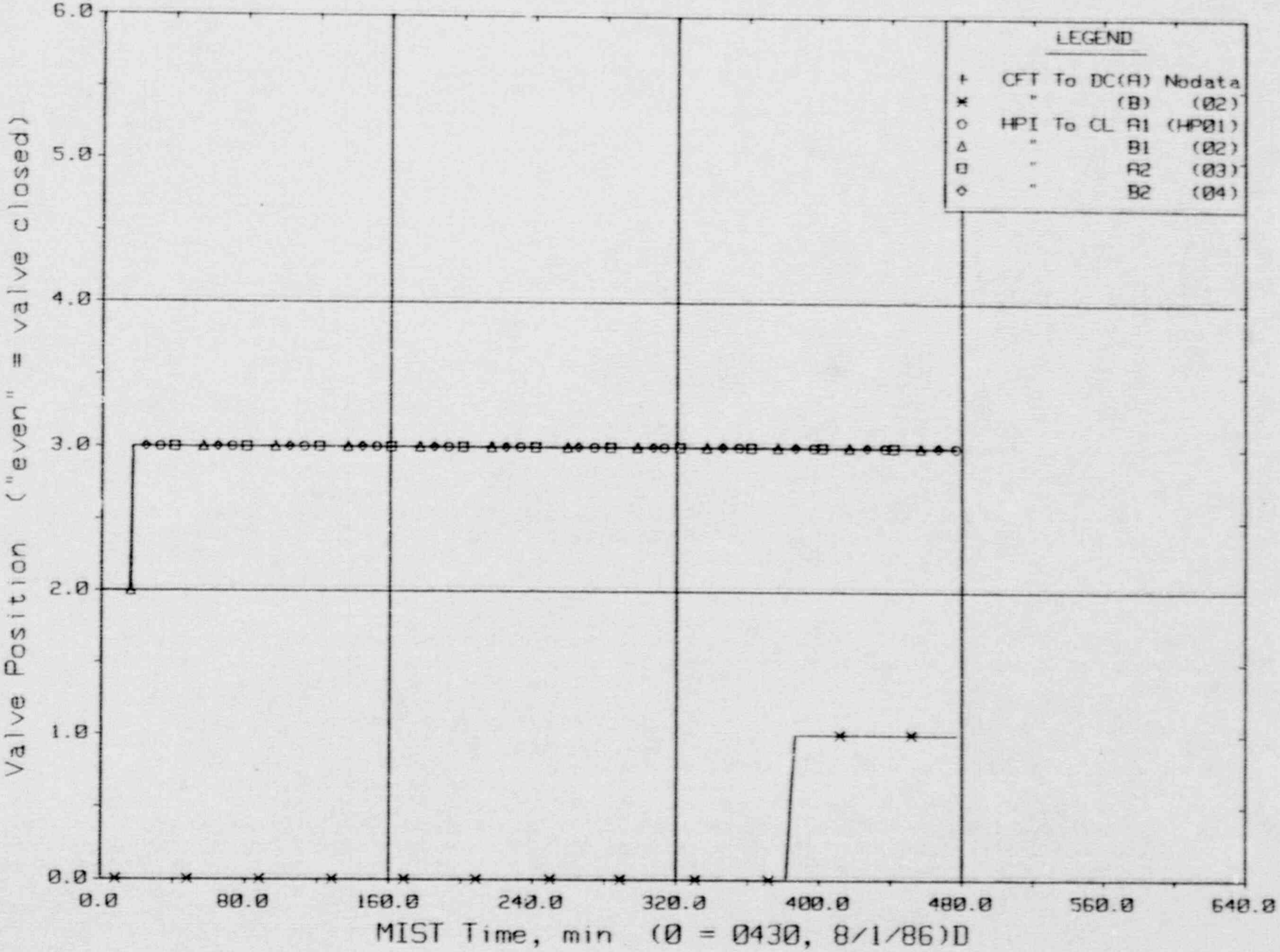
Primary System Discharge Limit Switch Indications (LSs).

Tue May 24 16:26:28 1988

PBLS1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



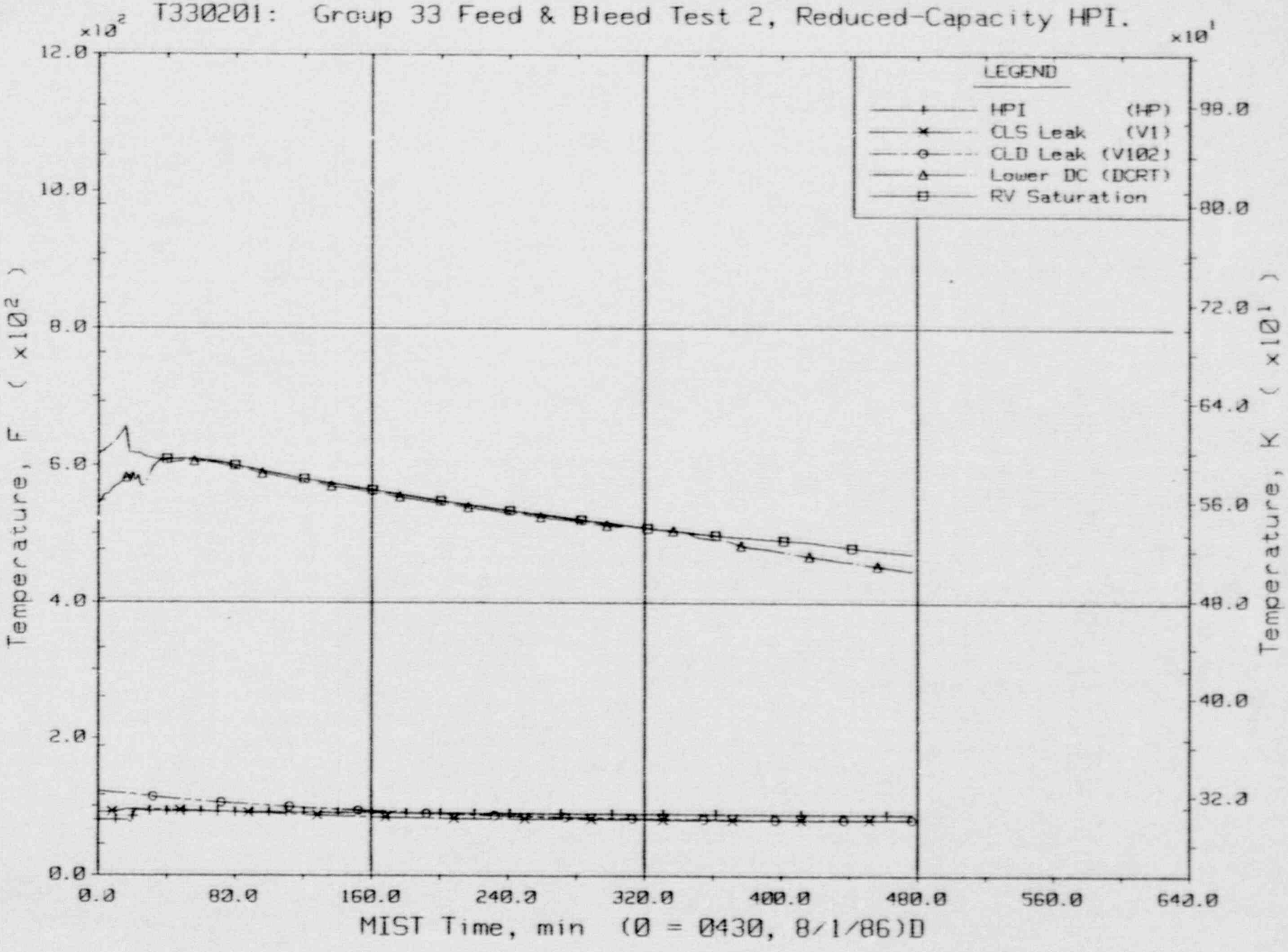
Primary System Injection Limit Switch Indications (LSs).

Tue May 24 16:29:35 1988

PBLS2

FINAL DATA

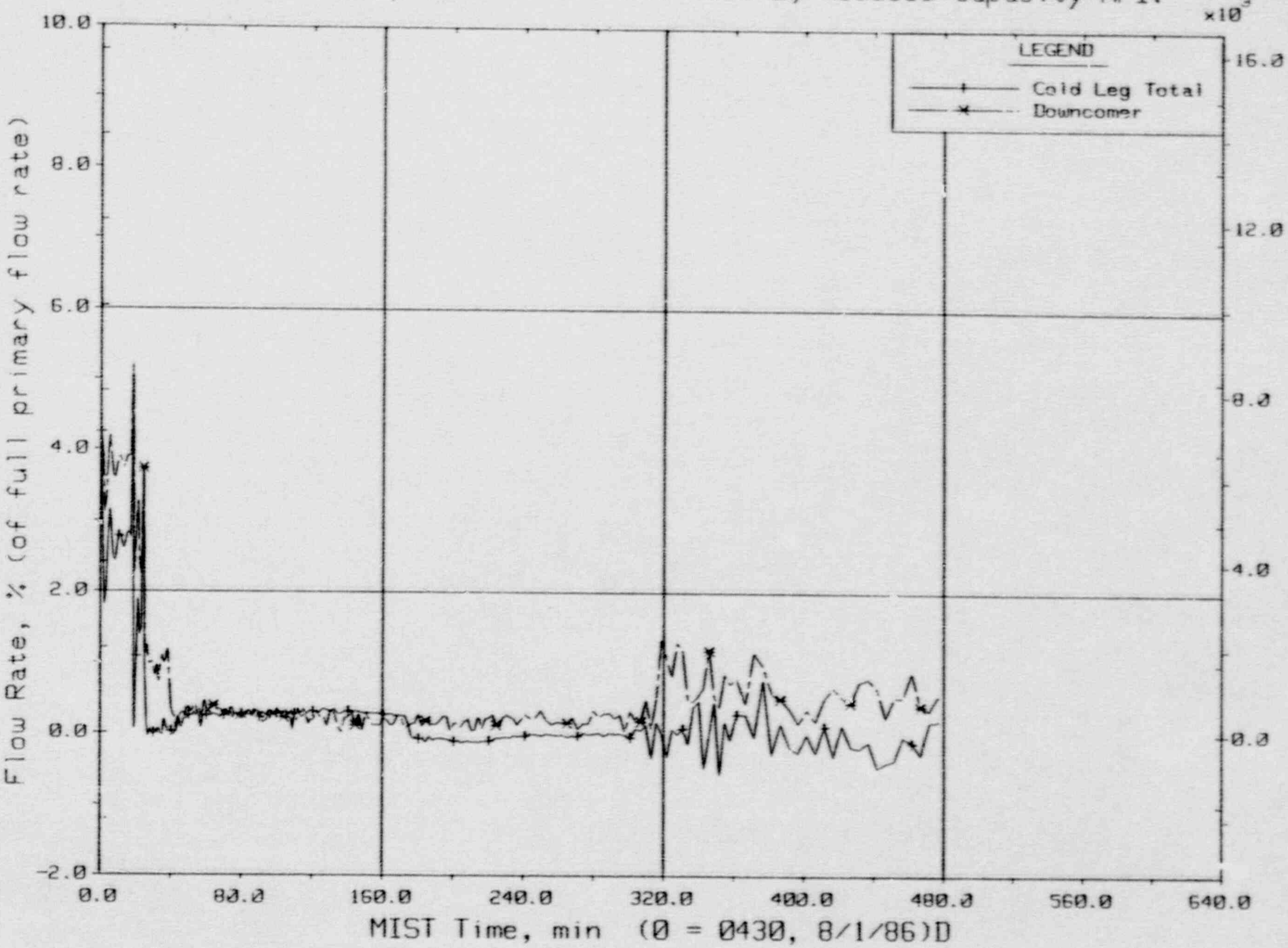
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Single-Phase Discharge and HPI Fluid Temperatures (TC01s).

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



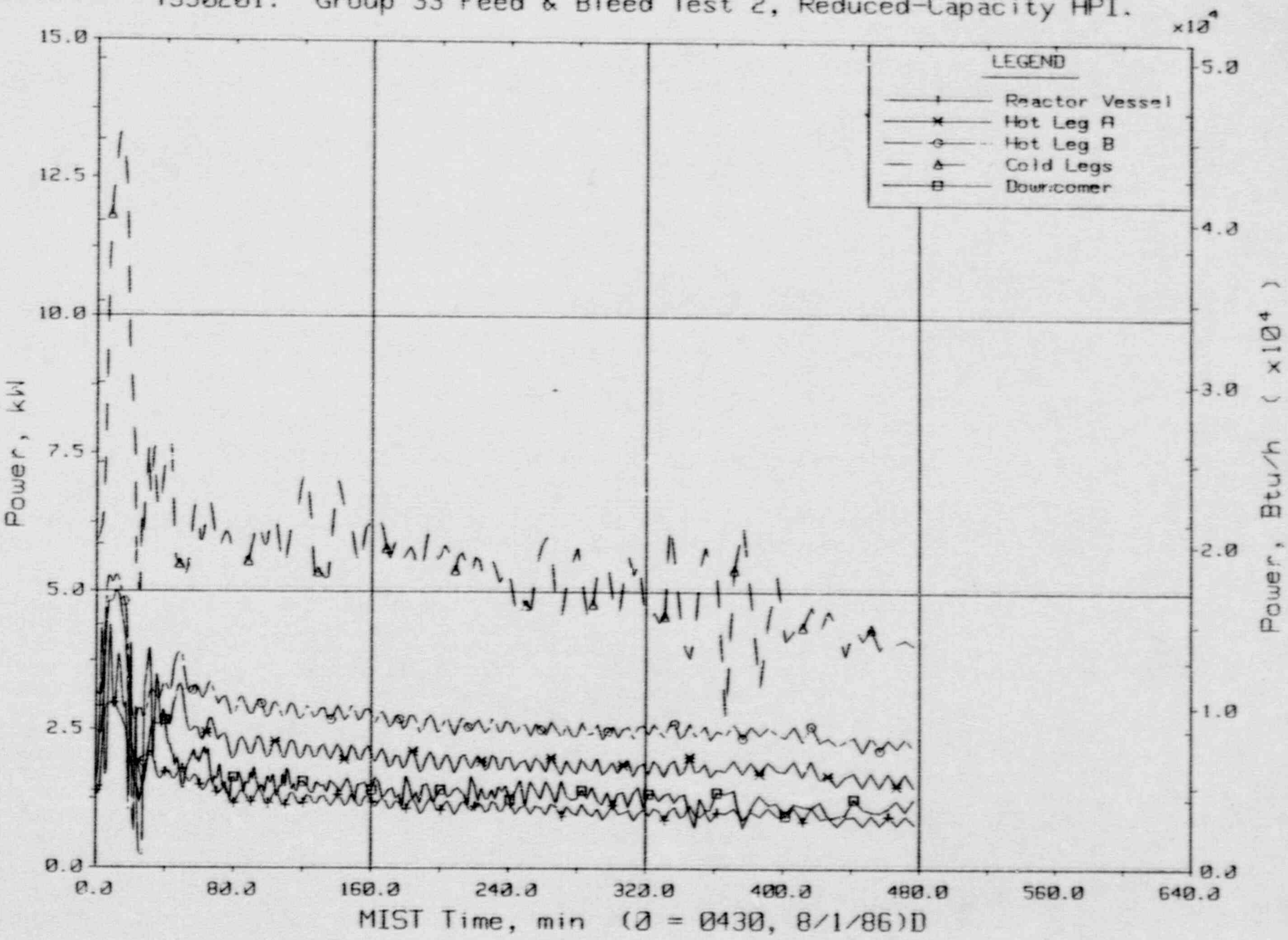
Primary System Venturi Flow Rates.

Tue May 24 16:35:58 1988

PRFL7

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



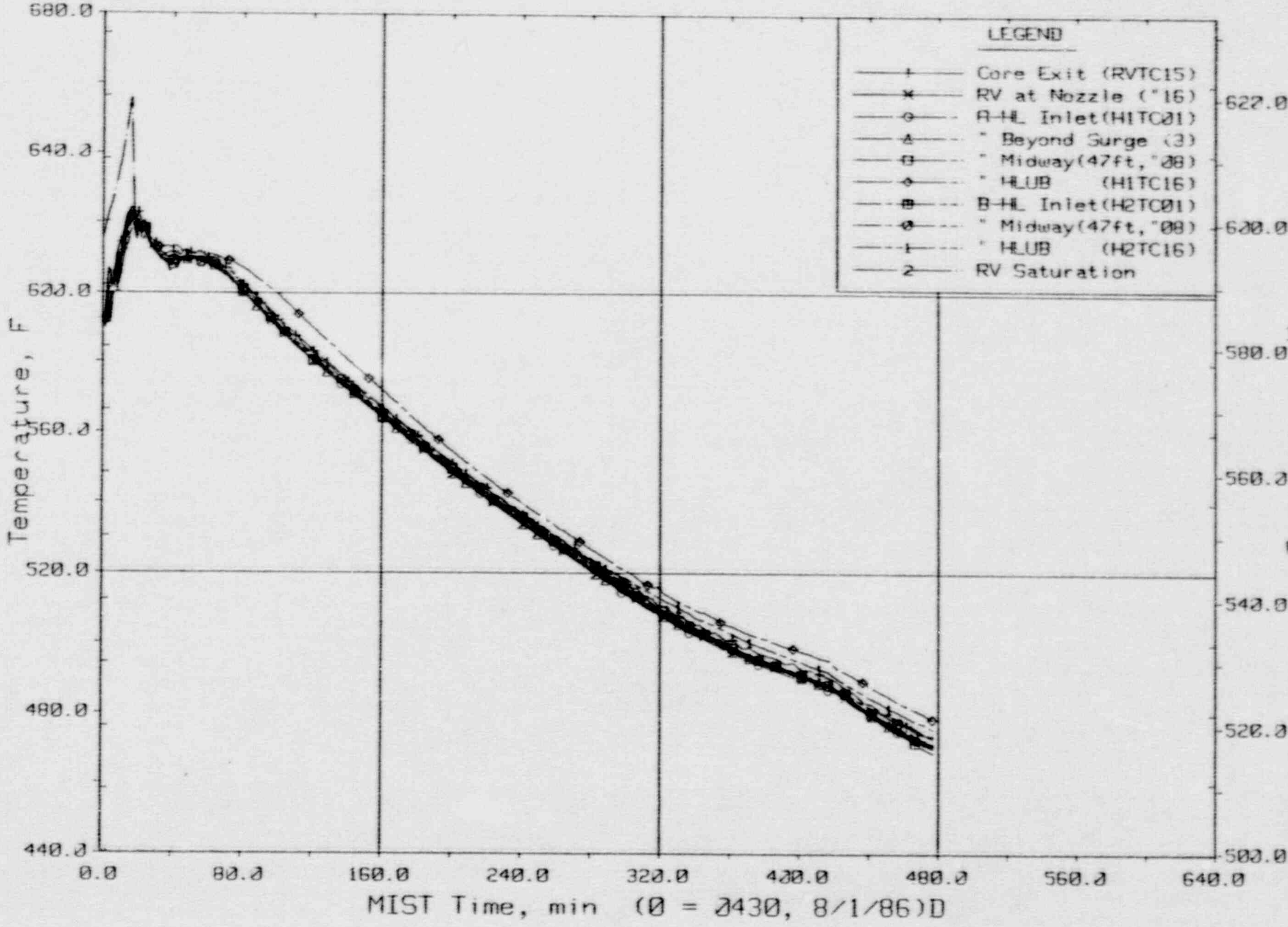
Guard Heater Specified Power Per Primary Component.

Tue May 24 16:39:26 1988

PRG01

FINAL DATA

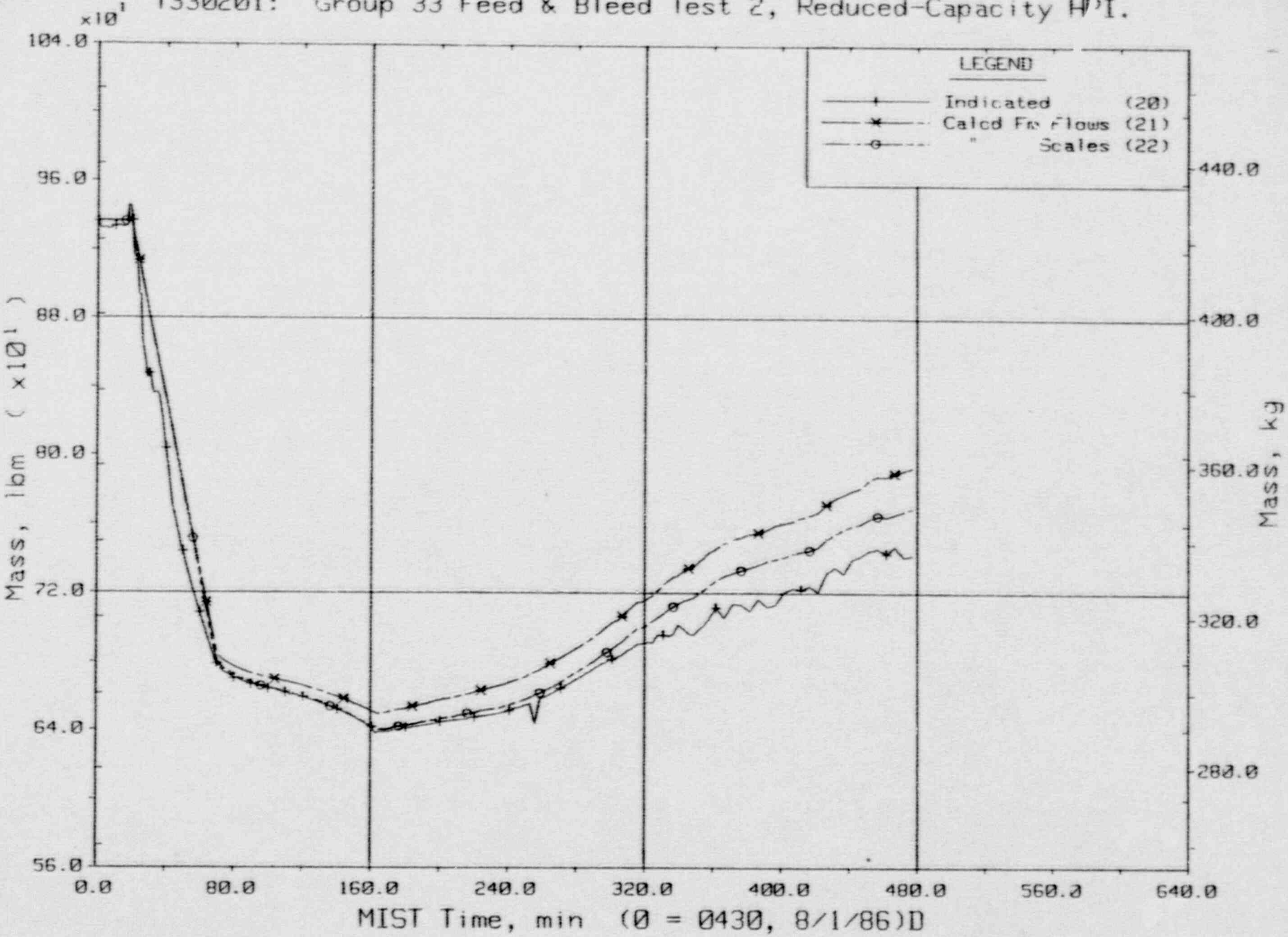
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Composite Core Exit and Hot Leg Fluid Temperatures.

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



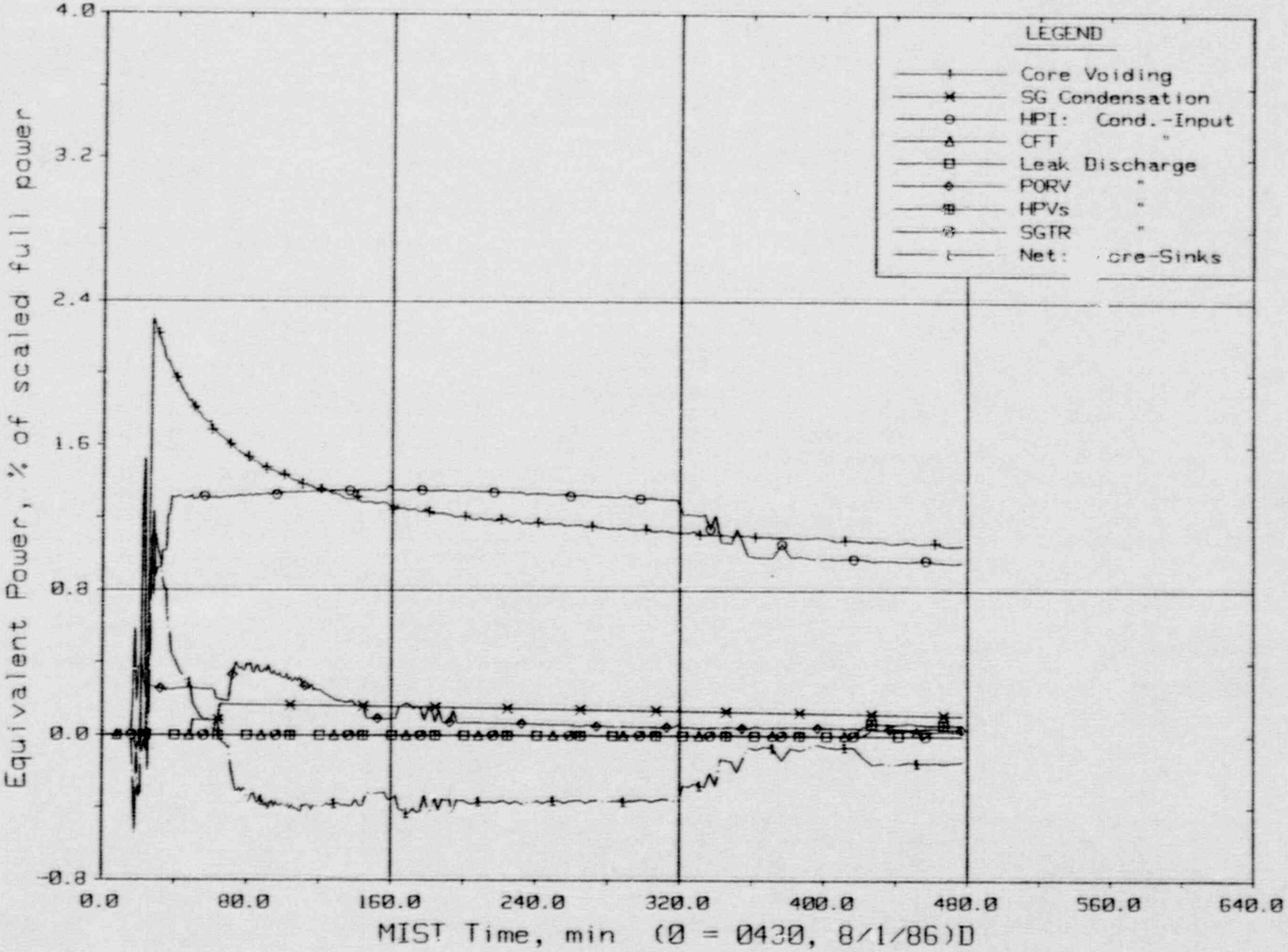
Primary System Total Fluid Mass (PLMLs).

Tue May 24 16:49:31 1988

PRML2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



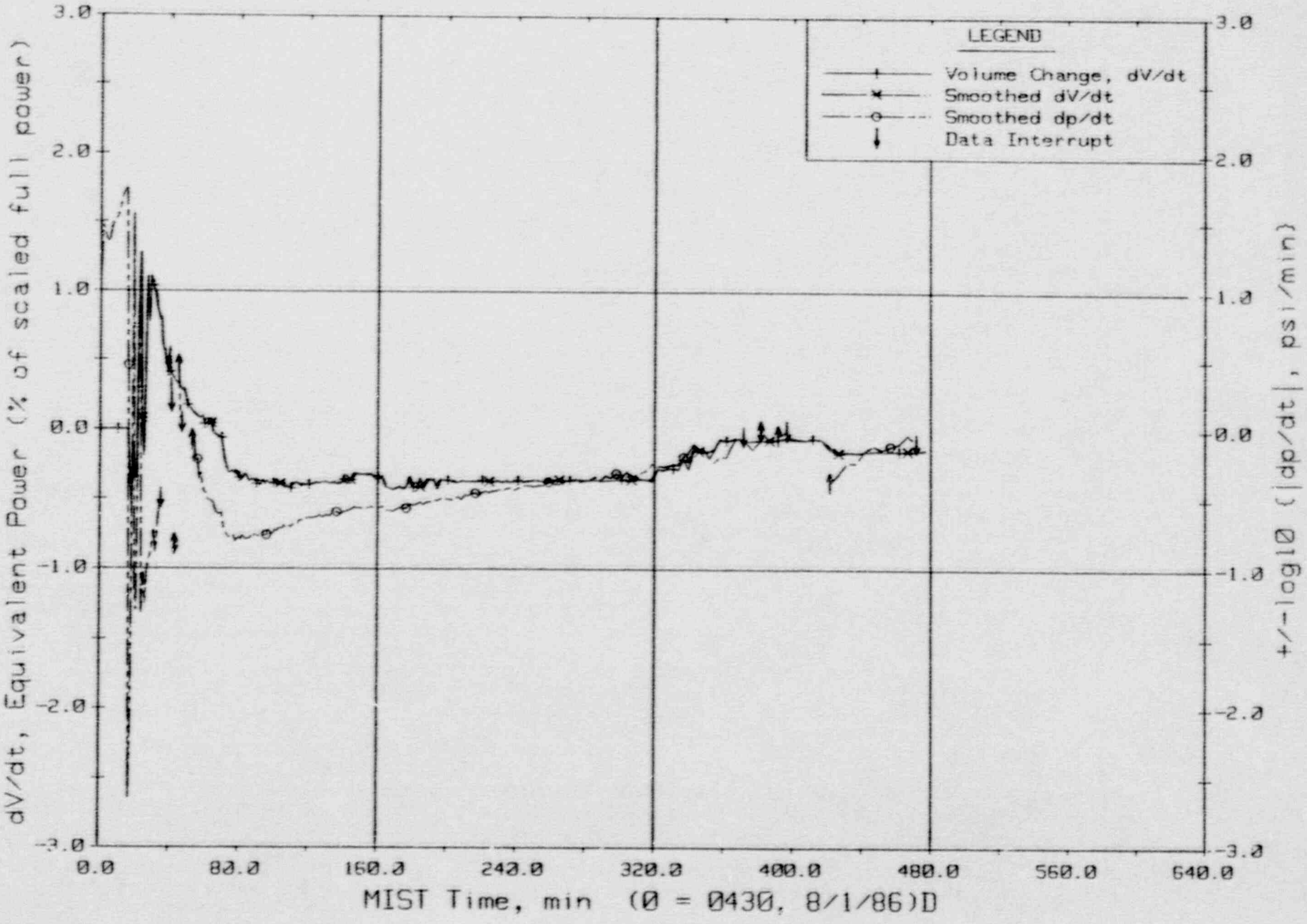
Primary Fluid Volume Changes By Components.

Tue May 24 16:55:49 1988

PRPA0

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



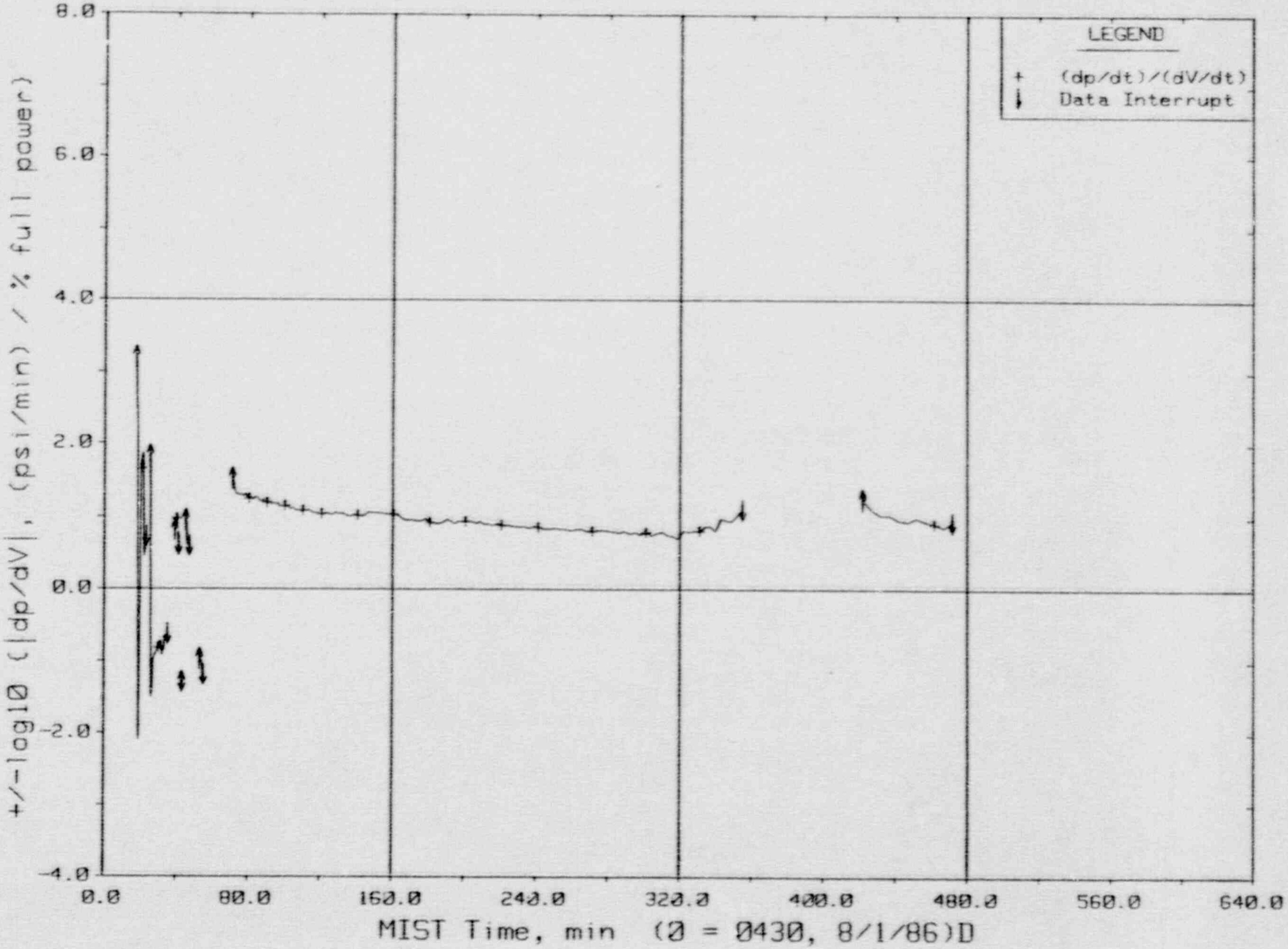
Primary Fluid Volume and Pressure Changes, dV/dt and dp/dt.

Tue May 24 16:58:57 1988

PRPA2

FINAL DATA

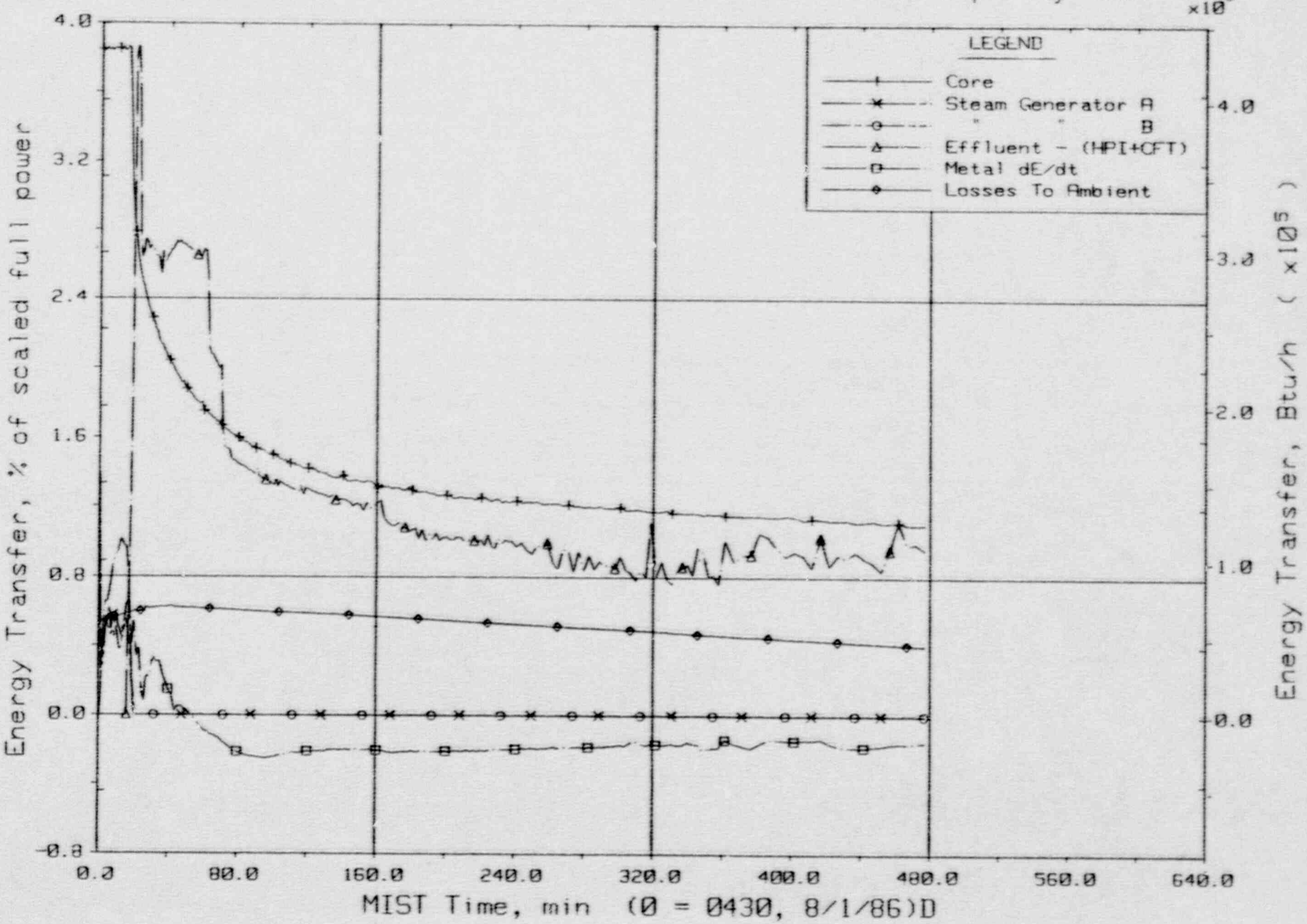
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Primary System Response: dp/dt divided by dV/dt.

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



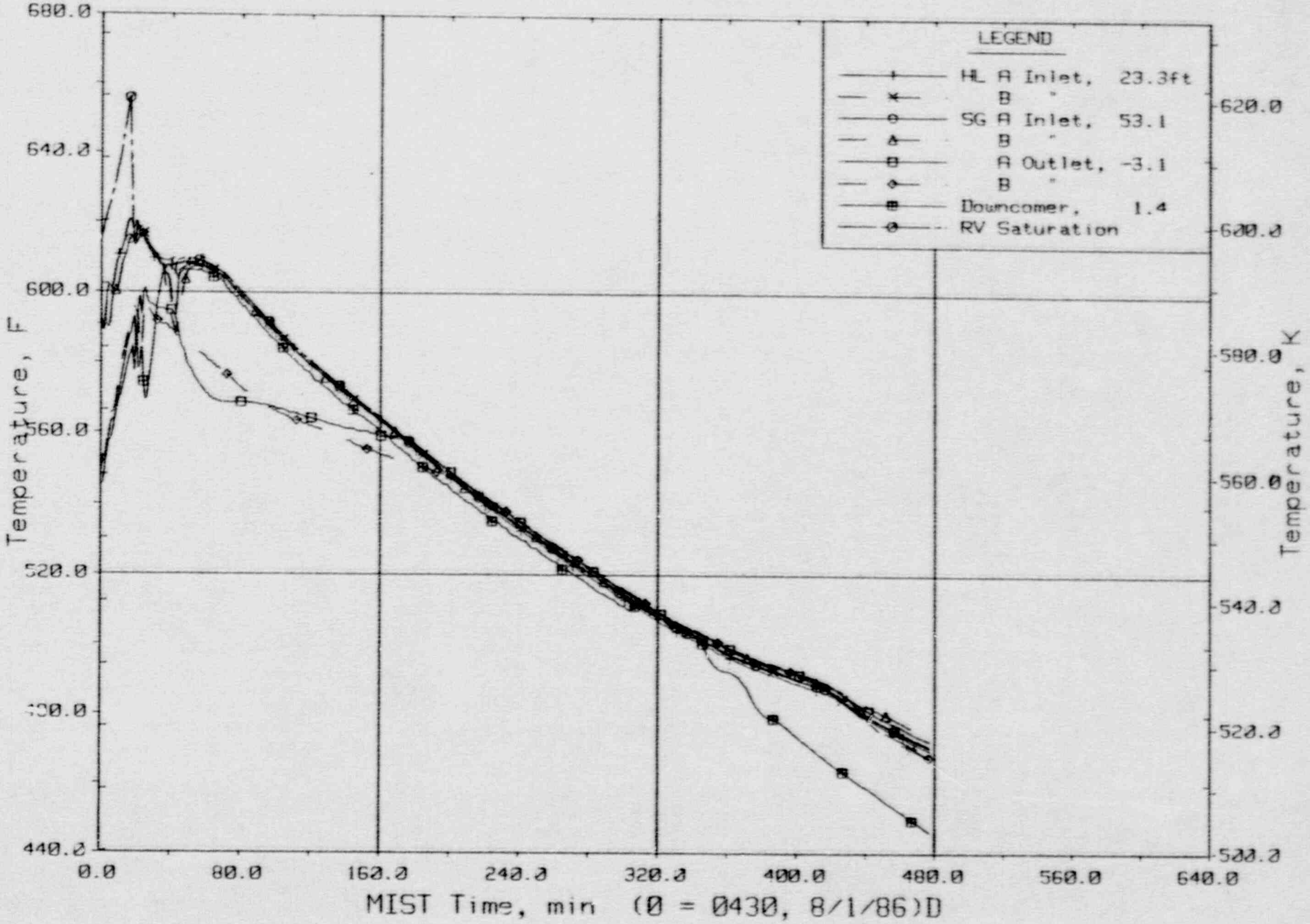
Primary System Energy Transfer.

Tue May 24 17:09:09 1988

PRQE2

FINAL DATA

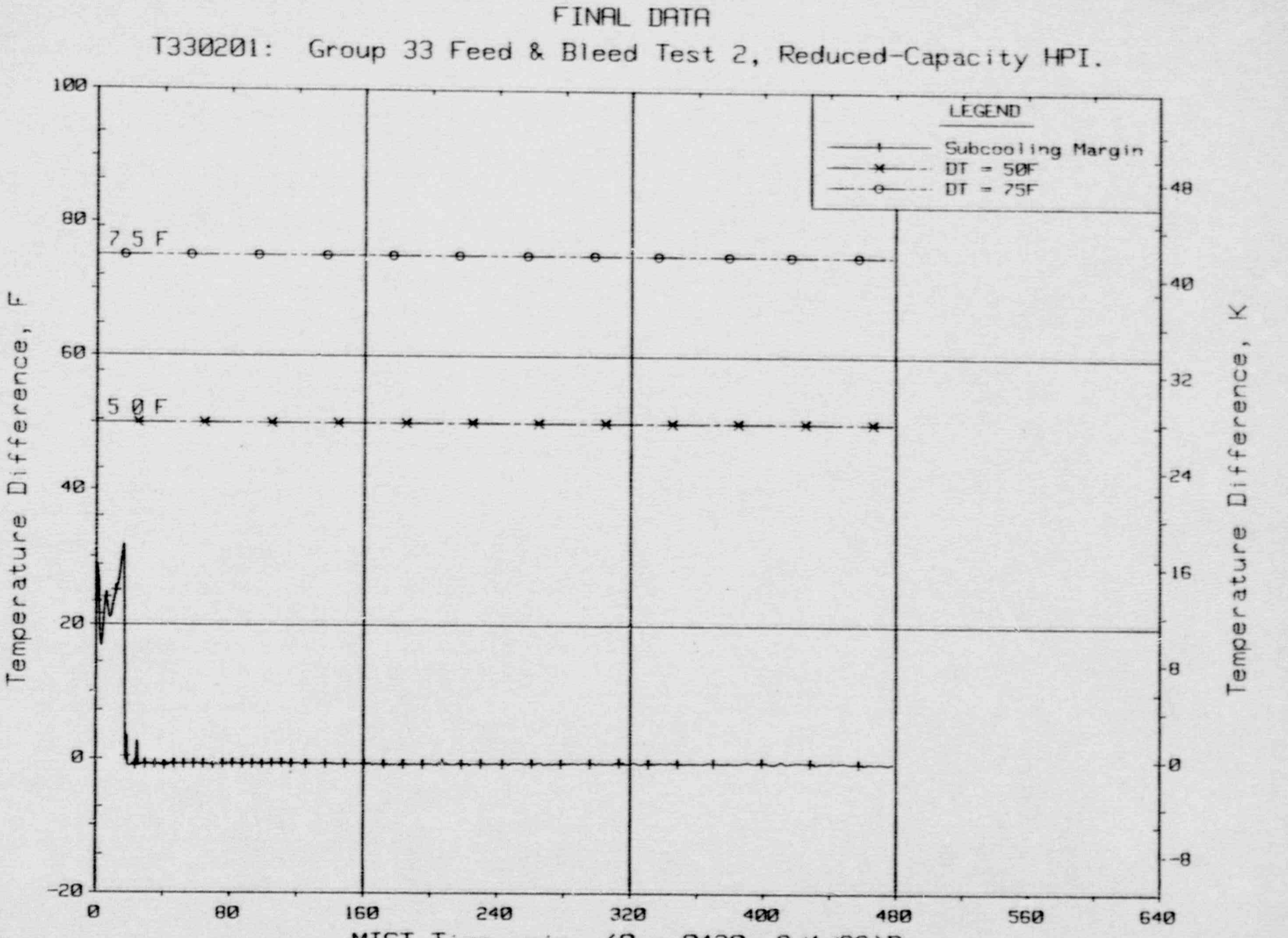
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Primary System Fluid Temperatures (RTDs).

Tue May 24 17:13:51 1988

PRRT0



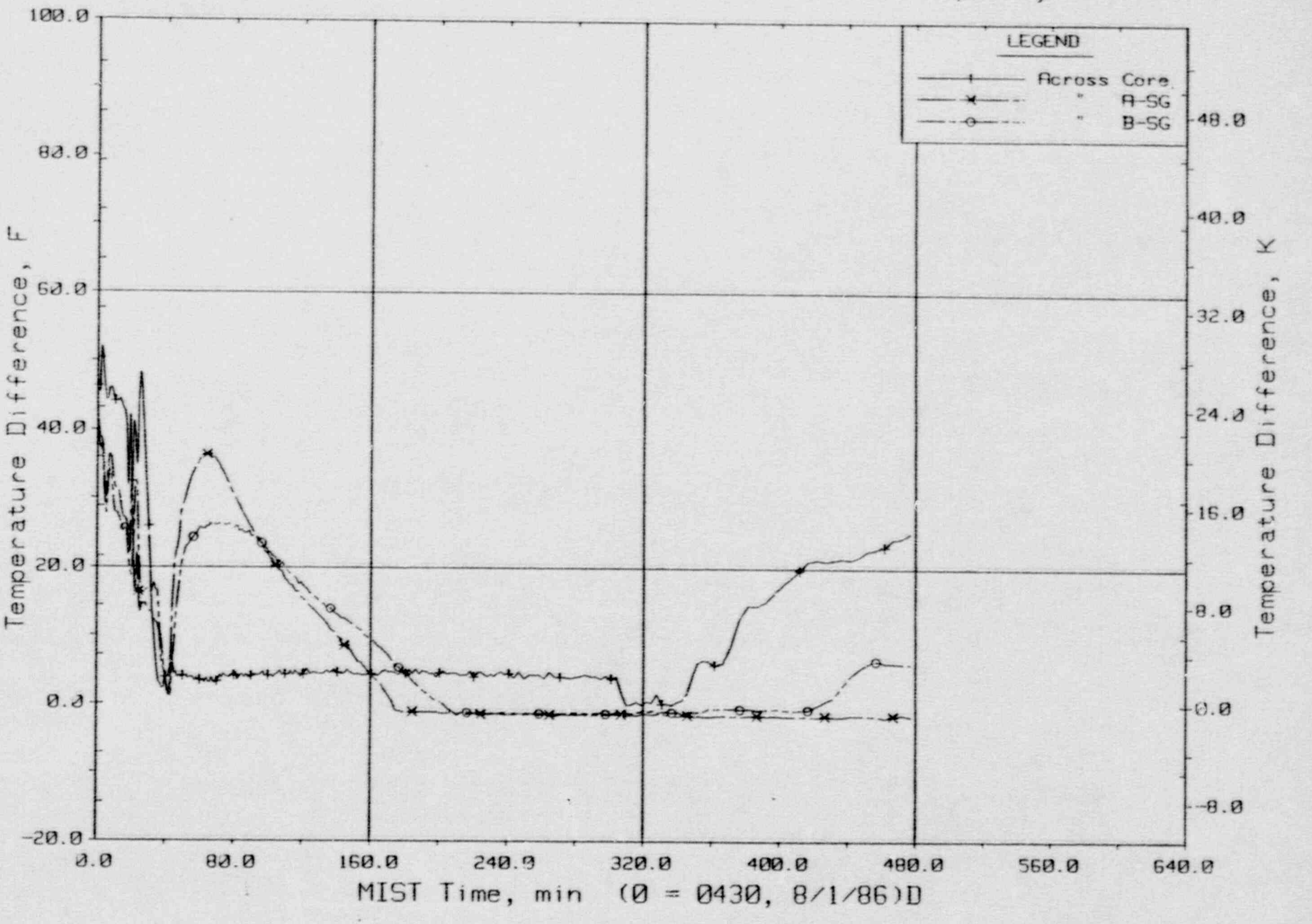
Control Temperature Differences.

Tue Nov 1 09:24:51 1988

PRTD0

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



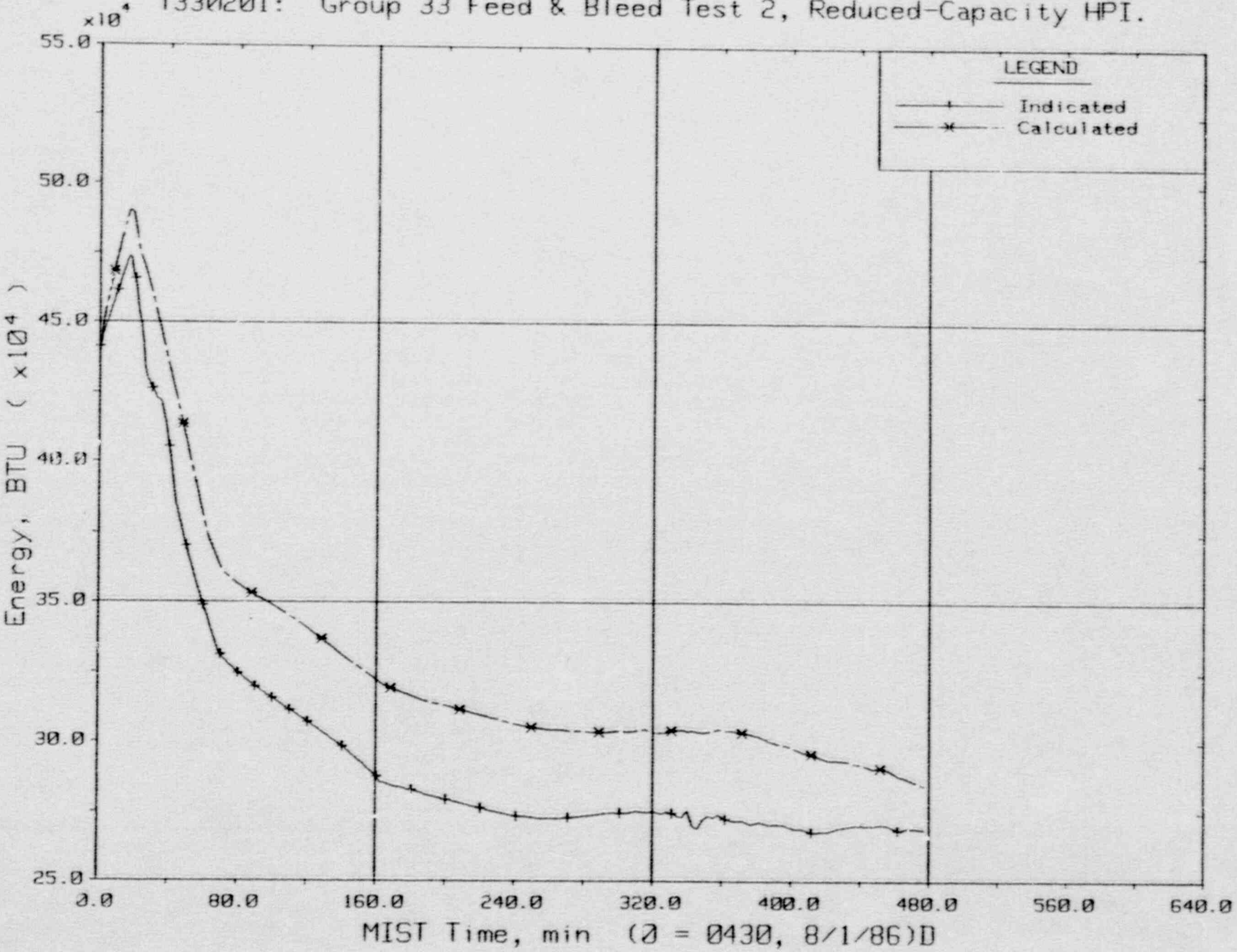
Key Temperature Differences.

Tue May 24 17:18:26 1988

PRTD2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



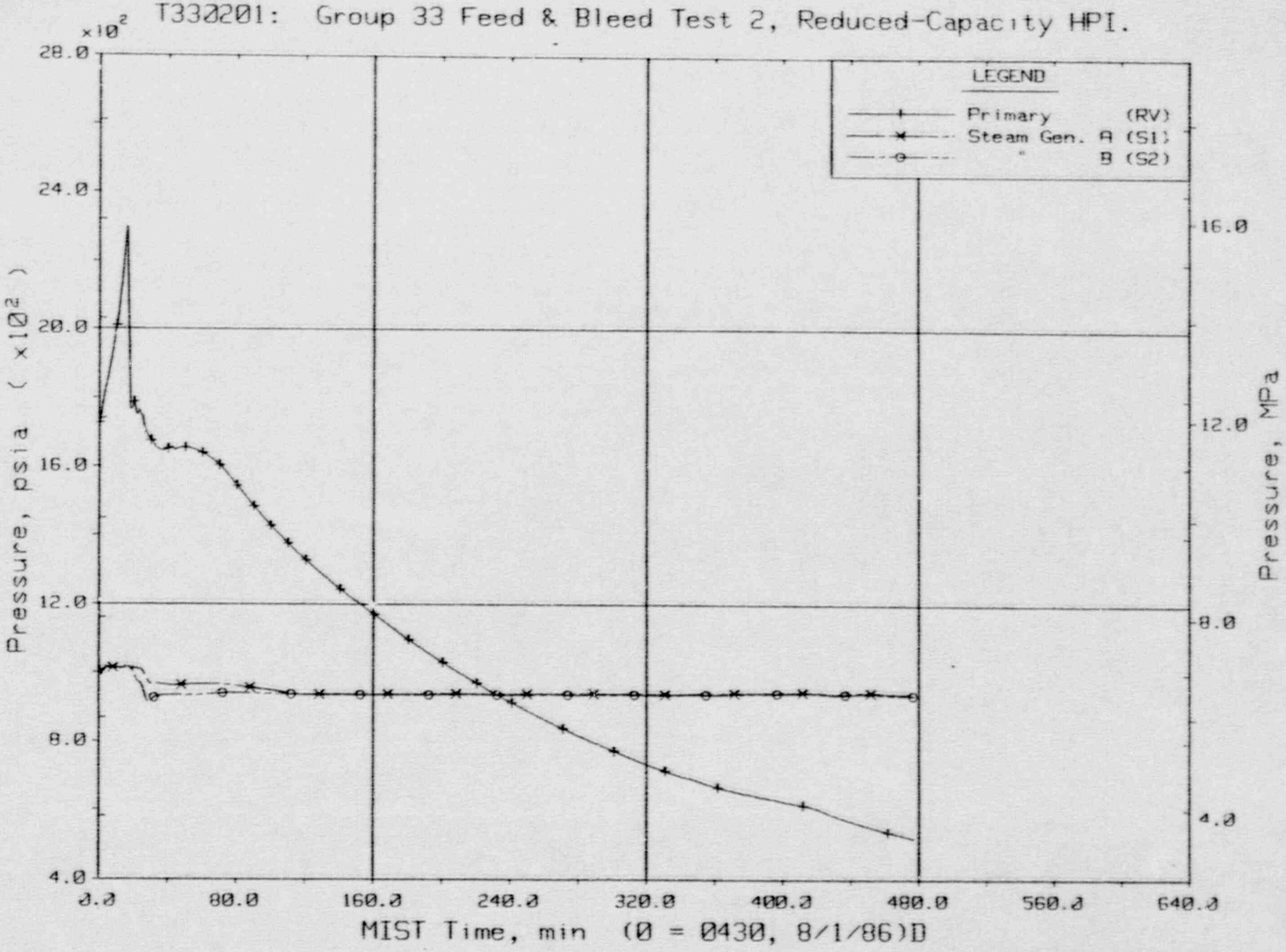
Primary System Total Fluid Energy.

Tue May 24 17:21:12 1988

PRTE2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



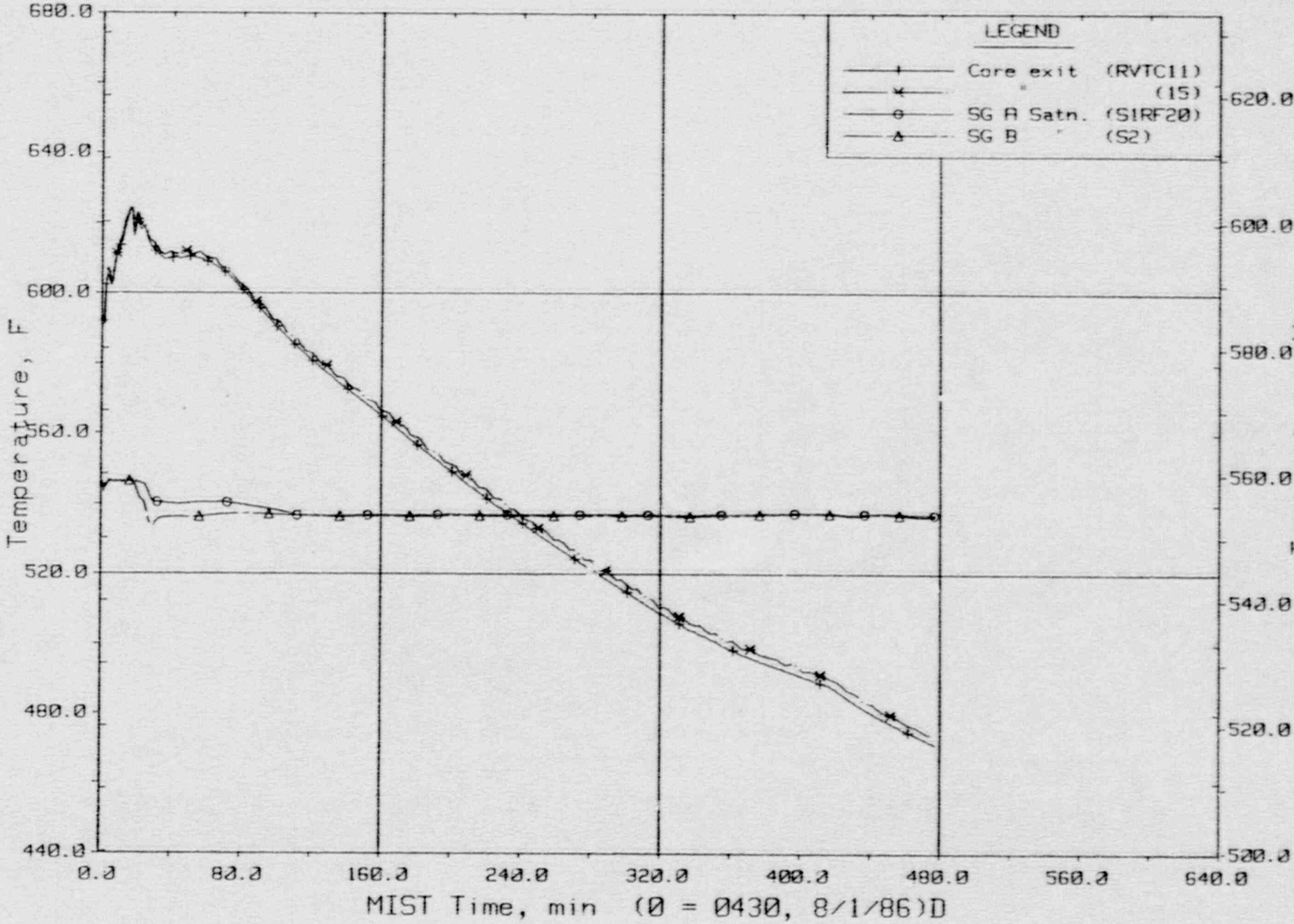
Primary and Secondary System Pressures (GP01s).

Tue May 24 17:24:26 1988

PSGP1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



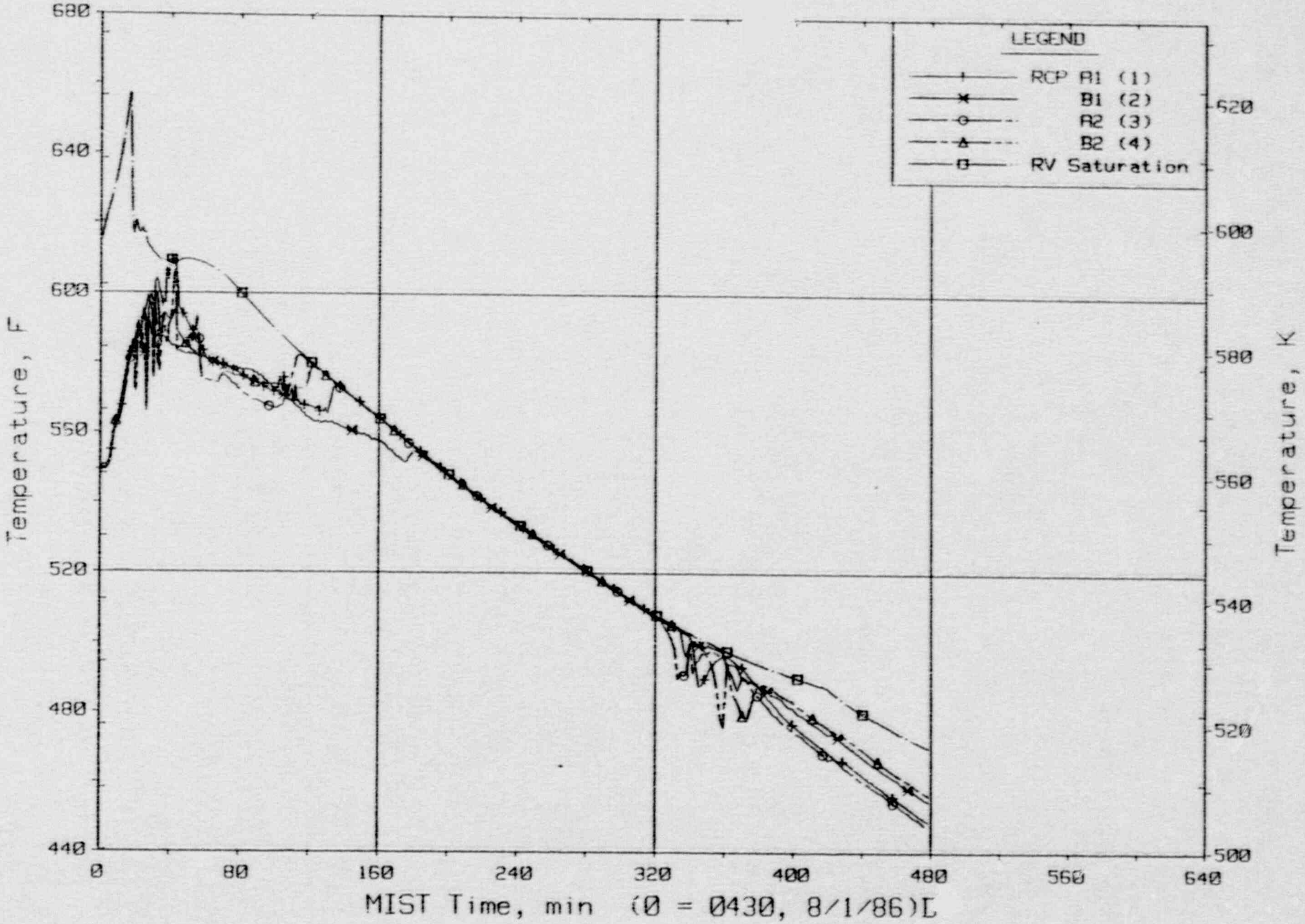
Core Exit and Steam Generator Secondary Saturation Temperatures.

Tue May 24 17:27:20 1988

PSTC3p

FINAL DATA

T330201: Group 33 Feed & Bleed Test ~, Reduced-Capacity HPI.



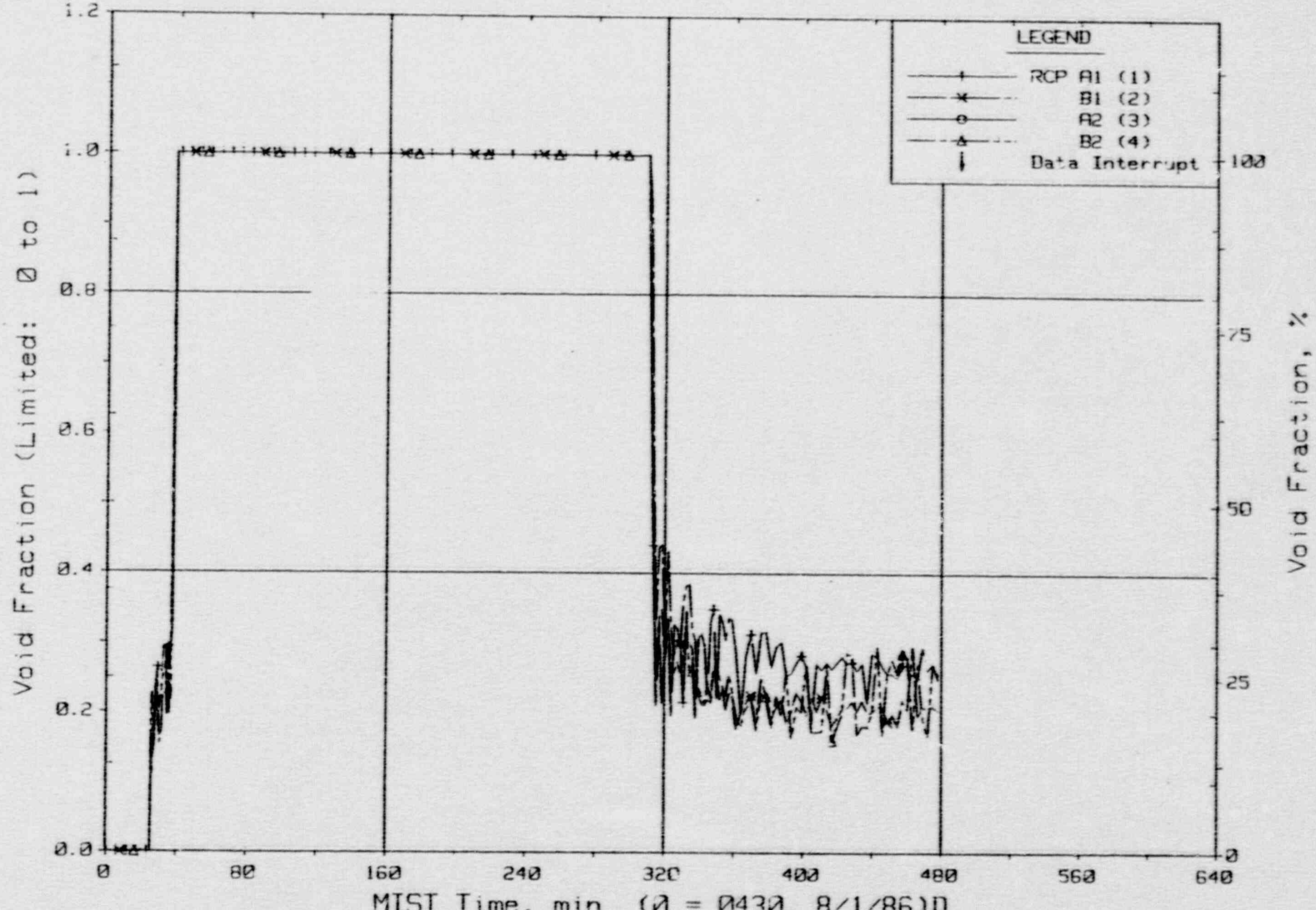
Pump Suction Fluid Temperature (CnRT01s).

Tue Nov 1 09:29:07 1988

PURT0

FINAL DATA

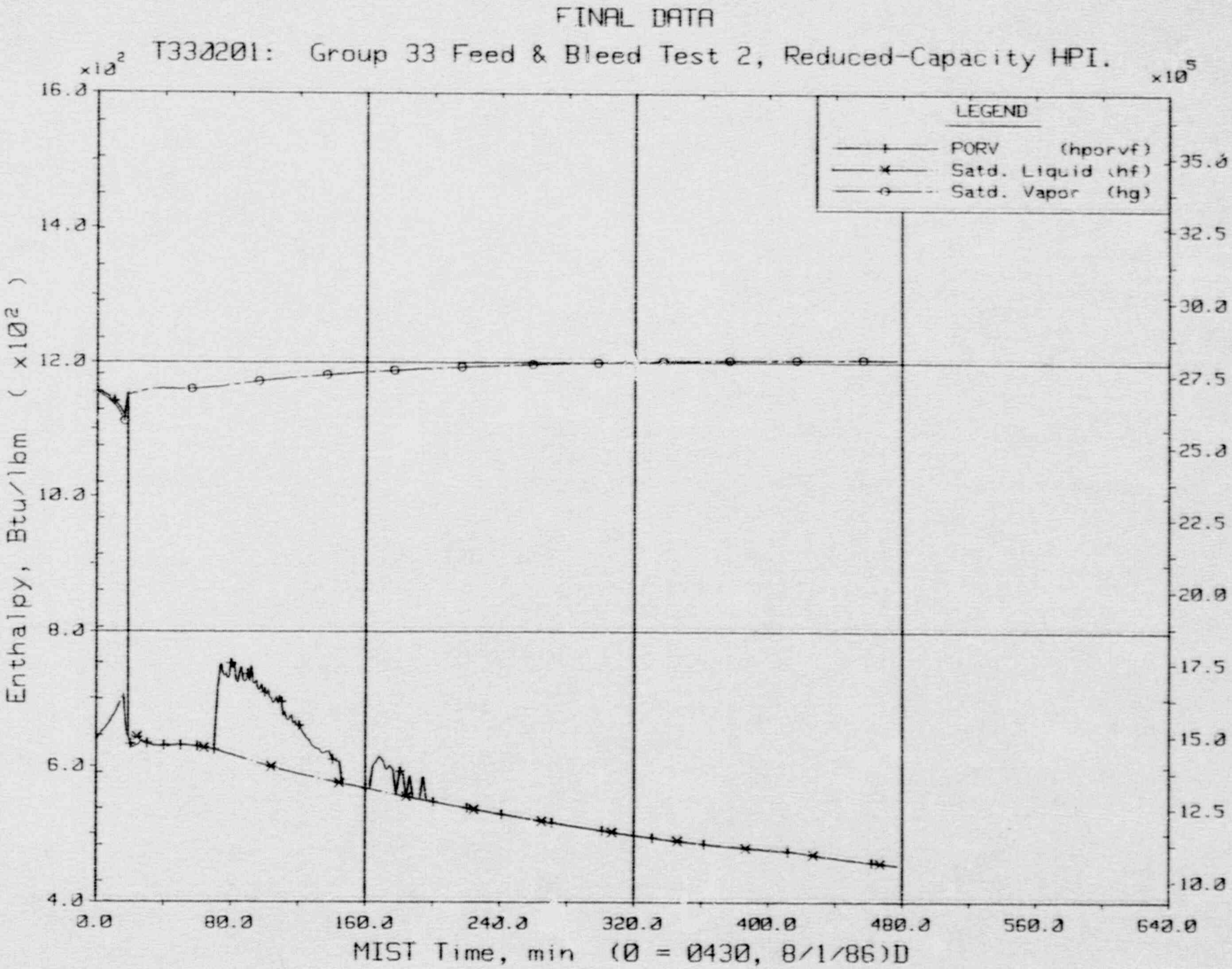
T332201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Pump Suction Void Fraction From Gamma Densitometers (CnGD2i).

Tue Nov 1 10:30:17 1988

PUVF2



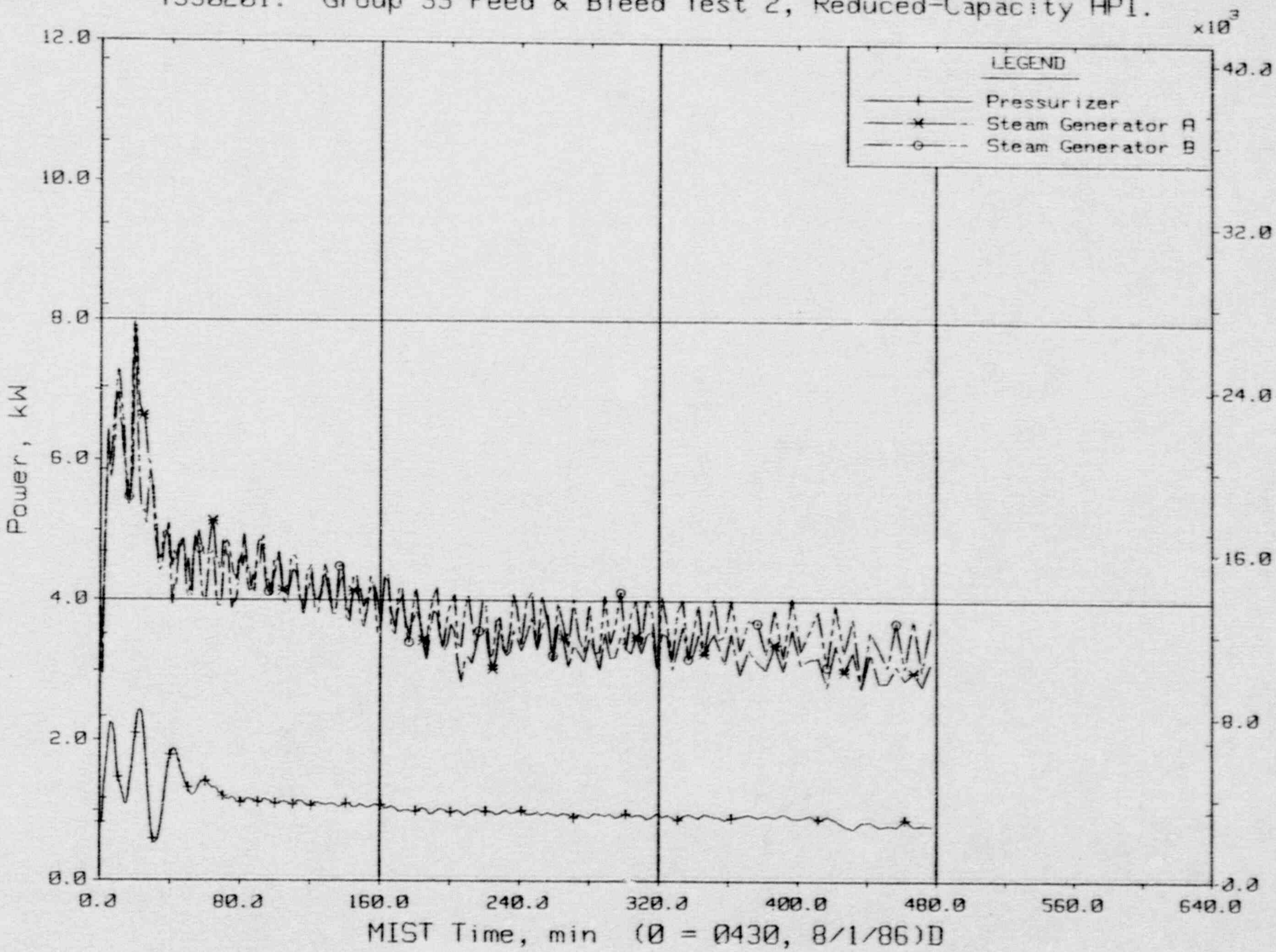
Power-Operated Relief Valve Enthalpy (Based On Flow Rate).

Tue May 24 17:37:10 1988

PZEN1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



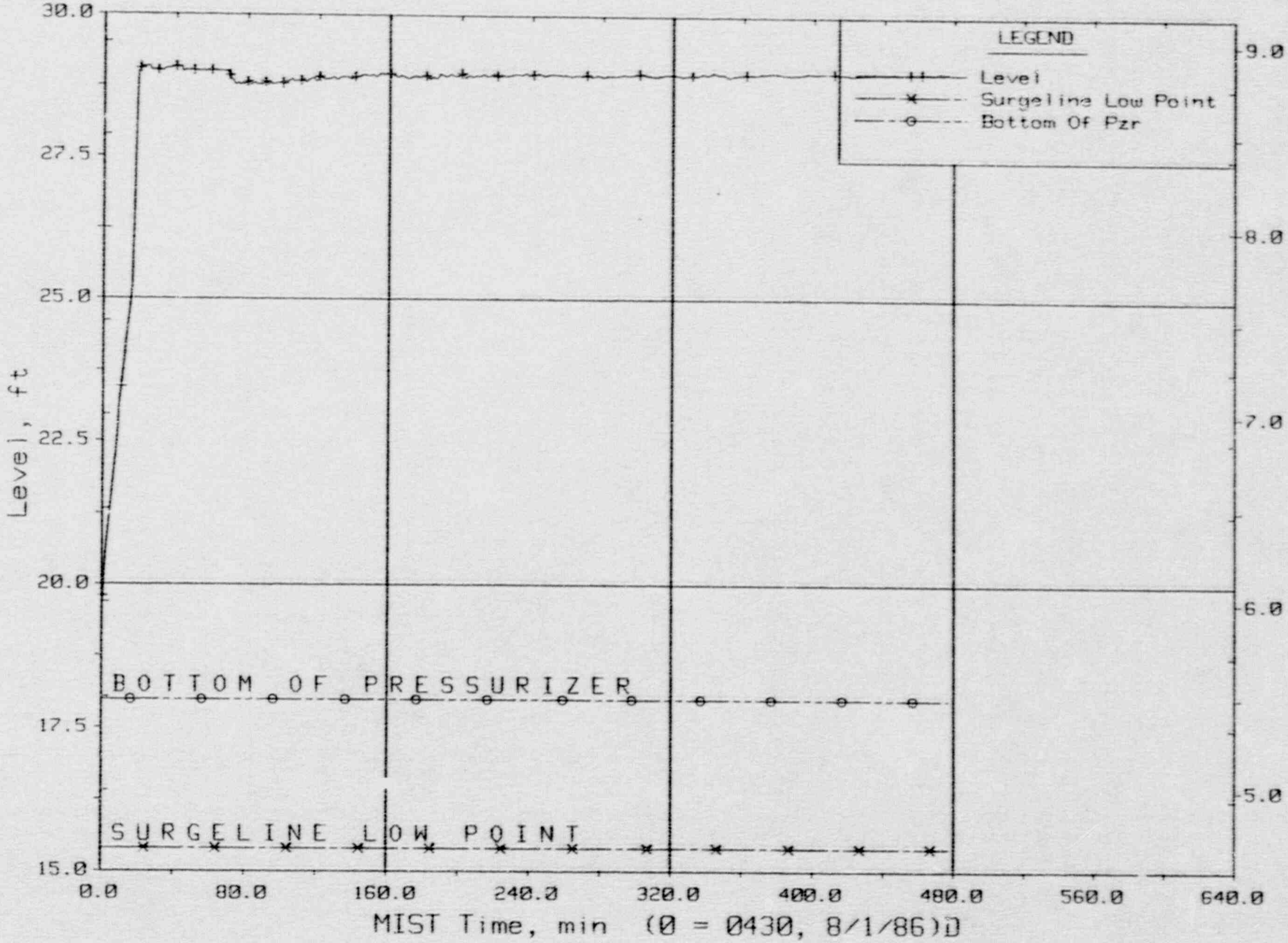
Guard Heater Specified Power, Pressurizer and Steam Generators.

Tue May 24 17:40:54 1988

PZGQ1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



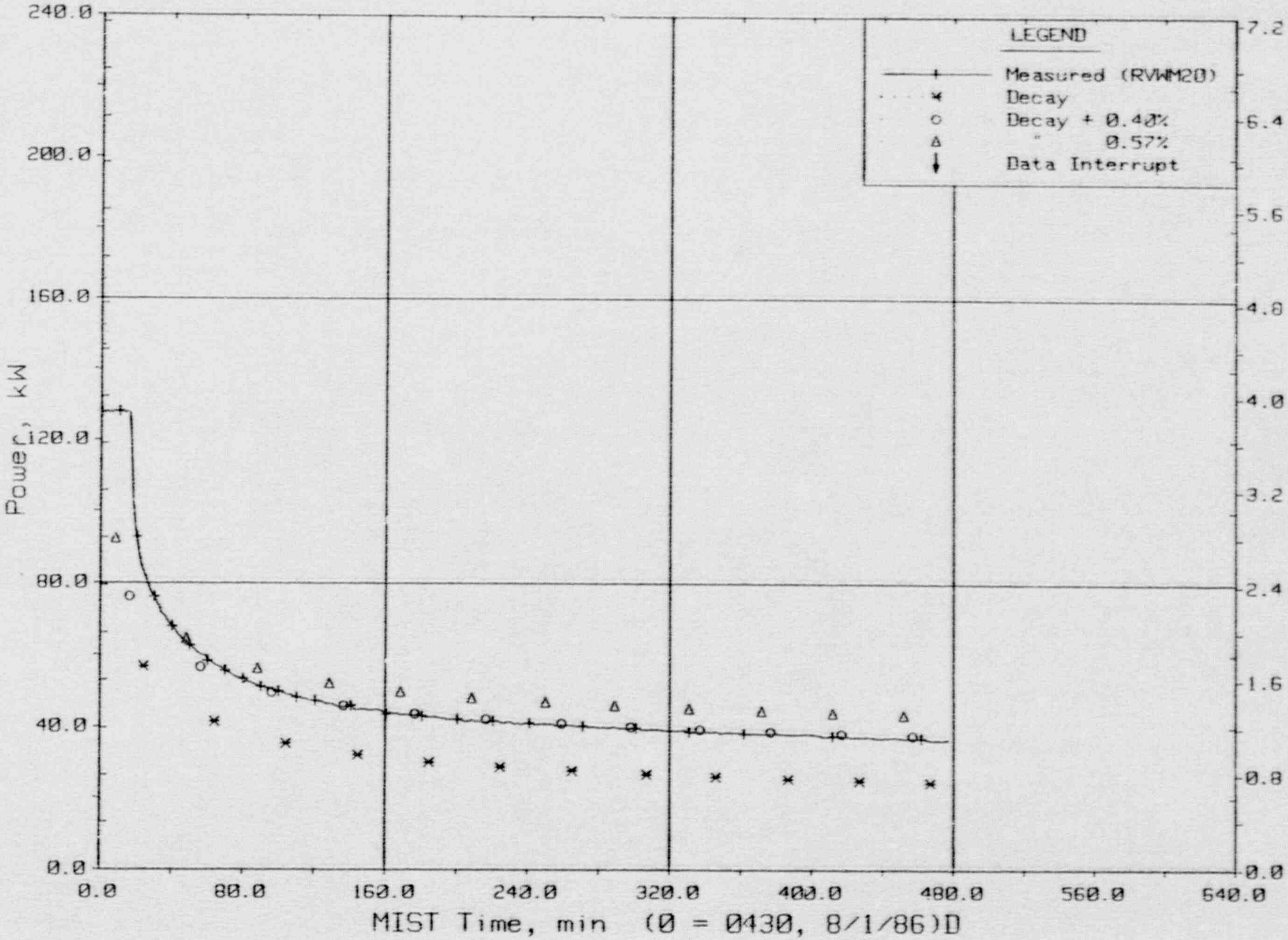
Pressurizer Collapsed Liquid Level (PZLV20).

Tue May 24 17:45:20 1988

PZLV1

FINAL DATA

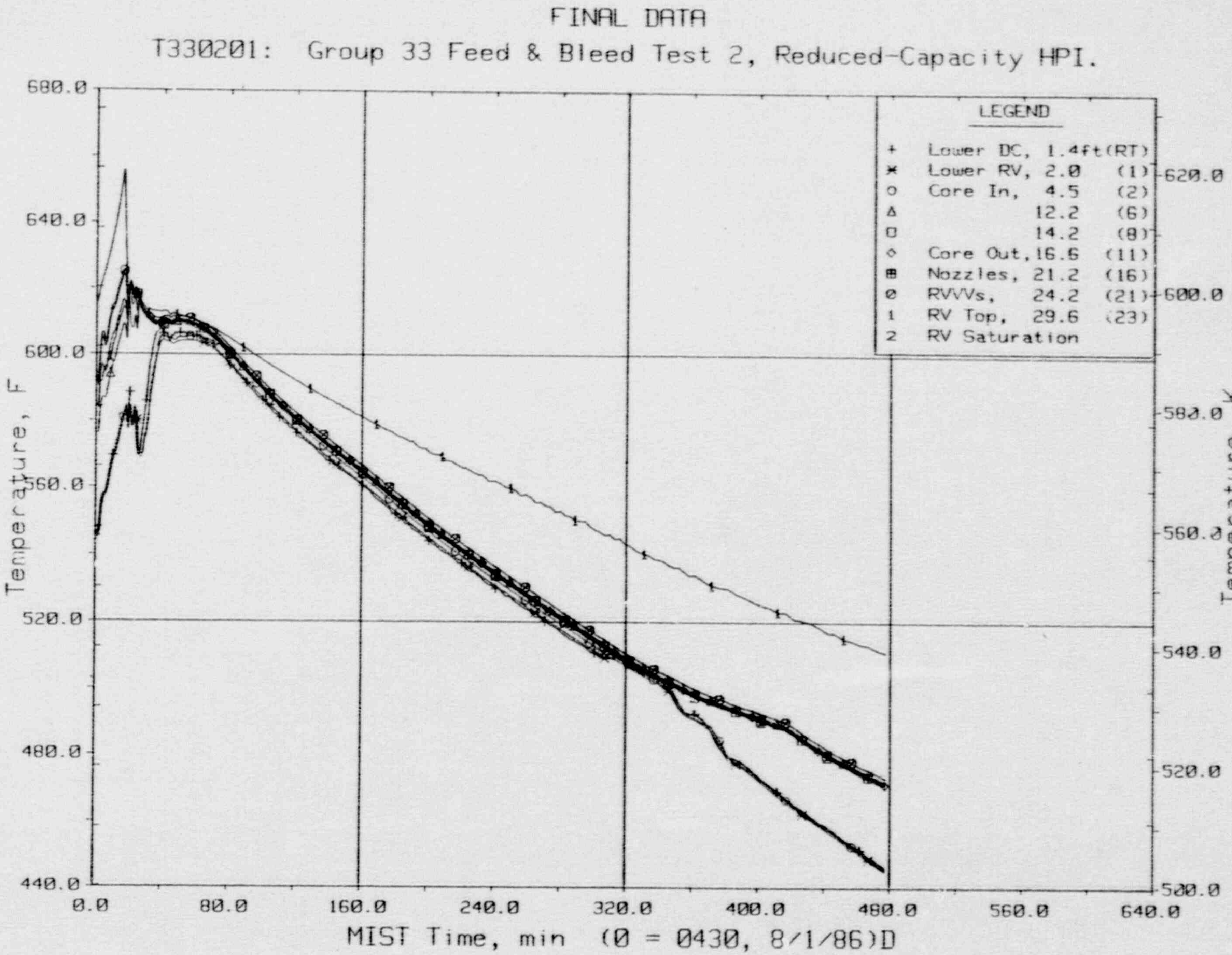
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Core Power.

Tue May 24 17:50:16 1988

RVKW0



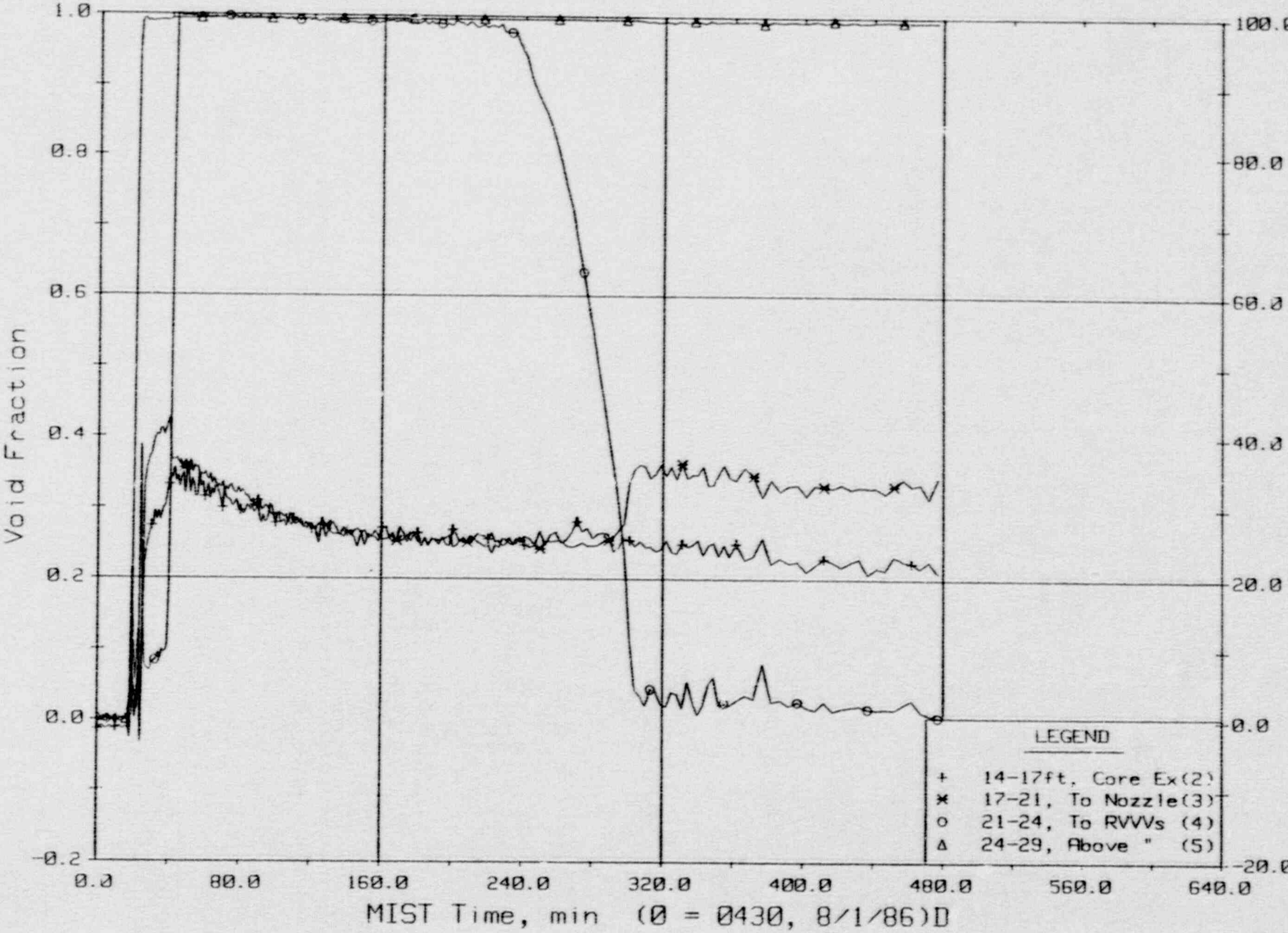
Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs).

Tue May 24 17:56:59 1988

RVTC0

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



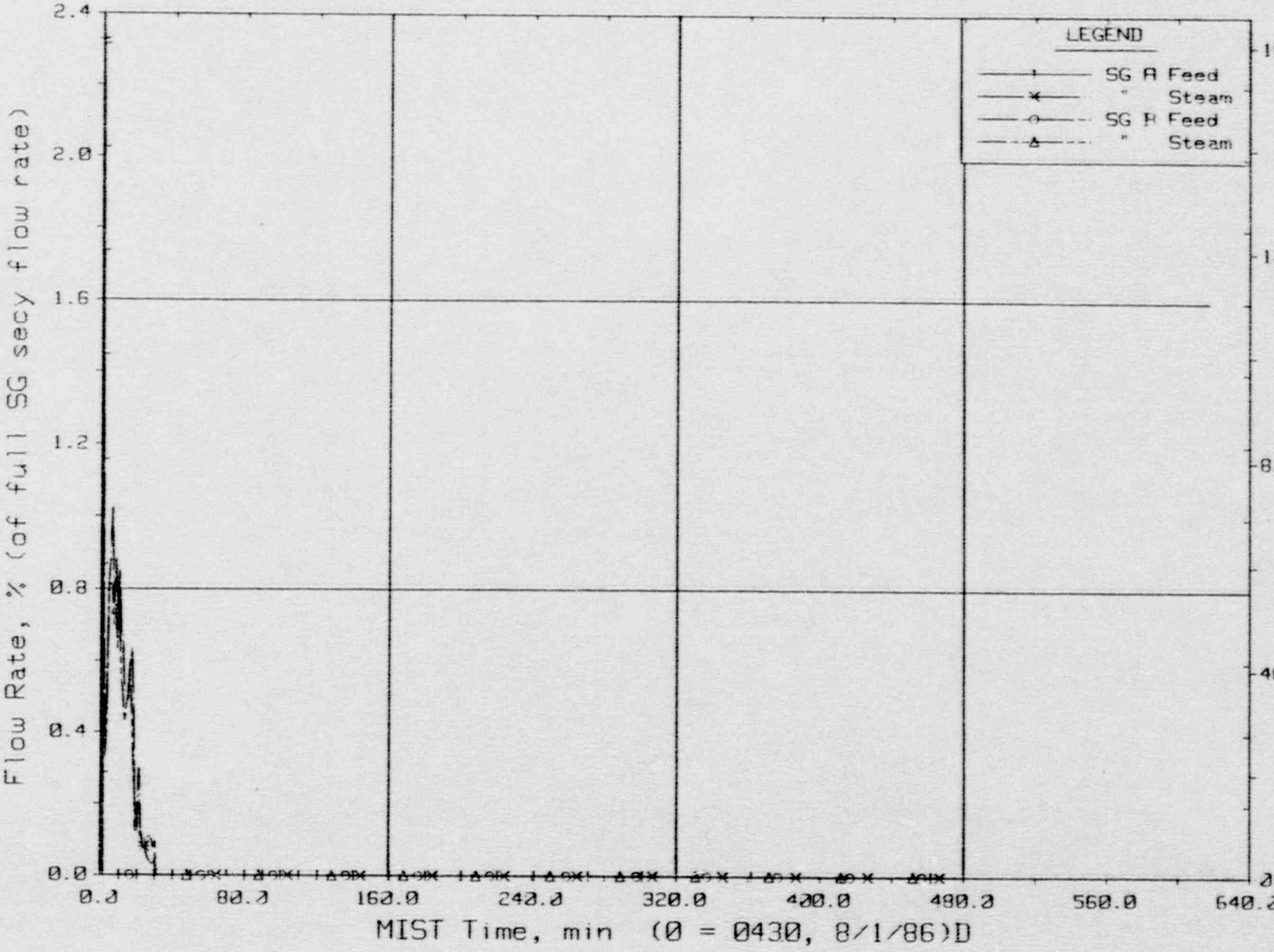
Reactor Vessel Void Fractions From Differential Pressures (RVVFs).

Tue May 24 18:00:58 1988

RVVF1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



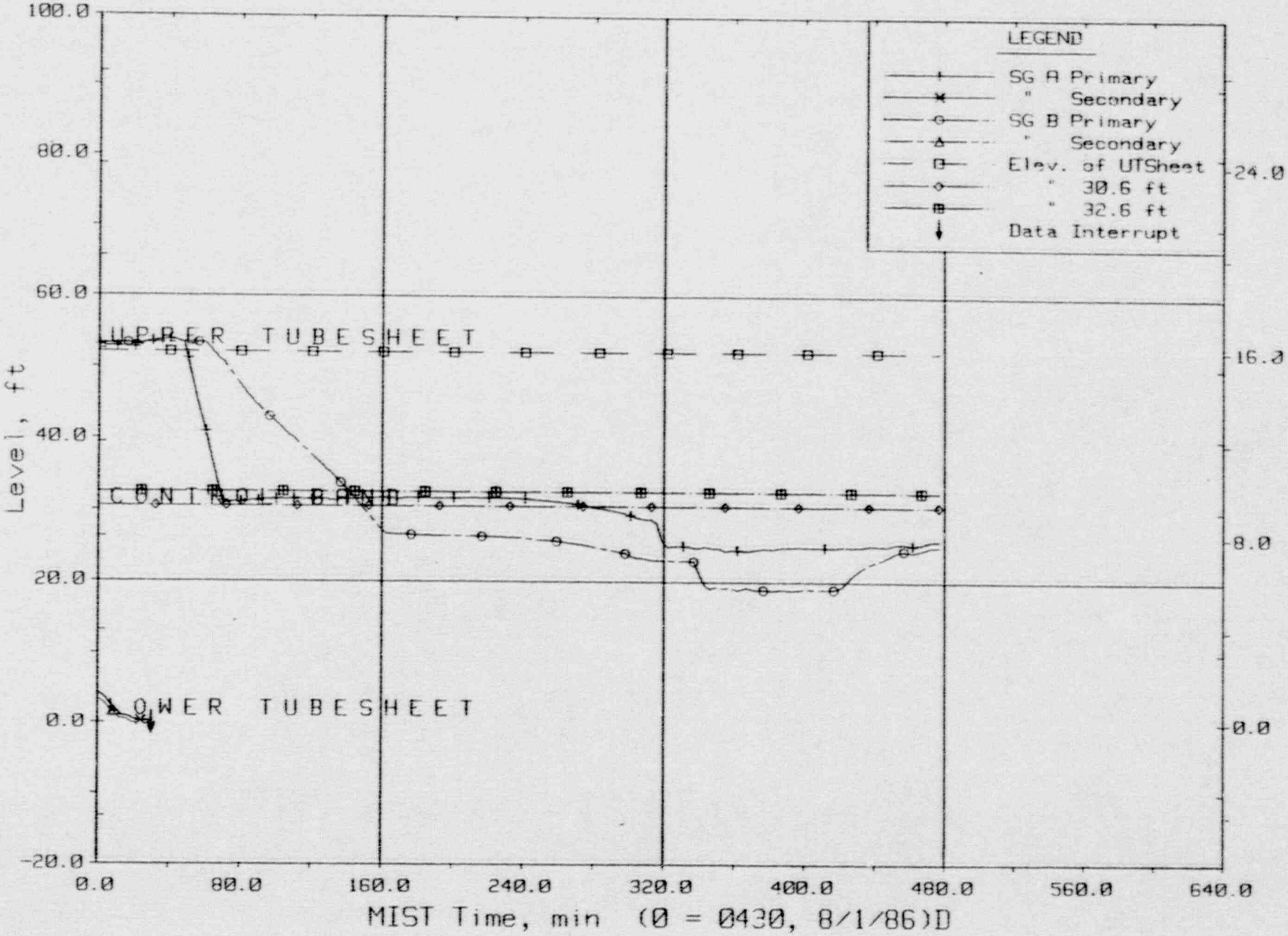
Steam Generator Secondary System Flow Rates.

Tue May 24 18:04:02 1988

SGFL2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



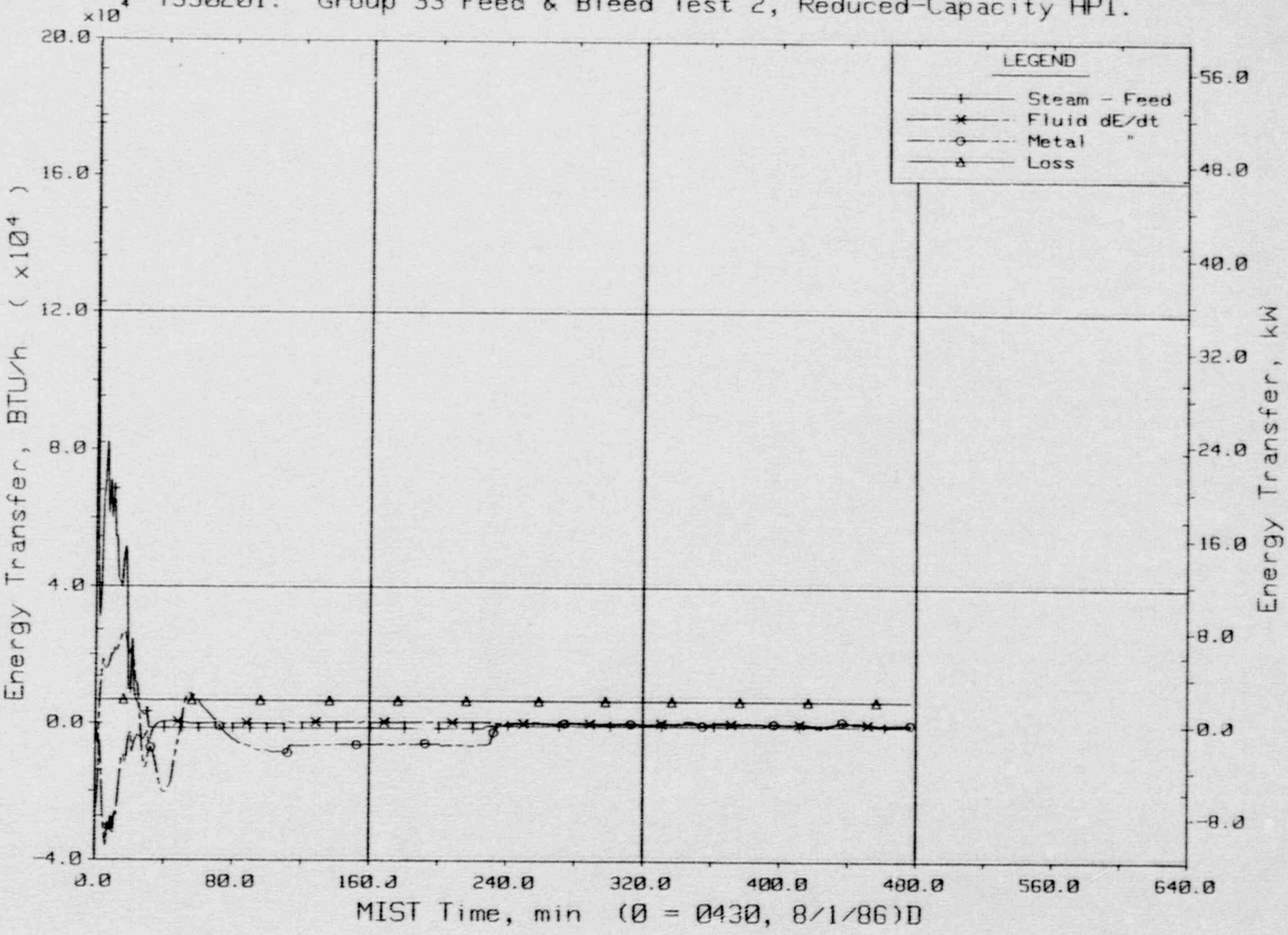
Steam Generator Collapsed Liquid Levels.

Tue May 24 18:07:23 1988

SGLV2

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



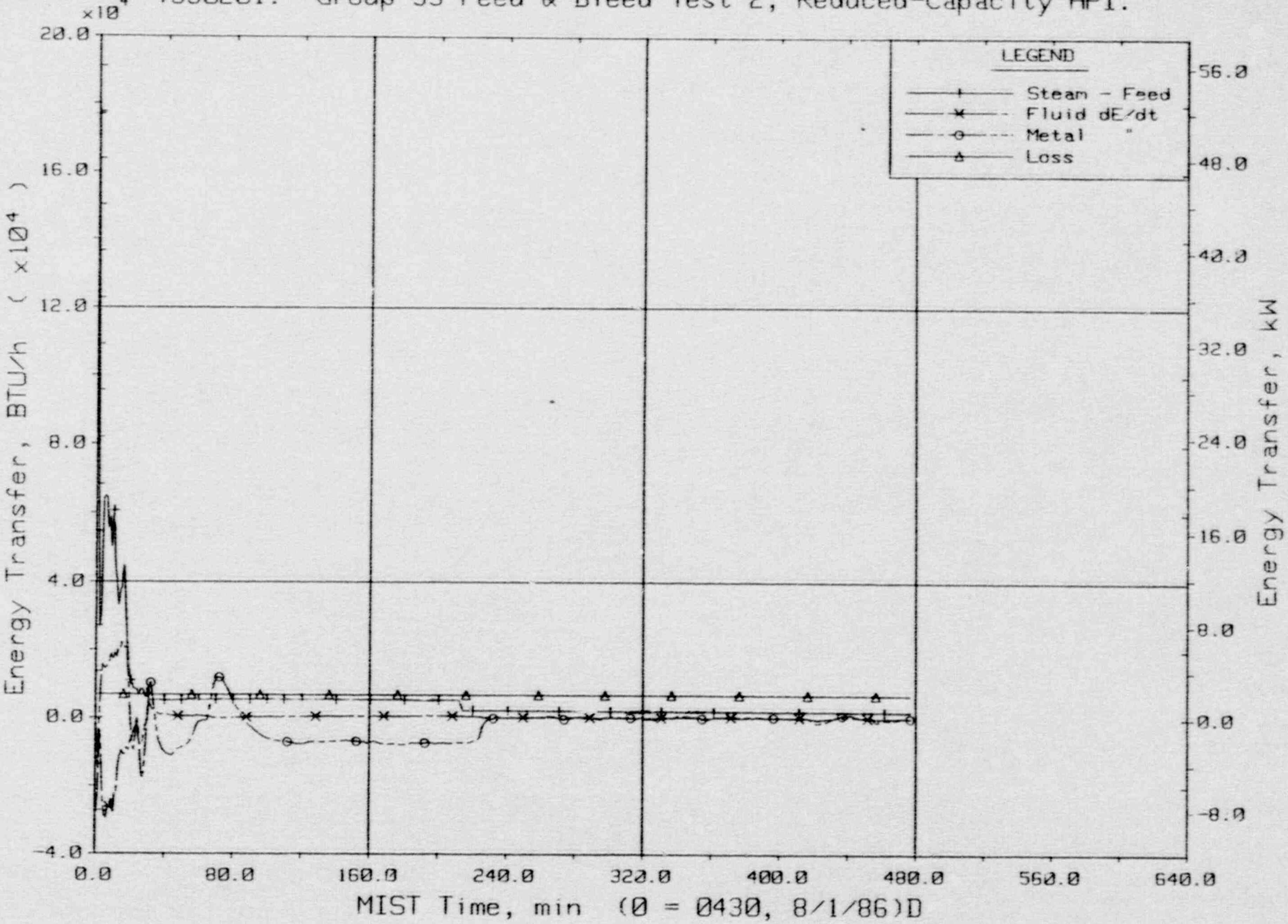
Steam Generator A Energy Transfer.

Tue May 24 10:14:02 1988

SGQE3

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



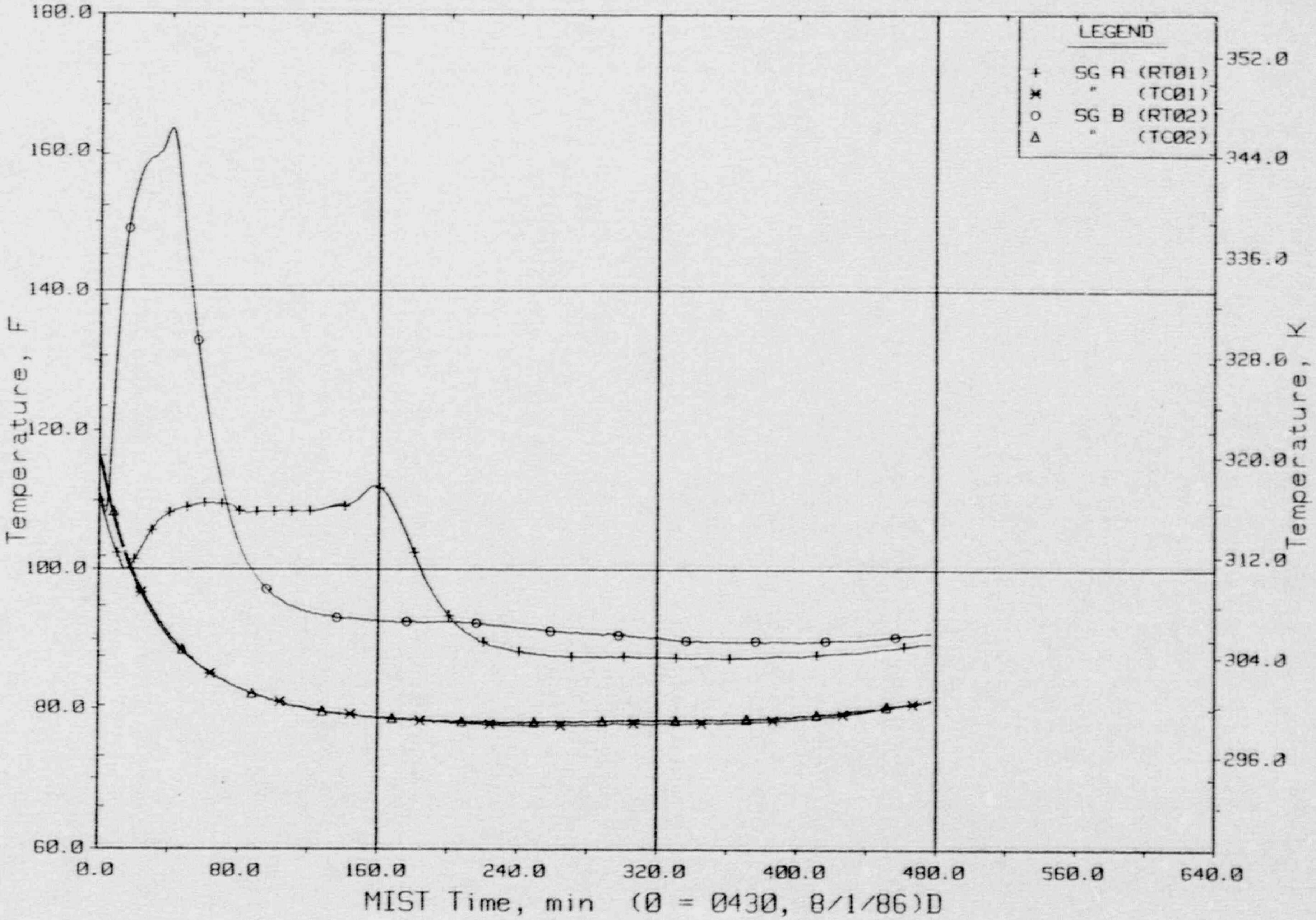
Steam Generator B Energy Transfer.

Tue May 24 18:17:26 1988

SGQE6

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



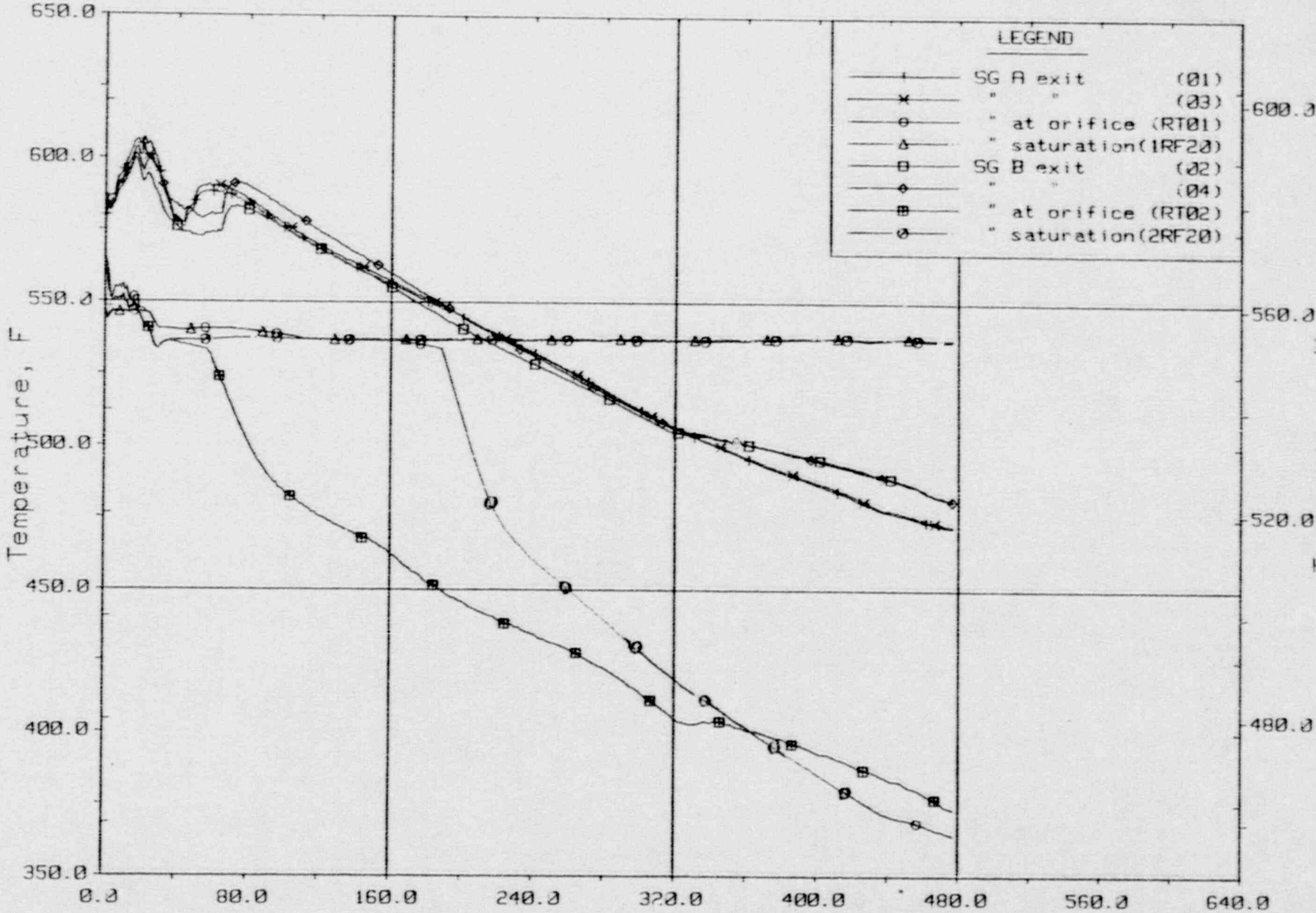
Feedwater Temperatures (SFs).

Tue May 24 10:20:52 1988

SGRT1

FINAL DATA

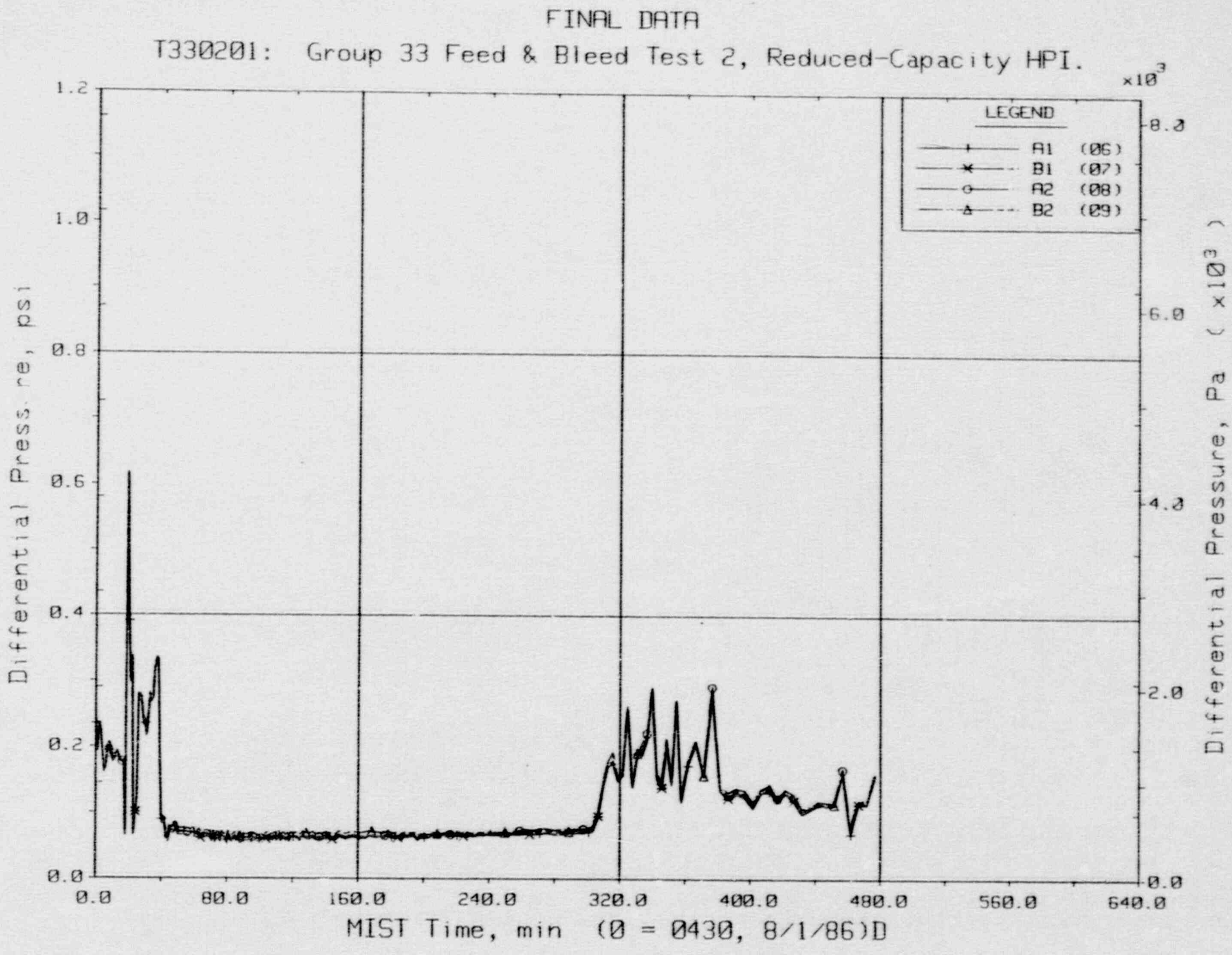
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Steam Generator Steam Outlet Temperatures (SSTCs).

Tue May 24 18:24:18 1988

SGRT2



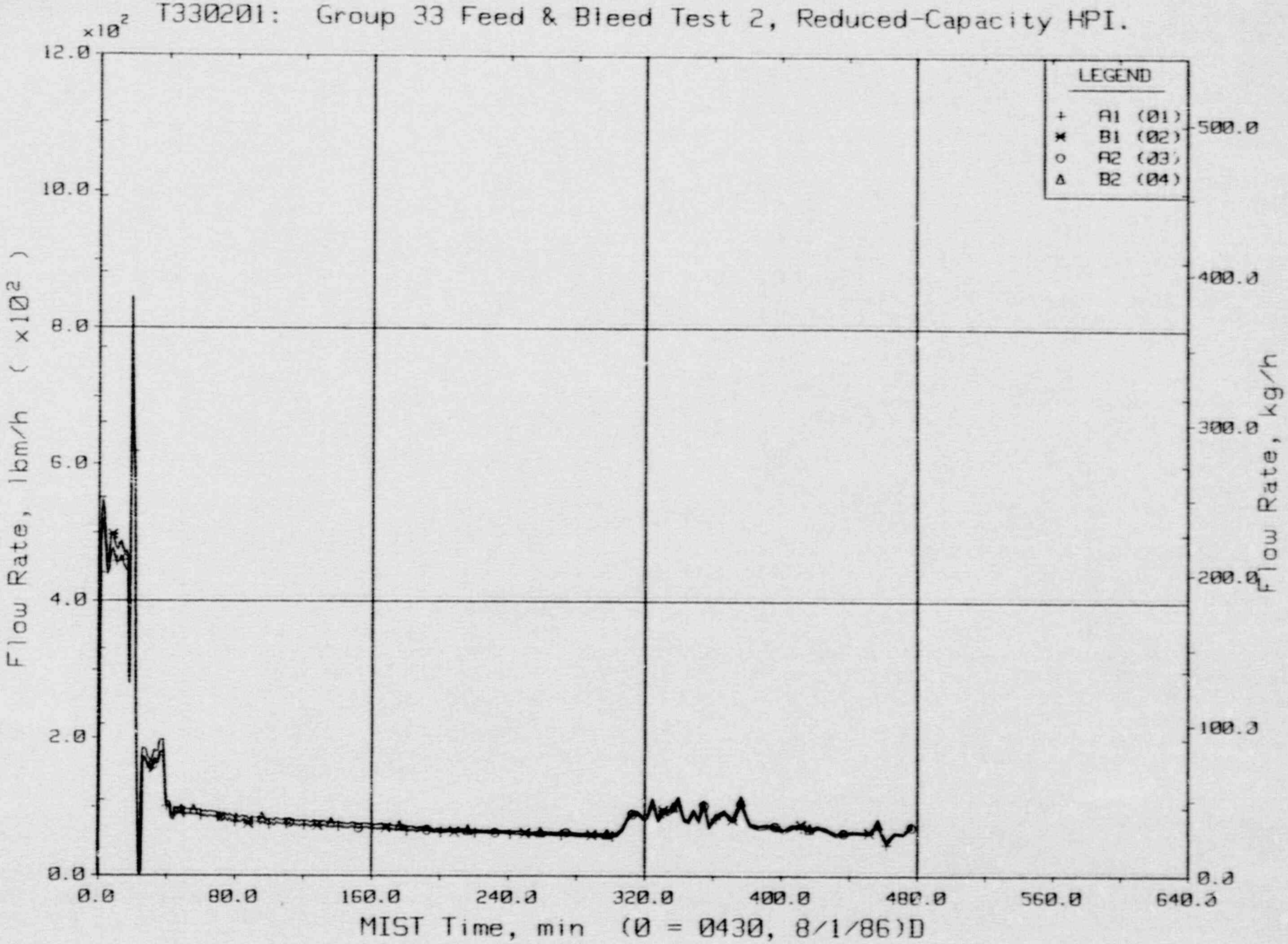
Reactor Vessel Vent Valve Differential Pressures (RVDPs).

Tue May 24 18:27:47 1988

VVDP1

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



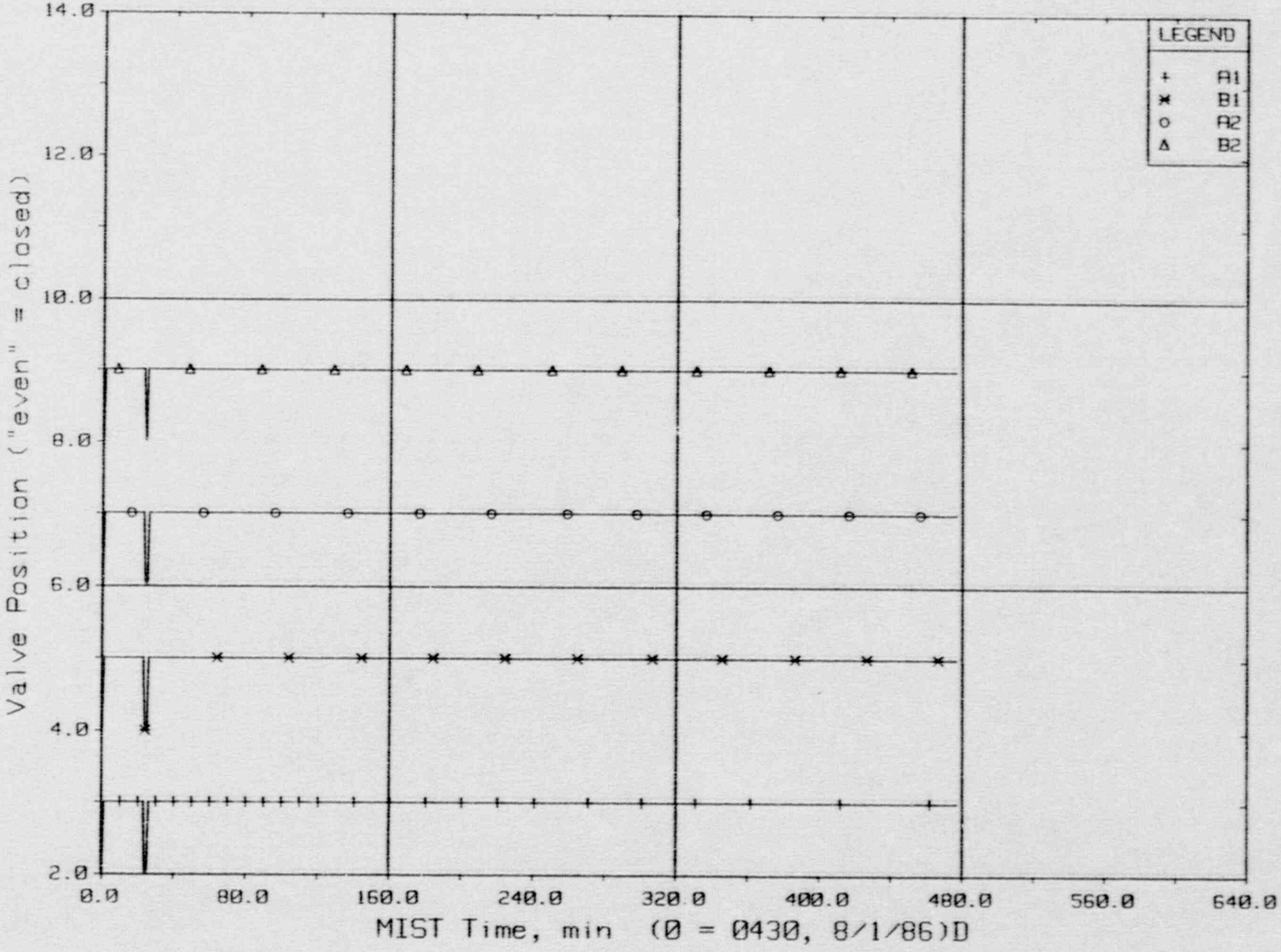
Reactor Vessel Vent Valve Flow Rates (RVORs).

Tue May 24 18:30:58 1988

VVFL1

FINAL DATA

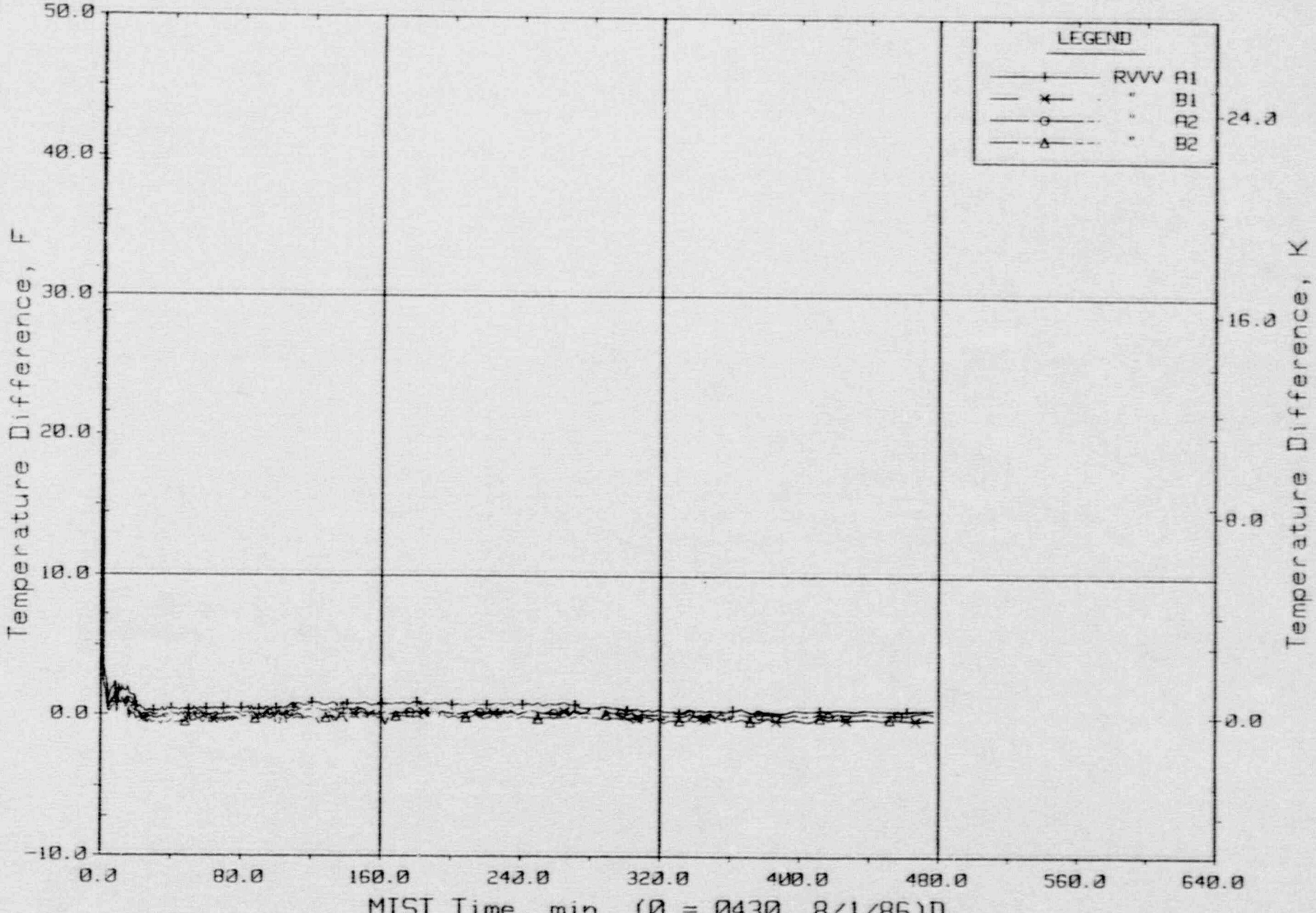
T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.



Reactor Vessel Vent Valve Positions.

FINAL DATA

T330201: Group 33 Feed & Bleed Test 2, Reduced-Capacity HPI.

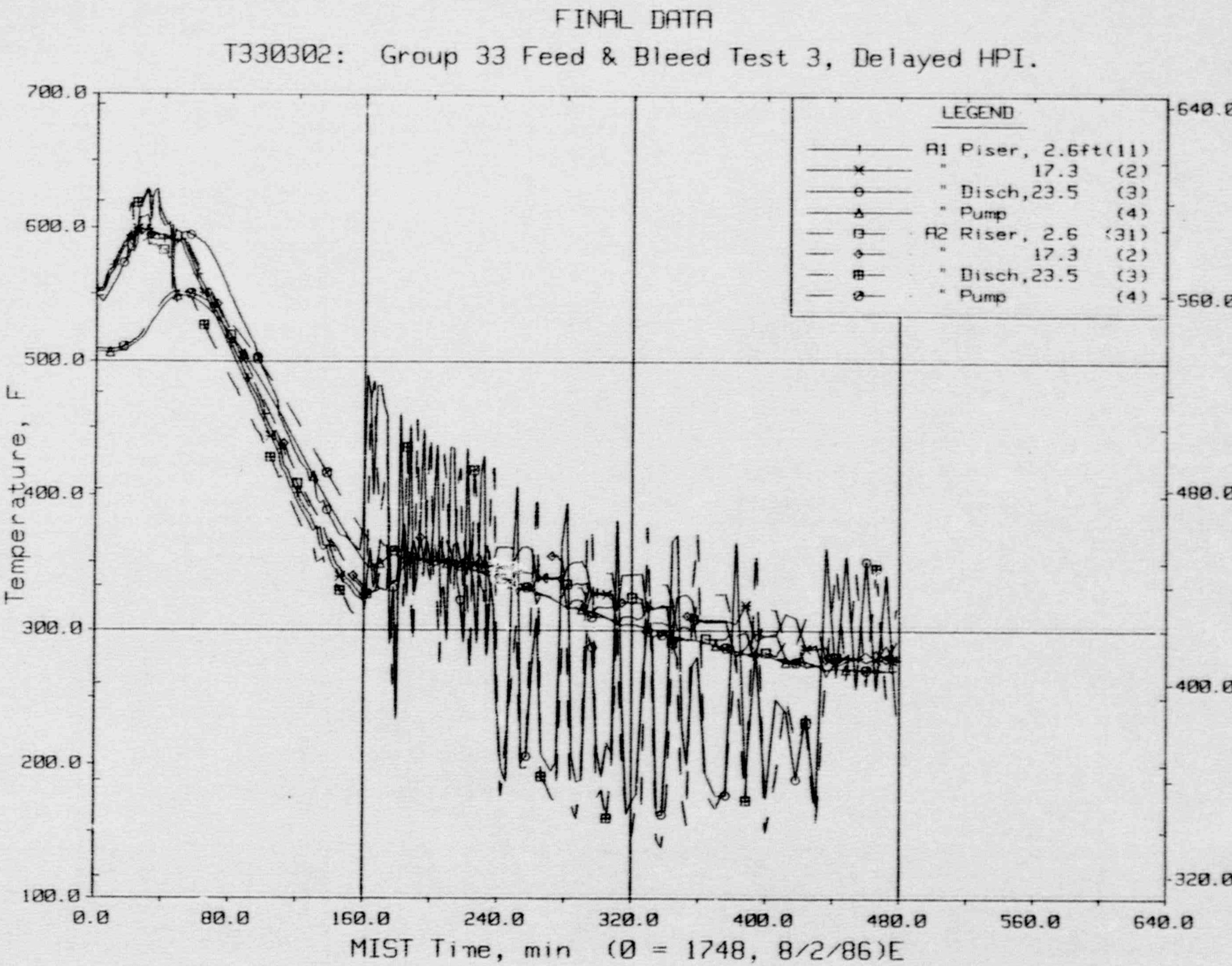


Temperature Differences Across Vent Valves.

Tue May 24 18:35:58 1988

VVTD1

T330302



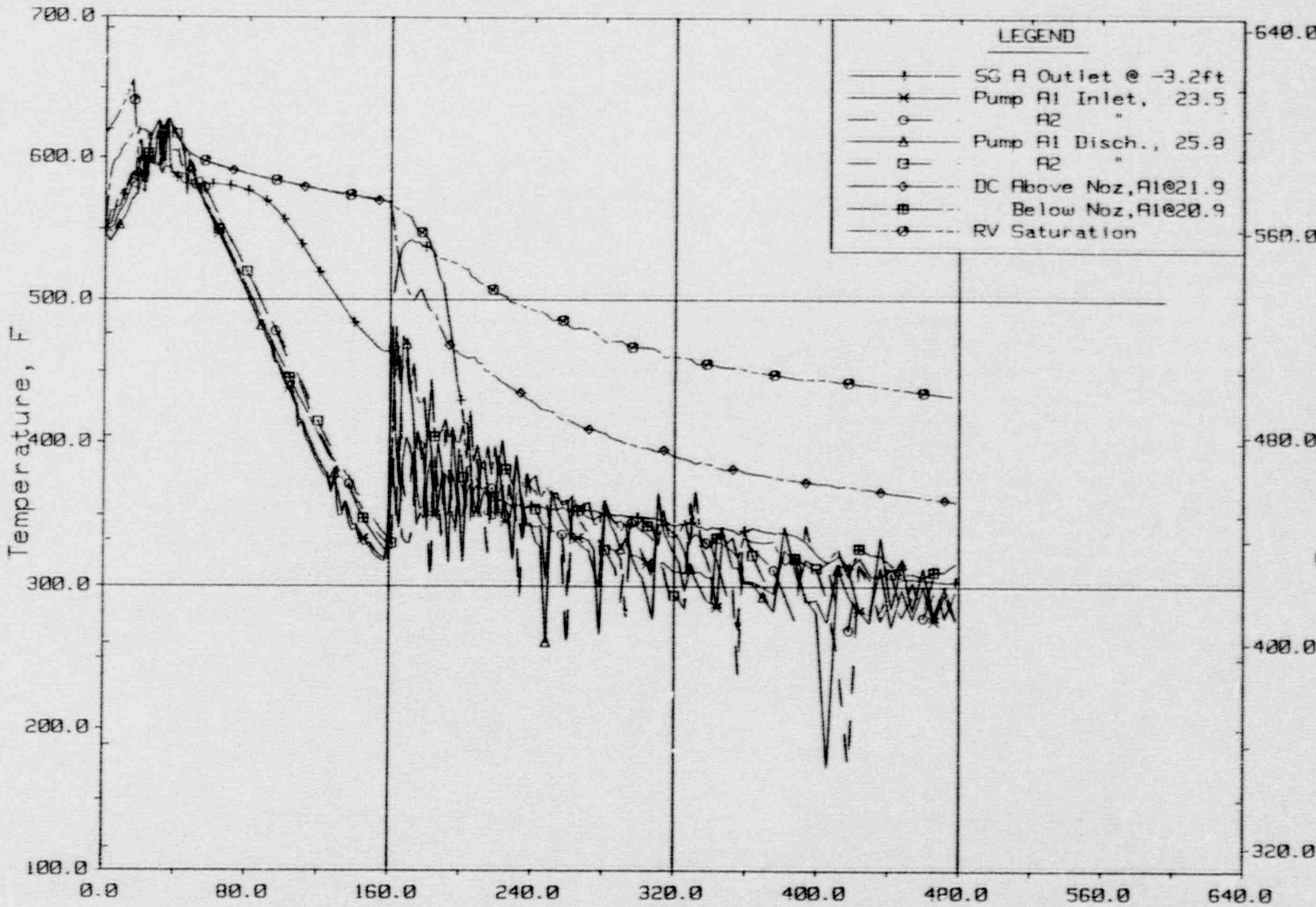
Loop A Cold Leg Metal Temperatures (C1,3MTs).

Tue May 24 15:35:15 1988

C1MT1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



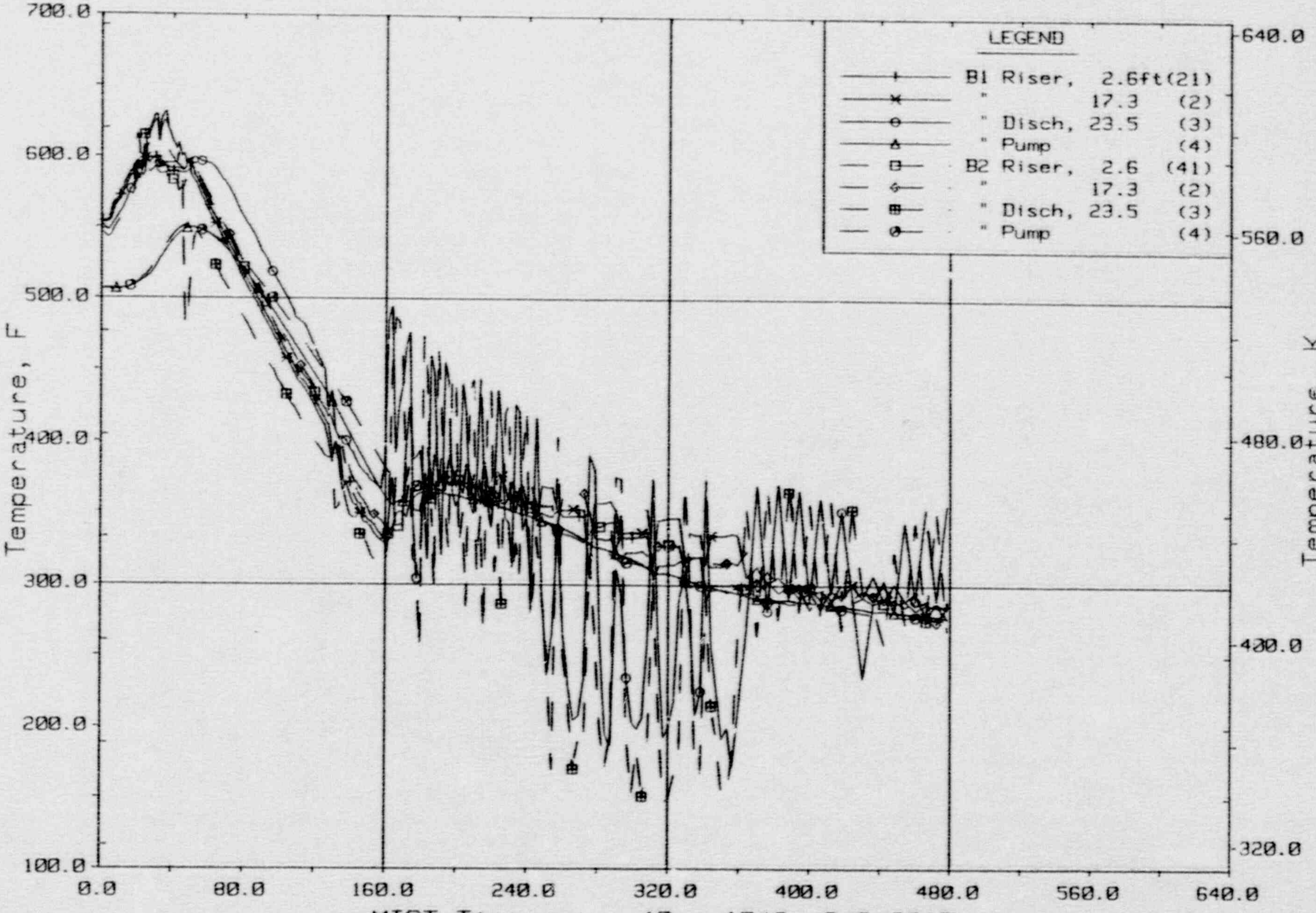
Loop A Cold Leg Fluid Temperatures (RTDs).

Tue May 24 15:40:00 1988

C1PT0

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



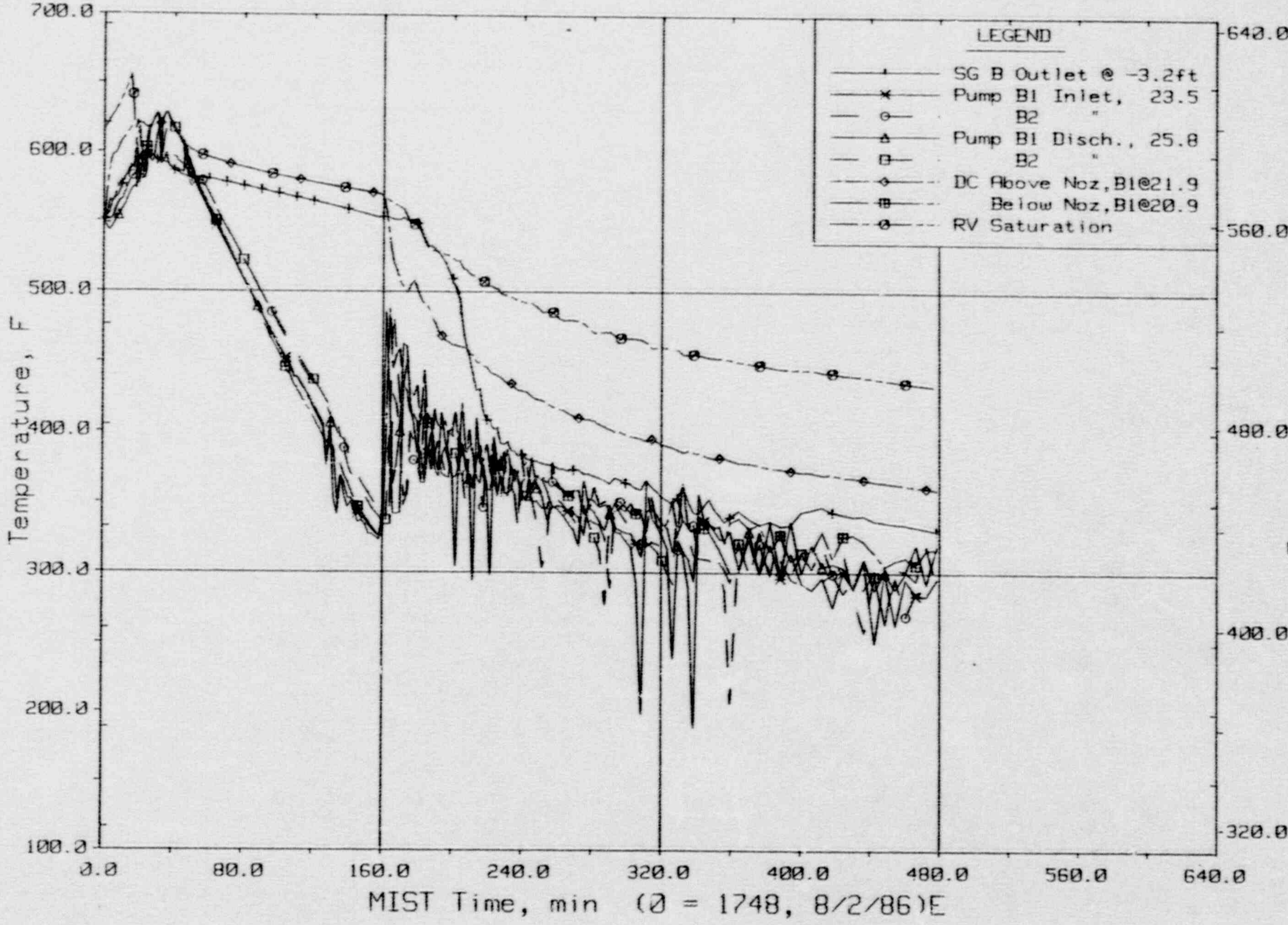
Loop B Cold Leg Metal Temperatures (C2,4MTs).

Tue May 24 15:44:34 1988

C2MT1

FINAL DATA

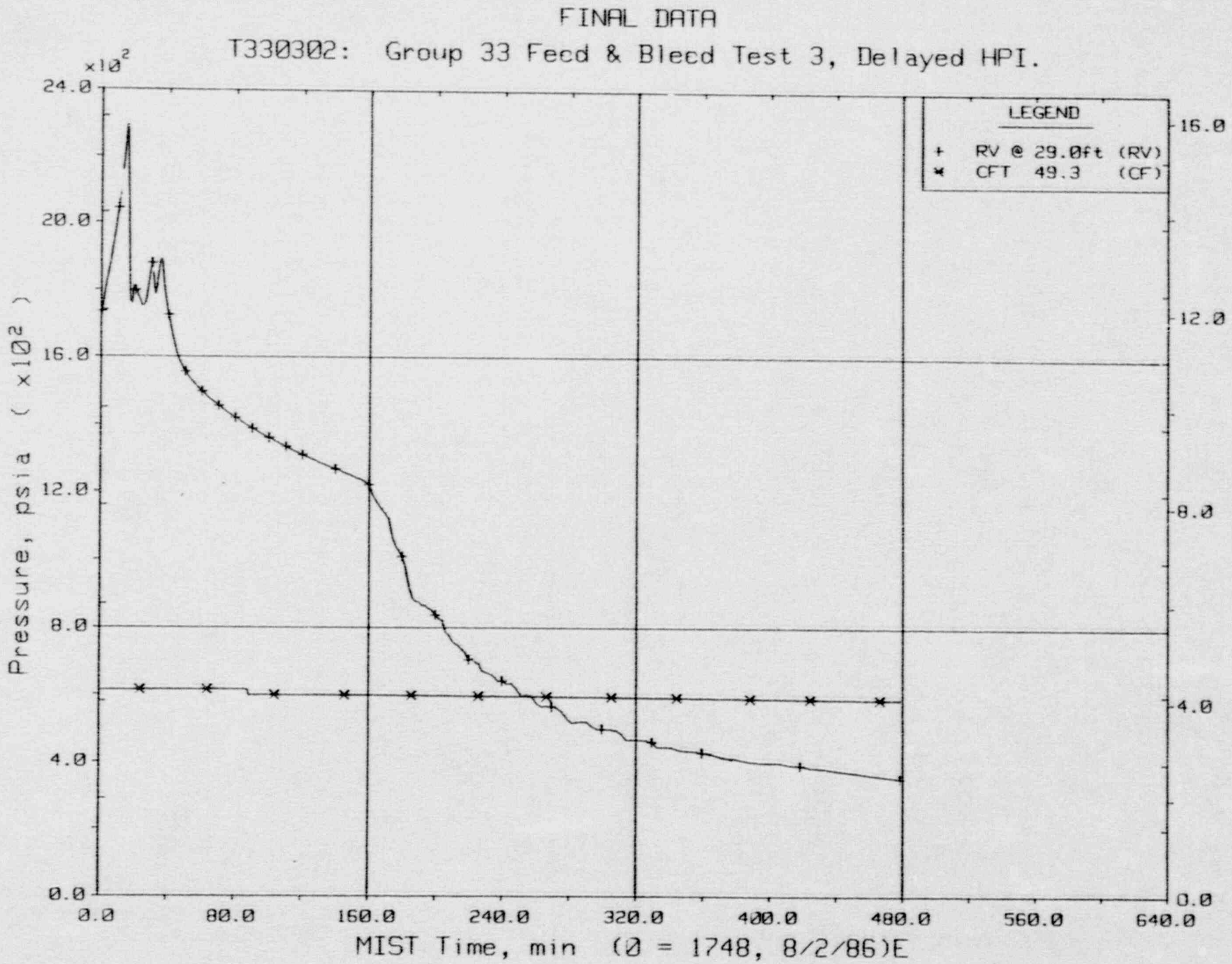
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Loop B Cold Leg Fluid Temperatures (RTDs).

Tue May 24 15:51:54 1988

C2RT0



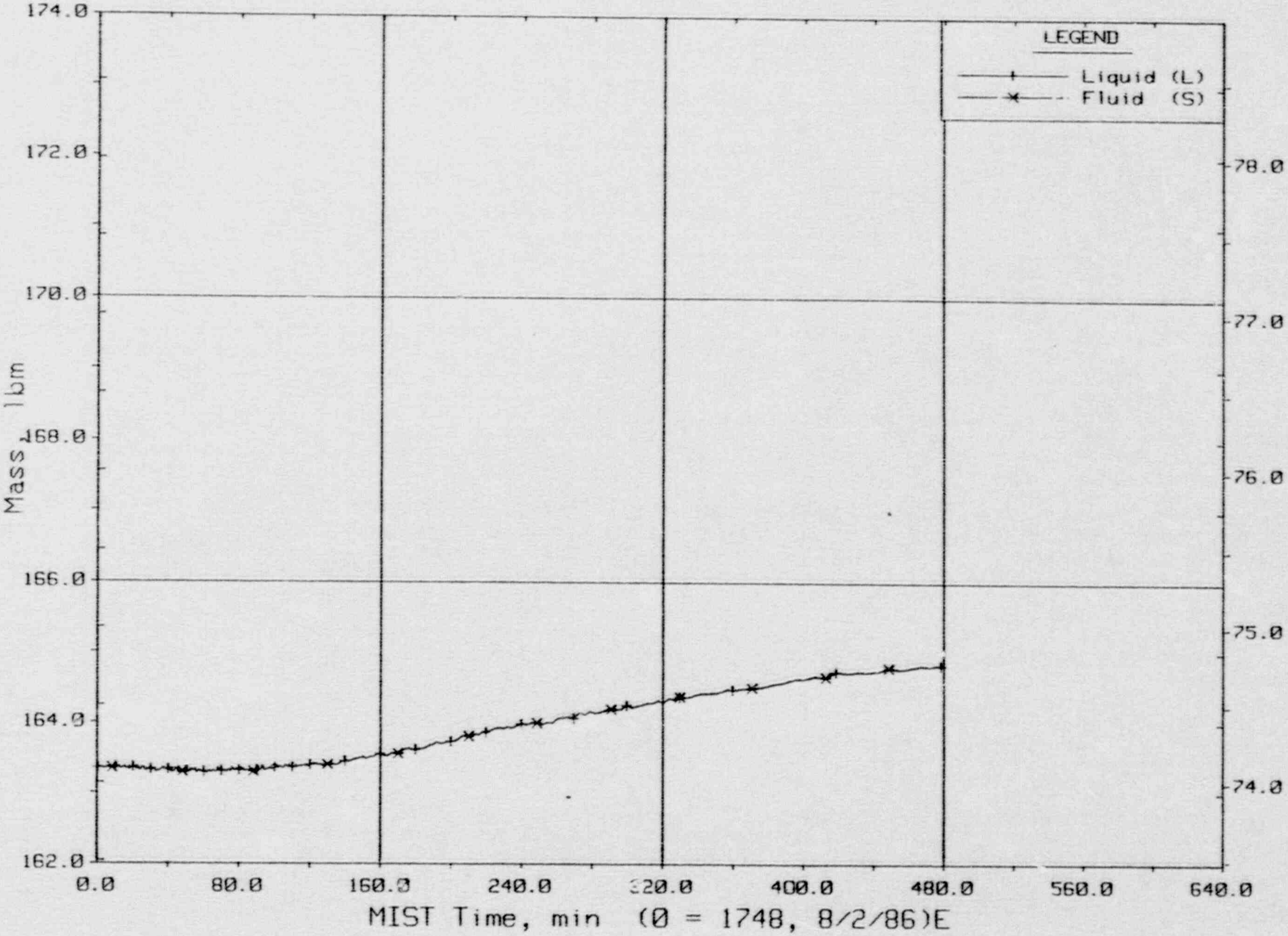
Primary System and Core Flood Tank Pressures (GP01s).

Tue May 24 15:55:13 1988

CFGP1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



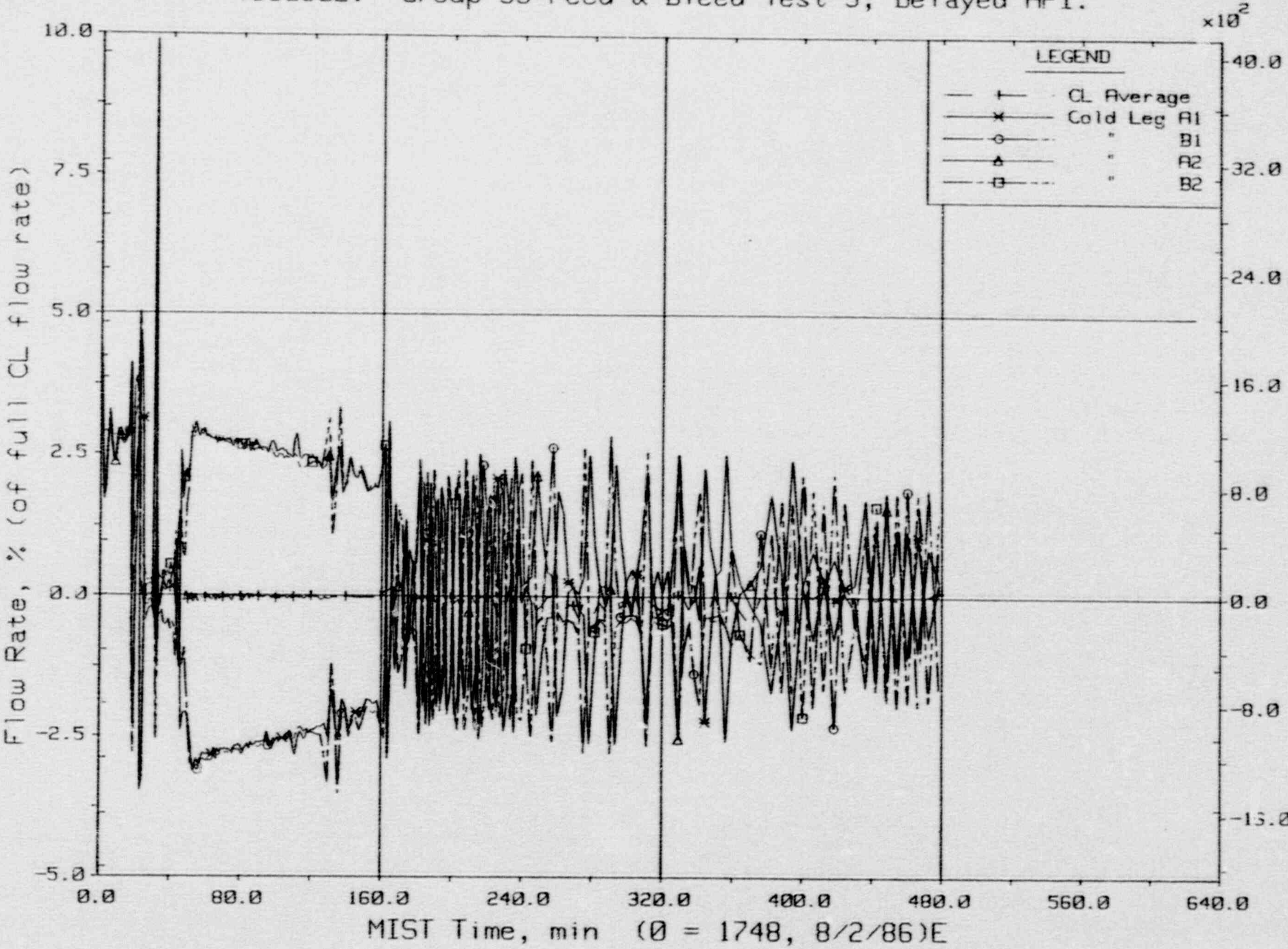
Core Flood Tank Liquid and Fluid Mass (CFMa20s).

Tue May 24 16:03:04 1988

CFML1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



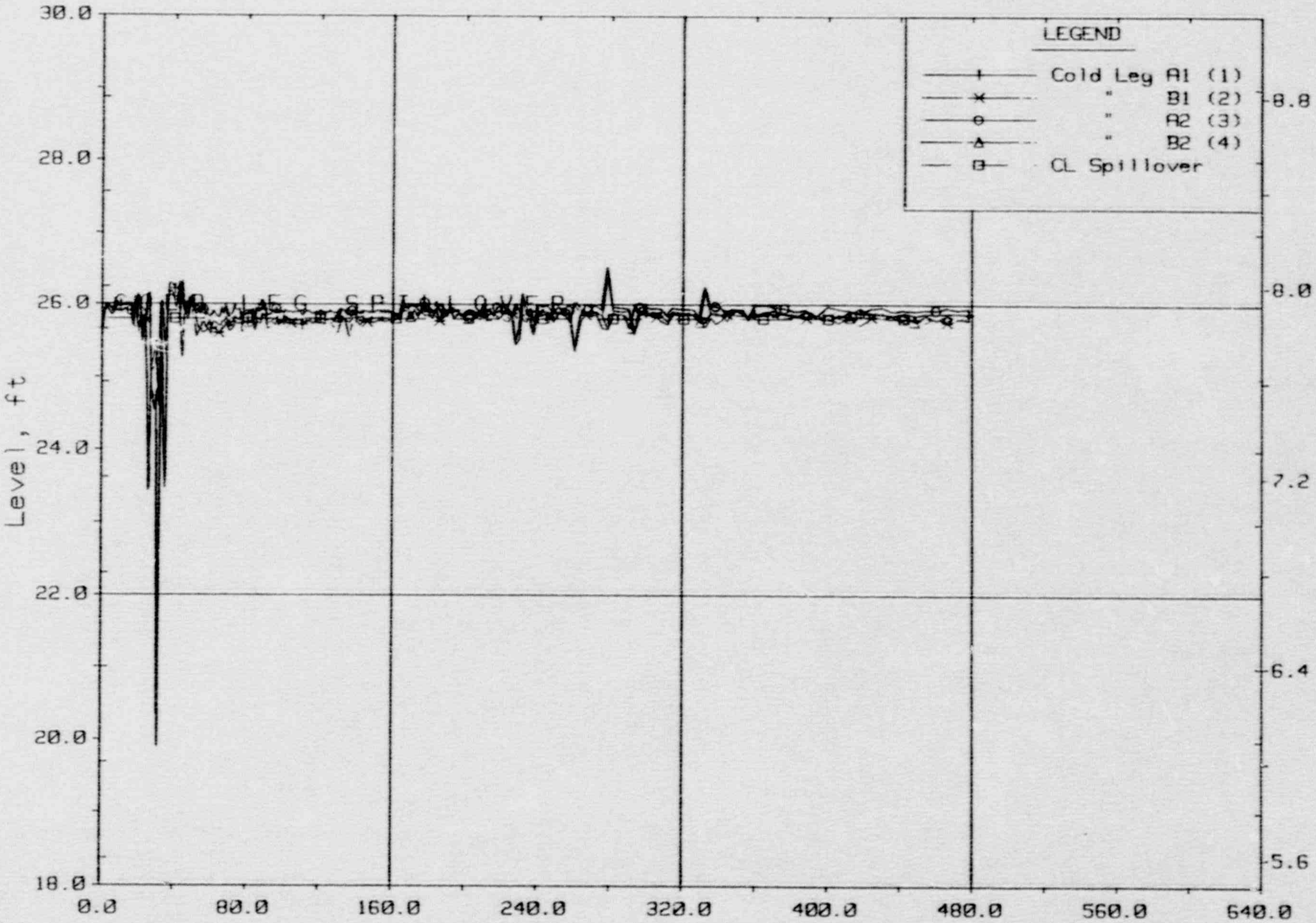
Cold Leg (Venturi) Flow Rates.

Tue May 24 16:07:42 1988

CLFL1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



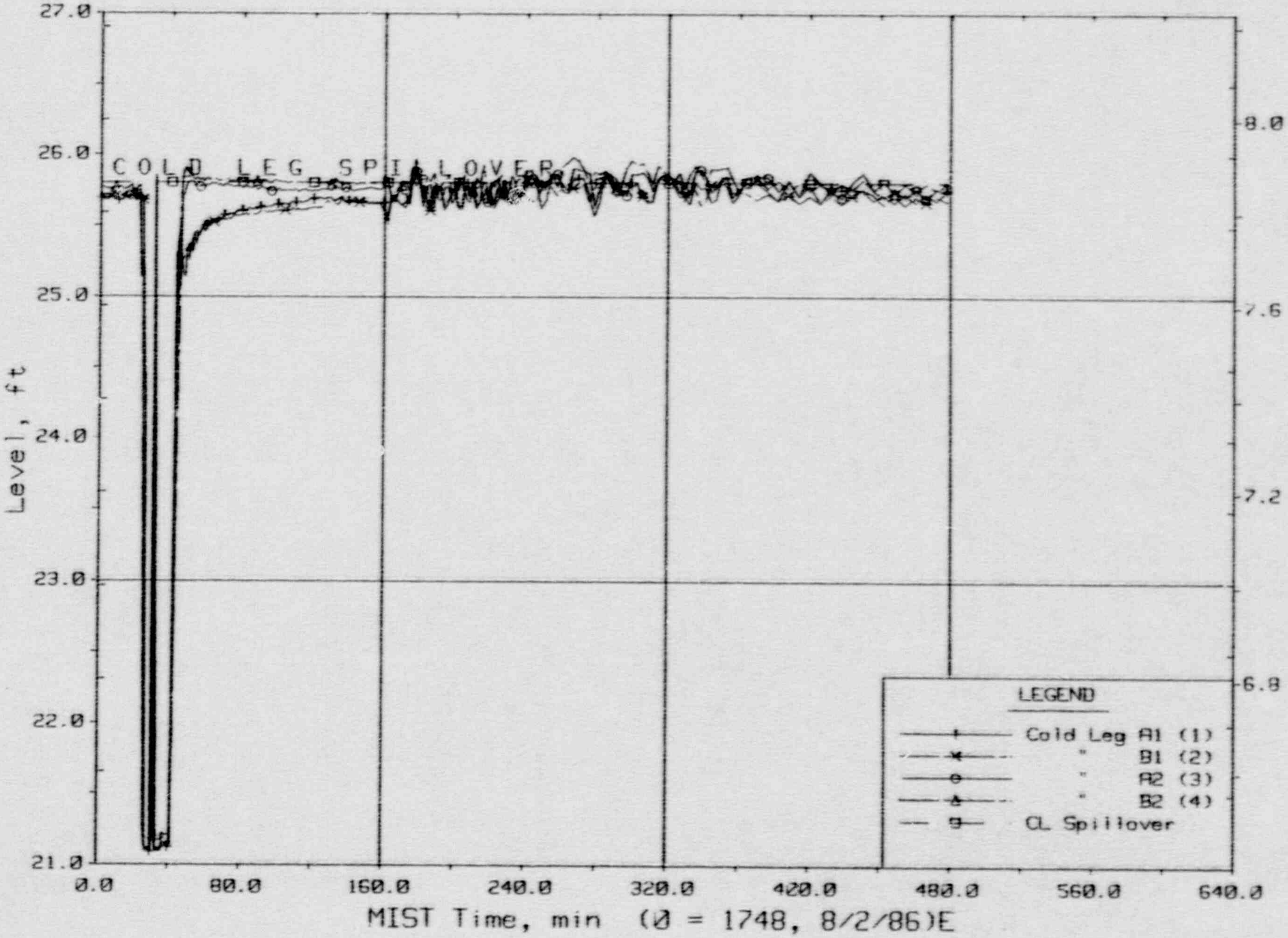
Cold Leg Suction Collapsed Liquid Levels (CnLV22s).

Tue May 24 16:11:49 1988

CLLV4

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



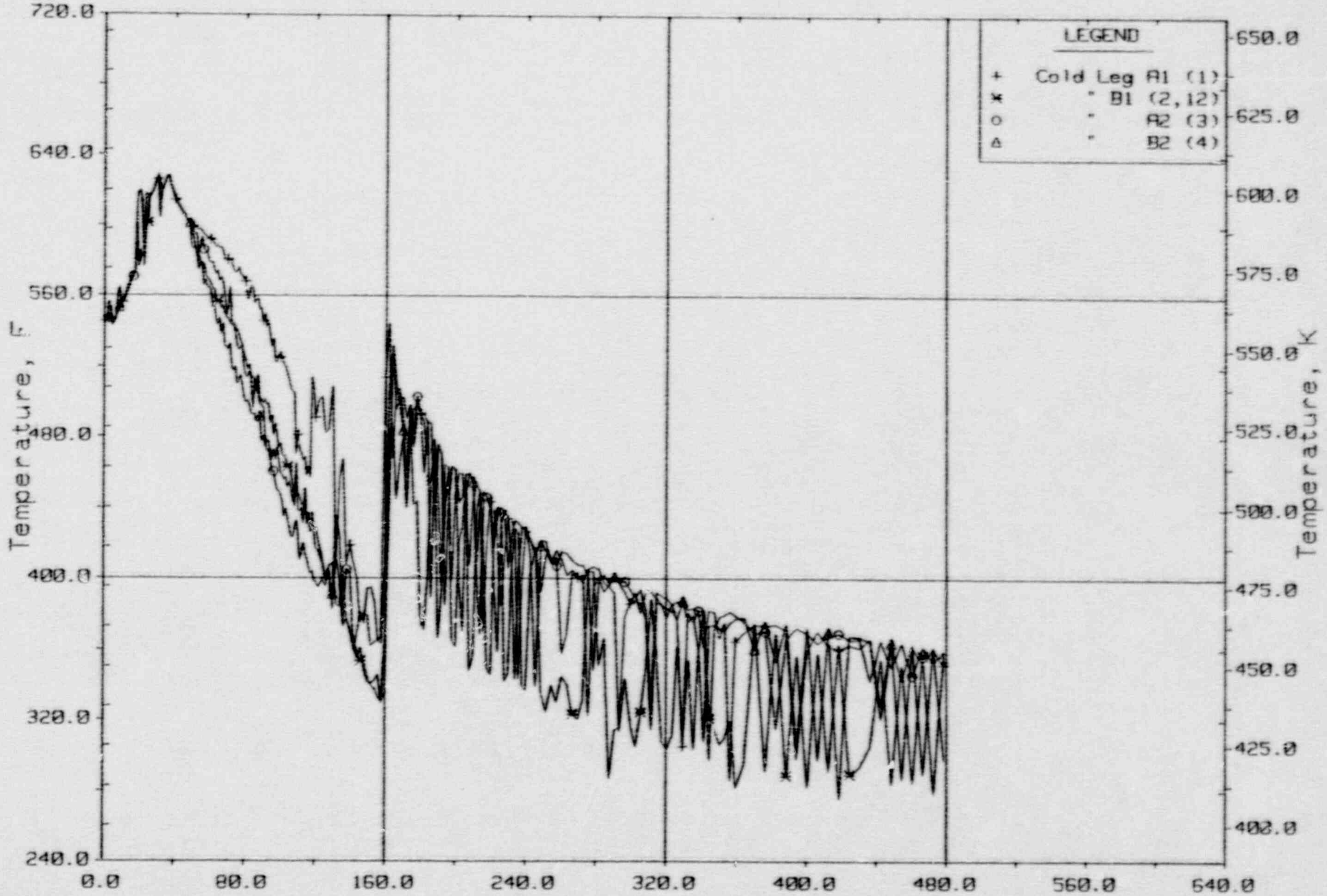
Cold Leg Discharge Collapsed Liquid Levels (CnLV23s).

Tue May 24 16:15:16 1988

CLLV5

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



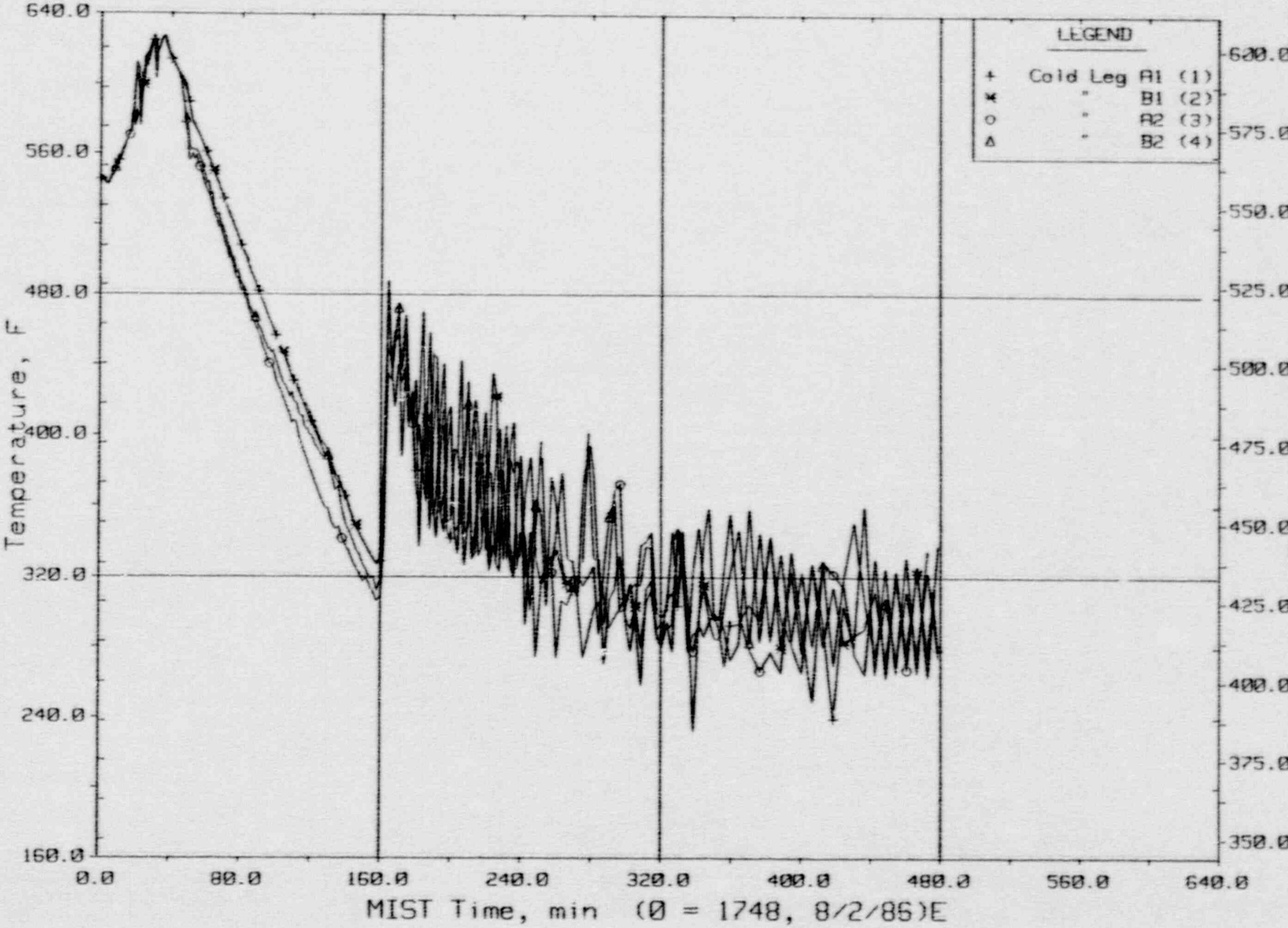
Cold Leg Nozzle Fluid Temperatures, Top of Rake (21.3ft, CnTCIls).

Tue May 24 16:20:40 1988

CLTC1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



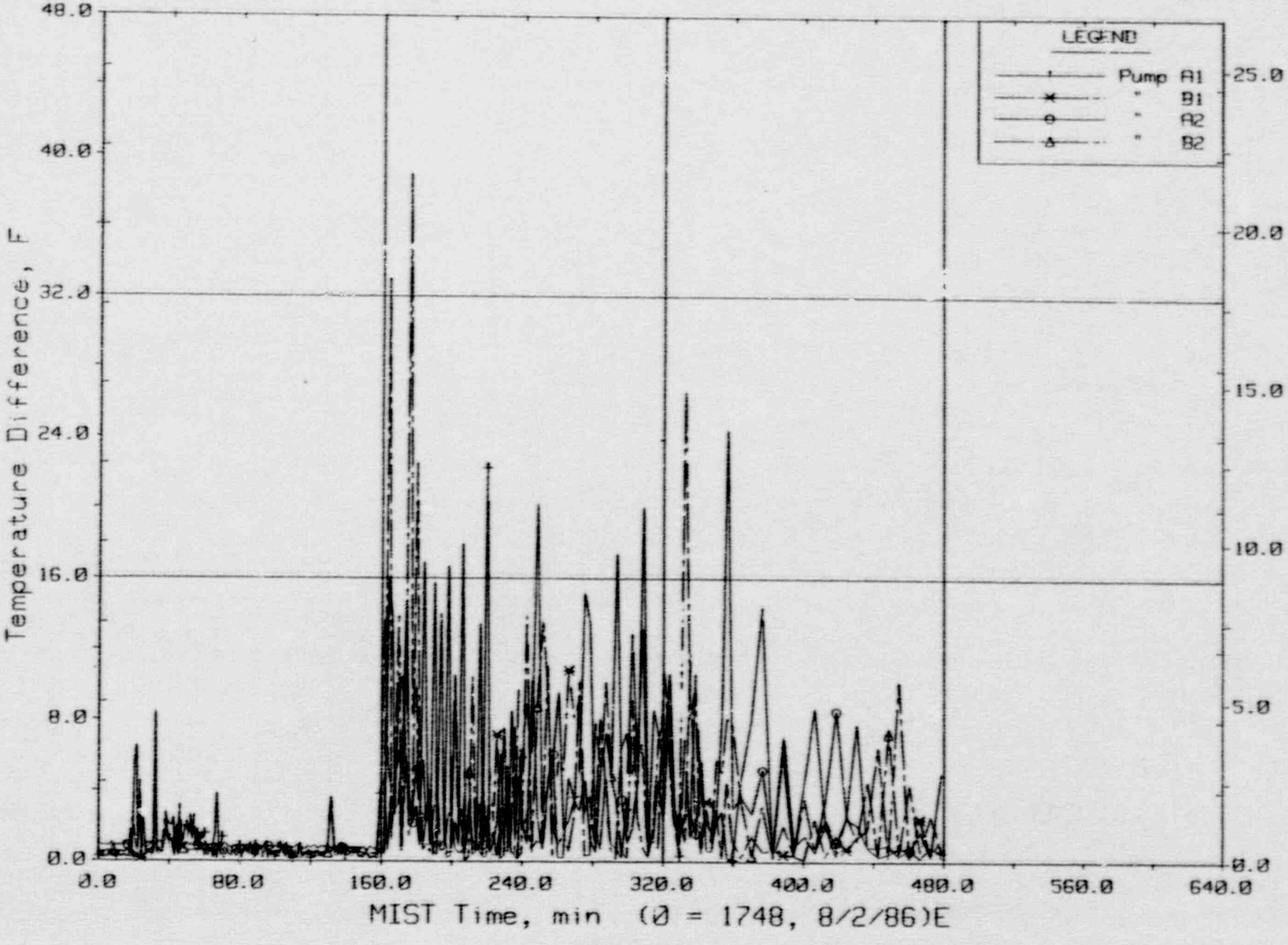
Cold Leg Nozzle Fluid Temperatures, Bottom of Rake (21.2ft, CnTC14s).

Tue May 24 16:24:03 1988

CLTC2

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



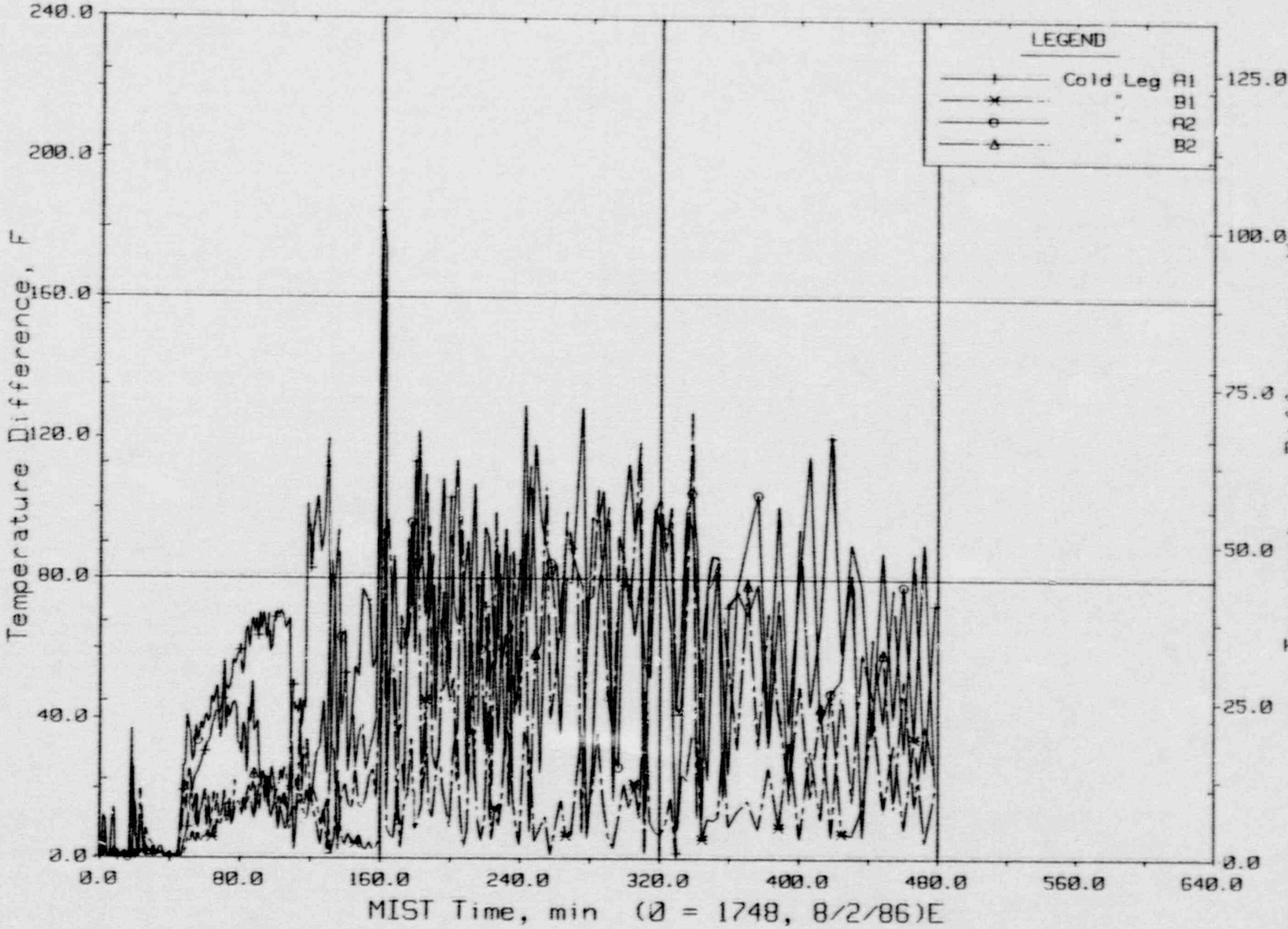
Maximum Differences Among RCP Rake FLuid Temperatures.

Tue May 24 16:27:03 1988

CLTD1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



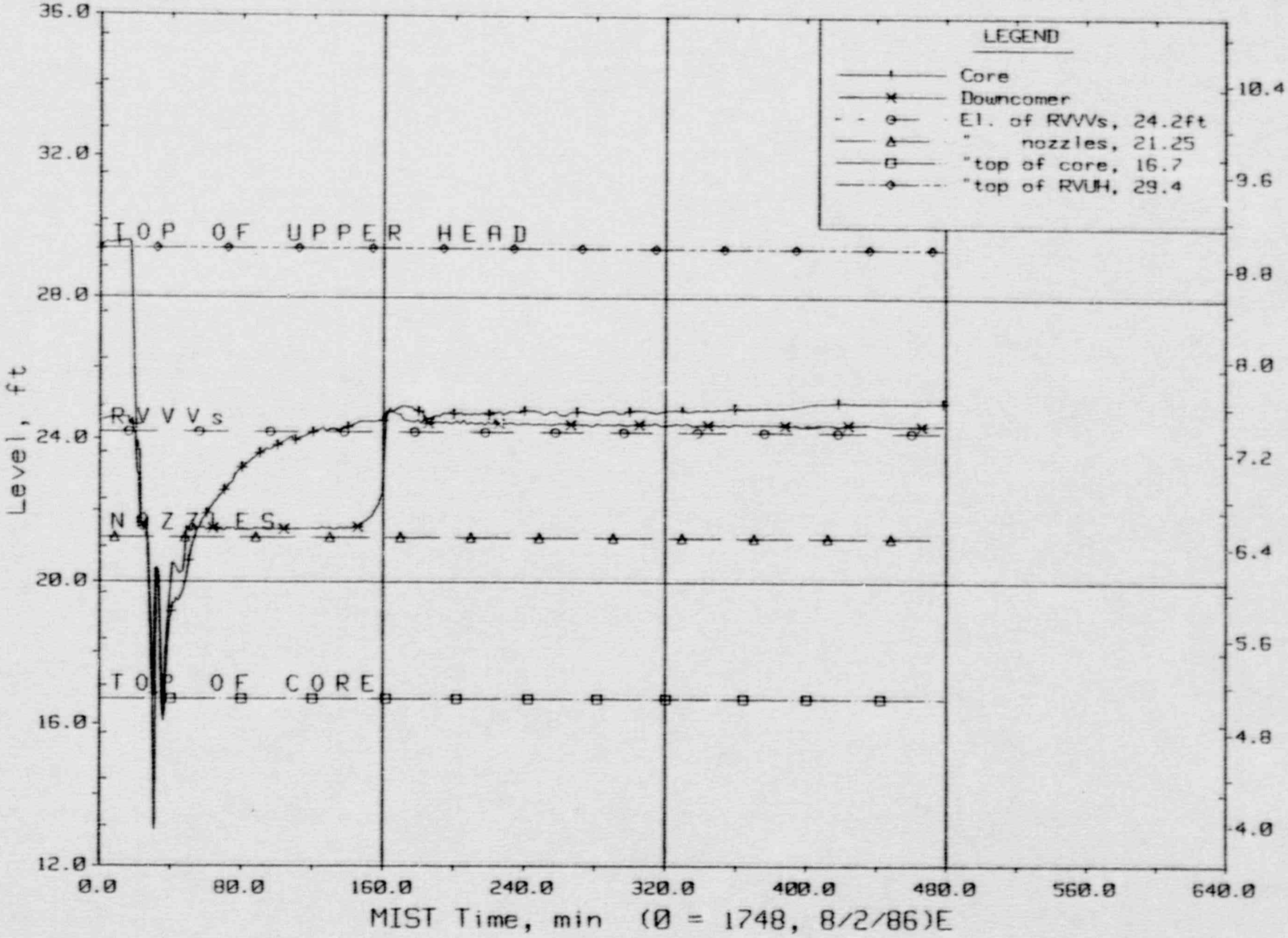
Maximum Differences Among CL Nozzle Rake Fluid Temperatures.

Tue May 24 16:30:22 1988

CLTD2

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



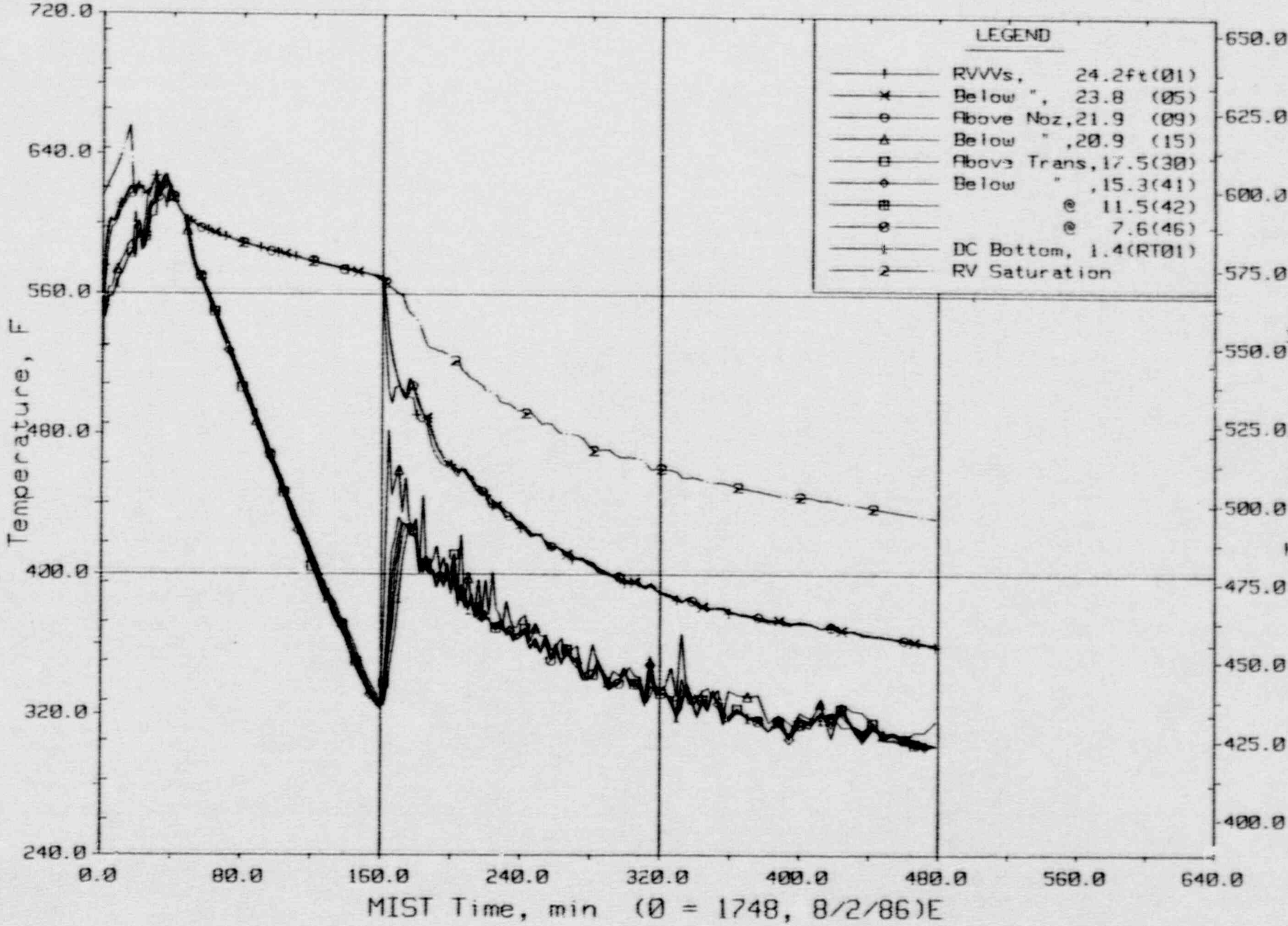
Core Region Collapsed Liquid Levels.

Tue May 24 16:34:22 1988

COLV1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



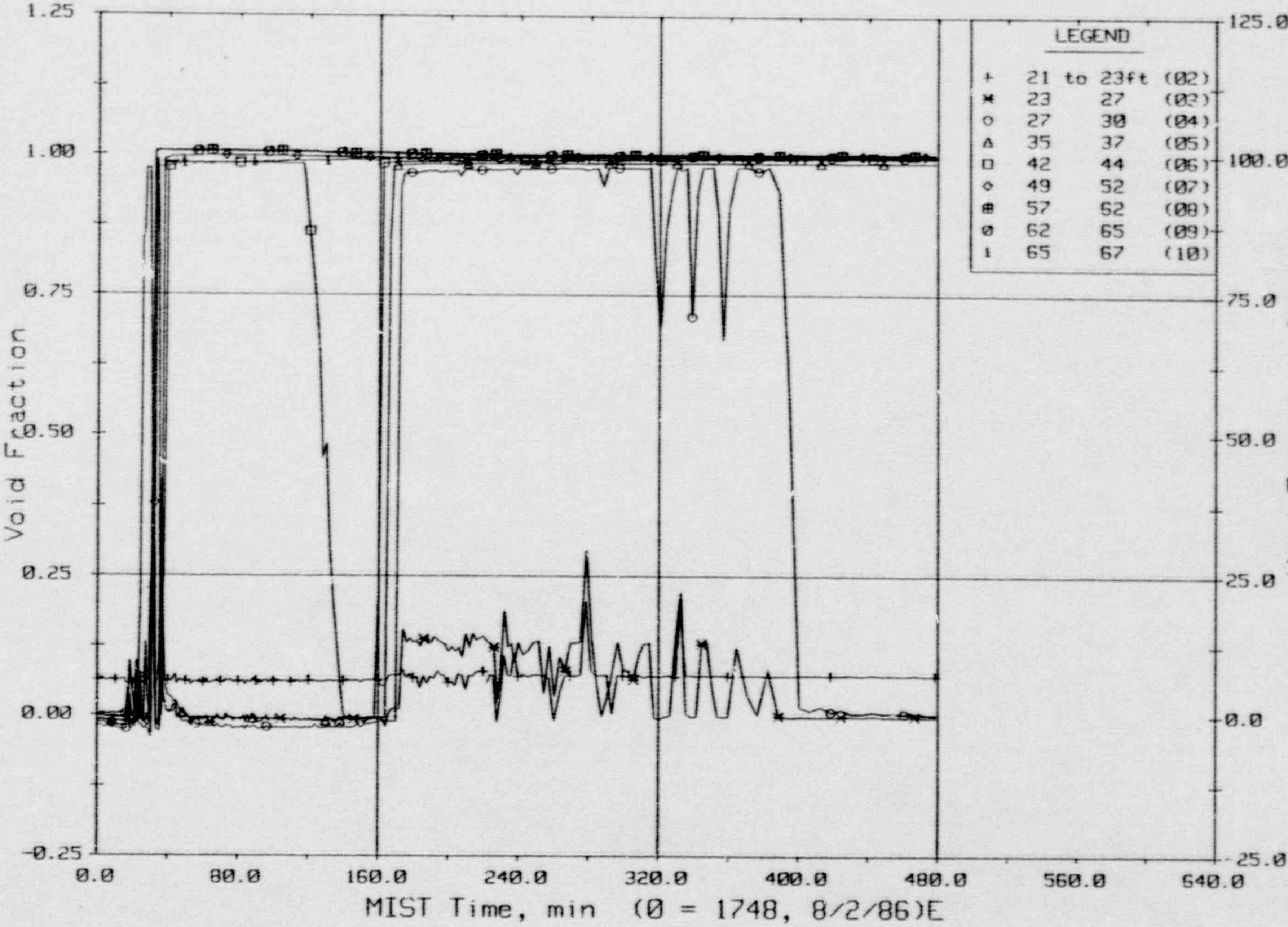
Downcomer Quadrant A1 Fluid emperatures (DCTCs).

Tue May 24 16:45:14 1988

DCTC6

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



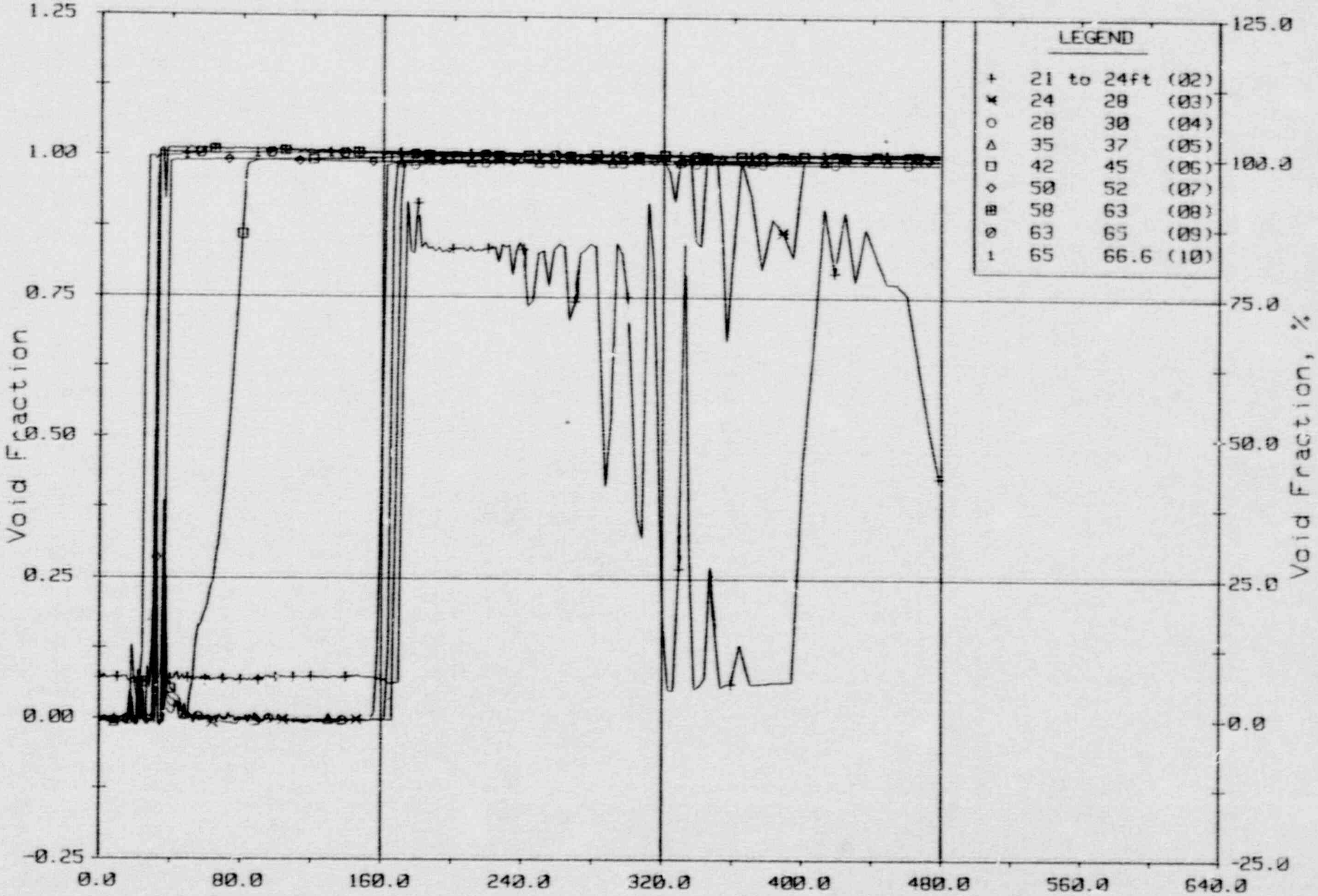
Hot Leg A Riser Void Fractions From Differential Pressures (H1VFs).

Tue May 24 16:55:10 1988

H1VF1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.

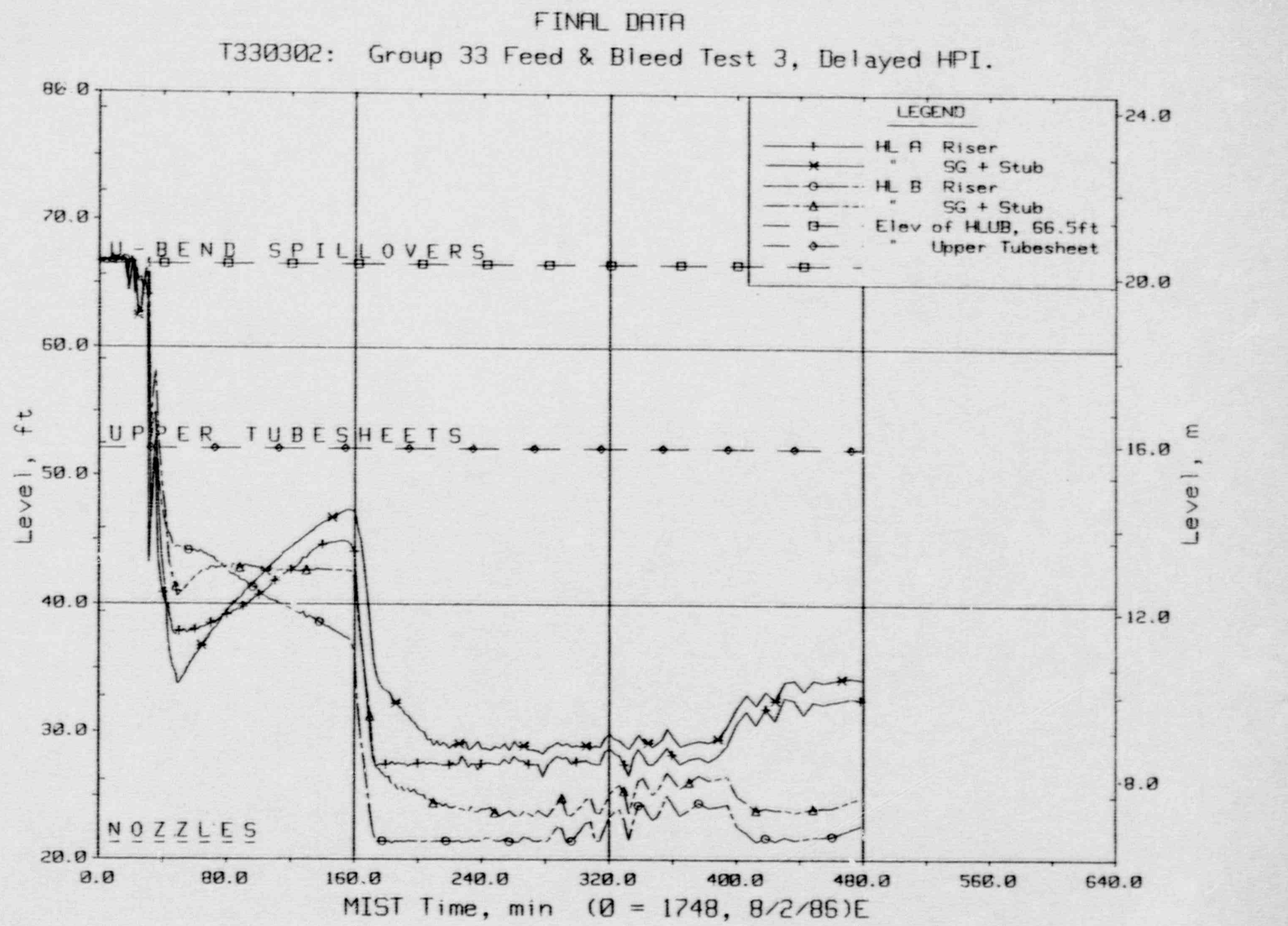


MIST Time, min (0 = 1748, 8/2/86)E

Hot Leg B Riser Void Fraction From Differential Pressures (H2VFs).

Tue May 24 16:59:52 1988

H2VF1



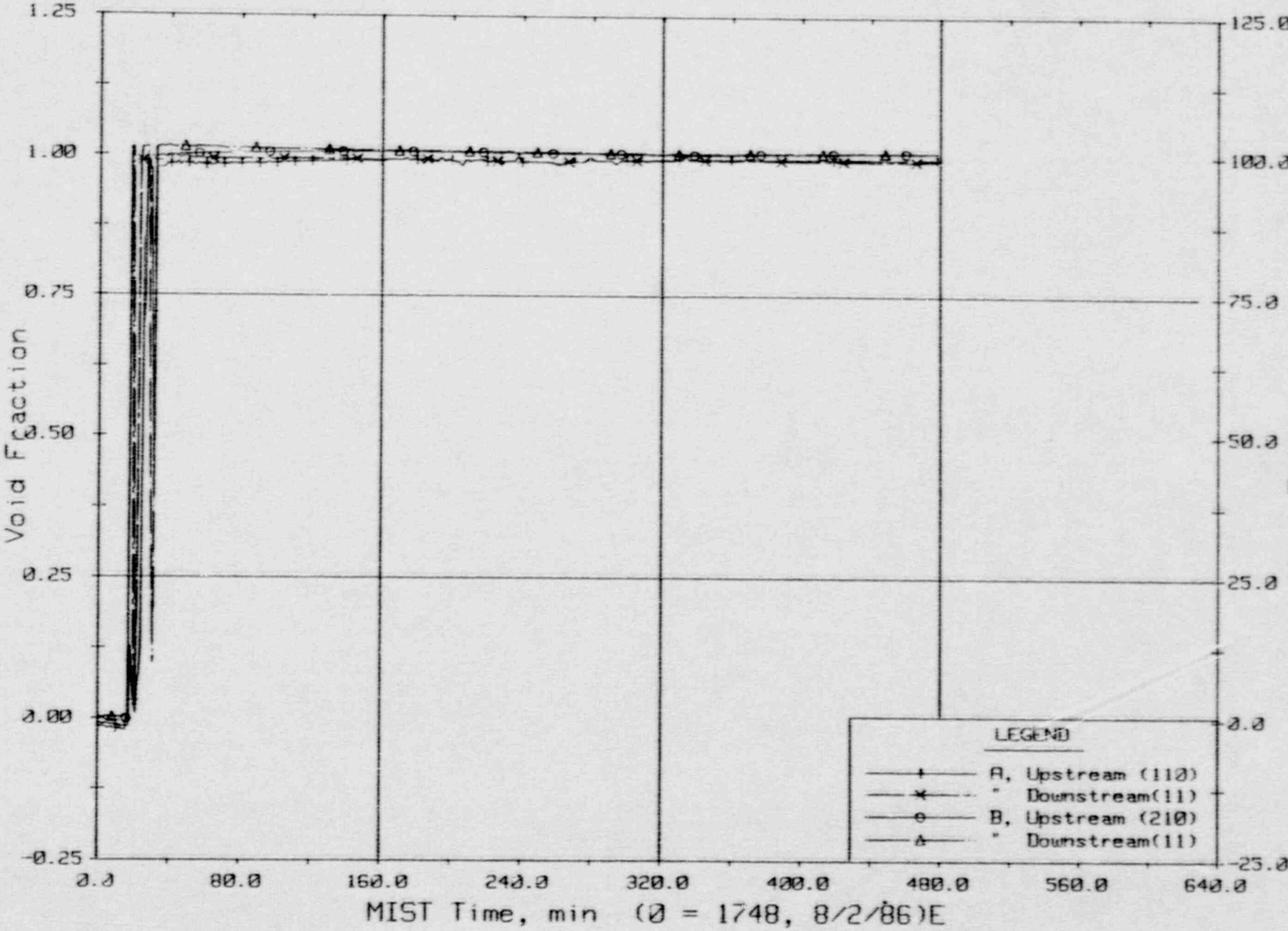
Hot Leg Riser and Stub Collapsed Liquid Levels.

Tue May 24 17:09:19 1988

HLLV1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



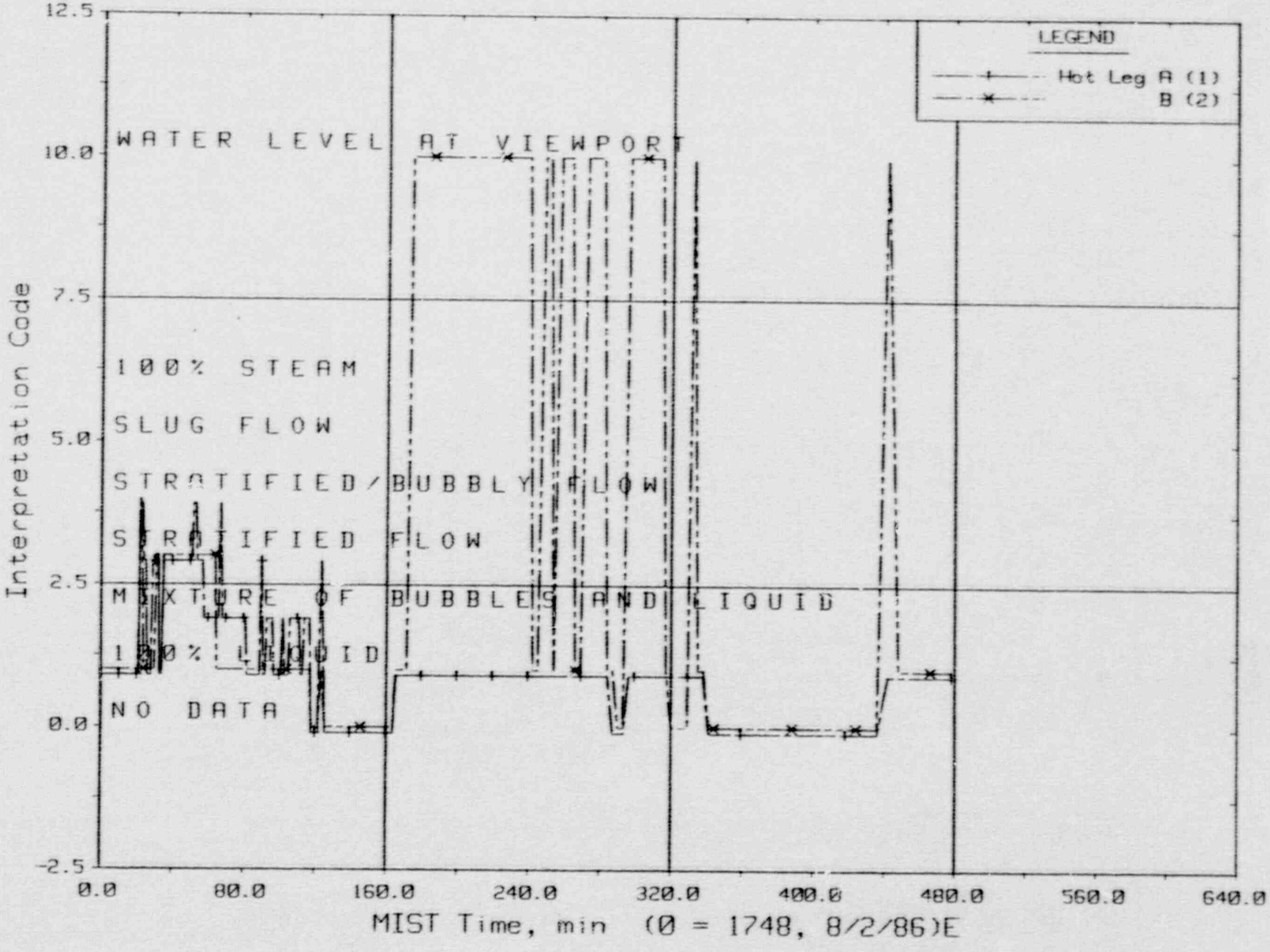
Hot Leg U-Bend Void Fractions From Diffl. Pressures (64.8 to 66.6 ft, HnVFs).

Tue May 24 17:15:03 1988

HLVF1

FINAL DATA

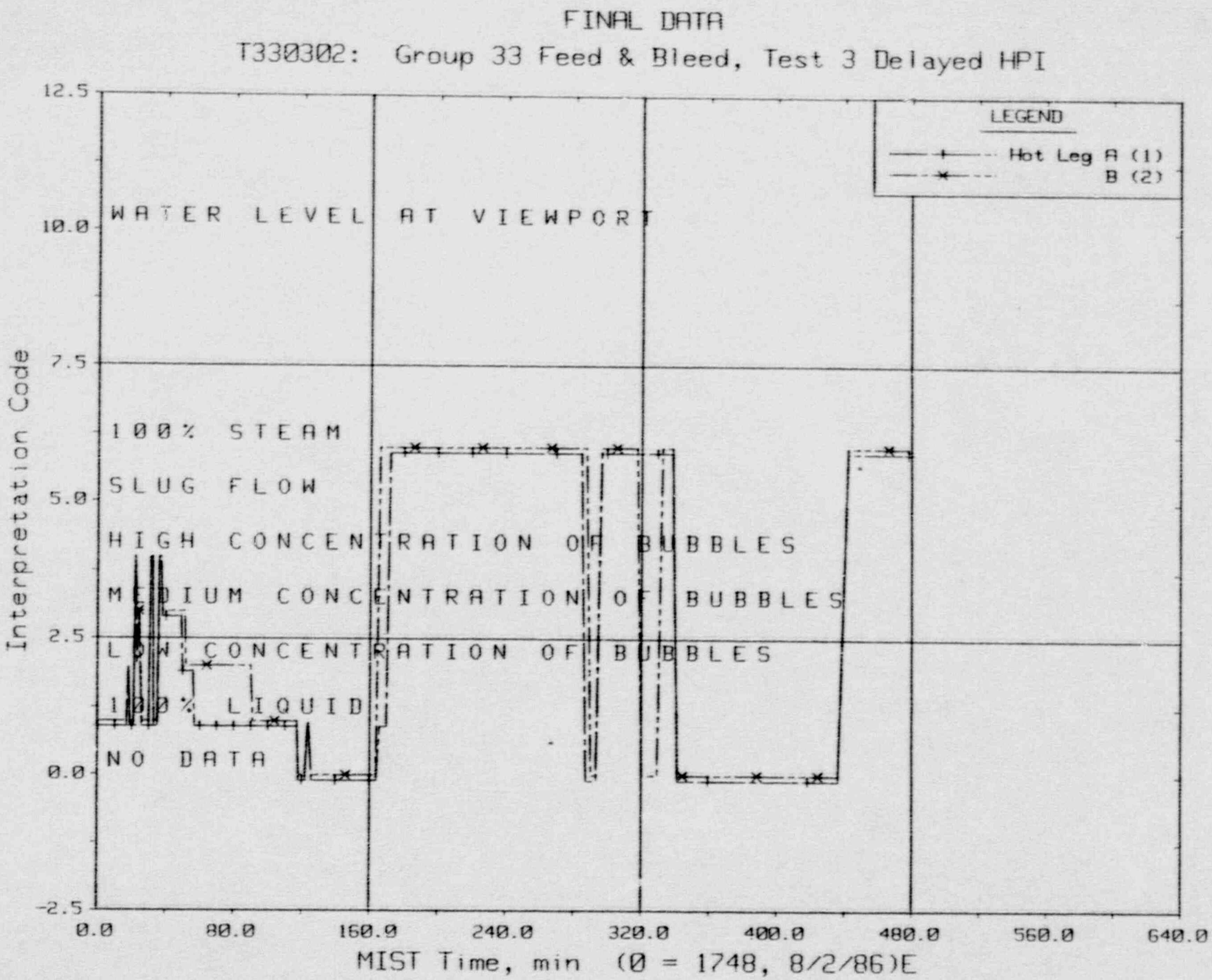
T330302: Group 33 Feed & Bleed, Test 3 Delayed HPI



Hot Leg Horizontal Viewport Indications (HnMS01s).

Thu Jun 2 11:22:25 1988

HLVP2



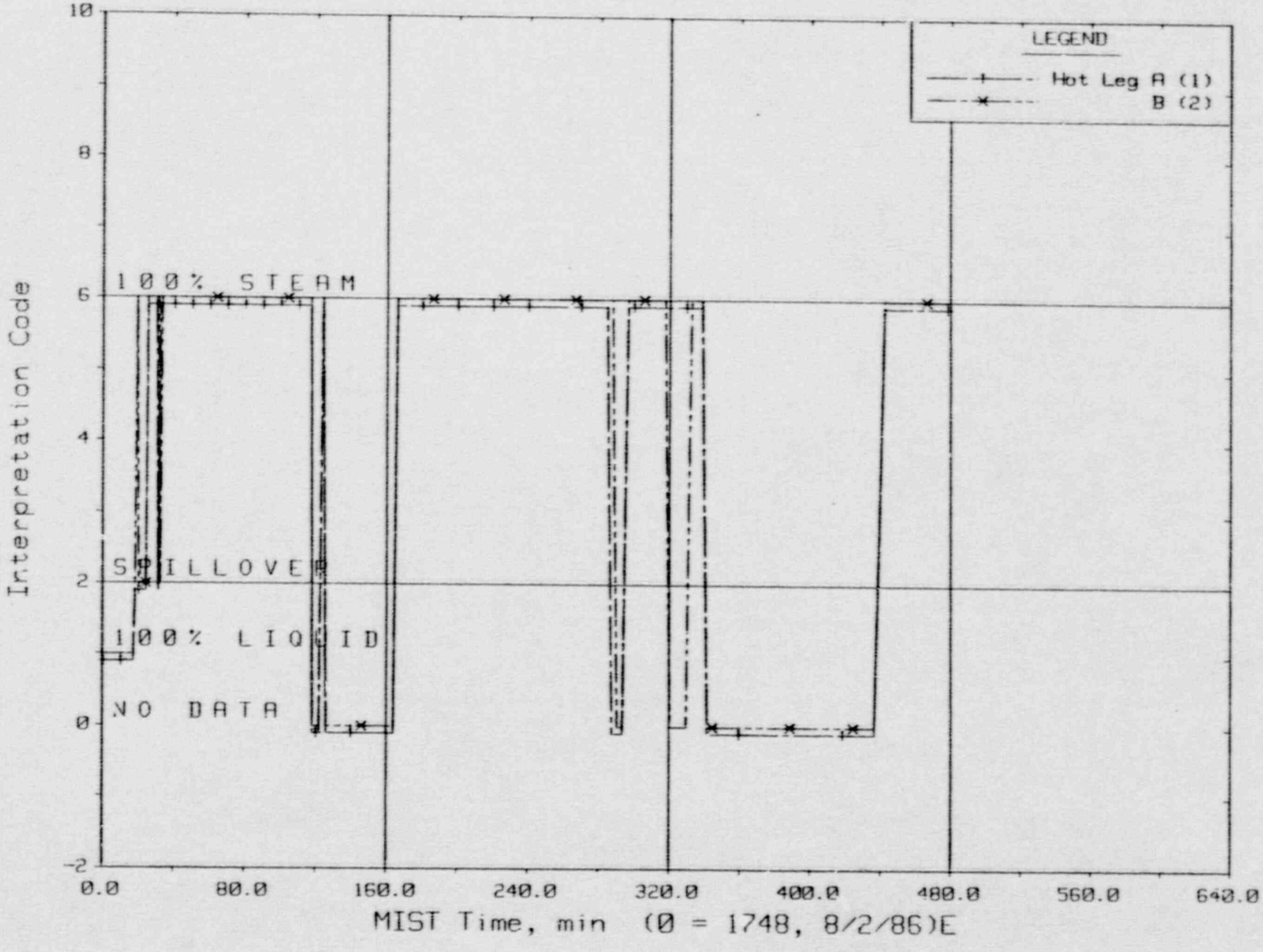
Hot Leg Riser Viewport Indications (HnMS02s).

Thu Jun 2 11:25:26 1988

HLVP3

FINAL DATA

T330302: Group 33 Feed & Bleed, Test 3 Delayed HPI



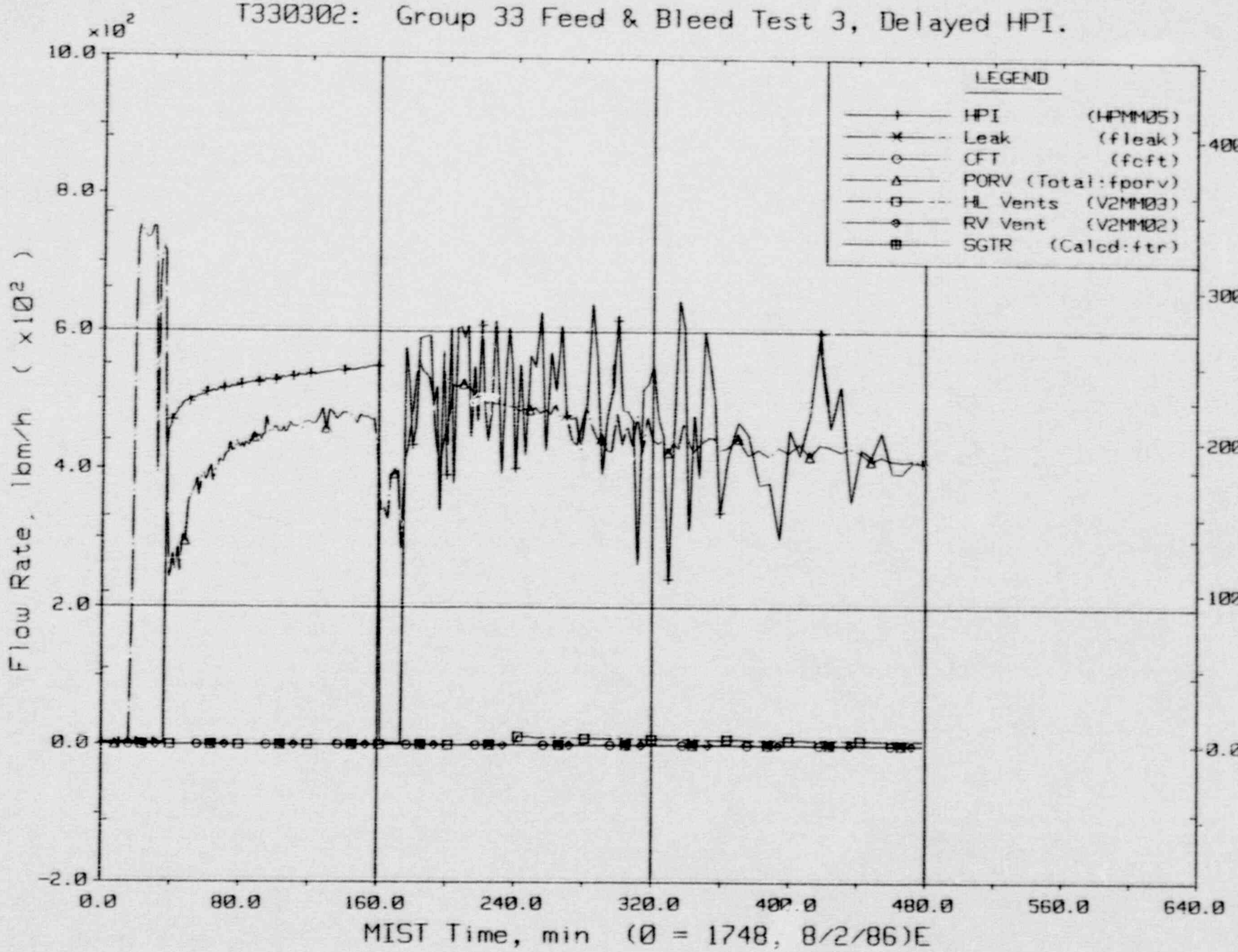
Hot Leg U-Bend Viewport Indications (HnMS03s).

Thu Jun 2 11:28:19 1988

HLVP4

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



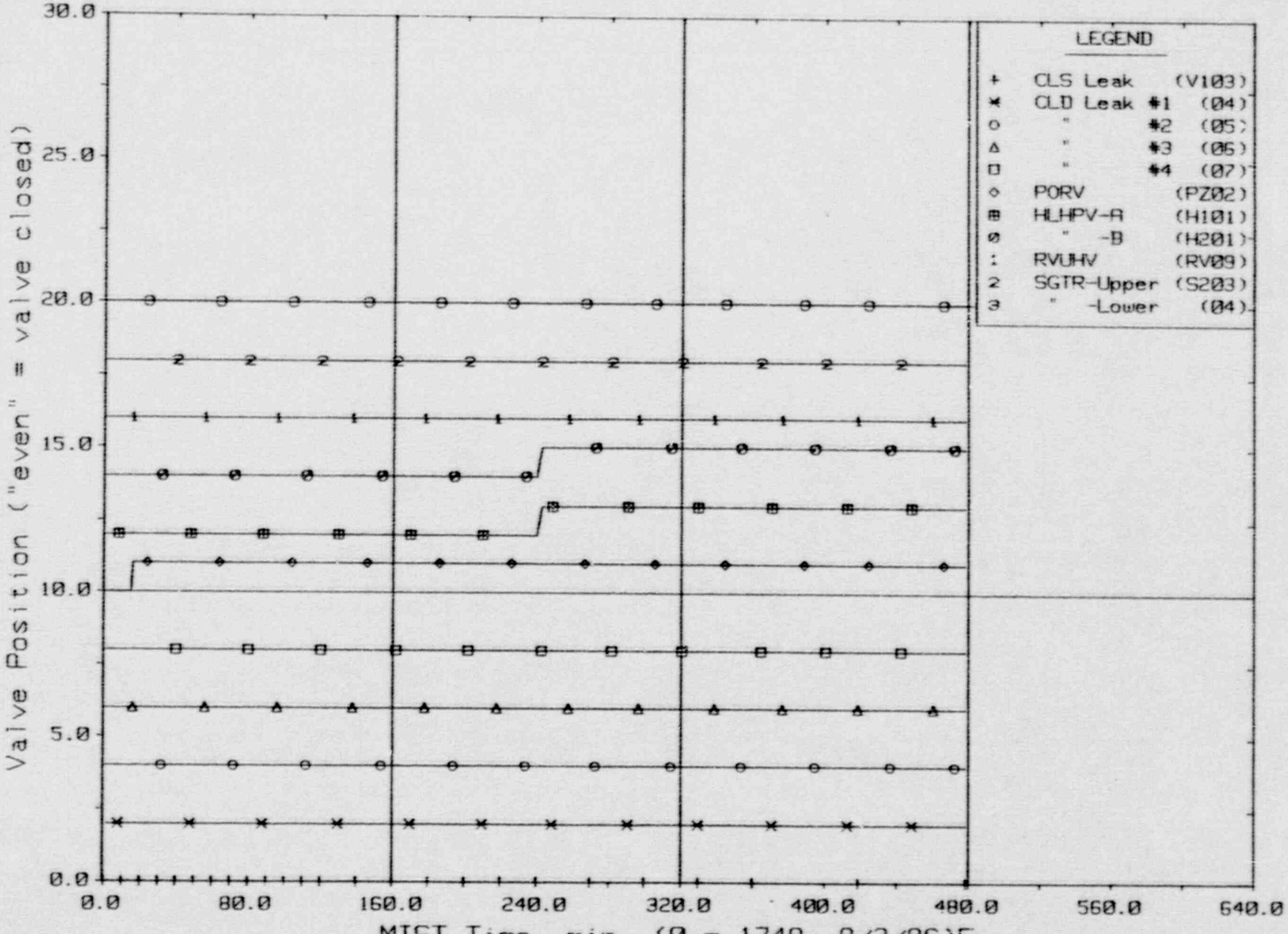
Primary System Boundary Flow Rates.

Tue May 24 17:21:28 1988

PBFL3

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



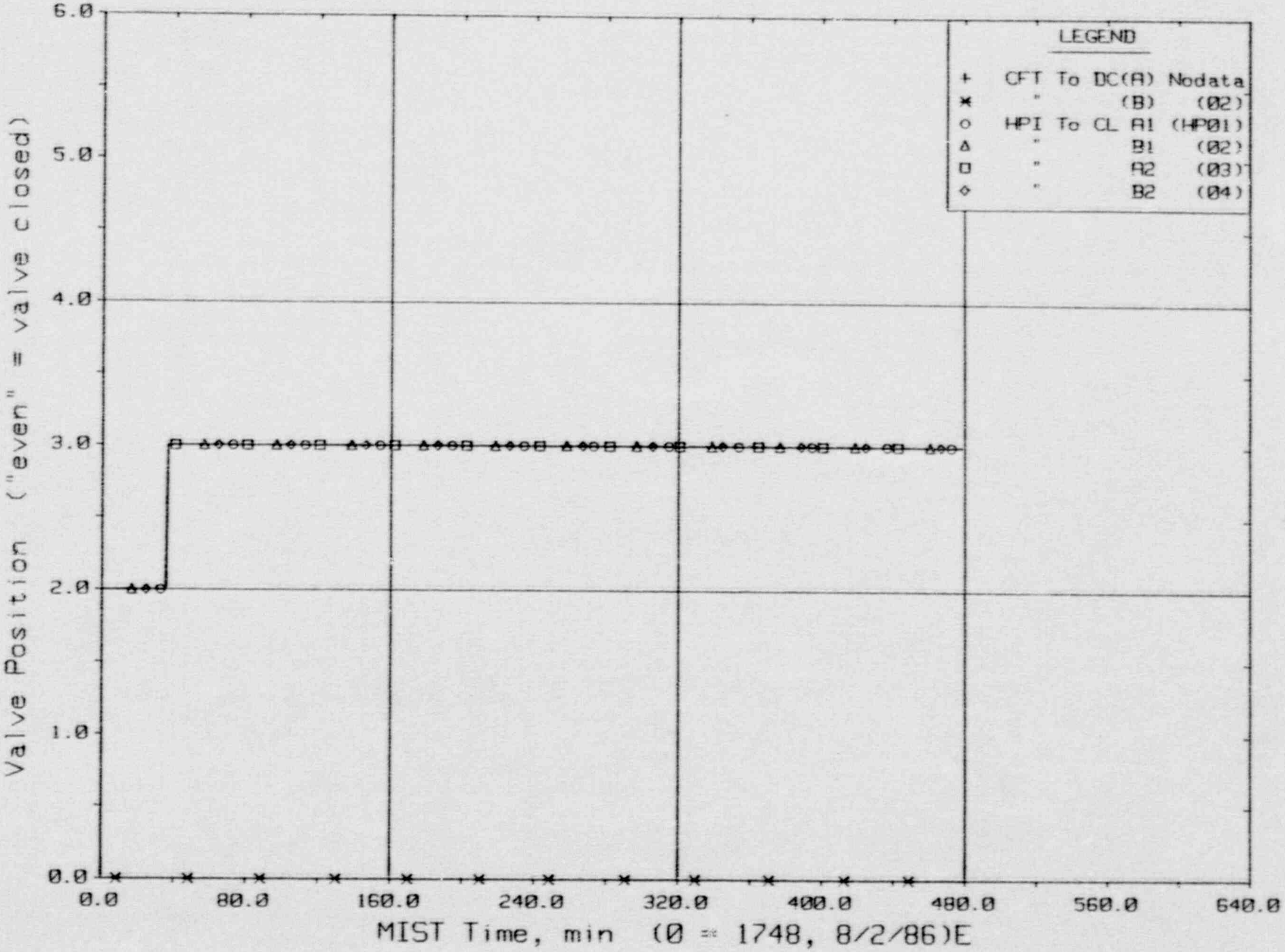
Primary System Discharge Limit Switch Indications (LSs).

Tue May 24 17:27:53 1988

PBLS1

FINAL DATA

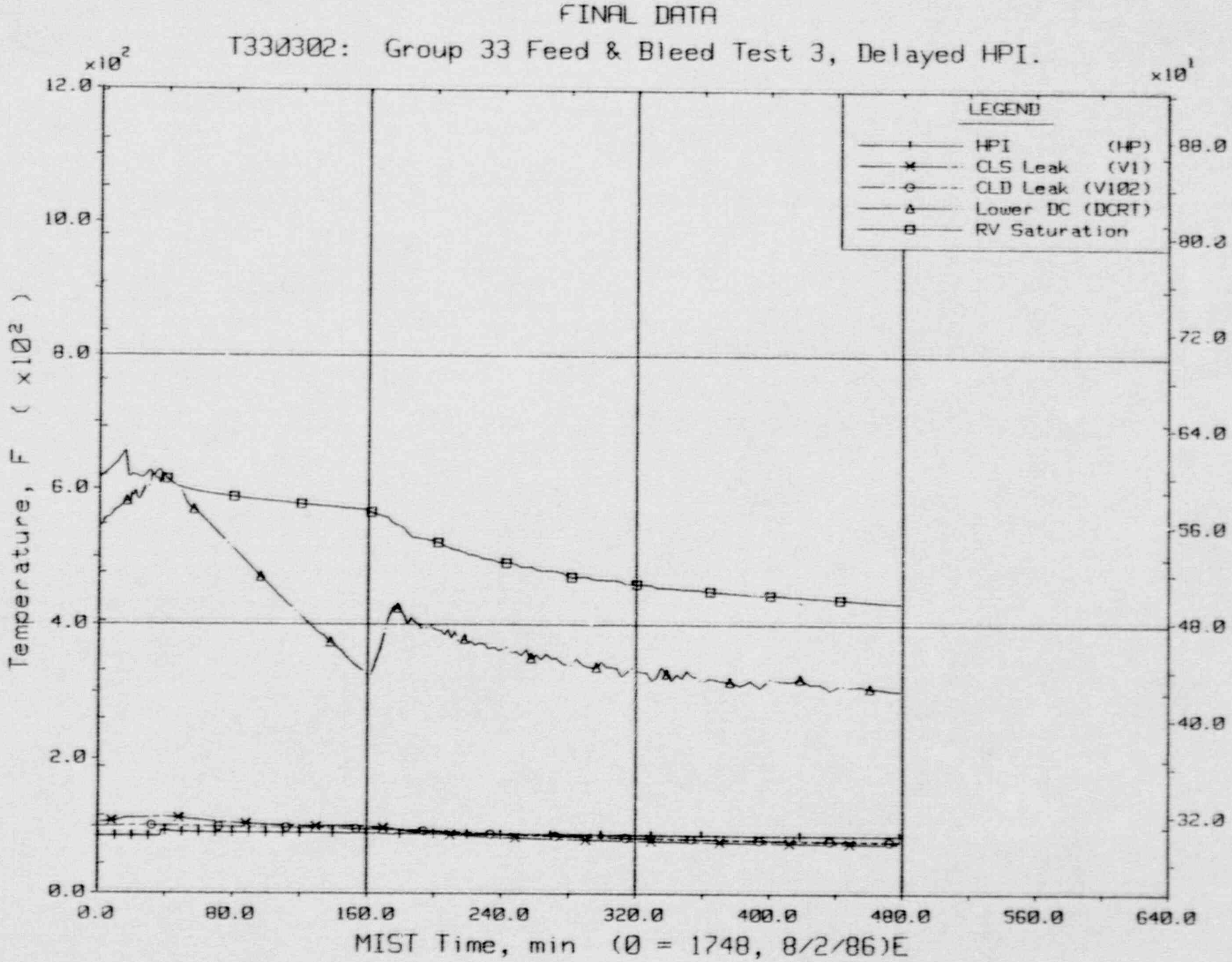
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Primary System Injection Limit Switch Indications (LSs).

Tue May 24 17:33:40 1988

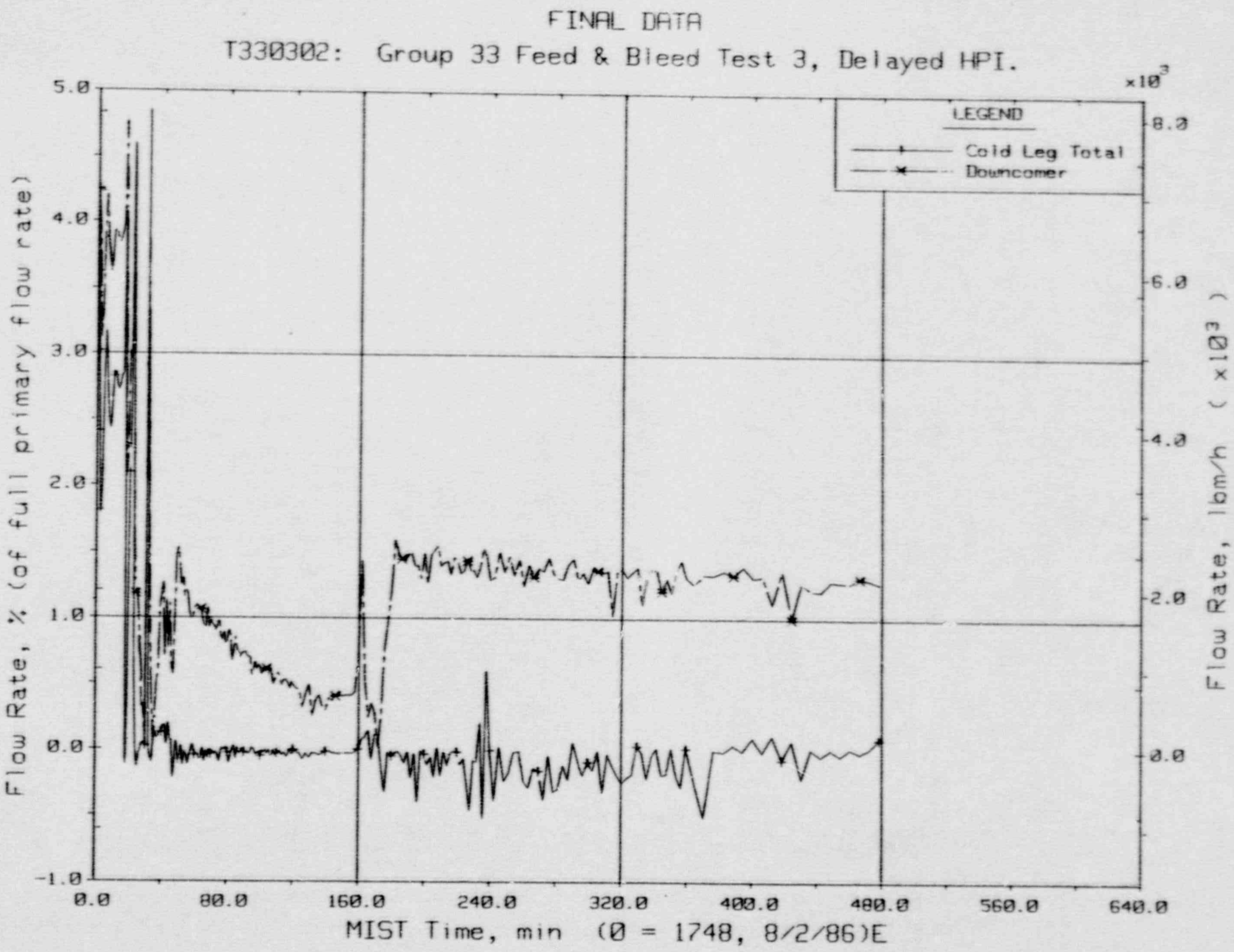
PBLS2



Single-Phase Discharge and HPI Fluid Temperatures (TC01s).

Tue May 24 17:40:19 1988

PBTC1p



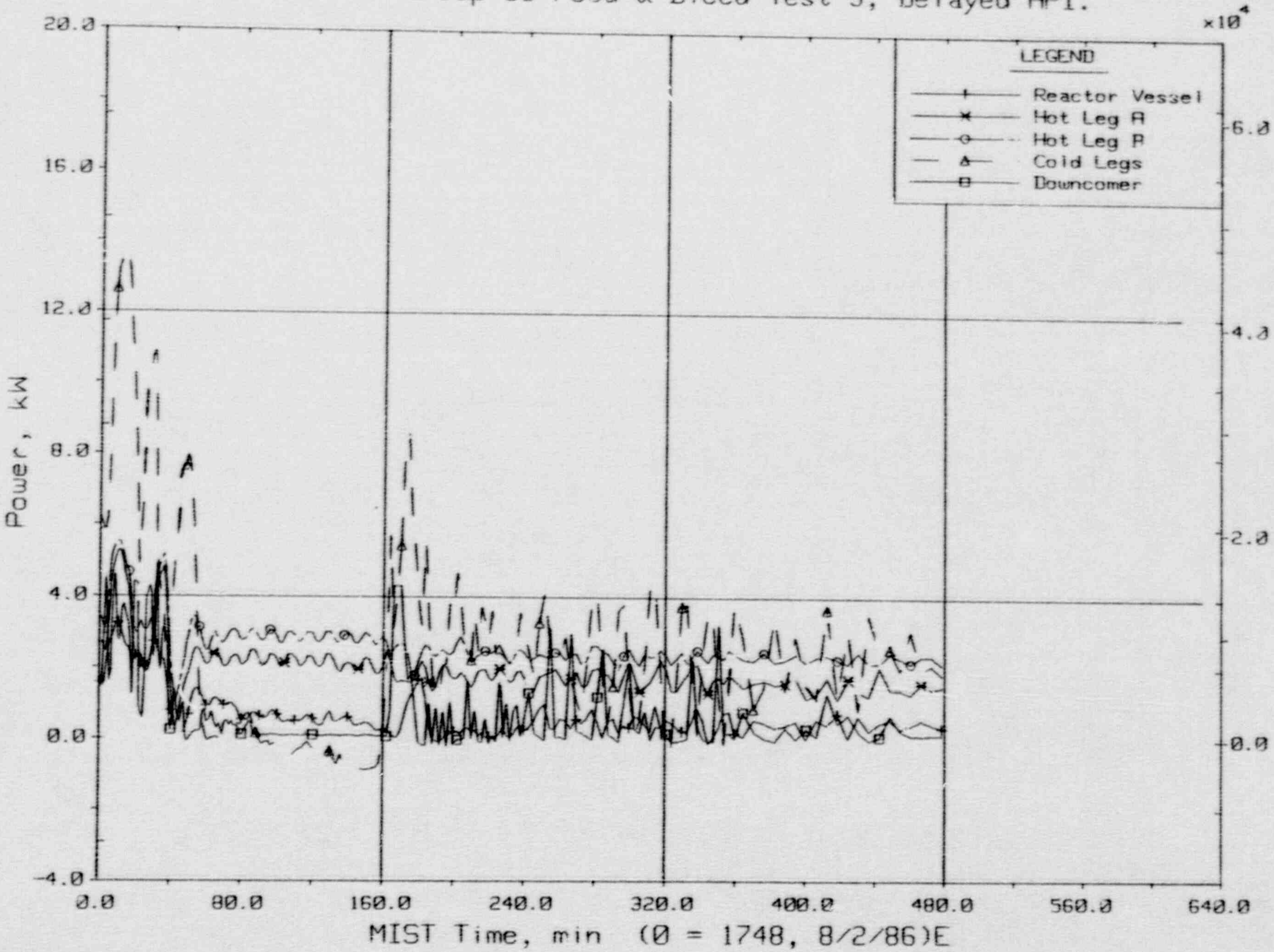
Primary System Venturi Flow Rates.

Tue May 24 17:48:07 1988

PRFL7

FINAL DATA

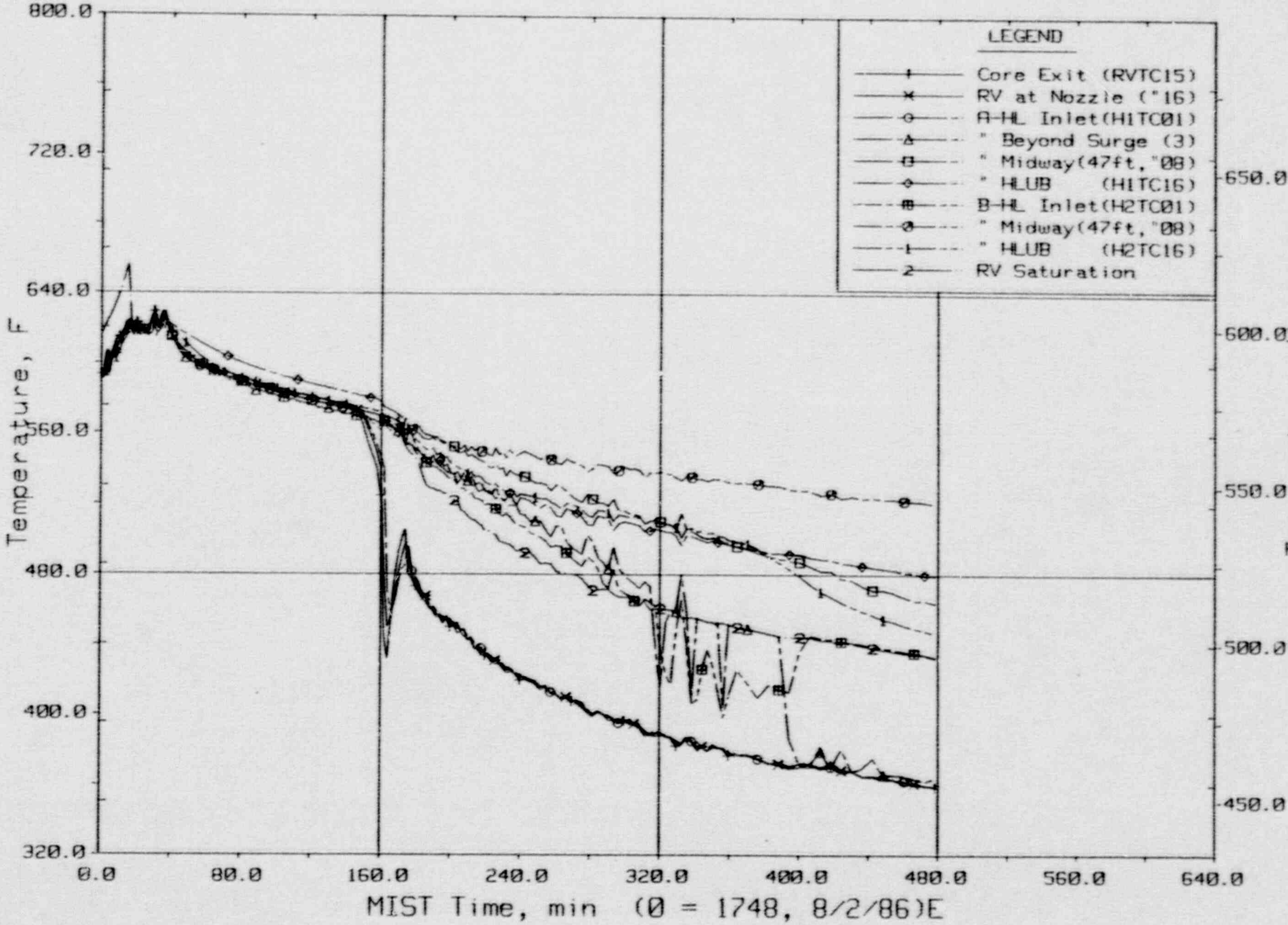
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Guard Heater Specified Power Per Primary Component.

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



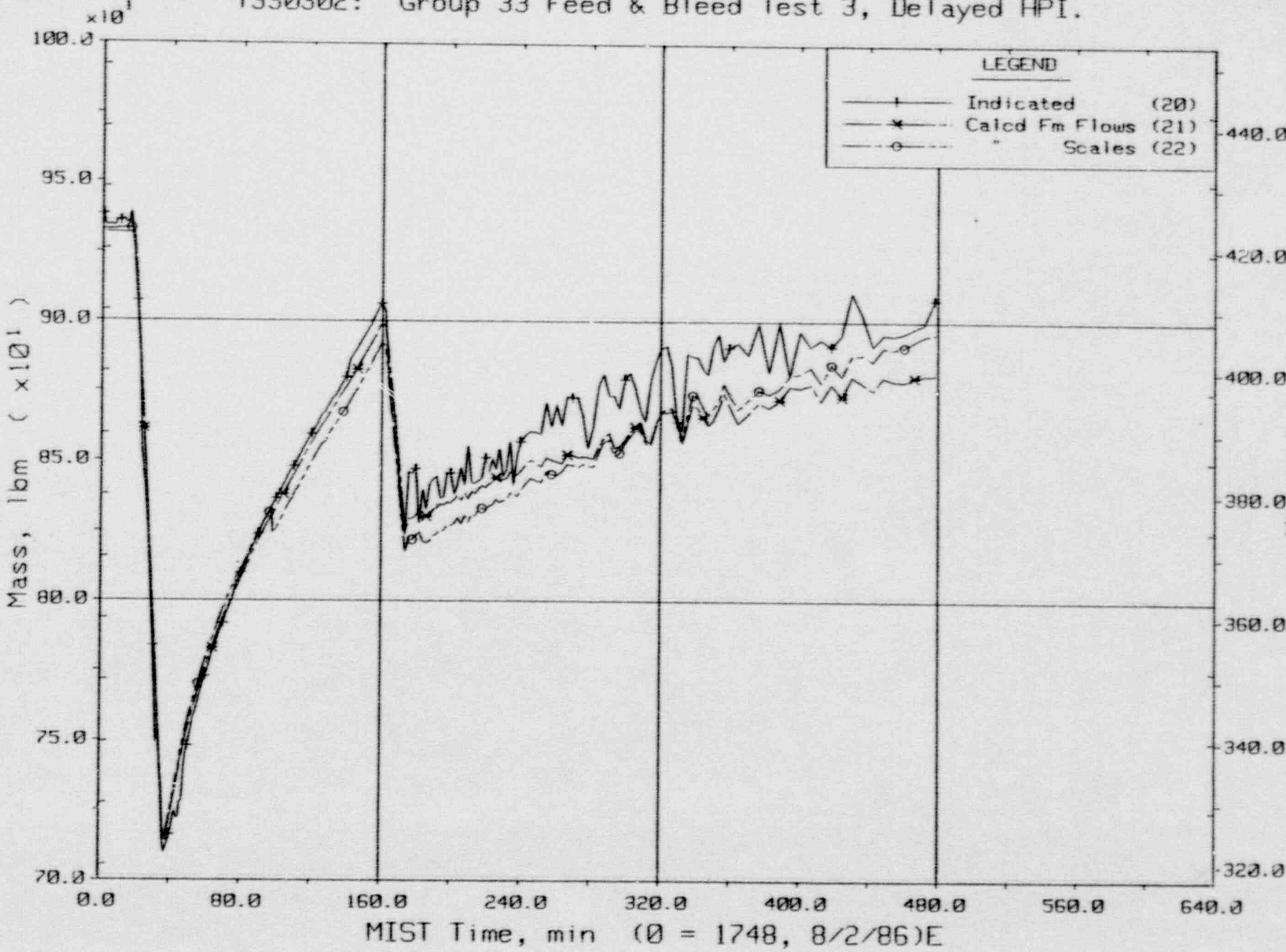
Composite Core Exit and Hot Leg Fluid Temperatures.

Tue May 24 10:00:52 1988

PRKT1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



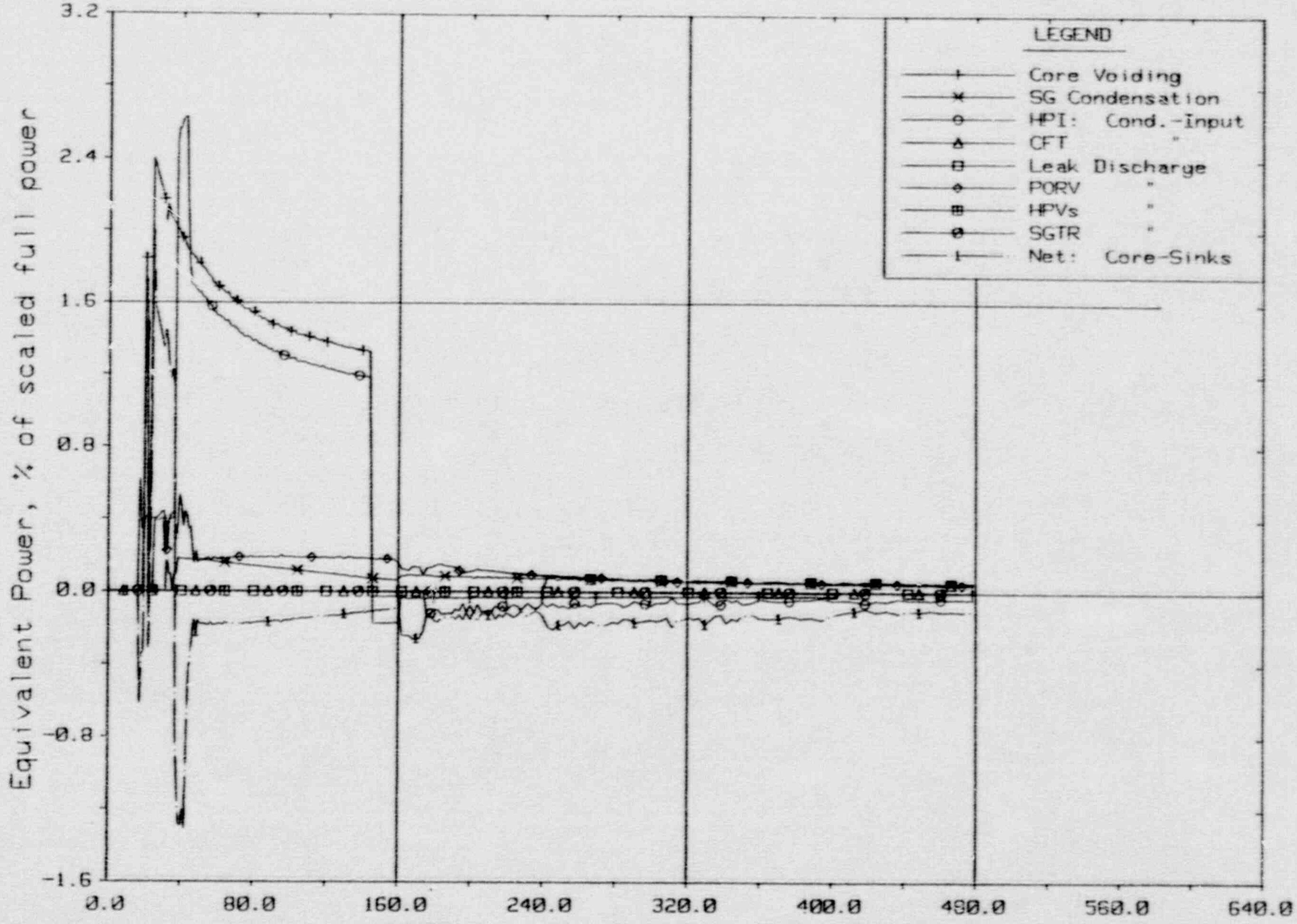
Primary System Total Fluid Mass (PLMLs).

Tue May 24 18:04:37 1988

PRML2

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



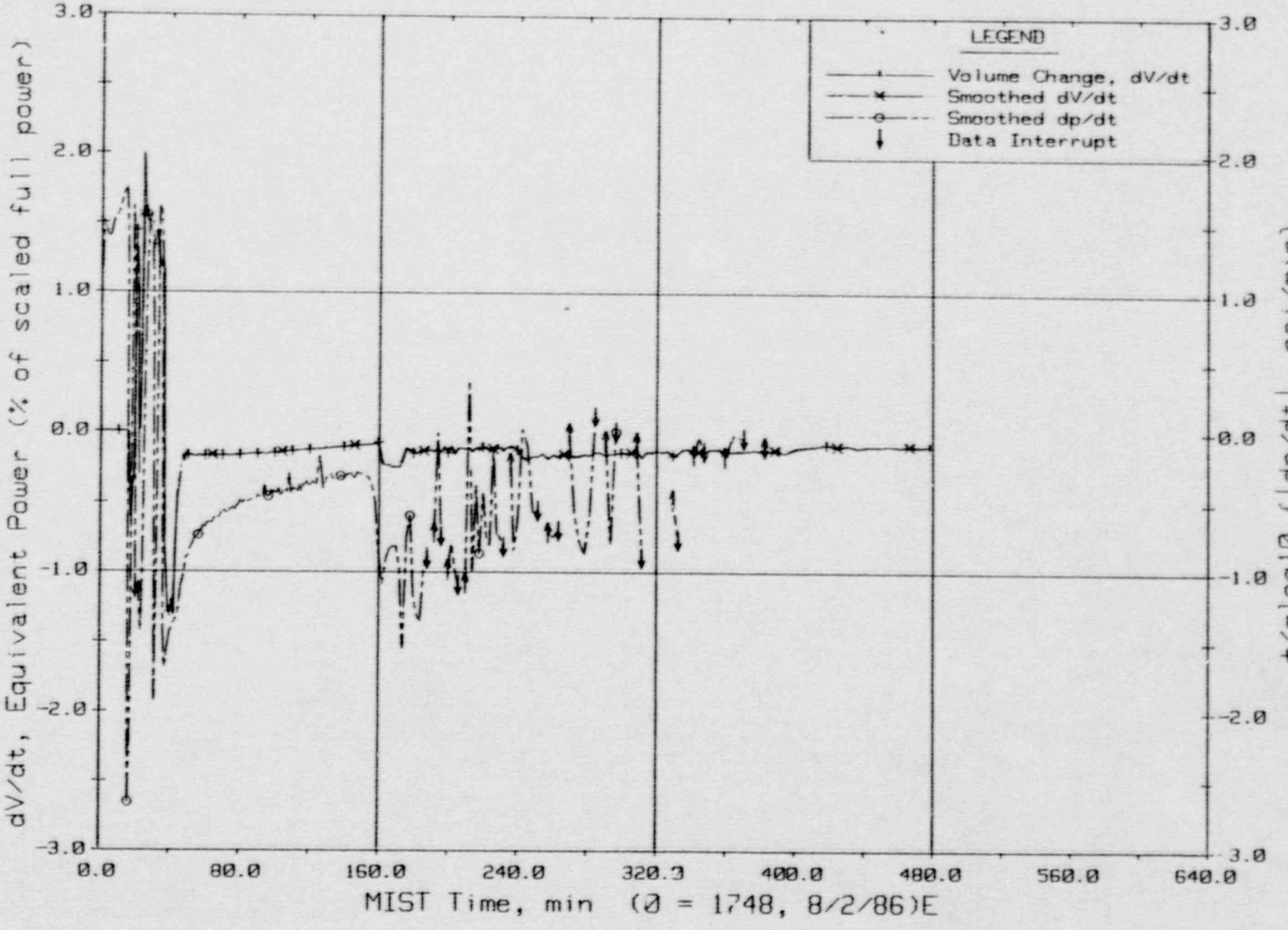
Primary Fluid Volume Changes By Components.

Tue May 24 18:08:45 1988

PRPA0

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



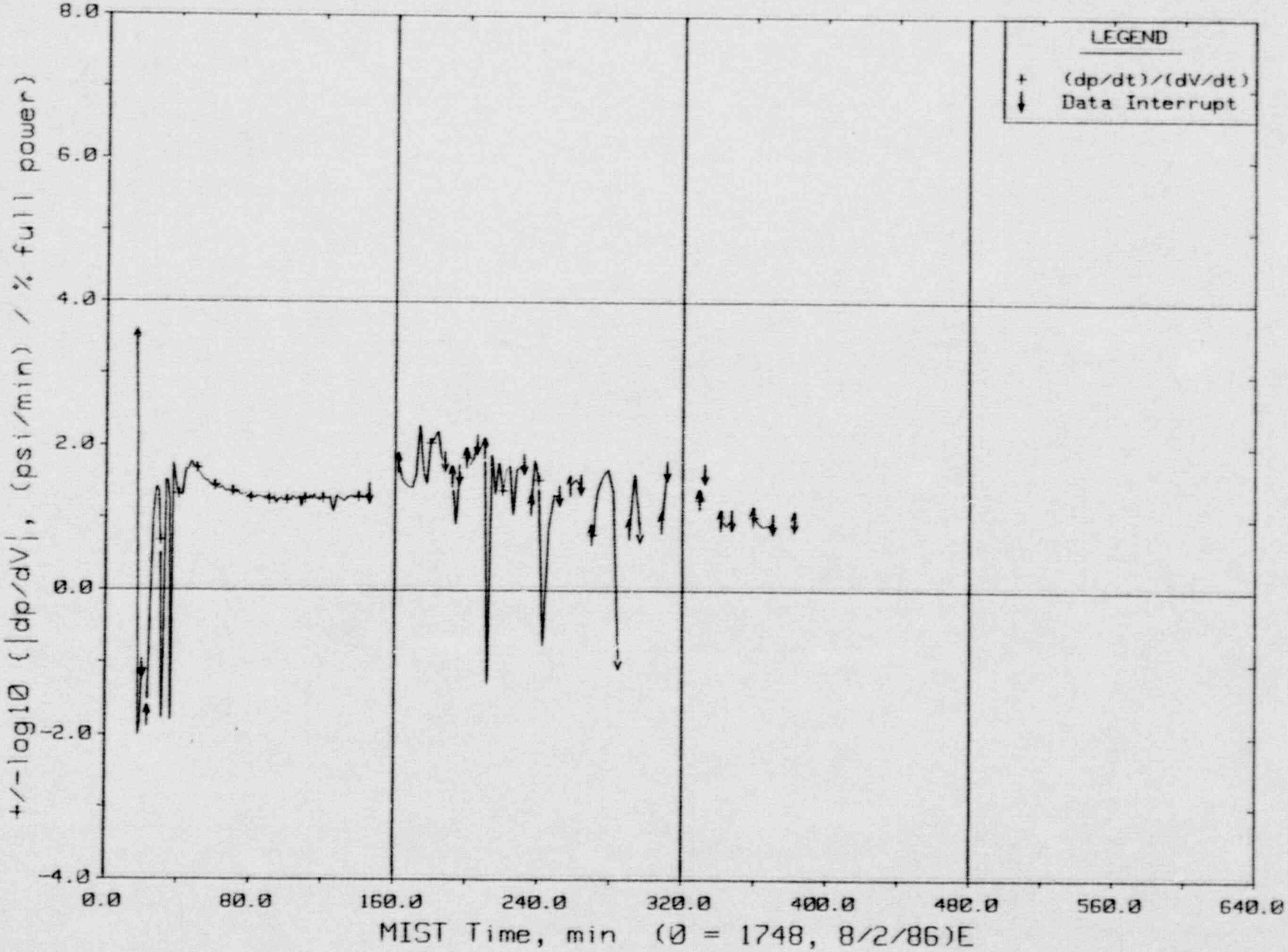
Primary Fluid Volume and Pressure Changes, dV/dt and dp/dt.

Tue May 24 18:11:50 1988

PRPA2

FINAL DATA

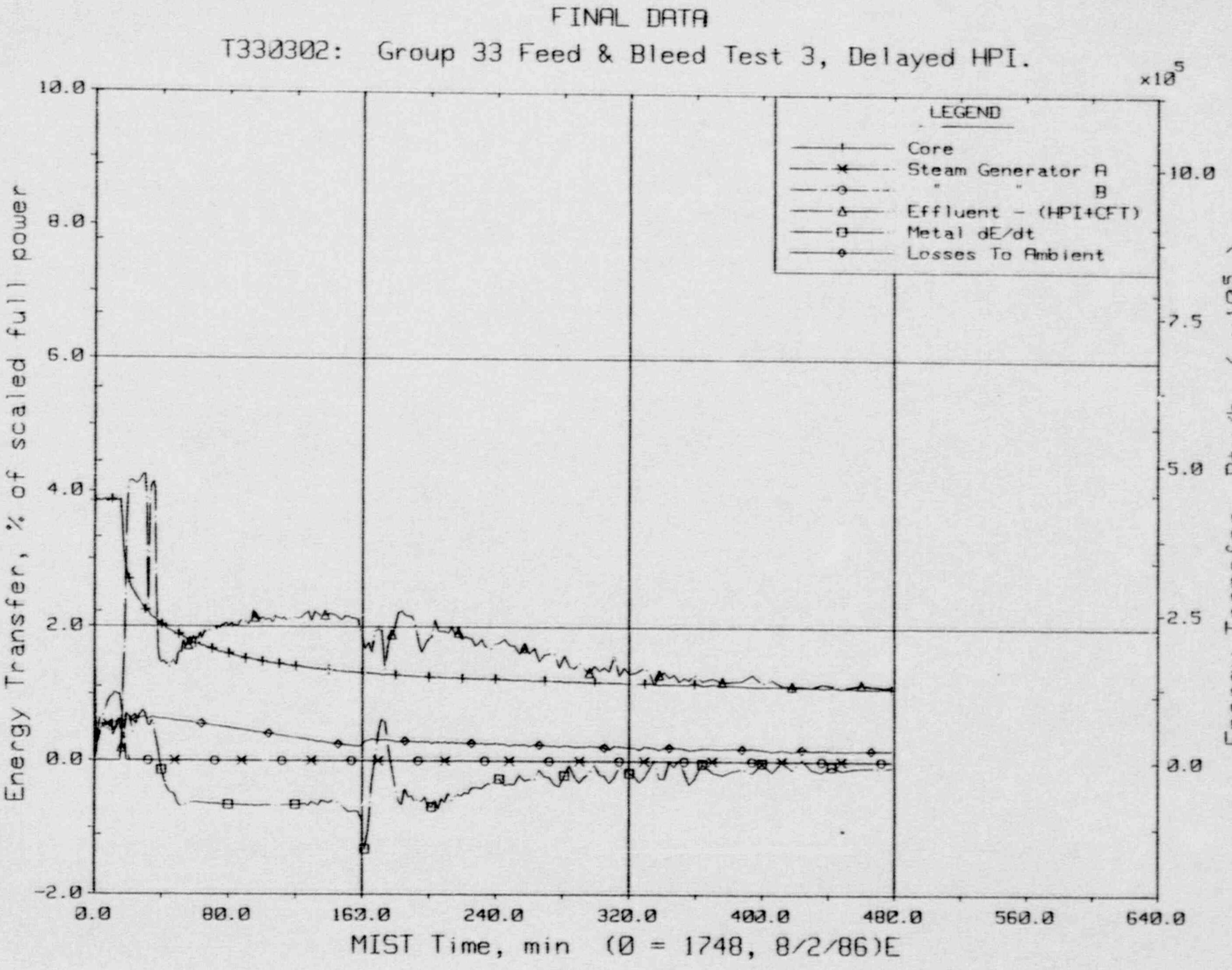
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Primary System Response: dp/dt divided by dV/dt.

Tue May 24 18:14:57 1988

PRPA3



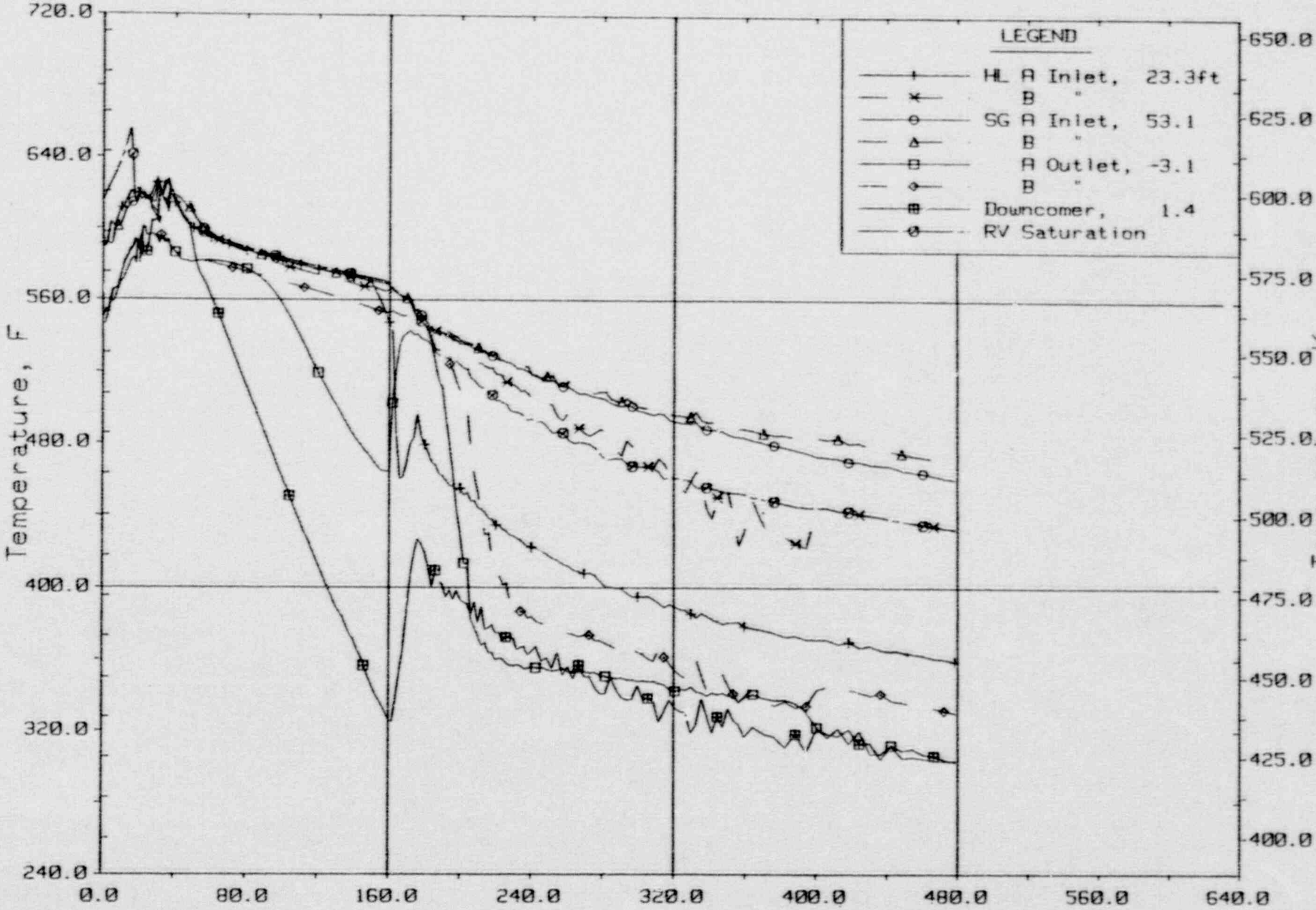
Primary System Energy Transfer.

Tue May 24 18:18:41 1988

PRQE2

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



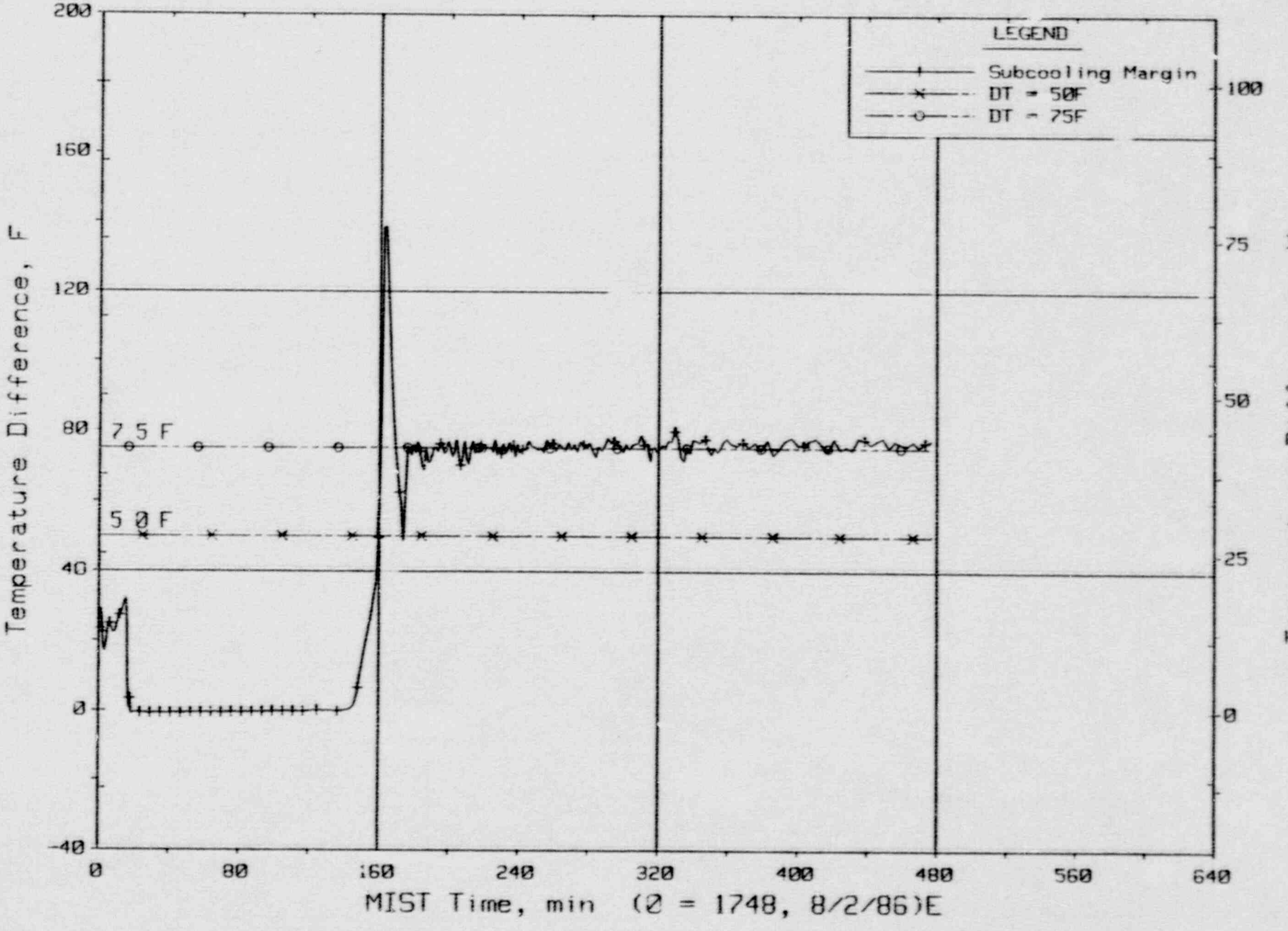
Primary System Fluid Temperatures (RTDs).

Tue May 24 18:22:59 1988

PRRT0

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



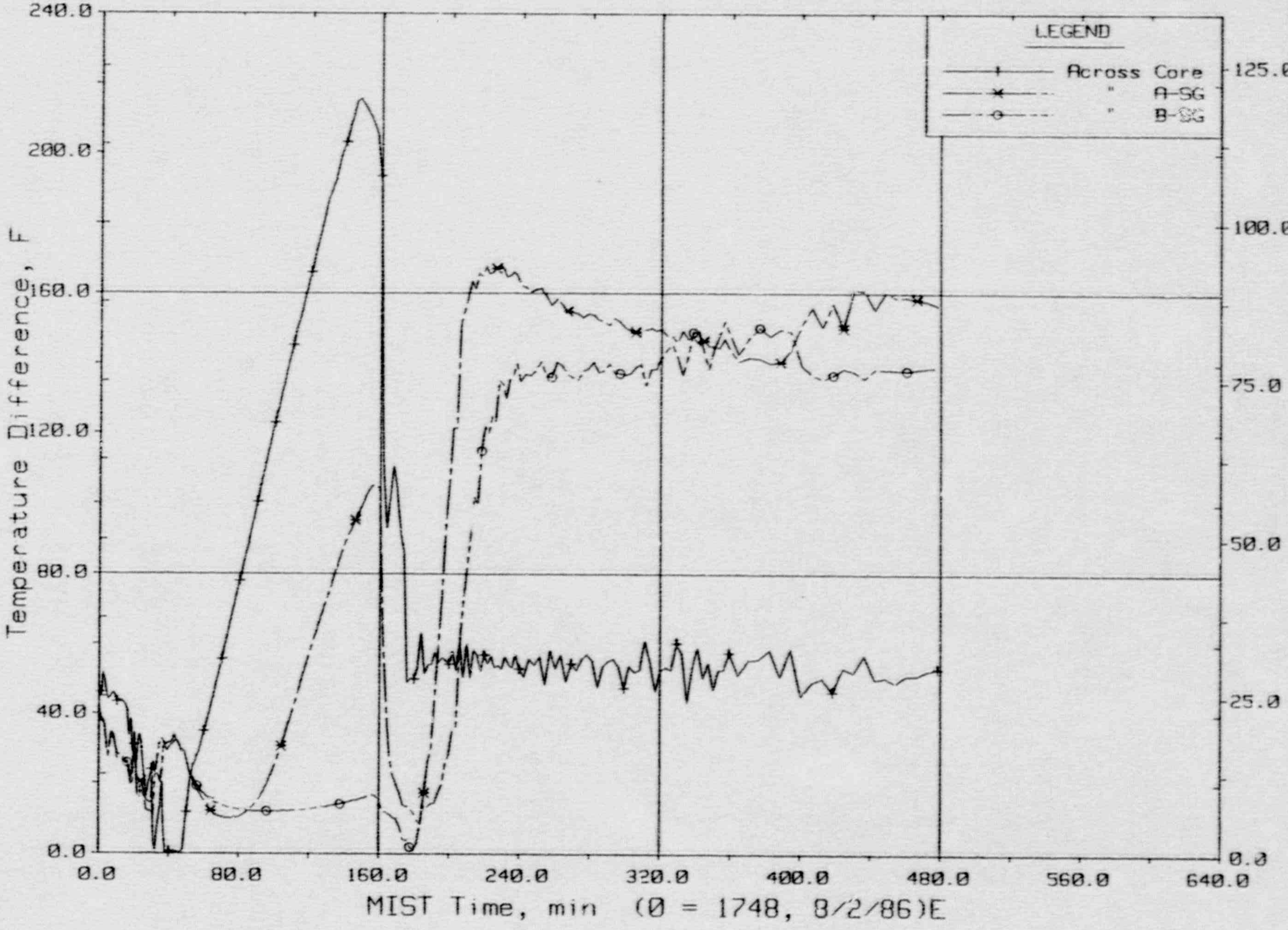
Control Temperature Differences.

Tue Nov 1 10:14:19 1988

PRTD0

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



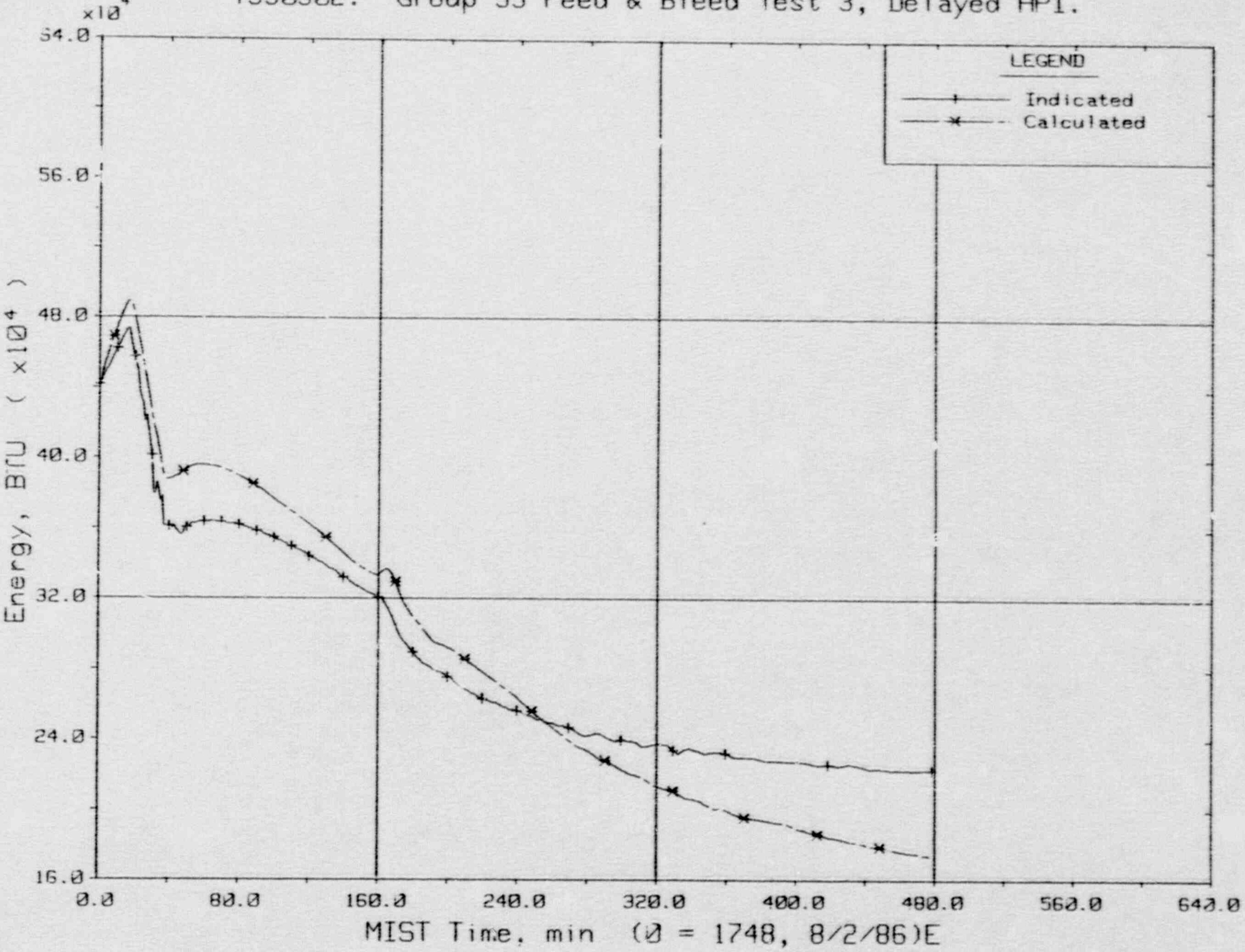
Key Temperature Differences.

Tue May 24 18:25:58 1988

PRTD2

FINAL DATA

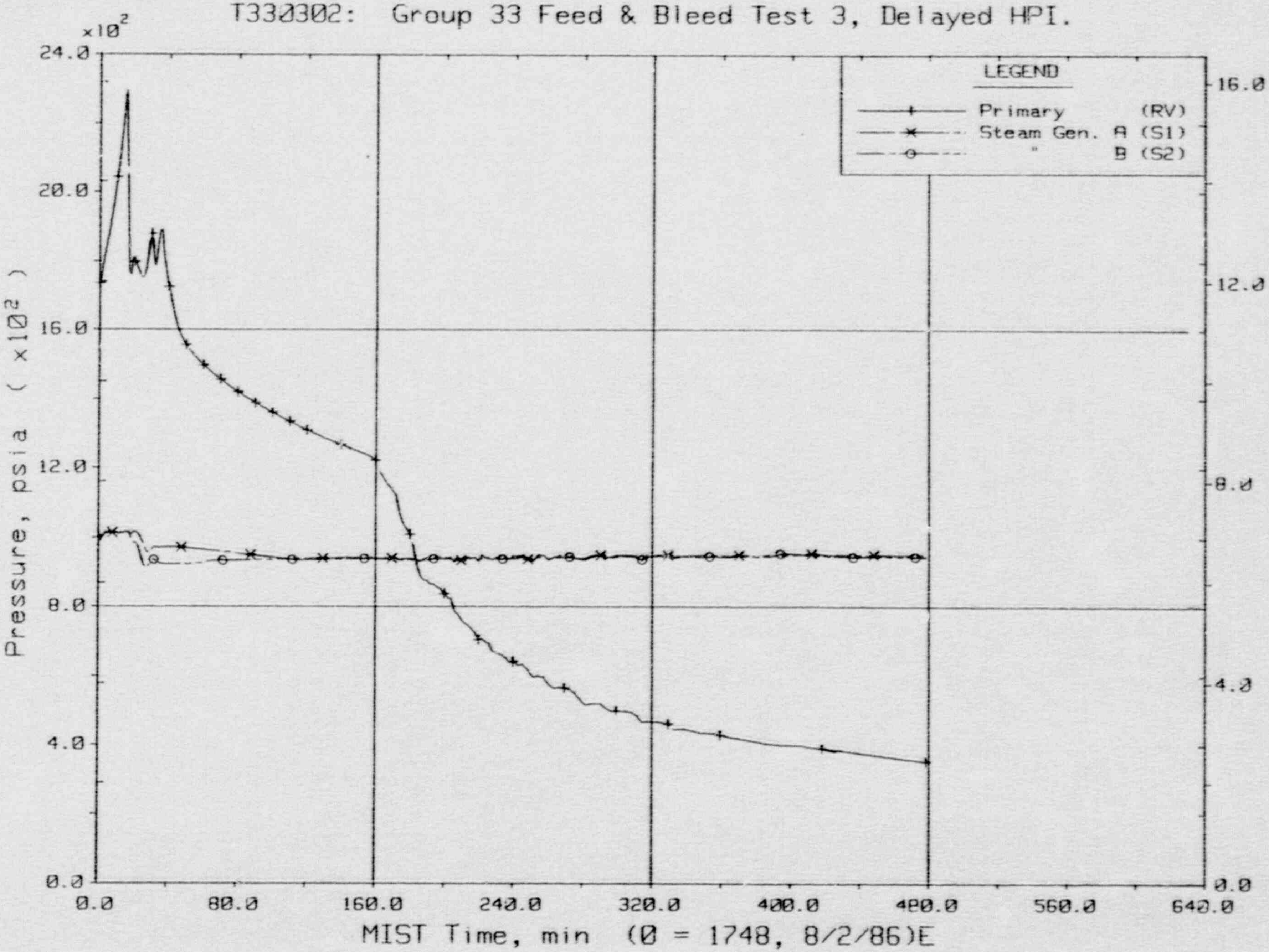
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Primary System Total Fluid Energy.

FINAL DATA

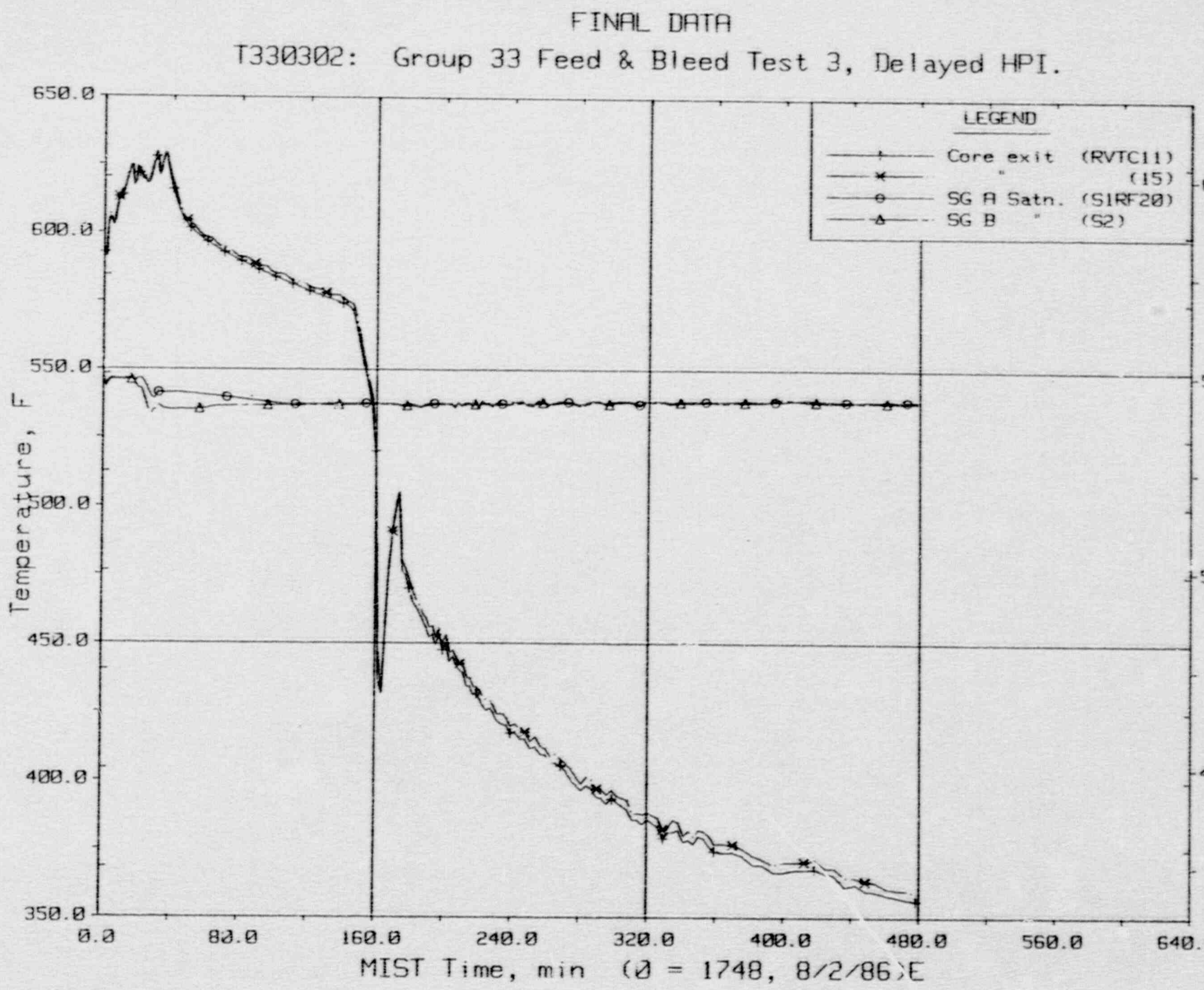
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Primary and Secondary System Pressures (GP01s).

Tue May 24 18:31:24 1988

PSGP1



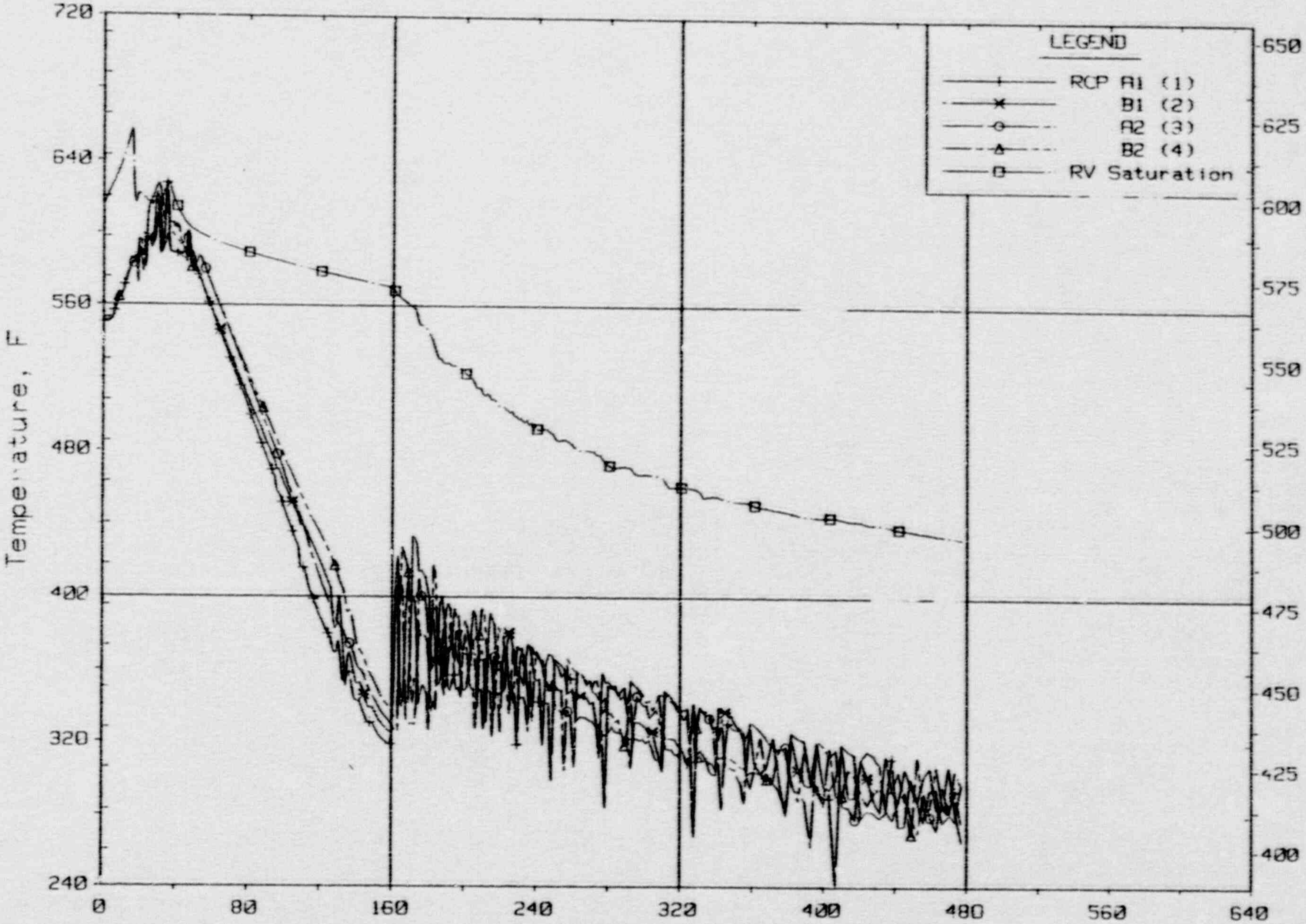
Core Exit and Steam Generator Secondary Saturation Temperatures.

Tue May 24 18:34:30 1988

PSTC3p

FINAL DATA

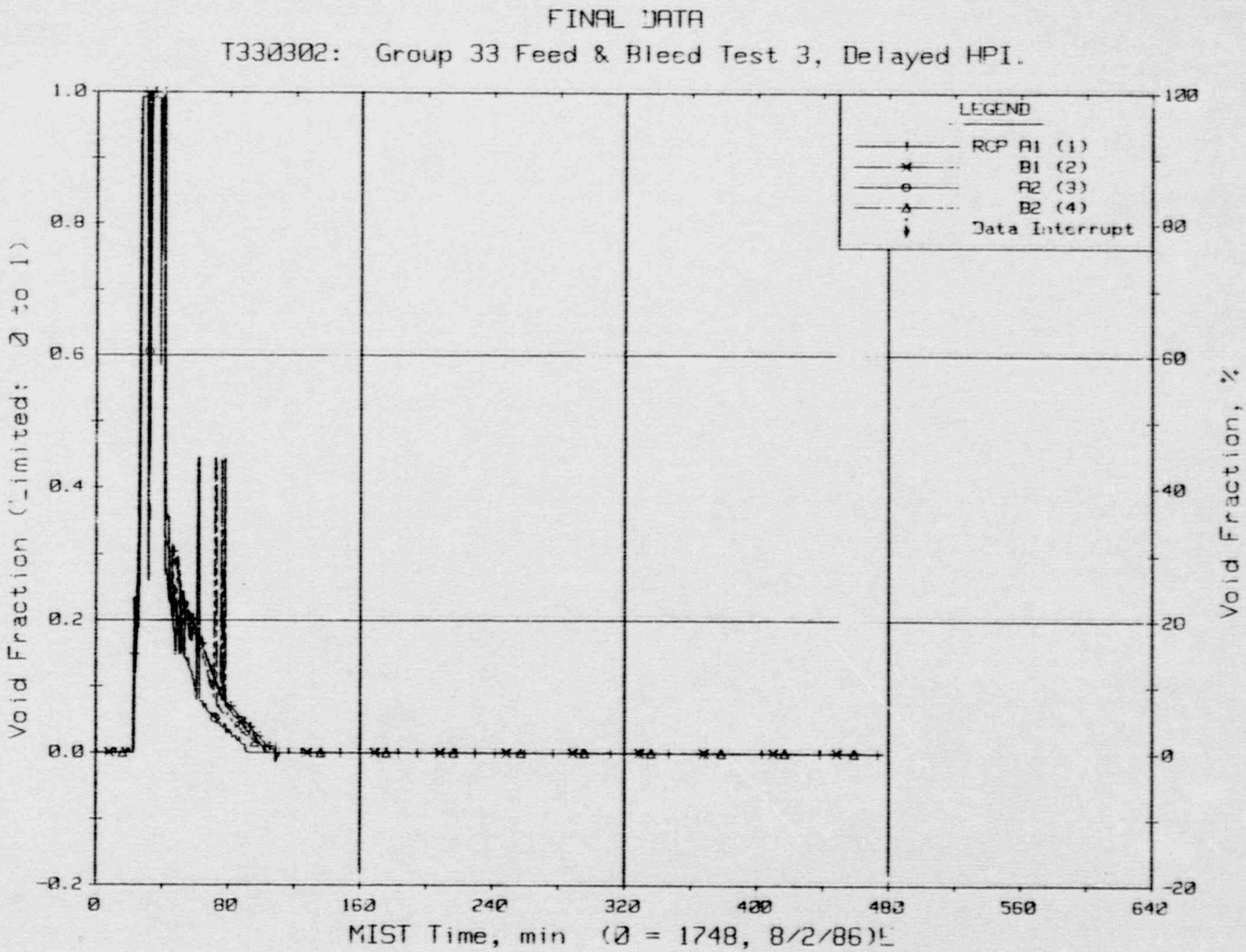
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Pump Suction Fluid Temperature (CnRT01s).

Tue Nov 1 10:19:48 1988

PURT0



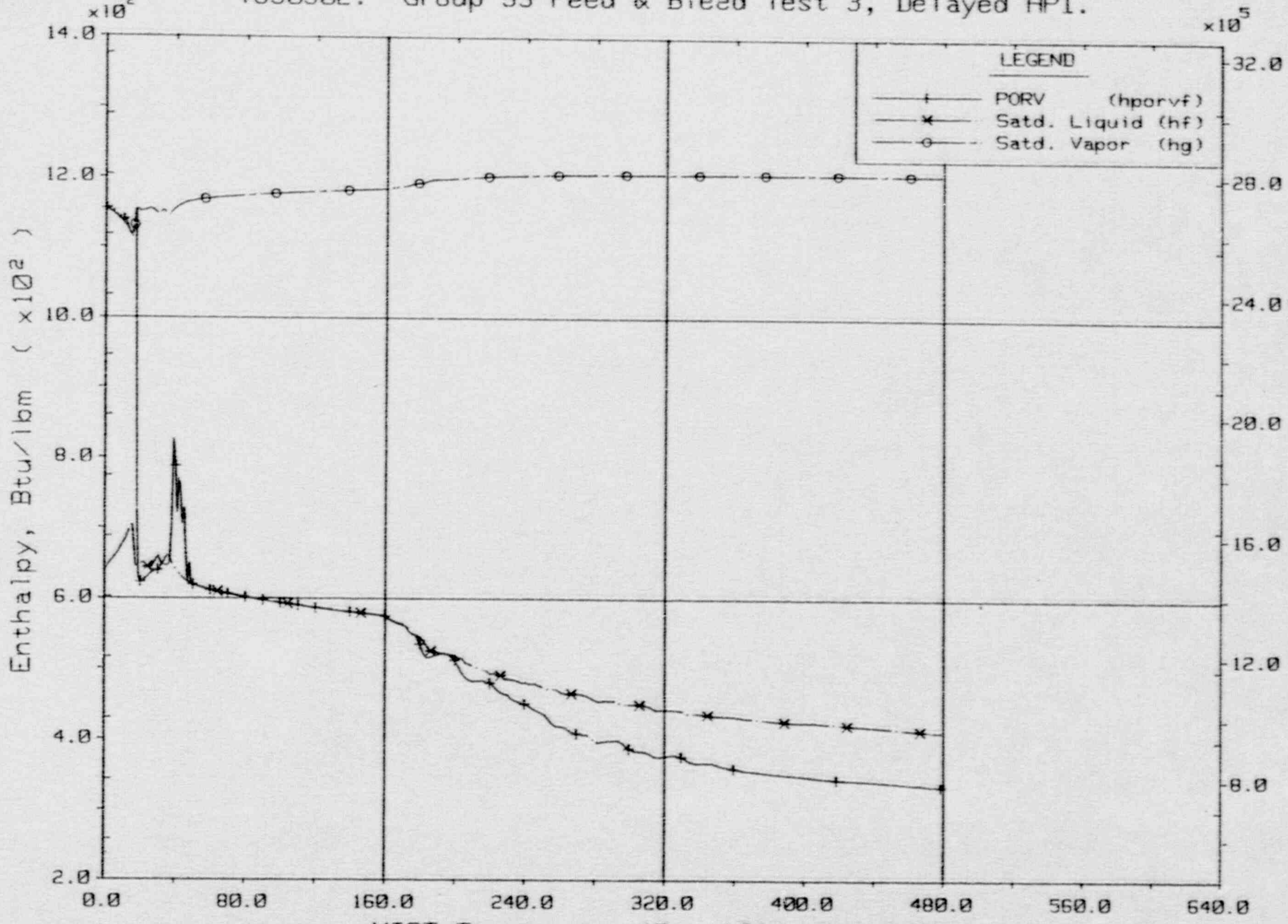
Pump Suction Void Fraction From Gamma Densitometers (CnGD21).

Tue Nov 1 10:27:01 1988

PUVF2

.FINAL DATA

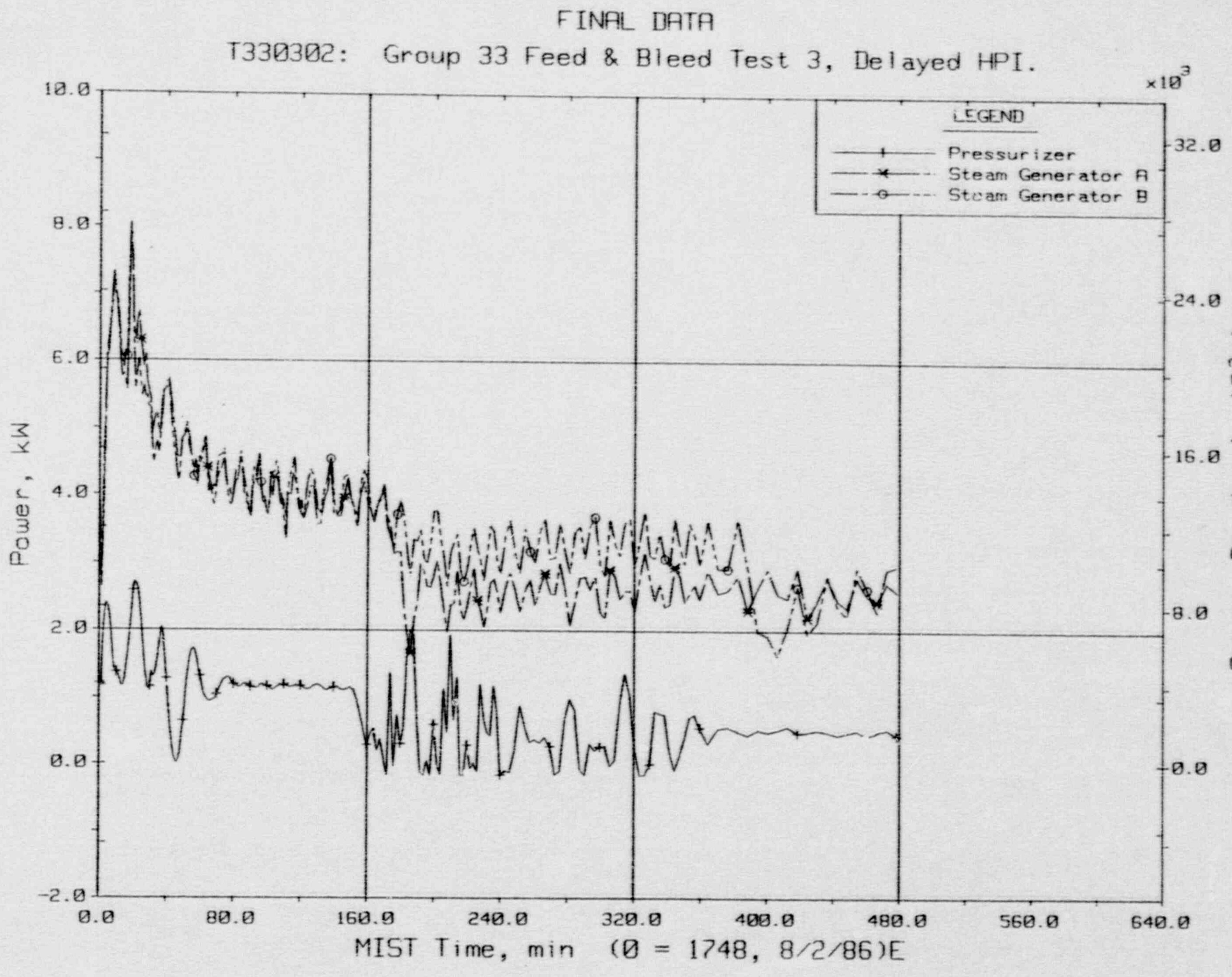
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Power-Operated Relief Valve Enthalpy (Based On Flow Rate).

Tue May 24 18:40:48 1988

PZEN1



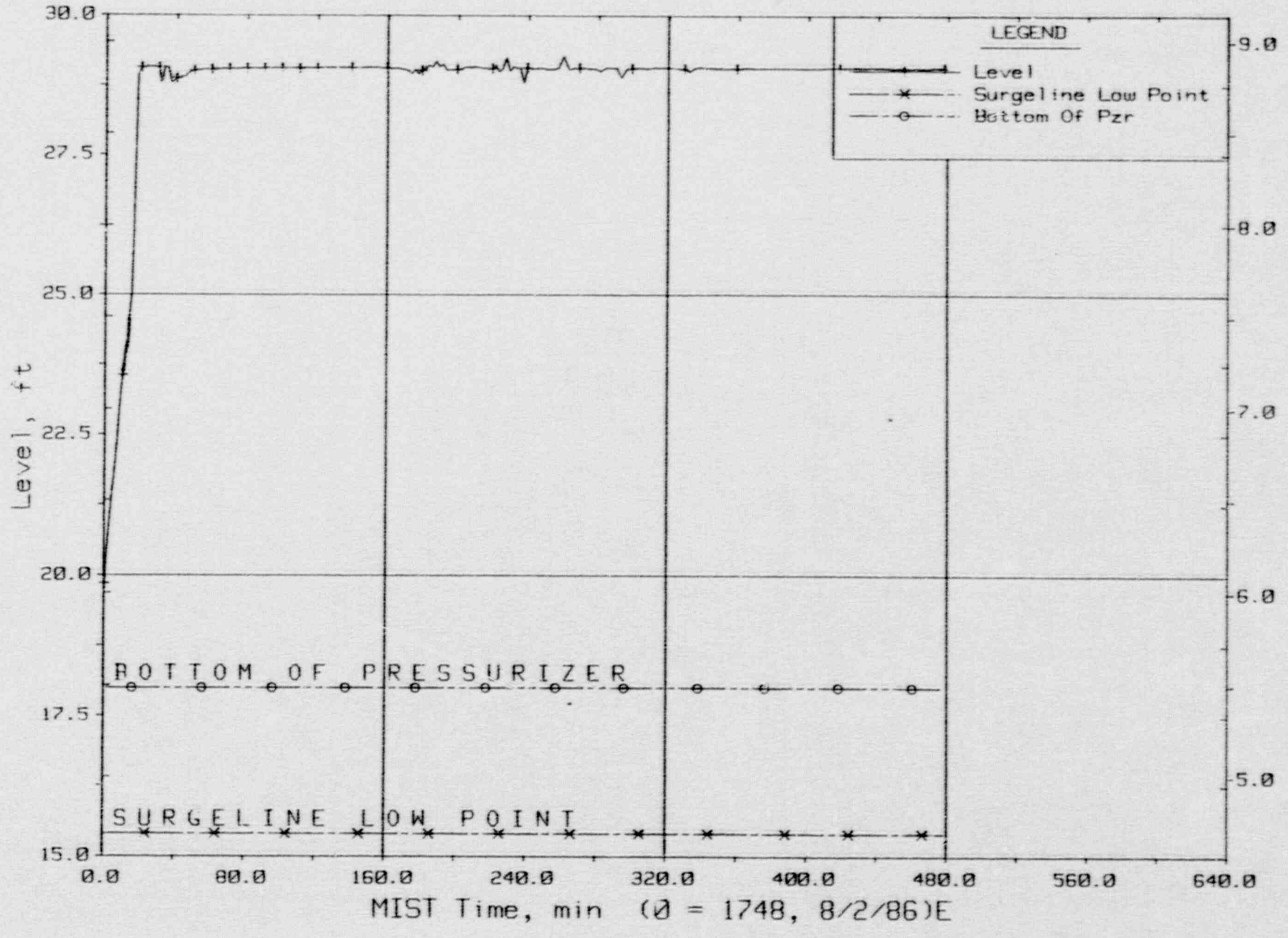
Guard Heater Specified Power, Pressurizer and Steam Generators.

Tue May 24 18:43:15 1988

PZGQ1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



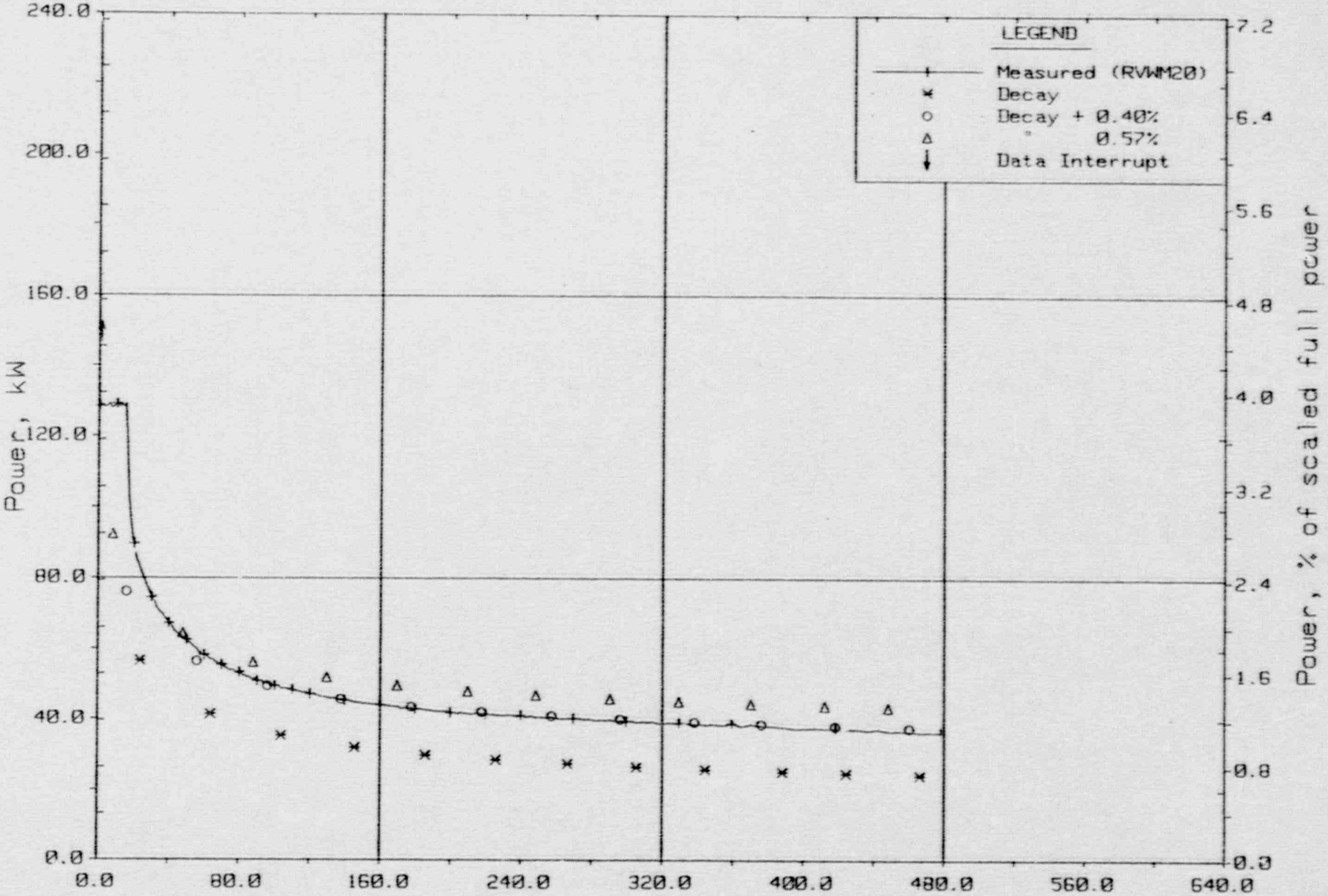
Pressurizer Collapsed Liquid Level (PZLV20).

Tue May 24 18:45:40 1988

PZLV1

FINAL DATA

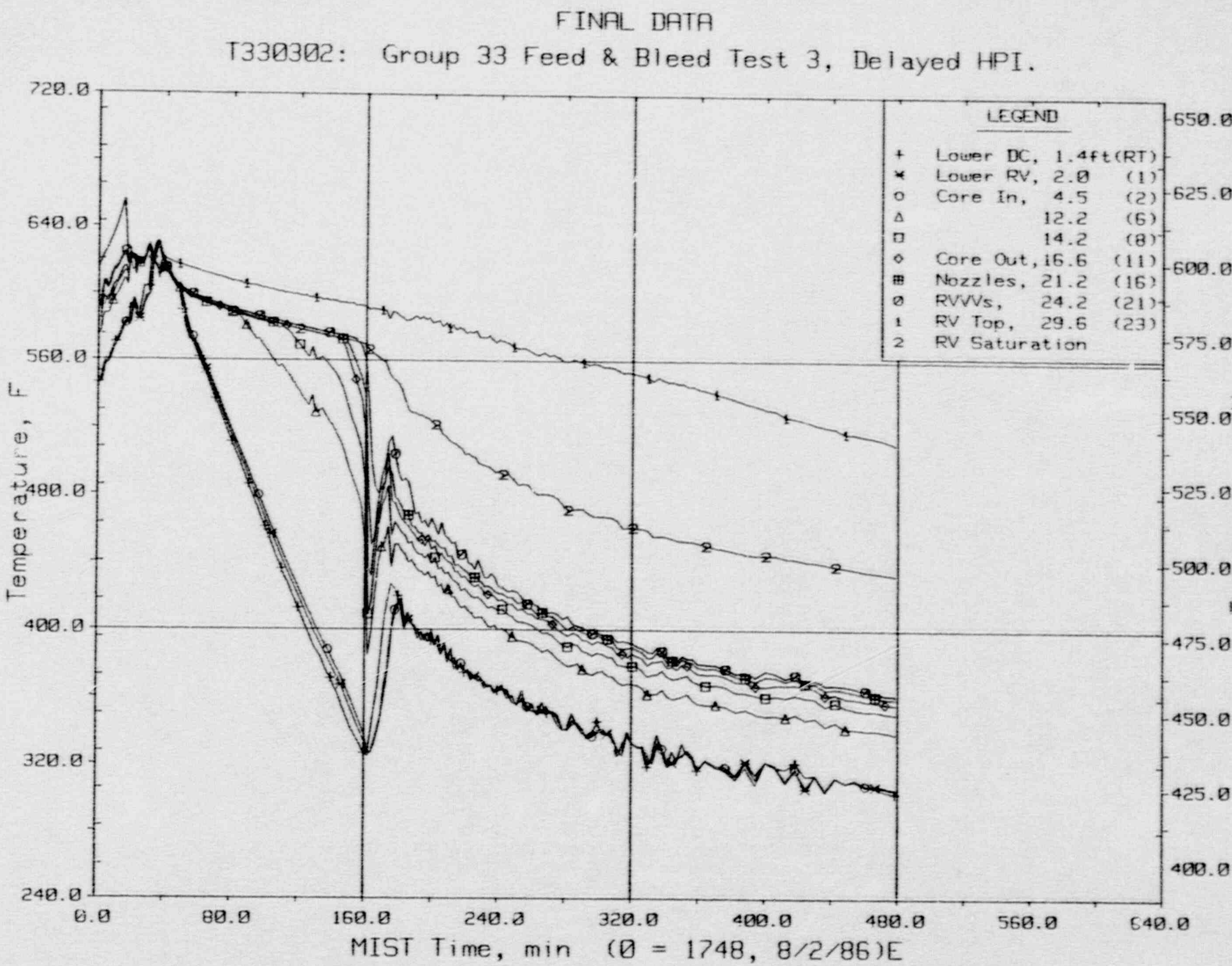
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Core Power.

Tue May 24 18:48:09 1988

RVKW0



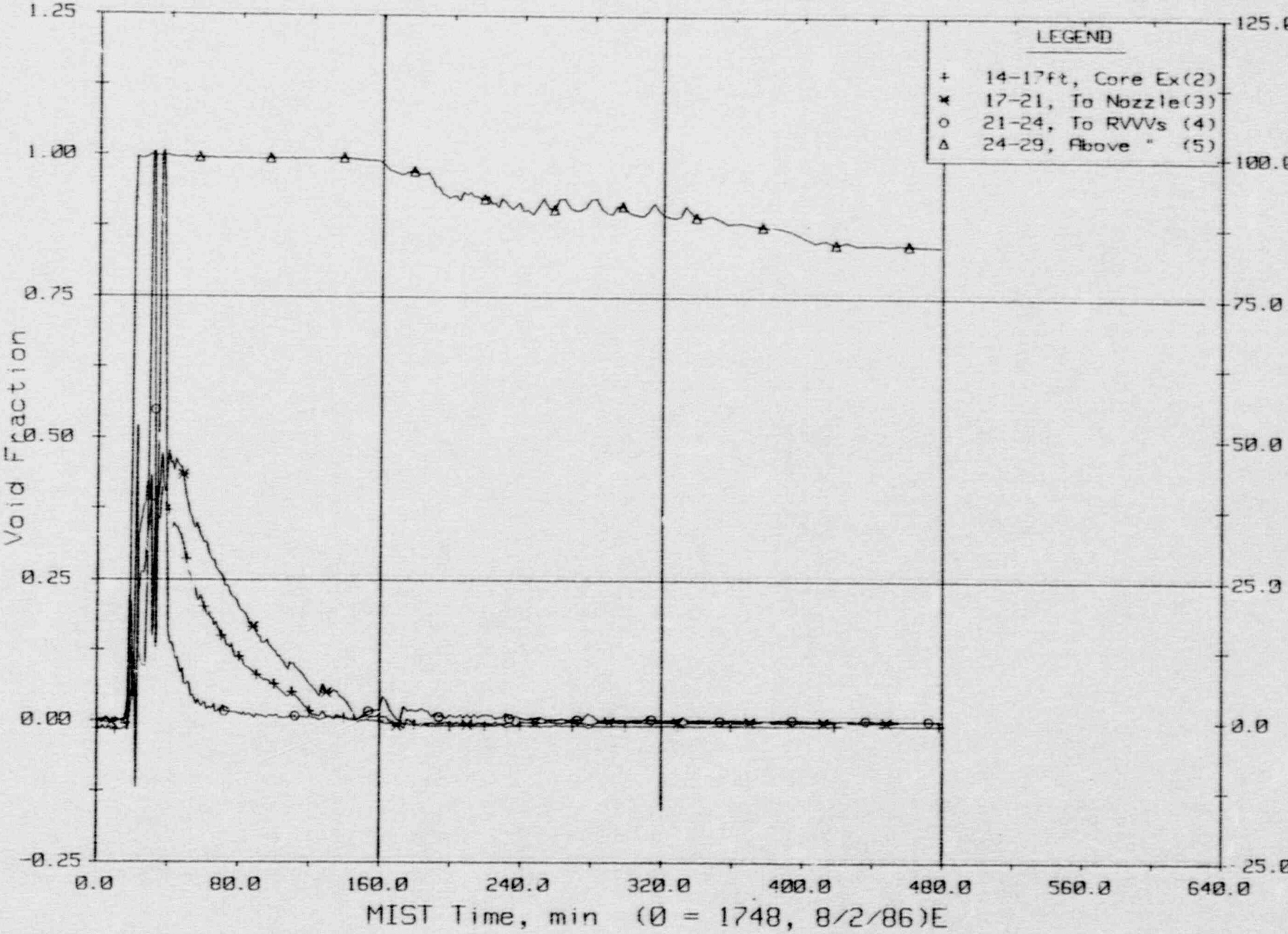
Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs).

Tue May 24 18:51 20 1988

RVTC0

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



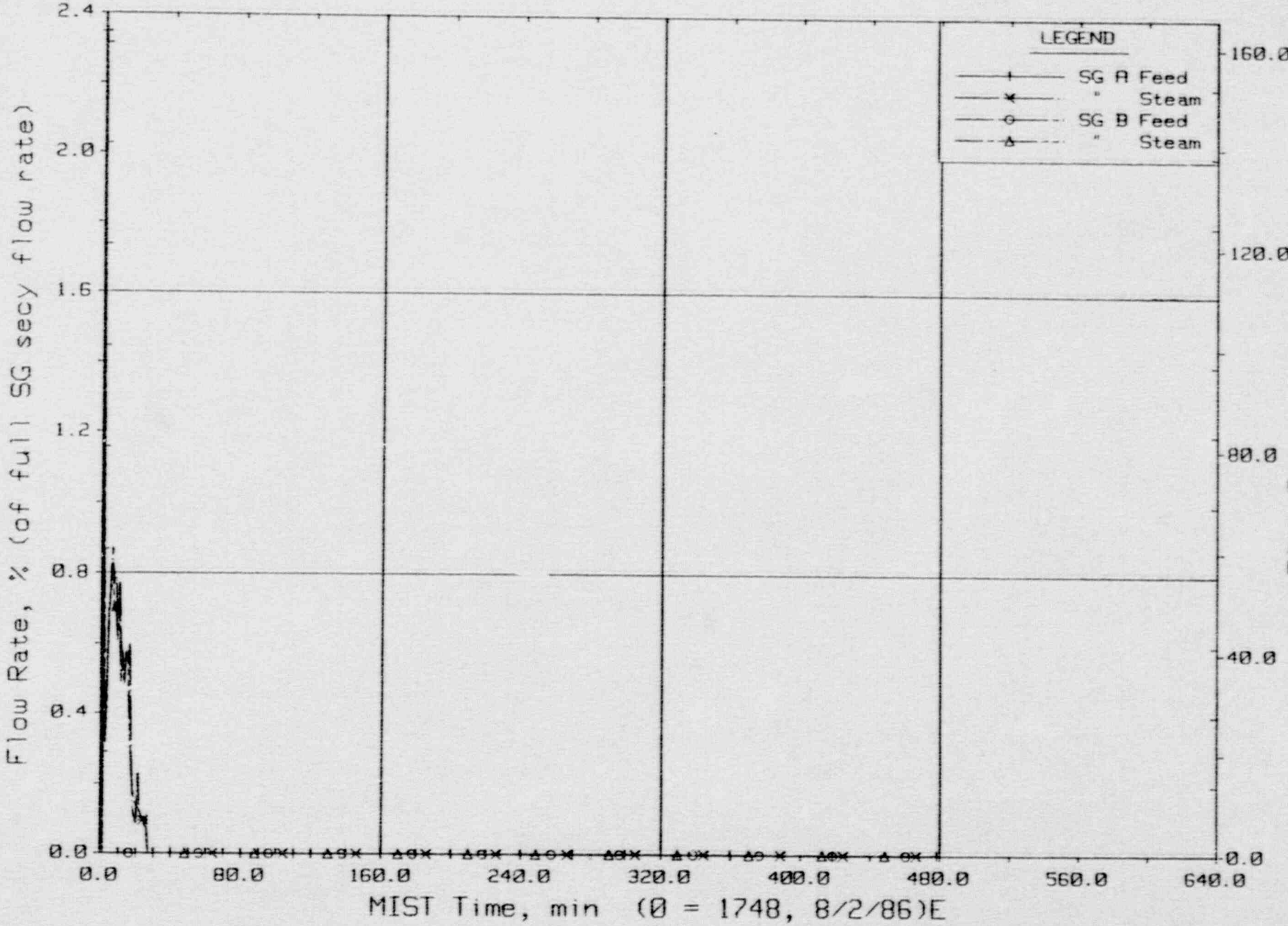
Reactor Vessel Void Fractions From Differential Pressures (RVVFs).

Tue May 24 18:54:03 1988

RVVF1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



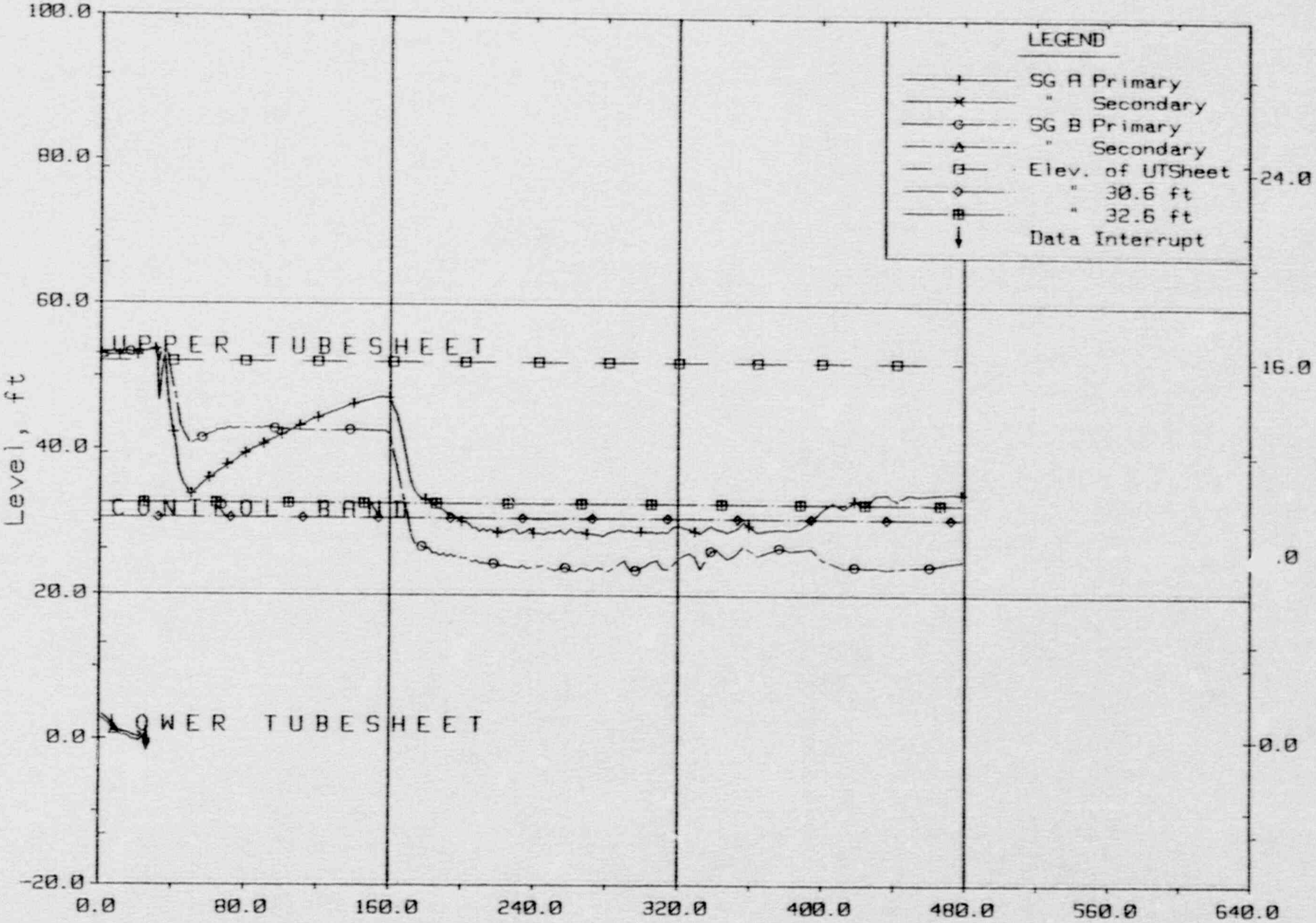
Steam Generator Secondary System Flow Rates.

Tue May 24 18:56:34 1988

SGFL2

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



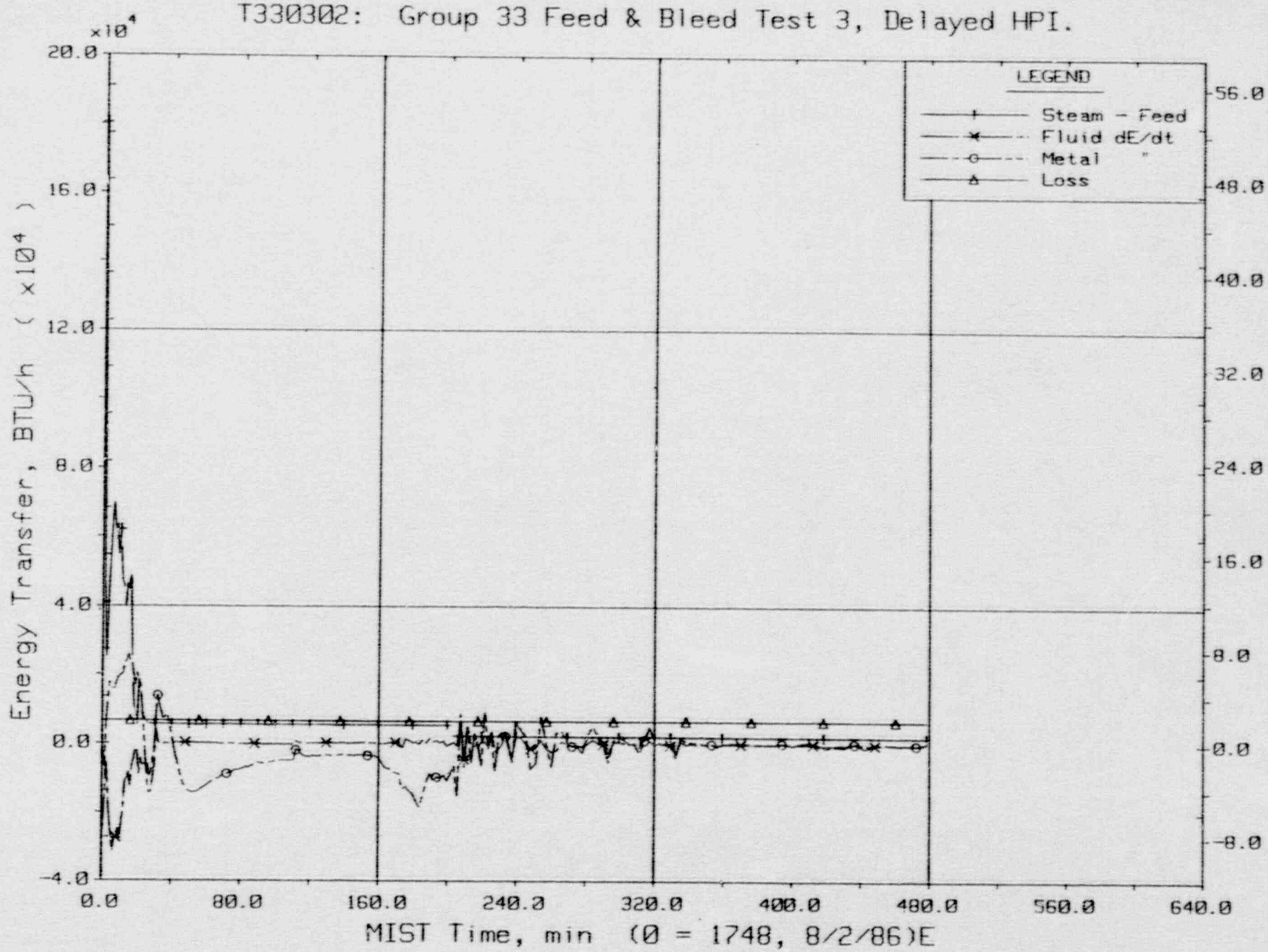
Steam Generator Collapsed Liquid Levels.

Tue May 24 18:59:18 1988

SGLV2

FINAL DATA

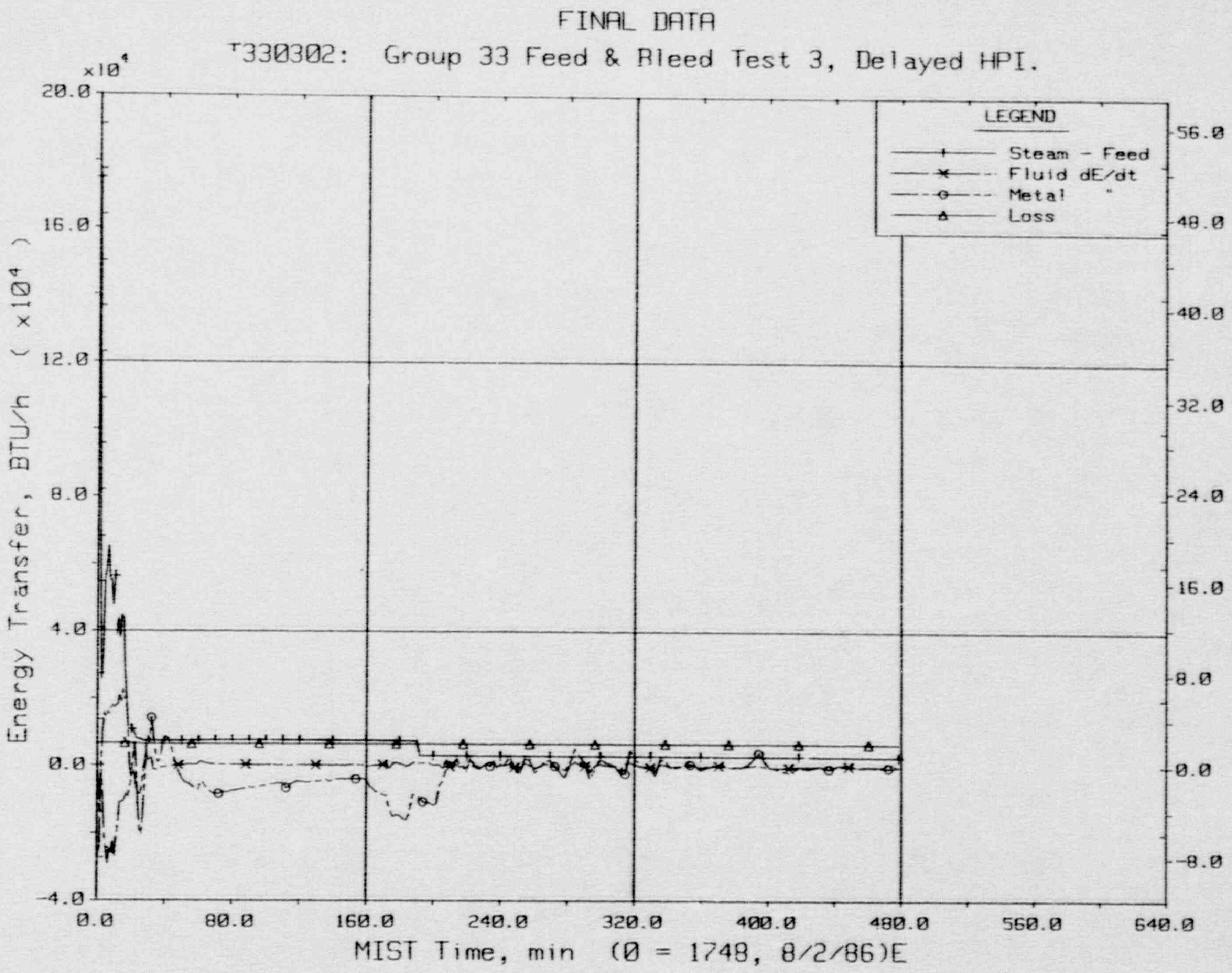
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



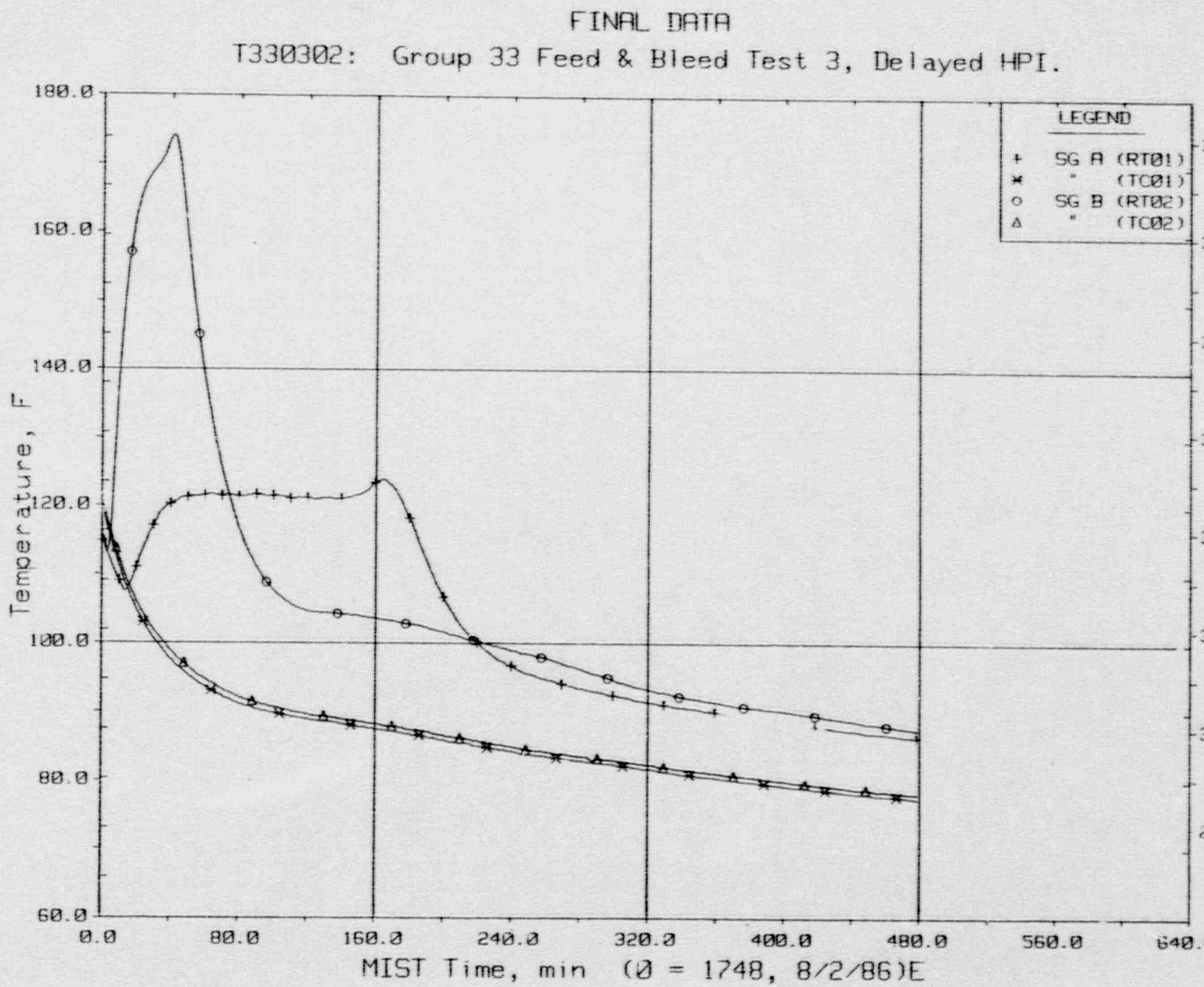
Steam Generator A Energy Transfer.

Tue May 24 19:04:37 1988

SGQE3



Steam Generator B Energy Transfer.



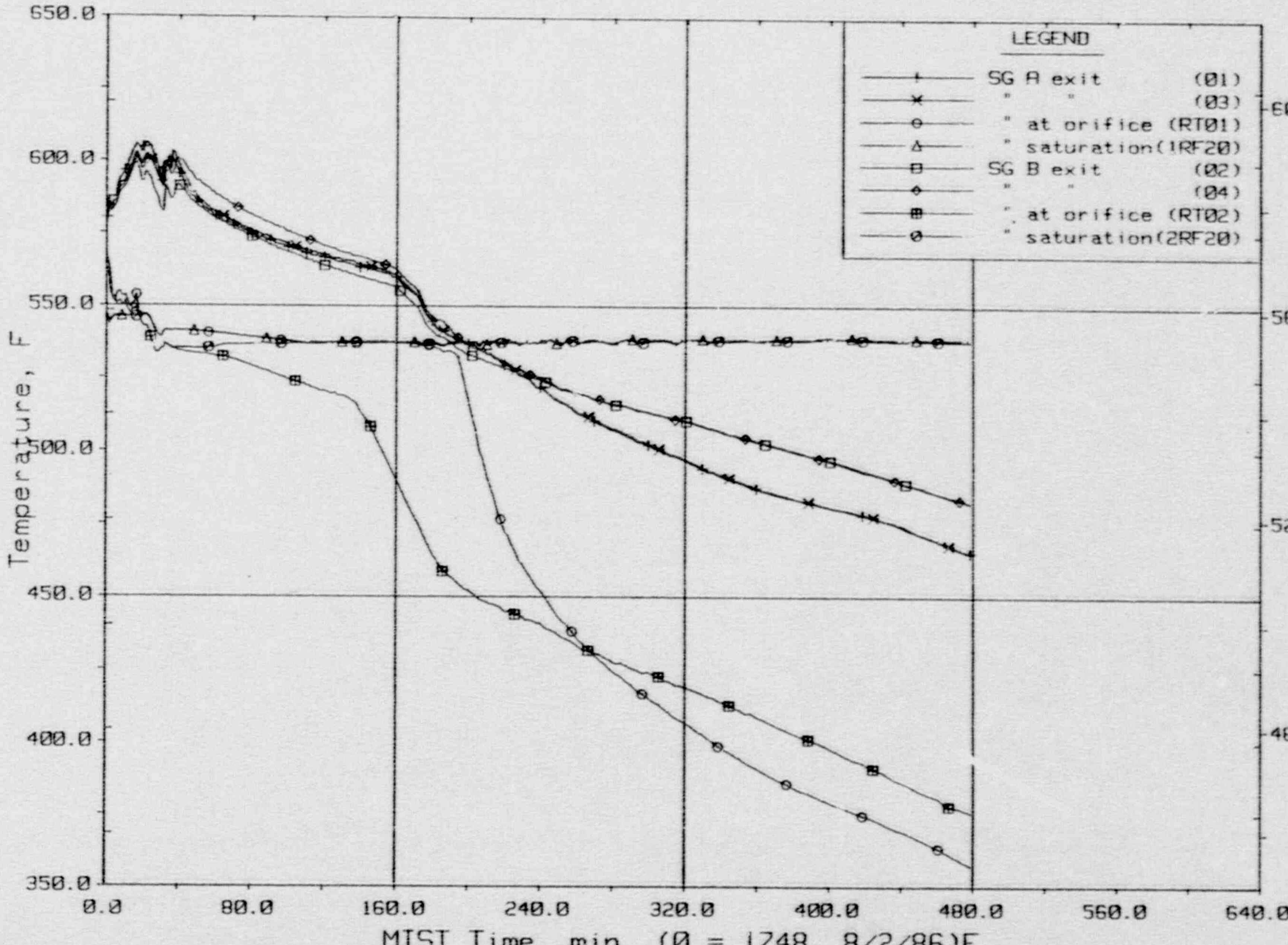
Feedwater Temperatures (SFs).

Tue May 24 19:09:51 1988

SGRT1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



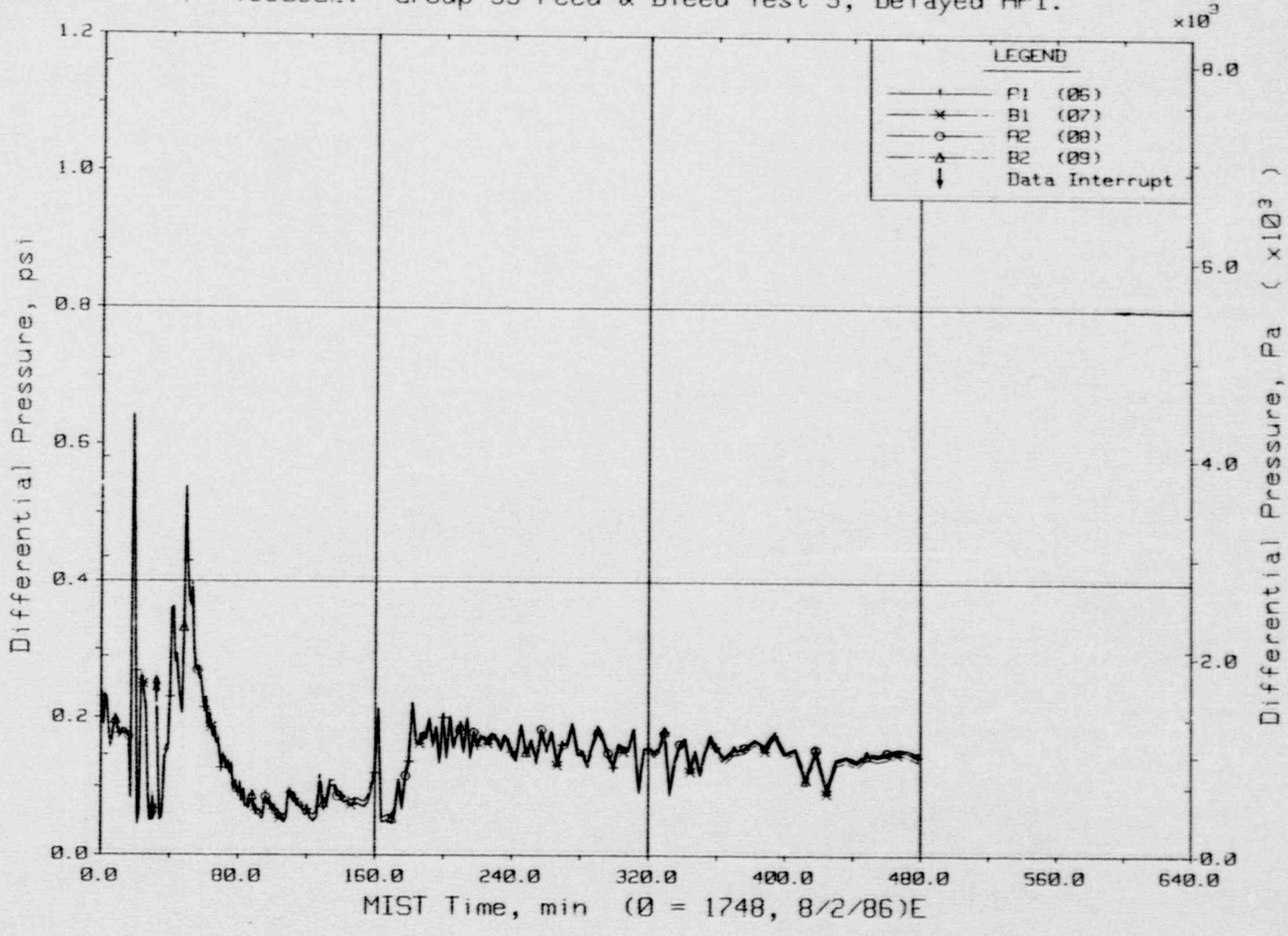
Steam Generator Steam Outlet Temperatures (SSTCs).

Tue May 24 19:12:47 1988

SGRT2

FINAL DATA

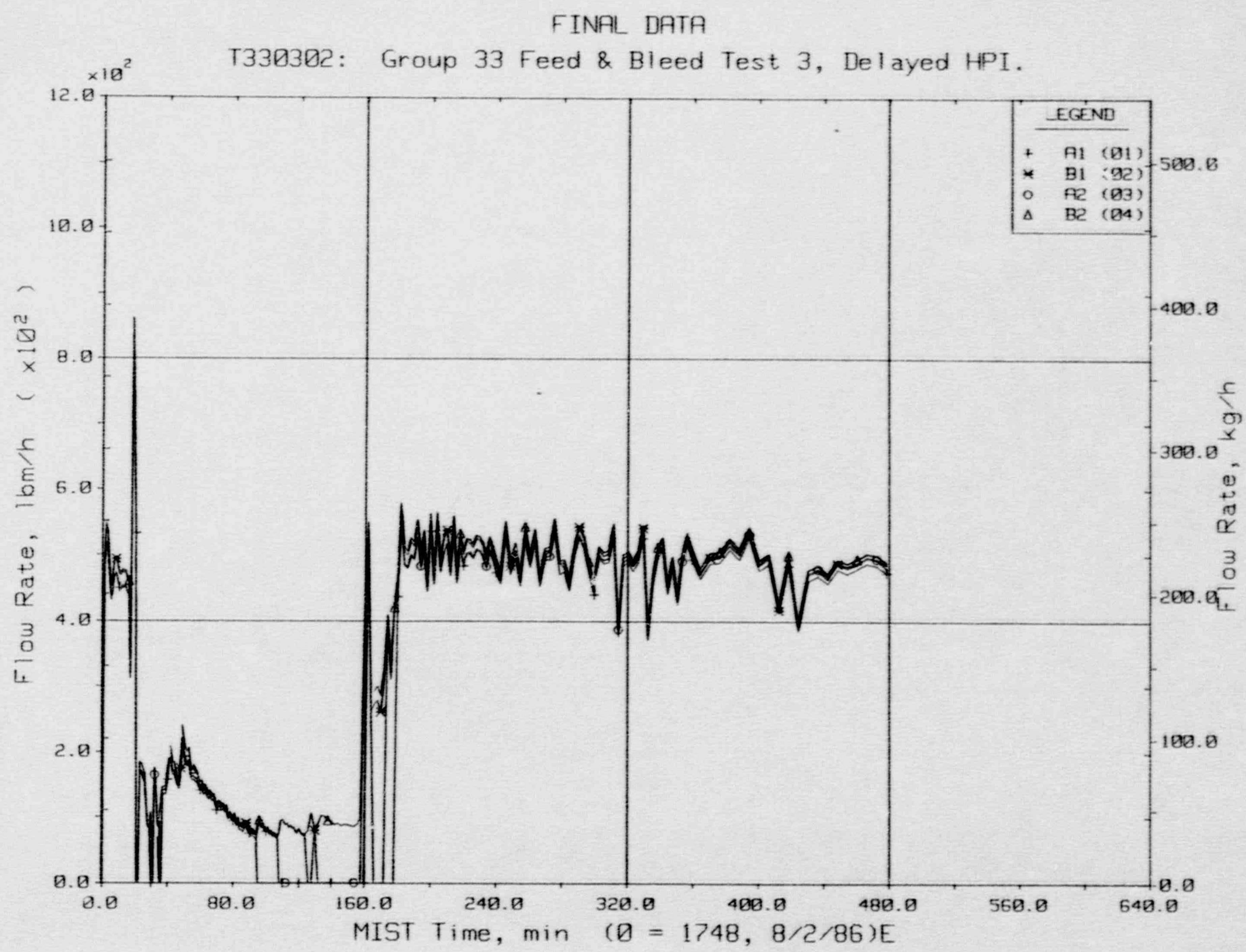
T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Reactor Vessel Vent Valve Differential Pressures (RVDPs).

Tue May 24 19:15:46 1988

VVDP1



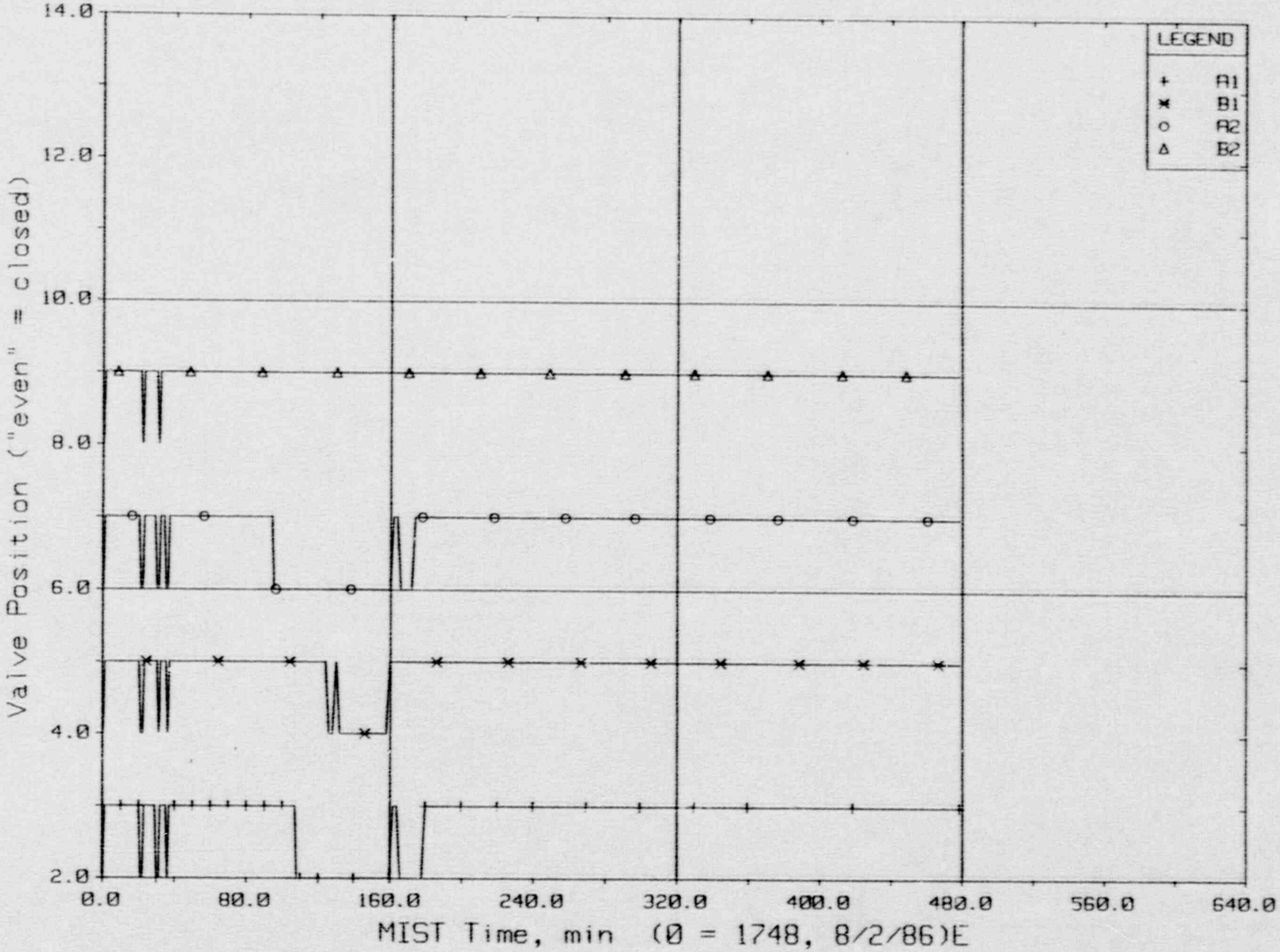
Reactor Vessel Vent Valve Flow Rates (RVORs).

Tue May 24 19:18:34 1938

VVFL1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



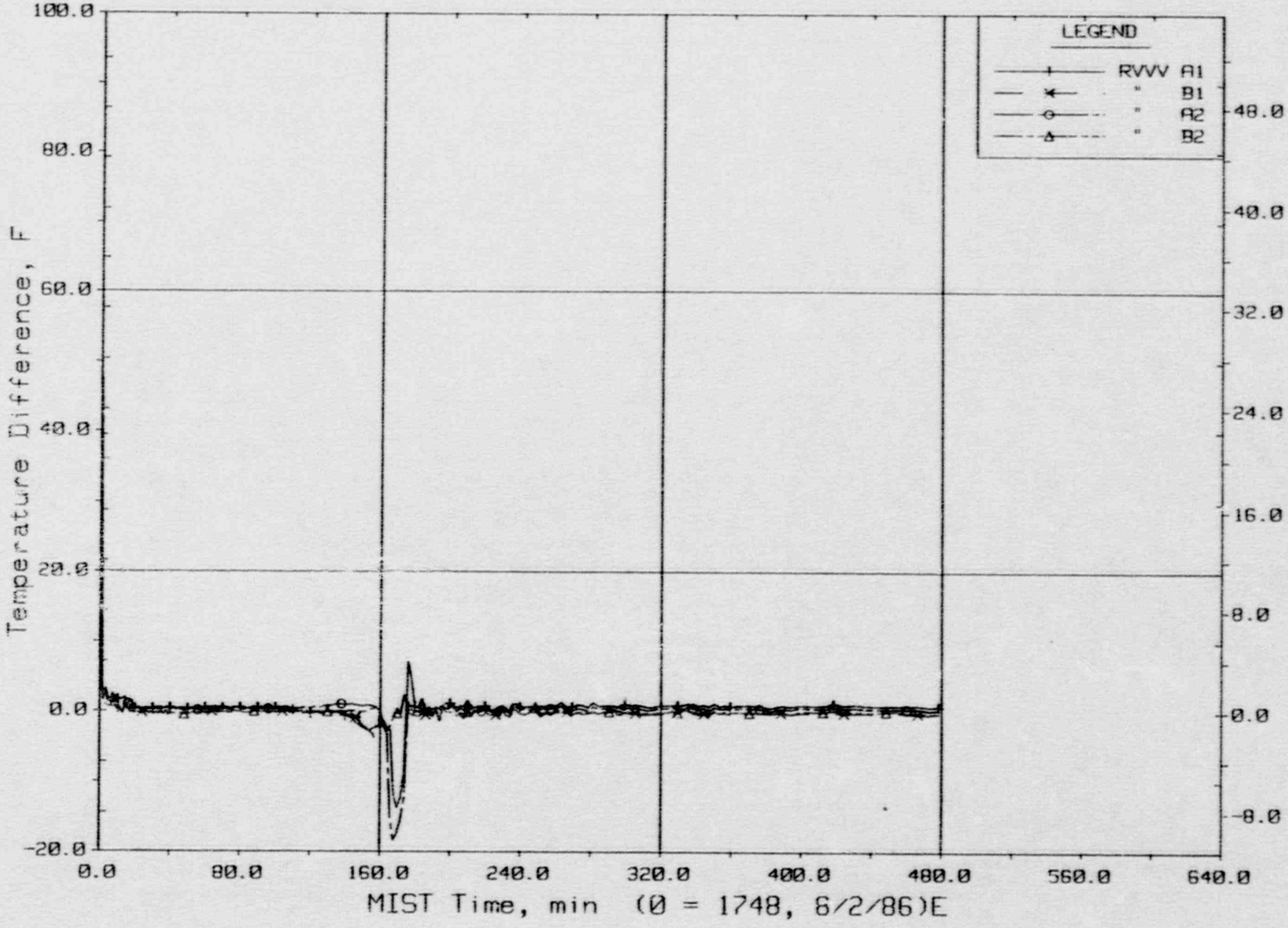
Reactor Vessel Vent Valve Positions.

Tue May 24 19:20:53 1988

VVLS1

FINAL DATA

T330302: Group 33 Feed & Bleed Test 3, Delayed HPI.



Temperature Differences Across Vent Valves.

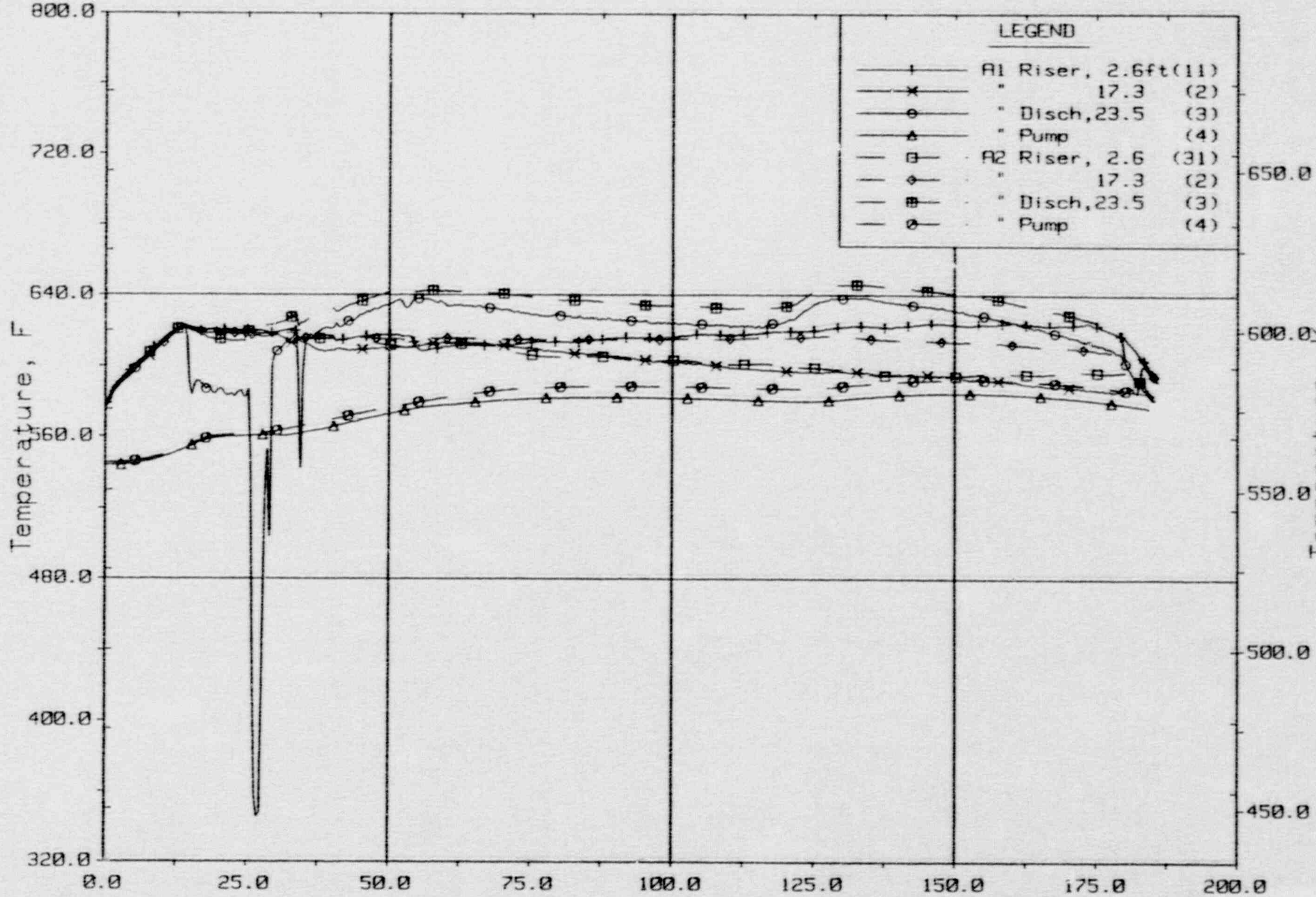
Wed May 25 06:05:49 1988

VVTD1

T330499

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



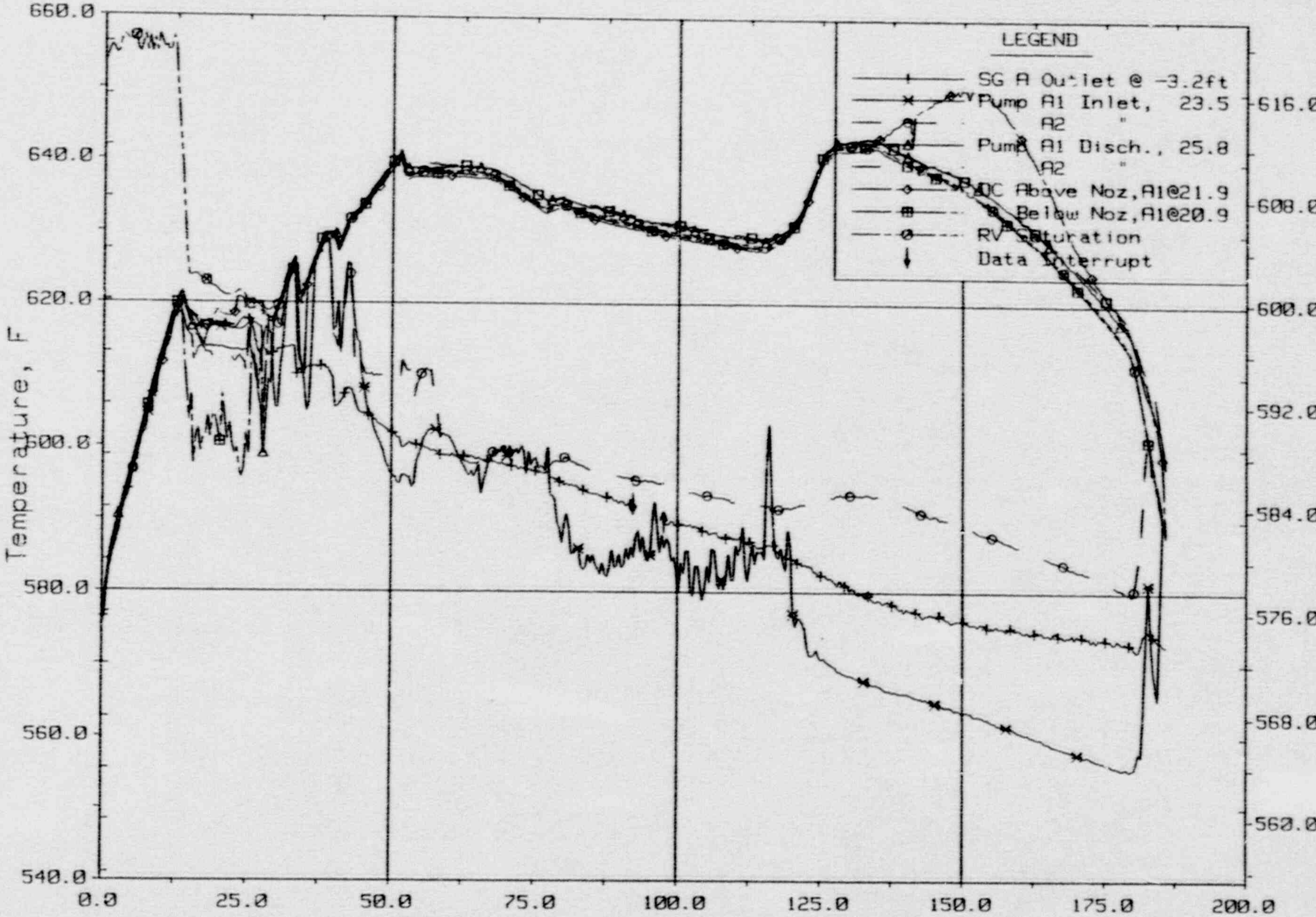
Loop A Cold Leg Metal Temperatures (C1,3MTs).

Tue Jun 7 10:00:02 1988

C1MT1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



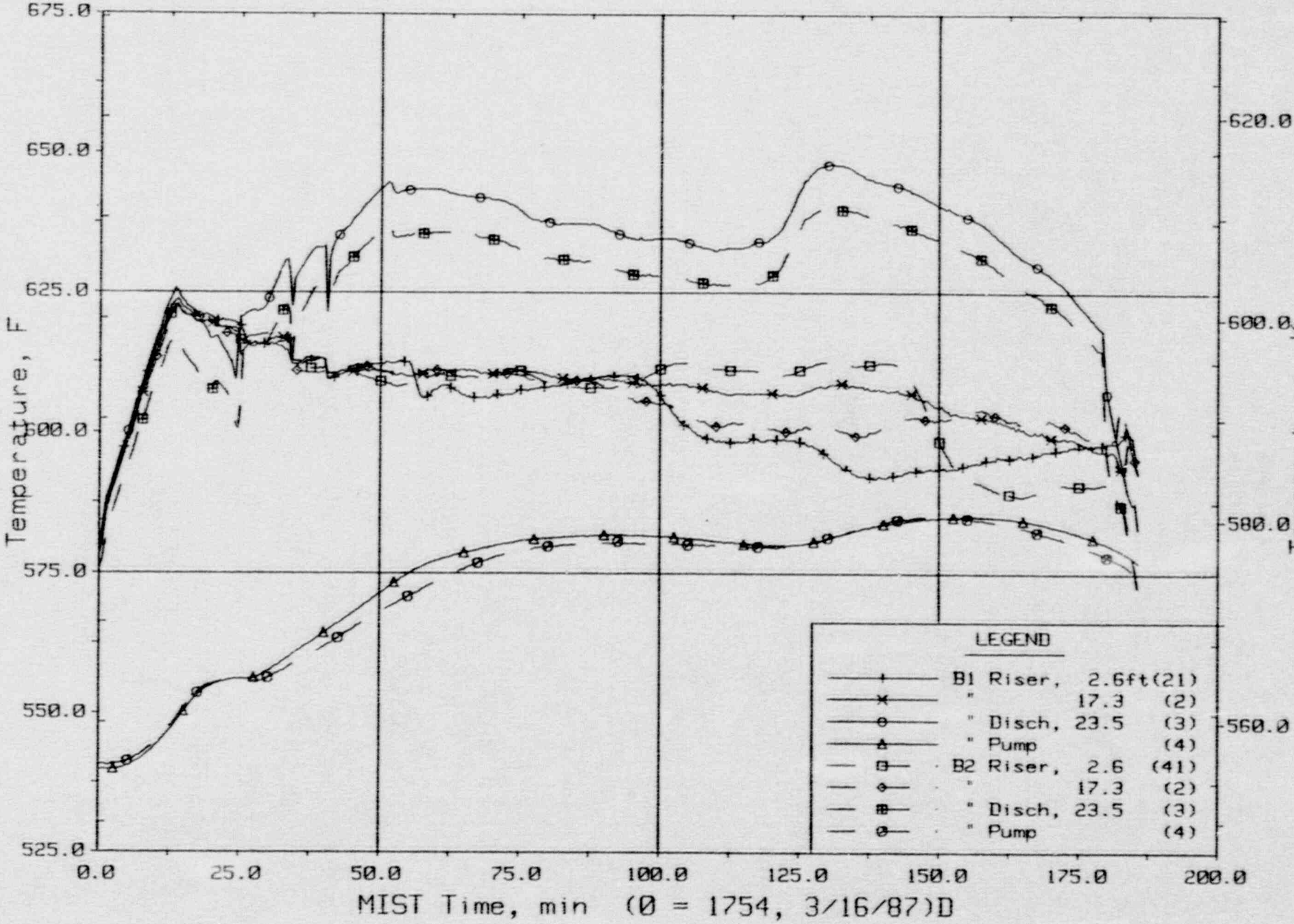
Loop A Cold Leg Fluid Temperatures (RTDs).

Tue Jun 7 10:04:11 1988

C1RT0

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



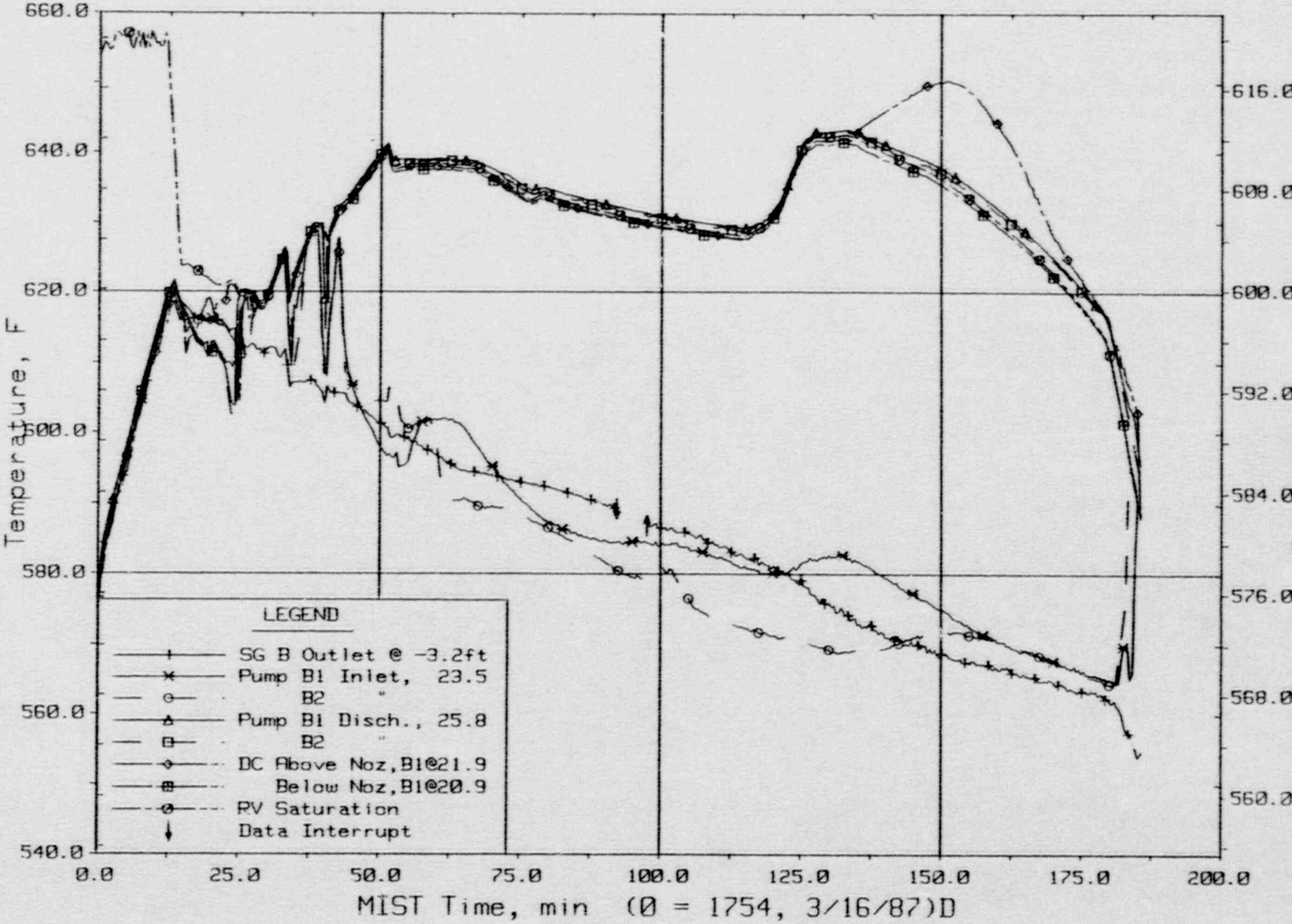
Loop B Cold Leg Metal Temperatures (C2,4MTs).

Tue Jun 7 10:08:19 1988

C2MT1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



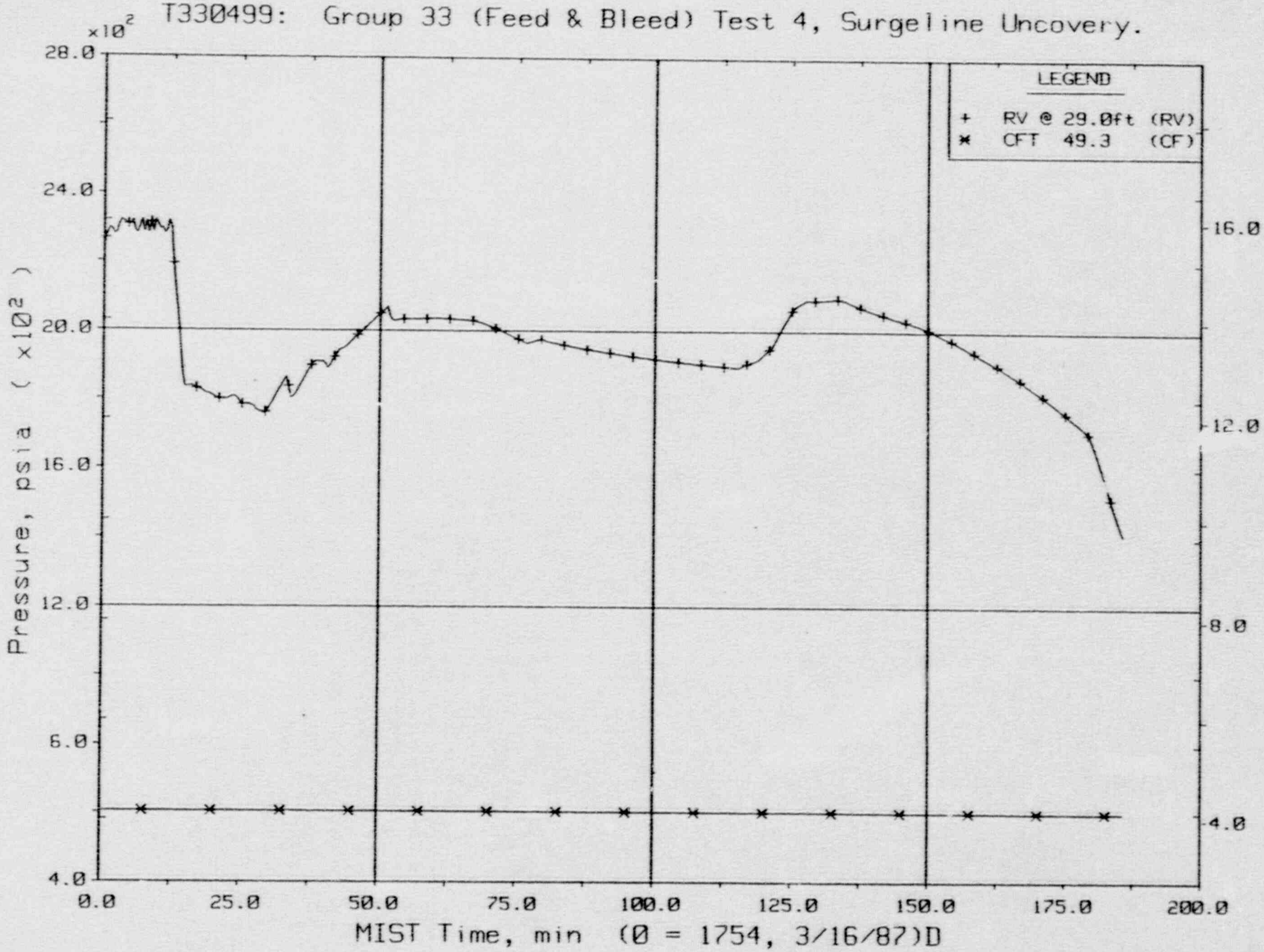
Loop B Cold Leg Fluid Temperatures (RTDs).

Tue Jun 7 10:14:55 1988

C2RT0

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



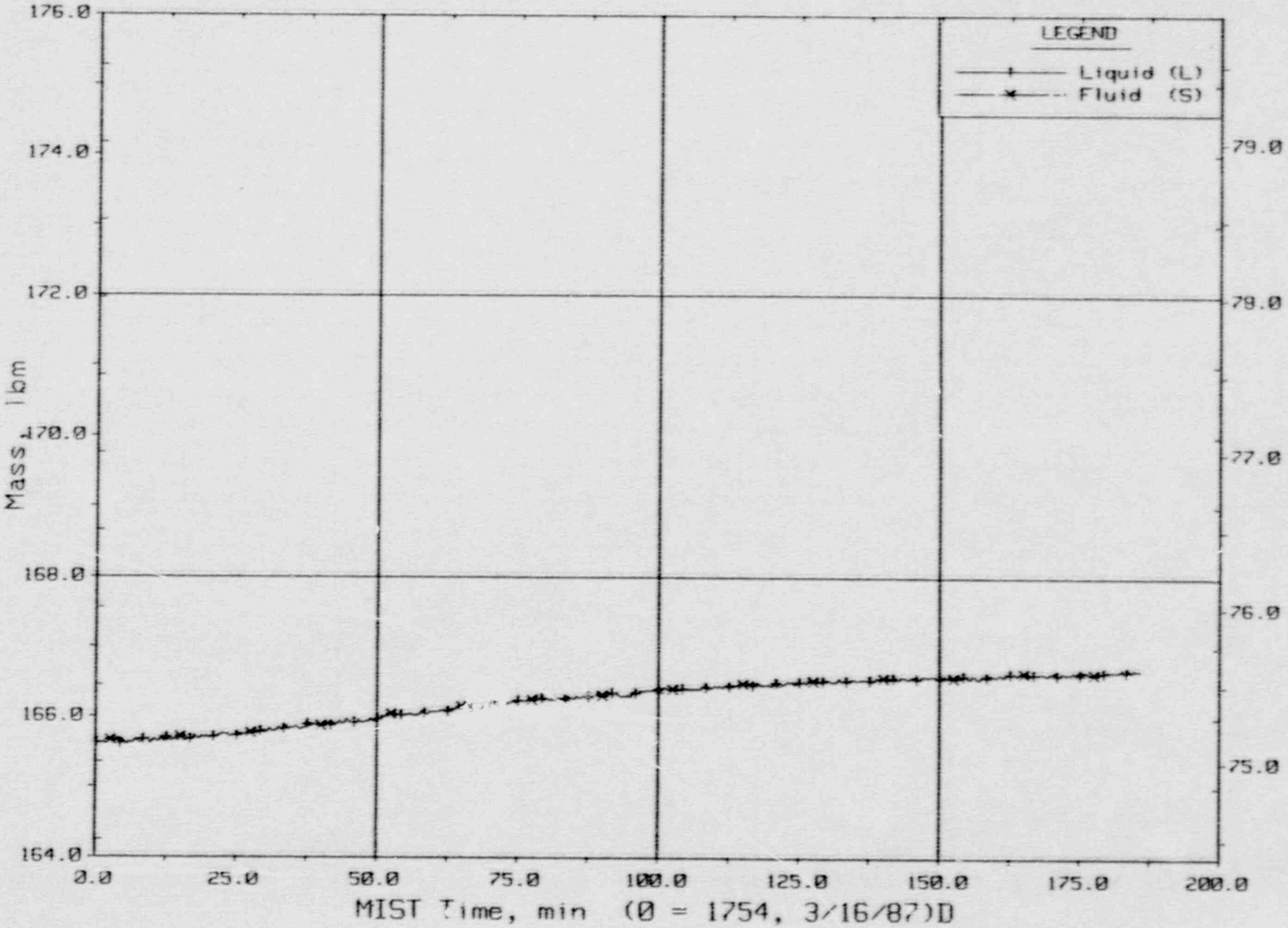
Primary System and Core Flood Tank Pressures (GP01s).

Tue Jun 7 10:18:07 1988

CFGP1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



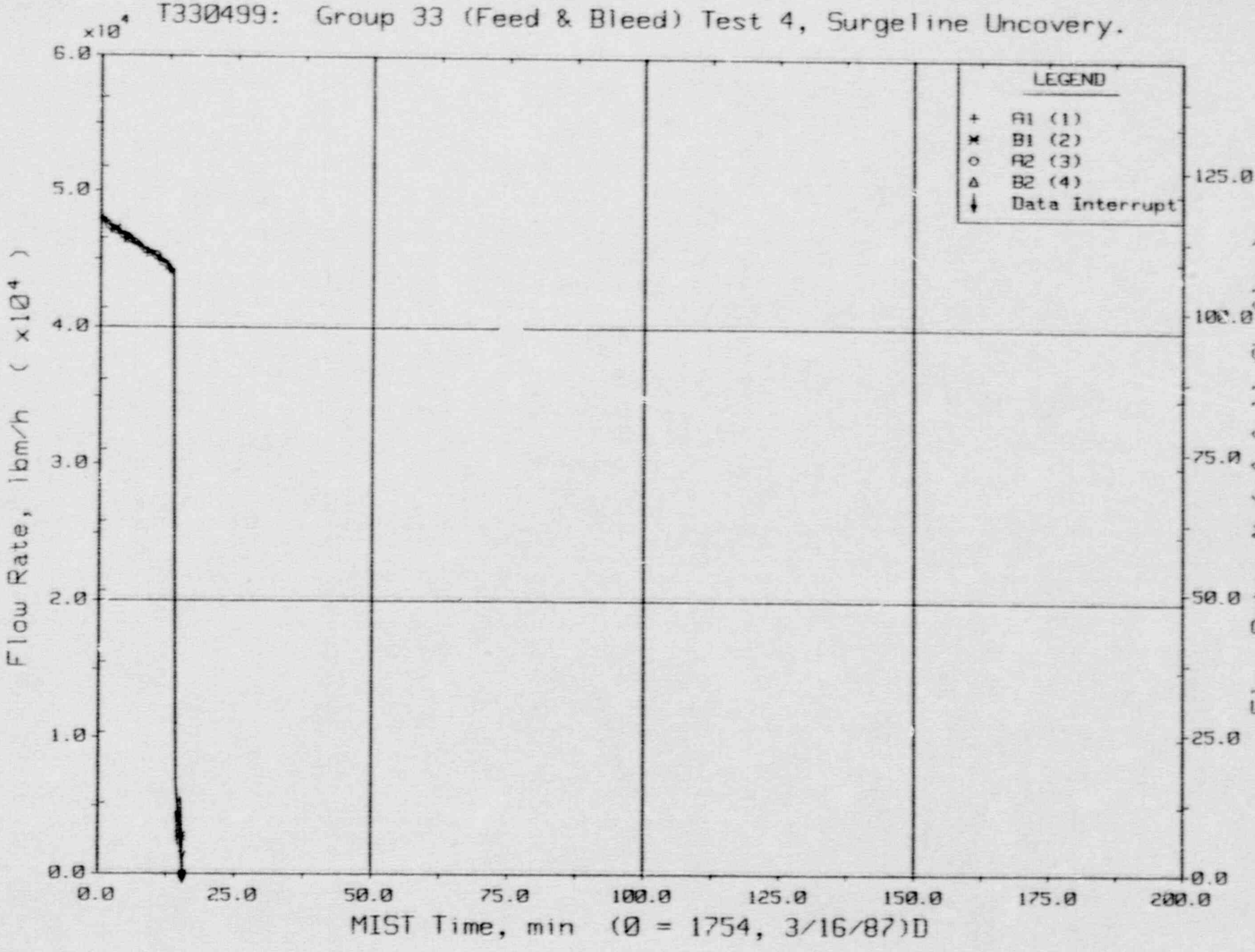
Core Flood Tank Liquid and Fluid Mass (CFMa20s).

Tue Jun 7 10:21:47 1988

CFML1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



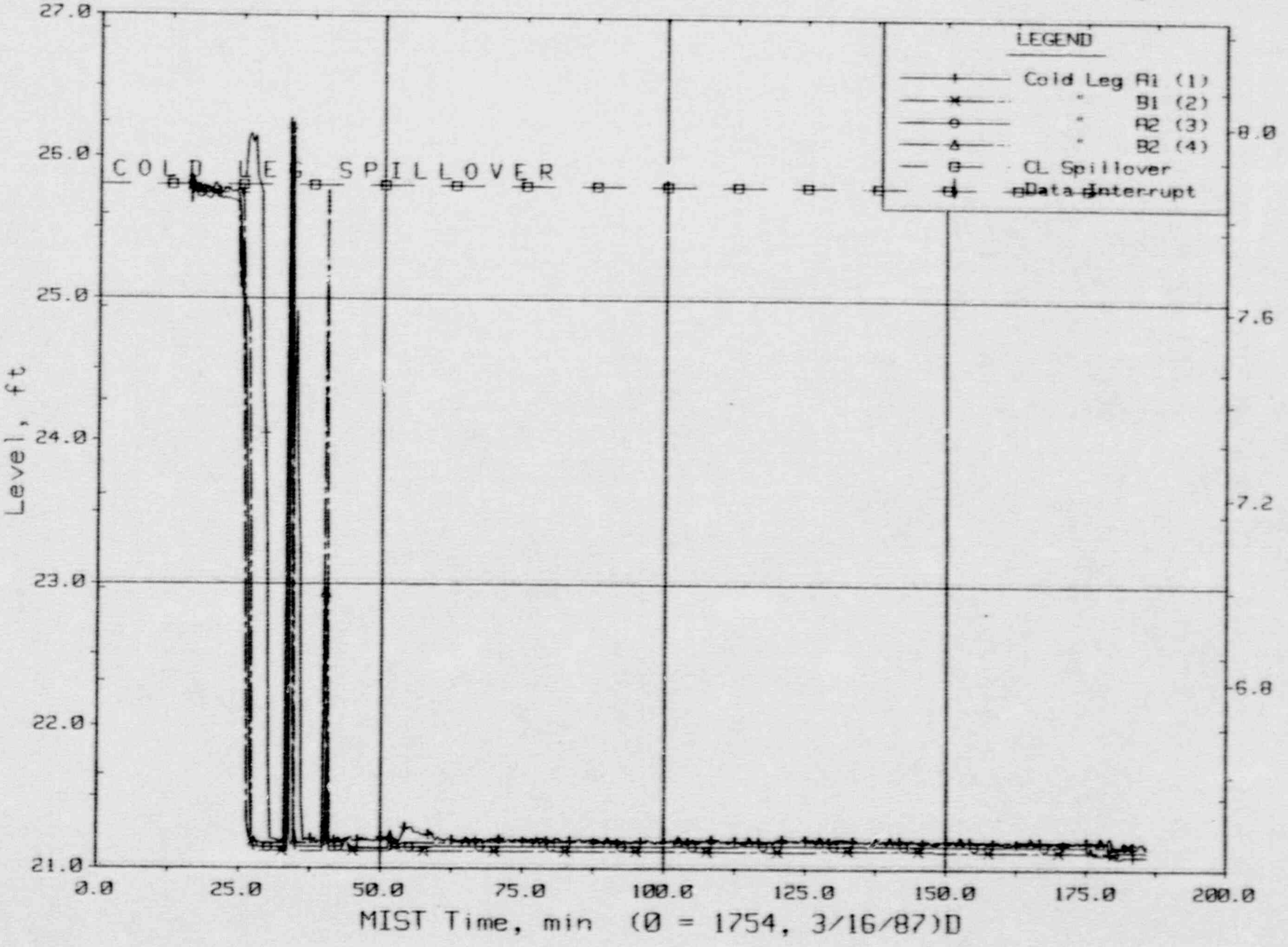
Cold Leg (Turbine Meter) Mass Flow Rates (CnTM01s).

Tue Jun 7 14:03:54 1988

CLFL3

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



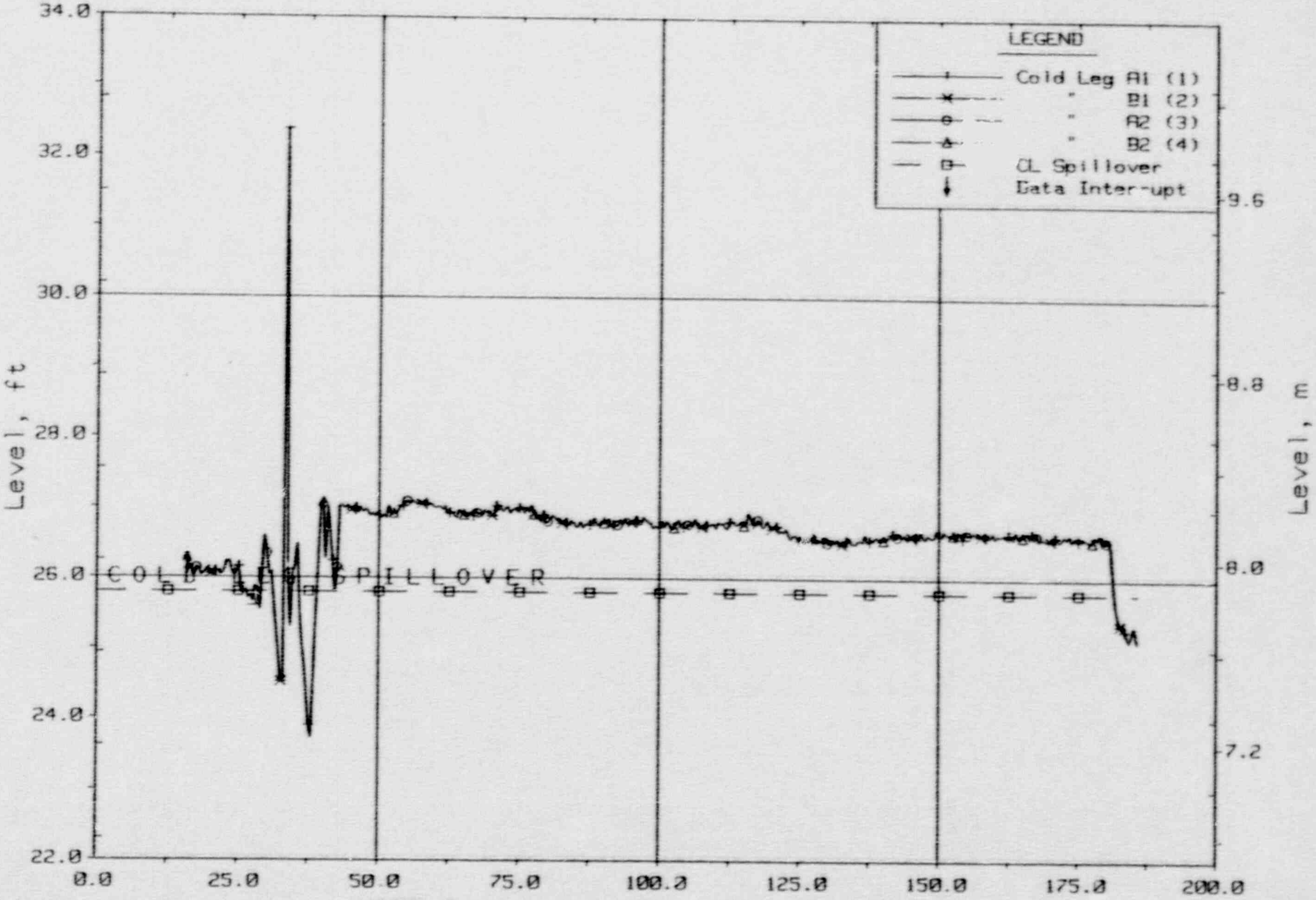
Cold Leg Discharge Collapsed Liquid Levels (CnLV23s).

Tue Jun 7 10:34:40 1988

CLLV5

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



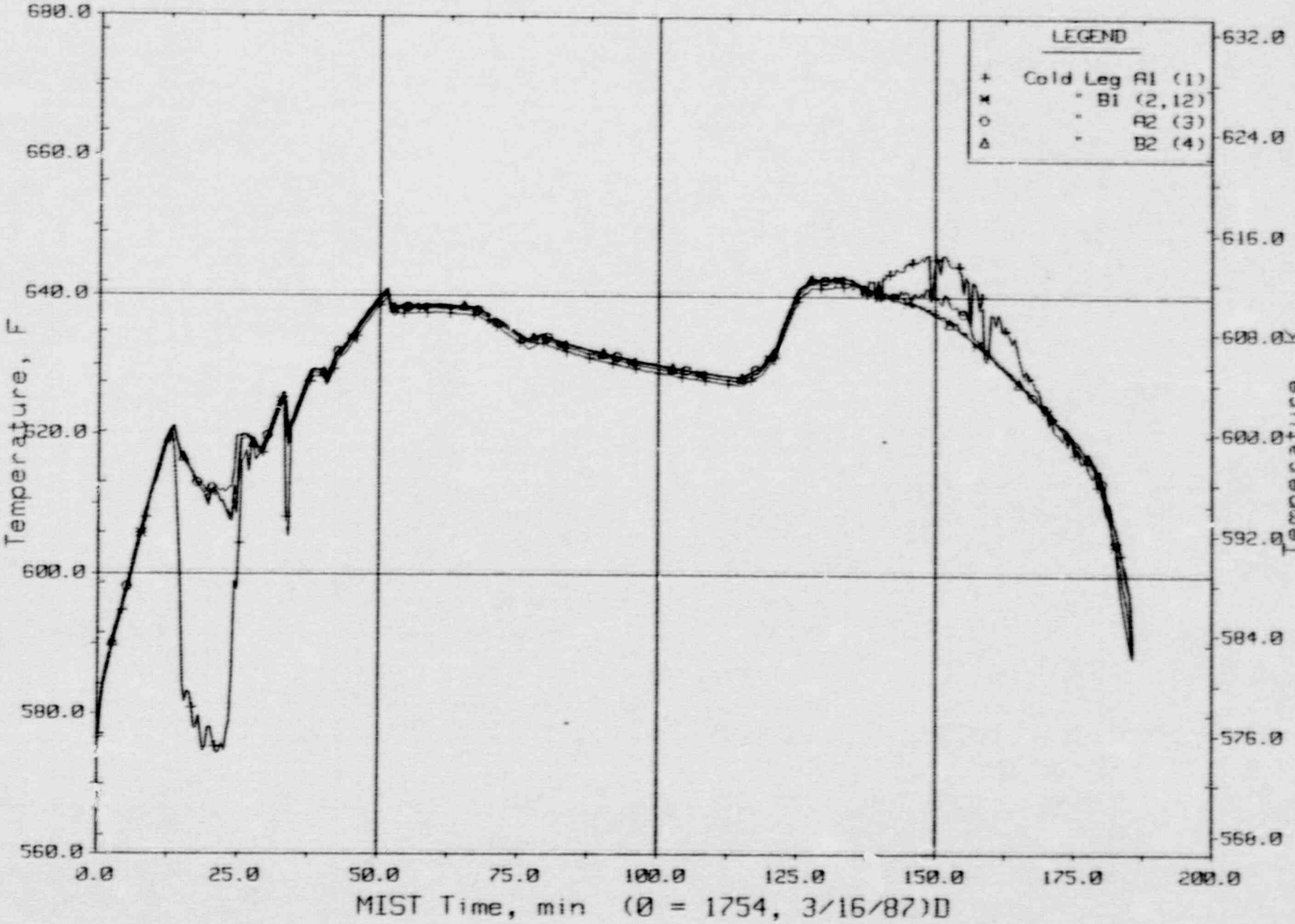
Cold Leg Suction Collapsed Liquid Levels (CnLV32s).

Tue Jun 7 10:38:42 1988

CLLV6

FINAL DATA

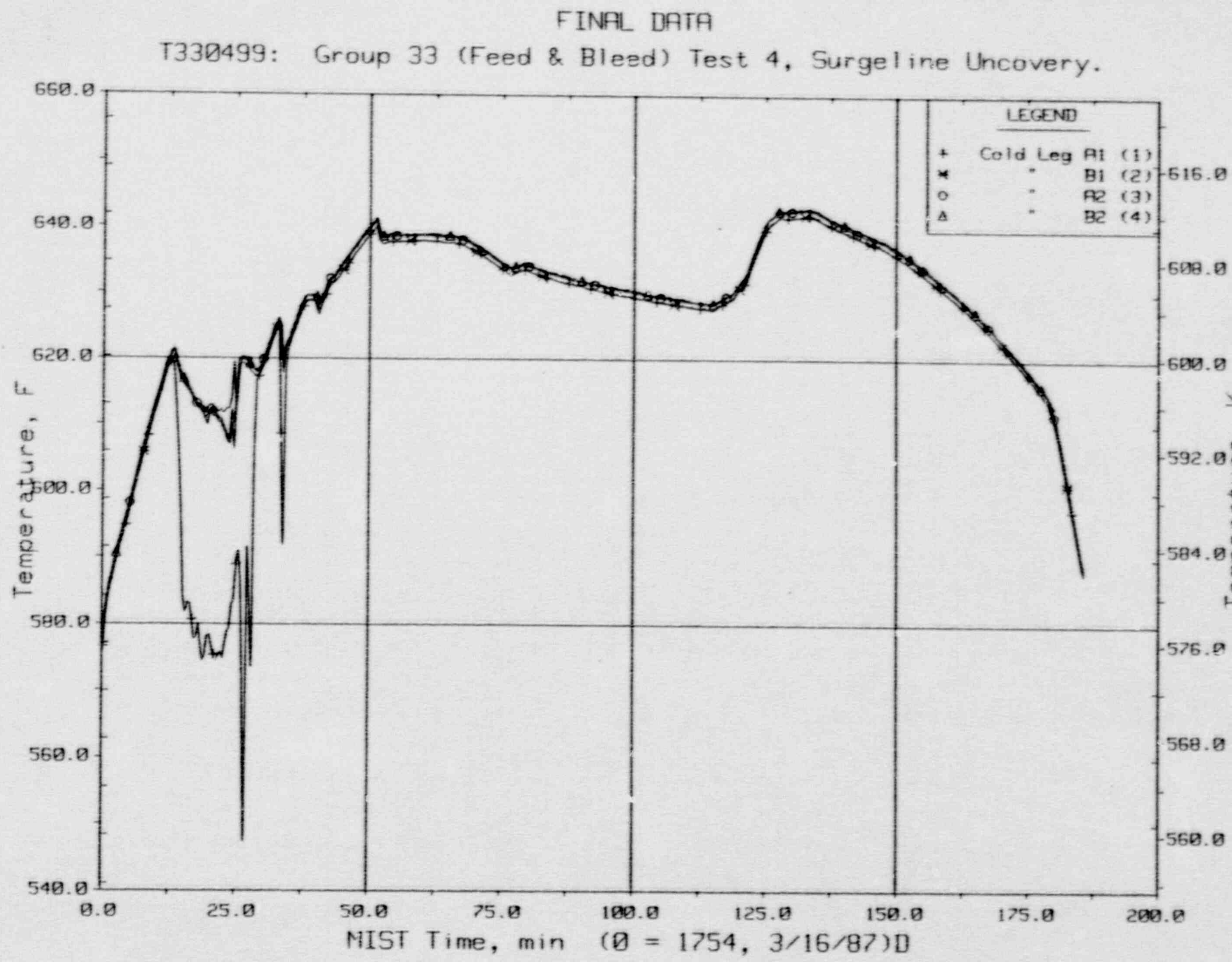
T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



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

Tue Jun 7 10:42:16 1988

CLTC1



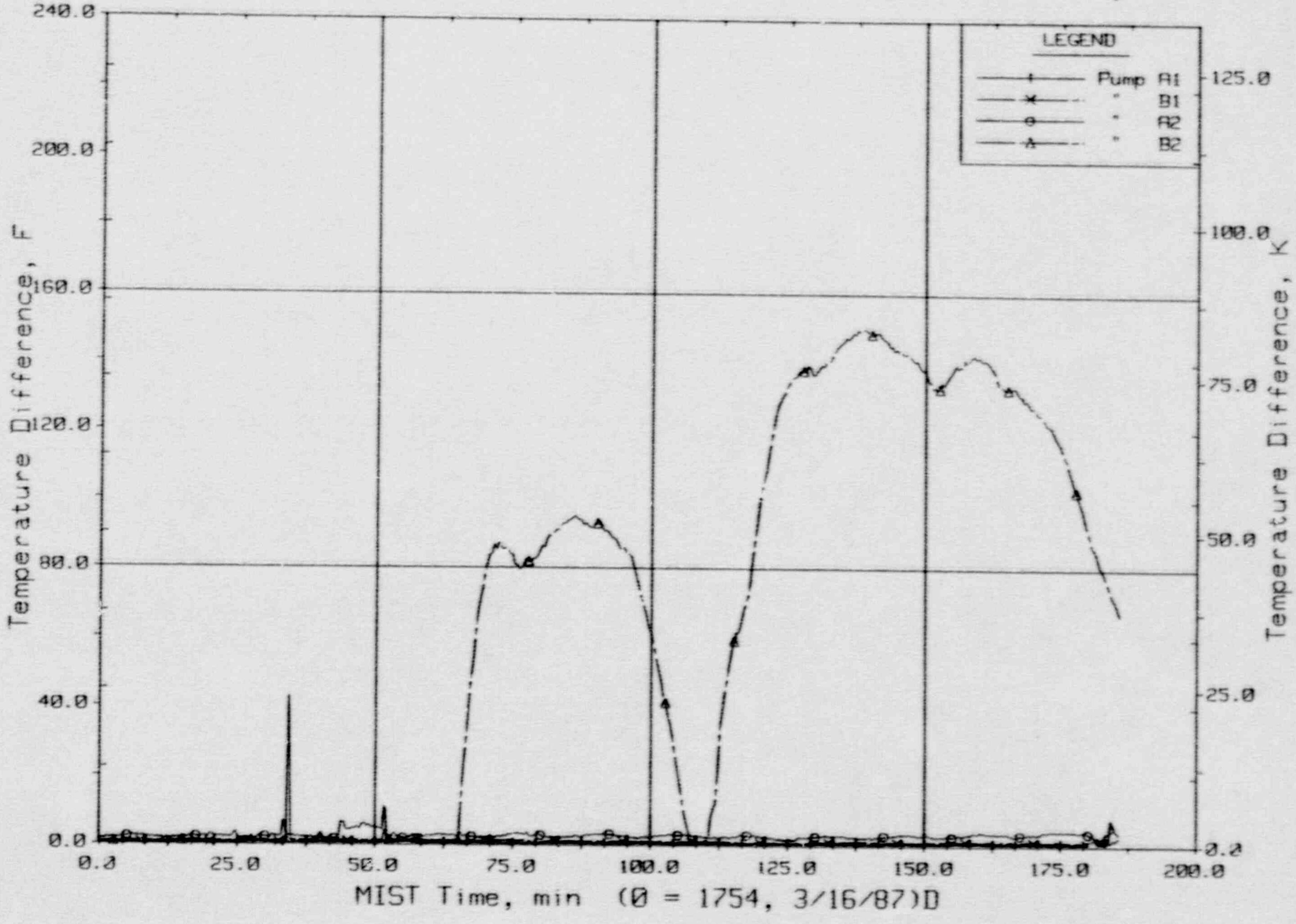
Cold Leg Nozzle Fluid Temperatures, Bottom of Rake (21.2ft, CnTC14s).

Tue Jun 7 10:46:04 1988

CLTC2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



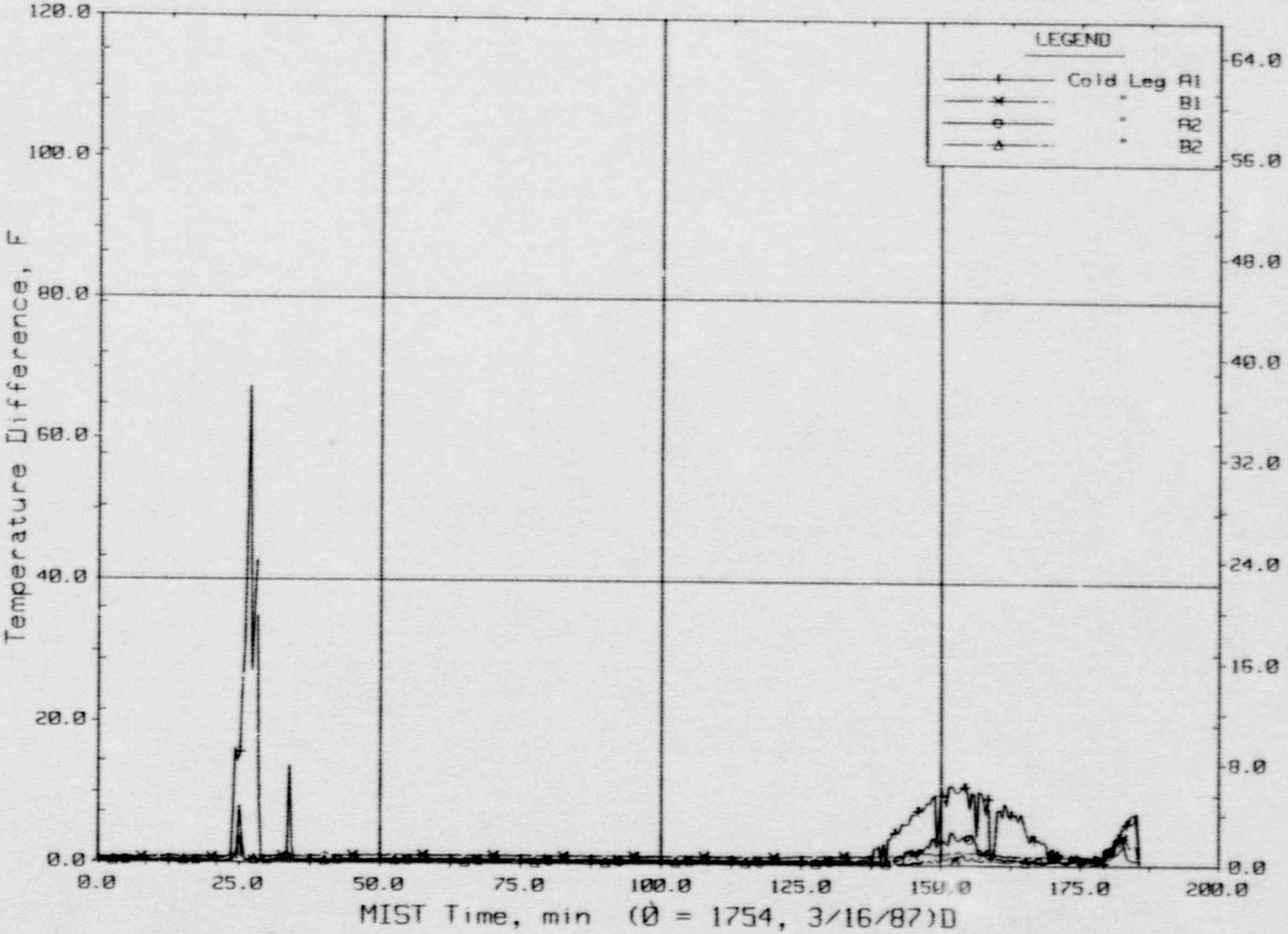
Maximum Differences Among RCP Rake Fluid Temperatures.

Tue Jun 7 10:49:03 1988

CLTD1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



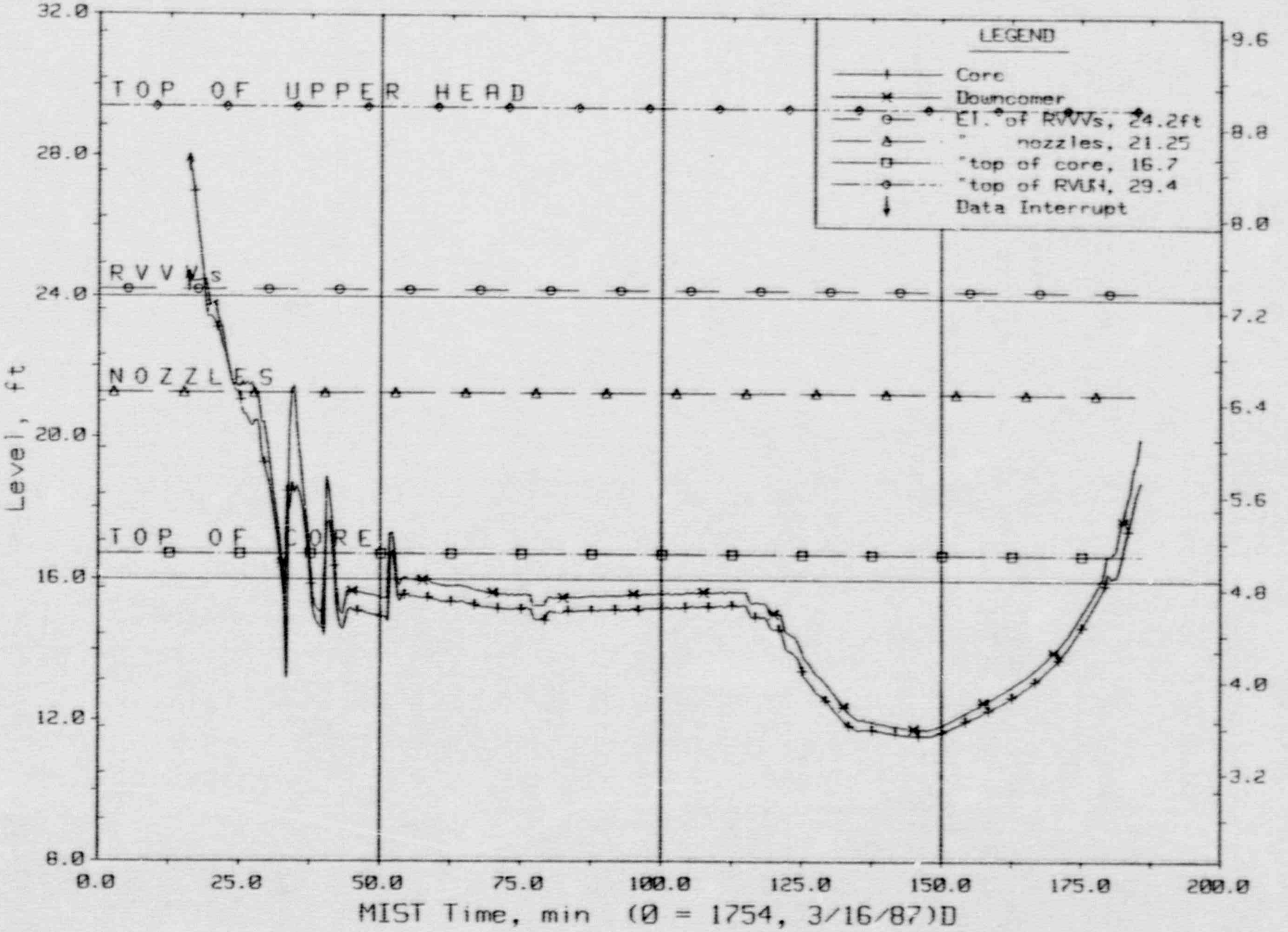
Maximum Differences Among CL Nozzle Rake Fluid Temperatures.

Tue Jun 7 10:52:51 1988

CLTD2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



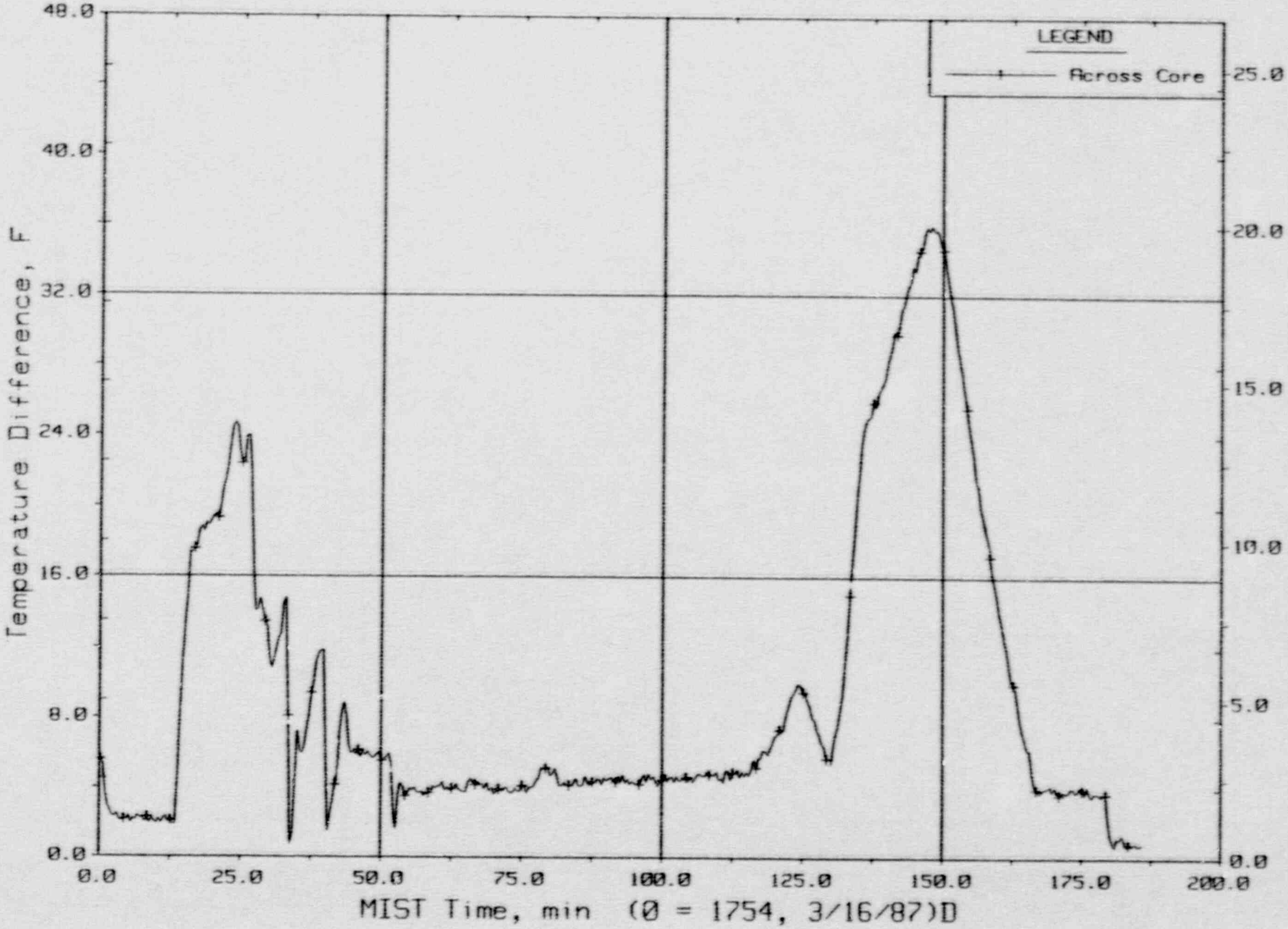
Core Region Collapsed Liquid Levels.

Tue Jun 7 10:57:40 1988

COLV1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



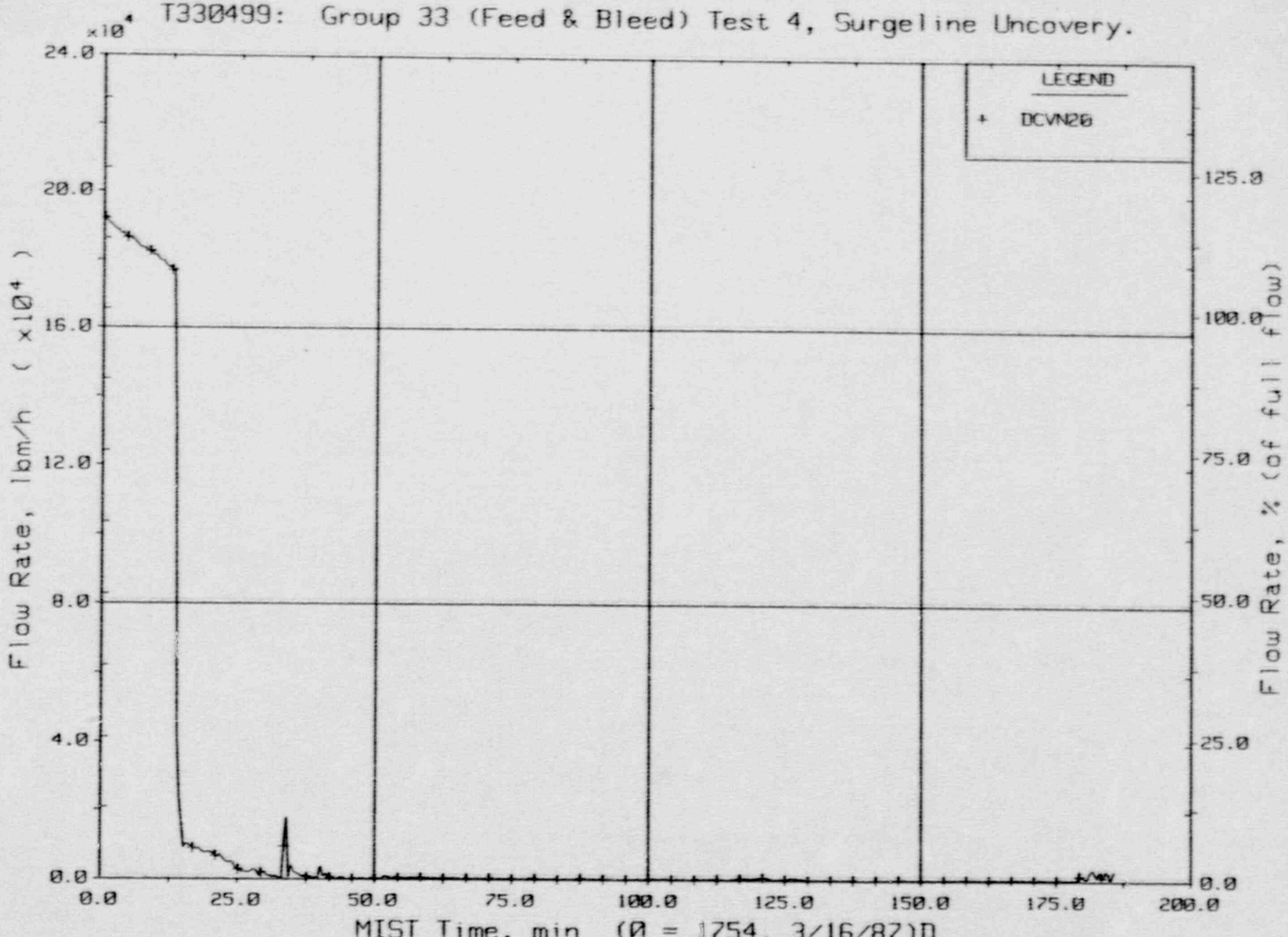
Core Fluid Temperature Rise.

Tue Jun 7 11:03:03 1988

COTD1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



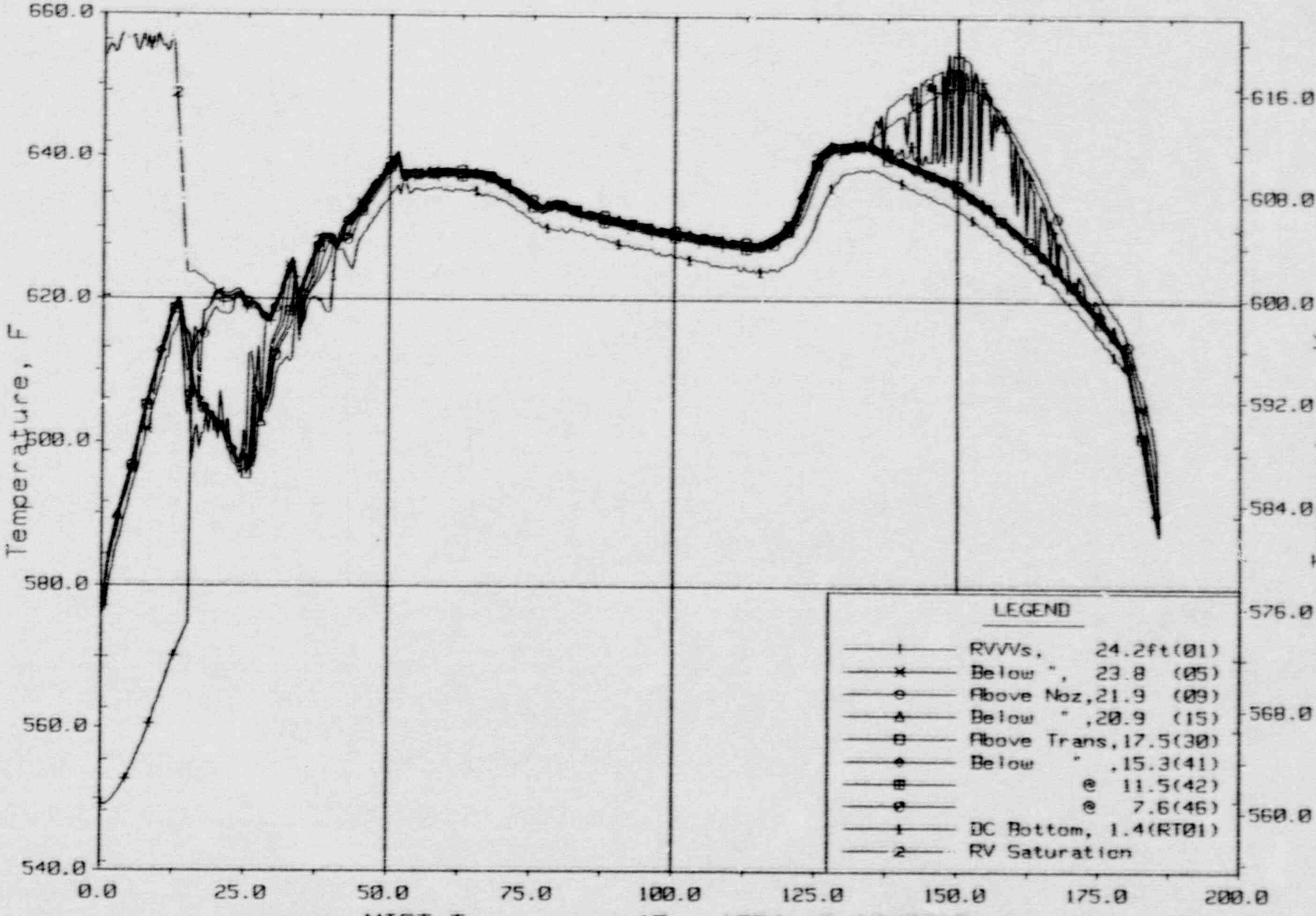
Downcomer (Venturi) Flow Rate.

Tue Jun 7 11:05:49 1988

DCFL1

FINAL DATA

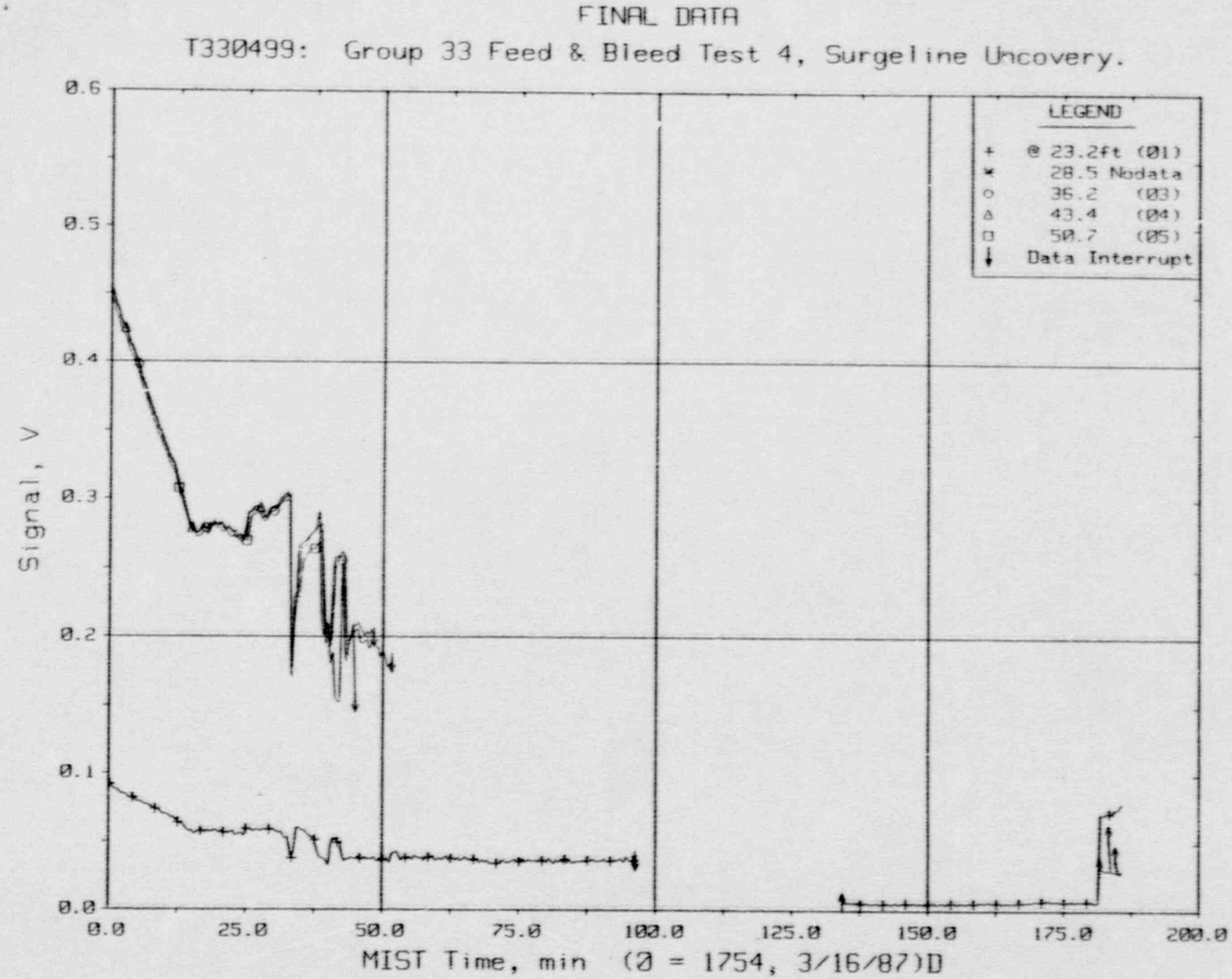
T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



Downcomer Quadrant A1 Fluid Temperatures (DCTCs).

Tue Jun 7 11:10:11 1988

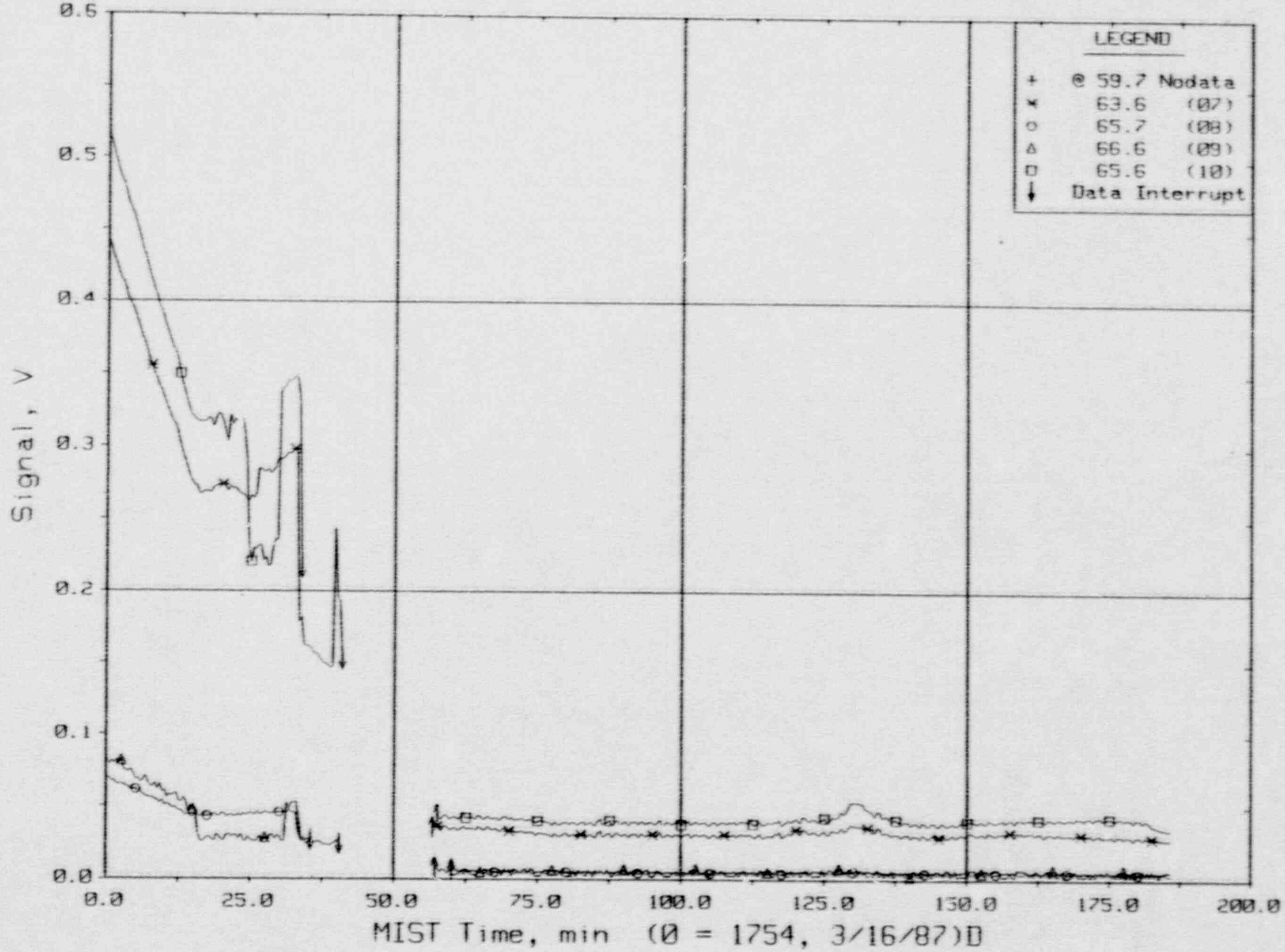
DCTC6



Hot Leg A Riser Conductivity Probe Signals (HICPs).

FINAL DATA

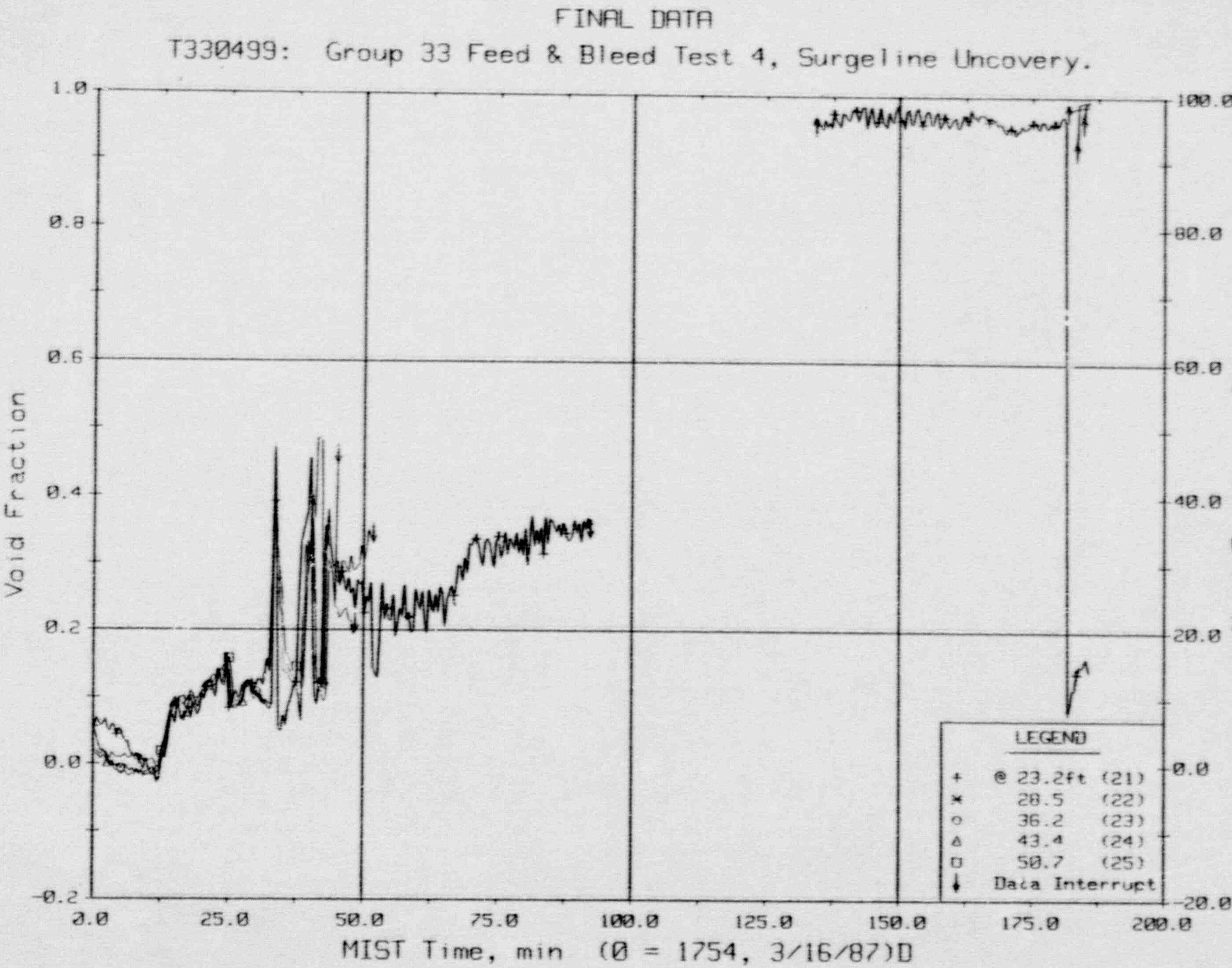
T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



Hot Leg A U-Bend Conductivity Probe Signals (H1CPs).

Thu May 19 13:23:16 1988

H1CP2



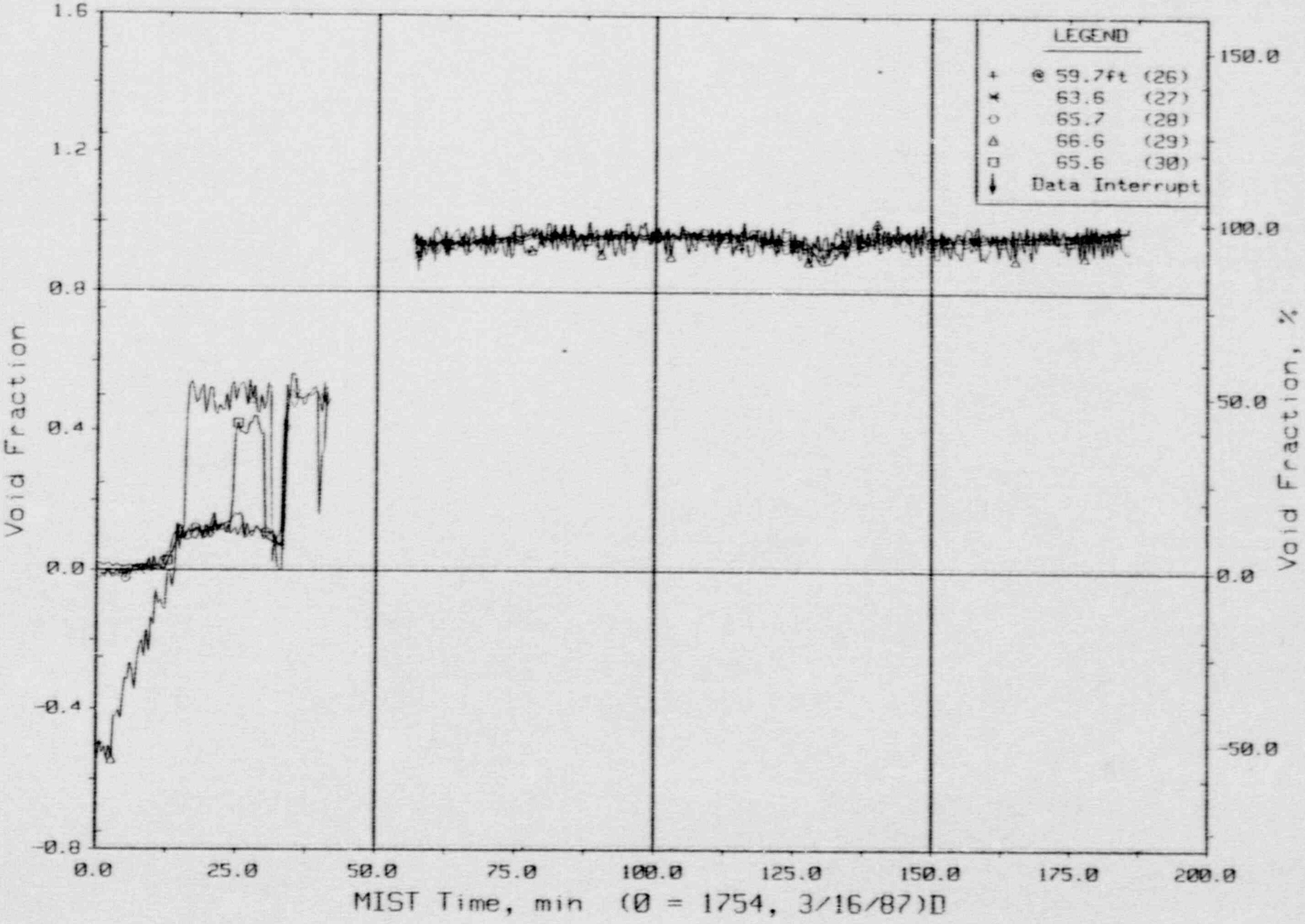
Hot Leg A Riser Void Fractions From Conductivity (HICPs).

Thu May 19 13:25:34 1988

H1VC1

FINAL DATA

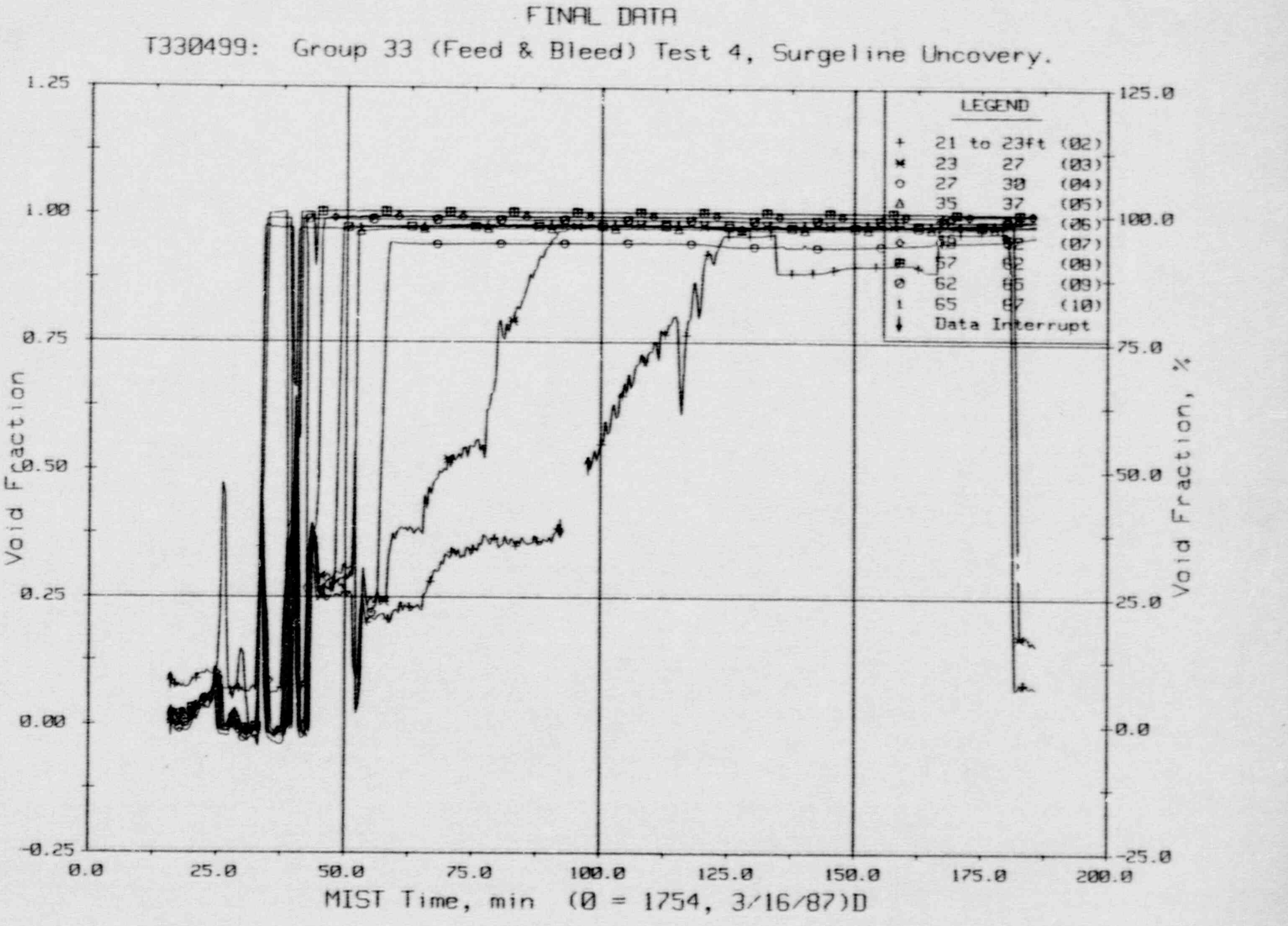
T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



Hot Leg A U-bend Void Fractions From Conductivity (HICPs).

Thu May 19 13:28:31 1988

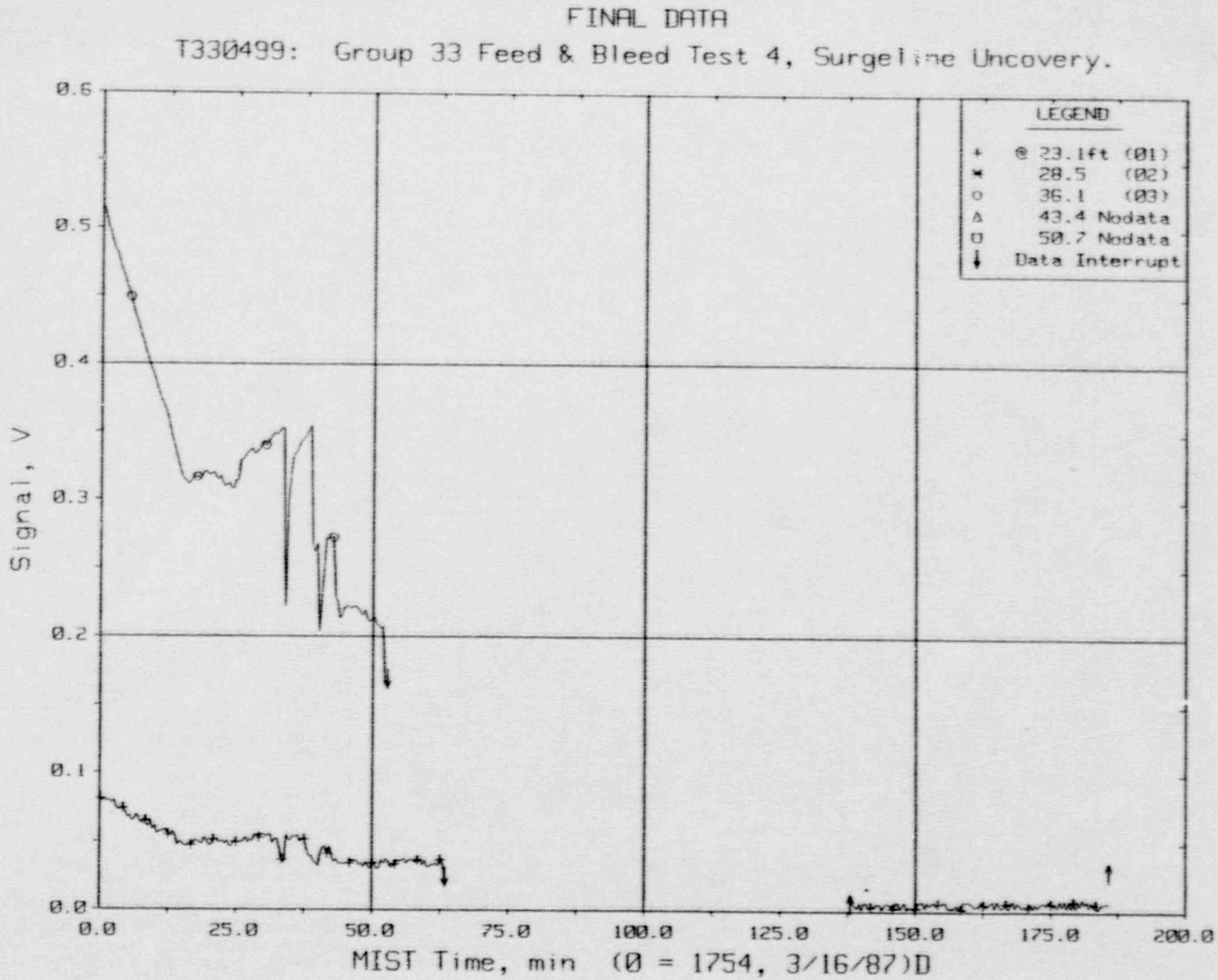
H1VC2



Hot Leg A Riser Void Fractions From Differential Pressures (H1VFs).

Tue Jun 7 11:20:13 1988

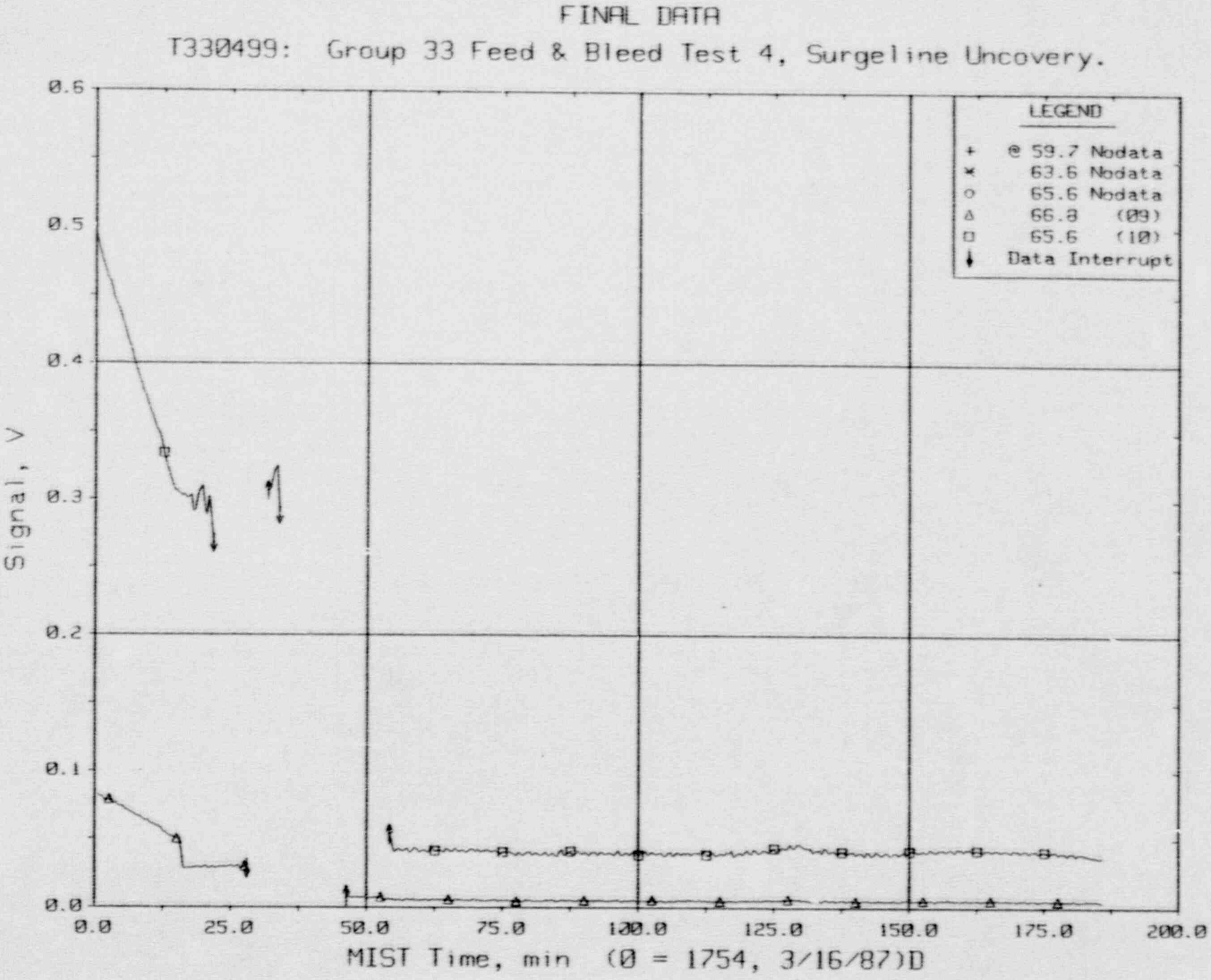
H1VF1



Hot Leg B Riser Conductivity Probe Signals (H2CPs).

Thu May 19 13:30:47 1988

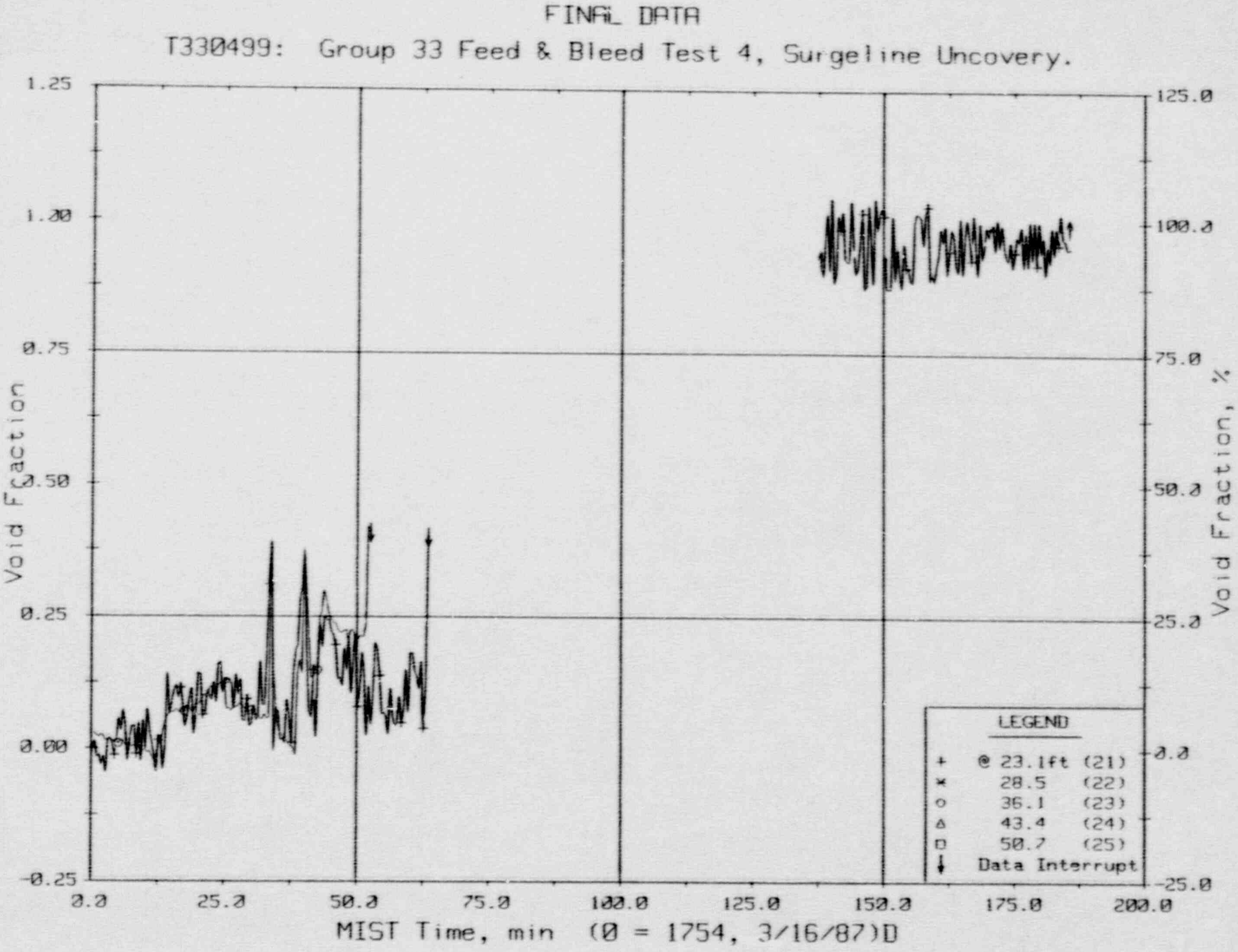
H2CP1



Hot Leg B U-Bend Conductivity Probe Signals (H2CPs).

Thu May 19 13:33:26 1988

H2CP2



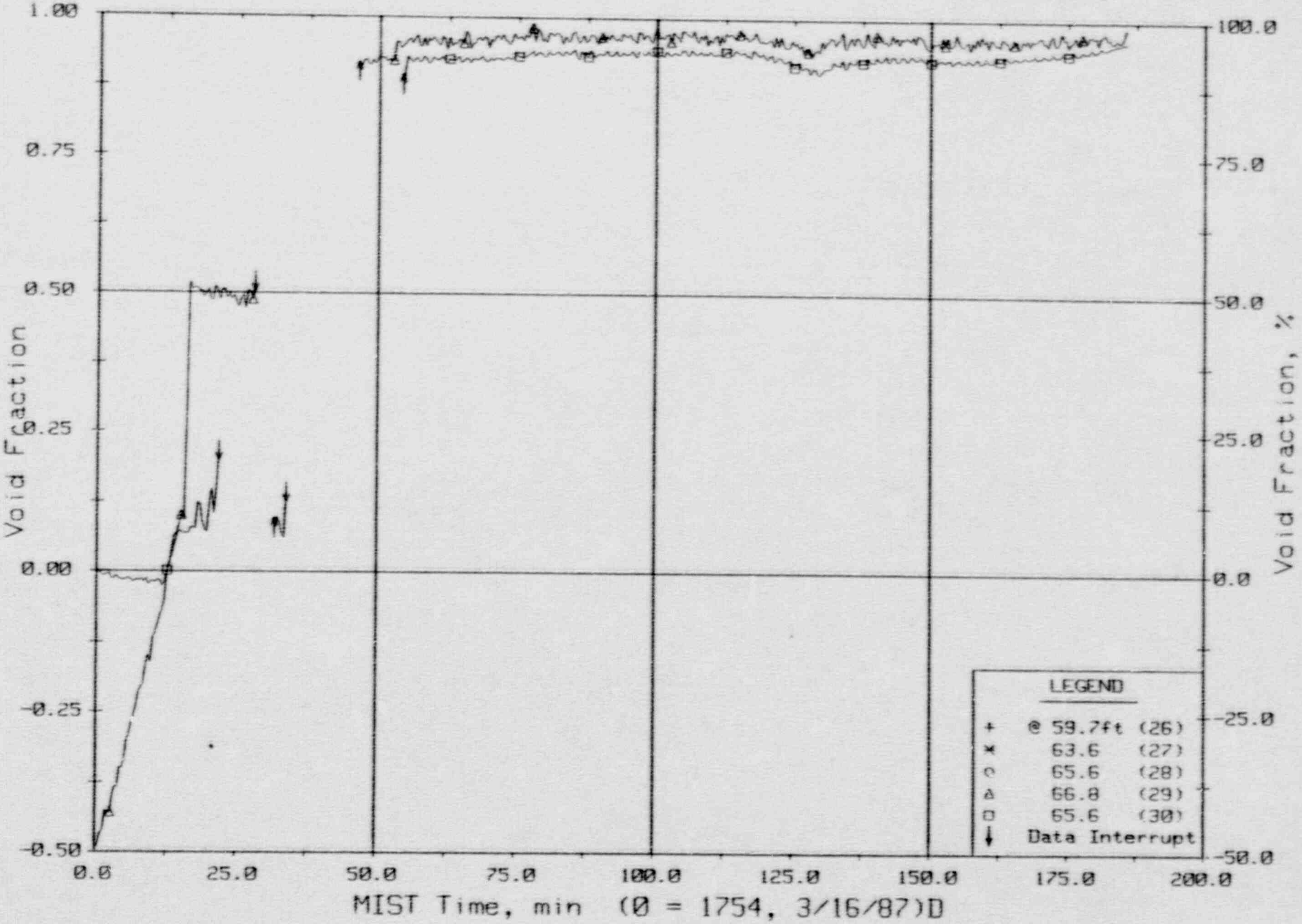
Hot Leg B Riser Void Fractions From Conductivity (H2CPs).

Thu May 19 13:38:24 1988

H2VC1

FINAL DATA

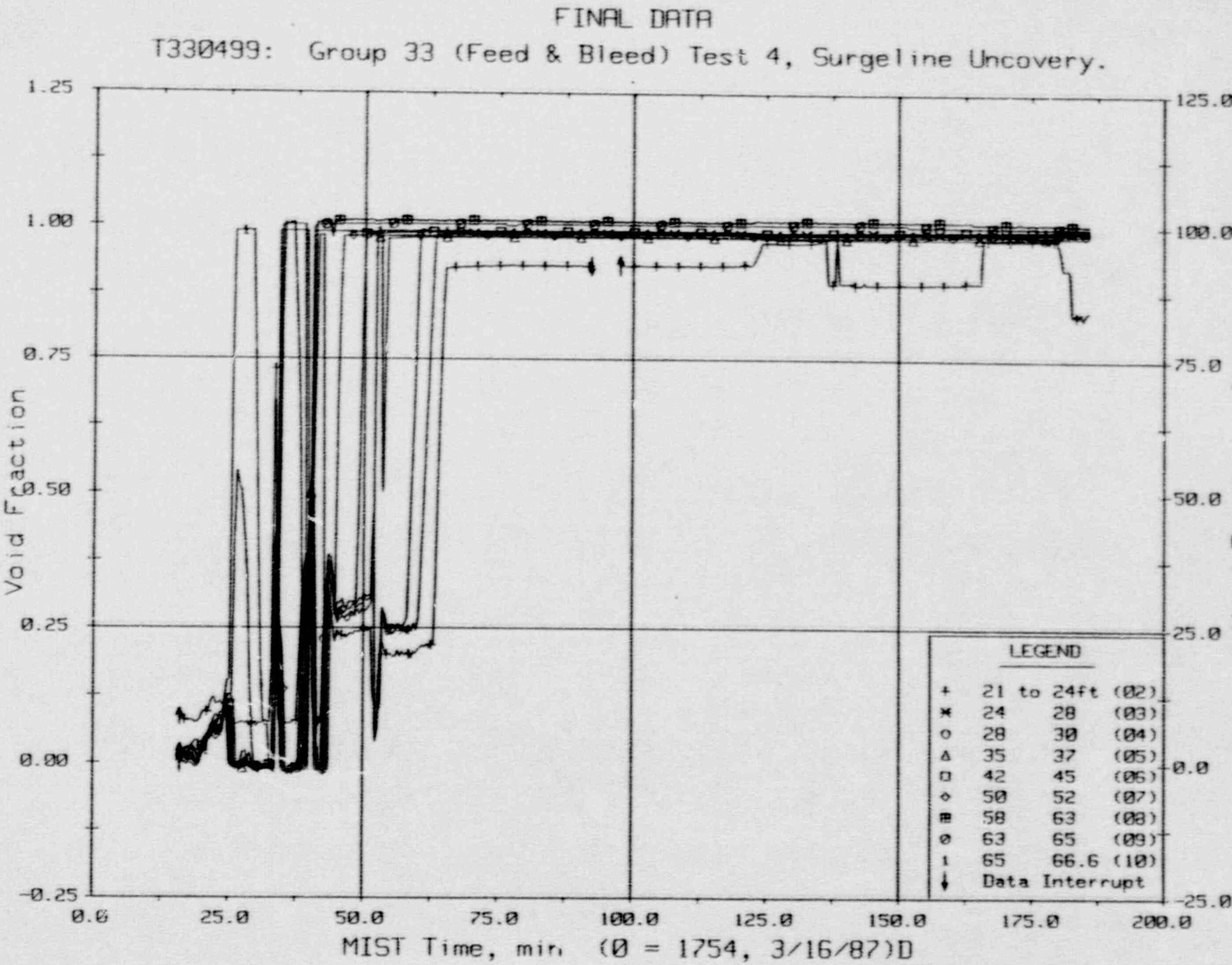
T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



Hot Leg B U-bend Void Fractions From Conductivity (H2CPs).

Thu May 19 13:47:41 1988

H2VC2



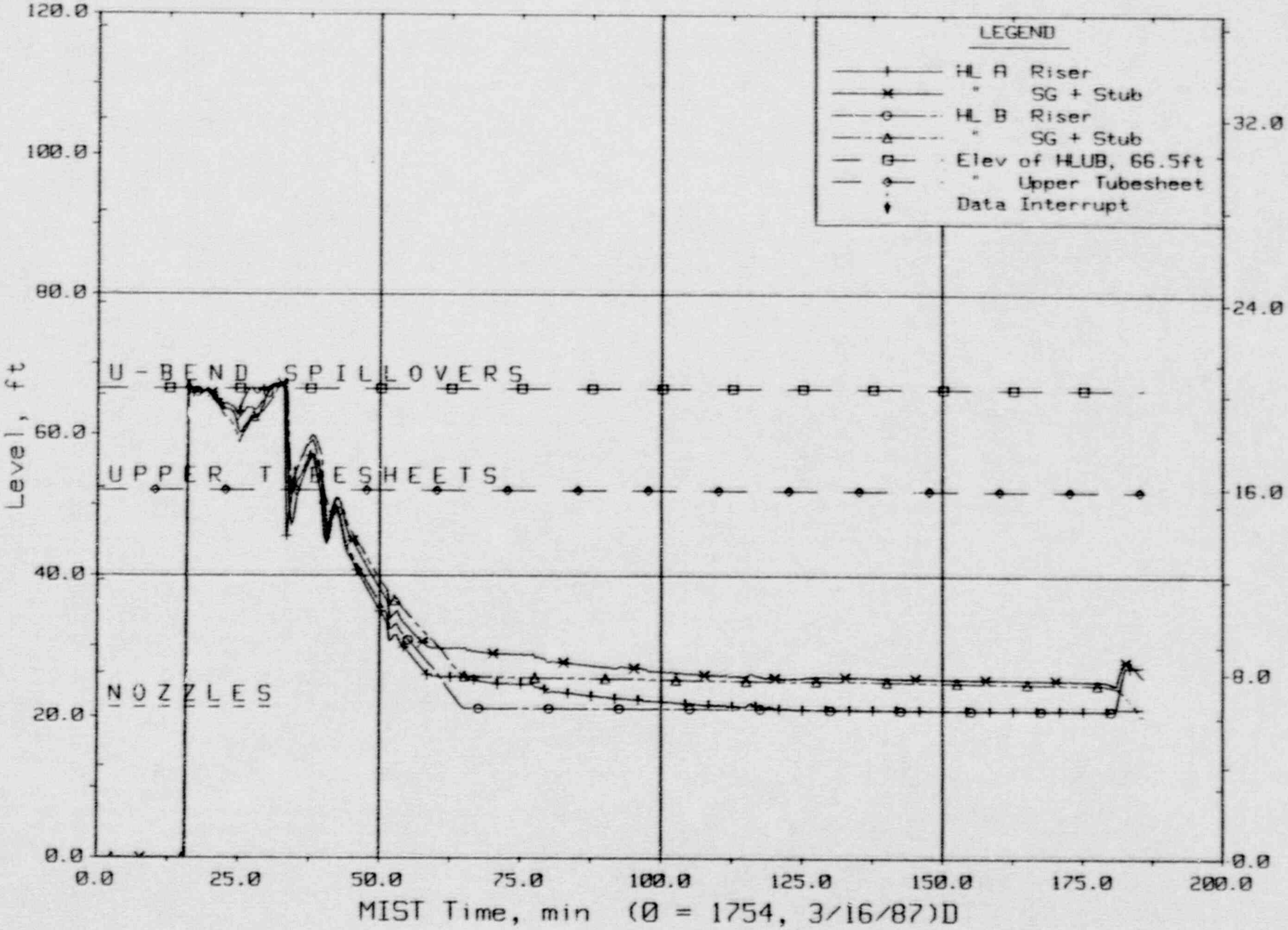
Hot Leg B Riser Void Fraction From Differential Pressures (H2VFs).

Tue Jun 7 11:31:16 1988

H2VF1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



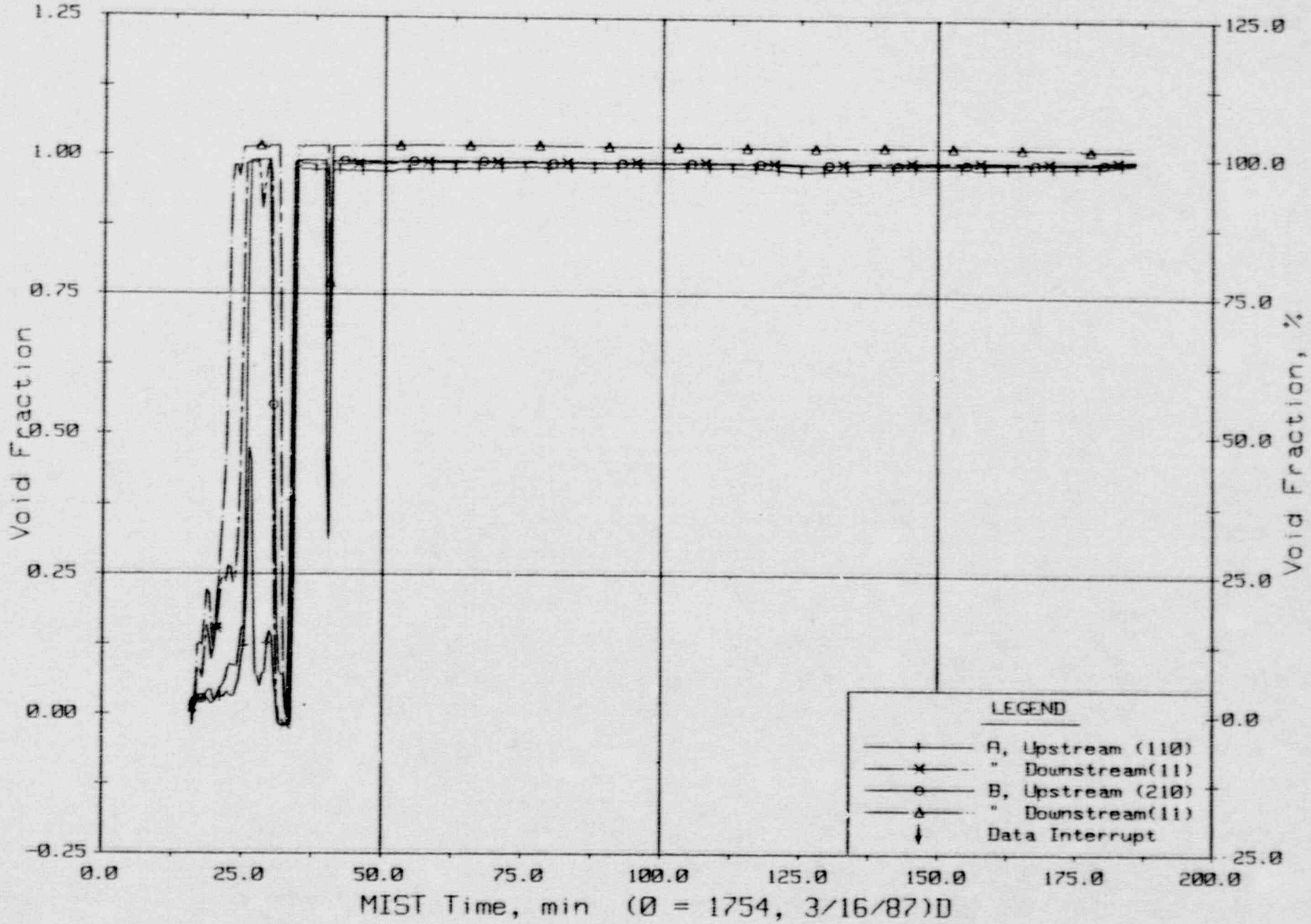
Hot Leg Riser and Stub Collapsed Liquid Levels.

Tue Jun 7 11:57:51 1988

HLLV1

FINAL DATA

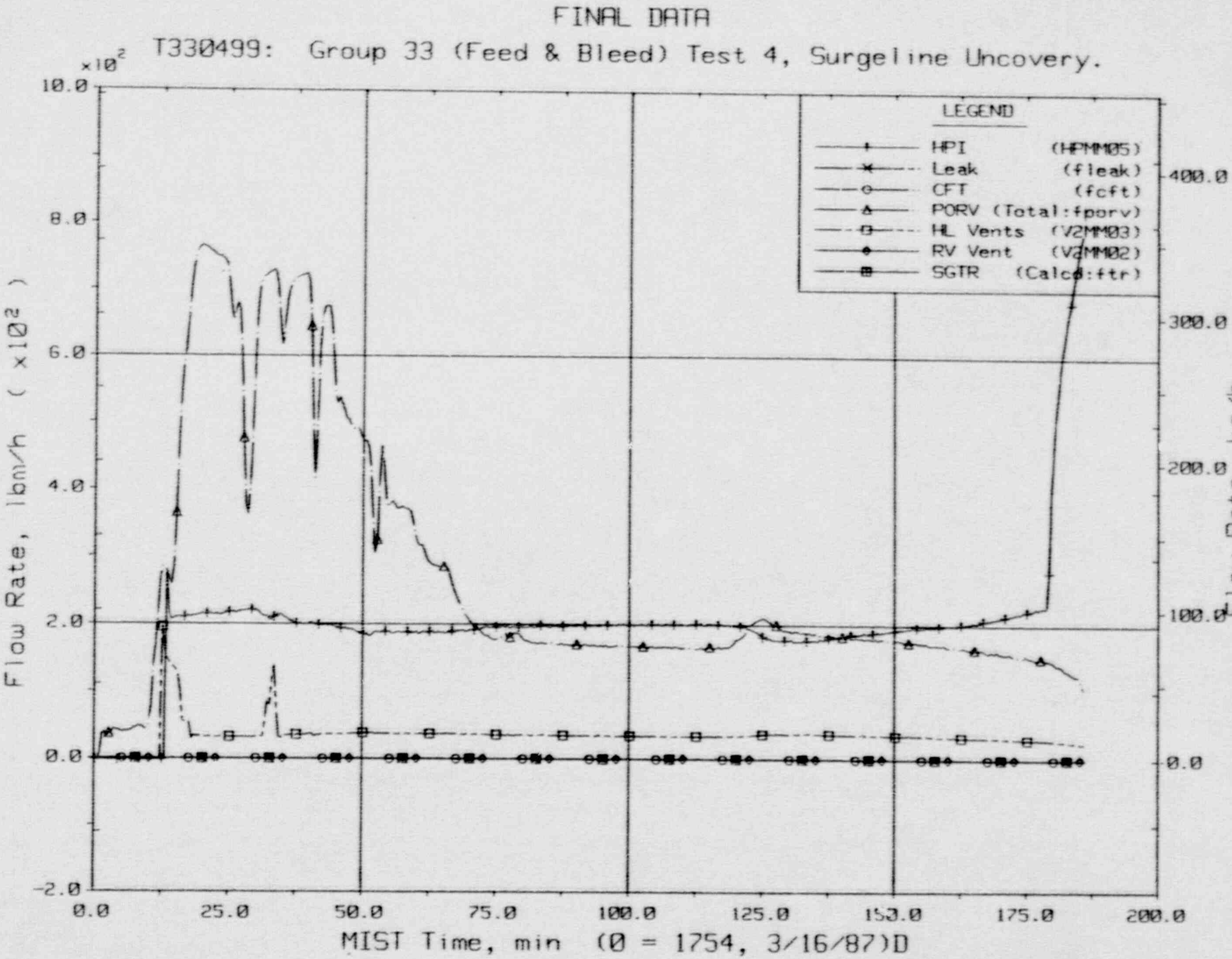
T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



Hot Leg U-Bend Void Fractions From Diffl. Pressures (64.8 to 66.6 ft, HnVFs).

Tue Jun 7 12:01:09 1988

HLVF1



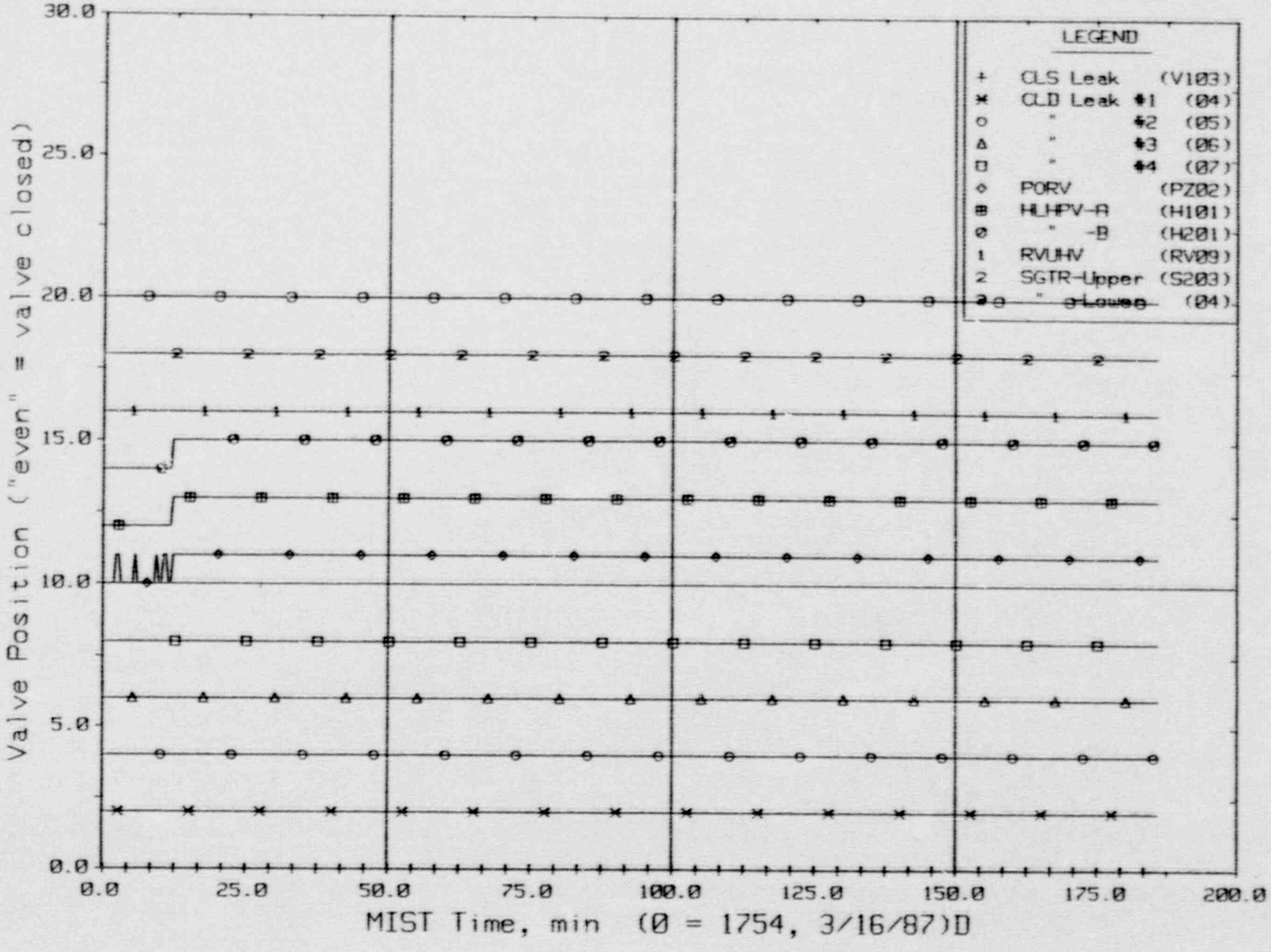
Primary System Boundary Flow Rates.

Tue Jun 7 12:05:14 1988

PBFL3

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



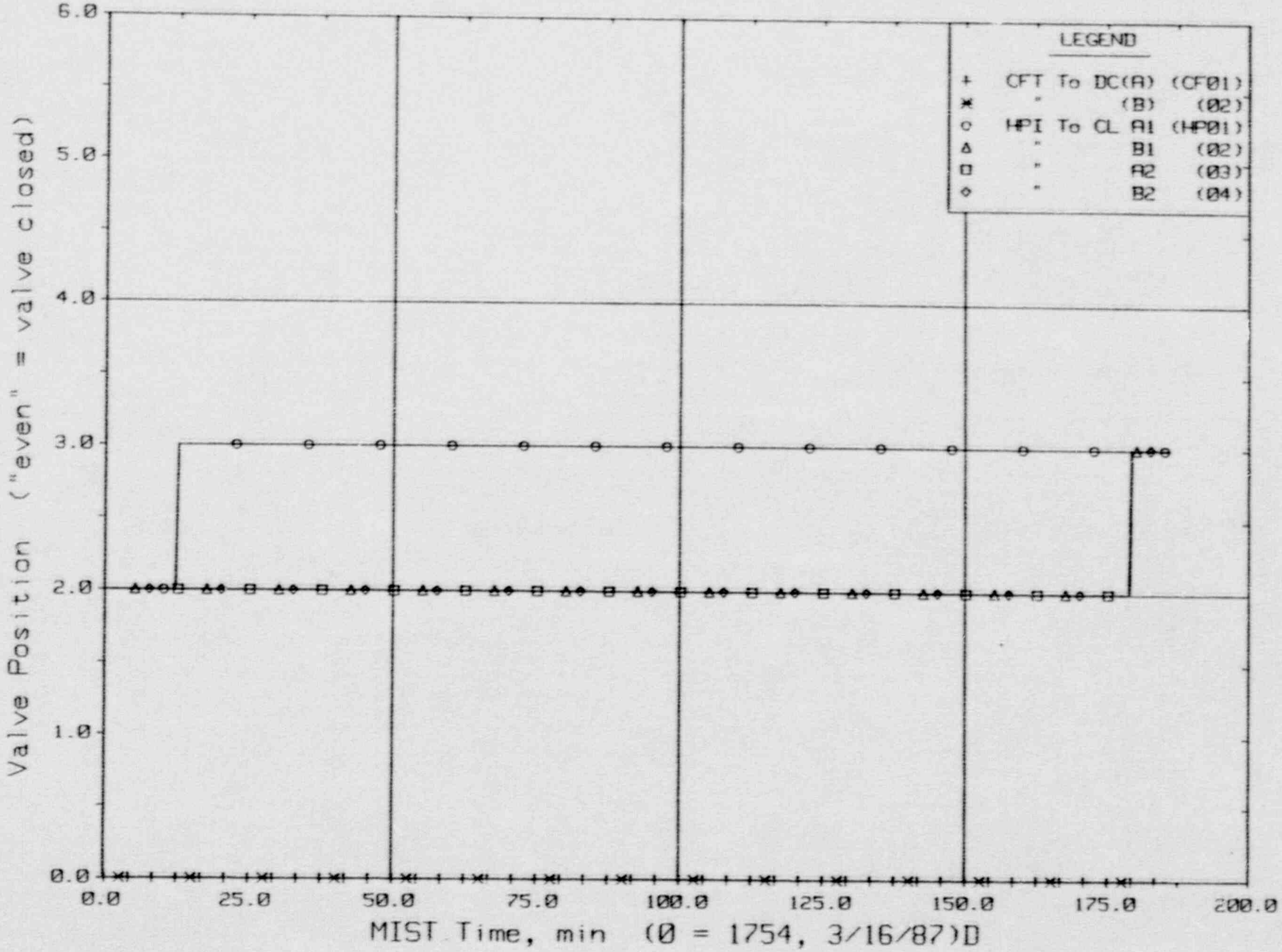
Primary System Discharge Limit Switch Indications (LSs).

Tue Jun 7 12:09:32 1988

PBLS1

FINAL DATA

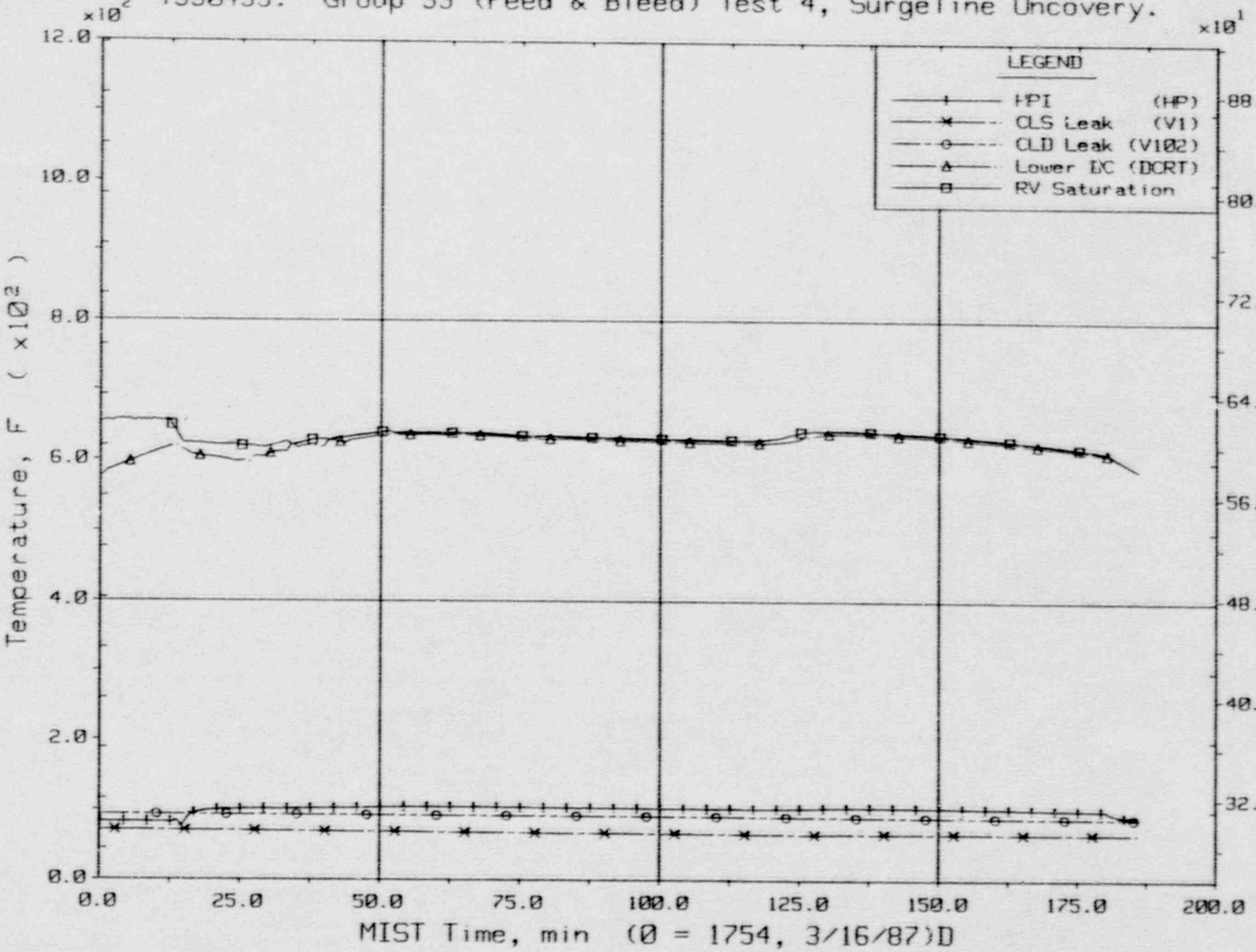
T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



Primary System Injection Limit Switch Indications (LSs).

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



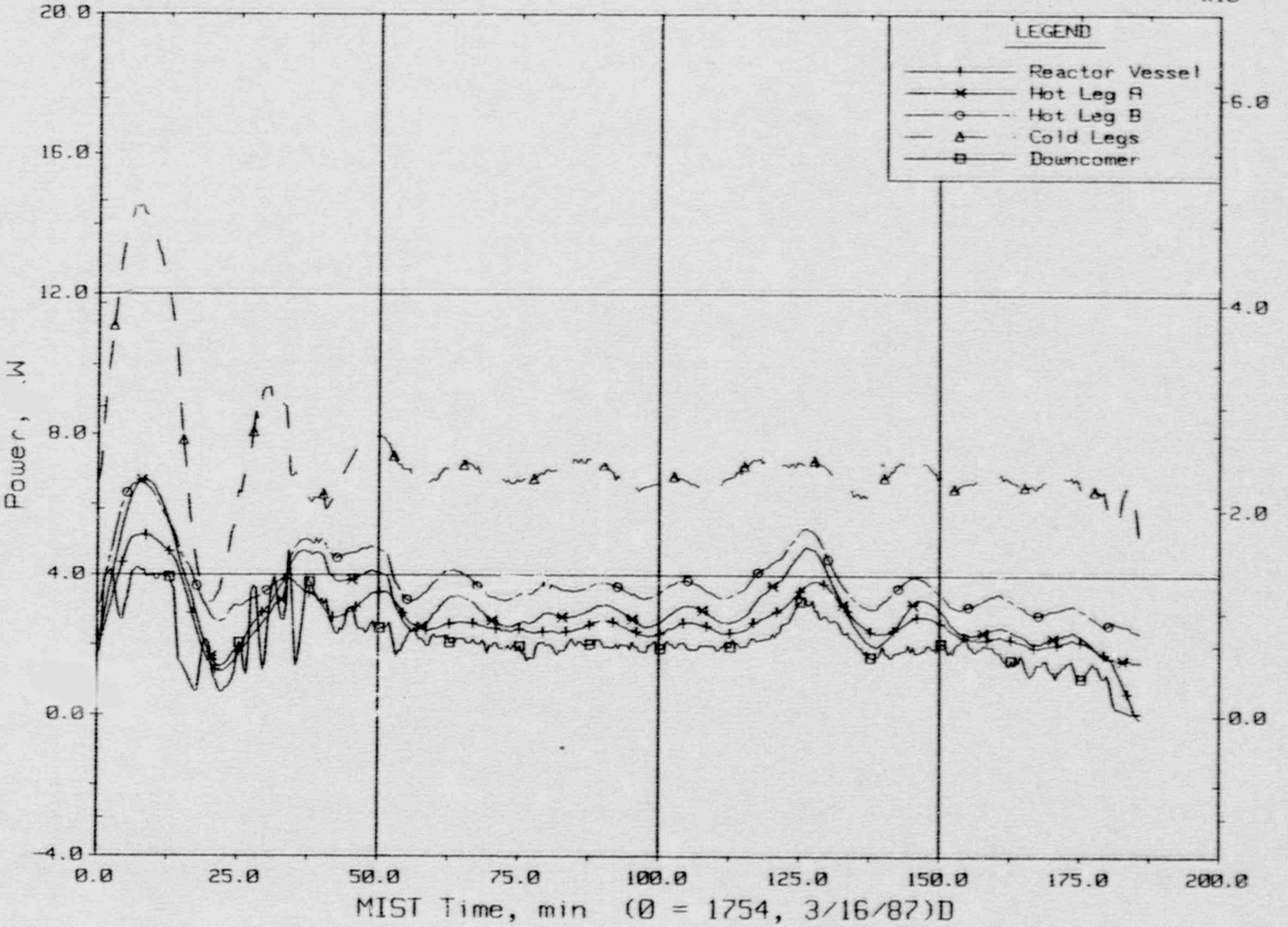
Single-Phase Discharge and HPI Fluid Temperatures (TC01s).

Tue Jun 7 12:15:38 1988

PBTC1p

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



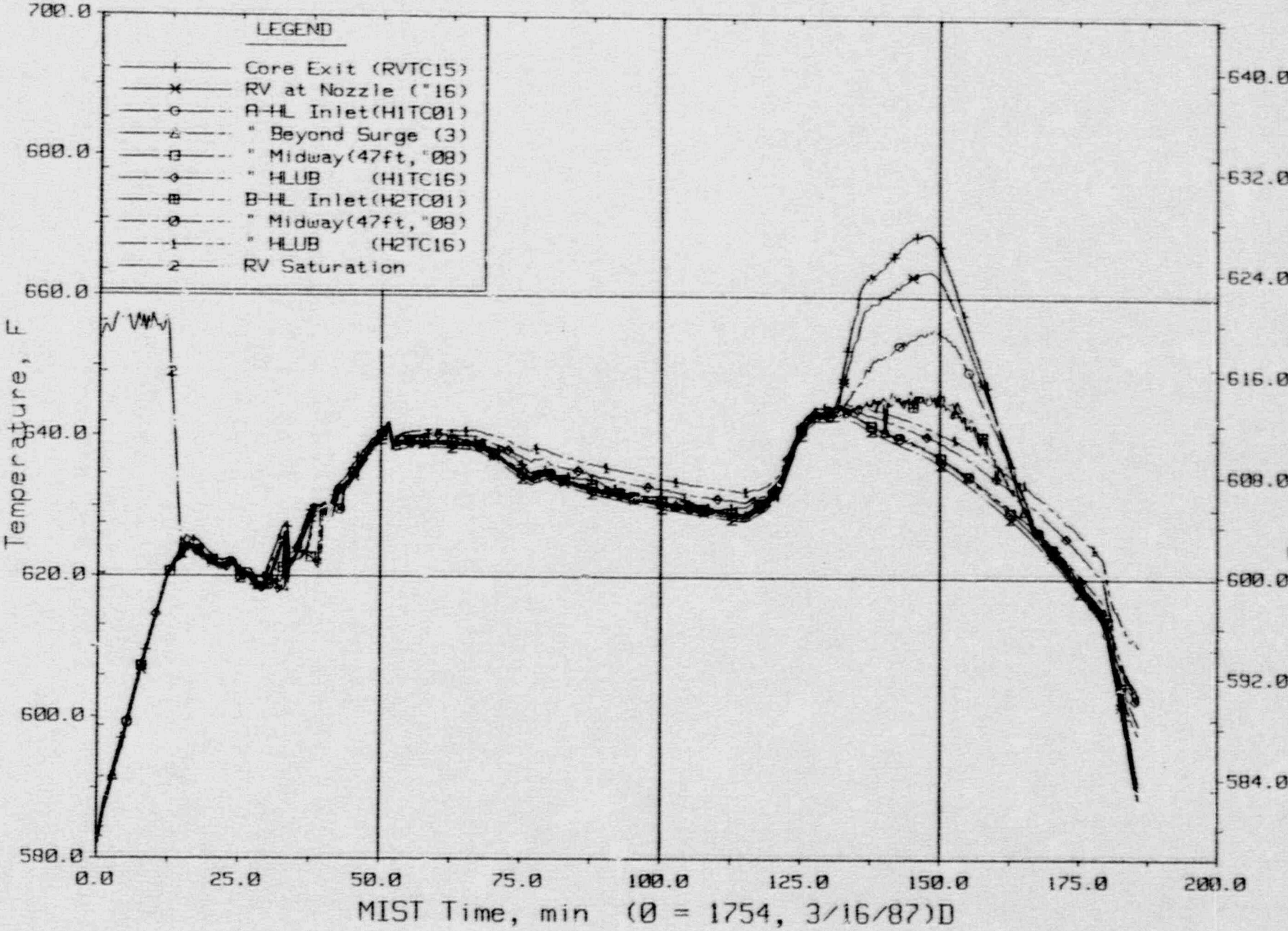
Guard Heater Specified Power Per Primary Component.

Tue Jun 7 12:21:08 1988

PRGQ1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



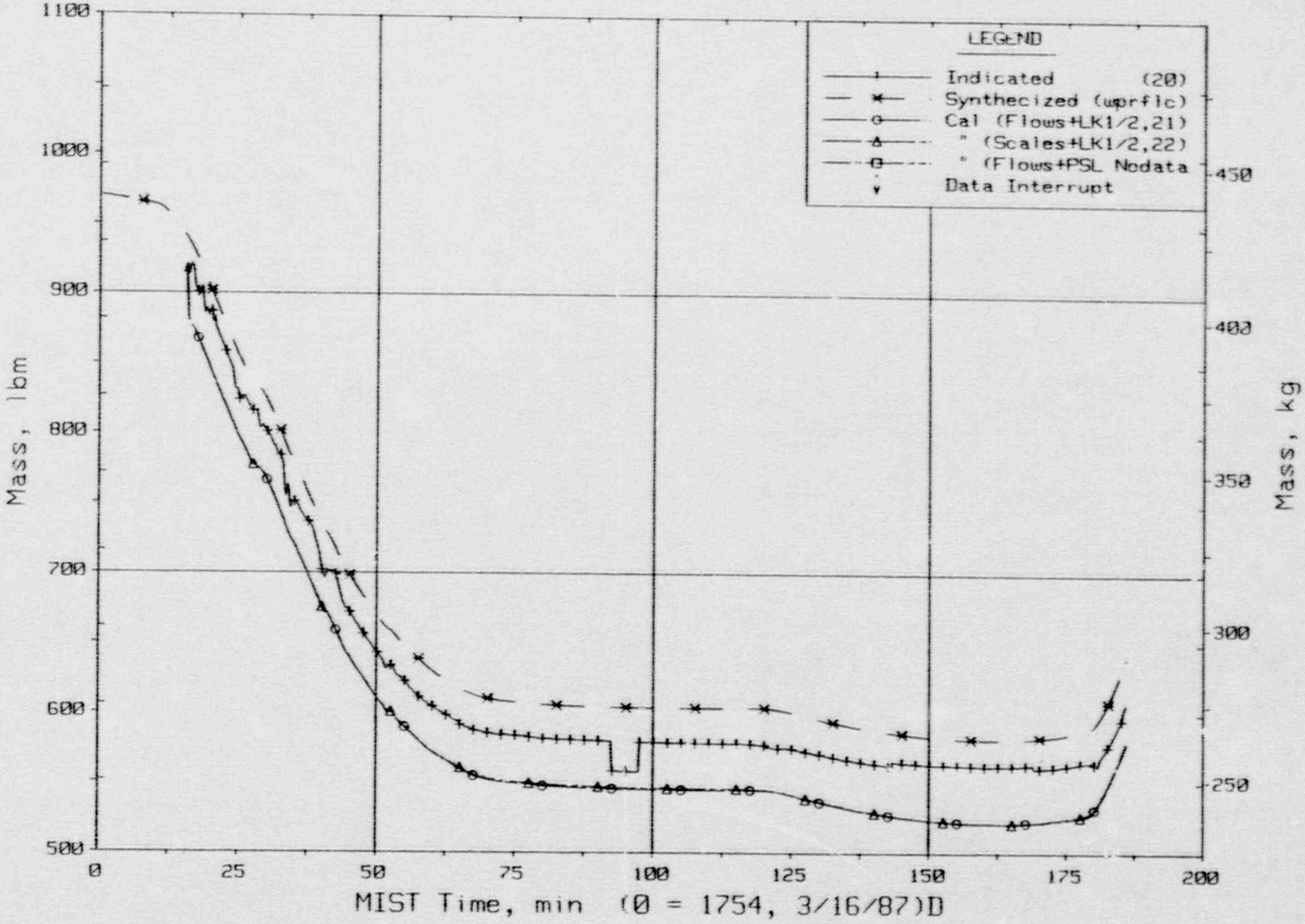
Composite Core Exit and Hot Leg Fluid Temperatures.

Tue Jun 7 12:25:59 1988

PRKT1

FINAL DATA

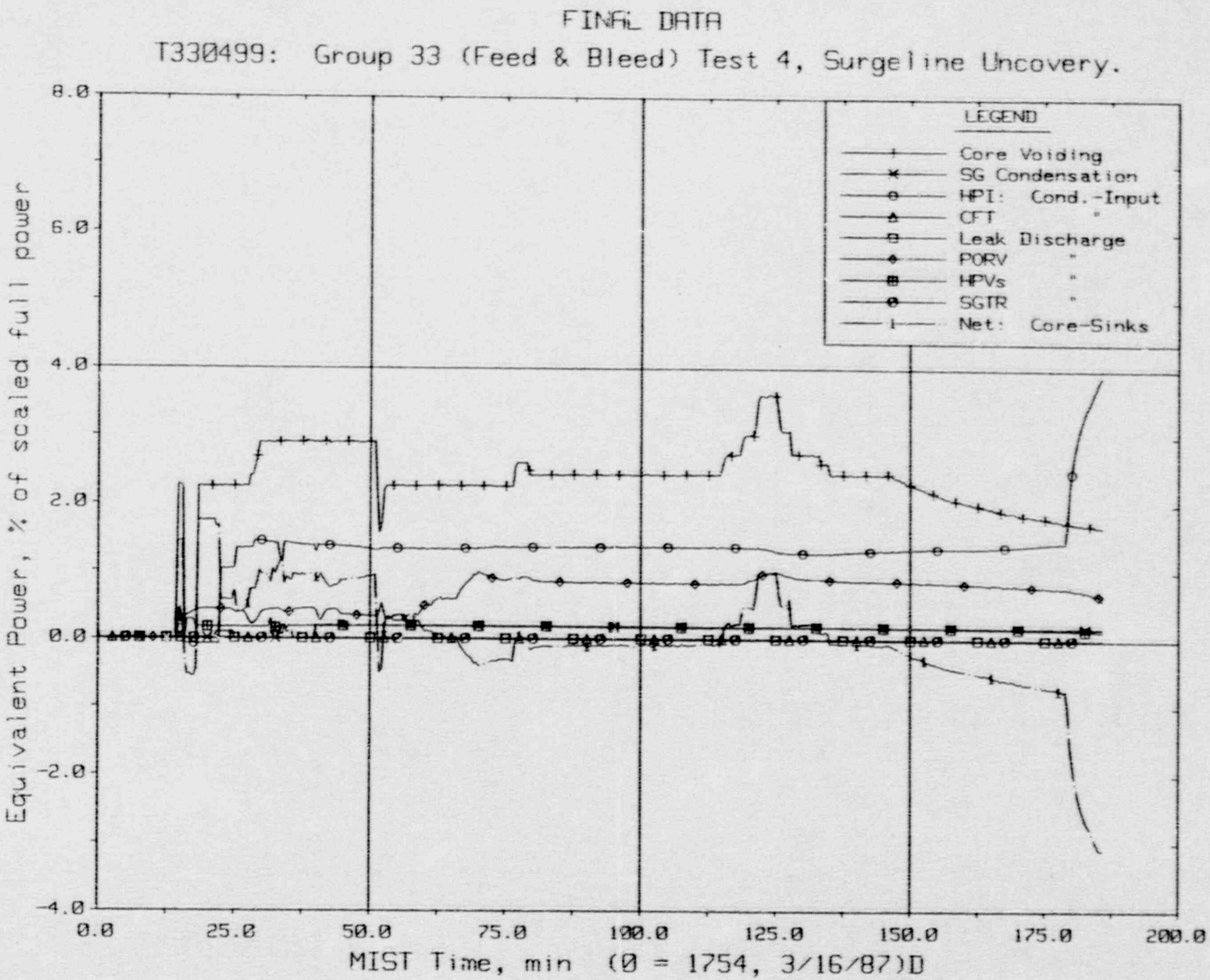
T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



Primary System Total Fluid Mass (PLMLs).

Thu Nov 3 17:17:25 1988

PRML0p



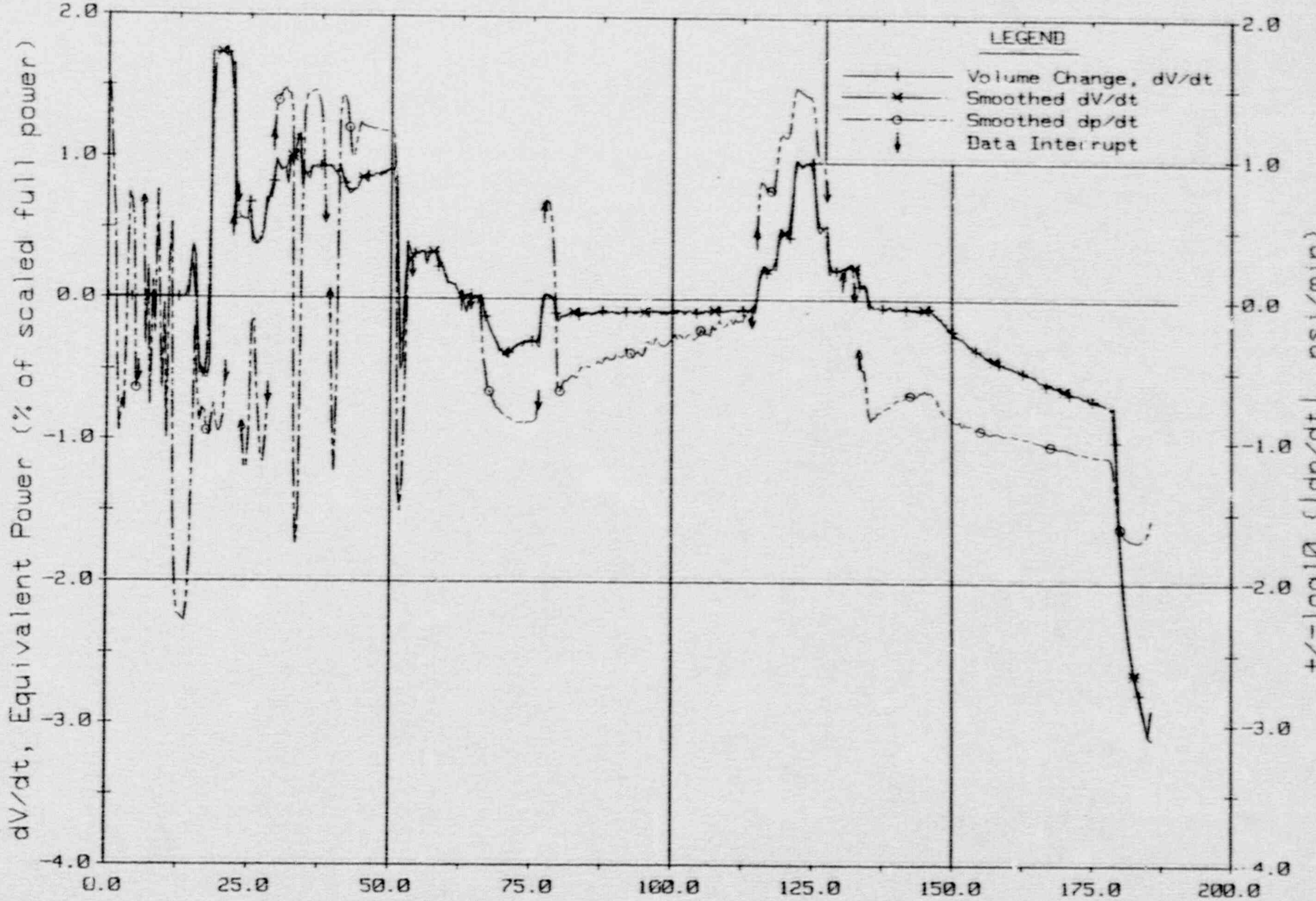
Primary Fluid Volume Changes By Components.

Tue Jun 7 12:33:01 1988

PRPA0

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



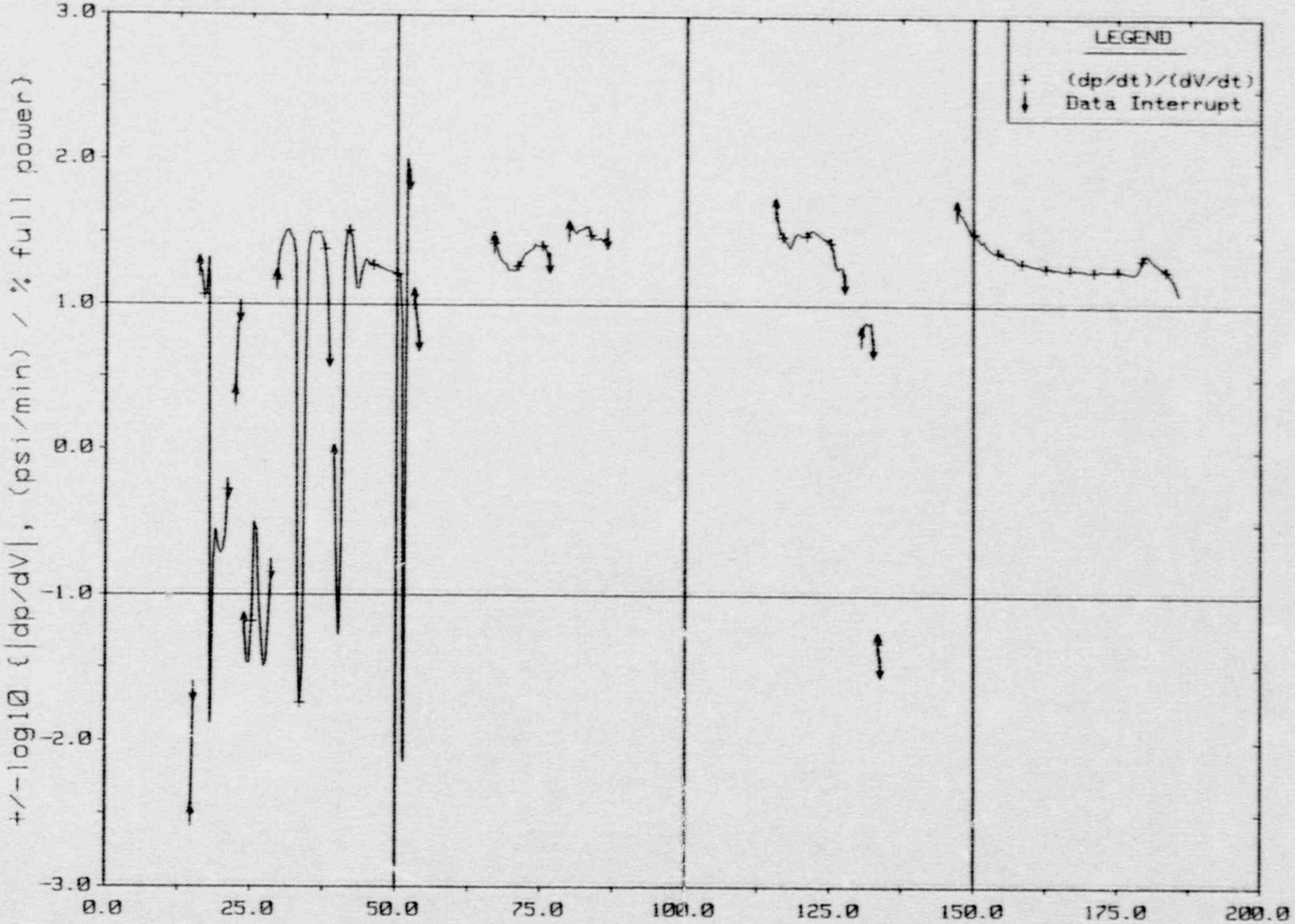
Primary Fluid Volume and Pressure Changes, dV/dt and dp/dt.

Tue Jun 7 12:36:10 1988

PRPA2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



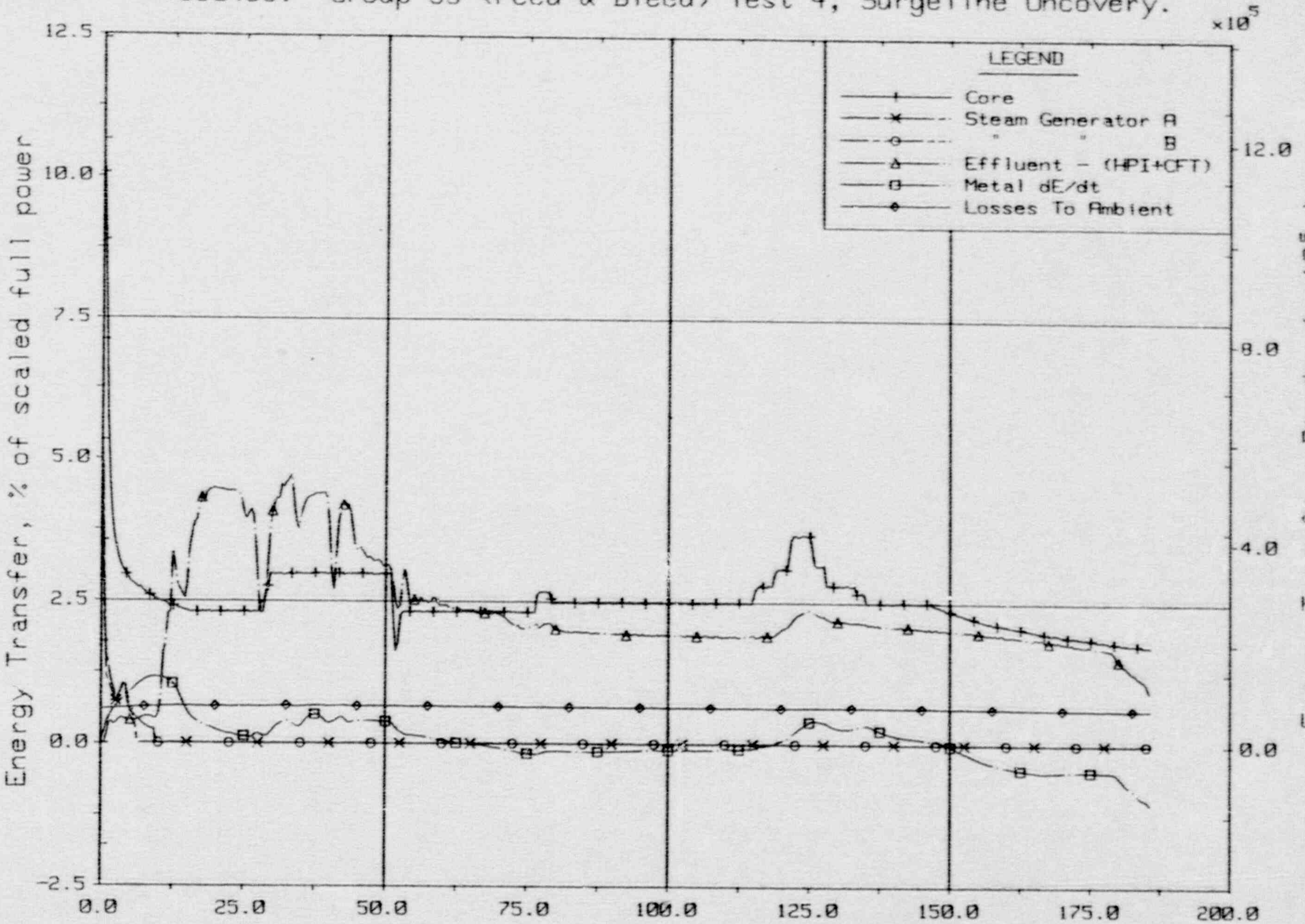
Primary System Response: dp/dt divided by dV/dt.

Tue Jun 7 12:39:28 1988

PRPA3

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



MIST Time, min (0 = 1754, 3/16/87)D

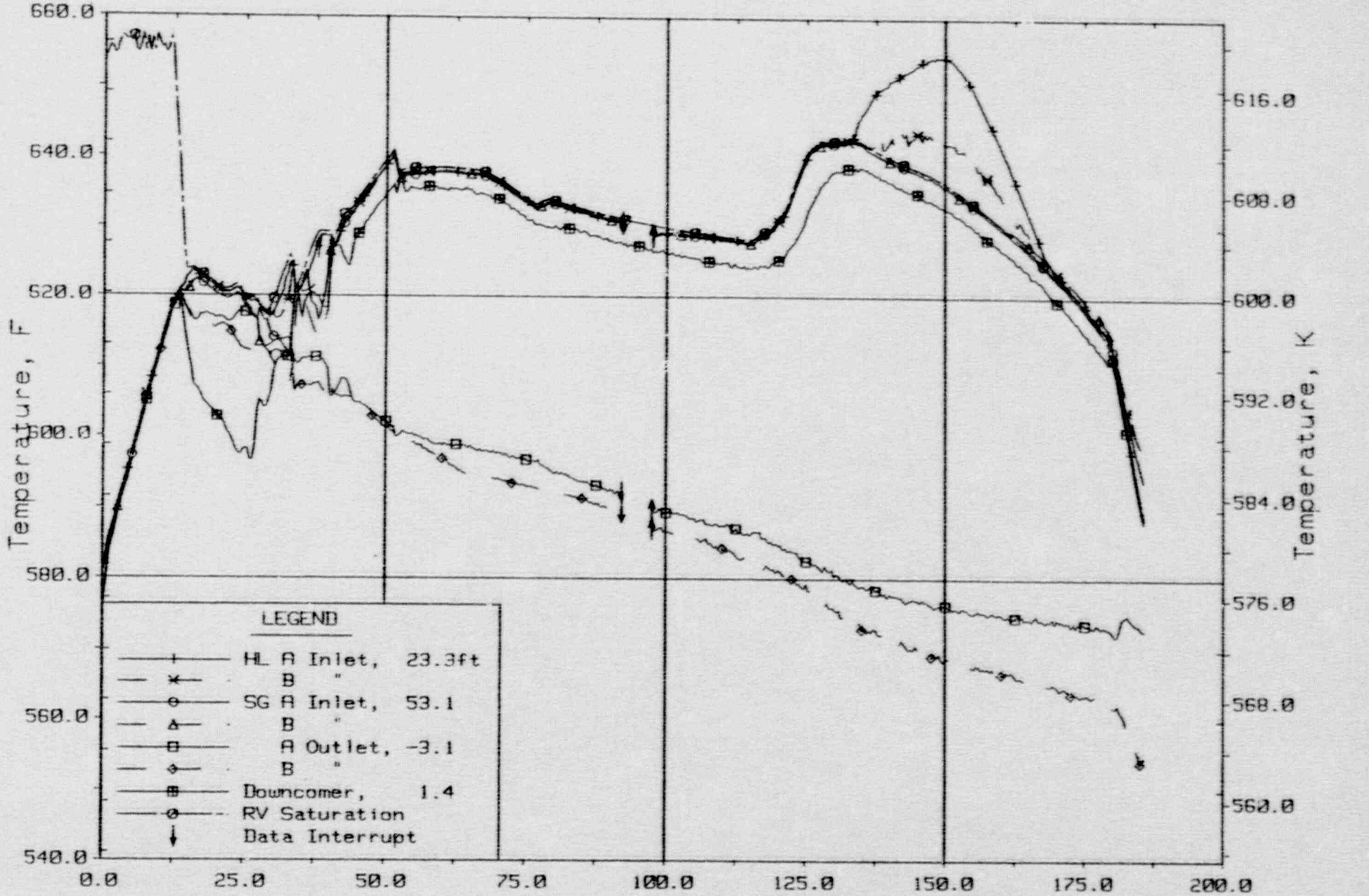
Primary System Energy Transfer.

Tue Jun 7 12:41:37 1988

PRQE2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



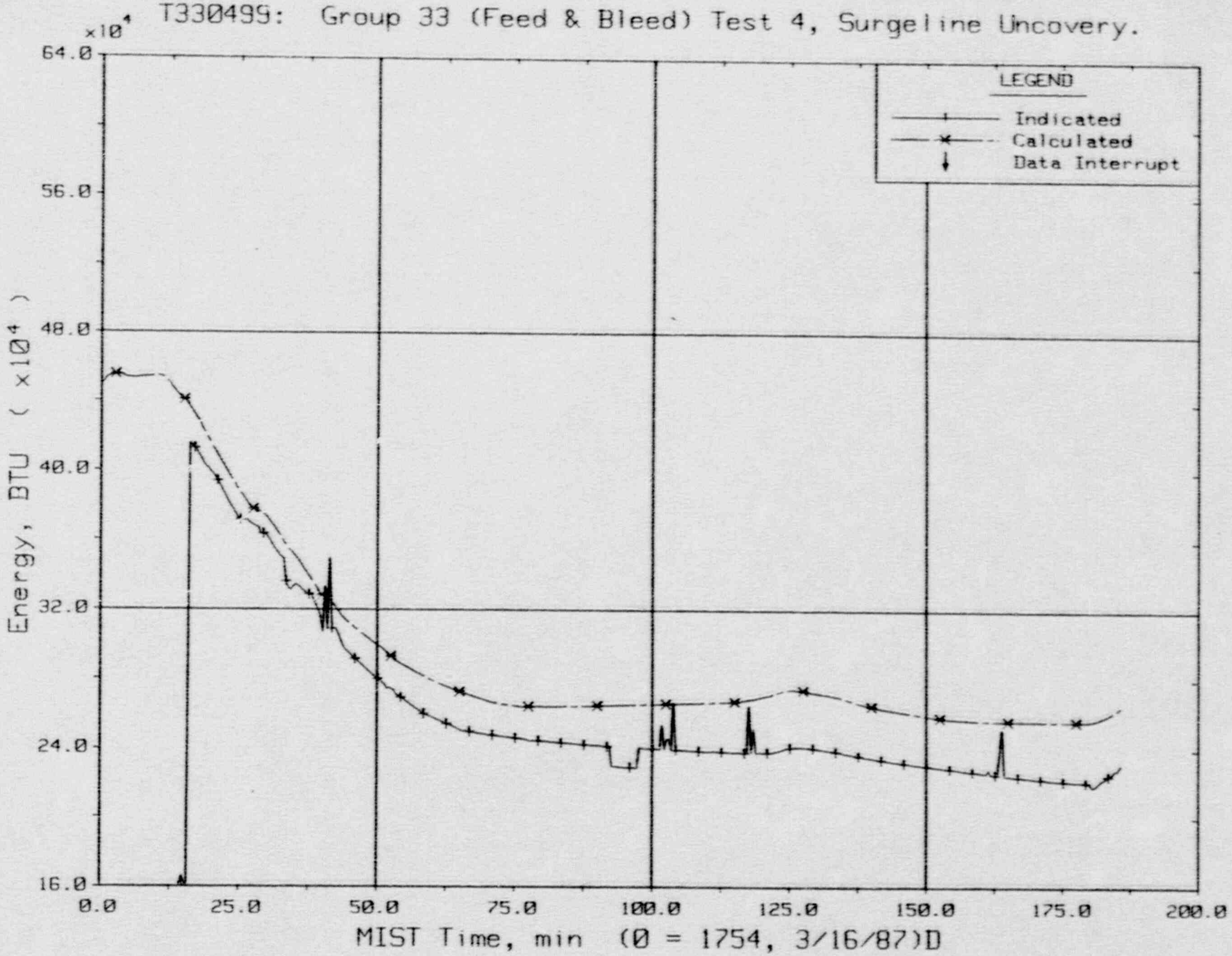
Primary System Fluid Temperatures (RTDs).

Tue Jun 7 12:46:11 1988

PRRT0

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



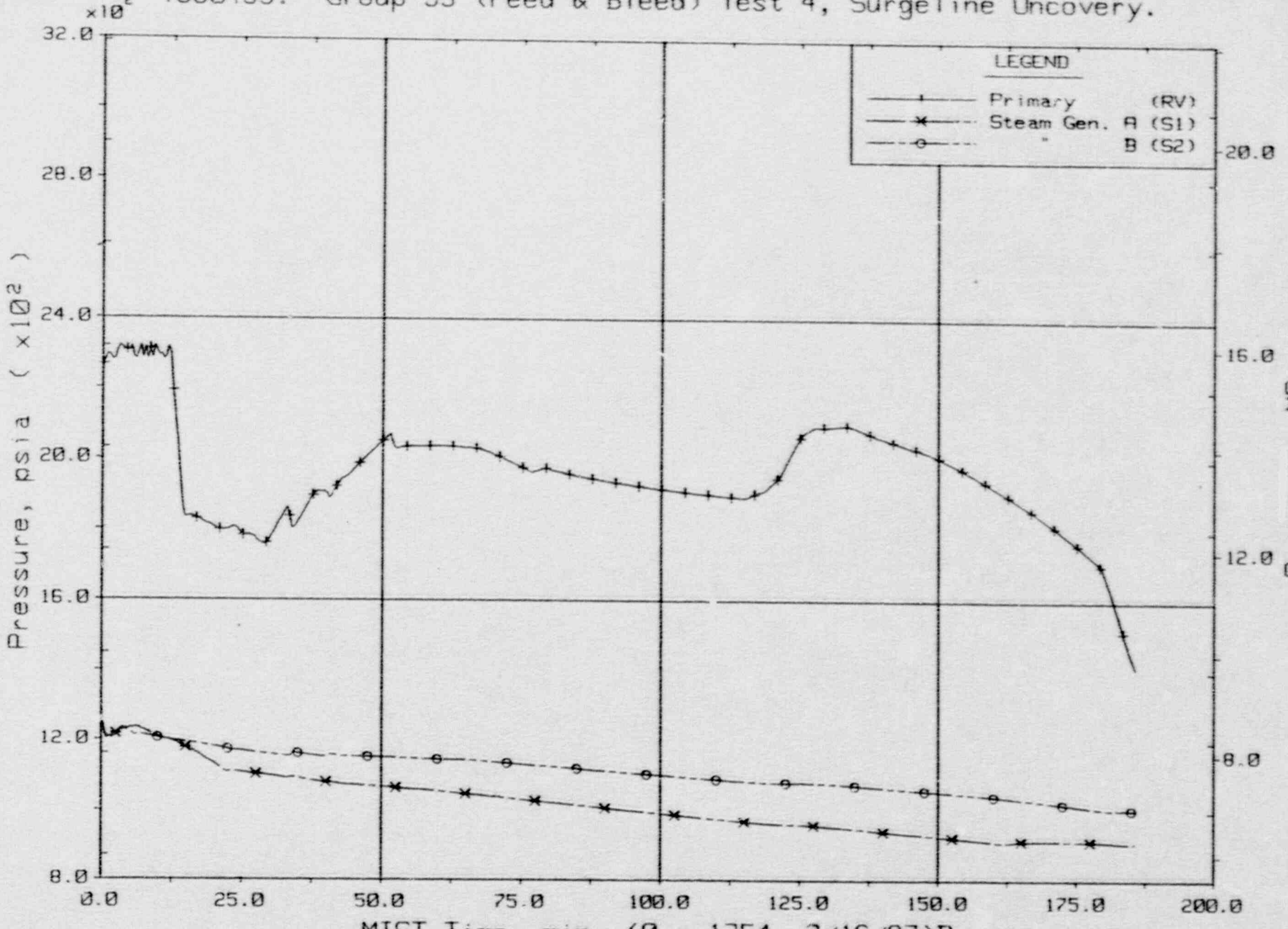
Primary System Total Fluid Energy.

Tue Jun 7 12:51:37 1988

PRTE2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



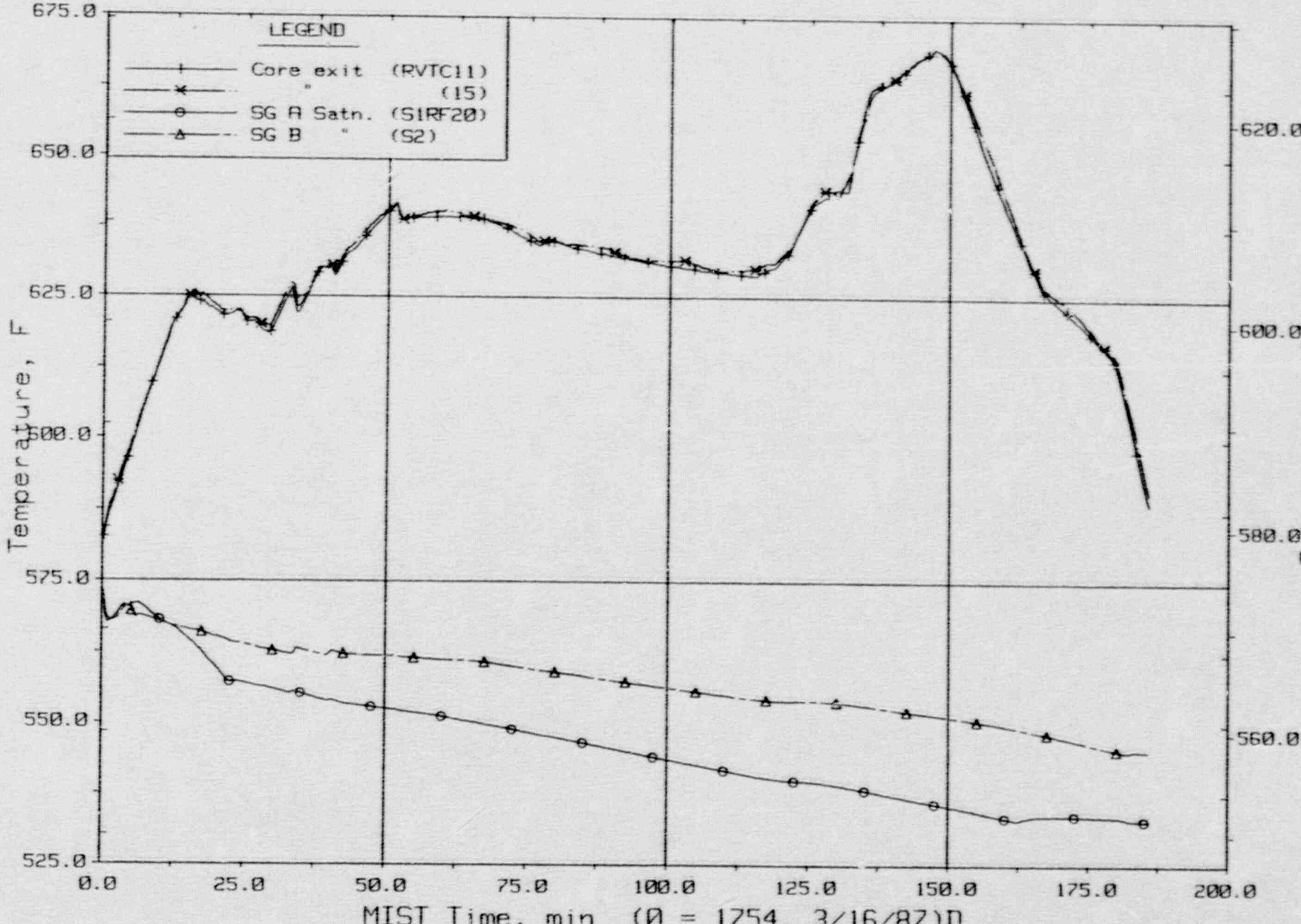
Primary and Secondary System Pressures (GP01s).

Tue Jun 7 12:54:07 1988

PSGP1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



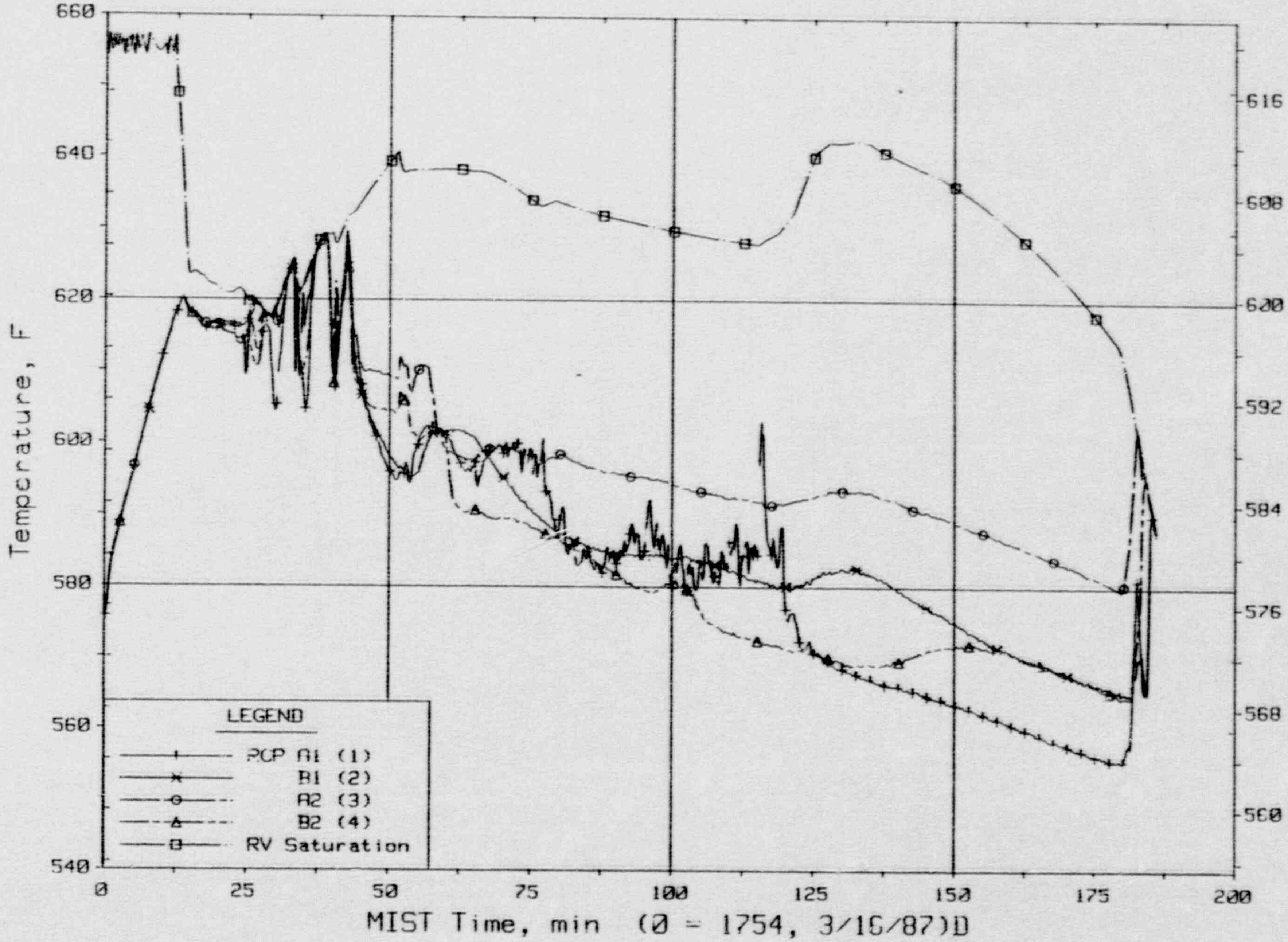
Core Exit and Steam Generator Secondary Saturation Temperatures.

Tue Jun 7 12:56:55 1988

PSTC3p

FINAL DATA

T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



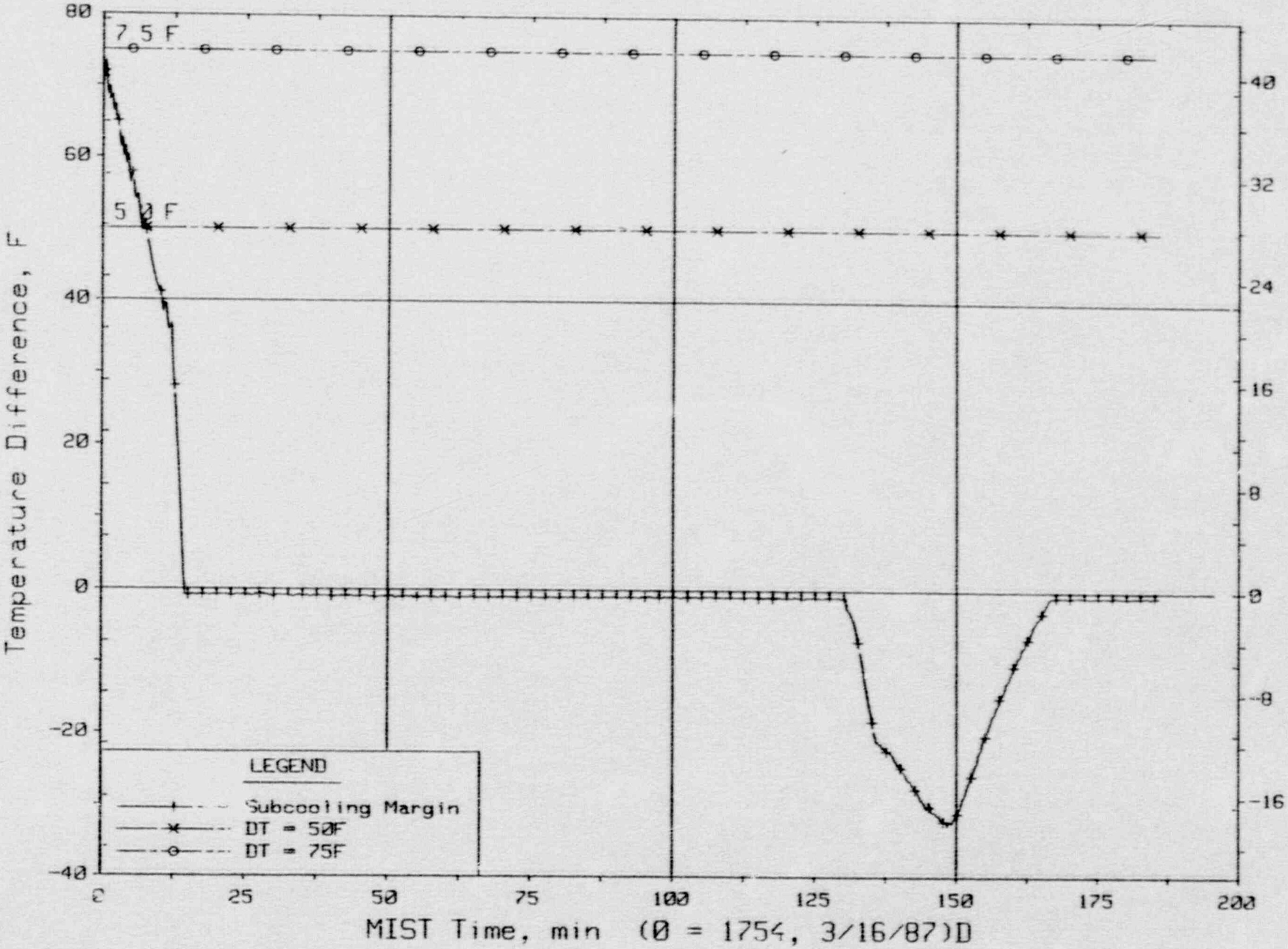
Pump Suction Fluid Temperature (CnRT01s).

Tue Nov 1 09:51:35 1988

PUPT0

FINAL DATA

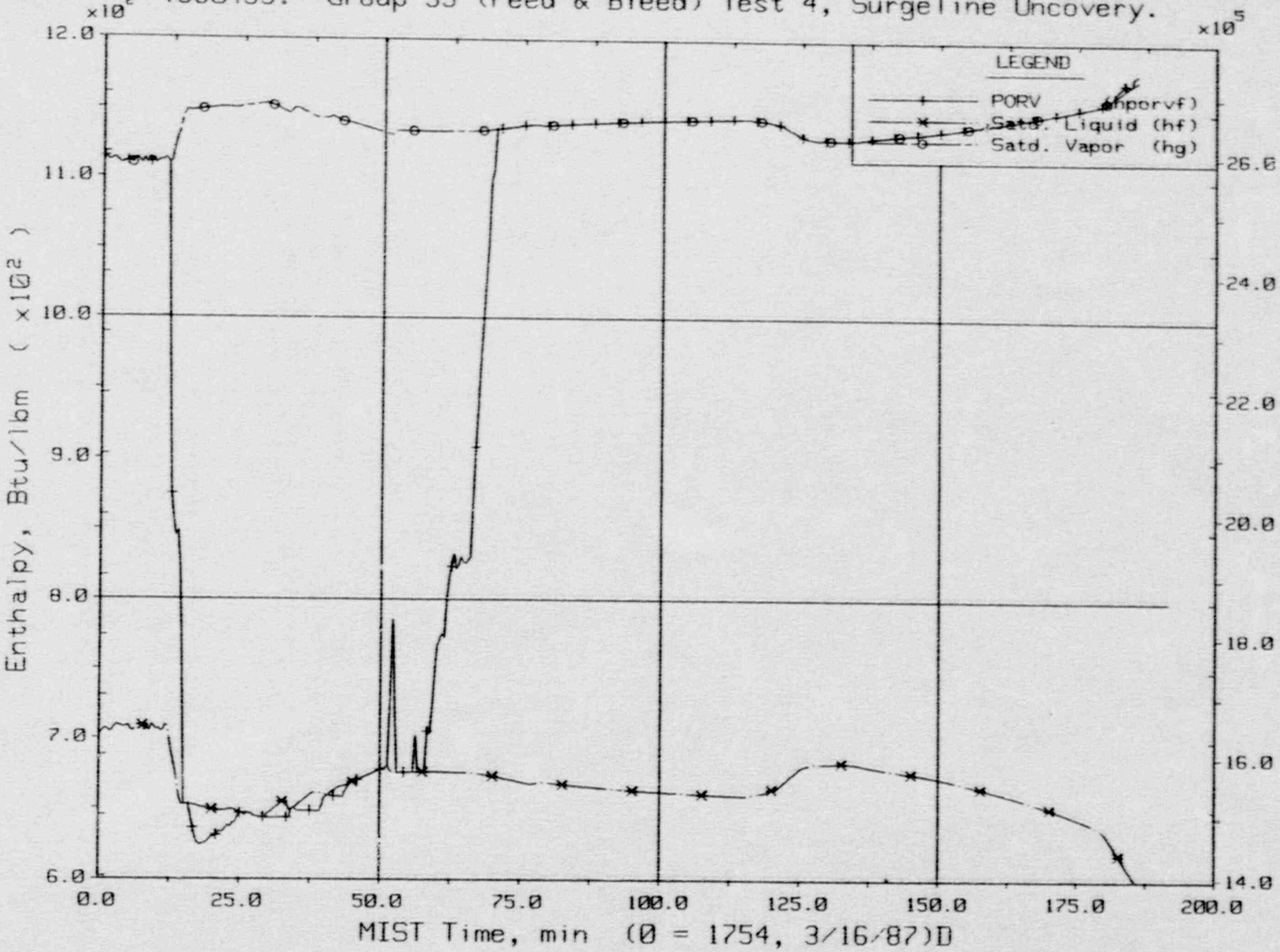
T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



Control Temperature Differences.

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



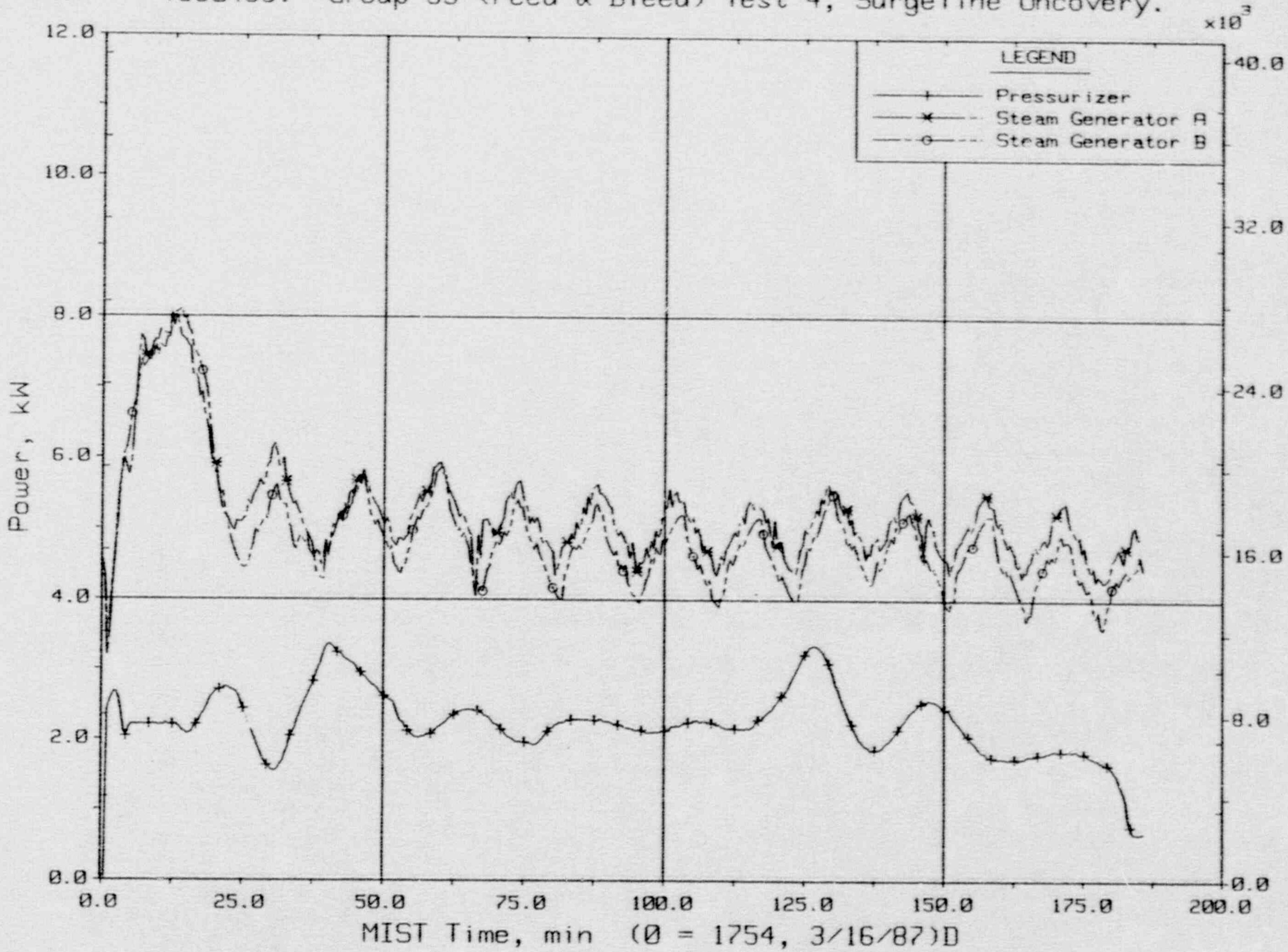
Power-Operated Relief Valve Enthalpy (Based On Flow Rate).

Tue Jun 7 13:03:17 1988

PZEN1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



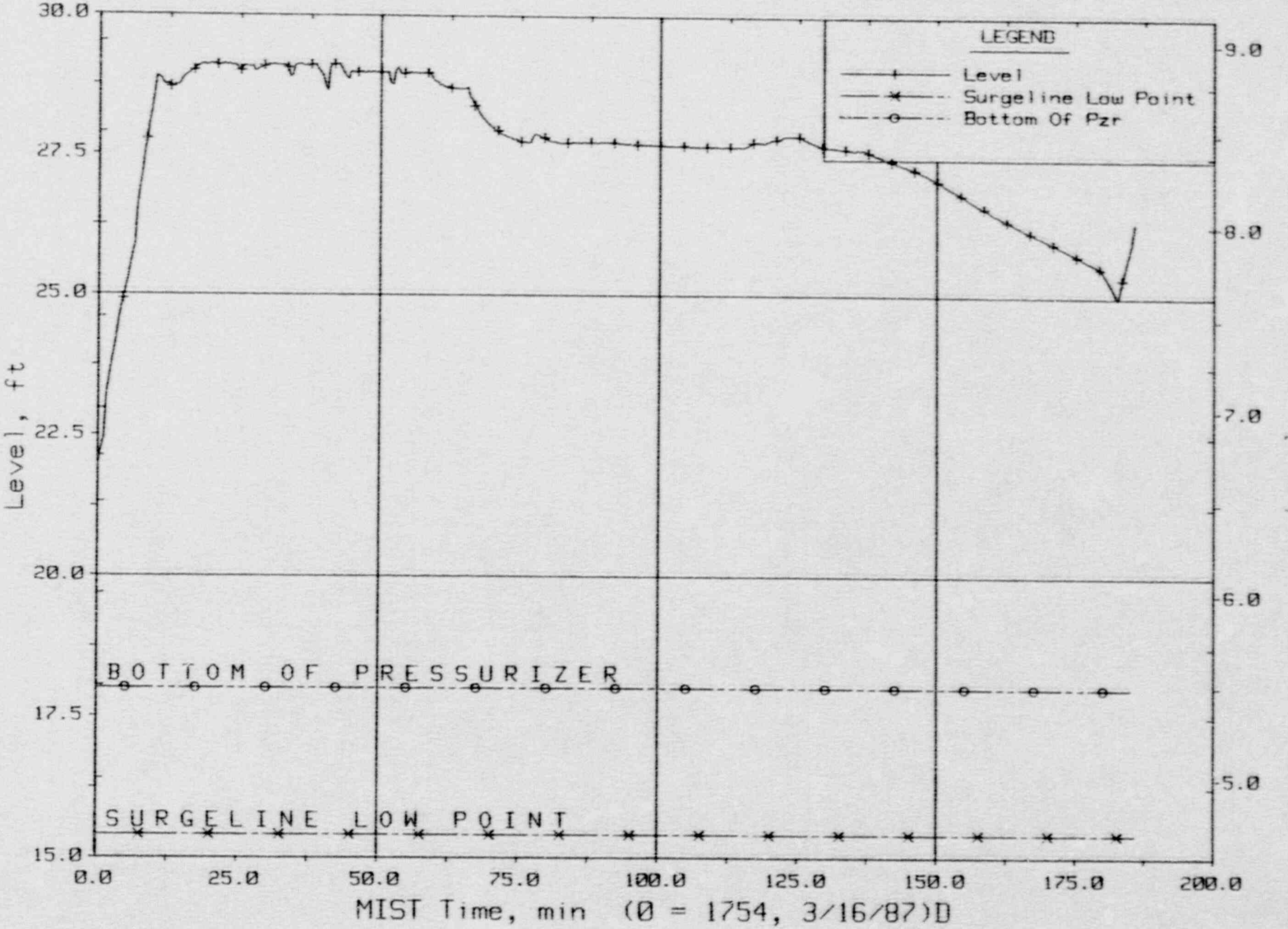
Guard Heater Specified Power, Pressurizer and Steam Generators.

Tue Jun 7 13:06:52 1988

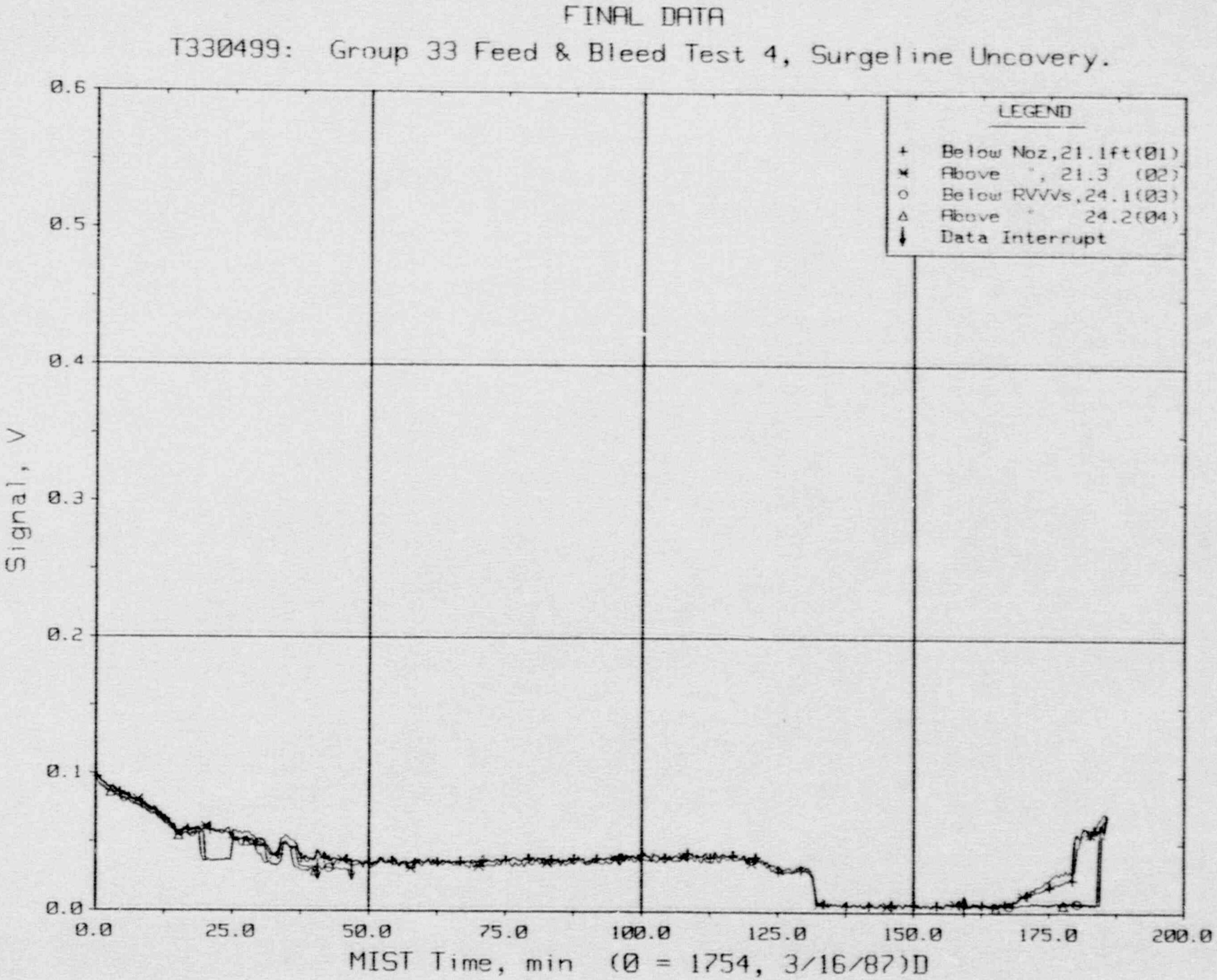
PZGQ1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



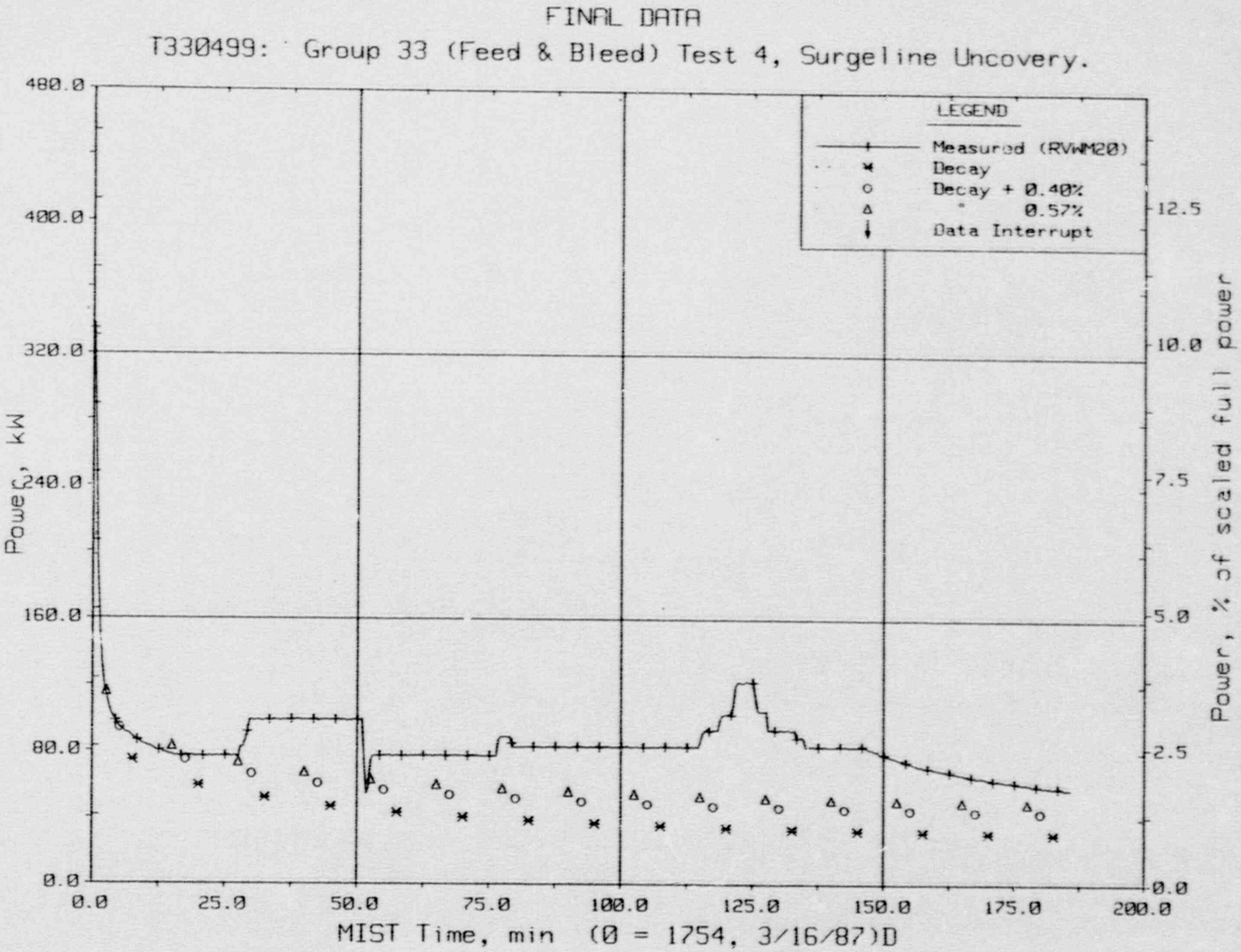
Pressurizer Collapsed Liquid Level (PZLV20).



Reactor Vessel Conductivity Probe Signals (RVCPs).

Thu May 19 13:51:30 1988

RVCP1



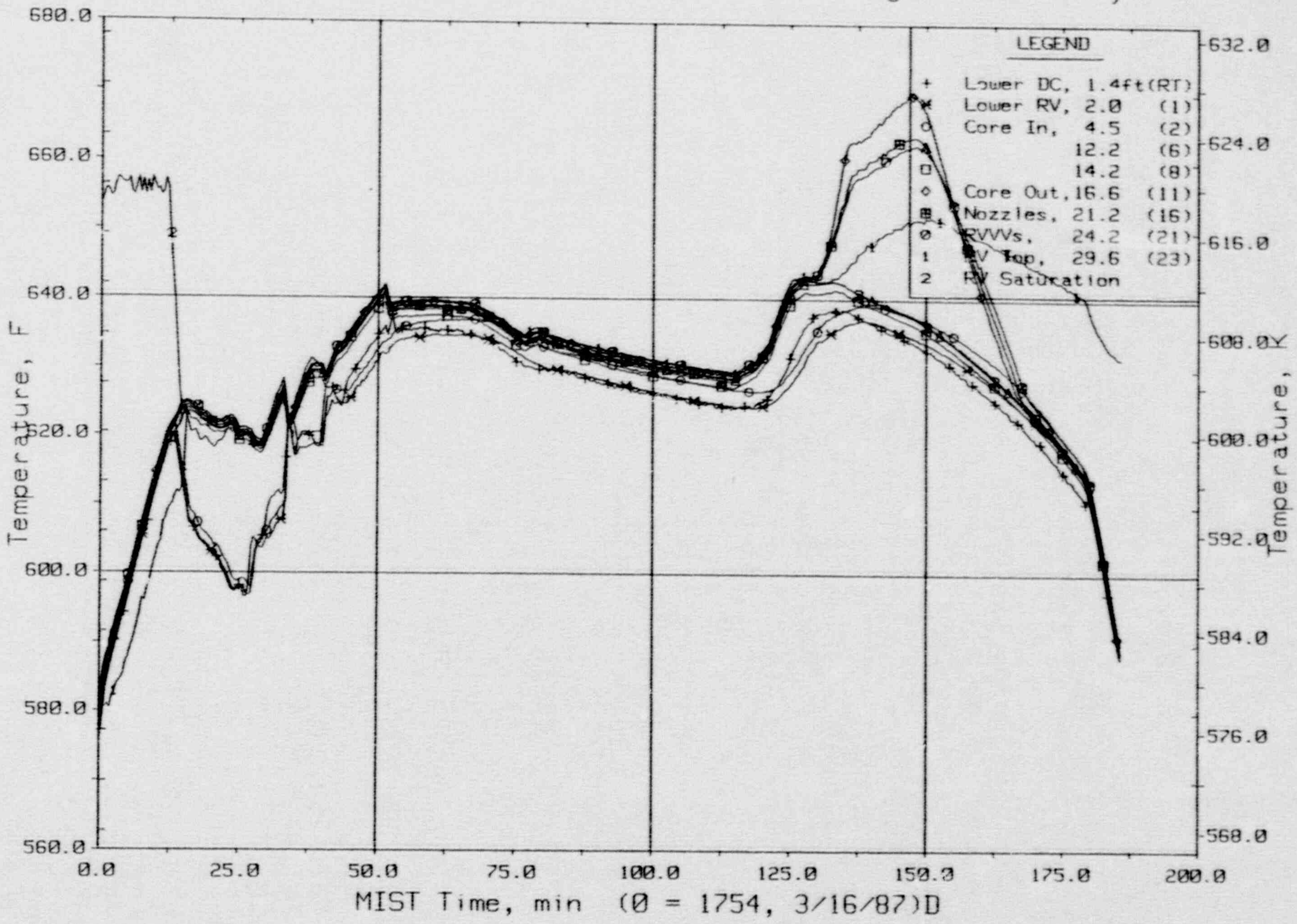
Core Power.

Tue Jun 7 13:13:37 1988

RVKW0

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



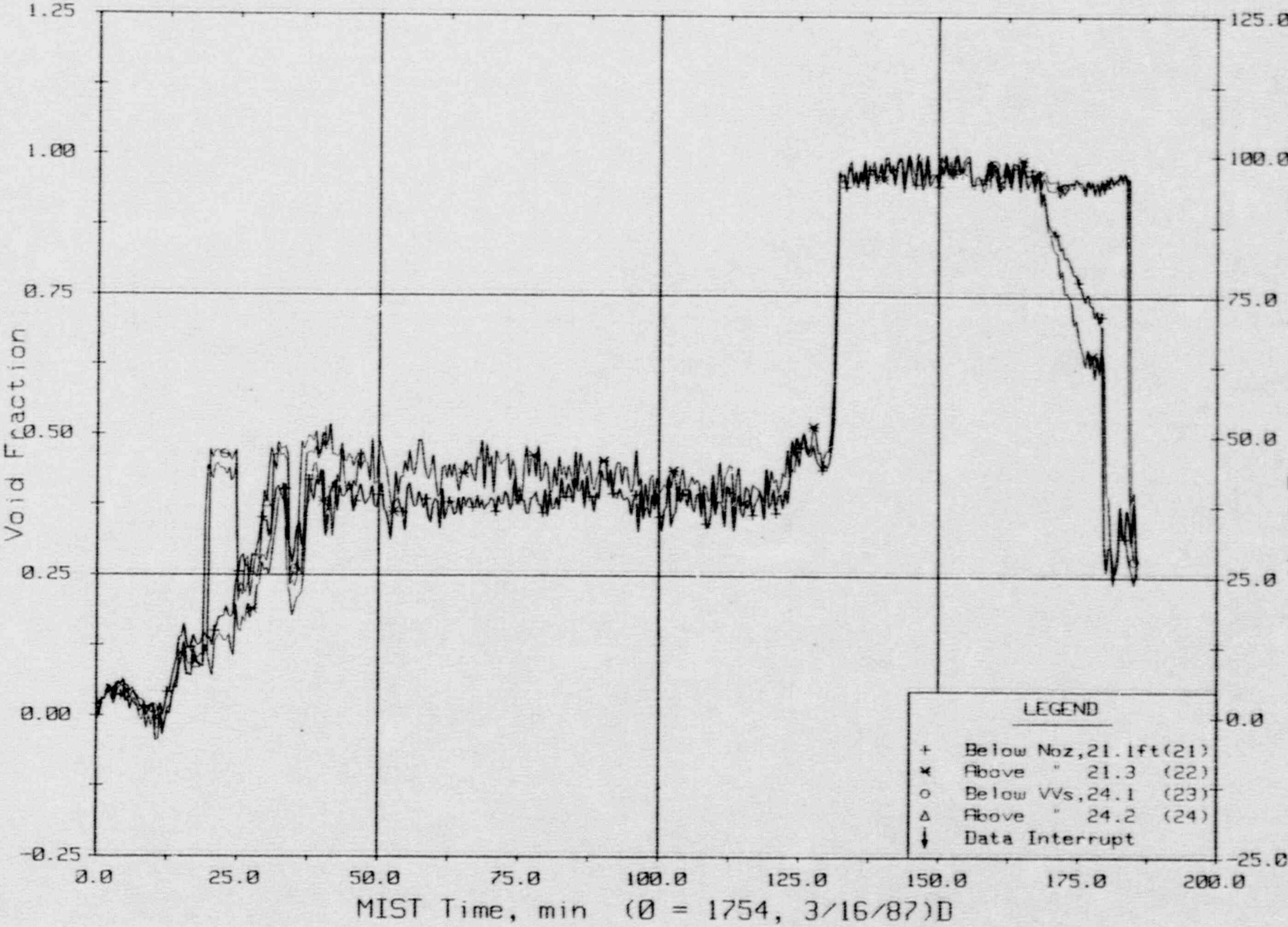
Core Unit Cell and Reactor Vessel Fluid Temperatures (RVTCs).

Tue Jun 7 13:19:08 1988

RVTC0

FINAL DATA

T330499: Group 33 Feed & Bleed Test 4, Surgeline Uncovery.



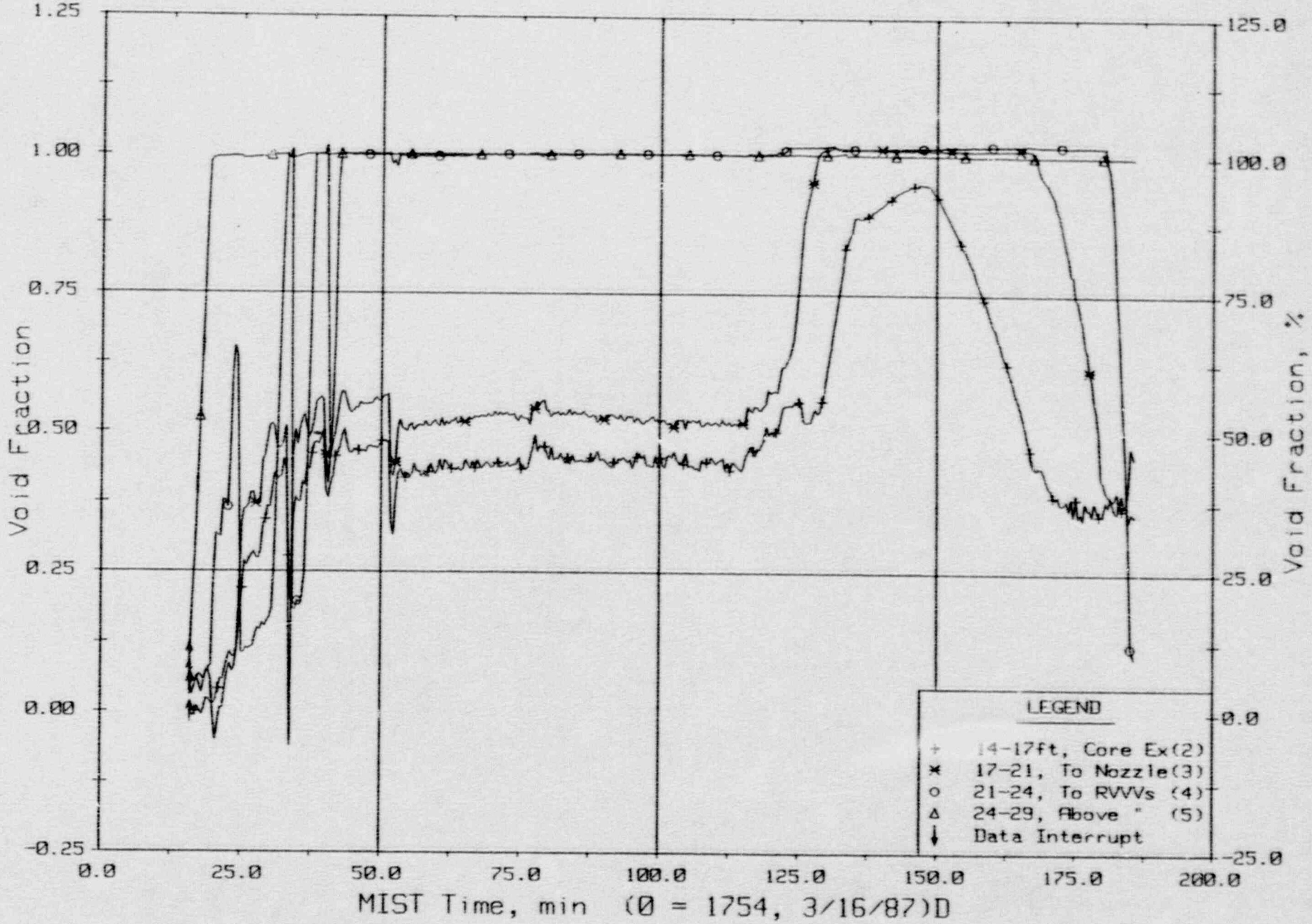
Reactor Vessel Void Fractions From Conductivity (RVCPs).

Thu May 19 13:54:06 1988

RVVC1

FINAL DATA

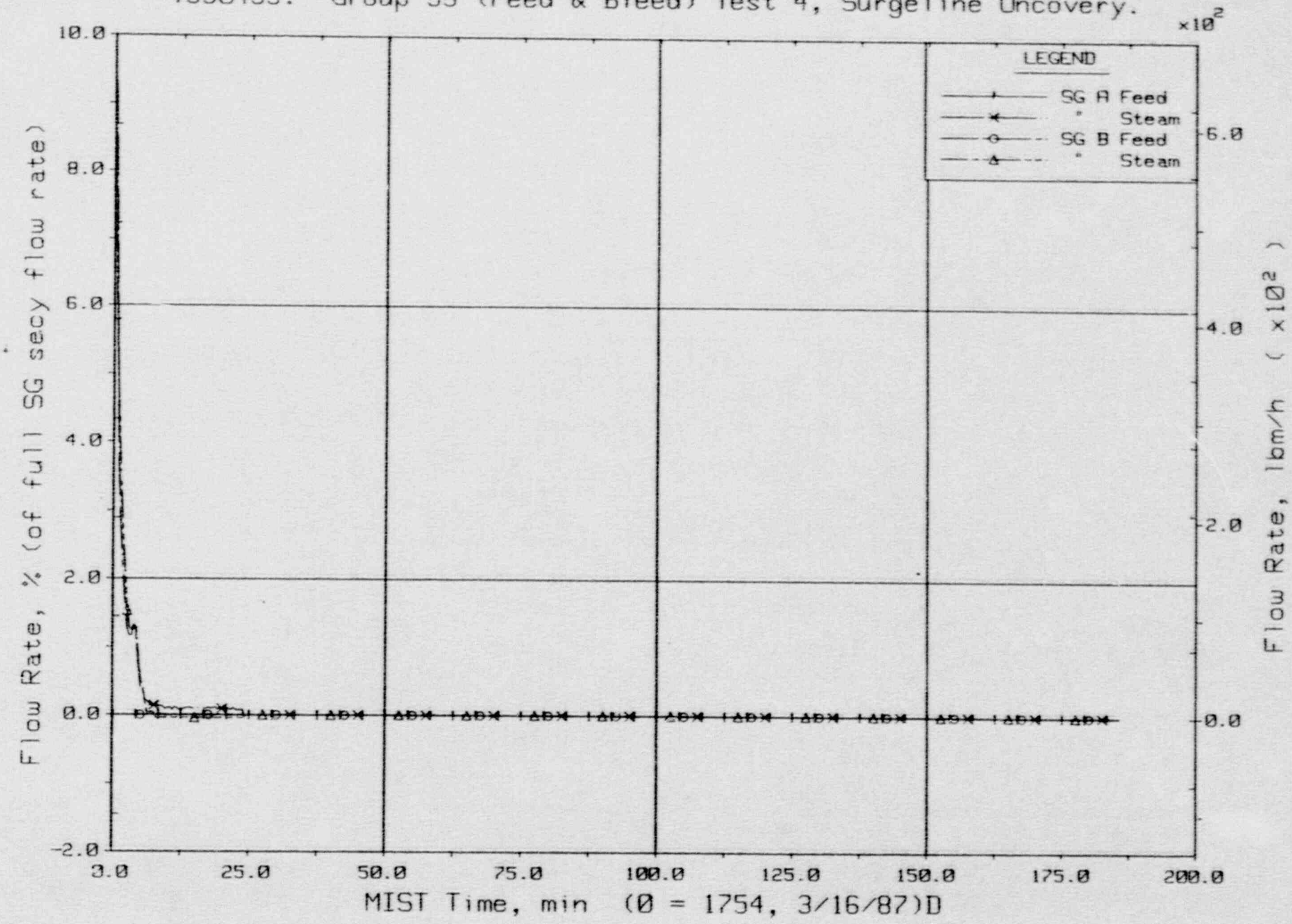
T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



Reactor Vessel Void Fractions From Differential Pressures (RVVFs).

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



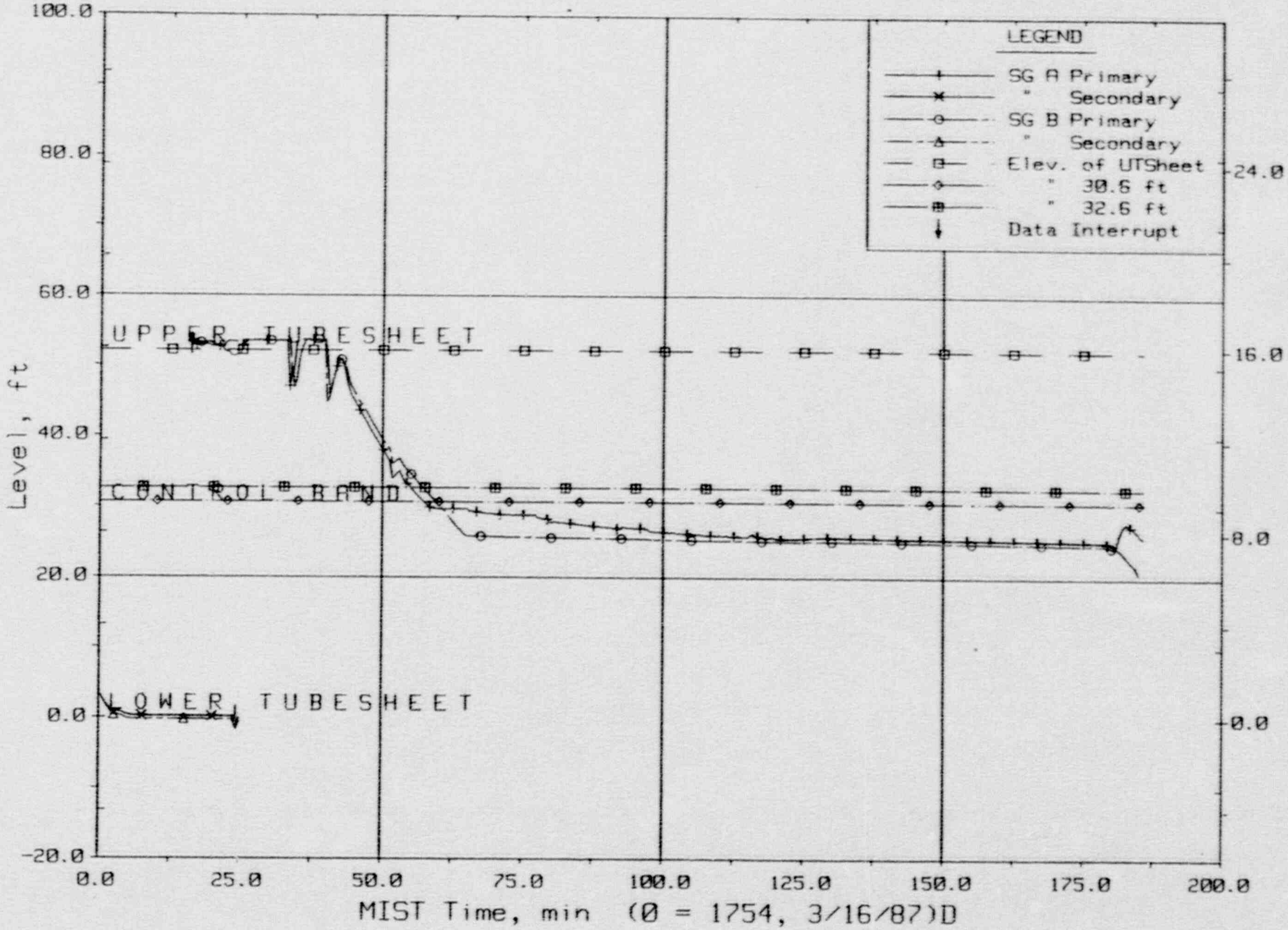
Steam Generator Secondary System Flow Rates.

Tue Jun 7 13:26:21 1988

SGFL2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



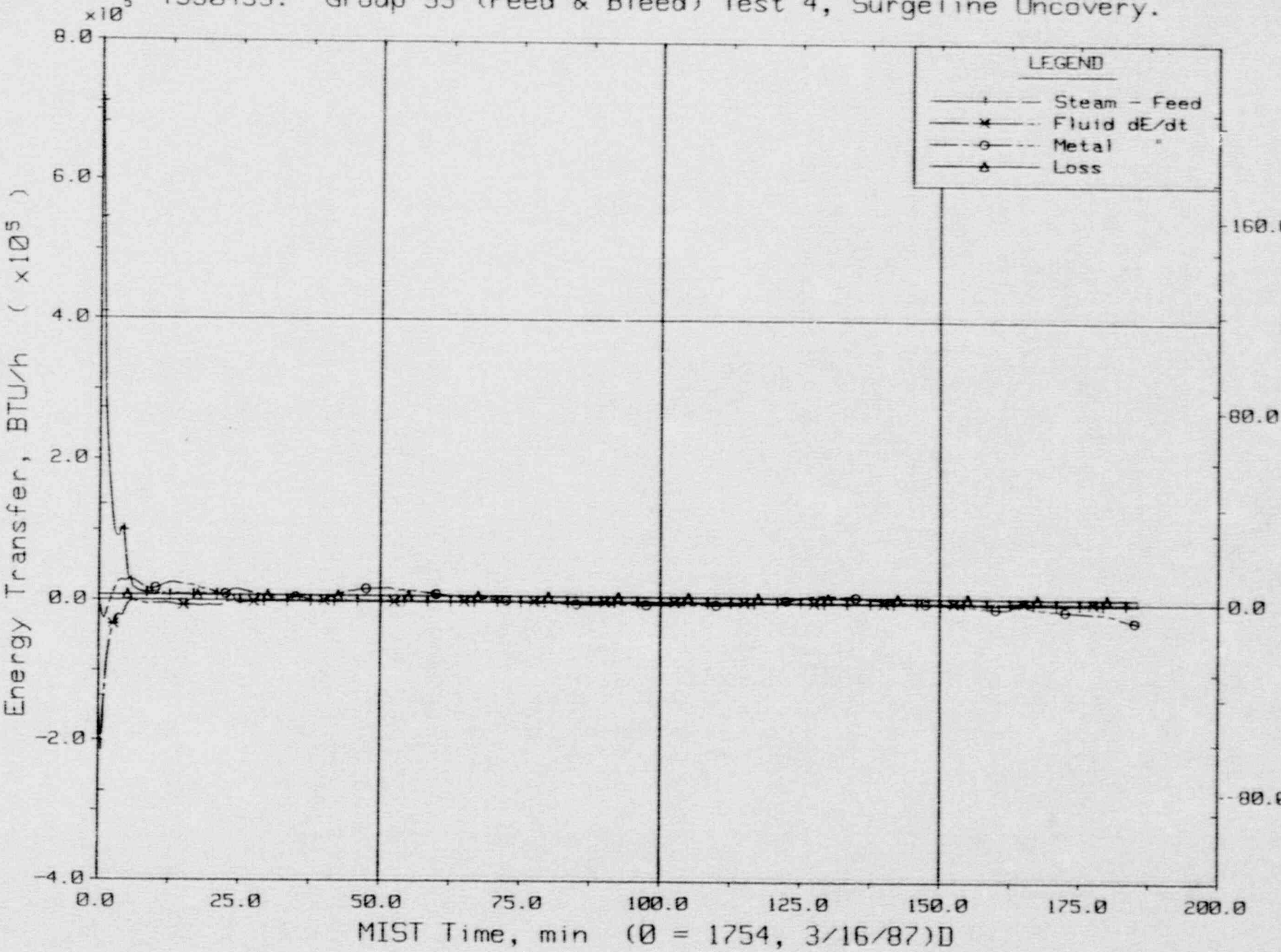
Steam Generator Collapsed Liquid Levels.

Tue Jun 7 13:31:44 1988

SGLV2

FINAL DATA

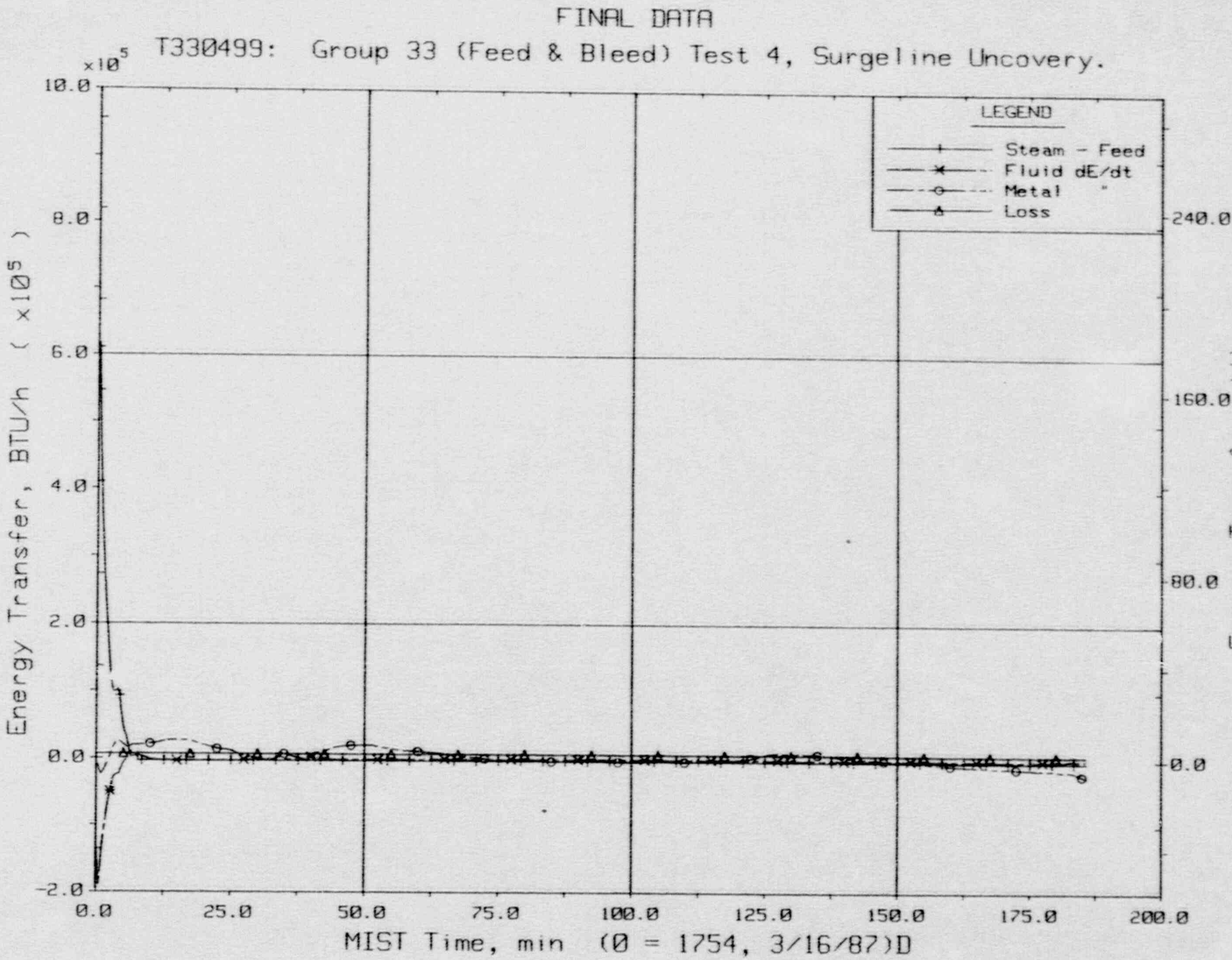
T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



Steam Generator A Energy Transfer.

Tue Jun 7 13:38:54 1988

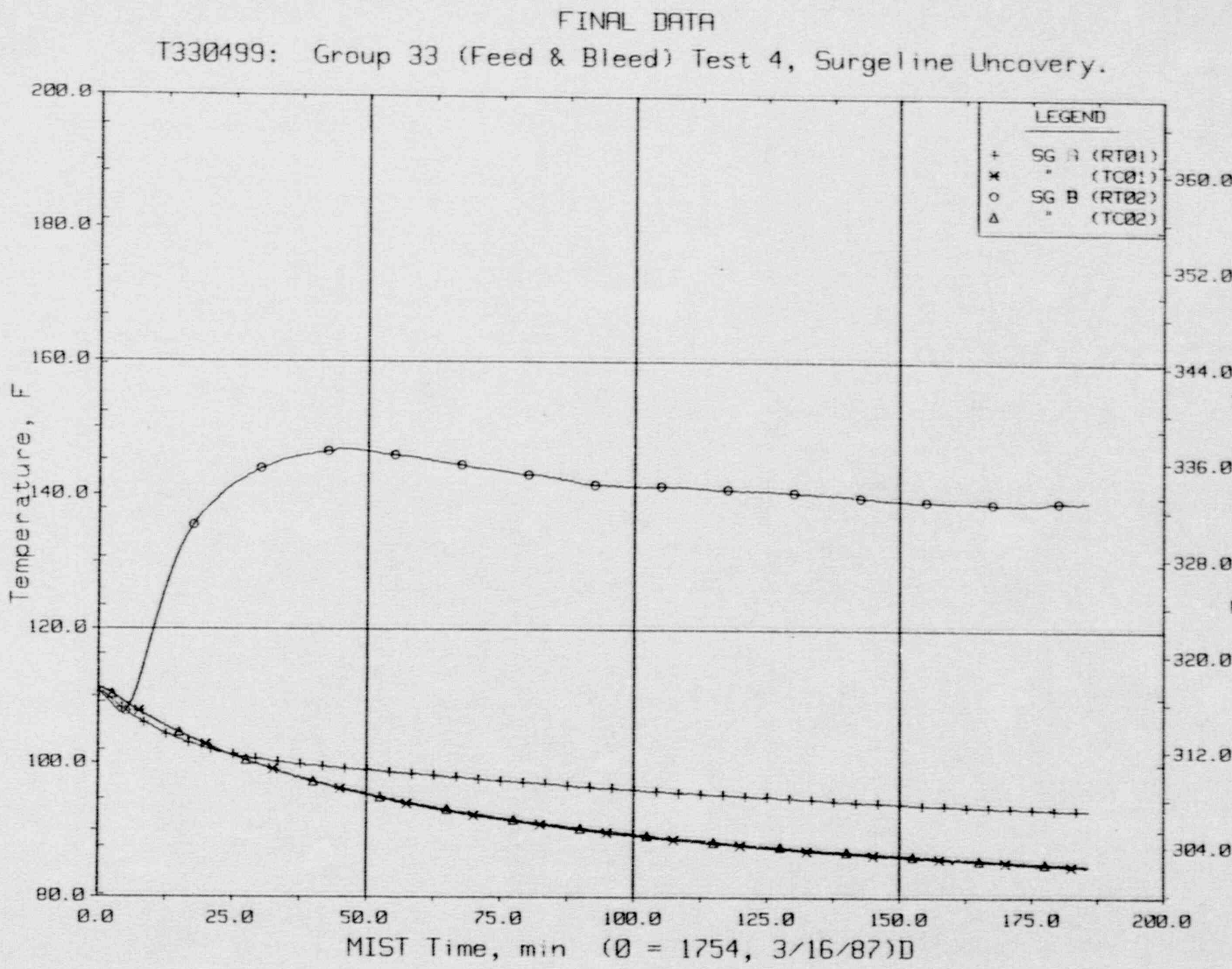
SGQE3



Steam Generator B Energy Transfer.

Tue Jun 7 13:41:53 1988

SGQE6



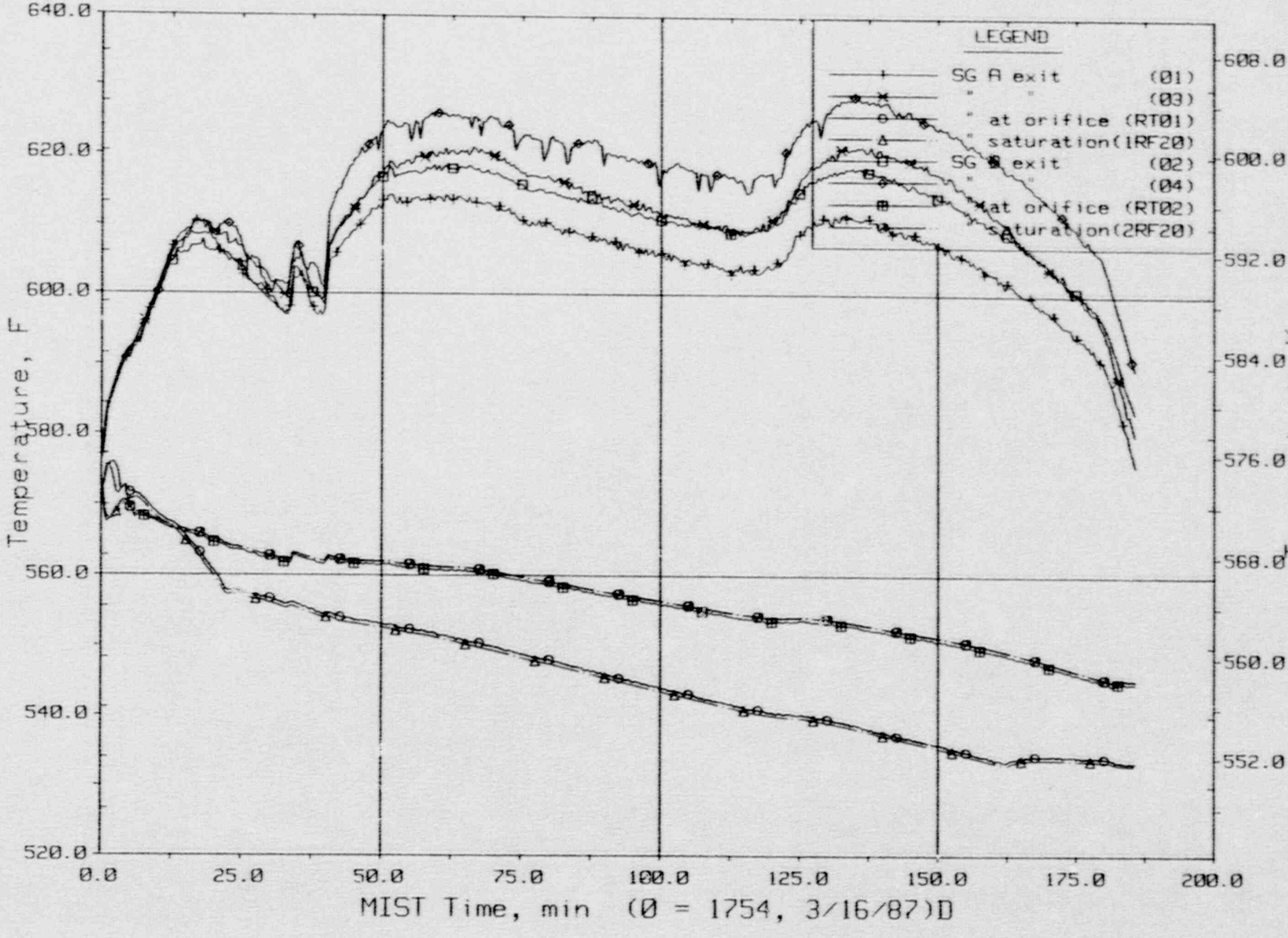
Feedwater Temperatures (SFs).

Tue Jun 7 13:44:35 1988

SGRT1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



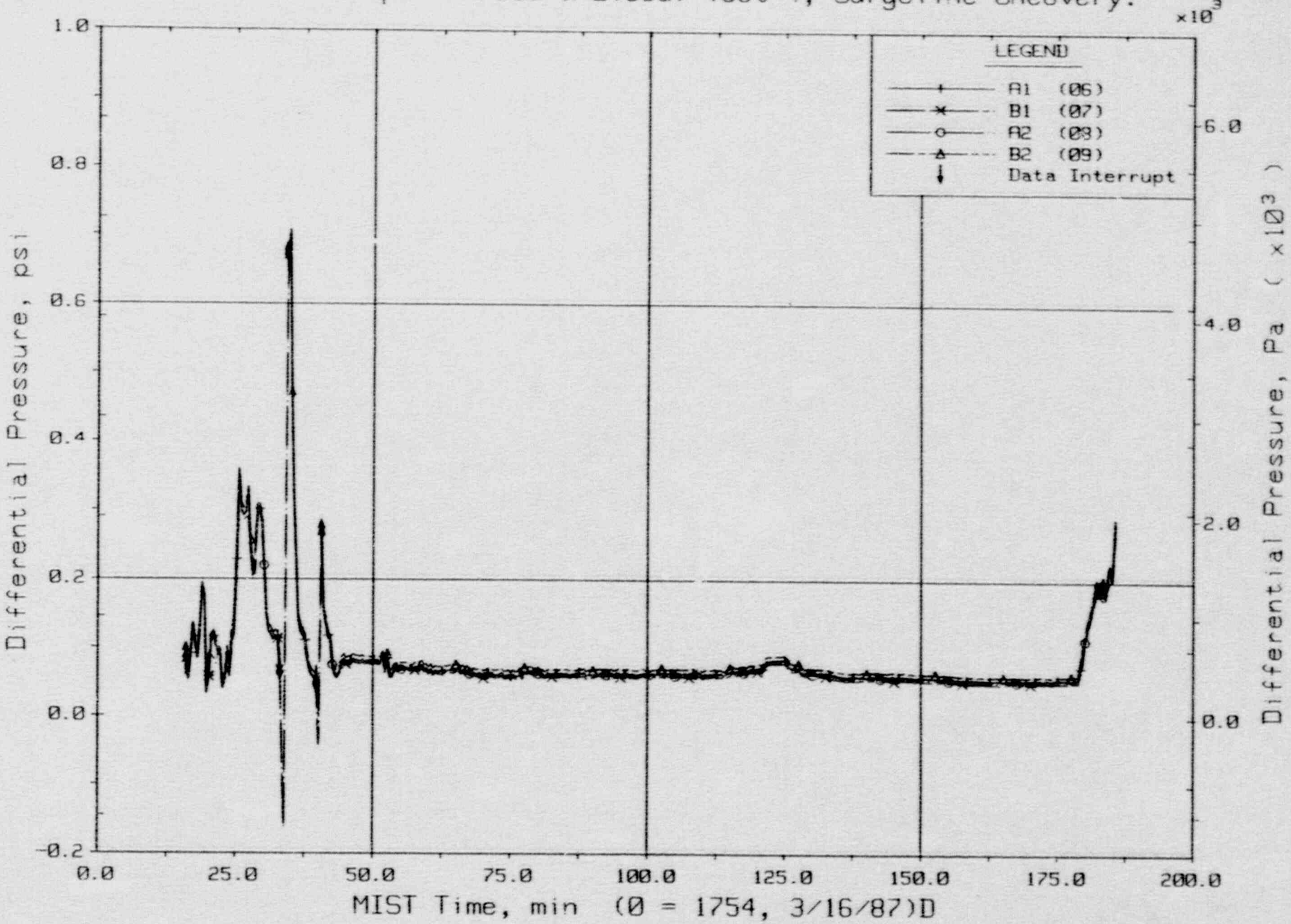
Steam Generator Steam Outlet Temperatures (SSTCs).

Tue Jun 7 13:48:11 1988

SGRT2

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



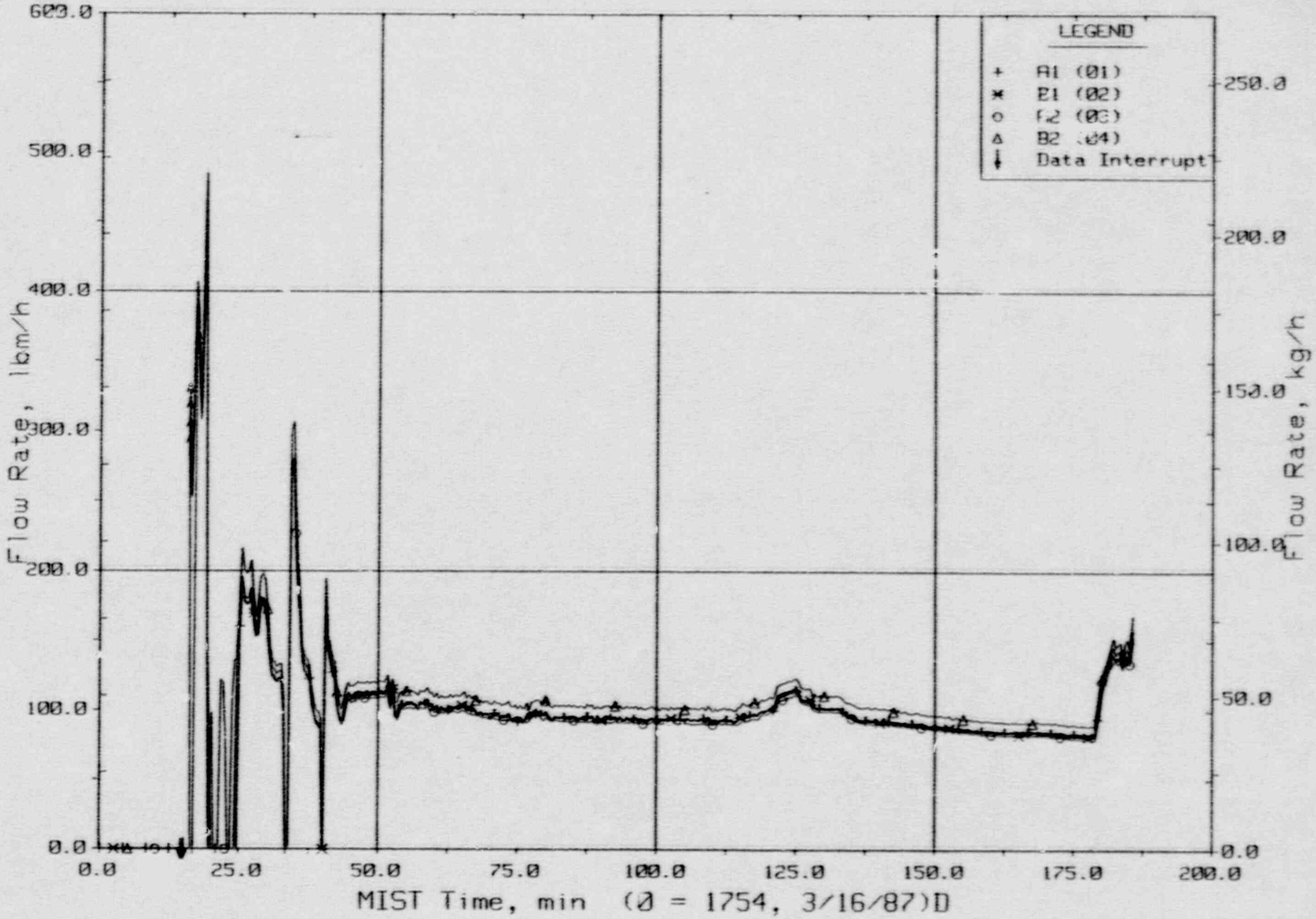
Reactor Vessel Vent Valve Differential Pressures (RVDPs).

Tue Jun 7 13:51:31 1988

VVDP1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



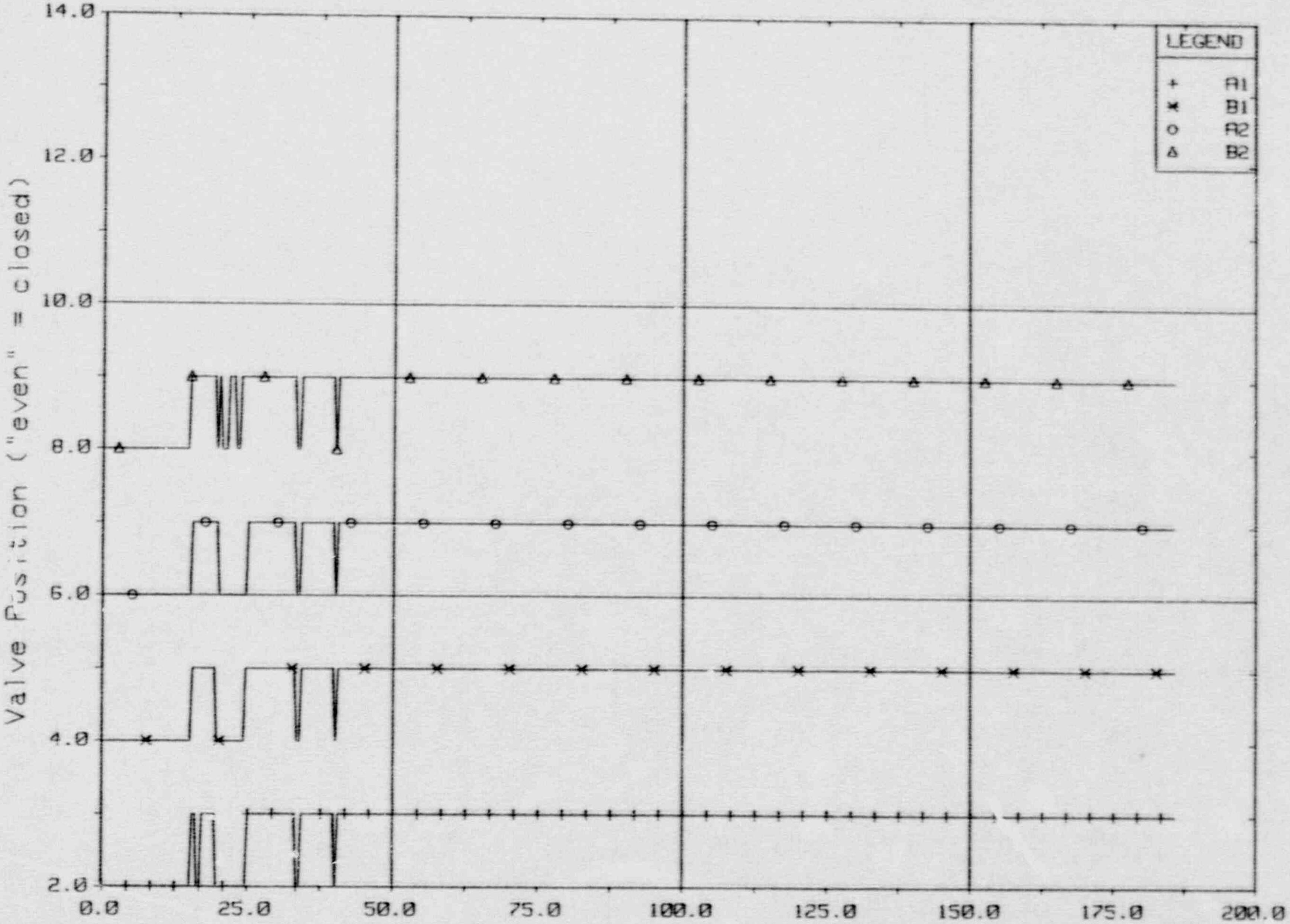
Reactor Vessel Vent Valve Flow Rates (RVORs).

Tue Jun 7 13:54:34 1988

VVFL1

FINAL DATA

T3??499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



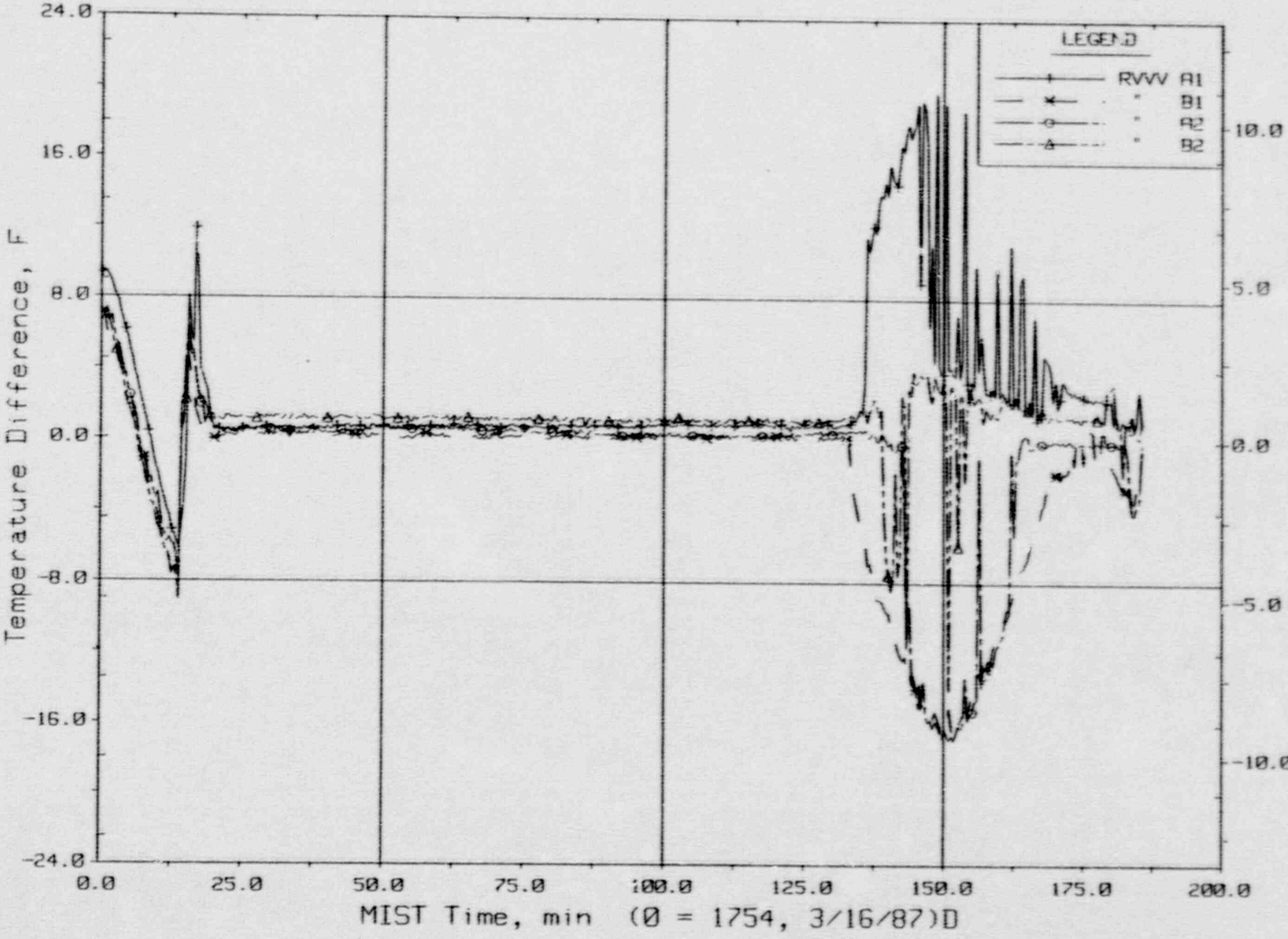
Reactor Vessel Vent Valve Positions.

Tue Jun 7 13:57:50 1988

VVLS1

FINAL DATA

T330499: Group 33 (Feed & Bleed) Test 4, Surgeline Uncovery.



Temperature Differences Across Vent Valves.

Tue Jun 7 14:00:30 1988

VVTD1