OTIS
Hot Leg
High Point Vent Test
#240200

Floriua Power Corporation
Sacramento Municipal Utility District

JULY 1984

12-1152308-00

Babcock & Wilcox
a McDermott company

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OTIS Test 240200: (HPI-PORV Cooling
With Loop Noncondensibles):
Preliminary Results

B&W Document Number 12-1152308-00

4 July 1984

ABSTRACT

OTIS Test 240200 evaluated the effectiveness of HPI-PORV cooling with a gas-laden primary loop. Approximately three loop volumes of noncondensible gas were injected before test initiation, and were recovered with the PORV and venting effluent. HPI-PORV cooling was used to reduce the lower-elevation primary fluid temperatures by 200F over a 4 hour period, the higher-elevation primary fluid was largely at saturation but still cooled. Other methods of heat removal were also exercised.

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1.0 INTRODUCTION

This is an initial report of OTIS Test 240200, which tests explores HPI-PORV cooling with an ncg (noncondensible gas) - laden primary loop. The OTIS model is outlined in Section 2, Section 3 gives test background, conduct, and a description of test performance by testing phases. The appendix describes the derivations of the plotting variables and loop instrumentation; Test 240200 plots are appended.

2.0 SYSTEM DESCRIPTION

OTIS is an experimental test facility at B&W's Alliance Research Center, designed to evaluate the thermal/hydraulic conditions in the reactor coolant system and steam generator of a raised-loop B&W reactor, during the natural circulation phases of a Small-Break-Loss Of Coolant Accident (SBLOCA). The test facility is a scaled 1x1 (one hot leg, one cold leg) electrically heated loop simulating the important features of the plant. The facility is used to perform separate effect and integral system tests at simulated scaled power levels of 1 to 5%.

The loop consists of one 19-tube Once-Through Steam Generator (OTSG), a simulated reactor, a pressurizer, a single hot leg, and a single cold leg. Reactor decay heat following a scram is simulated by electrical heaters in the reactor vessel. No pump is included in the basic system, but a multipurpose pump in an isolatable cold leg bypass line may be used to provide forced primary flow. The test loop is full raised-loop plant elevation, approximately 95 feet high, and is shortened in the horizontal plane (to approximately 6 feet) to maintain approximate volumetric scaling.

Other primary loop components include a reactor vessel vent valve (RVVV), pressurizer power-operated relief valve (PORV) or safeties, and hot leg and RV high point vents. Auxiliary systems are available for scaled high pressure injection (HPI), controlled primary leaks in both the two-phase and single-phase regions, a secondary forced circulation system for providing auxiliary feedwater (AFW) to the OTSG, steam piping and pressure control, a cleanup system for the secondary loop, gas addition, and gas sampling.

Scaling

The configuration of the test loop is dictated by scaling considerations. The four scaling criteria used to configure OTIS, in order of priority, are:

- o Elevations
- o Post-SLBOCA Flow Phenomena
- o Volumes
- o Irrecoverable Pressure Loss Characteristics

A more detailed discussion of the scaling considerations is presented in Reference 3. OTIS power and volume scaling originates with the size of the model OTSG. The model OTSG contains nineteen (19) full-length and plant-typical tubes, which represent the 16013 tubes in each of the two steam generators used in the 205-FA plants. Therefore, the dominant power and volume scaling in the loop is:

$$\text{Scaling Factor} = \frac{19}{2 \times 16013} = \frac{1}{1686}$$

The distance between secondary faces of the lower and upper tubesheets in the 19-tube OTSG is full length. Auxiliary feedwater nozzles are located in the model steam generator at two elevations. The tubesheet thicknesses in the model OTSG are not plant-typical, and the model inlet and outlet plenums are reducers. Therefore, the hot leg-to-steam generator inlet and steam generator-to-cold leg lengths are atypical. Piping runs beyond the steam generator and plenums are used to retain plant-typical elevations.

The hot leg inside diameter is scaled to preserve Froude number, and thus the ratio of inertial to buoyant forces. This criterion is considered to preserve two-phase flow regimes and reflooding phenomenon according to certain correlations. Scaling with Froude number results in a hot leg diameter twice that indicated by ideal volumetric scaling. Although this adds approximately 20% to the ideal system (total loop) volume, this choice of hot leg inside diameter is considered most likely to avoid the whole-pipe slugging behavior observed in other scaled SBLOCA test facilities.

The spillover elevation of the plant hot leg U-bend is retained in OTIS by matching the elevations of the bottom (inside) of the plant and model hot leg U-bend pipes. The radius of the U-bend obtains exact volumetric scaling.

The pressurizer in OTIS is volume and elevation scaled. The elevation of the bottom of the pressurizer is plant typical, as is the spillunder elevation of the pressurizer surge line. The centerline elevation of the hot leg-to-pressurizer surge connection matches that of the plant.

An electrically heated reactor vessel provides heat input to the primary fluid to simulate reactor decay heat levels up to 5% scaled power. Based on a plant power rating of 3600 mwt, 1% of scaled full power in OTIS is 21.4 kw. The model core heat input capacity is 180 kw. OTIS primary flow scaling obtains 1% of scaled full flow = 0.259 lbm/s; on the secondary side, 1% of scaled full secondary flow = 0.0265 lbm/s.

The annular downcomer of the plant reactor vessel is simulated by a single external downcomer in OTIS. The spillunder elevation in the horizontal run at the bottom of the model downcomer corresponds to the elevation of the uppermost flow hole in the plant lower plenum cylinder. The OTIS reactor vessel consists of three regions: a lower plenum, a heated section, and an upper and top plenum. The center of the heated length of the core vessel corresponds to the center of the active fuel length in the plant core. The core region of the model reactor vessel contains excess volume due to construction constraints; therefore, to maintain the total reactor vessel scaled volume, the reactor vessel is shorter than plant-typical. Non-flow lengths were sacrificed to maintain reactor vessel scaled volume.

Cold primary fluid enters the downcomer from the cold leg, and heated primary fluid leaves the upper plenum to enter the hot leg. The center of the cold leg to downcomer connection in OTIS corresponds to the cold leg-to-reactor vessel nozzle centerline in the plant. Similarly, the center of the hot leg-to-upper plenum connection in OTIS corresponds to the reactor vessel-to-hot leg nozzle centerline in the plant.

The model cold leg does not contain an in-loop pump, since OTIS is designed to simulate the natural circulation phases of a SBLOCA. A flange is provided in the cold leg piping upstream of the reactor coolant pump spillover point to admit a flow restrictor which simulates the irrecoverable pressure loss characteristic of a stalled reactor coolant pump rotor.

The model cold leg originates at the lower plenum of the 19-tube OTSG and extends downward to match the spillunder elevation of the plant cold leg. The highest point in the cold leg (the spillover into the sloping cold leg discharge line) matches the reactor coolant pump spillover elevation in the plant. Because horizontal distances are shortened in OTIS, the slope of the cold leg discharge line is atypically large.

OTIS atypicalities are summarized as follows:

- OTIS is predominantly a one-dimensional, vertical system, due to the shortened horizontal distances and small cross sections of the various components such as steam generator and reactor vessel.
- Because of the small size of the piping used in the model, the ratio of loop piping wall surface to fluid volume is approximately 20 times that of the plant. Therefore, the fluid and wall-surface temperatures are much more closely coupled than those of a plant.
- In high-pressure models, the ratio of metal volume to fluid volume increases as the model piping is made smaller. The ratio of model metal volume to fluid volume in OTIS is approximately twice that of the plant.

The pipe surface to fluid volume ratio atypicality of scaled facilities results in higher heat losses in the scaled facilities than in the plants. This atypicality can be minimized by using both guard heaters and passive insulation on the model piping. Guard heating is used for the OTIS hot leg, pressurizer, surgeline, and RV upper head.

The OTIS secondary system provides the steam generator secondary inventory, and those fluid boundary conditions which impact SBLOCA phenomena. These include steam generator level control, auxiliary feedwater, and steam pressure control valves.

The OTIS instrumentation includes pressure and differential-pressure measurements; thermocouple (TC) and resistance temperature detector (RTD) measurements of fluid, metal, and insulation temperatures; level and phase indications by optical-ports and conductivity probes as well as by differential pressures; and pitot tubes and flowmeters for measurements of flowrates in the loop. In addition to these measurements, loop boundary conditions are metered: HPI, HPV (hot leg and RV), (controlled) leak, PORV, and secondary steam and feed flow are measured; noncondensable gas (NCG) injections are controlled and metered; NCG discharges with the two-phase primary effluent streams are measured; and the aggregate primary effluent are cooled and collected for integrated metering. OTIS instrumentation consists of approximately 250 channels of data which are processed by a high-speed data acquisition system. The data acquisition rate can be either event-actuated or adjusted by the loop operator to acquire and store a full set of data as often as every 5 seconds. Instruments are described further in Section 4 of the appendix.

Features

OTIS consists of a closed primary loop, closed secondary loop, and several auxiliary systems. A general arrangement showing the relationship of the key components of these systems is shown in Figure 2-1. The key features are:

- Multiple leak locations,
- Guard heating,
- Scaled high pressure injection (HPI),
- Simulated reactor vessel vent valve (RVVV),
- OTSG level control,
- Automatic cooldown, and
- High and low elevation auxiliary feedwater addition.

Multiple leak locations in OTIS allow a controlled SBLOCA. Controlled leaks are located at the bottom of the lower plenum of the reactor vessel, in the cold leg upstream of the simulated reactor coolant pump (RCP) spillover, in the cold leg downstream of the RCP spillover, a high point vent (HPV) at the top of the hot leg U-bend (HLUB) and in the RV upper head, and a simulated pilot operated relief valve (PORV) at the top of the pressurizer. Leak flow is controlled by an orifice located just downstream of the leak site. The leak flow control orifice is located in a 5/8" diameter tube as shown in Figure 2-2, to form the leak flow control orifice assembly. The details of the orifice design are illustrated in Figure 2-3. Scaled leaks of 10 cm^2 and 15 cm^2 were tested in the single phase regions (cold leg leaks), while ~10 cm^2 leaks were tested at the PORV. The actual diameter of the scaled leak was obtained from the ideal volume scaling factor of 1686. Thus a scaled leak of 10 cm^2 has a diameter of 0.34 inches in OTIS. For Test 2402 the HL High Point Vent and PORV orifice sizes were the (scaled equivalent of 2.11 and 9.64 cm^2 respectively.

To preclude leakage from the loop, sealed-steam valves were used where posible throughout the loop. Additionally, all instrument fittings in the reator coolant system above the top of the core heaters were seal welded. To characterize the leak tightness of the loop, a helium leak check was performed.

As a result of the large surface area to fluid volume ratio, heat loss in the loop was proportionally greater than that in a plant. To minimize this effect, guard heaters were used along the hot leg piping, pressurizer, surge line, and RV upper head. The objective of the guard heating system was to provide heat to the components in an amount equal to the heat loss of that component to ambient. The concept used for guard heating is illustrated in Figure 2-4.. A layer of control insulation, approximately 1/2" thick, enclosed by a thin shell of stainless steel lagging, was placed over the pipe sections to be guard heated. The heater tapes were spirally wrapped over the lagging material, covering nearly 100% of the pipe section. Two layers of passive insulation then covered the guard heaters. The heaters were controlled based on thermocouples located on the pipe OD and at a point mid-way into the control insulation. Tests were performed to evaluate the heat loss from the loop and to characterize the operation of the guard heaters.

Two high pressure injection (HPI) locations were provided - one at the cold leg low point, upstream of the simulated RCP spillover, the other in the downward sloping cold leg, downstream of the simulated RCP spillover. A scaled HPI flow was provided by a positive displacement pump. The flow into the loop was controlled to simulate the scaled heat-flow curves o the plant pumps. In OTSI, HPI flow was directed exclusively to the cold leg discharge piping.

The reactor vessel vent valve (RVVV) was simulated by a single pipe extending from the upper plenum of the reactor vessel to the external downcomer. The pipe elevation matched the spillover elevation of the plant RVVV. A pneumatically-operated, automatically-controlled valve was located in the pipe. This valve was controlled to open and close when the differential pressure between the reactor vessel and downcomer reached preset values. A vertically-oriented slit orifice in the pipe, downstream of the valve, set the flow through the simulated vent valve.

The secondary loop consisted of the 19-tube OTSG, steam piping, a water cooled condenser, hot well, feedwater pump, feedwater heater, and feedwater piping. The secondary side simulation of the plant was limited to the steam generator and the elevation of the auxiliary feedwater (AFW) inlets. Additionally, several control functions were used to simulate plant performance. These included:

- Continuous level (inventory) control,
- Band level control,
- Steam pressure control, and
- Automatic cooldown.

Two modes of steam generator level control were available, continuous level control and band level control. With continuous level control, the operator set the desired steam generator level from 0 to 100%. The controller maintained the collapsed water level at this setpoint by adjusting the feedwater flowrate. The signal for the collapsed level, for both modes of level control, was based on a differential pressure measurement.

The secondary loop could operate at steam pressures of approximately 200 to 1200 psia. Steam pressure was automatically controlled by a steam control valve, based on a signal from the steam pressure transmitter. In addition to automatic steam pressure control, the steam pressure could be controlled to decrease at a pre-programmed rate. This feature allowed simulation of a plant-operator-controlled cooldown. The desired cooldown rate was keyed into the controller as a series of linear segments of pressure versus time. When activated, the steam pressure control valve modulated to obtain the stipulated depressurization.

Auxiliary feedwater addition could be made at either of two locations in the steam generator - at a high feed elevation, typical of the B&W domestic plants, and at a low feed elevation. The AFW nozzle at each elevation could be configured for maximum wetting or for minimum wetting of the steam generator tubes. The two configurations allowed comparison of the effects of a spray pattern on heat transfer (typical of the outer rows of tubes near the AFW nozzles in the plant), to the effects of pool heat transfer (typical of the large majority of tubes that are away from the AFW nozzles in the plant).

The OTIS arrangement and instrumentation are further illustrated in the following figures:

Figure 2-5 Reactor Vessel and Downcomer Arrangement
Figure 2-6 Reactor Vessel and Downcomer Instrumentation
Figure 2-7 Hot Leg Instruments: Temperatures, Conductivities, and Viewports
Figure 2-8 Hot Leg Instruments: Differential Pressure
Figure 2-9 OTSG Temperature Measurements
Figure 2-10 OTSG Differential Pressures
Figure 2-11 Cold Leg Piping
Figure 2-12 Pressurizer

The instrument indications are tabulated in the final pages of the appendix. This tabulation is arranged by component, instrument type, and elevation.

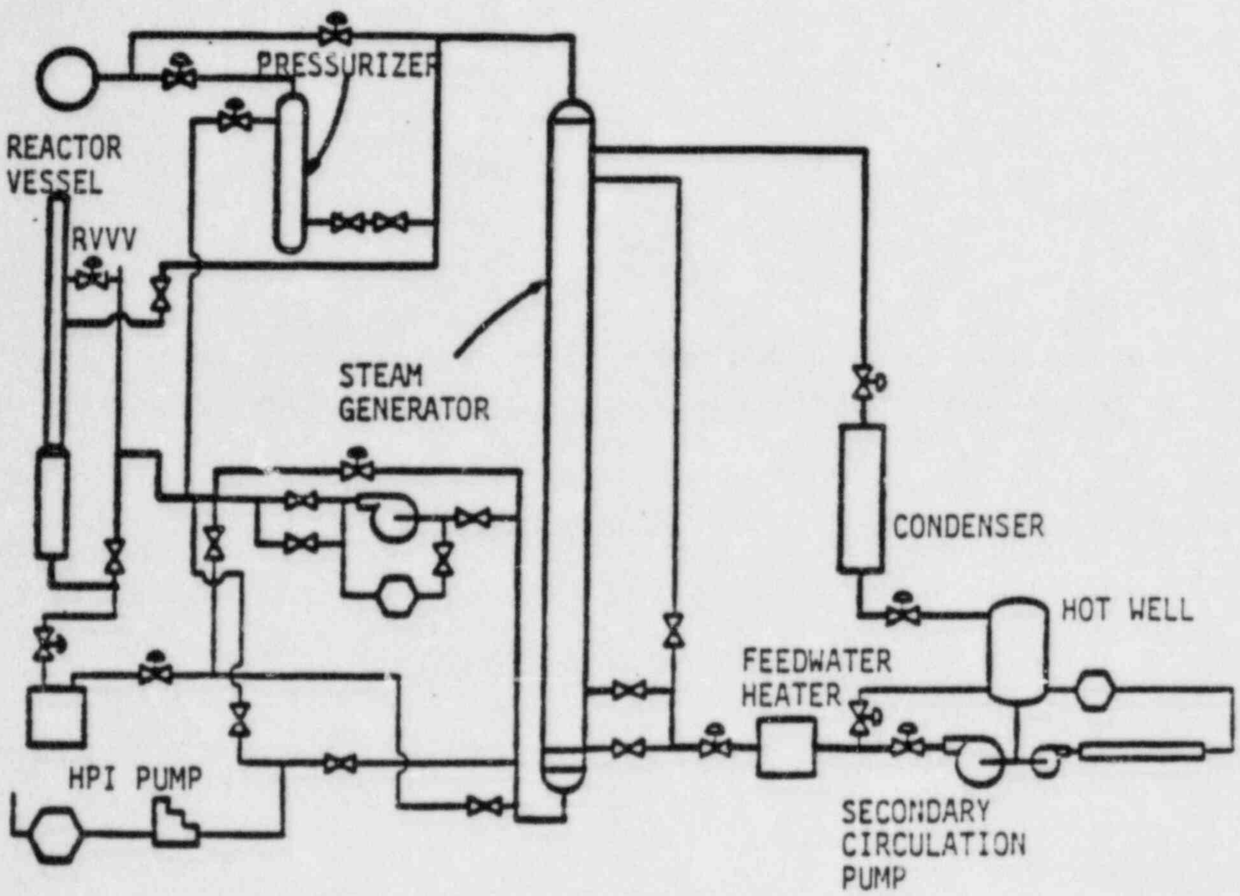

Figure 2-1. OTIS General Arrangement

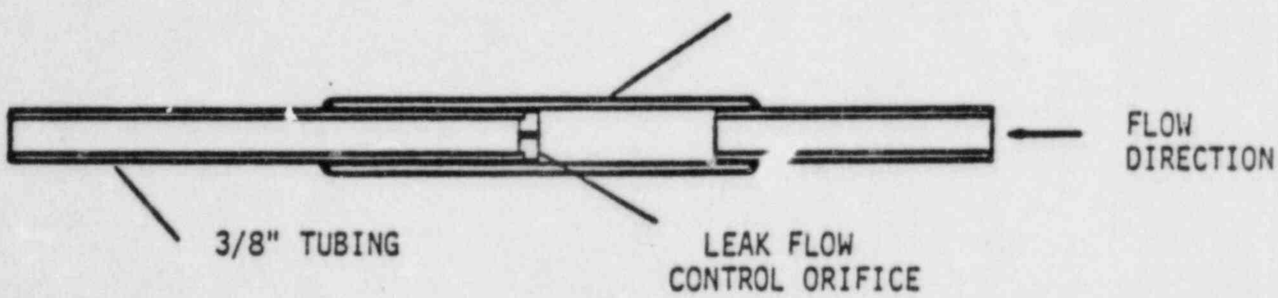

Figure 2-2 Leak Flow Control Orifice Assembly

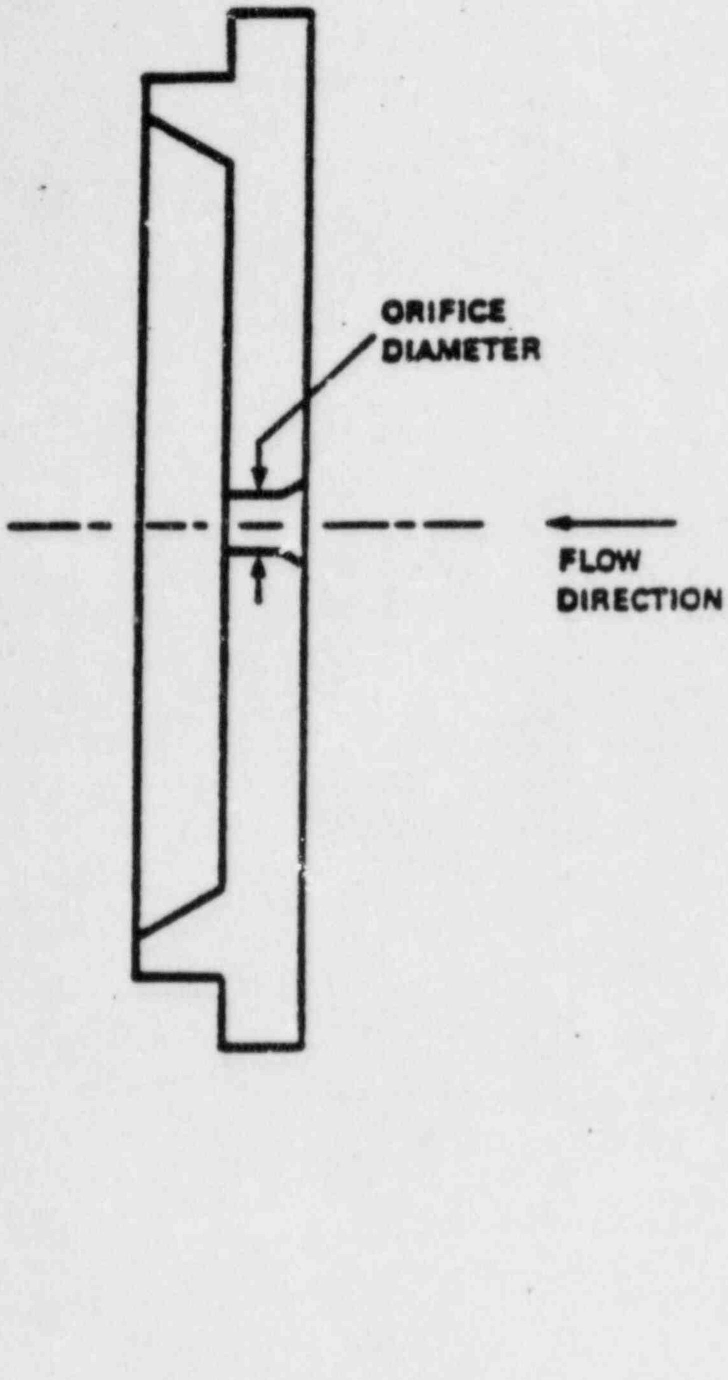

Figure 2-3 Leak Flow Control Orifice

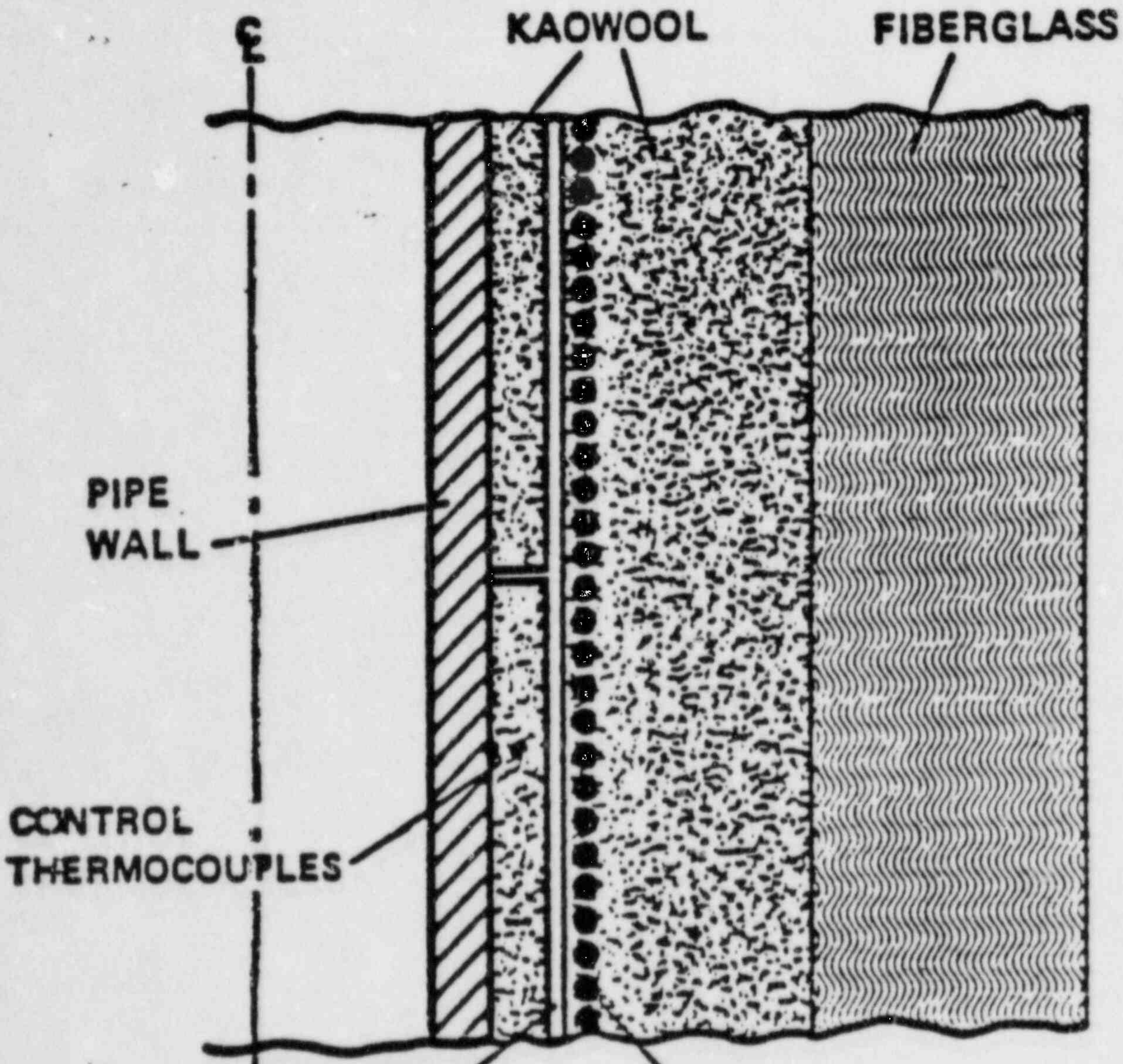

Figure 2-4 Guard Heater Concept

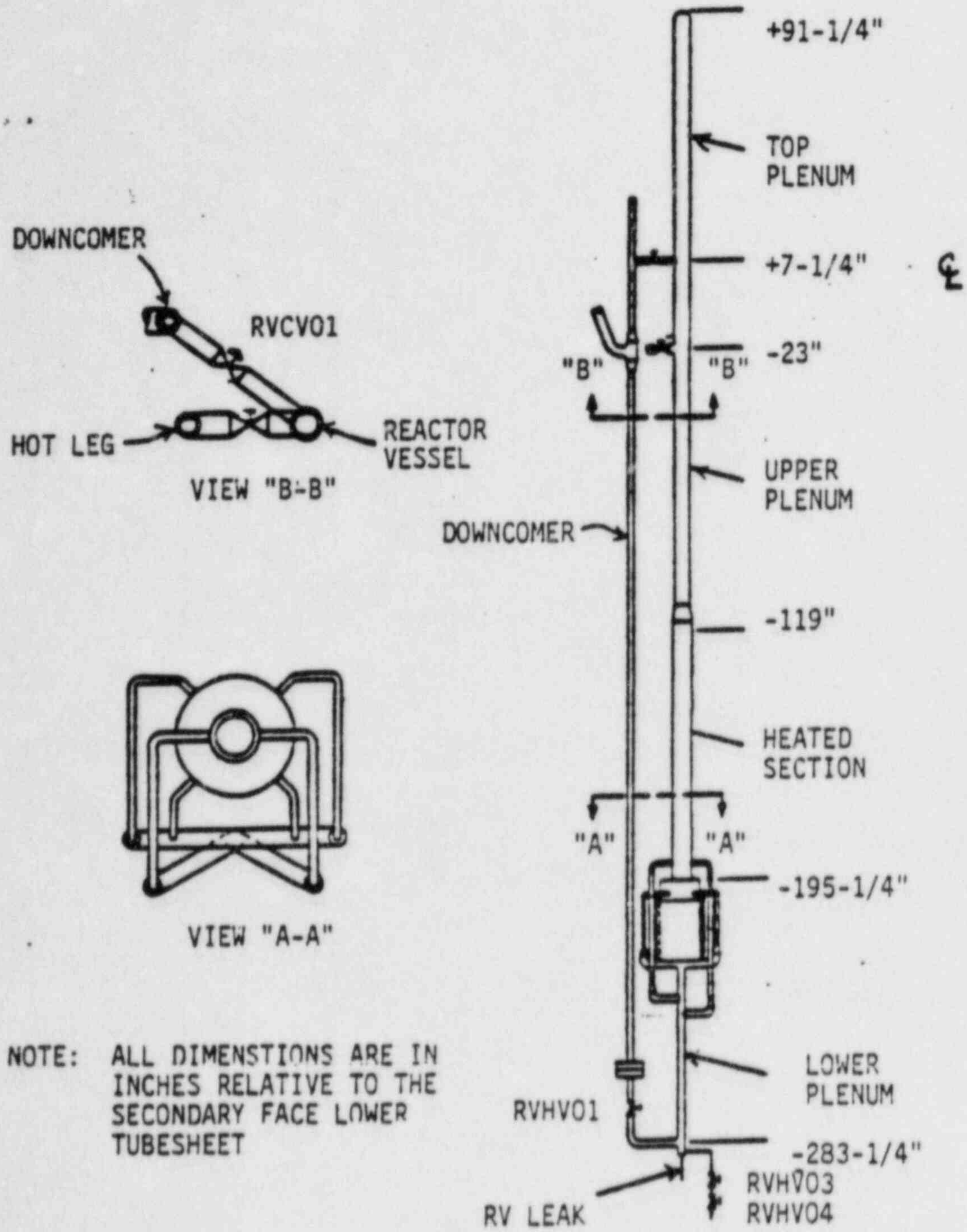

Figure 2-5. Reactor Vessel and Downcomer General Arrangement

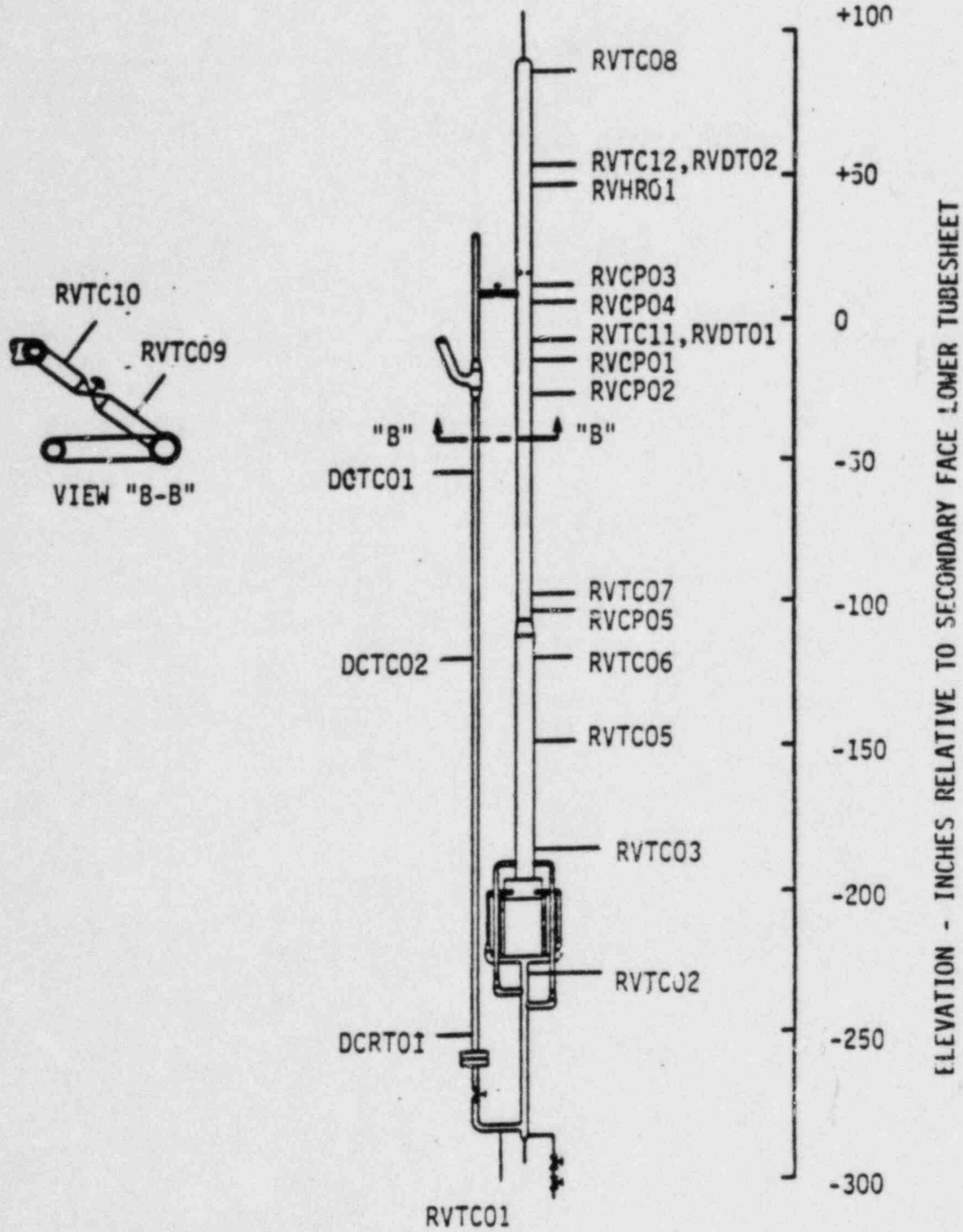

Figure 2-6. Reactor Vessel and Downcomer Instrumentation
- Thermocouples, RTDs, and Conductivity Probes.

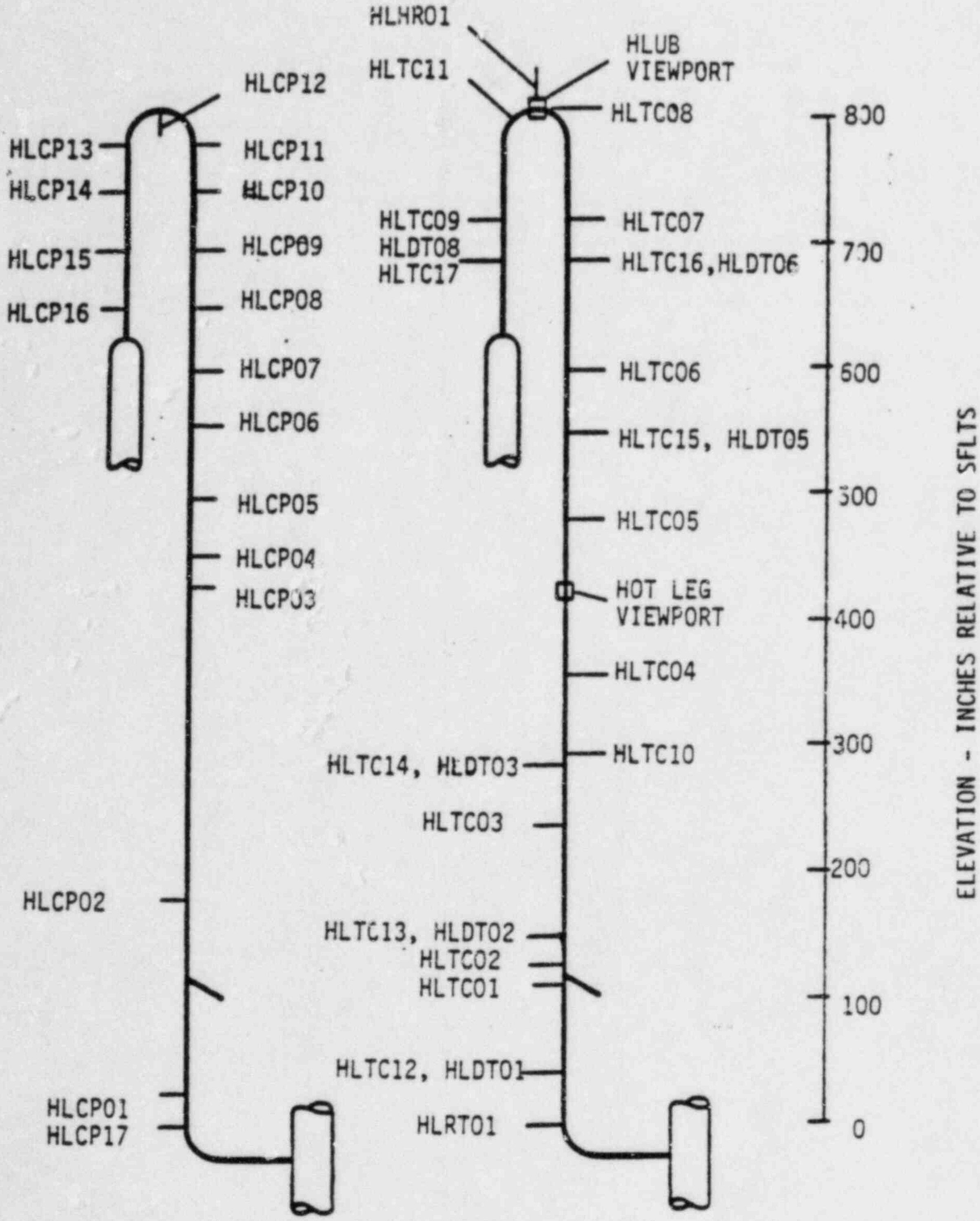

Figure 2-7. Hot Leg Instrumentation - Thermocouples, RTDs, Conductivity Probes and Viewports

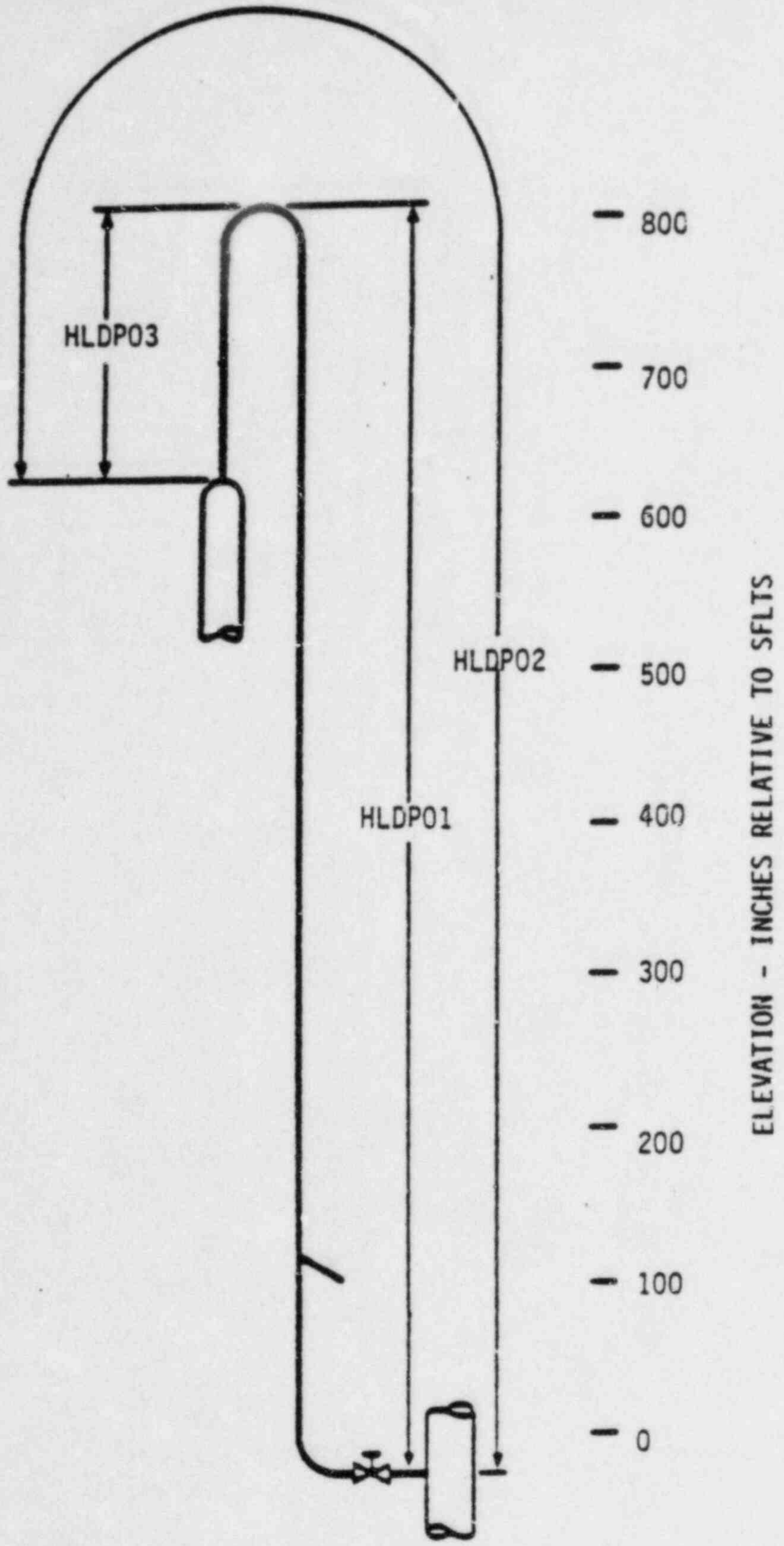

Figure 2-8. Hot Leg Instrumentation - Differential Pressure Measurements

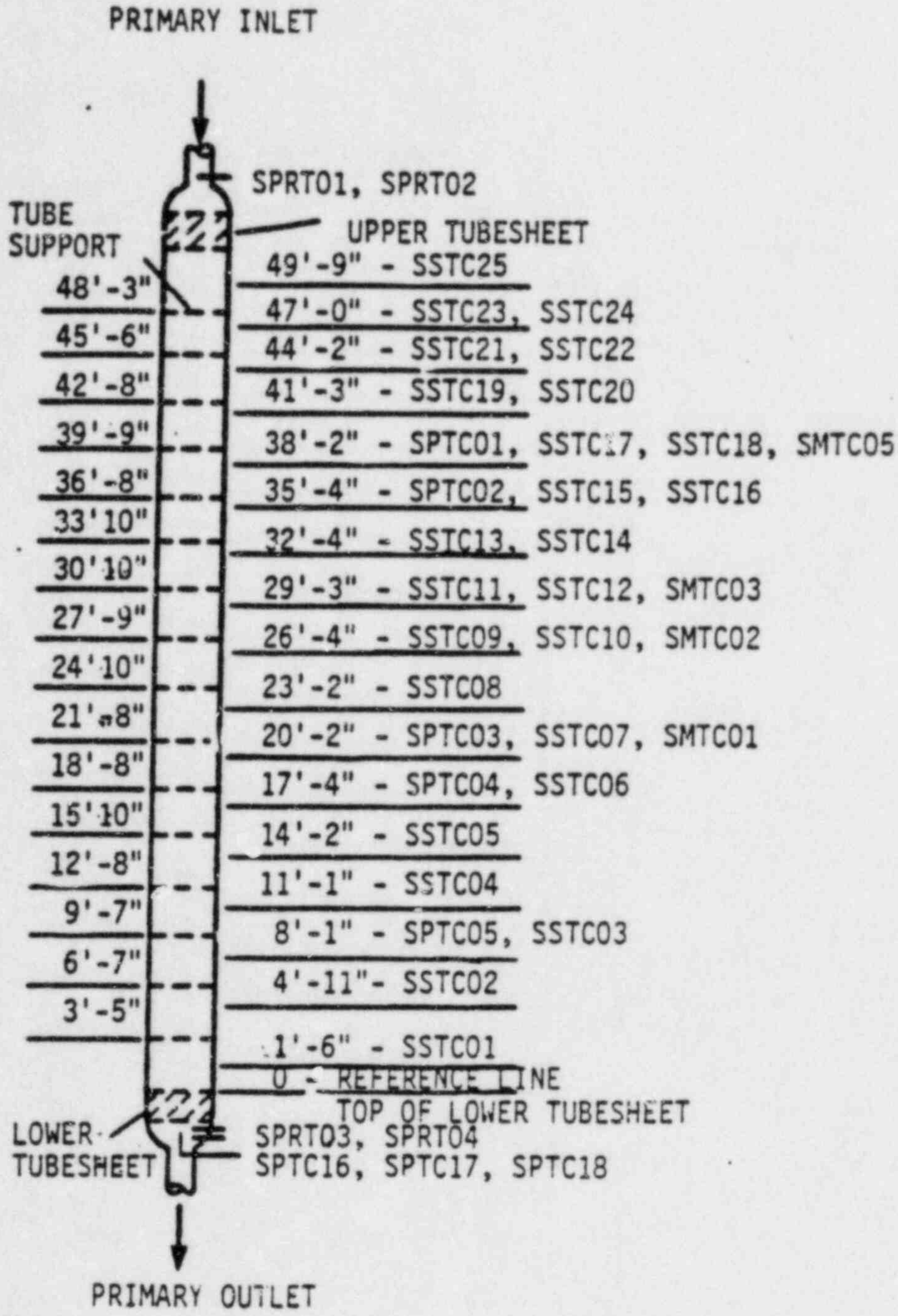

Figure 2-9. OTSG Temperature Measurements and Tube Support Plate Elevations

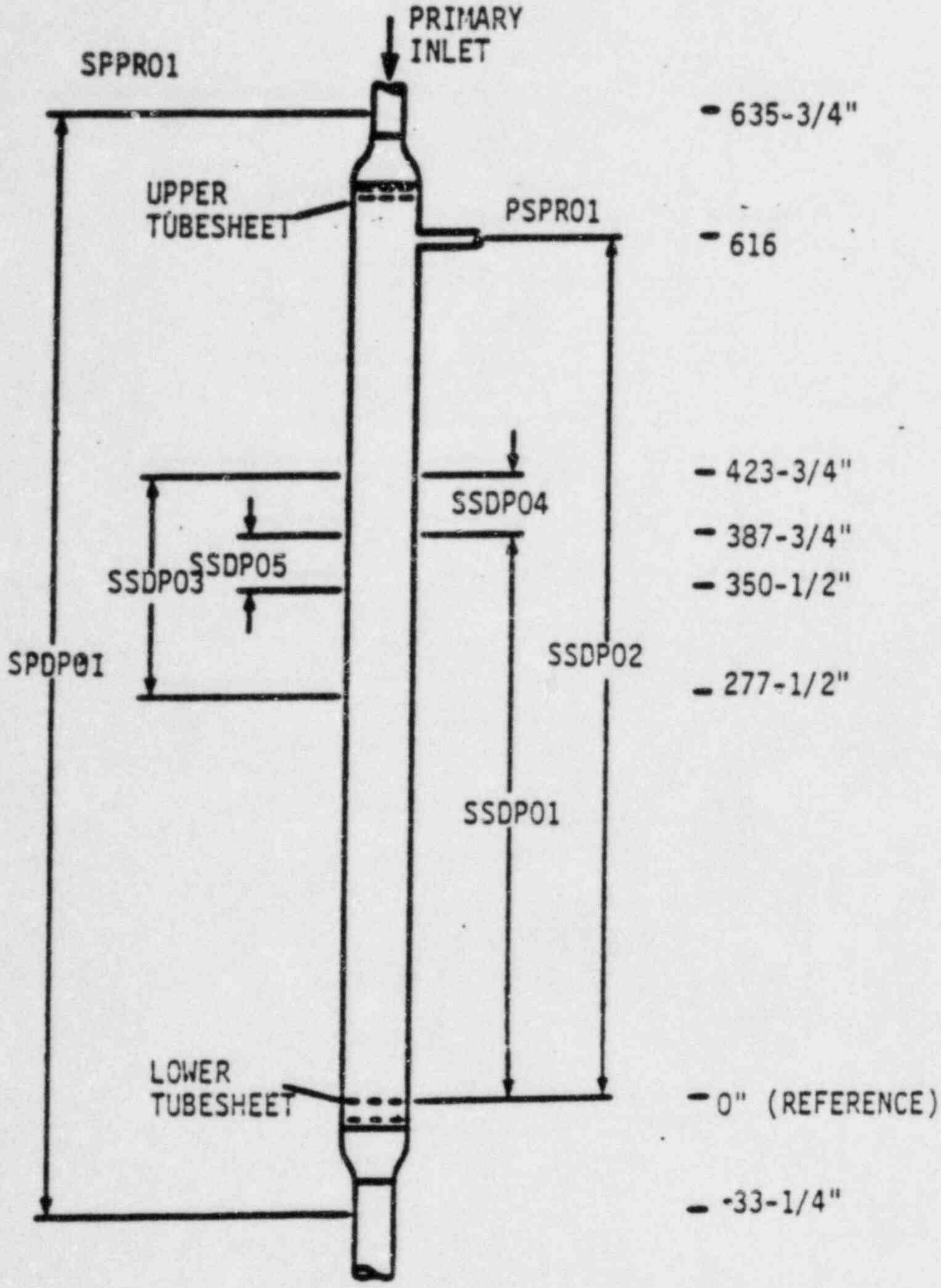

Figure 2-10. OTSG Pressure and Differential Pressure Measurements

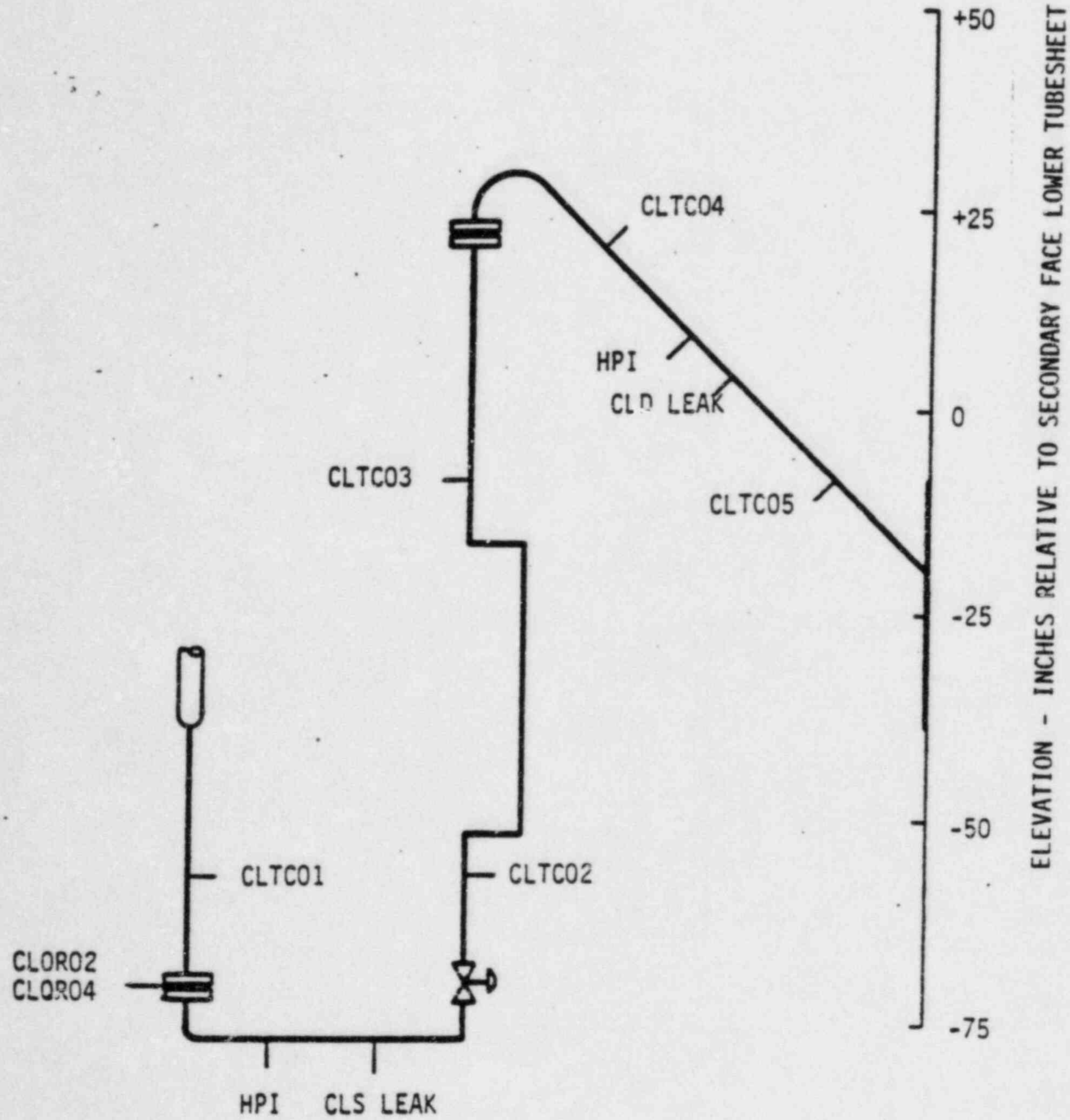

Figure 2-11. Cold Leg Piping - Temperature and Flow Measurements, Location of High Pressure Injection and Cold Leg Leaks

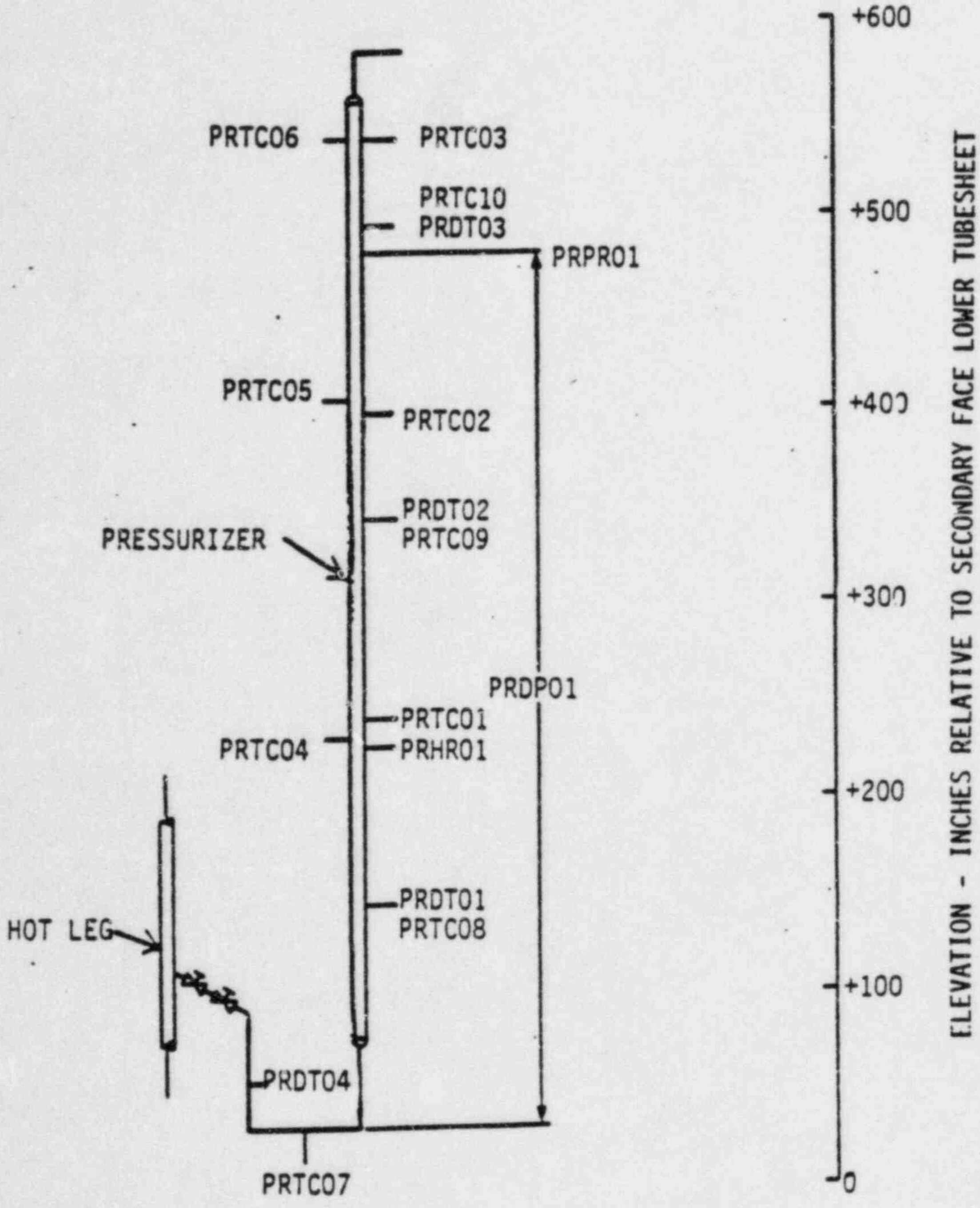

Figure 2-12. Pressurizer Instrumentation

3.0 TEST DESCRIPTION

Test background and performance are addressed in Sections 3.1 and 3.2. Test observations are then given according to test phase, in subsections 3.3.1 through 3.3.6. These phases are outlined in Table 3-1, and are shown on the several figures.

3.1. Background

The background of Test 240200 resembles that of the preceding gas test, 240100, cf. B&W Doc. NO. 12-1152307-00. Both tests have an ncg-laden primary system; Test 240200, unlike 240100, explores the effects of HPI-PORV cooling.

3.2. Performance

The initialization of Test 240200 parallels that of Test 240100, cf. B&W Doc. No. 12-1152307-00. The sequence of gas additions is given in Table 3-2; a total of 34.7 scf of nitrogen was injected into the loop over a 3 hour initialization period. The loop burden of ncg before testing has been estimated to be 0.13 scf; the amount added with HPI during testing has been estimated at 0.60 scf (from 230 to 570 minutes after Data Acquisition System Activation, or from 38 to 378 minutes after test initiation). Thus the maximum amount of ncg during testing is approximately 35.4 scf. The ncg vented from the loop during testing has also been metered. Comparing the total additions to the total collected, the amount remaining after testing is estimated to be 1.6 scf. The addition and collection measurements are thereby compatible, and the loop appears to be virtually leak free.

At test initiation, 192 minutes after DAS activation, the loop contains 35 scf of nitrogen which is the equivalent of more than 3 loop volumes. Primary flow is stalled, primary-to-secondary heat transfer is being interrupted, and the primary is pressurizing. The operator initiates loop cooldown by opening the HL High Point Vent (HPV) and raising SG secondary level. HPI-PORV cooling is introduced at 230 minutes, 38 minutes after test initiation, and continued for almost 4 hours. Then the HL HPV is reopened, accelerating the gas venting rate; next the SG secondary level is raised at 561 minutes (6 hours after test initiation). The primary cooldown is essentially completed after 8 hours of testing, as post-cooldown testing is continued for the final 2 hours conditions become progressively more stable. Operator comments are summarized in Table 3-3. The apparent subcooling margin is shown in Figures 3-2a through c.

Measurements unavailable are summarized in Table 3-4. None of these measurements were essential for the examination of loop events and interactions during the test. Noncondensible gas additions have been listed in Table 3-2. Figure 3-3 presents loop burden of noncondensible throughout testing. This gas volume trend is obtained by subtracting the amounts collected from the initial inventory (plus HPI additions); the agreement between the amount added and that collected substantiates these measurements and attests to loop leak tightness.

3.3. Observations

Test observations are conveniently grouped according to phases of test conduct and interactions. These six phases are identified in Table 3-1 and the several figures, and are addressed chronologically in the following paragraphs.

3.3.1. Initialization (0 to 192 minutes)

The DAS (Data Acquisition system) is activated at 1544 on 1 May 84. Initial conditions are: Primary full and in subcooled natural circulation at 3% flow, core power at 1% of scaled full power (1% = 21.4 kW), primary pressure 1700 psia, and hot leg temperature 582F (~30F subcooled); secondary pressure is 1200 psia, SG level is 6', SG steam and AFW flow are negligible.

Initialization of the loop extends for more than 3 hours, until 192 minutes (referenced to the time of DAS (Data Acquisition System) activation, which is the datum for the time-based plots). Initialization consists mainly of 19 injections of noncondensible gas, viz. nitrogen. The volume of all but the last injection is on the order of 1 to 2 scf (standard cubic feet, the gas volume equivalent to that measured at standard temperature and atmospheric pressure). The final addition, ~7 scf, voids the HLUB (HL U-Bend) region and precipitates test initiation. The cumulative loop gas burden, the sum of these incremental injections plus 0.13 scf pre-test burden, is 34.8 scf or more than 3 loop volumes. (The amount collected from the discharge streams during subsequent testing confirms this initial burden and attests to the gas closure of the model).

The individual gas additions (preceding the final gas injection to the HLUB) are performed similarly. Additions are made at the bottom of the RV. Usually the cold leg throttle valve is closed just before each addition (and reopened after addition), to interrupt loop flow and thus to suppress transport of the gas out the HL nozzle. Gas accumulation in the RV upper head is thereby promoted. With continuing additions the pressurizer level increases, and the RV top plenum begins to void after one hour of additions; the rate of Pr (pressurizer) level increase with additions is enhanced after the RV begins to void. Primary pressure also increases with each injection, it is permitted to subside between injections; the final primary pressure, just before the larger volume of ncg (noncondensible gas) is injected at the HLUB, is roughly 1750 psia.

The operator visually observes bubbles at the HL viewport (35' elevation) at approximately the same time that the RV begins to void. The loop burden of ncg at this time is 10 scf, roughly one loop volume. These bubbles are observed only briefly, but the incidence of their observation increases with continued injections.

At 187 minutes core power is increased from 1% of scaled full power (1% = 21.4 kw) in preparation for test initiation. Within a minute primary flow begins to increase from 2.85% of scaled full flow (Figure 3-4c, 1% = 0.259 lbm/s), the fluid temperature rise across the core begins to increase (Figure 3-4g) and primary pressure begins to increase (Figure 3-4a); core power stabilizes at 2% of scaled full power at 189.2 minutes.

At 190 minutes, the cold leg throttle valve is closed in preparation for the test-initiating gas addition to the HLUB. Primary flow rate decreases from 3.7% of scaled full flow (Figure 3-4c), Pitot tube indications of SG primary tube flowrate decrease concurrently. The core-region conditions respond rapidly to this flow interruption. At 190.2 minutes the RV upper and Top Plenum fluid temperatures increase approximately 25F (Figure 3-4g)*, the RVVV differential pressure increases toward the actuation setpoint, and the upper DC fluid temperature downstream of the valve increases.

At approximately 190.5 minutes the relatively large volume (~7 scf) of nitrogen is added to the HLUB, bringing the total loop burden of ncg to almost 35 scf. The RV collapsed liquid level increases ~2' from +1' (Figure 3-4b), the RV conductivity probe above the RVVV elevation wets, the HL level decreases ~2', and the HLUB fluid temperature plummets ~100F (Figure 3-4h) (in response to the injection of unheated gas).

As a result of the flow interruption, primary pressure begins to increase from 1770 psia (Figure 3-4a), Pr level begins to rise (Figure 3-4b), and the upper Pr fluid temperatures increase. At 190.8 min the level in the HL stub (the HL extension downward from the HLUB to the SG) decreases from full toward 65' and the conductivity probe at 65' indicates decreased wetting.

3.3.2. Initiation (192 to 230 minutes)

At 192 minutes, the cold leg throttle valve is reopened and the operator begins a cooldown (thereby initiating the test). The operator de-energizes the Pr main heaters, opens the HPV (Hot Leg High Point Vent), and actuates AFW to raise the SG secondary level. The operator also initiates step-reductions of SG secondary pressure (20 to 50 psi per step) beginning at approximately 194 minutes (Figure 3-4a).

System conditions at and just after test initiation at 192 minutes change rapidly. Primary flow reactivates (Figure 3-4c), AFW flowrate increases from zero to 4% of scaled full secondary flow (Figure 3-4d) (1% = 0.0265 lbm/s). The HPV limit switch indicates open, liquid discharged with the HPV effluent is immediately recorded. The HL stub conductivity probe at 65' indicates increased wetting.

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*The core outlet fluid temperature, which is closer to the apparent saturation temperature, begins to increase slightly after the higher-elevation RV fluid temperatures (Figure 3.4g).

At 192.2 minutes SG secondary pressure begins to decrease from 1220 psia due to AFW introduction, also the SG secondary fluid temperatures begin to cool toward secondary saturation temperature. The off-nozzle as well as the on-nozzle SG primary tube flowrates, again begin to register. In response to the reactivated loop flow and primary-to-secondary heat transfer, 3-4a), and the core outlet fluid temperature begins to decrease from 625F (which corresponds to primary saturation temperature, at total system pressure (Figure 3.4g).

The HPV actuation causes a minor redistribution of primary liquid. At 192.5 minutes the HL stub level (downstream of the HLUB) begins to increase from 65' and the RV liquid level decreases below the elevation of the RVVV (Figure 3-4b). The depressurization (due primarily to recoupling of the primary to the secondary) and the heatup of the core-region fluid (attributable to the preceding flow interruption) combine to cause a brief period of core-region voiding: The approximate core region void fraction peaks (Figure 3-4e), and all four RV conductivity probes (spanning the elevations from just below the HL nozzle at -1.9', to just above the RVVV at +0.6') briefly indicate decreased wetting. Also at 192.5 minutes, the SG secondary level begins to increase from 6' in response to AFW activation (Figure 3-4b).

By approximately 193 minutes the Pr level begins to decrease from 38' in response to the primary depressurization, and the HLUB-region void fraction is decreasing. The operator observes a spillover at the HLUB viewport monitor.

At 194 minutes the SG secondary level peaks at ~12' and the AFW flowrate diminishes (Figure 3-4d). Also at this time, the operator initiates the previously-mentioned stepwise reduction of secondary pressures; steam flow and feed flow respond accordingly; SG secondary heat transfer (based on steam and feed flows and enthalpies) increases toward 2 1/2% of scaled full power; primary flow peaks at ~6% of scaled full flow in response to this enhanced primary-to-secondary heat transfer (Figure 3-4c).

Secondary pressure is re-stabilized at 1070 psia by 194.5 minutes. The SG primary wetted-tube fluid temperatures spread as primary flow and primary-to-secondary heat transfer increase (Figure 3-4i). AFW-caused heat transfer also accentuates radial variations within the SG -- the Pitot indications of SG tube primary flow become increasingly divergent, and the AFW-wetted tube exit primary fluid becomes discernibly cooler than the fluid exiting the other tubes. The elevated cold thermal center within the SG, and its enhanced fluid density change, deplete the differential pressure across the RVVV; the temperature of the upper DC fluid (downstream of the RVVV) ceases to increase, indicating that the RVVV remains closed beyond 195 minutes.

The RV liquid level continues to decrease slowly. The RV conductivity probe just above the HL nozzle at -1.9' indicates decreased wetting at 195.8 min., and at 196.5 min. the RV level stabilizes near -1'. The RV top plenum void fraction stabilizes at 95% by 197 min.

At approximately 197.5 minutes the operator closes the HPV. This is confirmed by various indications: The HPV discharge ceases and the valve limit switch indicates closed. Repetitive 20 psi secondary depressurization steps are also begun at this time. The Pr main heaters are activated at 199 min. The primary pressure reduction is slowed near 1725 psia, and the HL (HLUB upstream) level indicates liquid full at 198 min (Figure 3.4b).

From 200 to 230 minutes the system is cooled using the SG and primary natural circulation. (Refer to Figures 3.4a through 3.4i for this time period). The HL Stub collapsed liquid level gradually decreases to 64'; and the Pr level decreases from 35' to 30'; as the primary liquid volume contracts. The RV remains voided above the elevation of the HL nozzle. The core outlet end HL fluid temperatures approximately parallel the apparent saturation temperature (610F) and remain roughly constant (at 585F). (This 25F difference between saturation temperature based on total pressure and the fluid temperature near the voided region beyond the HLUB is attributable to the partial pressure of the noncondensible gas). The lower-elevation primary fluid temperatures, on the other hand, follow the SG secondary saturation temperature; they decrease from 550F to 515F as the secondary pressure is reduced. Loop flow decreases as the temperature difference across the core (and SG) thus increase. The resulting primary system single-phase energy transfer rate is approximately constant and equal to core power.

3.3.3. HPI-PORV Cooling (230 to 467 minutes)

At 230 minutes the operator activates HPI-PORV Cooling: HPI flow is initiated and adjusted, and the PORV is manually opened (Figure 3-5f). With HPI actuation, the CL (Cold Leg) fluid downstream of the point of HPI introduction cools rapidly, decreasing by 200F in 4 minutes (Figure 3-5i). The total primary fluid mass begins to increase concurrently. But the PORV actuation precipitates primary flow interruption.

The PORV limit switch indicates open at 230.5 minutes, primary pressure begins to decrease from 1655 psia (Figure 3-5a), the Pr level begins to rise (Figure 3-5c), and the HL stub level (downstream of the HLUB) decreases from 63 1/2'. By 231 minutes the HL (upstream of the HLUB) begins to empty (to preserve the whole-loop manometric balance). Primary flow stalls (Figure 3-5d), secondary steam and feed flow begin to decrease, as does SG secondary energy transfer; subsequently the SG primary and secondary fluid temperatures begin to decrease toward secondary saturation temperature (Figure 3-5m). The DC (downcomer) fluid temperatures decrease abruptly (in response to HPI cooling, Figure 3-5n), this increased DC fluid density both increases the RVVV pressure differential to the actuation point and increases the core-region liquid level required for inner-loop (DC-core-RVVV) manometric balance. The RVVV actuates causing the upper-DC fluid temperature (beyond the valve) to increase from 515 to 585F by 237 minutes (Figure 3-5p). The upper DC begins to void and the RV liquid level begins to increase from -1/2' (reaching +1 1/2' by 233 minutes); the RV top plenum void fraction decreases from 86% (reaching 70% by 233 minutes). The cooled DC fluid reaches and cools the RV inlet fluid temperature from 515F at 231 minutes to 480F (which is less than the SG secondary saturation temperature) by 232 minutes (Figure 3-5k).

As primary loop flow decreases the effects of HPI cooling begin to be observed at the upstream CL fluid temperature (CLTC04), by 231.5 minutes, cf. Figure 3-5i. Also at this time, the SG primary wetted-tube flow, because of the attenuation of AFW flowrate, abruptly diminishes. At 231.6 min. the HL stub conductivity probe at 61' indicates decreased wetting; by

232 minutes the conductivity probe at the HLUB also indicates less wetting. At 232.7 min., liquid is recorded in the PORV discharge. The RV conductivity probes bracketing the RVVV elevation, reflecting the increasing RV liquid level, indicate wetting at 233.3 min.

The core exit and outlet plenum fluid temperatures have been roughly 25F below apparent primary saturation temperature based on total pressure since test initiation (Figure 3-5k); this saturation temperature difference indicates the presence of noncondensible gas. At 233.6 minutes the core exit fluid temperature abruptly increases toward the saturation temperature, followed by the outlet plenum fluid temperature. This increase may be attributable to the preceding decreased core flowrate, to the transport of noncondensible gas out the RVVV, and to the compression of the RV-region noncondensible gas into the upper elevations as the RV liquid level increases (leaving relatively noncondensible gas-free vapor at the lower RV elevations).

The decreased heat transfer highlights the effects of metal heat, beginning at ~230 minutes. All the SG primary fluid temperatures are subcooled and cooling, but the lowest-elevation fluid (in the CL suction piping beyond the SG) is slightly hotter (Figure 3-5m); this apparently relates to heat transfer from the SG lower tubesheet metal and from the CLS orifice flanges, to the stagnant primary fluid -- by 480 min the lower fluid temperatures are 50F higher than those in the SG.

At 235 minutes the Pr fills (Figure 3-5c). Primary pressure stabilizes at 1515 psia, the PORV discharge rate stabilizes at a value indicative of liquid discharge (Figure 3-5f) and the heat dissipation rate of the PORV discharge of heated HPI approximately equals core power (2% of scaled full power, cf. Figure 3-5g "EFFLUENT"). The RVVV differential pressure reaches 0.35 psi, then oscillates; valve opening is evidenced by heating of the fluid downstream of the valve (RVTC10, cf. Figure 3-5p).

The HPI-cooling of the core inlet fluid (which began at 230 minutes) finally subcools the core-region fluid at 245 minutes as inner-loop flow (DC-RV-RVVV) becomes active (Figures 3-5d and k). The lower-elevation HL fluid also begins to subcool beyond this time (Figure 3-5l). HPI-PORV cooling is increasingly apparent by 255 minutes. The Pr fluid temperatures subcool sequentially with increasing elevation; the highest-elevation HL conductivity probes indicate increased voiding, the RV conductivity probes indicate liquid. The Hot Leg fluid temperatures segregate by their relation to the surgeline -- those below the elevation of the surgeline connection cool sequentially with increasing elevation (reflecting HPI flow up the HL and into the surgeline), those above generally remain near saturation (Figure 3-5l).

At 257 minutes the operator initiates a series of HPI flowrate adjustments (Figure 3-5f). These adjustments are performed occasionally over the next 5 hours. The HPI flowrate is initially reduced from approximately 0.08 lbm/s (from time 230 min.) to 0.05 lbm/s (at time 260 min.), then it is returned to 0.08 lbm/s from 270 to 280 minutes. During this time the PORV discharge rate is comparable to the HPI flowrate; the magnitude of the PORV flowrate indicates liquid rather than vapor. But the PORV discharge rate decreases with the HPI flowrate reduction between 260 and 270 minutes (from roughly 0.08 lbm/s to 0.06 lbm/s). The pressurizer (fluid and metal) temperatures do not indicate steam production within the Pr. The concurrent primary pressure decrease does not support the appparent decrease of critical flow of liquid. Therefore the observed reduction of PORV (liquid plus water vapor) flowrate implies the increased presence of noncondensible gas within the PORV discharge stream. (Subsequent HPI reductions, such as from 370 to 405 minutes, are not accompanied by similar PORV discharge rate reductions).

This HPI flowrate reduction from 260 to 270 minutes causes a corresponding heatup of the downcomer and RV fluid (Figures 3-5k and n); the lower DC and RV inlet fluid temperatures peak at 505F at ~270 minutes, the core outlet, outlet plenum, and RVVV-downstream fluid temperatures reach ~550F by 275 minutes. At approximately the same time the RVVV differential pressure stabilizes at 0.2 psi, the valve remains open rather than cycling, and the valve-bracketing fluid temperatures equalize beyond 260 minutes; the DC flowrate begins to stabilize at ~2-1/2% of full scaled flowrate beyond 275 minutes (loop flow remains approximately stagnant).

HPI-PORV cooling continues until 467 minutes (275 minutes after test initiation). The cooler primary loop fluid temperature roughly parallels SG secondary saturation temperature, the warmer primary loop fluid maintains saturation temperature at primary pressure (Figure 3-5b). These warmer loop temperatures include the HL fluid above the Pr surgeline, and the HL stub fluid beyond the HLUB. The relatively slow cooling of this upper-elevation primary fluid governs the rate of the primary system depressurization. The HPI cooldown of the DC, RV (to mid-height), lower HL, and Pr fluid slightly exceeds the rate of primary saturation temperature decrease, therefore the subcooling margin gradually increases (Figures 3-2a-c). At ~370 minutes (178 minutes after test initiation) the apparent subcooling margin has increased to 85F. The operator throttles HPI flowrate from 0.1 lbm/sec to 0.085 lbm/sec (Figure 3-5f). The cooldown of the lower-elevation primary fluid is quickly interrupted (Figures 3-5k and n). The HL fluid just above the surgeline connection rapidly reheats from the temperature corresponding to the core outlet fluid temperature (485F) toward primary saturation temperature (560F) (Figure 3-5l), as the HL level decreases bringing warmer fluid to lower elevations.

The HL levels upstream and downstream of the HLUB had been relatively constant at 58' and 51' (Figure 3-5c). Upon the HPI flowrate reduction at 370 min., the PORV discharge flowrate exceeds the rate of HPI by 0.01 lbm/sec (Figure 3-5f) and the HL and SGP levels begin to decrease. The SGP level drops well below the elevation of AFW injection; but the SG secondary level is at or near its control point, no AFW flowrate is discernible, and no BCM (condensation of primary steam within the SG) is observed. But primary pressure decreases relatively rapidly during this time period (Figure 3-5a), due to the juxtapostion of primary vapor and the relatively cold SG tube metal, and to the imbalance of PORV and HPI flowrates.

It has previously been noted that the SG outlet fluid temperatures, being heated by SG lower tube sheet and CL flange metal stored heat, were becoming progressively warmer than the (lower-elevation) SG primary and secondary fluid. Now the primary fluid movement within the SG (accompanying the primary level reduction with HPI throttling) brings slightly colder fluid down to the SG exit, causing these exit temperature indications to decrease more rapidly beyond 370 minutes than before that time (Figure 3-5m).

As the primary level within the SG decreases, the SG wetted-tube primary fluid temperatures increase rapidly, and sequentially with decreasing elevation, from just above secondary saturation temperature (~425F) to primary saturation temperature (~550F) (Figure 3-5e); the timing of these temperature changes approximately matches the level-versus-time transient of the SG primary fluid (Figure 3-5c). The reduced HPI flowrate also slightly decreases the HPI-PORV heat removal rate; the net primary system energy transfer rate (predominated by core power, PORV-HPI heat transfer, and to a lesser degree, system losses to ambient) becomes almost zero (Figures 3-5g and h).

It is of interest to examine the trends of CL and DC liquid volume at this time (Figure 3-5j). Before the HPI flowrate reduction at 370 minutes, the CL liquid volume was gradually decreasing, while that of the DC was increasing at a similar rate. (The upper DC has remained voided since 231 minutes). The apparent subcooling of the CL fluid near the voiding region (CLTC03) gives evidence that this CL void contains noncondensible gas. After the HPI flowrate reduction at 370 minutes, the primary fluid slowly draining from the SGP apparently displaces this CL void into the downcomer -- the CL level increases to full and the indicated DC level decreases.

The indicated CL fluid temperature profile at approximately 400 minutes is noteworthy (Figure 3-5i): All (5) CL temperature indicators are 100F or more below primary saturation temperature based on (total) primary pressure (i.e., not reduced for the pressure contribution due to noncondensibles). The highest CL temperature occurs at the SG exit, still reflecting the transfer of stored heat from the relatively large amount of metal in that region, to the quasi-stagnant CL fluid. The two fluid thermocouples in the vertical CLS piping (CLTC02 and 3) indicate approximately 80F less than CLTC01 (SG exit), and 200F below saturation. The CLD (CL Discharge) exit fluid thermocouple (CLTC05) apparently reflects HPI cooling, indicating 250F. But CLTC04 (high in the CLD piping just beyond the pump-site spillover) indicates 425F, significantly higher than its bracketing thermocouples. This situation may be attributable to the transfer of metal stored heat, or to stratified counterflow within the CL.

The HPI flowrate is adjusted upward at 406 minutes and several times thereafter (Figure 3-5f). The HL levels upstream and downstream of the HLUB begin to increase (Figure 3-5c). The lower-elevation primary fluid immediately resumes cooling. As the excess of HPI greater than the PORV discharge rate causes loop refill, the HPI backflowing in the CL rapidly cools the temperature indication just upstream of the HPI point (CLTC04), from 430F at 400 min. to 110F by 450 min. (Figure 3-5i) (because this backflowing HPI fluid is further removed from RVVV-effluent heating than the CLD exit fluid, the CL fluid temperature upstream of the HPI point becomes more than 100F colder than that downstream of the HPI point). The increased HPI flow and accompanying refill is also noticeable in the HL: The hot leg fluid just above the elevation of the surgeline connection rapidly cools from saturation to the core outlet temperature (550F at 410 minutes, to 490F by 420 minutes, Figure 3-5l).

With refill the wetted tube primary fluid temperatures at the upper elevations of the SGP, from 49' to 51', subcool sequentially with increasing elevation from 407 minutes to 420 minutes (Figure 3-5e). But the SGP collapsed liquid level has increased only to 46' by 420 minutes (Figure 3-5c).

This difference between subcooling elevation and collapsed liquid level suggests that a several-foot column of noncondensible gas overlays the SGP liquid-vapor interface.

PORV-HPI cooling is continued until 467 minutes, 275 minutes from test initiation. The lower-elevation primary fluid continues to cool following the HPI increase at 406 minutes (Figure 3-5b). By 467 minutes the DC fluid temperatures (below the CL nozzle) and the lower RV fluid temperatures are at 415F. The core outlet, lower HL, and Pr fluid temperatures are at 470 to 480F. Primary saturation temperature (based on total primary pressure) is 550F, thus the apparent subcooling of the core outlet fluid is 75F. The upper loop elevations are voided, the HLUB-region fluid is slightly superheated. The uppermost RV fluid temperature (in the top plenum) is near saturation, but it has been unresponsive to the preceding saturation temperature variations. Primary pressure is increasing gradually, and has been since the slight adjustment (increase) of HPI flowrate at 435 minutes. Primary system total fluid energy is roughly constant (Figure 3-5g), system specific fluid energy is decreasing with refill. The energy dissipated by HPI-PORV cooling is diminishing as the PORV discharge stream progressively cools (following the lower-elevation primary fluid cooling), and to a lesser extent, as the PORV discharge rate decreased with the earlier system depressurization. The primary system is 85% liquid full by 467 minutes

(Figure 3-5j). The Pr remains completely full; the upper RV, HL, and SGP are voided as is the upper CL Suction piping.

3.3.4. HPI-PORV Cooling With High Point Venting (467 to 561 Minutes)

At 467 minutes, 275 minutes after test initiation, the operator opens the HL HPV (High Point Vent). The rate of venting noncondensible gas from the loop increases. Approximately 8 SCF are removed during the next 100 minutes, which halves the current loop burden, cf. Figure 3-3). Primary system pressure decreases rapidly (from 1060 psia at 467 minutes to 1010 psia at 470 minutes, Figure 3-6a); the subsequent rate of depressurization is more gradual (obtaining 900 psia by 508 minutes). This decreased rate of depressurization is caused by HPI flowrate adjustments (Figures 3-6e).

The HL (upstream) collapsed liquid level spike of more than 10 feet (Figure 3-6b), coincident with HPV actuation at 467 min., is apparently spurious and attributable to local pressure perturbations in the vicinty of the pressure top as sensed by the differential pressure transmitter. There is no apparent source for the fluid mass corresponding to this level change.

HPI flowrate is adjusted upward to 0.105 lbm/s by time 472 minutes, well in excess of the PORV plus HPV (vapor) combined discharge of 0.09 lbm/s (Figure 3-6e). The HL and SGP levels increase accordingly. The backflow of HPI within the cold leg was previously indicated by the reduction of the fluid temperature just upstream of the HPI point (CLTC04), to $\sim$100F; now the indicators further upstream begin to cool, finally reaching the SG outlet primary fluid temperature (CLTC01) beyond 470 minutes (Figure 3-6g).

The operator increases the SG secondary steam pressure control point to 350 psia at 506 minutes. The HL level upstream of the HLUB indicates full at time 507 minutes, the HL stub level downstream of the HLUB follows at 532 minutes (Figure 3-6b). A brief primary repressurization begins at 507 minutes. This 50 psi repressurization may be attributable to the complete decoupling of primary-to-secondary heat transfer and to quenching of the HL piping beyond the U-bend.

The HL fluid temperatures upstream of the bend converge upon refill, then decrease toward the temperatures of the lower HL fluid sequentially with increasing elevation (Figure 3-6j). Beginning at the time the HL upstream of the bend refills, the temperatures downstream of the HLUB increase toward saturation, sequentially with decreasing elevation, signaling the arrival of the hotter fluid which had resided upstream (Figure 3-6k). (The time intervals between temperature increases at adjacent indicators yields an apparent fluid transport rate of only 2 to 3 ft/min.) The CL fluid temperatures similarly begin to indicate slight forward flow at 575 minutes, by beginning to converge toward the SG outlet temperature (Figure 3-6g).

At 518 minutes the HPI flowrate is throttled toward the PORV discharge flowrate, ~0.08 lbm/s, then returned to 0.105 lbm/s at 522 minutes (Figure 3-6e); the core-region fluid temperatures change correspondingly. The RVVV differential pressure becomes less constant beyond this time, but the valve-bracketing fluid temperatures remain coupled (Figure 3-6m). At approximately 525 minutes the SG secondary fluid temperatures increase (responding to the warmer primary-side fluid, Figure 3-6n) and secondary pressure increases slightly, both indicating incipient primary-to-secondary heat transfer.

The operator reduces the secondary pressure control point to 130 psig at 542 minutes. The operator also terminates HPI flow and closes the PORV at 542 minutes, then restores both within 3 minutes (Figure 3-6e). The system responds by depressurizing at a somewhat enhanced rate with HPI off, then repressurizing after HPI is restarted. Downcomer flow is interrupted during the interim (Figure 3-6c), a brief period of positive loop (CL) flowrate is recorded. At approximately this same time the HPV flowrate briefly increases toward a magnitude indicative of liquid versus vapor flow, confirming HLUB refill (Figure 3-6e). At 546 minutes the operator increases the SG secondary control pressure to 300 psia (SG pressure is currently 160 psia).

3.3.5. Elevated SG Secondary Level (561 to 680 Minutes)

At 560 minutes the operator again closes the PORV and stops the HPI flowrate (Figure 3-6e). Primary pressure decreases from 815 psia (Figure 3-6a), the RV collapsed liquid level decreases from +1.5'. At 561 minutes the operator increases the SG secondary liquid level from 11' to 14' (cf. Figure 3-6b) and reduces the secondary control pressure to 120 psig. The loop response is immediate and pervasive.

SG secondary pressure increases in response to primary-to-secondary heat transfer, primary pressure decreases rapidly from 810 psia (to 570 psia by 567 minutes, Figure 3-6a). The RV and DC levels decrease, reaching 0' by 568 minutes. The loop fluid temperatures begin to converge (reflecting loop flow). The cold leg and downcomer flowrates converge at 1% of full flow (then increase in an oscillatory fashion to 3% flow, Figure 3-6c). The AFW flowrate initially increases to more than 10% of scaled full secondary flow (1% = 0.0265 lbm/s), then subsides to $\sim$2% flow; SG steam flow also activates (Figure 3-6d).

The SG primary fluid temperatures quickly realign downward, from temperatures as high as primary saturation temperature to a profile indicative of flow (with temperatures as low as secondary saturation temperatures). The RVVV-bracketing temperatures diverge (Figure 3-6m), the RVVV indicates closed. The HPI and PORV flowrates are zero after 570 min., the HPV flowrate has increased to 0.015 lbm/s indicative of a liquid phase at the vent (at 550 min., Figure 3-6e); net system fluid mass rate of change (responding only to HPV flow) is negative (Figure 3-6f).

The Pr begins to void at 570 minutes, (cf. Figures 3-6b and f).

The primary system energy balance, which had long been dominated by HPI-PORV cooling (offsetting core power less losses to ambient), now becomes responsive to primary-to-secondary heat transfer (Figure 3-6d).

The oscillatory primary flowrate preceding stable natural circulation is particularly highlighted by the HL fluid temperatures (Figrue 3-6j). As flow diminishes, the core outlet and lower hot leg fluid temperatures increase with core heating, tending to increase natural circulation flows; increasing flow soon draws cooler fluid into the bottom of the hot leg and transports the warmer fluid toward the upper elevations, obtaining an elevated HL thermal center and retarding flow. These temperature perturbations and their accompanying flow variations are largely damped by 600 minutes, fluid temperatures decrease generally throughout this period as primary-to-secondary heat transfer continues. Also during this period of developing natural circulation, the SG primary per-tube flowrates regain their inter-tube differences characteristic of enhanced heat transfer within the tube most wetted by AFW (cf. appended plot 133); the tube-exit primary fluid temperatures also become slightly unequal. The Pr fluid temperatures superheat as the Pr level and primary pressure decrease.

HPI is activated briefly at 567 minutes obtaining a 90 psi primary repressurization. The PORV is opened from 585 to 588 minutes, from 596 to 604 minutes, from 613 to 626 minutes, and again from 654 to 659. Each actuation decreases primary pressure but the Pr level is not observed to increase. HPI is activated periodically to adjust Pr level, cf. Figures 3-6a, b and e and operator's comments (Table 3.3).

The oprator reduces the secondary control pressure by 30 psi at 573 minutes; the controller is placed in the cooldown depressurization mode, at 100 F/hr, at 581 minutes.

Beyond approximately 600 minutes the primary loop fluid is cooling regularly and tracking secondary saturation temperature, cf. Figures 3.6 (g-n). By 680 minutes the primary cooldown has largely been completed. Primary cold and hot liquid temperatures are 260F and 300F, with a primary saturation temperature of 380F. Secondary pressure is 30 psia, 250F saturation temperature.

3.3.5. Post-Cooldown Stabilization (Beyond 680 Minutes)

Testing is continued until 824 minutes (10-1/2 hours from test initiation) with little change during the final two hours. The primary remains coupled to the secondary in subcooled natural circulation (3% flow), the HPV is kept open and discharges liquid, and the PORV and HPI are actuated from time to time to adjust primary pressure and pressurizer level. At test termination the loop is full, the reactor vessel level is near the elevation of the HL nozzle, and the Pr level is 20'. Primary and secondary pressures are 200 and 30 psia, their saturation temperatures are ~380 and 250F. The SG secondary fluid is at the secondary saturation temperature, the primary cold leg fluid is 5F above secondary saturation, and the hot leg fluid temperatures (300F) are 80F subcooled.

The upper RV fluid temperatures remain superheated; their unresponsiveness to primary saturation temperature changes indicates that this upper RV volume may yet contain noncondensible gas. The residual loop burden of ncg is estimated to be 1-1/2 scf (a few percent of the burden at test initiation, based on a comparison of the amount injected and that collected over the testing period). Testing is completed at 0528 on 2 May, 13.7 hours after initialization and 10.5 hours after test initiation.

Table 3-1. Testing Phases

Times of major testing phases according to types of loop interactions and/or methods of loop control. The DAS (Data Acquisition System) was activated at 1544 on 1 May 84; times tabulated indicate the end of the corresponding test phase.

End Times

Clock Time	DAS Time (Min)	Time After Test Initiation (min)	Phase	
1856	192	0	I.	Initialization.
1934	230	38	II.	Initiation (and initiation transient with high point venting).
2331	467	275	III.	HPI-PORV Cooling.
0105	561	369	IV.	HPI-PORV Cooling With High Point Venting.
0304	680	488	V.	Elevated SG Secondary Level.
0528	824	632	VI.	Post-Cooldown Stabilization.

Table 3-2. Gas Addition Sequence

The estimated pre-test loop burden of noncondensible gas is 0.13 scf. The estimated ncg addition with HPI is 0.60 scf; this addition occurs after test initiation, from 230 to 570 min. DAS time (DAS - Data Acquisition System).

Number	Clock Time	DAS Time (min)	Addition (scf)	Cumulative Additions (scf)
1	1601	17	2.18	2.18
2	1608	24	1.31	3.49
3	1615	31	1.71	5.20
4	1622	38	1.94	7.14
5	1628	44	1.76	8.90
6	1636	52	1.59	10.5
7	1644	60	1.94	12.4
8	1652	68	1.87	14.3
9	1700	76	1.44	15.7
10	1707	83	1.40	17.1
11	1717	93	1.44	18.6
12	1724	100	1.39	20.0
13	1732	108	1.32	21.3
14	1739	115	1.26	22.6
15	1749	125	1.43	24.0
16	1801	137	1.66	25.6
17	1812	148	1.42	27.1
18	1837	173	0.58	27.6
19	1854:30	190.5	7.09	34.7

Table 3-3. Operator Comments

TIME	COMMENT
15:44	START DATA SAVE FOR TEST # 240200
15:47	RVVV TO MANUAL CLOSE
16:01	GAS ADDITION 1 (2.7 SCF)
16:08	GAS ADDITION 2 (1.92 SCF)
16:14	CLCV01 CLOSED
16:15	GAS ADDITION.3 (2.17 SCF)
16:17	CLCV01 OPEN
16:21	CLCV01 CLOSED
16:21:40	GAS ADDITION 4 (2.44 SCF)
16:23	CLCV01 OPEN , FLOW STARTED
16:27:35	CLCV01 CLOSED
	GAS ADDITION 5 (2.45 SCF)
16:29	CLCV01 OPENED
16:35	CLCV01 CLOSED
16:35:50	GAS ADDITION 6 (2.46 SCF)
16:37	CLCV01 OPEN , FLOW STARTED
16:43	CLCV01 CLOSED
16:44:20	GAS ADDITION 7 (2.67 SCF)
16:45	CLCV01 OPENING , FLOW STARTEL
16:50	CLCV01 CLOSED
16:51:30	GAS ADDITION 8 (2.40 SCF)
16:56	OPENED CLCV01
16:58	CLOSING CLCV01
17:00	GAS ADDITION 9 (..96 SCF)
17:01	CLCV01 OPENED
17:06	CLOSING CLCV01
17:06:45	GAS ADDITION 10 (1.98 SCF)
17:07	OPENED CLCVC1 , FLOW STARTED
17:16	CLCV01 CLOSED
17:17:10	GAS ADDITION 11 (2.07 SCF)
17:19	OPEN CLCV01
17:24	CLCV01 CLOSED
17:24:15	GAS ADDITION 12 (2.03 SCF)
17:26	CLCV01 OPENED
17:32	CLCV01 CLOSED AGAIN
17:32:50	GAS ADDITION 13 (2.06 SCF)
17:34	OPEN CLCV01
17:38	CLOSING CLCV01
17:39:00	GAS ADDITION 14 (1.74 SCF)
17:40	OPENING CLCV01
17:42	CLOSING CLCV01
17:49:15	GAS ADDITION 15 (2.06 SCF)
17:50	CLCV01 OPENED
17:59	SOUTH ACCUMULATING TANK FILL VALVE OPENED
18:00	CLCV01 CLOSED
18:01:20	GAS ADDITION 16 (2.42 SCF)
18:03	OPENING CLCV01
18:10	CLCV01 OPEN 100 %
18:12:20	GAS ADDITION 17 (2.01 SCF)
18:36	CLOSING CLCV01
18:37:05	GAS ADDITION 18 (1.08 SCF)
18:38	OPENING CLCV01
18:48	RVVV TO AUTO POSITION
18:51:30	INCREASING CORE POWER TO 42.6 KW
18:53	DCDP01 OUT OF SERVICE
18:54	CLCV01 CLOSED , FLOW STALLED

Table 3-3. (Cont'd)

18:54:30	GAS ADDITION 19 AT HLUB (ABOUT 9.7 SCF)
18:56	CLCV01 OPEN
	PRESSURIZER MAIN HTRS OFF
	· HPV OPEN
	AUX FEEDWATER ON
18:57	SPILLOVER AT HLUB
18:58	LOWERED SEC STEAM PRESSURE 50 PSI
19:00	CLDP02 OUT OF SERVICE
19:01:39	· HPV CLOSED
	LOWERED SEC STEAM PRESSURE 20 PSI
19:02	LOWERED SEC STEAM PRESSURE 20 PSI
19:03	PRESSURIZER MAIN HTS ON
19:06	LOWERED SEC STEAM PRESSURE 20 PSI
19:08	LOWERED SEC STEAM PRESSURE 20 PSI
19:09	DCDP01 AND CLDP02 IN SERVICE
19:11	LOWERED SEC STEAM PRESSURE 20 PSI
19:12	LOWERED SEC STEAM PRESSURE 20 PSI
19:15	LOWERED SEC STEAM PRESSURE 20 PSI
19:18	LOWERED SEC STEAM PRESSURE 20 PSI
19:19	OPENING NORTH ACCUMULATING TANK FILL VALVE
19:20	LOWERED SEC STEAM PRESSURE 30 PSI
	CLOSED SOUTH FILL VALVE ON ACCUM. TANK
19:22	DRAINED SOUTH ACCUM. TANK
19:23	LOWERED SEC STEAM PRESSURE 30 PSI
19:24	LOWERED SEC STEAM PRESSURE 30 PSI
19:27	SOUTH ACCUM. TANK DRAIN CLOSED
19:28	LOWERED SEC STEAM PRESSURE 30 PSI
19:32	LOWERED SEC STEAM PRESSURE 30 PSI
19:34:24	HPI PUMP FLOW INITIATED
19:34:36	· PORV OPENED
19:36	ADJUSTING HPI PUMP SPEED TO 20 %
19:44	ALL PRESSURIZER HEATERS OFF (MAIN & GUARD)
19:47	PRESSURIZER GUARD HEATERS ON
20:01	THROTTLING BACK HPI FROM .086 LBM/SEC TO .070 LBM/SEC
20:03	THROTTLING BACK HPI FROM .071 LBM/SEC TO .050 LBM/SEC
20:10	THROTTLING BACK HPI FROM .050 LBM/SEC TO .060 LBM/SEC
20:12	THROTTLING BACK HPI FROM .060 LBM/SEC TO .065 LBM/SEC
20:19	THROLLLING BACK HPI FROM .065 LBM/SEC TO .085 LBM/SEC
20:46	THROTTLING BACK HPI FROM .085 LBM/SEC TO .090 LBM/SEC
20:52	SOUTH TANK FILL OPEN , NORTH TANK FILL CLOSED
20:56	THROTTLING BACK HPI FROM .090 LBM/SEC TO .095 LBM/SEC
20:58	DRAINING NORTH ACCUM. TANK
21:02	NORTH TANK DRAIN CLOSED
21:03	DRAINING SURGE TANK
21:15	THROTTLING BACK HPI FROM .095 LBM/SEC TO 0.10 LBM/SEC
21:54	THROTTLING BACK HPI FROM 0.10 LBM/SEC TO .085 LBM/SEC
22:30	THROTTLING BACK HPI FROM .085 LBM/SEC TO .095 LBM/SEC
22:38	OPEN NORTH TANK FILL VALVE
22:40	CLOSE SOUTH TANK FILL VALVE
22:42	THROTTLING HPI BACK FROM .095 LBM/SEC TO 0.10 LBM/SEC
22:44	SOUTH TANK DRAIN OPEN
22:48	SOUTH TANK DRAIN CLOSED
22:58	THROTTLING BACK HPI FROM 0.10 LBM/SEC TO .105 LBM/SEC
23:03	THROTTLING BACK HPI FROM .105 LBM/SEC TO .099 LBM/SEC
23:31	HPV OPENED TO RECOVER NATURAL CIRCULATION
23:35	THROTTLING BACK HPI FROM .101 LBM/SEC TO .105 LBM/SEC
00:10	CHANGED SEC STEAM PRESSURE SET POINT TO 23.3 %

Table 3-3. (Cont'd)

00:15	OPEN SOUTH ACCUM. TANK FILL VALVE
	CLOSED NORTH FILL VALVE
00:17	DRAINING NORTH ACCUM TANK
00:22	THROTTLING BACK HPI FROM .105 LBM/SEC TO .090 LBM/SEC
00:24	THROTTLING BACK HPI FROM .090 LBM/SEC TO .082 LBM/SEC
00:25	CLOSED NORTH TANK DRAIN
00:26	THROTTLING BACK HPI FROM .082 LBM/SEC TO .105 LBM/SEC
00:27	THROTTLING BACK HPI FROM .105 LBM/SEC TO .100 LBM/SEC
00:31	THROTTLING BACK HPI FROM .100 LBM/SEC TO .095 LBM/SEC
00:38	LEVEL NOW ABOVE VIEWPORT
00:41	THROTTLING BACK HPI FROM .095 LBM/SEC TO .055 LBM/SEC
00:46	HPI OFF
00:46	PORV CLOSED
	LOWERED SEC STEAM PRESSURE TO 130 PSIG
00:48	PORV OPEN
00:49	HPI FLOW STARTED
00:50	RAISE SEC STEAM PRESSURE SET POINT TO 300 PSIA
01:04	CLOSED PORV
	HPI OFF
01:05	SEC STEAM LOWERED TO 120 PSIG
01:05	ADJUSTED AUX FEEDWATER TO RAISE LEVEL TO ABOUT 13 FT
01:10	ADJUSTED AUX FEEDWATER TO RAISE LEVEL TO ABOUT 14 FT
01:11	HPI FLOW ON
01:13	HPI FLOW OFF
01:16	PSDP03 , PSDP04 , PSOR03 , AND PSOR04 ON READ
	LARGE STEAM HAND VALVE OPENED
01:17	LOWERED SEC STEAM 30 PSIG
01:20	DCDP01 AND CLDP02 OUT OF SERVICE
01:25	STEAM RAMP CONTROLLER ON 100 DEG/HR COOLDOWN
01:27	OPEN NORTH ACCUM. TANK FILL VALVE
	CLOSED SOUTH ACCUM. TANK FILL VALVE
01:29	DRAIN SOUTH ACCUM TANK
	PORV OPEN
01:32	CLOSED PORV
01:34	SOUTH TANK DRAIN CLOSED
01:40	PORV OPEN
01:48	PORV CLOSED
01:57	PORV OPEN
02:06	BROUGHT IN SERVICE DCDP01 AND CLDP02
02:10	PORV CLOSED
02:26	STARTED HPI

Table 3-3. (Cont'd)

02:33	HPI SHUT OFF
02:38	OPENED PORV
02:43	CLOSED PORV
03:04	THROTTLING HPI TO HOLD PRESSURIZER LEVEL @ 18 +/- 5 FT
03:09	SOUTH TANK FILL OPEN
03:11	NORTH TANK FILL CLOSED
03:20	DRAINING NORTH TANK
03:25	NORTH TANK DRAIN CLOSED
03:39	PORV OPEN
03:41	PORV CLOSED
03:51	HPI FLOW OFF
04:10	HPI ON
04:50	PORV OPEN
04:52	PORV CLOSED
05:28	RVTC07 IS ABOUT 300 DEG F
	HPV CLOSED
	HPI STOPPED
	DATA SAVE STOPPED

Table 3-4. Unavailable Measurements

SUMMARY OF VARIABLES DISCARDED ON INPUT, TEST 240200

NO.	VTAB	SYSTEM	INST.	ELEVATION	DESCRIPTION
1	199HLTC06	2HL	2FTC	50.00	HOT LEG FLUID TEMP (F)
2	262HLCP05	2HL	16 CP	41.00	HOT LEG CONDCTVTY (WET/DRY)
3	263HLCP06	2HL	16 CP	45.00	HOT LEG CONDCTVTY (WET/DRY)
4	264HLCP07	2HL	16 CP	49.00	HOT LEG CONDCTVTY (WET/DRY)
5	265HLCP08	2HL	16 CP	53.00	HOT LEG CONDCTVTY (WET/DRY)
6	266HLCP09	2HL	16 CP	57.00	HOT LEG CONDCTVTY (WET/DRY)
7	274HLCP17	2HL	23RCP	.50	HOT LEG REF. C.P.
8	272HLCP15	3SGP	16 CP	56.90	SG PRIMRY. CONDCTVTY (WET/DRY)
9	26SPTC19	3SGP	21STC	23.10	SG PRIMRY. STRING TC (F)
10	27SPTC20	3SGP	21STC	30.10	SG PRIMRY. STRING TC (F)
11	28SPTC21	3SGP	21STC	35.10	SG PRIMRY. STRING TC (F)
12	29SPTC22	3SGP	21STC	39.10	SG PRIMRY. STRING TC (F)
13	30SPTC23	3SGP	21STC	43.10	SG PRIMRY. STRING TC (F)
14	31SPTC24	3SGP	21STC	47.10	SG PRIMRY. STRING TC (F)
15	32SPTC25	3SGP	21STC	49.10	SG PRIMRY. STRING TC (F)
16	33SPTC26	3SGP	21STC	50.10	SG PRIMRY. STRING TC (F)
17	35SPTC28	3SGP	21STC	51.10	SG PRIMRY. STRING TC (F)
18	103PRDT03	6PR	10 DT	42.80	PRESURIZR. INSUL. DT (F)
19	223HPTM02	10HPI	13TMF	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
20	219V1AC01	11V1	19ACC	-999.00	1-PH VENT. ACCD.FLOW (LBM)
21	317V1RF20	11V1	38FLO	-999.00	1-PH VENT. CALD.FLOW (LBM/SEC)
22	53SSTC13	22SGS	2FTC	32.30	SG SECOND.FLUID TEMP (F)
23	79SMTC02	22SGS	25MTC	26.30	SG SECOND. METAL TC (F)
24	76SMTC06	22SGS	25MTC	44.20	SG SECOND. METAL TC (F)
25	289SSCP20	22SGS	32KCP	0.00	SG SECOND. UP.WET.CP (REF. FT)
26	344V1TC03	34CLD	2FTC	-999.00	CLD LEAK FLUID TEMP (F)

Figure 3-1. Test Phases (Pressure Vs Time)

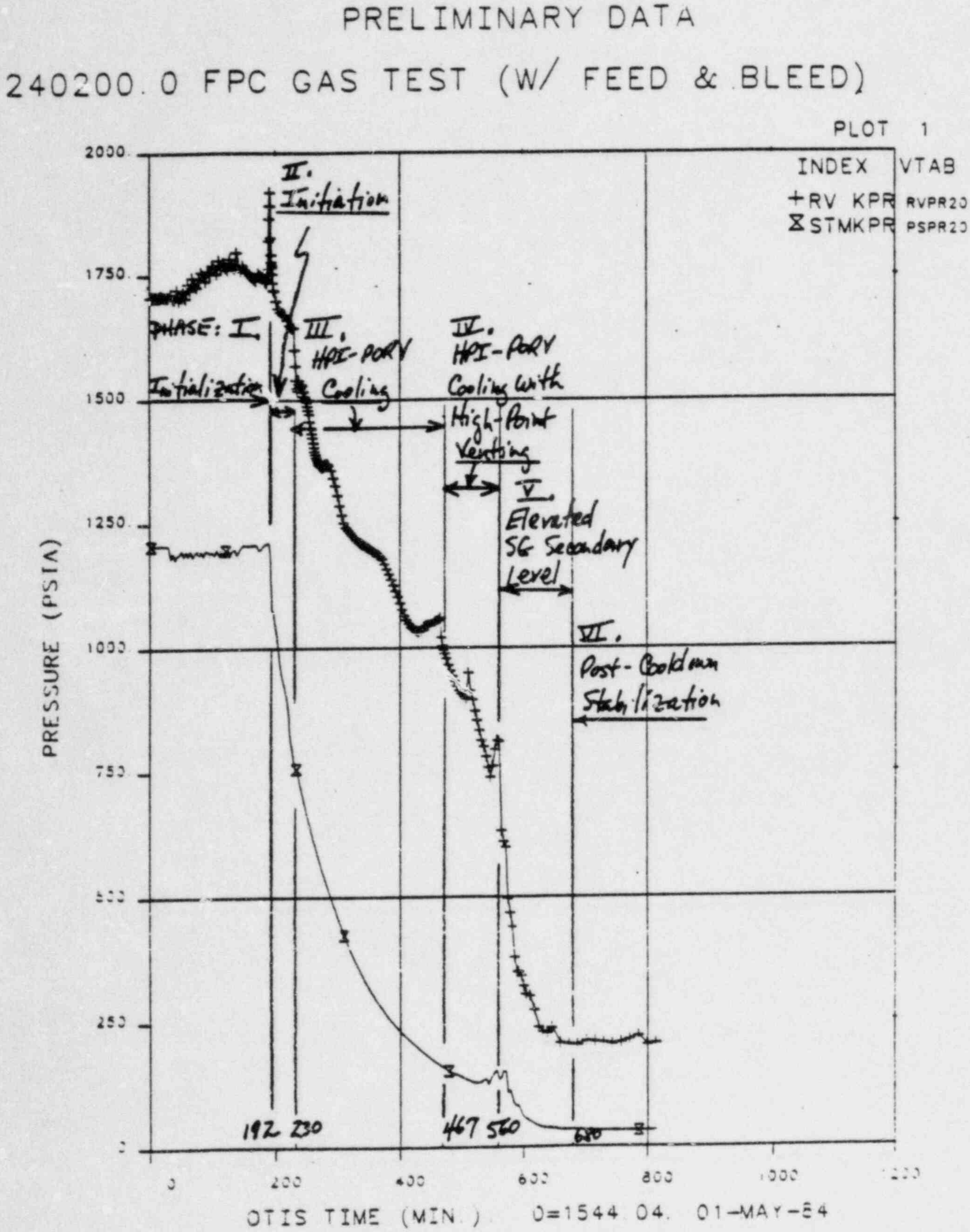
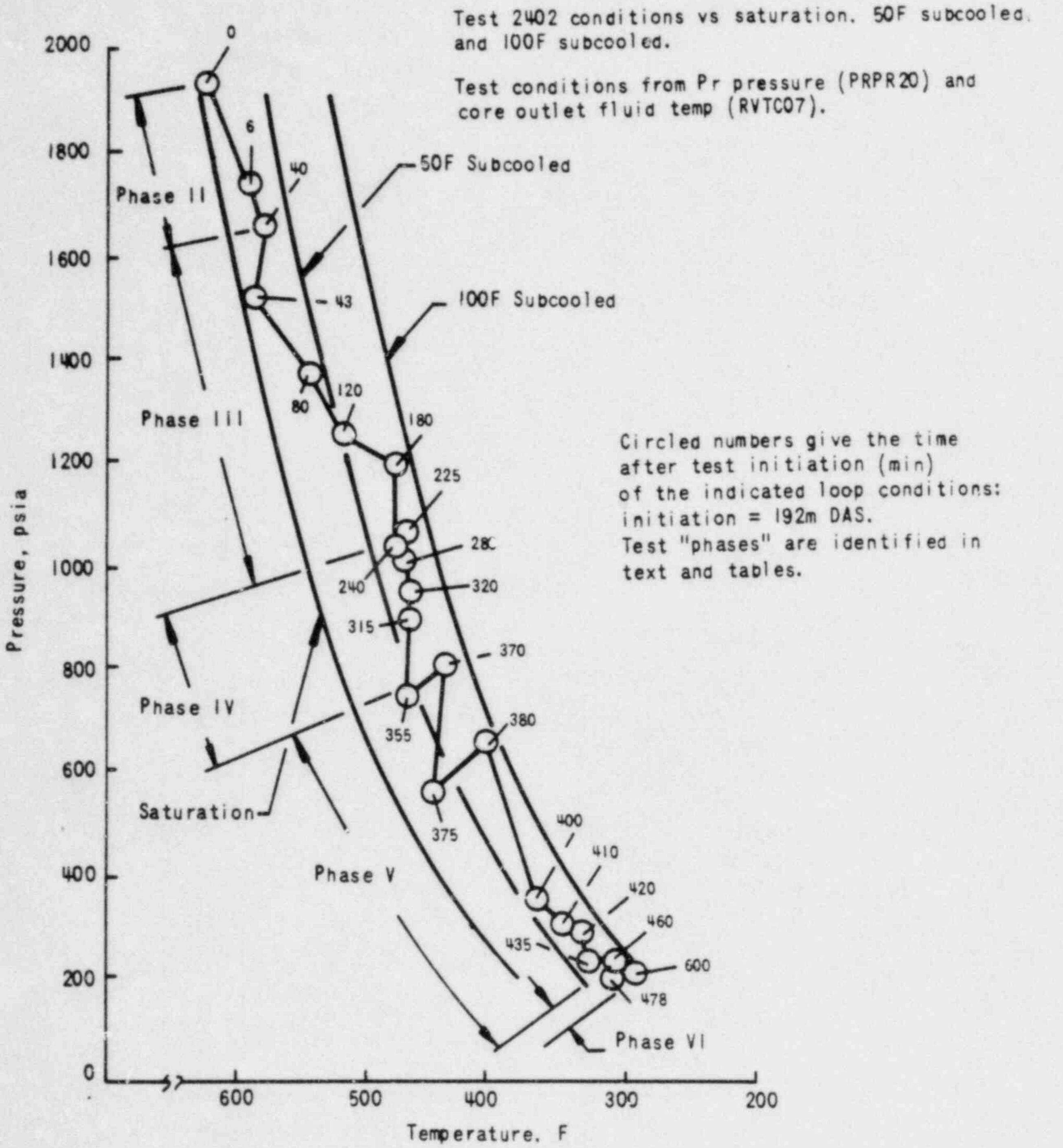


Figure 3-2a. Pressure-Temperature Trace



Note: The measured primary pressure used to determine saturation temperature is in actuality the sum of the partial pressures of water vapor and of ncg. The water vapor pressure is thus less than the measured (total) pressure, the actual water saturation temperature is correspondingly reduced.

Figure 3-2b. Subcooling Margin (Early in Test)

Apparent subcooling margin from saturation temperature at system total pressure, and core outlet fluid temperature (RVTC07).

Note log (t) - scale on abcissa.

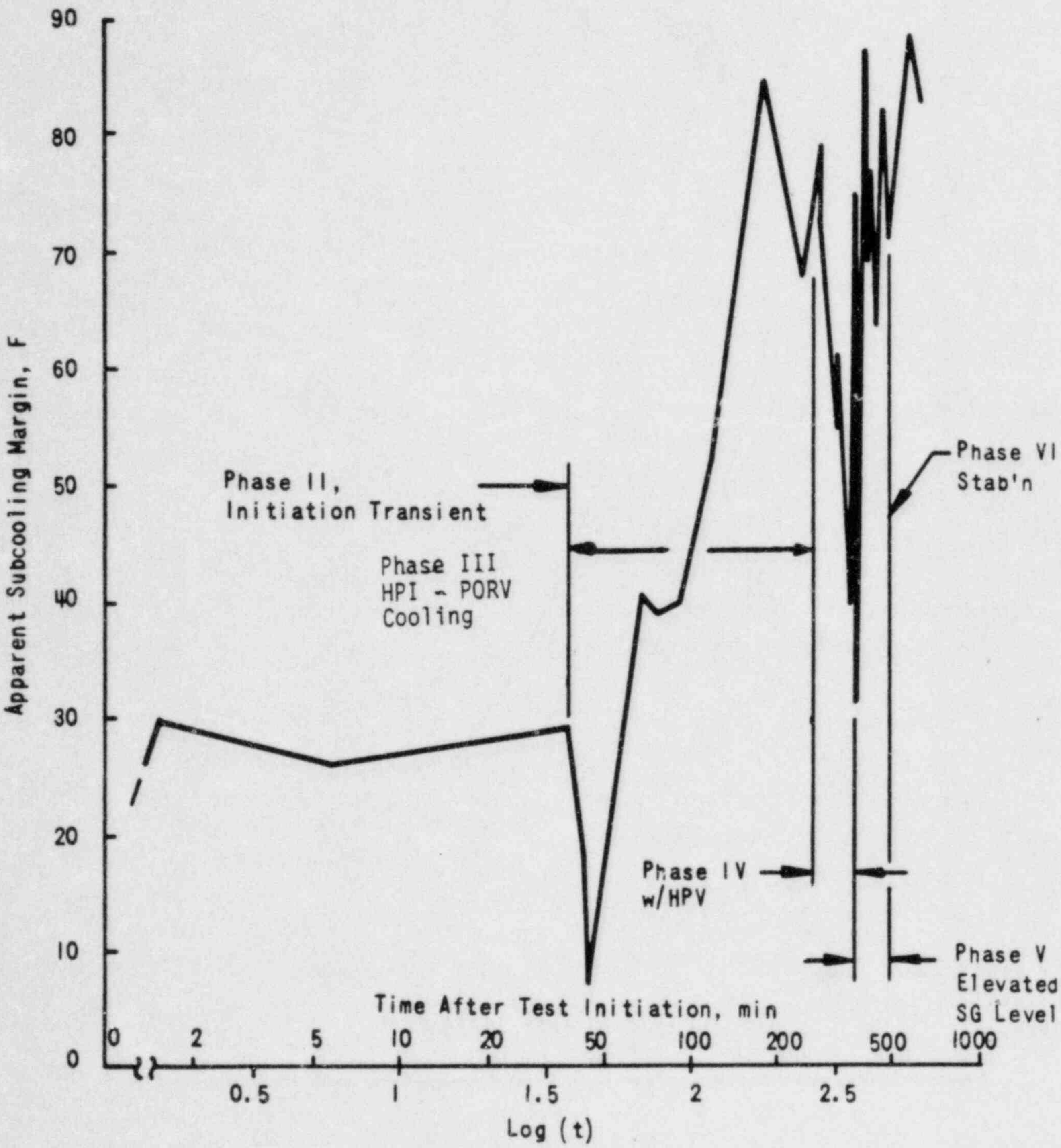


Figure 3-2c. Subcooling Margin (Late in Test)

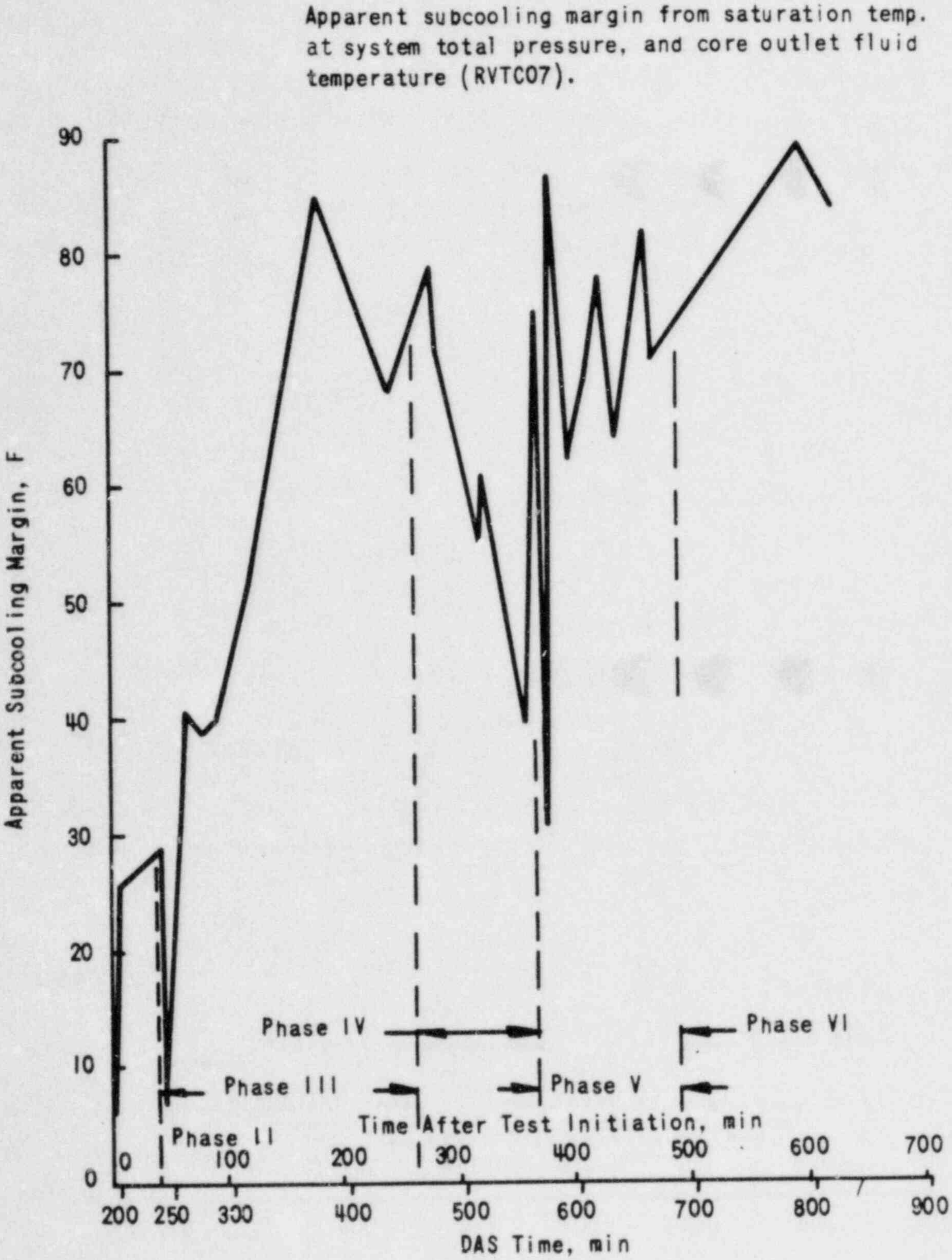


Figure 3-3. Loop Gas Inventory

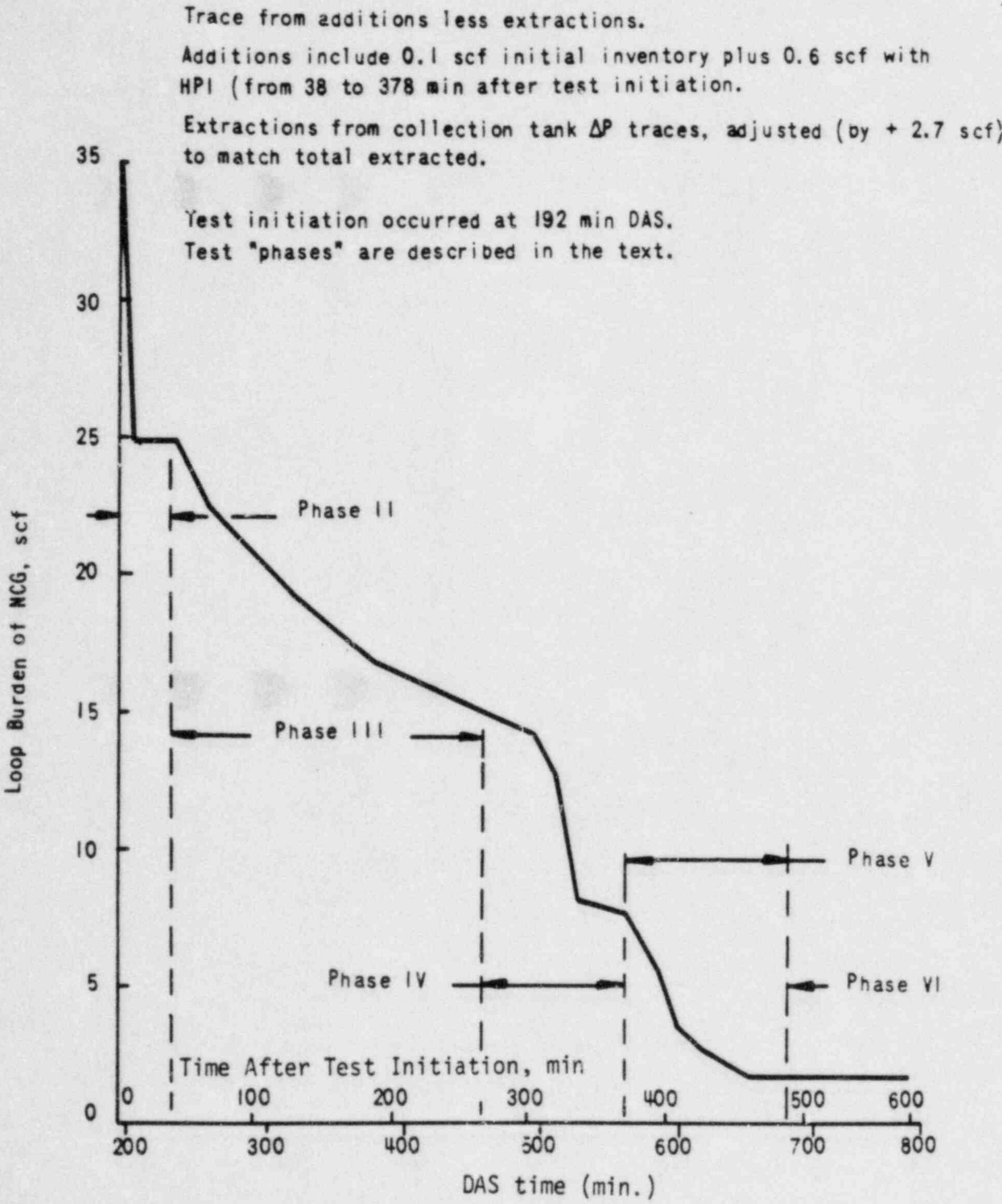


Figure 3-4. Test Initiation (Test Phase II)

Figure 3-4a. Primary and Secondary Pressures

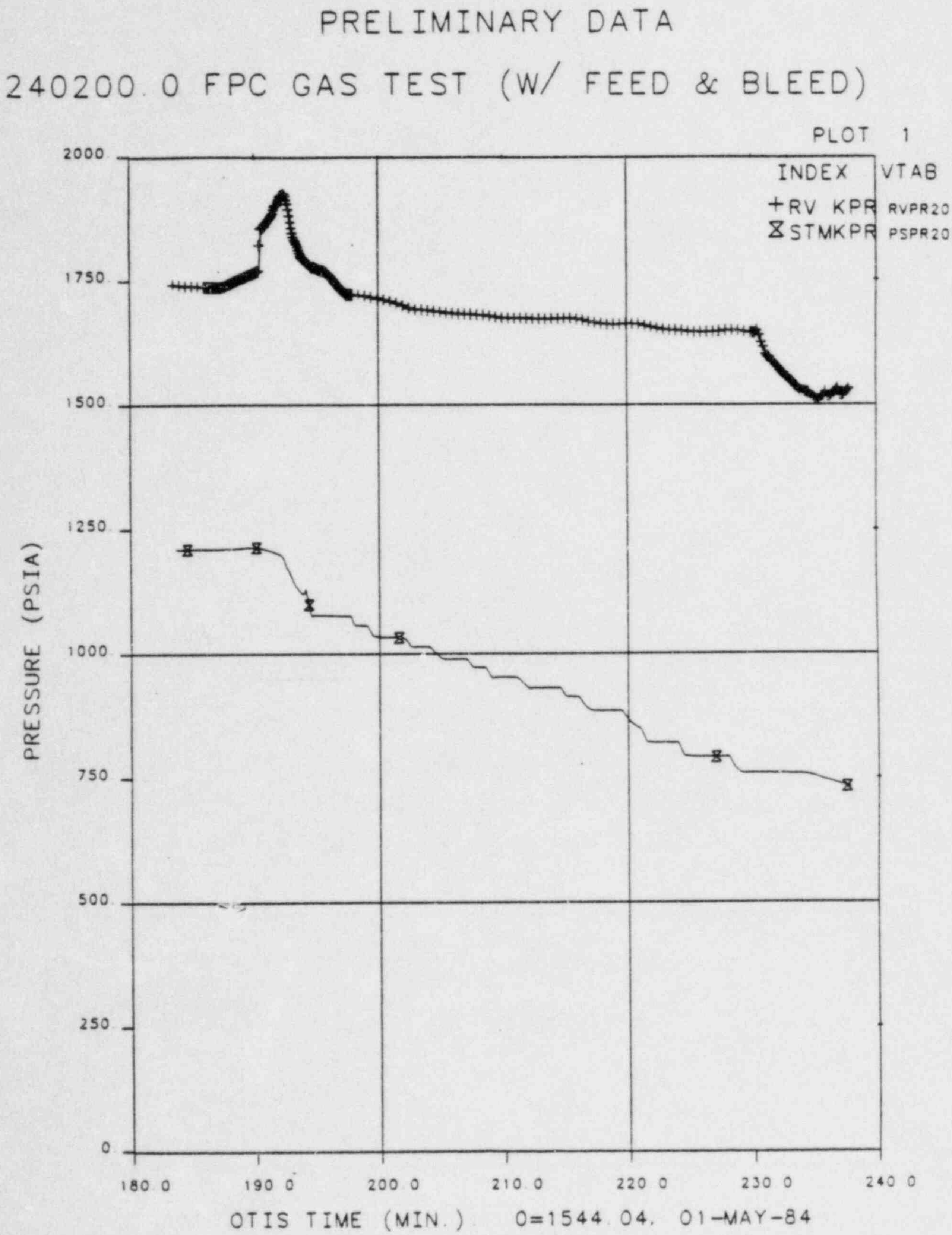


Figure 3-4b. Liquid Levels

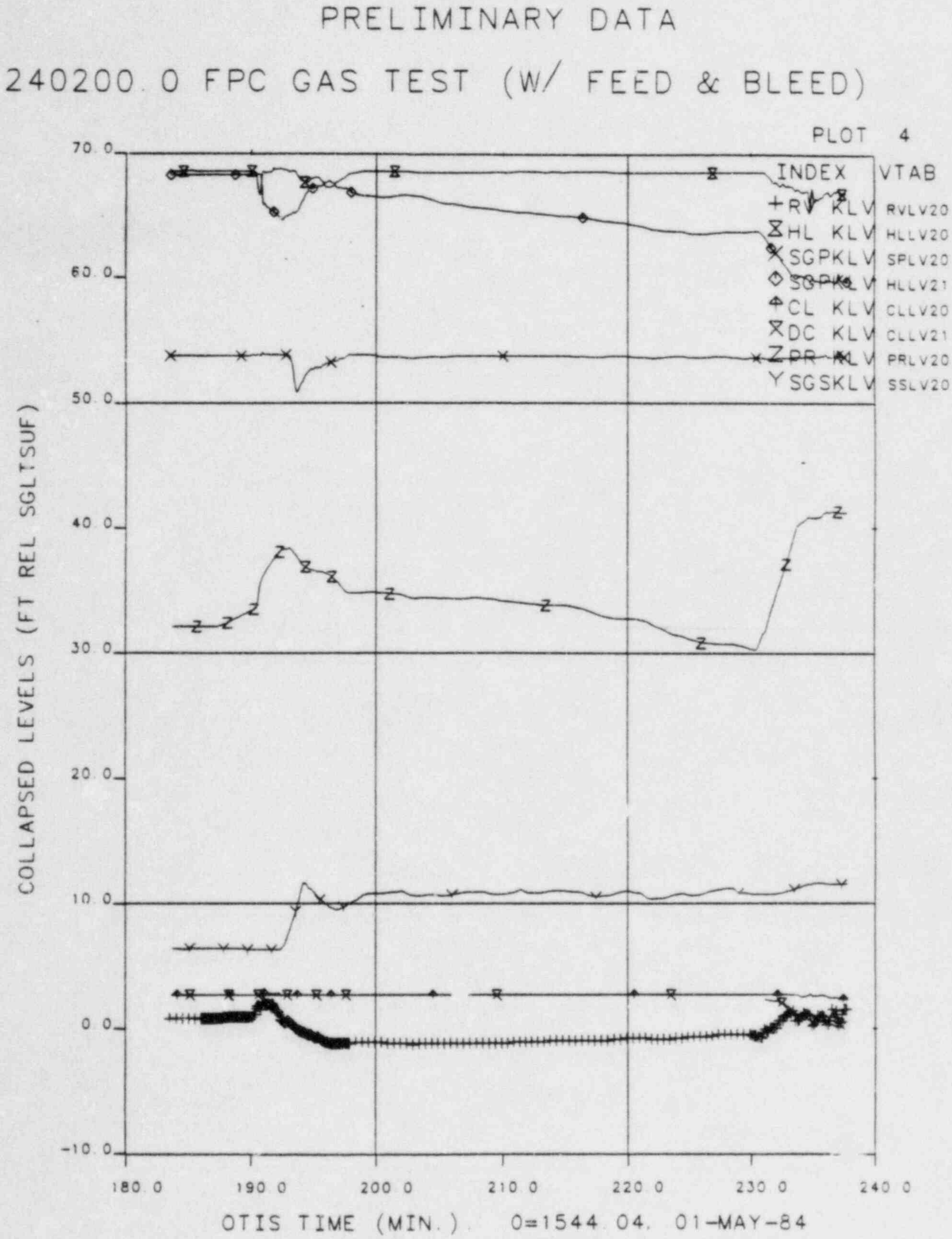


Figure 3-4c. Primary Flowrates

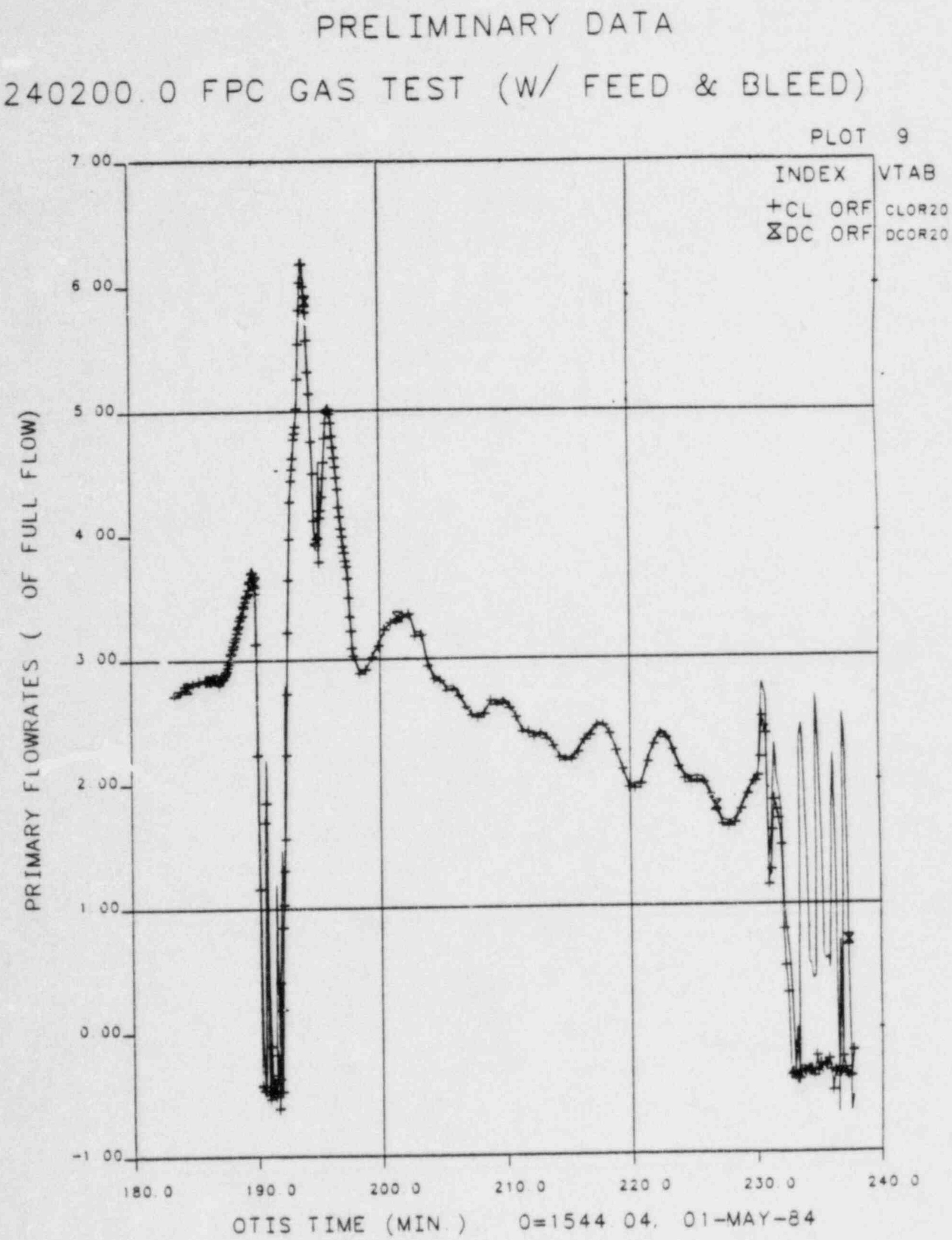


Figure 3-4d. Secondary Flowrates

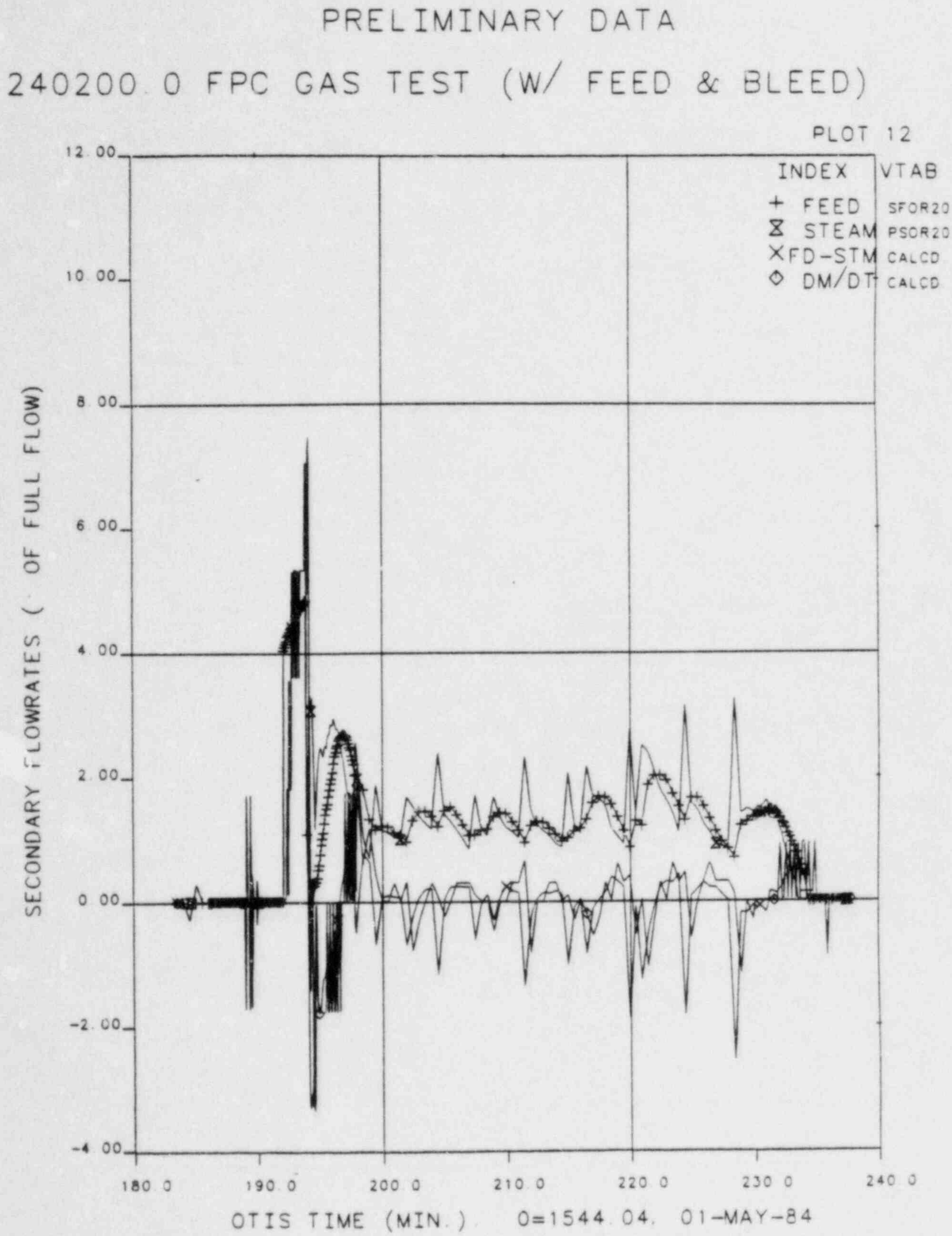


Figure 3-4e. Approximate Core Region Void Fraction

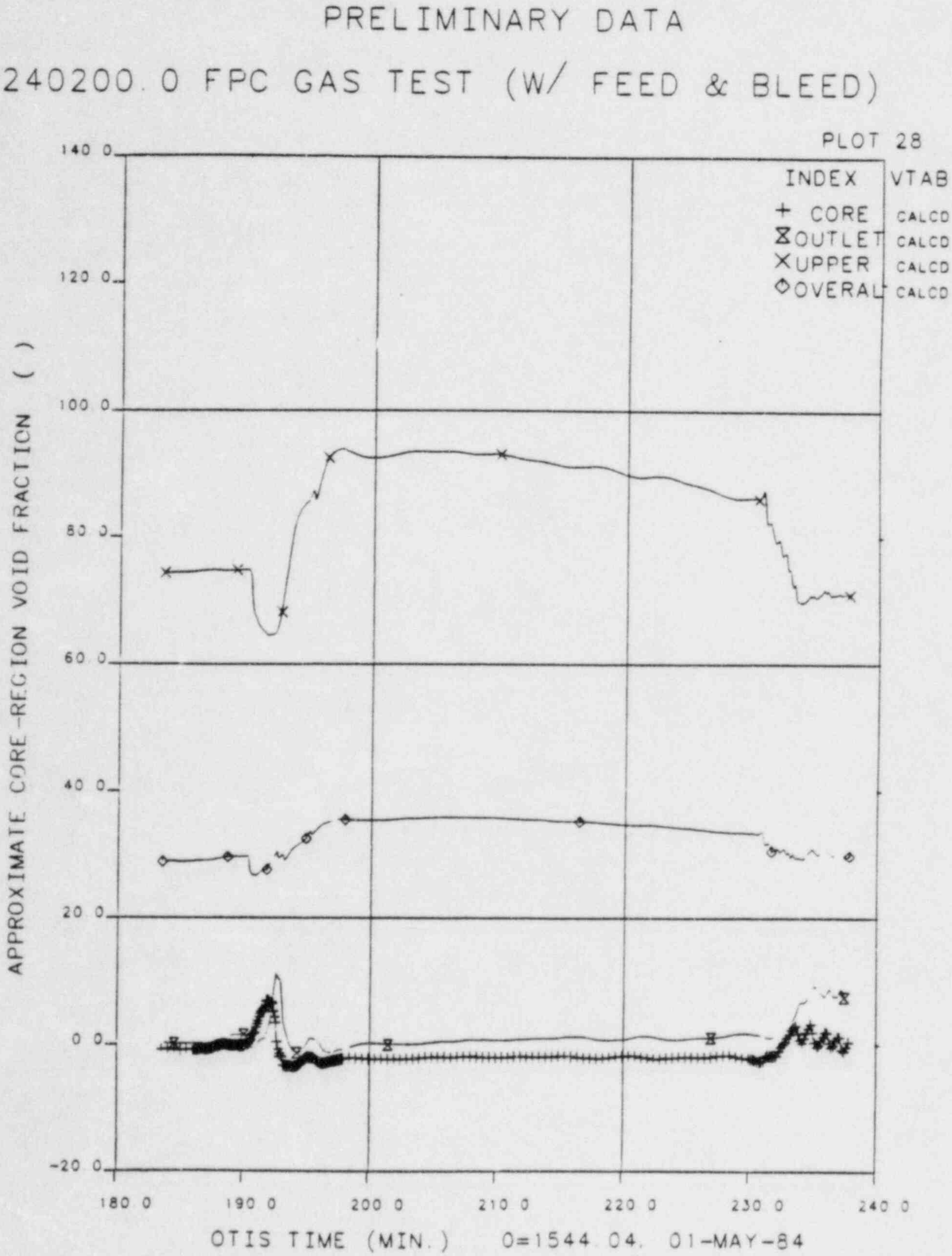


Figure 3-4f. Saturation Temperatures

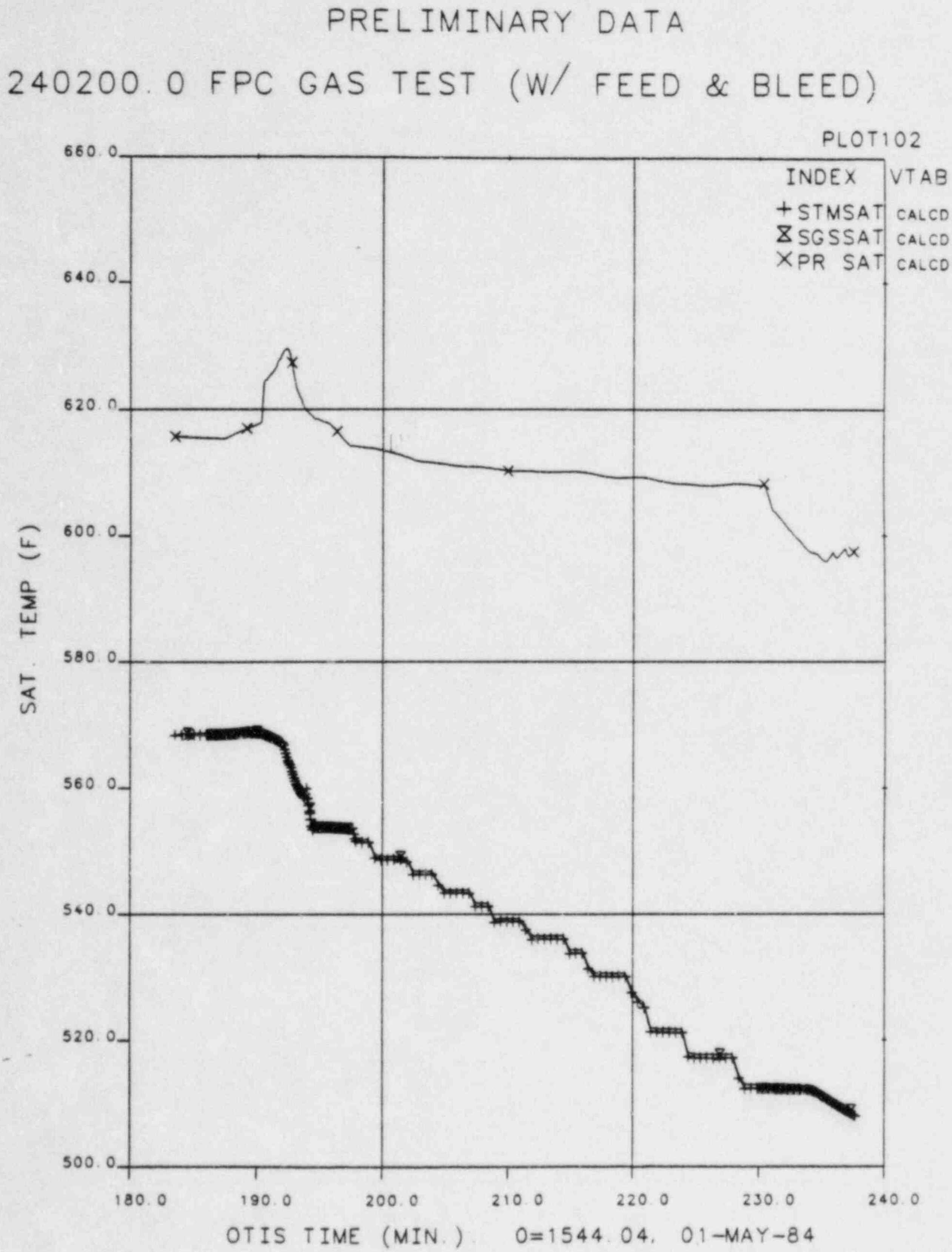


Figure 3-4g. Core Region Fluid Temperatures

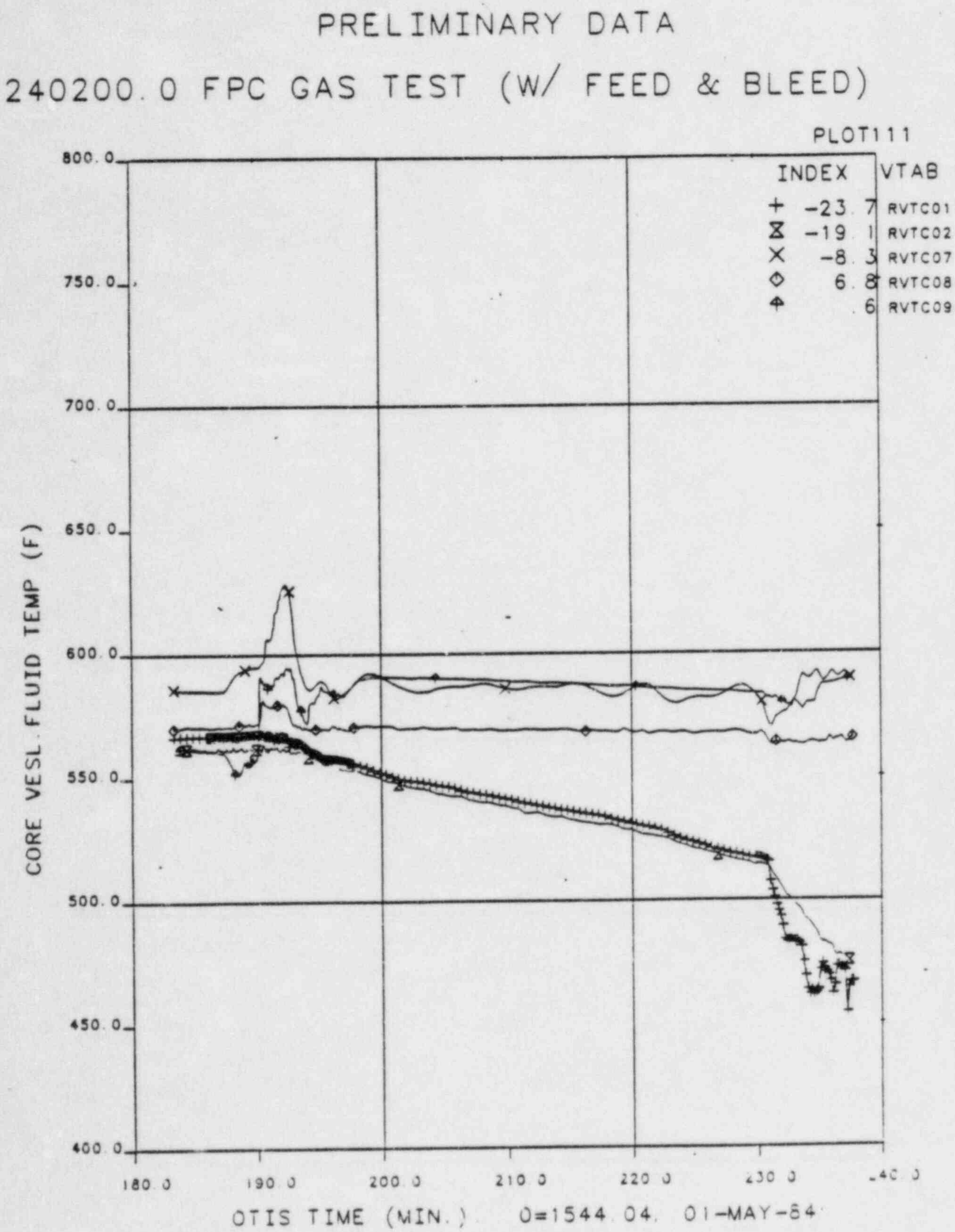


Figure 3-4h. Hot Leg Fluid Temperatures

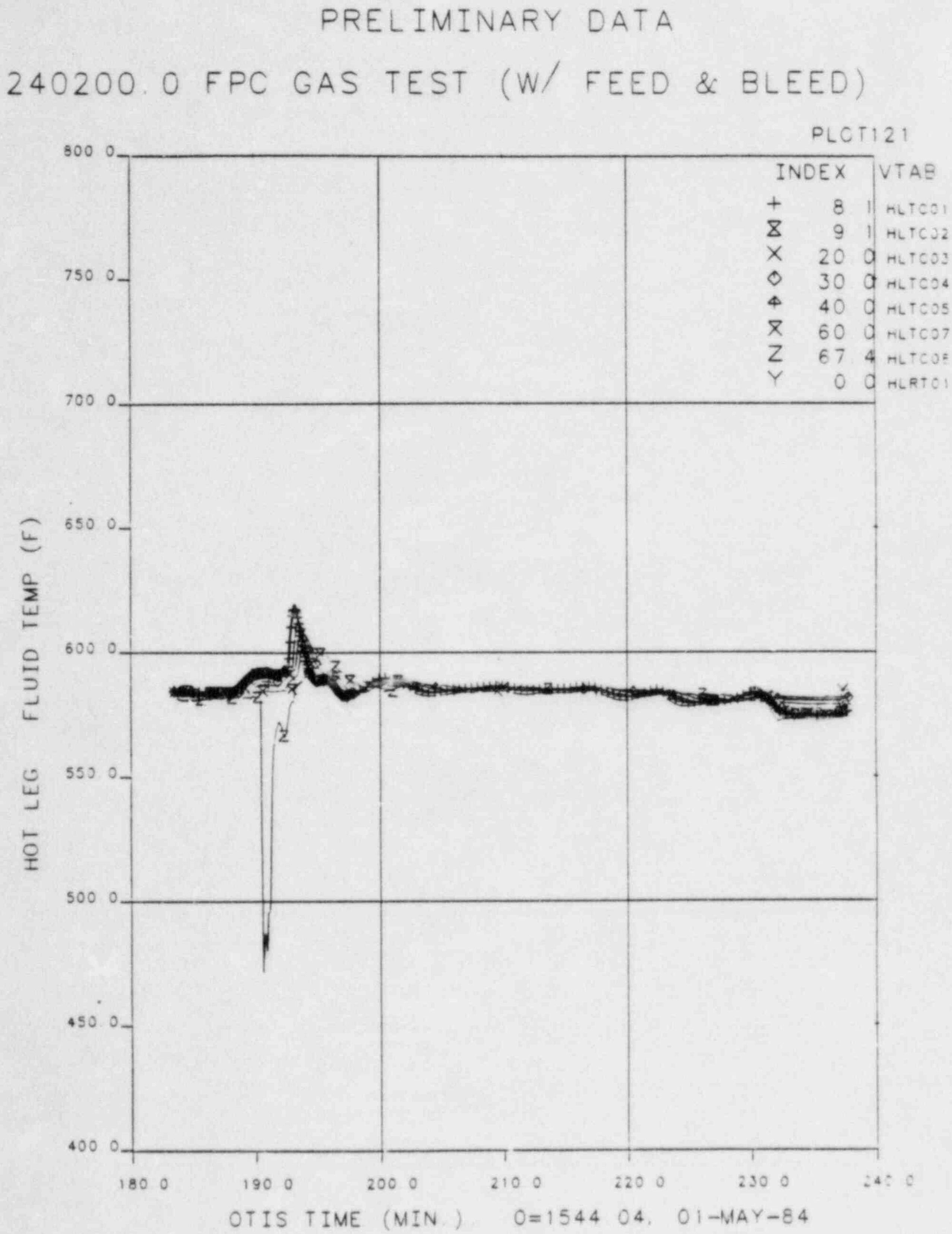


Figure 3-4i. SG Primary Wetted-Tube Fluid Temperatures

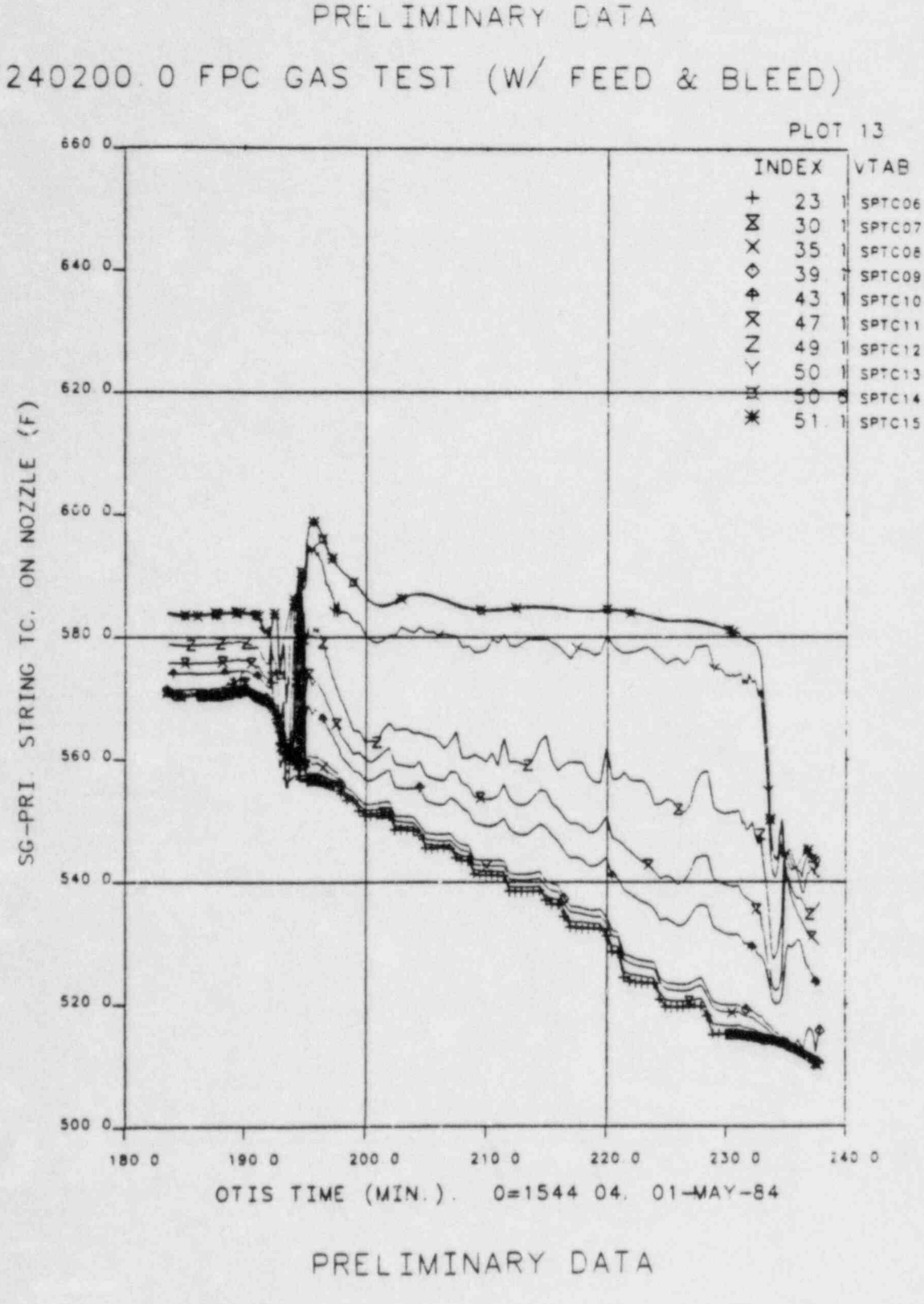


Figure 3-5. HPI-PORV Cooling (Test Phase III)

Figure 3-5a. Primary and Secondary Pressures

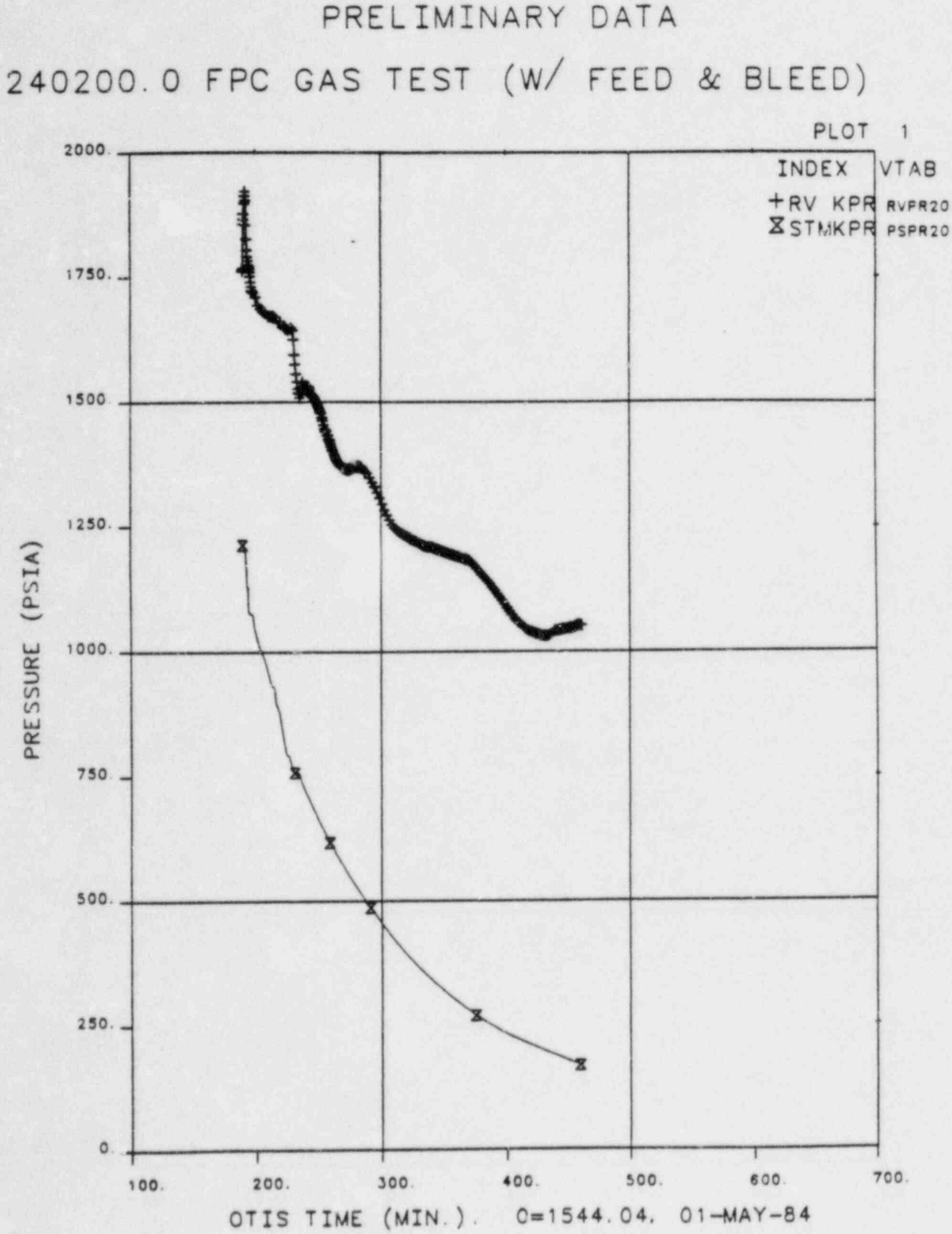


Figure 3-5b. Average Fluid Temperatures

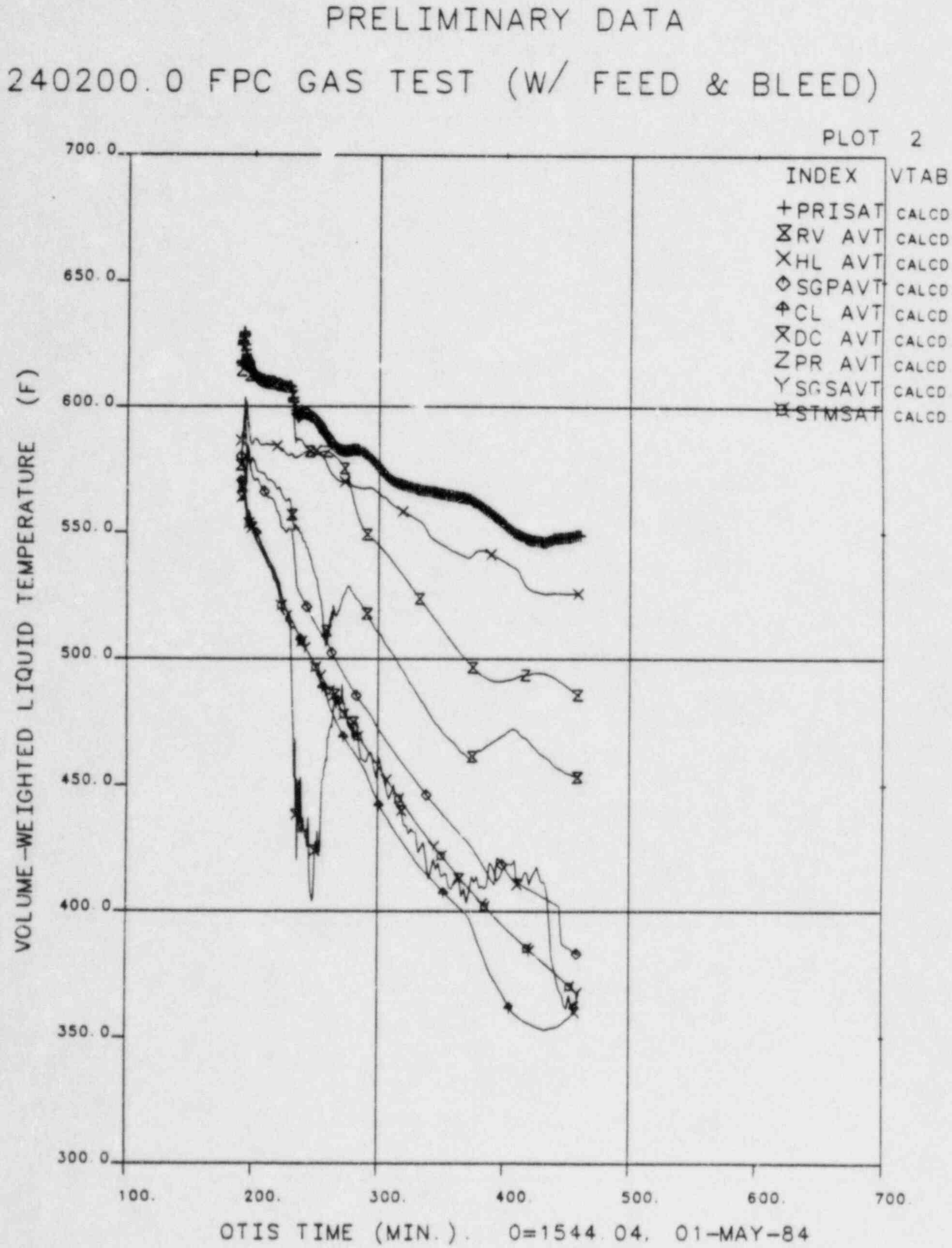


Figure 3-5c. Levels

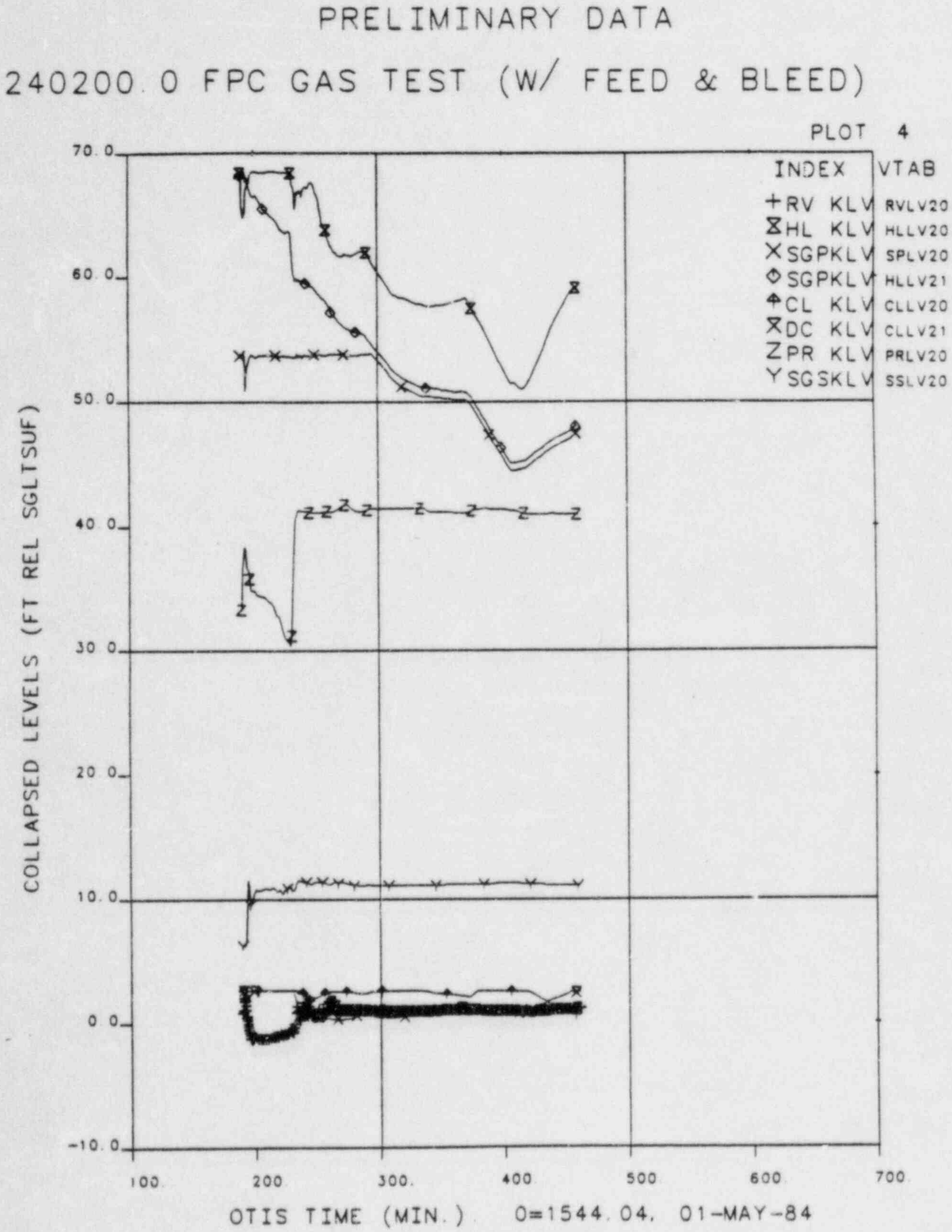


Figure 3-5d. Primary Flowrates

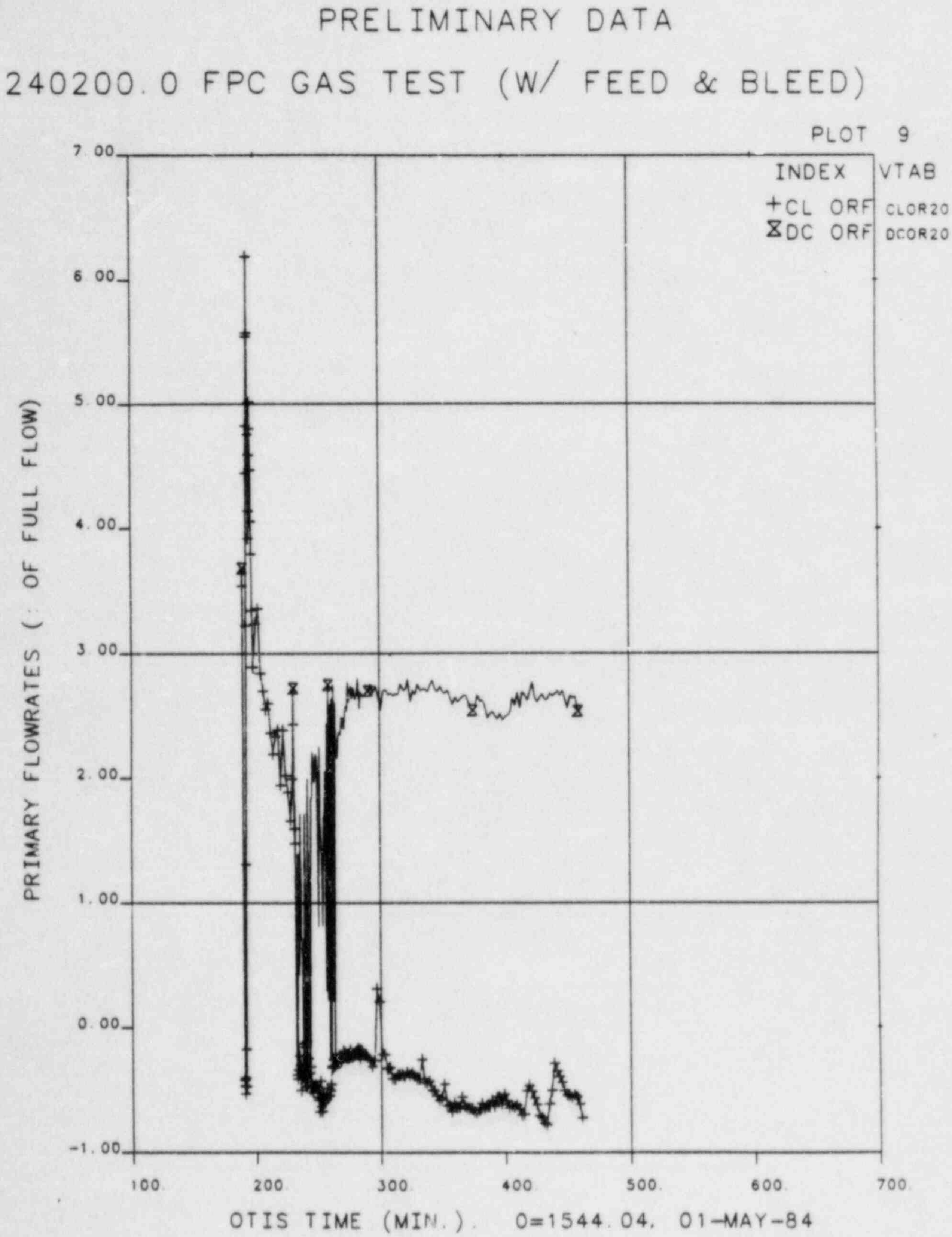


Figure 3-5e. Wetted Tube Primary Fluid Temperatures

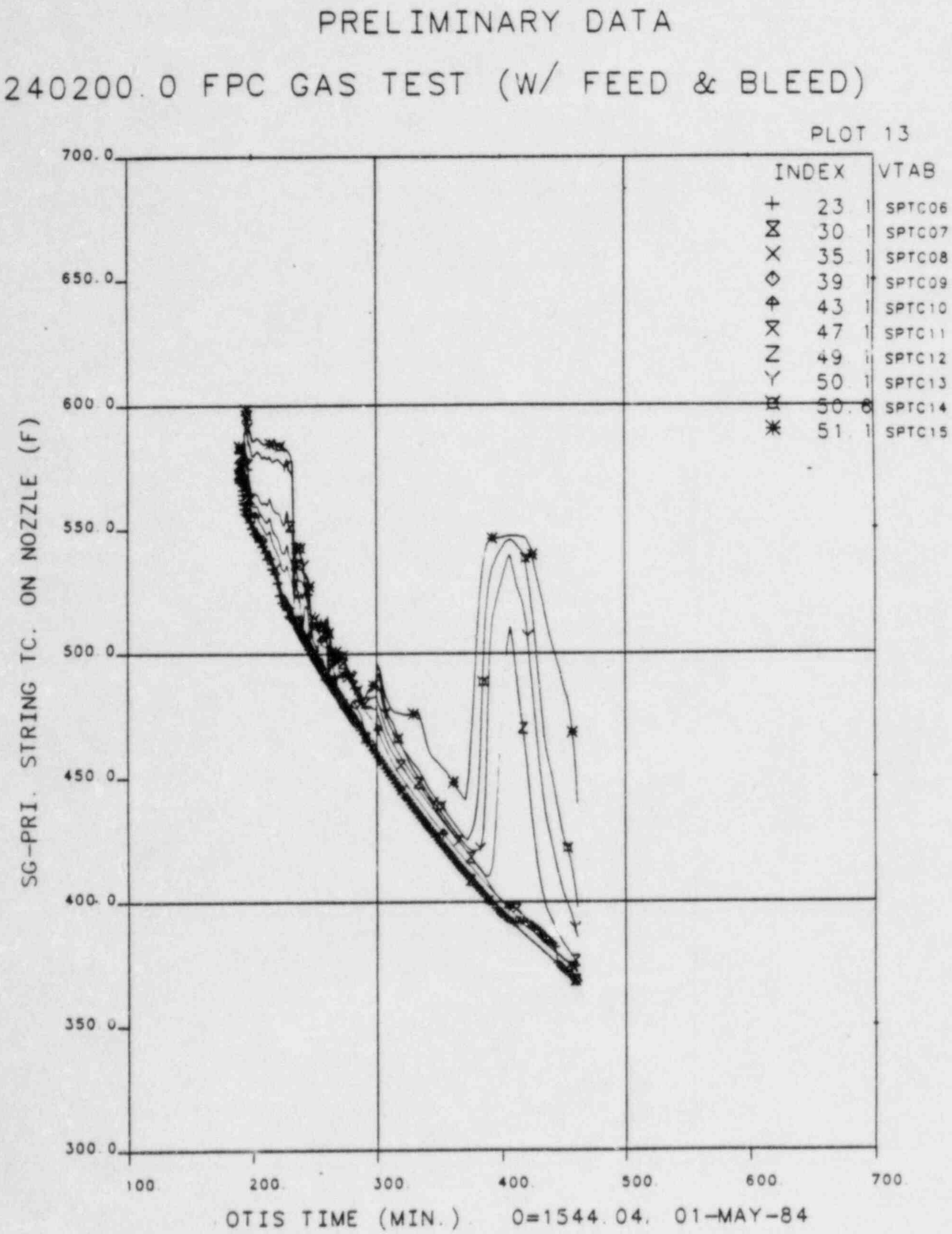


Figure 3-5f. Primary Boundary Mass Flowrates

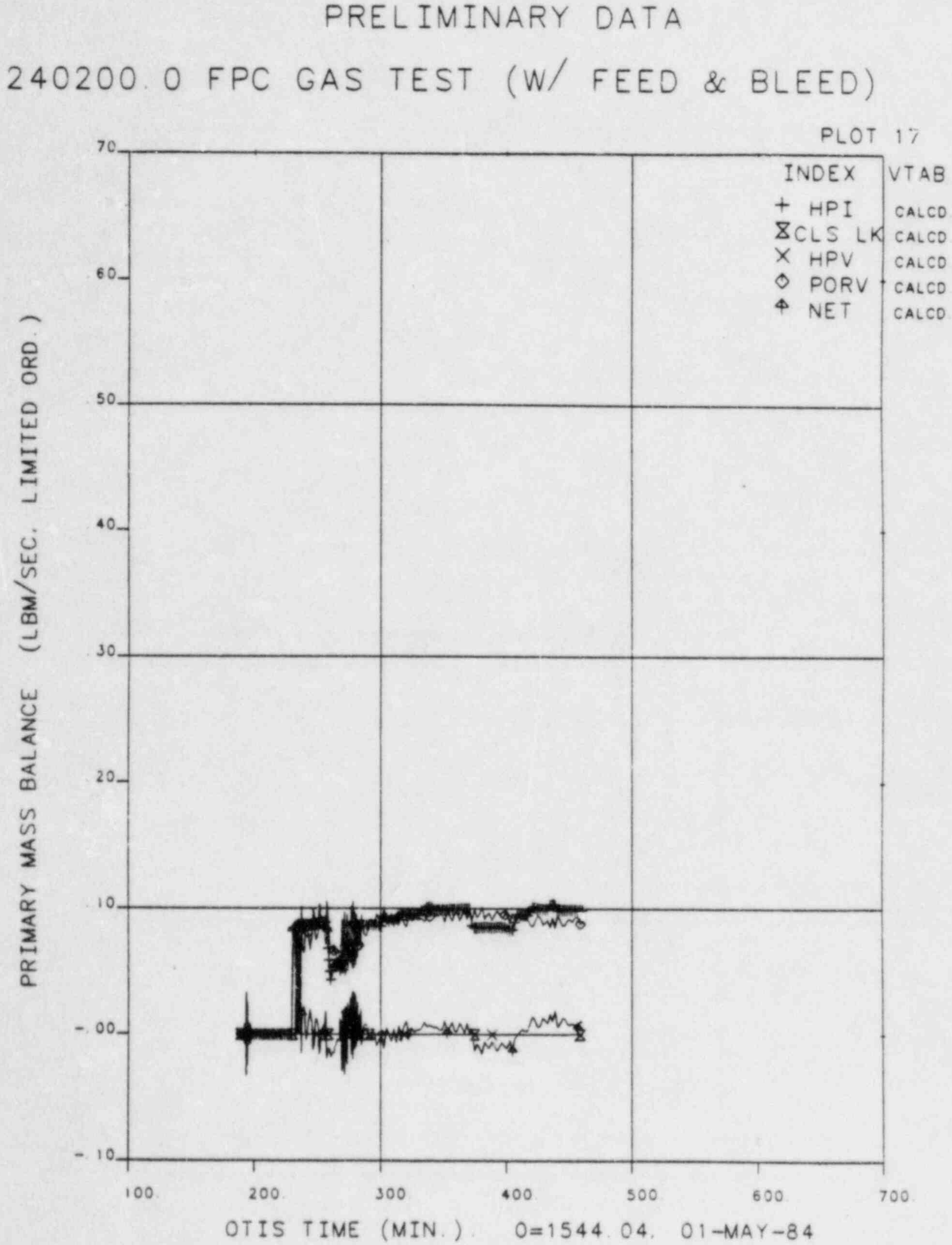


Figure 3-5g. Primary Energy Balance

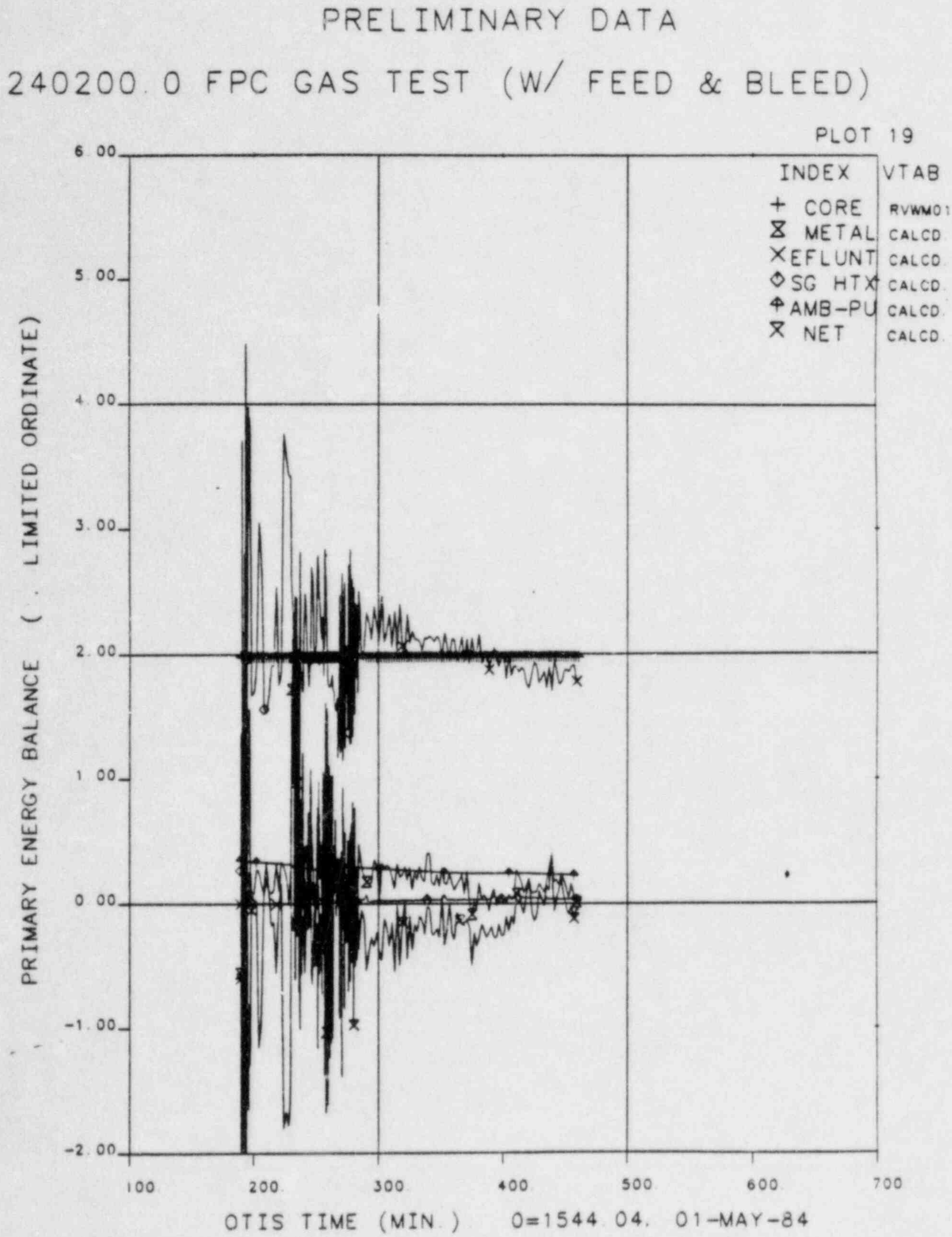


Figure 3-5h. Total Primary Fluid Energy

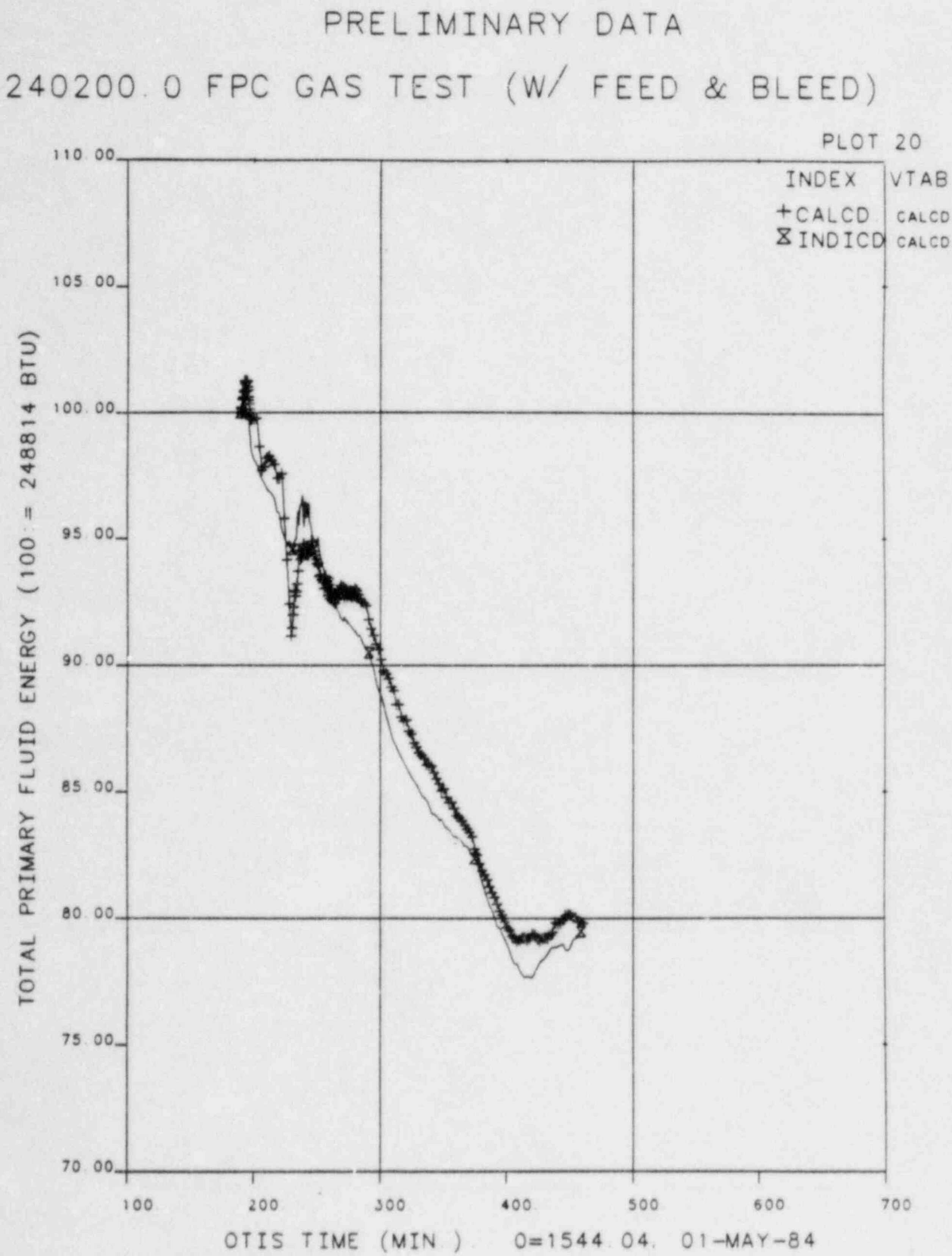


Figure 3-51. Cold Leg Fluid Temperatures

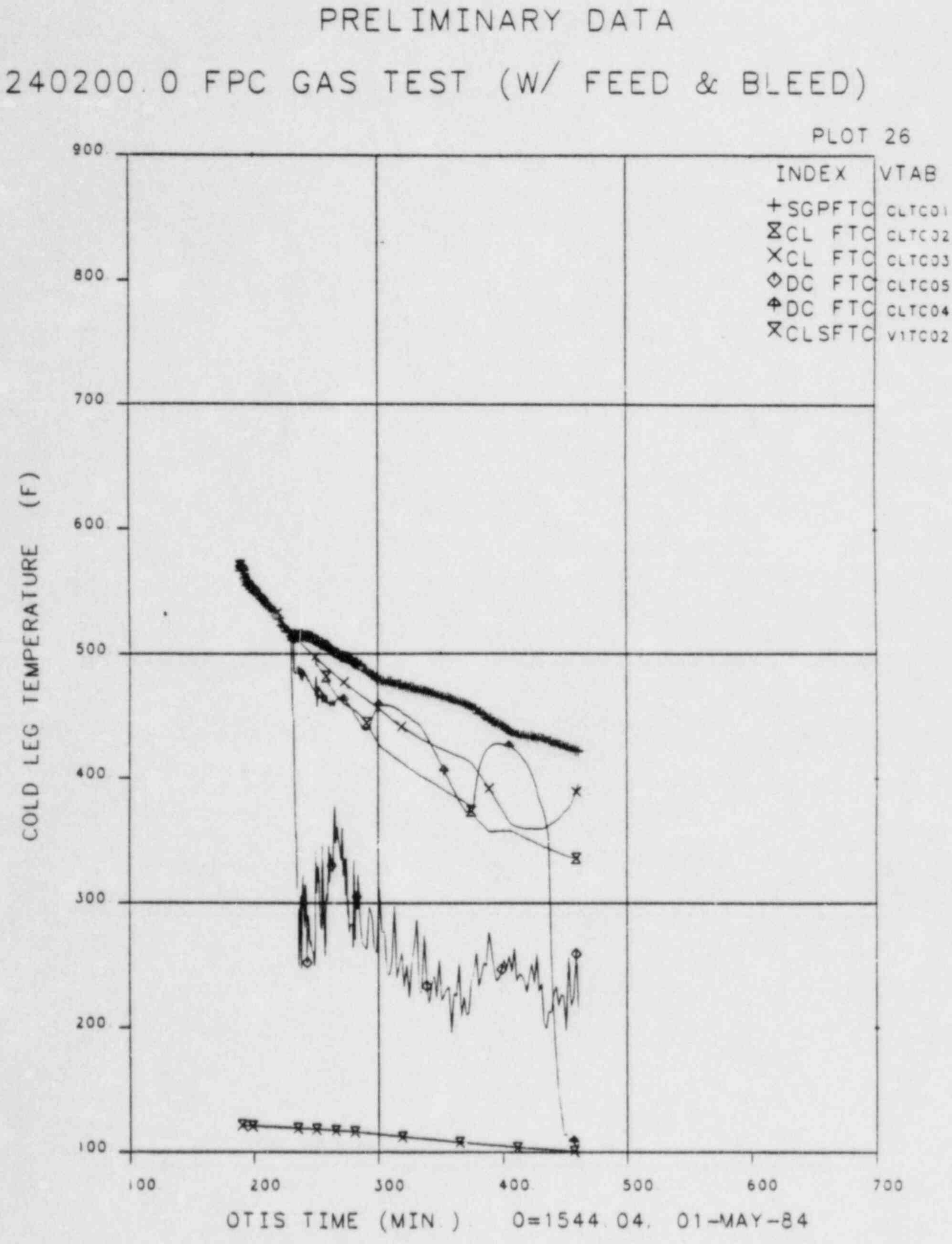


Figure 3-5j. Liquid Volume Fractions

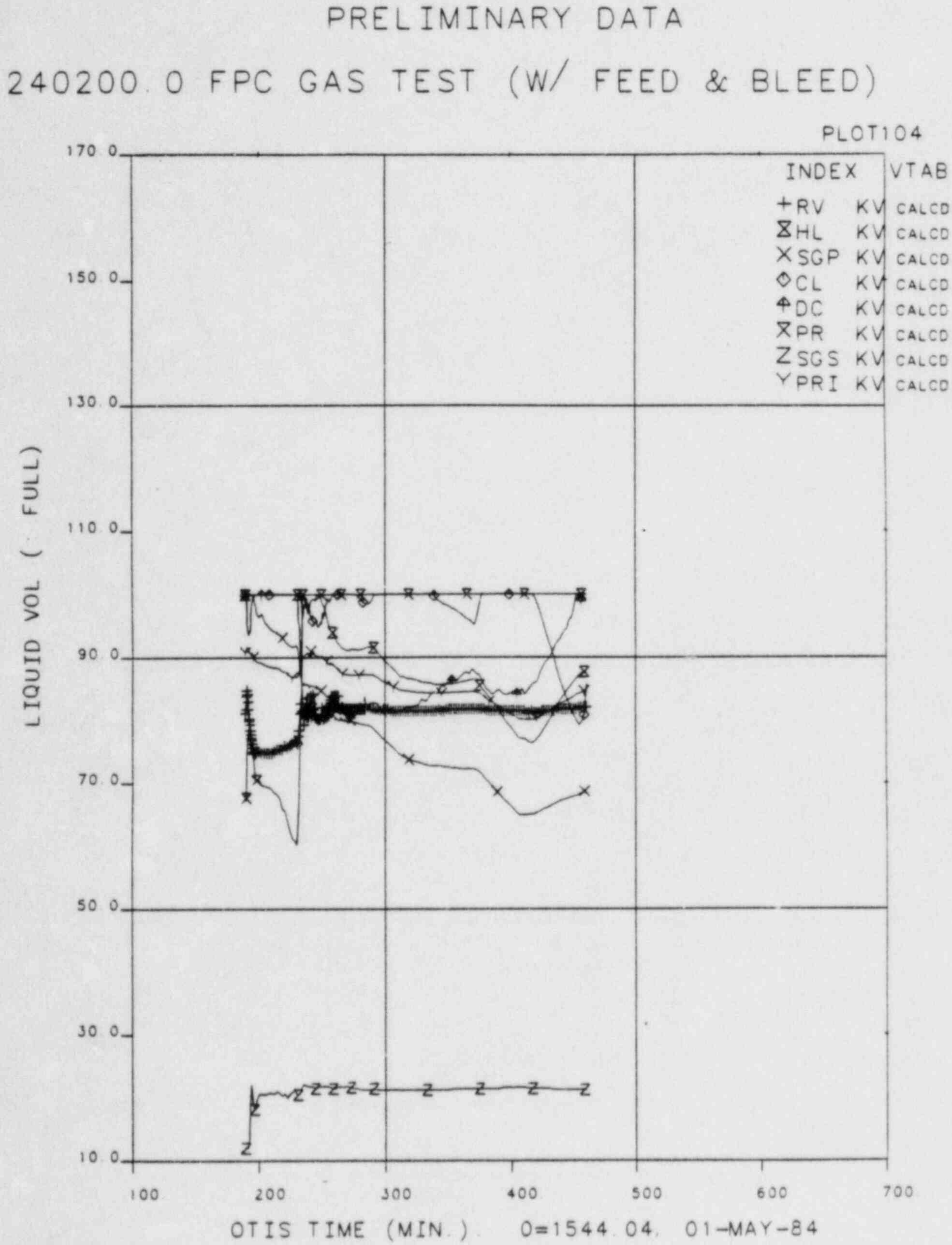


Figure 3-5k. Core Region Fluid Temperatures

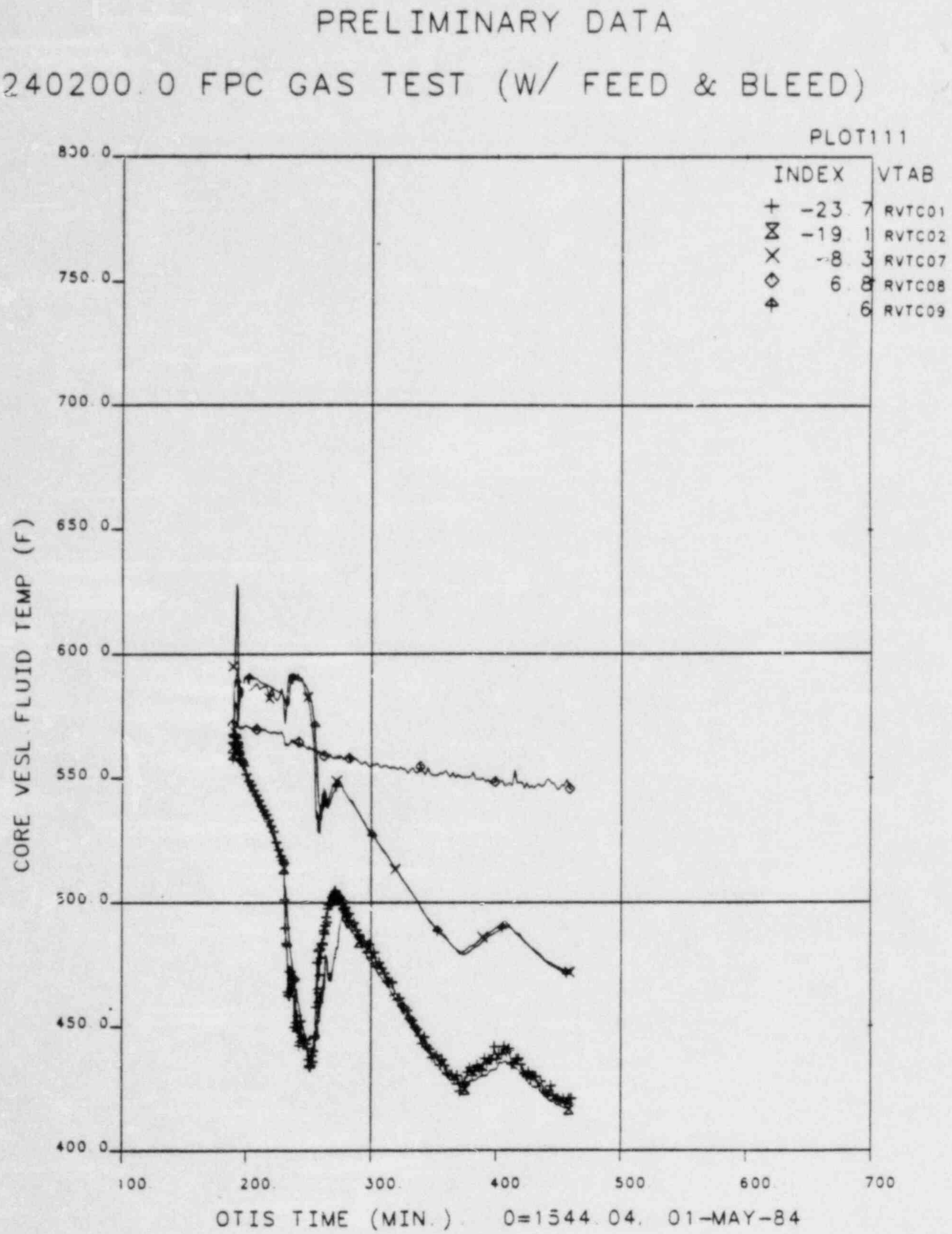


Figure 3-51. Hot Leg Fluid Temperatures

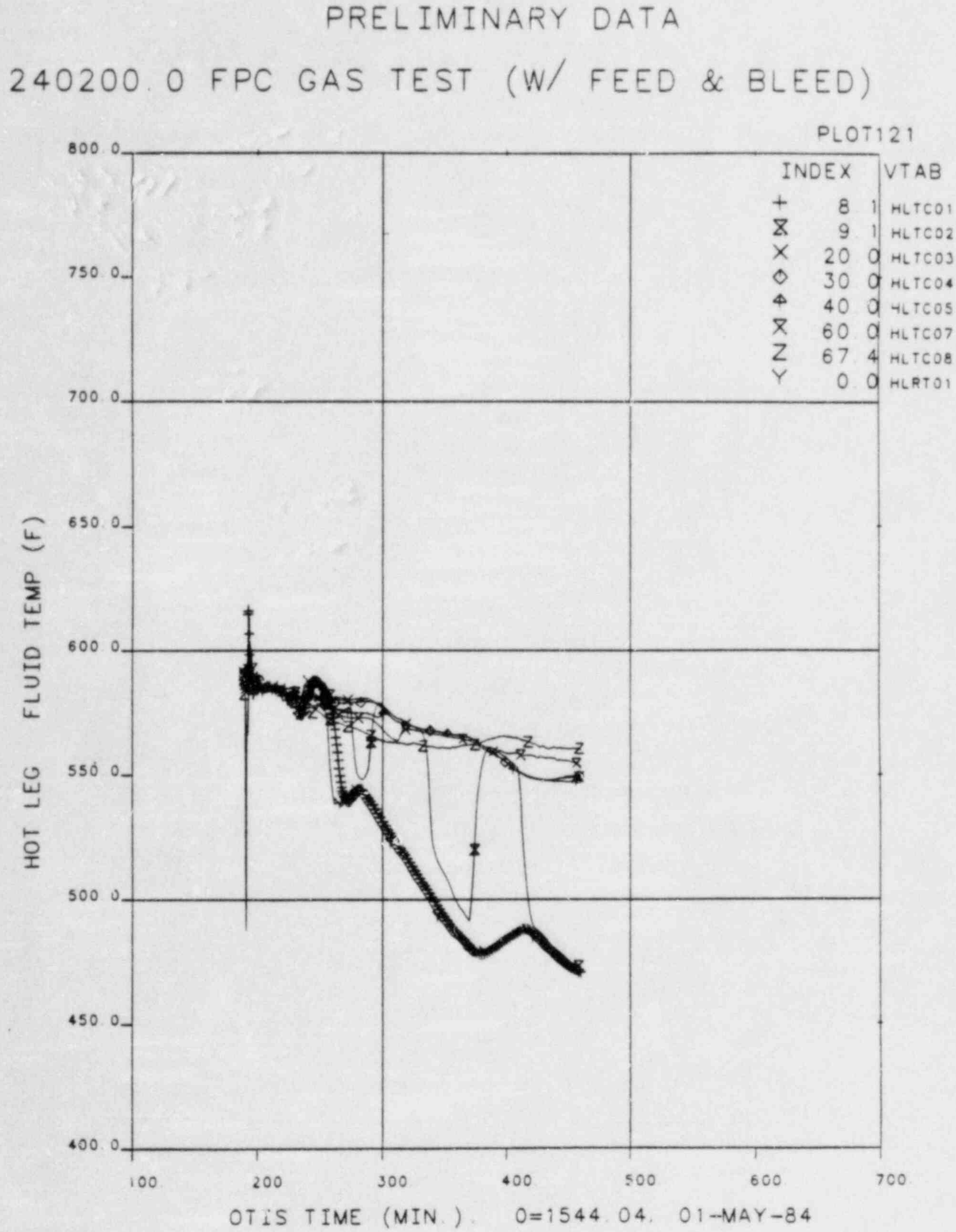


Figure 3-5m. SG Primary Fluid Temperatures

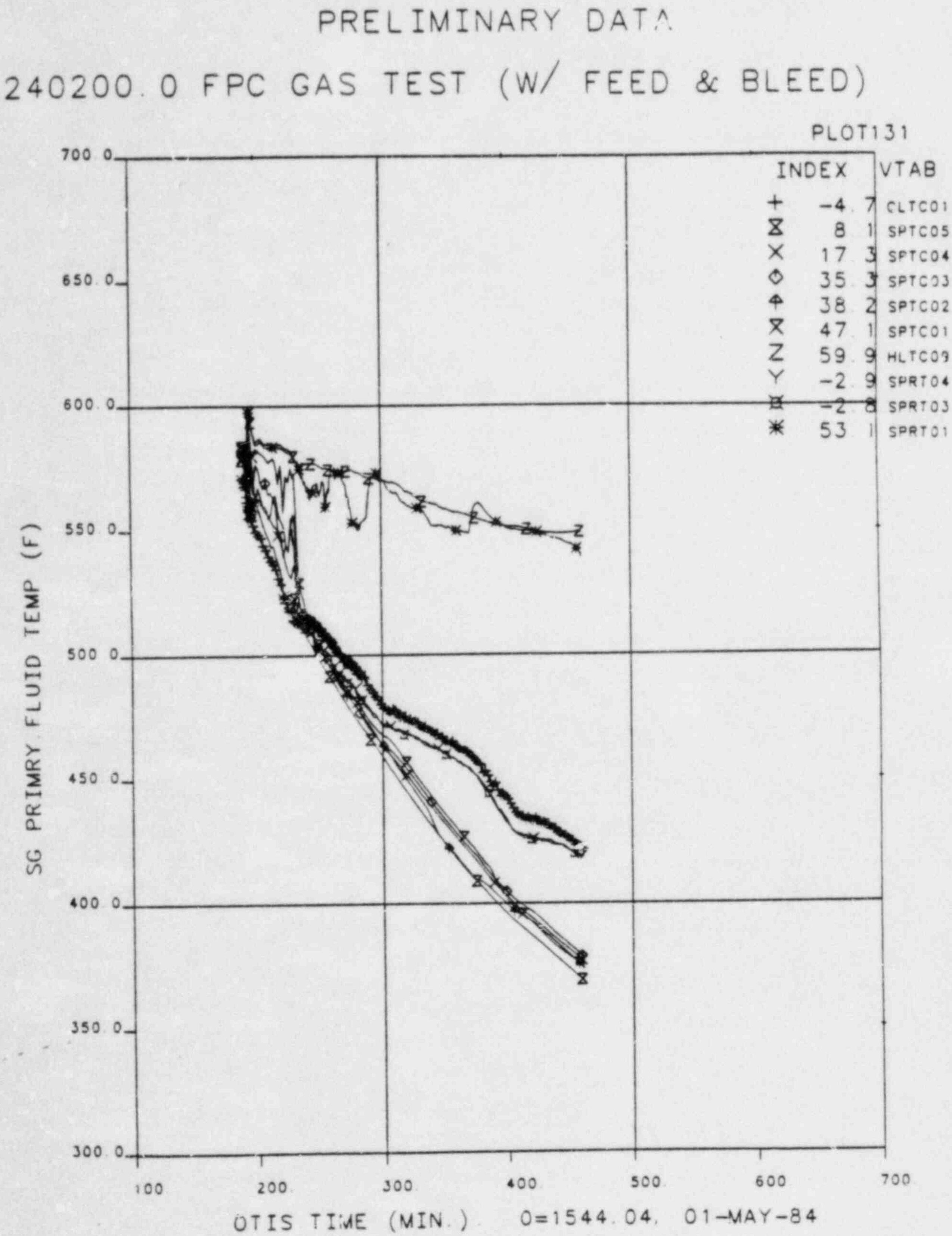


Figure 3-5n. Downcomer Fluid Temperatures

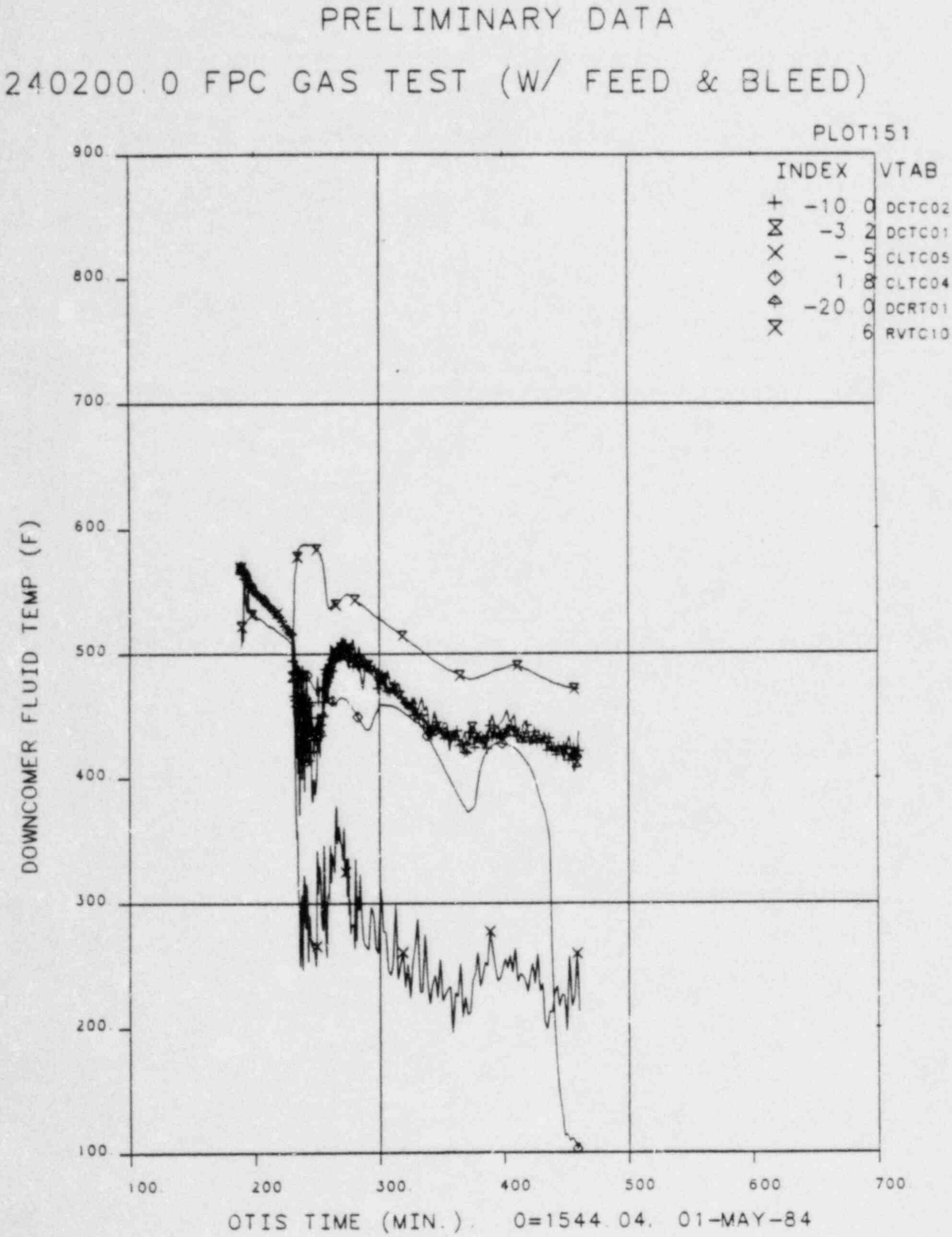


Figure 3-5o. Pressurizer Fluid Temperatures

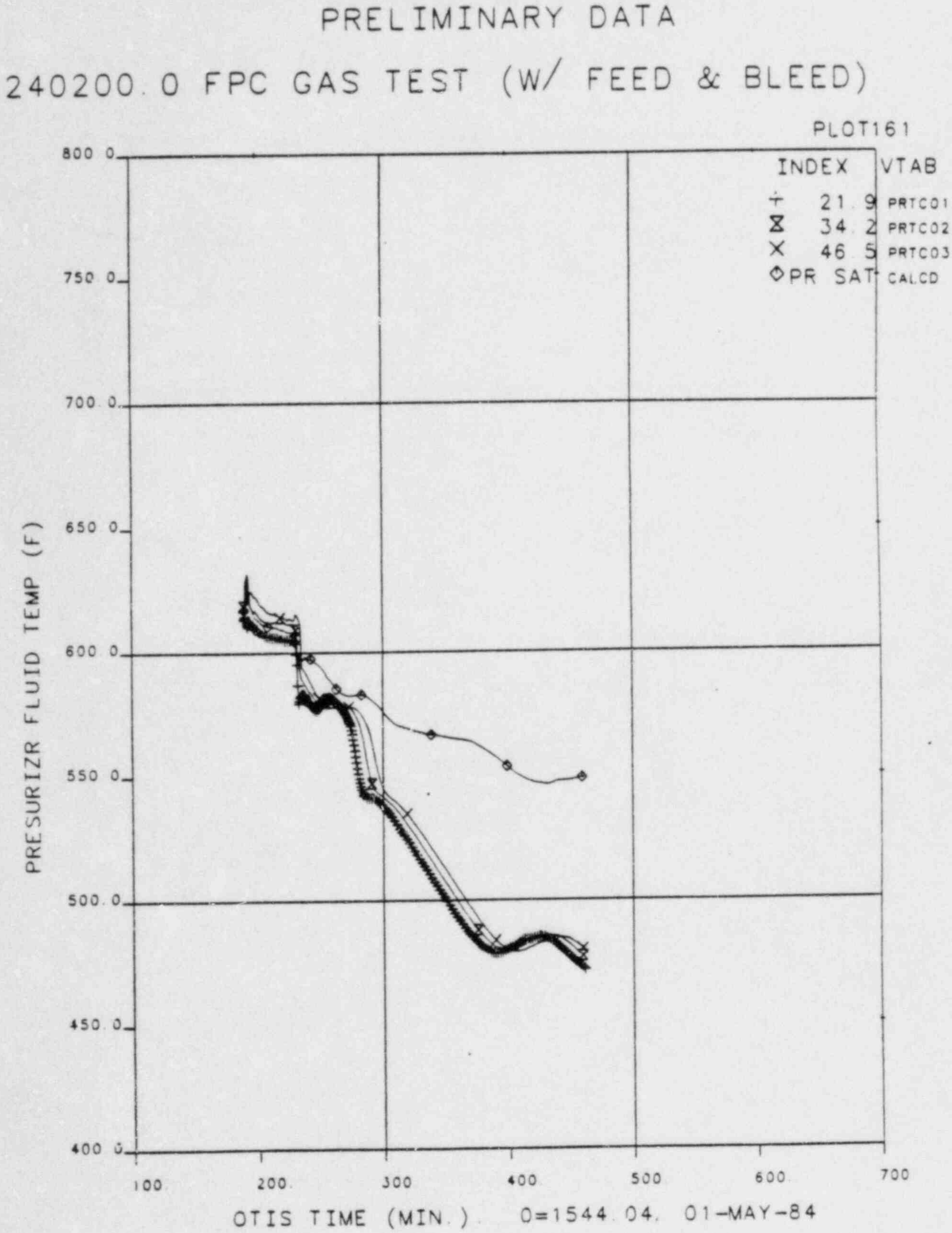


Figure 3-5p. RVVV Fluid Temperatures

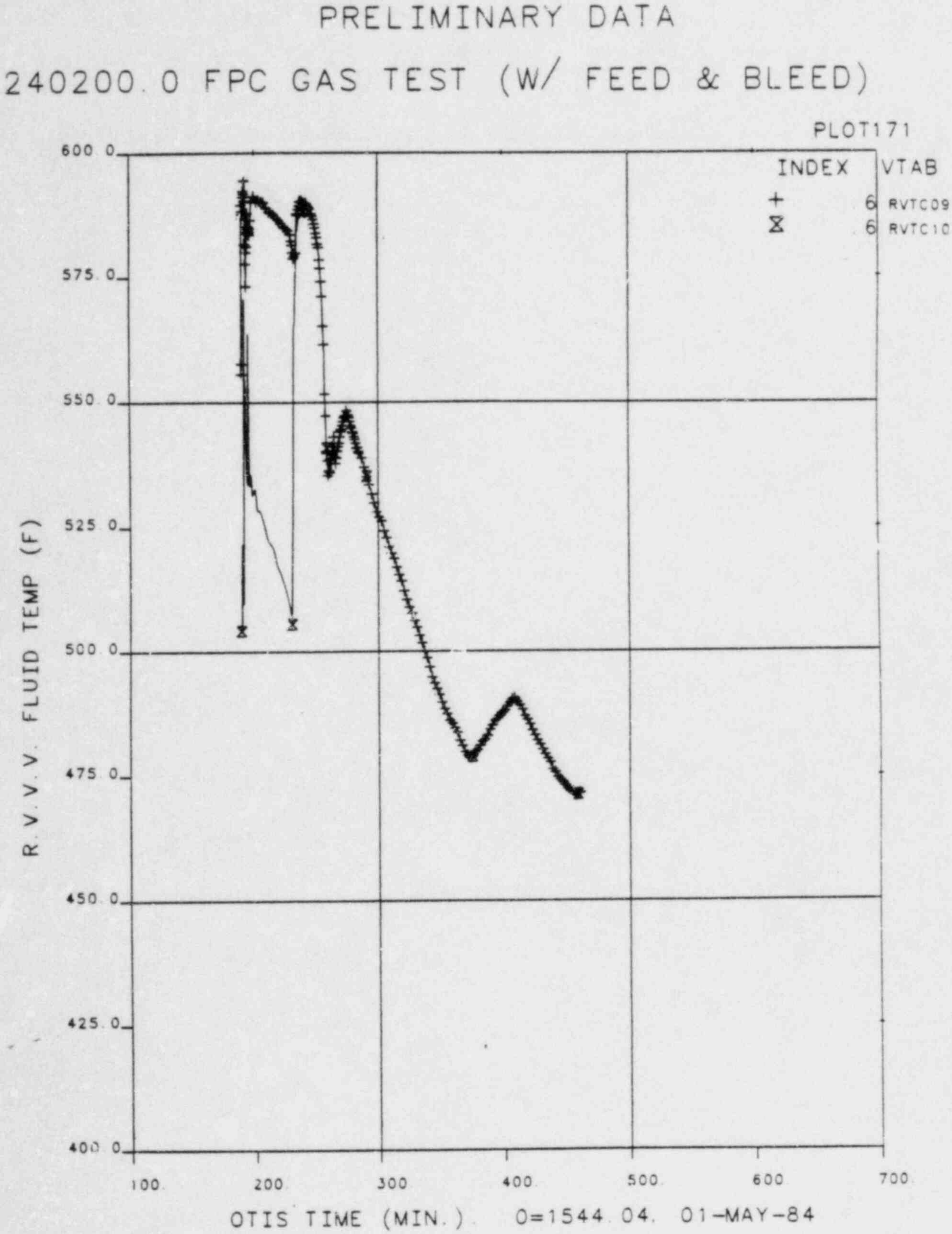


Figure 3-6. HPI-PORV Cooling With High Point Venting (Test Phase IV), and Elevated SG Secondary Level (Test Phase V)

Figure 3-6a. Pressures

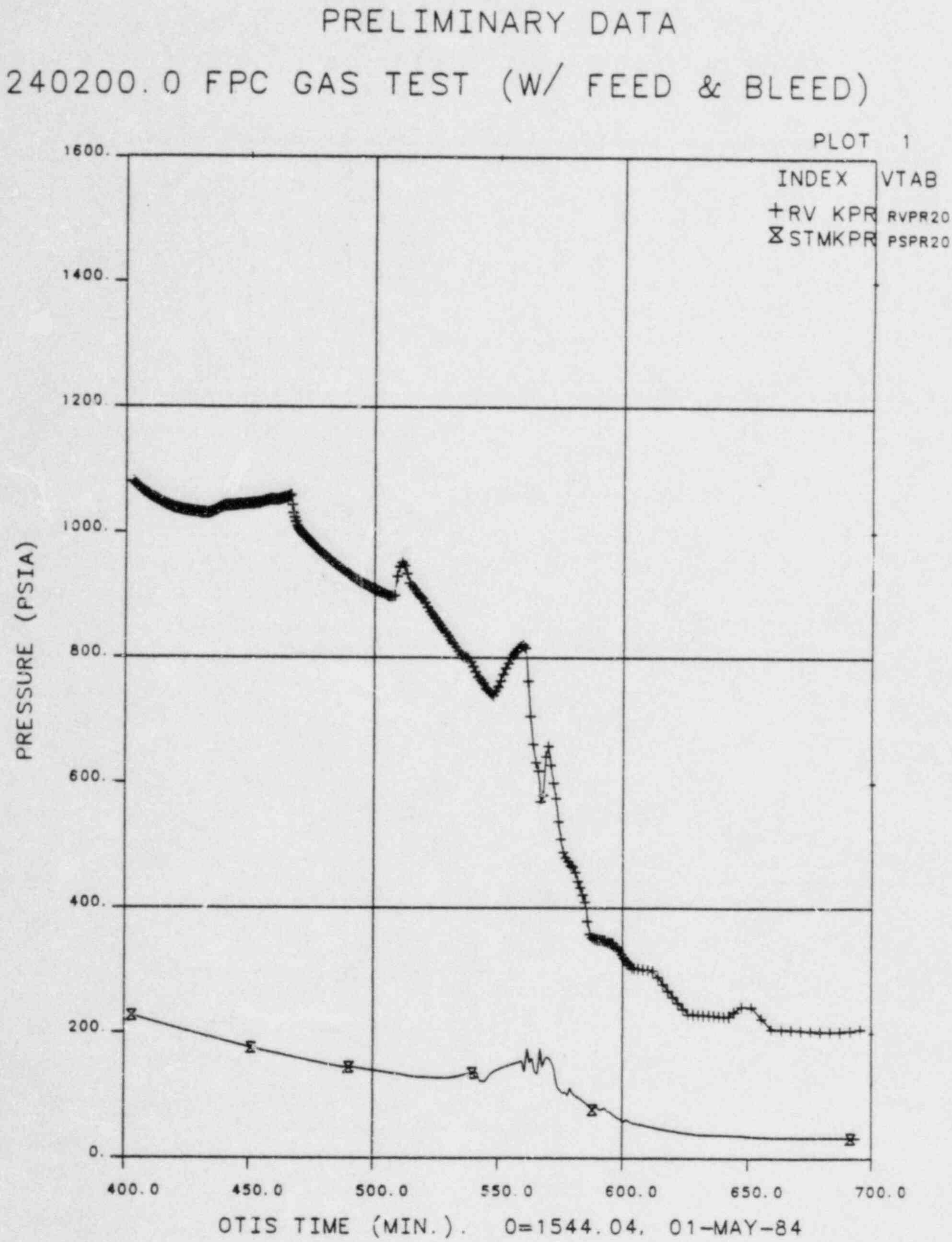


Figure 3-6b. Levels

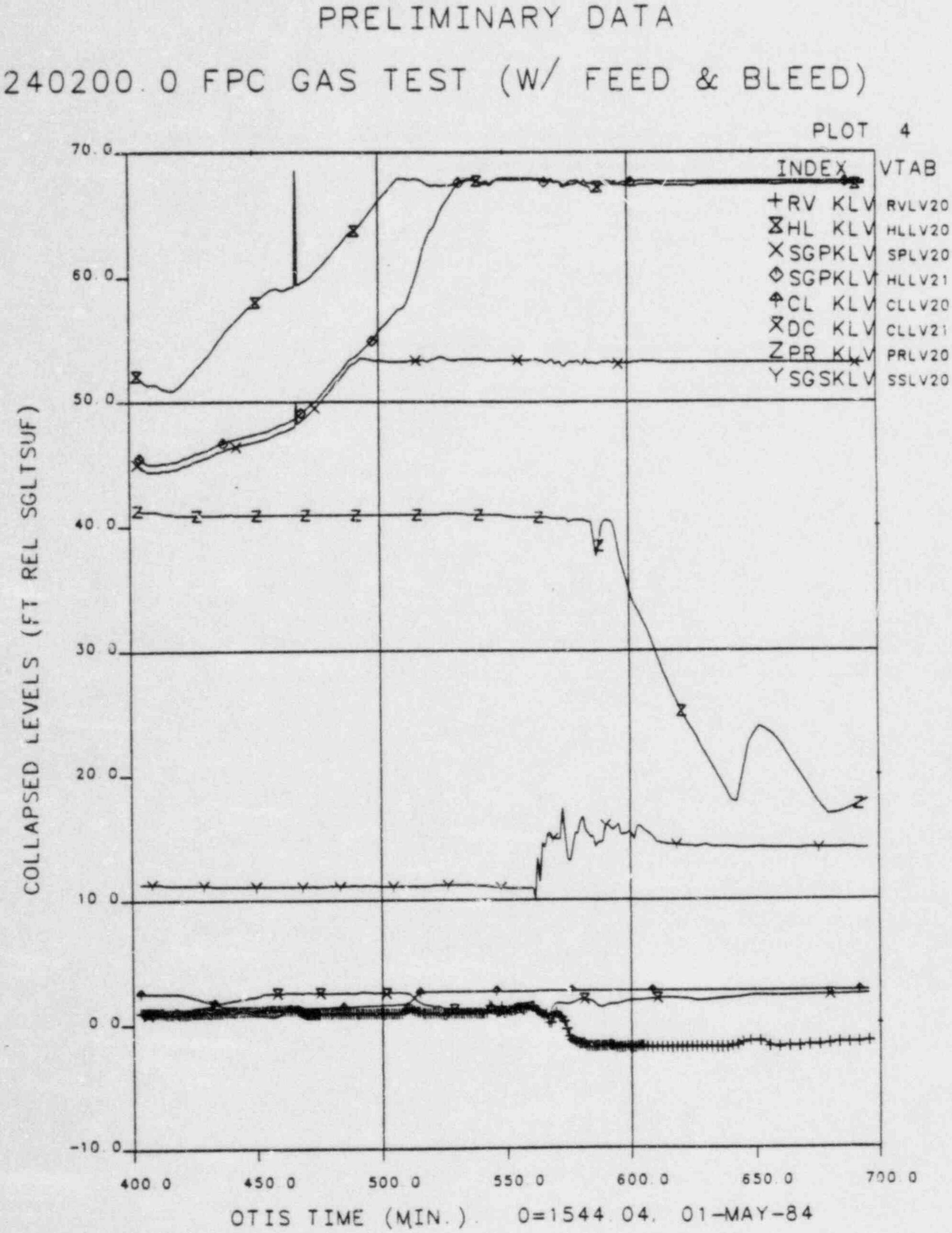


Figure 3-6c. Primary Flowrates

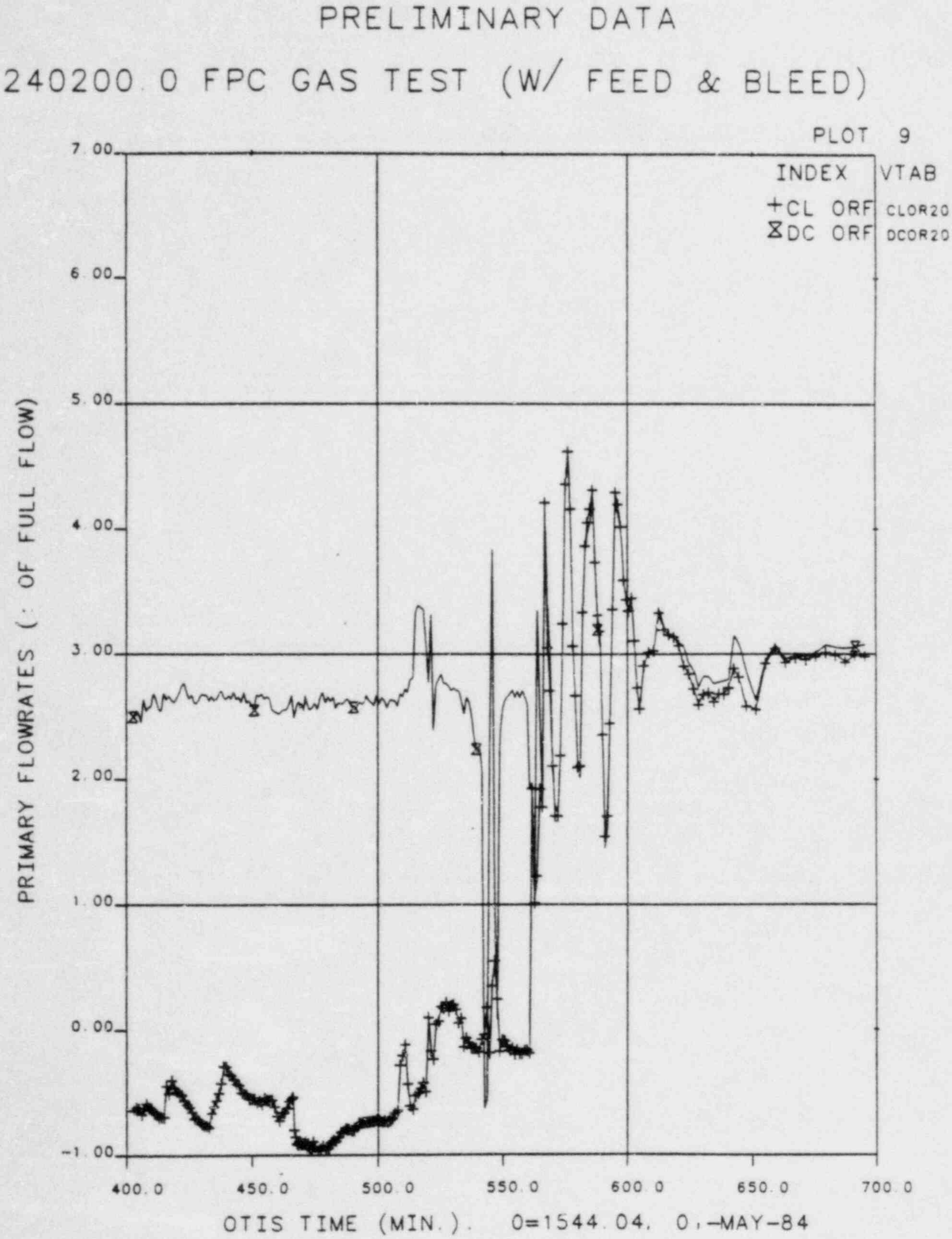


Figure 3-6d. Secondary Flowrates

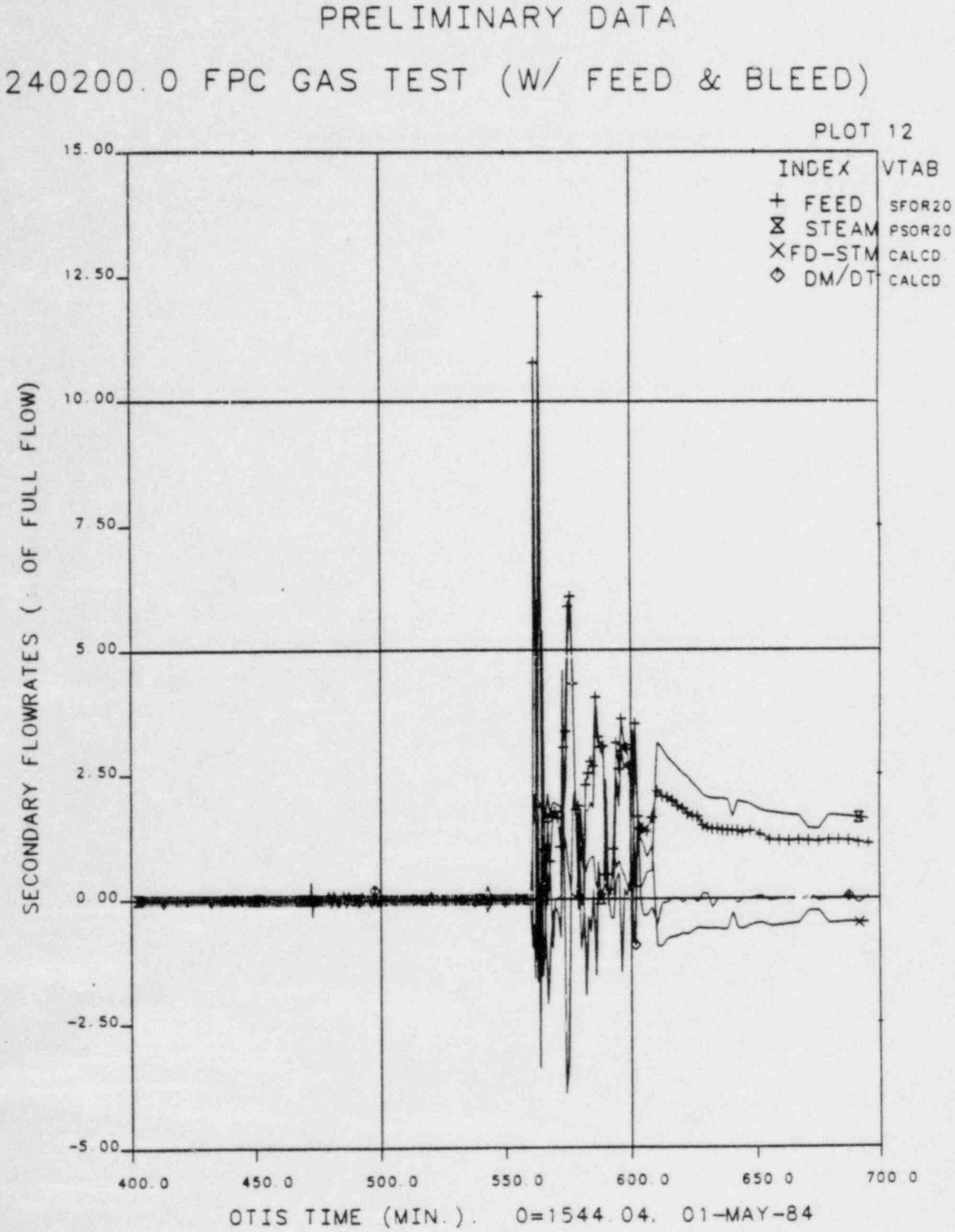


Figure 3-6e. Primary Bounda'; Mass Balance

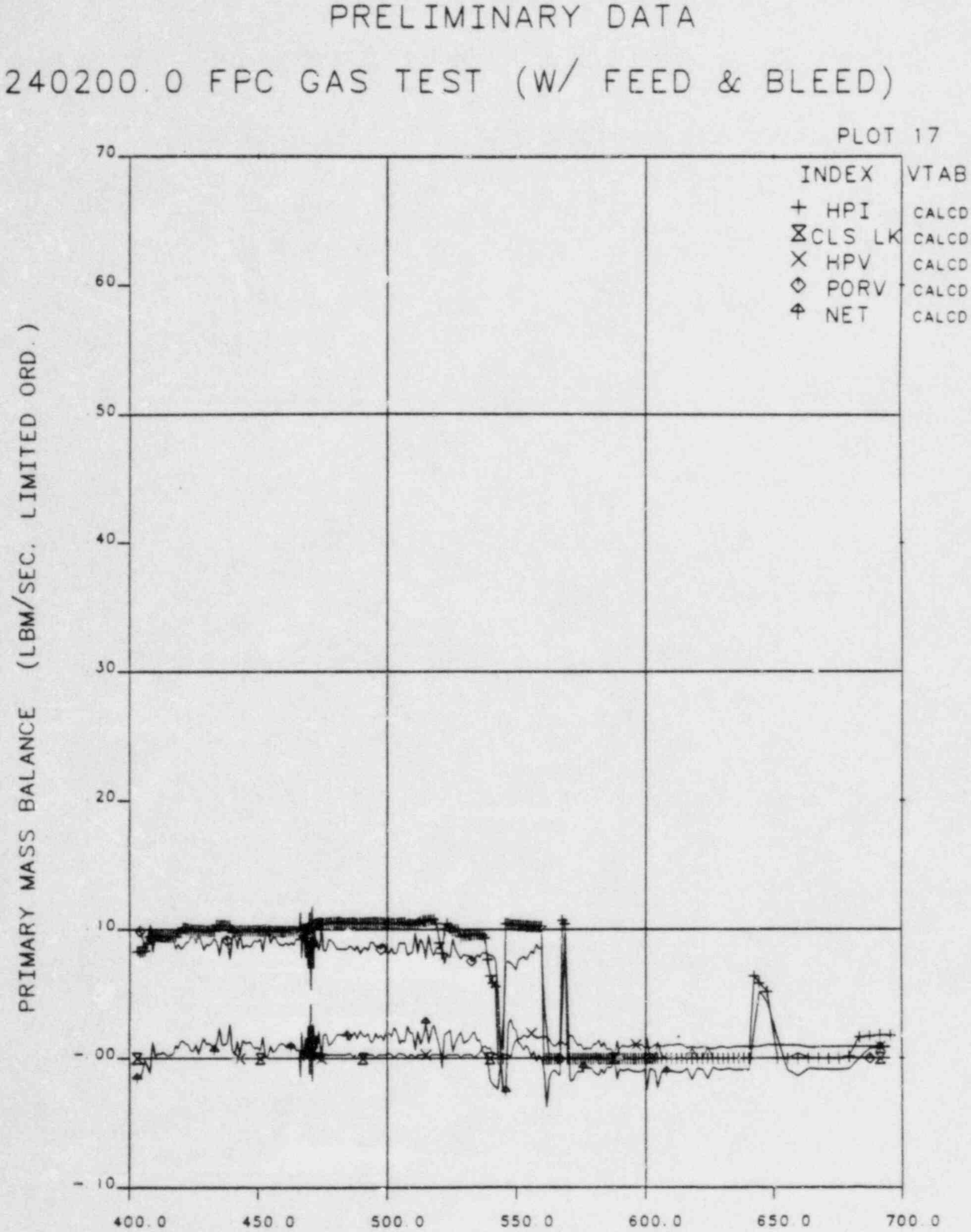


Figure 3-6f. Cumulative Primary Fluid Mass

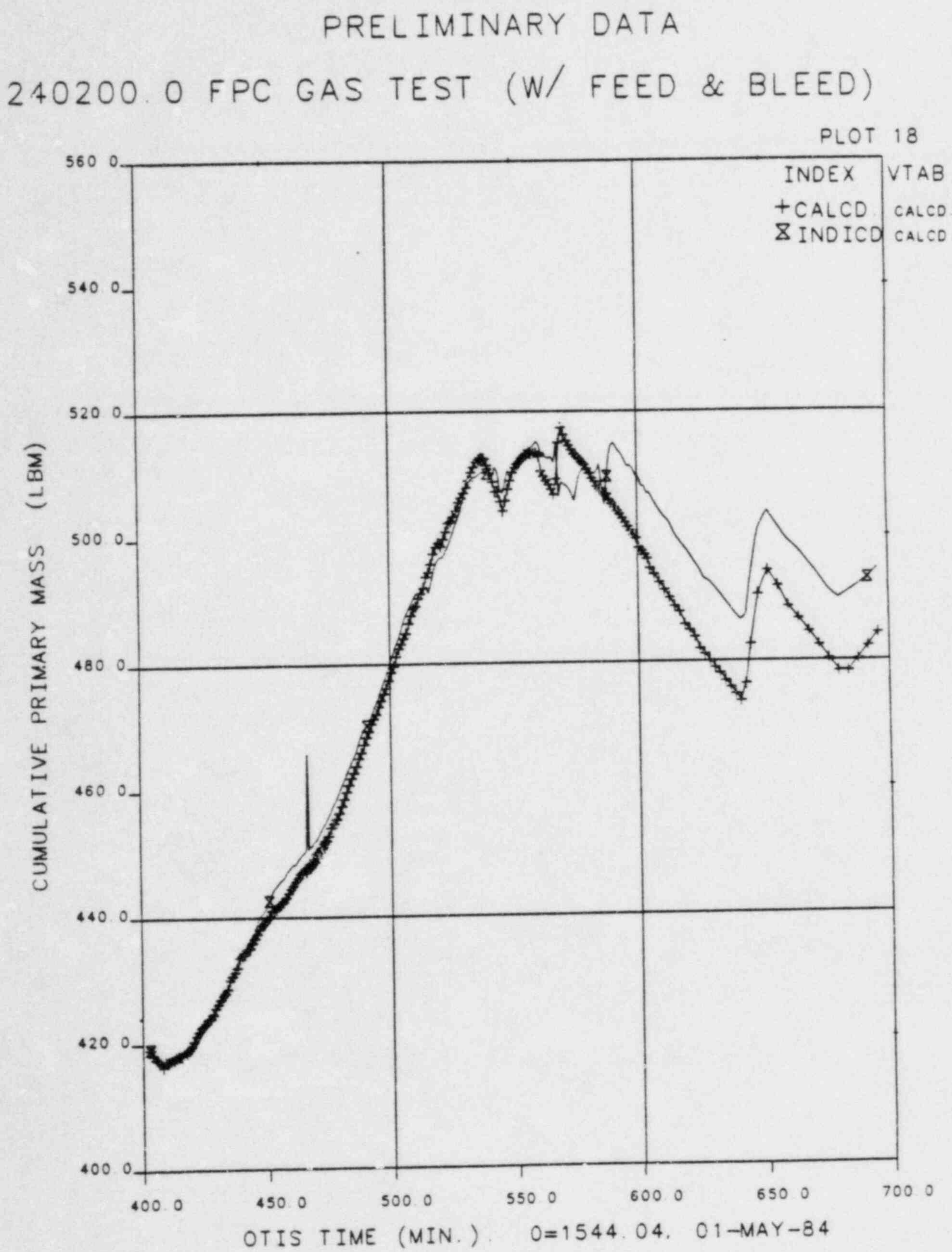


Figure 3-6g. Cold Leg Fluid Temperatures

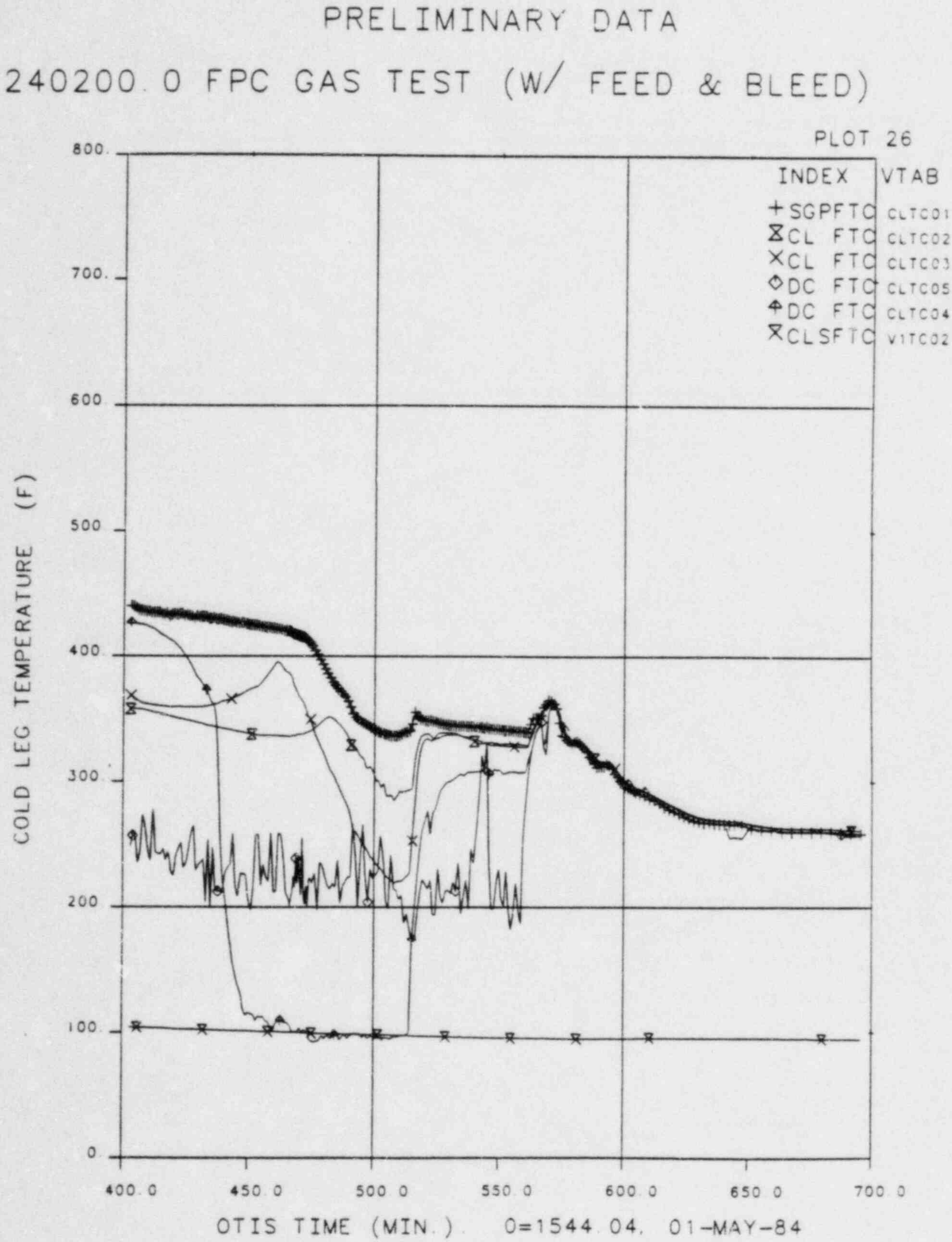


Figure 3-6h. Saturation Temperatures

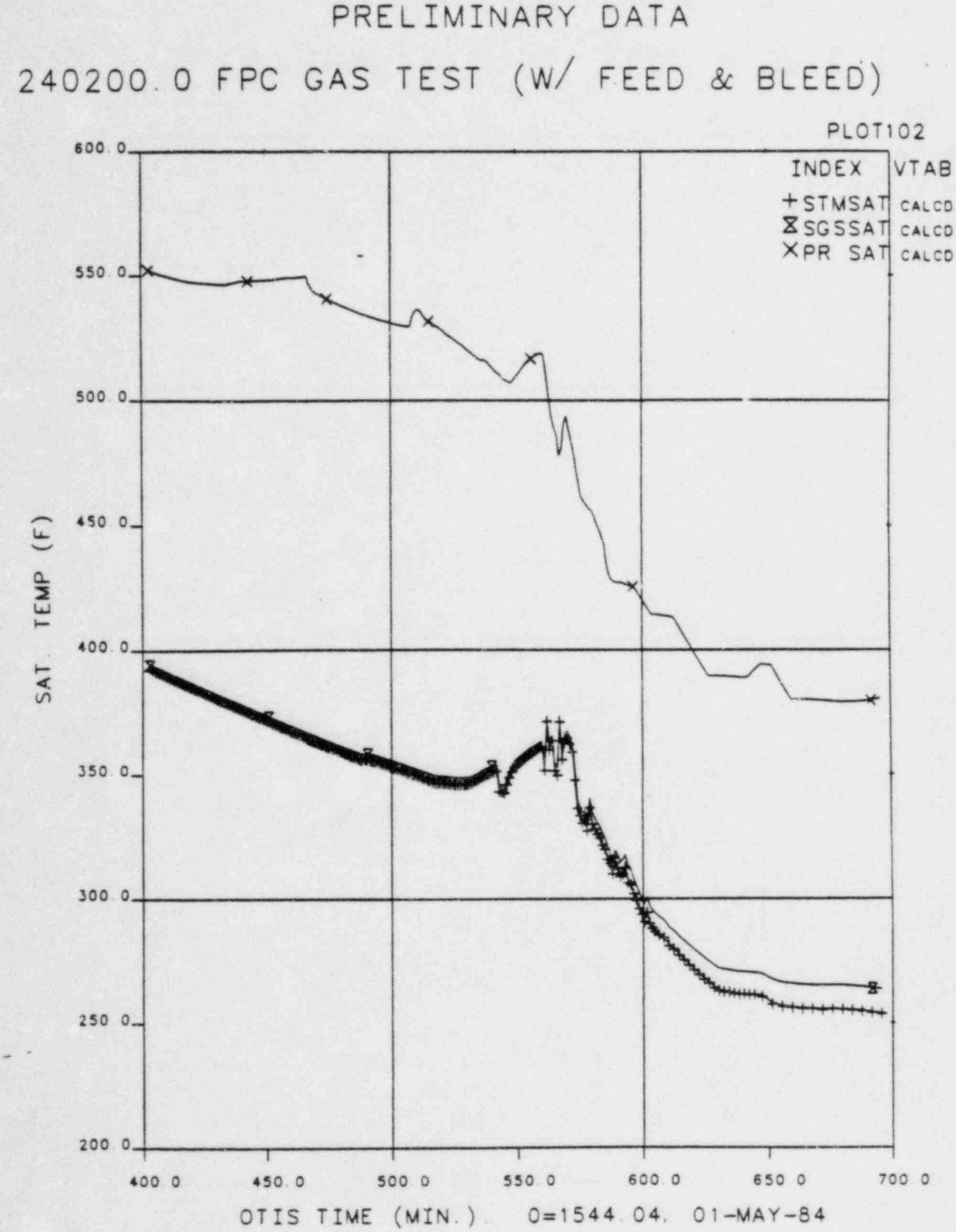


Figure 3-6i. Core Region Fluid Temperatures

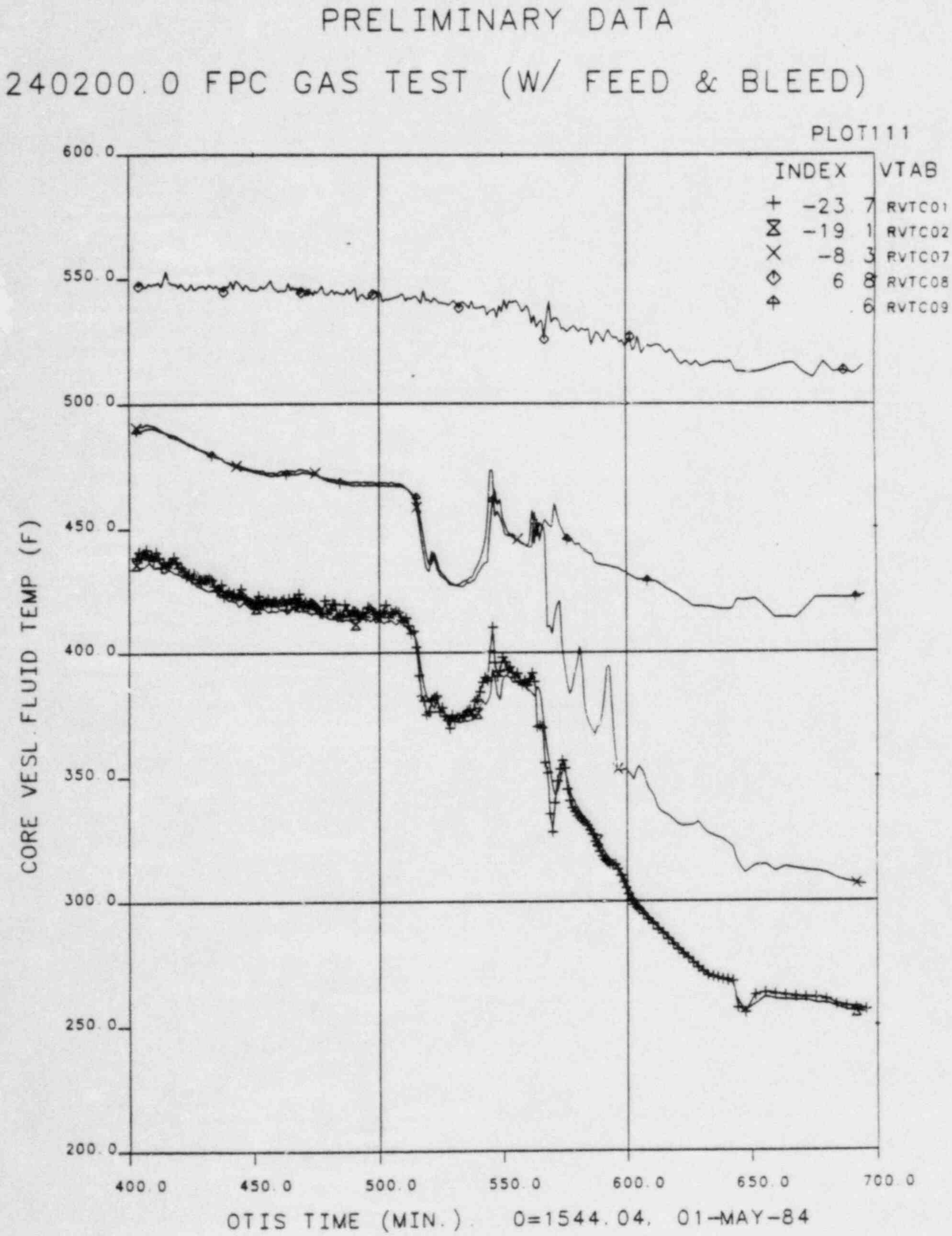


Figure 3-6j. Hot Leg Fluid Temperatures

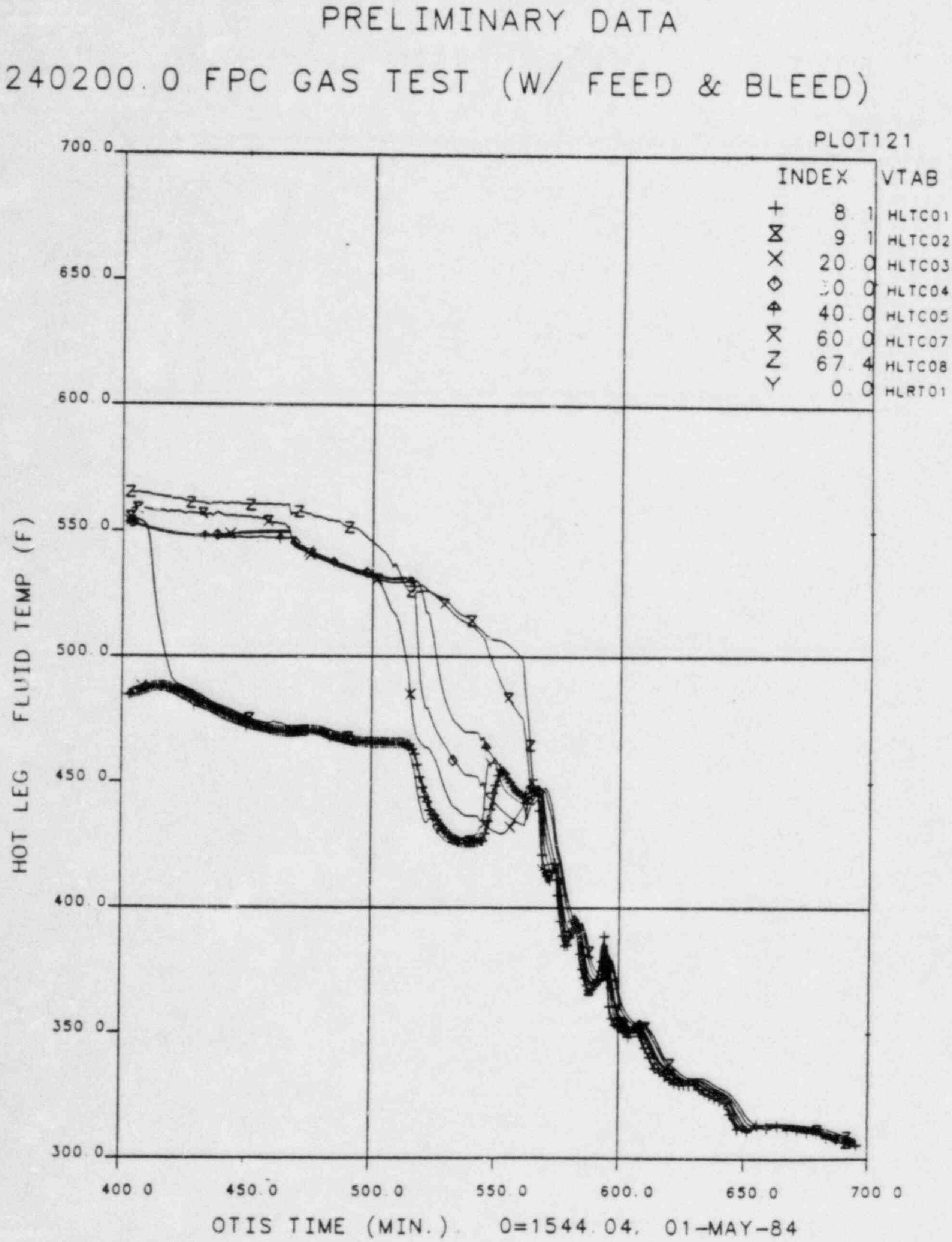


Figure 3-6k. SG Primary Fluid Temperatures

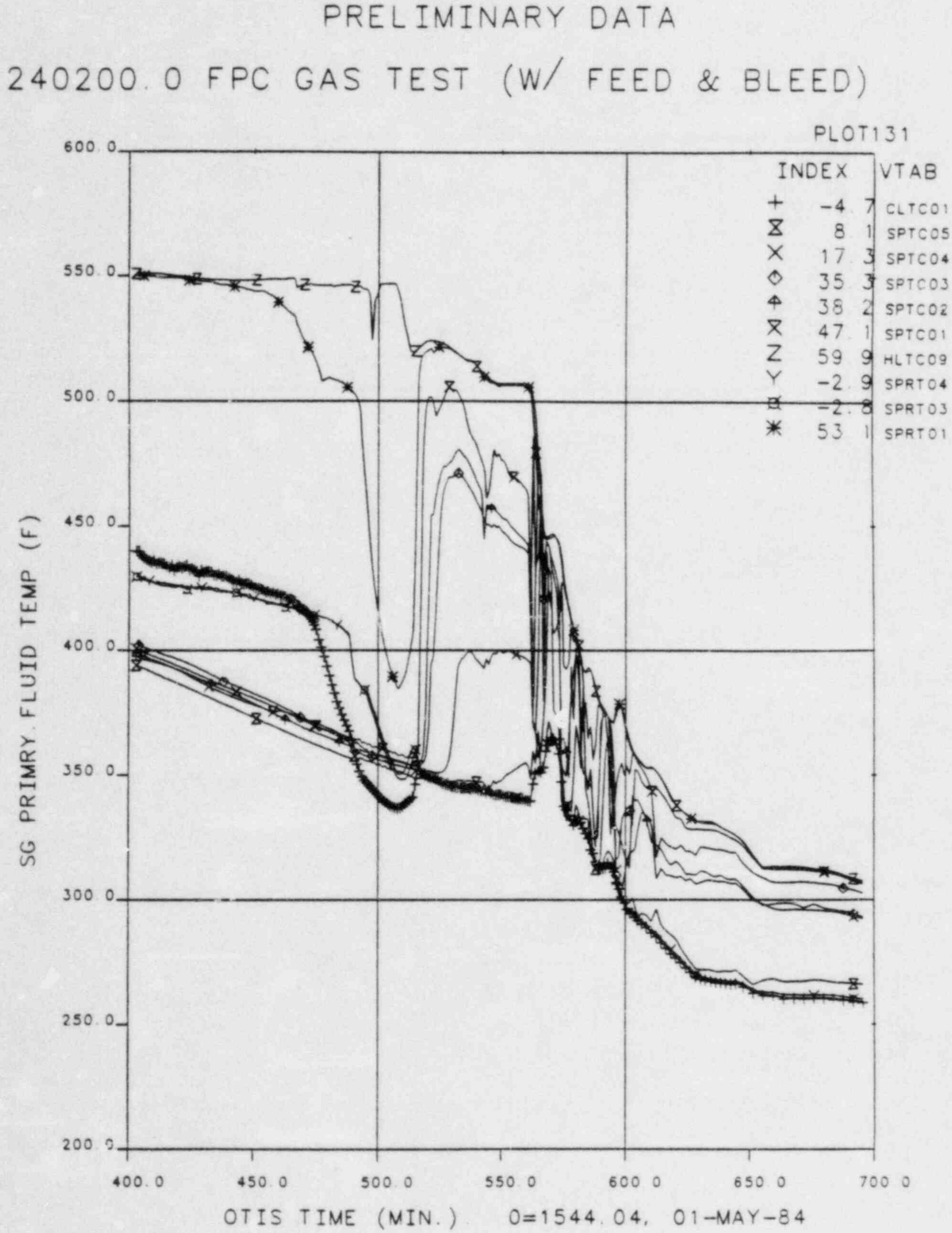
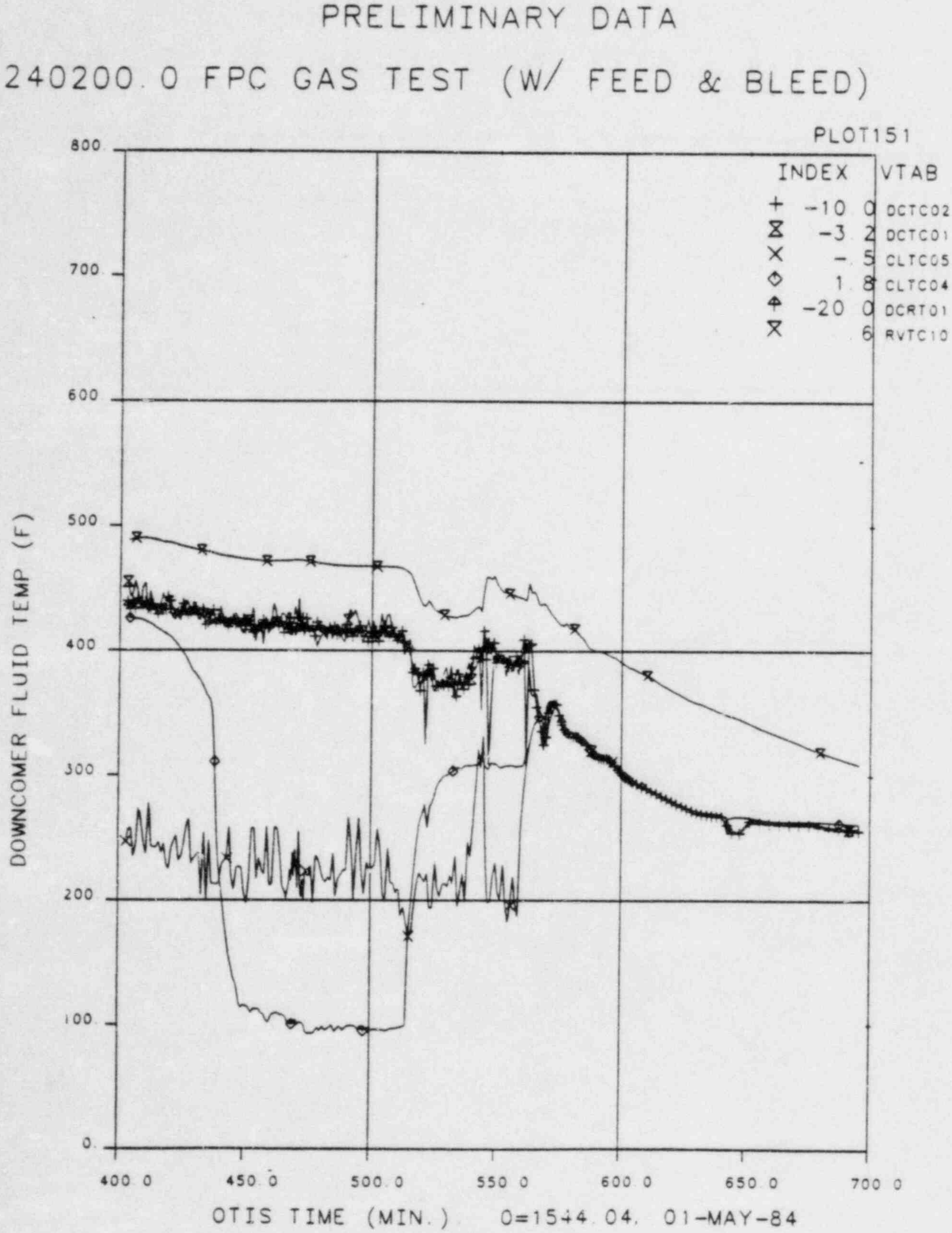


Figure 3-61. Downcomer Fluid Temperatures



Figu e 3-6m. RVVV Fluid Temperatures

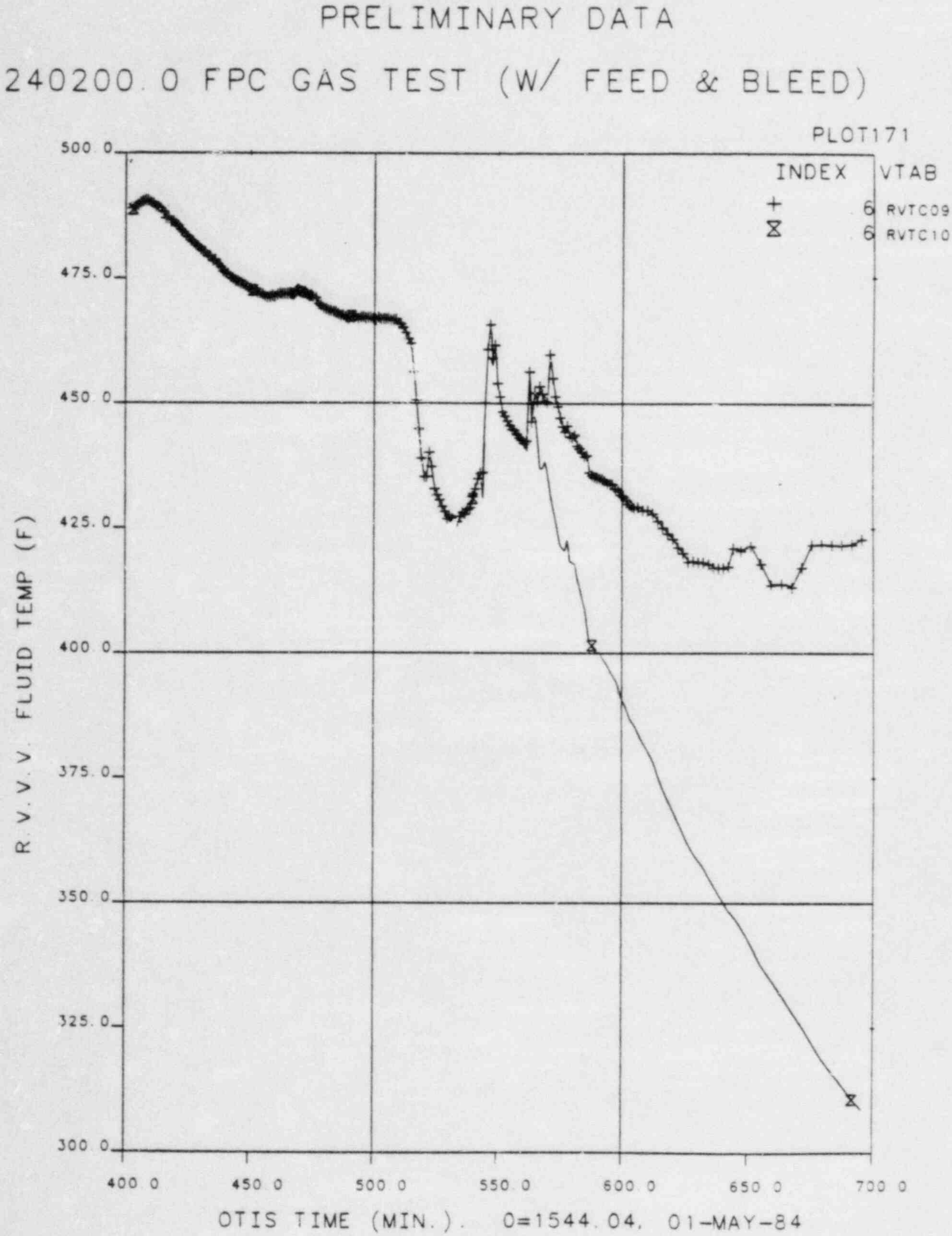
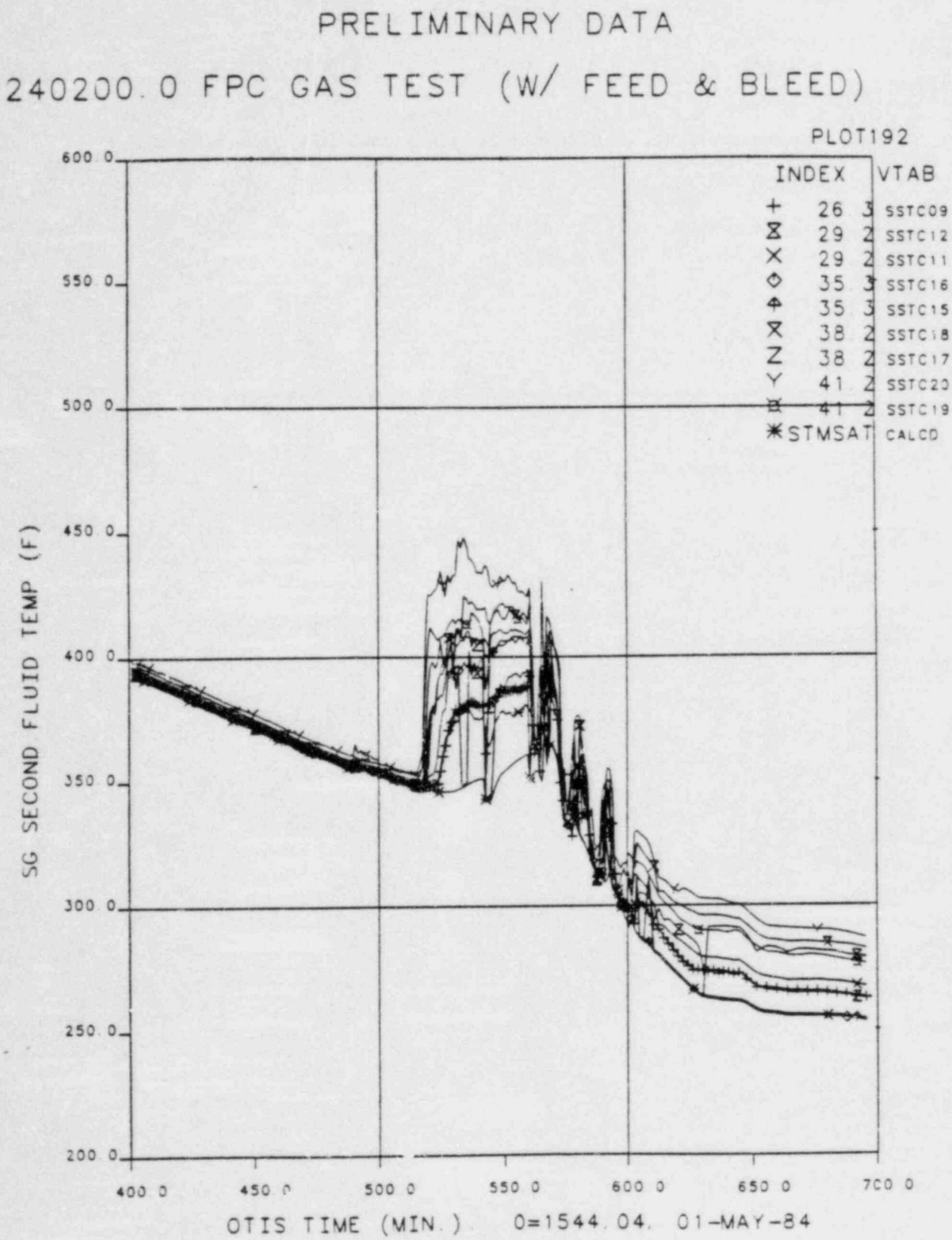


Figure 3-6n. SG Secondary Fluid Temperatures (Middle Elevation)



4.0 CONCLUSIONS

HPI-PORV cooling has been evaluated with a gas-laden loop. Lower-elevation primary fluid temperatures were reduced by roughly 200F over a 4-hour period; the saturated upper-elevation (HL and SG primary) fluid cooled more slowly and sustained primary pressure. Except for the early stages of HPI-PORV cooling, the apparent subcooling margin of the core outlet fluid (based on total pressure) was maintained between approximately 40 and 85F.

Later testing stages also used the HL High Point Vent (HPV) with concurrent HPI-PORV cooling, and later transferred from HPI-PORV cooling to SG heat transfer with an increased secondary level. HLHPV actuation accelerated the gas venting rate; then SG heat transfer regained natural circulation and was used to complete the cooldown.

APPENDIX - DATA PLOTS

1.0 INTRODUCTION AND SUMMARY

The OTIS (Once Through Integral System) data processing program is called OTIS. The program provides plots and printout of the data obtained from the OTIS test program performed at the Alliance Research Center (ARC). In addition to the data reduction routine OTIS also provides plots and printout of several derived quantities. The plots are used for assessing the performance of the OTIS test facility and for qualitatively assessing the performance of B&W raised loop plants during SBLOCA related transient conditions.

The OTIS data processing program is supplied engineering-units data from the VAX computer at ARC either electronically or via tape. The outputs from OTIS readily differentiate between supplied and derived variables by assigning no "VTAB" identifier to all derived variables.

The OTIS data processing program is a collection of subroutines whose functions are as follows:

- o List the supplied data without alternation (System Subroutine INLIST).
- o Identify the supplied variables (Subroutine SETUP).
- o Read the input (Subroutine READIT).
- o Reject meaningless data (Subroutine WEEDIT).
- o Convert the input data to the desired units (Subroutine CONVERT).
- o Derive information from the supplied data (Subroutine DERIVE).
- o Calculate mass and energy closure (Subroutine CLOSURE).
- o Perform primary system mass, energy, and fluid and vapor volume calculations (Subroutine BALANCE).
- o Print the indexed and derived data (Subroutine PRINTIT).
- o Generate basic plots (Subroutines TESTIT, STUFFIT, and PLOTIT).
- o Create general plots (Subroutine GENPLOT).
- o Plot SG temperature profiles (Subroutine PLOTVSZ).
- o Evaluate and plot SG heat transfer (Subroutine SGHTRAN).
- o Evaluate and plot natural circulation characteristics (Subroutine NATURAL).

A description of each subroutine and the function it performs is provided in Section 2. Derived quantities are identified and the formulation of the equations used in their derivation is also provided in Section 2.

This data processing program requires essentially no user input. Exceptions to this occur only when insufficient or a lack of data occurs, i.e. failure of an instrument required to determine a derived variable.

Section 3 provides a directory of plots which is the output from the OTIS data processing program. An instrument key and location diagram are given in Section 4.

2.0 PROGRAM DESCRIPTION

This section presents a description and the function of each subroutine used in the OTIS data processing computer program.

2.1 Subroutine INLIST

This subroutine provides an engineering units printout of all the OTIS test data obtained and transferred from the VAX computer at ARC.

2.2 Subroutines SETUP and READIT

These subroutines provide the necessary identification of the variables from the VAX computer at ARC and arranges the data into pre-ordered arrays.

More than 300 OTIS test variables are transferred and each variable is assigned to a numbered position within the complete table of variables. Each position is thus associated with an alpha-numeric identifier (the "VTAB" identifier), and its system, instrument, and elevation. (Instrument elevations are referenced to the upper, or secondary face of the SG Lower Tube Sheet, the "SGLTSUF"; instruments are identified in Section 4.)

Upon execution of OTIS, Subroutine SETUP sets these descriptor arrays, which are subsequently associated with the supplied variables based on their position in the VTAB variable table. An ancillary subroutine (INDEXIT) reorders the supplied variables by system, instrument, and elevation, respectively. Subroutine READIT then installs the supplied data into the pre-ordered arrays. Associated Subroutines TAPED and TEXPAND read data from tape and permit analysis of time-based subsets of the supplied data, respectively.

2.3 Subroutine WEEDIT

The electronic and immediate transfer of preliminary test data necessitates at least a coarse review of supplied data for validity. This is the function of Subroutine WEEDIT. The general constraint on input data is that it must vary at least 10^{-10} between any two successive points during the test period (the total duration of data acquisition for the testpoint being considered). Only limit-switch signals bypass the WEEDIT checks.

Separate validity checks are used for pressures, temperatures, core power, collapsed levels, and auctioneered Conductivity Probe (CP) indications.* Pressures are discarded if they are outside the range 14 to 3000 psia. Temperatures are tested against the range 32 to 1500F. Core power and collapsed levels are retained if they are ever non-zero, even if they are invariant. Finally, an auctioneered CP indication is retained if it reads both non-zero and not equal to -99.* Variables removed from the supplied data base will read identically zero (within the field length of the supplied data); "-99" is obtained when all of the CPs of the associated string indicate wetted.

A variable which is found to be invalid by the aforementioned checks is deleted from further consideration (within the calculations for the associated testpoint), and is flagged by a appropriate print statement.

2.4 Subroutine CONVERT

The input data is converted to the desired units in Subroutine CONVERT. The affected variables are: Time, power, flowrates, level, conductivity probes, limit switches, and accumulated flows.

2.4.1 Time

Each data scan has an associated scan clock-time. These times are converted to decimal minutes at input (Subroutine READIT). The clock times are then converted to minutes after test-initiation by subtracting the "reference time" (the time at which the Data Acquisition System was started for the testpoint). Therefore all variables will be keyed to time zero which is defined as the time when the data acquisition system was actuated.

*The"auctioneered" CP indicates the elevation of the highest wetted CP below which all CP's of that string are also wetted.

2.4.2 Power

The OTIS core power is converted from Kw to percent of scaled full power. The conversion factor is obtained by dividing the 205FA full thermal power of 3600 MW by the OTIS power scaling factor (1685.6)*

OTIS full scaled power = 3600 MW/1685.6 = 2136 Kw

Therefore the OTIS power conversion factor is 21.36 Kw per 1% of full scaled power.

2.4.3 Flowrates

The OTIS primary and secondary system flowrates are converted to the percent of full (scaled) flow.

The conversion factor for the OTIS primary system flowrate, based upon the simulation of a domestic 205 FA plant, is obtained as follows:

205 FA plant flowrate at 100% flow = 157.4×10^6 lbm/hr

OTIS primary system scaled flowrate at 100% flow
= 205 FA Plant Flow Rate at 100% Flow/OTIS Power Scaling Factor
= (157.4×10^6 lbm/hr)/(1685.6x3600 sec/hr)
= 25.94 lbm/sec (for 100% or full scaled flow)

Therefore the OTIS primary flowrate conversion factor is 0.2594 lbm/sec per 1% of full scaled flow.

The conversion factor for the OTIS secondary system flowrate, based upon the simulation of a domestic 205 FA plant, is obtained by dividing the 205 FA plant secondary flowrate by the OTIS scale factor.

*The OTIS power scaling factor is defined as:

S = Total number of steam generator tubes in a 205 FA plant/Total number of steam generator tubes in OTIS
= 16013x2/19
= 1685.6

OTIS secondary system scaled flowrate at 100% flow

$= (16.1 \times 10^6 \text{ lbm/hr})/(1685.6 \times 3600 \text{ sec/hr})$

$= 2.653$ lbm/sec

Therefore the OTIS secondary flowrate conversion factor is 0.02653 lbm/sec per 1% of full scaled flow.

Primary boundary flowrates (leak, HPI, etc.) are converted from lbm/hr to lbm/sec. Pitot tube indicated flowrates are converted to equivalent Primary flowrate; the input flowrate (lbm/hr) is multiplied by the number of SG tubes (19), multiplied by the inverse of the approximate integral of the 1/7th-power velocity profile over the SG tube area subtended by the Pitot tube (0.847), and divided by the conversions to obtain % of full Primary flow (0.259 lbm/sec per % full flow).

2.4.4 Collapsed Levels

Input collapsed levels are referenced to the SG Lower Tube Sheet Upper Face (SGLTSUF) using the elevation of the appropriate lower level tap. (Corrections for thermal expansion are applied elsewhere). The supplied Hot Leg level downstream of the HLUB is combined with the input SG Primary level to obtain the composite collapsed level on the SG side of the HL U-Bend.

2.4.5 Miscellaneous Conversions (CP, LS, and Accumulated Flow)

The auctioneered CP is supplied as "-99" when all probes of that string indicate wetted. To limit the scale of the CP-plot ordinates, auctioneered CP (elevation) indications are limited to not less than the lowest elevation of the probed component. (The "auctioneered" CP is discussed further in Paragraph 2.5.3).

Limit switches (LS) are arbitrarily offset 0.02 each, to separate their plots for readability.

Accumulated flowrates are converted from gallons to lb_m by multiplying by $(62.4 \text{ lbm/ft}^3)/(7.481 \text{ gal./ft}^3)$.

2.5 Subroutine DERIVE

This subroutine is used to derive additional indicators of testing behavior. The derived quantities are obtained by combining various supplied variables. The derived quantities include: Component average temperatures, Secondary saturation temperatures, fluid properties, CP indication corrected for thermal expansion, flowrate from accumulated flow, Primary system boundary flowrates, and differenced Secondary flowrates.

2.5.1 Component Average Temperatures

Component average temperatures (for each data scan time) are formed for the Primary system components and for the SG Secondary. Primary components include the Reactor Vessel (RV), Hot Leg (to the HL U-Bend Spillover), SG Primary (including the HL downstream of the HL U-Bend), Cold Leg, Downcomer, and Pressurizer. All available fluid thermocouples and resistance temperature detectors are used. (Averaging is performed in the ancillary Subroutine PROPS).

2.5.2 Subroutine PROPS

Liquid and vapor properties are determined for each Primary Component (RV, HL, SGP, CL, DC, and Pr) and for the SG Secondary. Properties include density and enthalpy. Determinations are made in Subroutine PROPS which calls the system subroutines ZZP and ZZTP, portions of the STP package. The STP package is self-consistent. Each property determination, irregardless of the supplied state properties, iterates about a single saturation state. Subroutine PROPS obtains volume-weighted liquid temperature, as well as volume-weighted liquid and vapor densities and enthalpies. The subroutine is written in four parts: (1) Initialization, (2) Temperature sorting, (3) Liquid region calculations, and (4) Vapor region calculations. Subroutine PROPS is called once for each loop component (Reactor Vessel, Hot Leg, Steam Generator Primary, Cold Leg, Downcomer, Pressurizer, and Steam Generator Secondary). Initialization thus consists of identifying the temperature sensors for the current component, using sensor elevation to find fluid volume up to this elevation (subroutine VOLFMZ), and ordering these temperature indications by increasing elevation (and the volume encompassed). This arrangement of temperature sensors is then used for the time-based evaluations. The first calculation at each time obtains saturated liquid and vapor properties at the current primary pressure, for use as bounding properties.

2.5.2.1 Liquid-Vapor Interface

The current (by-component) collapsed liquid level is used to estimate the liquid-vapor interface. Temperature sensors below the collapsed level are assigned to liquid-region calculations, the remaining sensors are assigned to the steam-region calculations. If there are no liquid-region temperature indications, the component is assumed to be steam filled and the liquid-region calculations are bypassed. Similarly, if the component is apparently liquid filled, only the liquid-region calculations are used.

2.5.2.1.1 Liquid-Region Calculations

The liquid-region calculations are considered in 4 parts: (1) Bottom liquid volume, (2) intermediate liquid volume, (3) top liquid volume at the top of the component, and (4) top liquid volume but with steam above. Each of these types of calculations requires the determination of a local temperature (T_i) and a local fluid volume (V_i) over which this temperature applies. Local volume is used to weight each of the three local properties: local temperature, density, and enthalpy; density and enthalpy are obtained from Subroutine ZZTP using the current primary pressure and the local temperature T_i. (If ZZTP finds that the state is indeterminate, usually because T_i and p approximately define saturation, the appropriate liquid or vapor saturation properties are substituted). Cumulative volume, and volume-weighted temperature, density, and enthalpy, are calculated at each time step; the final properties are these accumulated sums divided by the accumulated volume.

1. Lowest Liquid Volume

   Volume is set equal to the volume up to the lowest sensor; temperature is taken from the lowest sensor, but limited to TSAT- = TSAT - 0.001, or less.

2. Intermediate Liquid Volume

This calculation is bypassed if only one sensor is in liquid. The number of intermediate liquid region volumes is one less than the number of liquid-region sensors. For each pair of liquid-region sensors, the temperature is taken from the average of the two, and the volume is obtained from the difference of the fluid volume at the higher sensor less that at the lower. The calculation is repeated over each pair of liquid-region sensors.

3. Highest Liquid Volume, No Steam

This calculation is bypassed if there are any steam-region temperatures. Temperature is the (single) indicated temperature, limited to TSAT -. Volume is component total fluid volume less the volume up to the highest sensor.

4. Highest Liquid Volume, Steam Above

Volume is the difference between volume to the collapsed liquid level and the volume up to the highest liquid-region sensor. Local temperature is the average of the indication from the highest-elevation liquid-region sensor (limited to TSAT-), and TSAT-.

2.5.2.1.2 Vapor-Region Calculations

If there are no vapor-region sensors, these calculations are bypassed. Vapor-region property calculations are analogous to those of the liquid region, and are also performed in four categories: (1) Lowest steam volume with liquid below, (2) Lowest steam volume but no liquid present, (3) Intermediate steam volume, and (4) Highest steam volume.

1. Lowest Vapor Region, Liquid Below

If there are no liquid-region sensors, this calculation is bypassed. Local volume is the volume up to the lowest vapor-region sensor minus the total liquid volume. Local temperature is the average of TSAT + = TSAT + 0.001 and indicated temperature (limited to TSAT+).

2. <u>Lowest Steam Volume, No Liquid</u>

This calculation is bypassed if there are any liquid-region temperatures. Local volume is the component fluid volume up to the lowest sensor. Local temperature is as indicated by this sensor, limited to TSAT+ or greater.

3. <u>Intermediate Steam-Region Volume</u>

This calculation is performed only if two or more temperature sensors are in the steam region. The calculation is repeated for each sequential pair of steam-region sensors, lowest to highest. Local volume is volume up to the higher sensor minus volume up to the lower sensor. Local temperature is the average of the two indicated temperatures, each limited to TSAT+ or greater.

4. <u>Highest Steam-Region Volume</u>

Local volume is total component fluid volume minus volume up to the highest-elevation sensor. Local temperature is as indicated by the highest (elevation) sensor.

<u>Summary</u>

PROPS calculates the following volume-weighted properties for each component, and at each time increment:

Liquid temperature,
Liquid density and enthalpy, and
Vapor density and enthalpy.

Temperature-sensor elevations and component volume-versus-elevation, as well as collapsed liquid level, are used to form these volume-weighted properties. Calculation sensitivity is limited to the maximum elevation span of component level indication. Properties for a state (liquid or vapor) apparently not present in the component default to the corresponding saturation properties.

2.5.3 Modification of Conductivity Probe Indications for Thermal Expansion

The "auctioneered" Conductivity Probe (CP) signal indicates the (unheated) elevation of the highest wetted CP below which all CPs of that string are also wetted. These indications are modified for thermal expansion by applying the appropriate material properties and component (fluid) average temperatures. This calculation is slightly encumbered by the juxtaposition of three materials in the OTIS loop -- Carbon Steel in the steam generator, Inconel 600 in most of the 60.5' vertical run of the Hot Leg, and Stainless Steel (SS 304) elsewhere; the respective thermal expansion coefficients are 6.85, 7.78, and 9.37, $\times 10^{-6}$ ft/ftF.

2.5.4 Flowrates From Accumulated Flows

Accumulated flows recorded at the Single Phase Venting, High Point Venting (HPV), and Relief Systems are differenced, and divided by the duration of the corresponding time increment to obtain flowrates.

2.5.5 Primary System Boundary Flowrates

HPI (High Pressure Injection) and total Primary system boundary flowrates are determined on the basis of the supplied indications. Total Primary system boundary flowrate is the difference between this HPI flowrate and sum of the Single Phase Venting System flowrate (assigned to one of the liquid-region leak sites), the High Point Vent flowrate, and the Relief flowrate.

2.5.6 Secondary System Derivations

Feed flowrate minus steam flowrate is installed as a derived indication. Also, two SG Secondary saturation temperatures are determined. Steam saturation temperature is found (using Subroutine STP, as before) at the current indicated steam pressure; maximum SG Secondary saturation temperature is found at the total pressure at the bottom of the SG, i.e. steam pressure plus the density head of the current collapsed Secondary level (this saturation temperature increase, usually resulting from 26' of liquid, is only a few degrees F but it is useful in the analysis of the SG temperature profiles).

The SG Secondary Outlet (steam) enthalpy is found (again using STP) at the highest current SG Secondary temperature (and indicated steam pressure). This highest-temperature feature is required to mitigate the effects of heat losses to ambient from the SG Outlet steam piping.

2.6 Subroutine CLOSURE

This subroutine determines the fluid mass, energy and their rates of change for the various components (RV, HL, SGP, CL, DC, PR and SG) and for the entire system. The component and system mass and energy content, as determined by this subroutine, are defined as the "indicated value" and are obtained by combining supplied and derived information.

2.6.1 Fluid Volume

The indicated collapsed liquid level (Section 2.4.4) and the average fluid temperature (Section 2.5.1) for each component are used to determine the volume of liquid contained in each component, and the current liquid fraction (% of full). Component volume-versus-elevation tables are corrected for thermal expansion (using component average fluid temperature and the appropriate linear expansion coefficients), and interpolated using the current collapsed liquid level to obtain an apparent liquid volume. These calculations are performed in the ancillary subroutine VOLFMZ. This apparent liquid volume is divided by component total volume to obtain the apparent liquid fraction, expressed as percent of full. The liquid volumes of the Primary system components are summed to obtain Primary liquid volume, and divided by total Primary volume to obtain Primary System liquid fraction.

2.6.2 Fluid Mass and Rate of Change

Because the apparent liquid volume (Section 2.6.1) is based on collapsed liquid level, it approximately reflects the volume of liquid required to match the sensed liquid elevation head. Thus the contained fluid mass is the product of contained fluid volume and the liquid density. The total Primary fluid mass is the sum of the Primary System component fluid masses. The mass rate-of-change is obtained by differencing the fluid masses between sequential time scans and dividing by the corresponding time between scans (mass rate-of-change at the first scan is arbitrarily set to zero, derivatives are installed at the time corresponding to the end of each time increment).

2.6.3 Inter-Component Flowrates

The Primary flowrate from one component to the next component is estimated based on the indicated Downcomer flowrate (obtained from the DC orifice flowmeter). The flowrate from the RV to the HL, ($\dot{m}$-RV), is the DC flowrate minus the Reactor Vessel Vent Valve (RVVV) flowrate, minus the RV fluid mass rate of change (dm/dt). Calculations proceed similarly from component to component around the Primary loop.

The primary flowrate from the HL to the HL U-Bend, $\dot{m}$-HL, is $\dot{m}$-RV (the flowrate from the RV to the HL) minus dm/dt-Pressurizer, minus dm/dt-HL, minus the Pr relief flowrate if any. The flowrate from the SG Primary to the Cold Leg, $\dot{m}$-SG, is $\dot{m}$-HL minus dm/dt-SG Primary and minus the HPV (High Point Vent) flowrate if any. The flowrate from the CL to the DC, $\dot{m}$-CL, is $\dot{m}$-SG plus HPI (High Pressure Injection) flowrate, minus CL Discharge leak rates, minus dm/dt-CL. Finally, the Primary flowrate from the DC to the RV, $\dot{m}$-DC, is $\dot{m}$-CL plus the RVVV flowrate minus dm/dt-DC (this flowrate should agree with the starting flowrate indicated by the DC Orifice flowmeter).

2.6.4 Heat Loss

Component heat losses are determined from component fluid average temperatures (Section 2.5.1). Each component is supplied a heat-loss function of the form:

CONSTANT X (TAVG - TZERO)

where TAVG is the component average fluid temperature, and the constant and intercept (TZERO) are determined from the OTIS heat loss tests. Hot Leg heat loss calculations are keyed to the HL Guard Heaters. If the supplied HL insulation temperature difference is negative, the Guard Heaters are assumed to be on and the HL heat loss is nulled.*

*The indicated insulation temperature difference, inside minus outside, is customarily much greater than zero with the guard heaters off, and vice versa.

2.6.5 Power: Available Primary Power, and SG Primary and Secondary Heat Transfer Rates

Comparisons of available and transferred power levels are useful for the evaluation of energy flow, storage and leak-HPI (High Pressure Injection) cooling effects. Available Primary power is Core power minus Primary system heat losses (Section 2.6.4).

SG Primary extracted power is the difference between the energy being convected into and out of the SG Primary. The flowrates for this calculation are the Primary System inter-component flowrates (Section 2.6.3). The specific energies being convected are calculated at the SG Primary pressure (or at another Primary pressure if the SGP pressure is not supplied); temperatures for this calculation are obtained from the SG Primary Inlet and Outlet RTDs (Resistance Temperature Detectors).

SG Secondary extracted power is calculated analogously to that of the SG Primary, except that SG Secondary heat losses are also included. SG Secondary extracted power is the steam flowrate times the steam enthalpy (determined at the highest SG Secondary temperature (Section 2.5.6), minus the product of feedwater flowrate and the feedwater enthalpy, plus the SG Secondary heat losses to ambient (Section 2.6.4).

The Primary available, SG Primary extracted, and SG Secondary extracted, should be coincident under steady state conditions when the Primary boundary systems are inactive. Any major differences in these powers would indicate Primary system boundary heat removal, and/or energy storage.

2.6.6 Fluid Energy and Rate of Change

Fluid energy and rate of change (de/dt) are estimated for each Primary System component (RV, HL, SG Primary, CL, DC, and Pressurizer), for the overall Primary, and for the Secondary. The rate of change of fluid energy may be compared to the three inter-system heat transfer rates (Paragraph 2.6.5), but it should be recalled that metal storage is not explicitly considered in these calculations.

Calculation of component fluid energy involves a combination of available quantities. The contained fluid energy is the sum of the liquid energy content and that of the vapor. Liquid energy content is the product of liquid mass (Paragraph 2.6.2) and liquid enthalpy (Paragraph 2.5.2.1.1). Similarly vapor energy is the product of vapor mass and vapor energy. The vapor mass is determined as follows:

Vapor mass (M_v) is vapor volume (V_v) times vapor density (ρ_v)

$$M_v = V_v \times \rho_v .$$

Vapor volume is total volume less liquid volume

$$V_v = V - V_l .$$

Because liquid volume has not been retained, but rather liquid mass (M_l) and liquid volume fraction (R_l), it is convenient to express total volume as liquid volume divided by liquid volume fraction

$$V = V_l / R_l ,$$

and to express liquid volume as the ratio of liquid mass (M_l) to liquid density

$$V_l = M_l / \rho_l$$

Then the expression for vapor mass is

$$M_v = V_v \times \rho_v$$

$$M_v = (V - V_l)\rho_v$$

$$M_v = (V_l/R_l - V_l)\rho_v$$

$$M_v = V_l \ (1/R_l - 1)\rho_v$$

$$M_v = (M_l/\rho_l) \ (1/R_l - 1)\rho_v$$

Therefore the determination of vapor mass and hence component fluid energy requires the introduction of no new variables. This is significant in the effort to minimize variable arrays, such that large input data blocks can be handled.

Energy content of the Primary fluid is obtained by summing over components. This energy content versus time is normalized to the initial energy content and expressed as percent of initial energy. Energy content is differenced between successive data scans and divided by the time between scans to obtain the energy rate-of-change. The standard conversion (1% of full power = 21.36 Kw) is used to express de/dt in the usual units of power and the calculated values are installed at the time corresponding to the end of the time increment.

2.7 Subroutine BALANCE

Calculated and indicated total primary fluid mass, fluid energy, and liquid volume are compared at each time step, as are calculated and indicated primary pressure change. Indicated total quantities are obtained directly from indications, they are largely calculated in Subroutine CLOSURE (and receive little emphasis herein).

Calculated total quantities at the first time of data are set equal to their counterpart indicated values (this also applies when a data reduction is started part way into the data set). Thereafter, each calculated total is set equal to its previous value plus the calculated change over the intervening time step:

$$M \text{ (calculated time} = t) = M \text{ (calculated time} = t - \Delta t) + \Delta t \left(\frac{\Delta m}{\Delta t}\right), \ lb_m$$

2.7.1 MASS: Total Primary System Flud Mass

2.7.1.1 Indicated

Total indicated primary fluid mass (lbm) is the sum of the primary component fluid masses (Mi):

$$M = \sum_{\text{component}} M_i \ , \ lb_m$$

Component fluid mass is component fluid volume (V_i, ft^3) times volume-weighted component fluid density ($\rho_{fl,i}$, lbm/ft^3):

$$M_i = V_i \rho_{fl,i} \ , \ lb_m$$

(Weighted densities have been calculated in subroutine PROPS).

2.7.1.2 Calculated

Total calculated primary fluid mass at time t is the sum of calculated mass at the preceding time, $M(t-\Delta t)$, and the intervening time increment (Δt) times the calculated mass rate of change over that increment ($\Delta m/\Delta t$):

$$M(t) = M(t - \Delta t) + \Delta t \ (\Delta m/\Delta t) \ , \ lb_m$$

Primary fluid mass rate of change ($\Delta m/\Delta t$, lbm/s) is the sum of the primary system boundary mass flowrates, i.e. HPI less discharge:

$$\Delta m/\Delta t = \dot{m}_{HPI} - \sum_{\substack{\text{active}\\ \text{discharges}}} \dot{m}_{discharge} \text{ , } lb_m/s$$

Discharges include liquid-region leaks and vapor-region leaks. One liquid-region discharge mass flowrate is supplied, it is linked to the appropriate discharge site using limit switch indications. The vapor-region discharges (HPV, PORV) are supplied separately.

2.7.2 <u>ENERGY: Total Primary System Fluid Energy</u>

2.7.2.1 <u>Indicated</u>

Total indicated primary fluid energy is found by summing over the primary components:

$$E = \sum_{\text{components}} E_i(\text{Btu}) \times (100/E_{total}(t{=}0)) \text{ , \% of initial E}$$

where (100/E(t=0) is used to reference E(t) to % of initial total energy (calculations done in CLOSURE).

Component fluid energy (Ei) is found by summing the component fluid and vapor energies:

$$E_i = M_{fl}\, h_l + V_v\, \rho_v\, h_v$$

where M_{fl} = component fluid mass (lbm),
h_l = liquid-volume-weighted h (B/lbm),
V_v = vapor volume (ft^3),
ρ_v = vapor-volume-weighted density (lbm/ft^3)
and h_v = vapor-volume-weighted enthalpy (B/lbm)
(calculations done in CLOSURE, properties from PROPS).

2.7.2.2 Calculated

Calculated total primary fluid energy at time t (E(t)) is that calculated at the preceding time (E(t-Δt)) plus the intervening change calculated:

$$E(t) = E(t-\Delta t) + \Delta E, \text{ (\% of initial fluid energy)}$$

$$\text{where } \Delta E = \Delta t \ \dot{e}_{net} \ \frac{100}{CE(t=0)}$$

Δt = duration of time increment (sec),

$\dot{e}_{net}$ = net primary fluid energy rate of change (calculated) (%full power),

100/E (t=0) converts energy in BTU to % of initial energy,

$$\text{and} \quad C = \frac{3600 \text{ s/hr}}{(3412 \text{ B/kw-hr})(21.4 \text{ kw/\% full power})}, \ \frac{\text{\% full power}}{\text{B/s}}$$

2.7.2.2.1 Net Primary Fluid Energy Rate Of Change - e_{net}

Calculated net primary fluid energy rate of change ($\dot{e}_{net}$) is the sum of the various energy sources and sinks:

$$\dot{e}_{net} = q_{core} + q_{primary\ metal} - q_{leak\text{-}HPI} - q_{SG} - q_{ambient}, \text{ \% full power}$$

where the individual terms are discussed below.

2.7.2.2.1.1 q Core

Core power is supplied (and converted to % full power in subroutine CONVERT).

2.7.2.2.1.2 q Primary Metal

Heat transfer from the primary metal to the primary fluid is considered in two regions, "low" metal adjacent to liquid and "high" metal adjacent to vapor; the "quenching" contribution is also estimated:

$$q_{primary\ metal} = q_{low} + q_{high} + q_{quench}, \text{ \% full power}$$

Low Primary Metal: q low is the contribution of primary metal adjacent to liquid. It is estimated by assuming that this metal temperature responds as the (component) volume-weighted fluid temperature. The "low" metal volume is obtained by multiplying total component metal volume by the fraction of the component fluid volume in liquid. Metal properties are approximated as $(\rho C_p)_{metal} = 60$ (B/ft^{3}F). The total primary contribution due to low metal is then the sum over the primary components:

$$q_{low} = \sum_{components} 60\left(\frac{B}{ft^3F}\right) \frac{V_{li}}{V_i} \; V_{mi}(ft^3) \left[\frac{T_{li}(t-\Delta t)-T_{li}(t)}{\Delta t}\right]\left(\frac{F}{s}\right) C\left(\frac{\%\text{ full power}}{B/s}\right)$$

where (V_{li}/V_i) is the ratio of component liquid to total fluid volume and C converts (B/S) to (% full power).

High Primary Metal: q high is the contribution of metal adjacent to vapor and is analogous to that preceding. Similar approximations are made, except that the metal adjacent to vapor is assumed to respond to primary saturation temperature:

$$q_{high} = \sum_{components} 60 \left(\frac{B}{ft^3F}\right) \frac{\bar{V}_{vi}}{V_i} V_{mi} \; (ft^3) \left[\frac{T_{sat}(t-\Delta t)-T_{sat}(t)}{\Delta t}\right]\left(\frac{F}{s}\right) \cdot C\left(\frac{\%\text{ full power}}{B/s}\right)$$

Noting the assignments of old and new temperatures ($T(t-\Delta t)$ and $T(t)$) in both q_{low} and q_{high}, it can be seen that fluid cooling is assumed to be accompanied by heat transfer from the primary metal to the primary fluid, and vice versa.

Quenching: q quench is estimated during component refill only, i.e., component liquid volume is increasing. Metal power is assumed to respond to the temperature difference between saturation and the current volume-weighted liquid average temperature. The amount of metal interacting is taken to be the fractional liquid volume increase times the component metal volume:

$$q_{quench} = \sum_{components} 60 \left(\frac{B}{ft^3F}\right)\left(\frac{V_{li}(t)-V_{li}(t-\Delta t)}{V_i \; \Delta t}\right) V_{mi} \left(\frac{ft^3}{s}\right) \cdot \left(T_{sat} - T_{li}\right) (F) \; C \left(\frac{\%\text{ full power}}{B/s}\right)$$

2.7.2.2.1.3 q Leak-HPI

The energy impact of discharges and HPI are:

$$q_{leak\text{-}HPI} = \sum_{discharges} q_{discharge} - q_{HPI}\text{, \% full power}$$

The components are addressed below.

Discharge:

The discharged power-equivalent is:

$q = C \dot{m} h$ (% full power),
where C converts (B/S) to (% fp),
$\dot{m}$ is indicated discharge mass flowrate (lbm/s), and
h is discharge enthalpy (BTU/lbm).

The determination of discharge enthalpy (as well as fluid density, for subsequent volume balance calculations) involves discharge-specific state checks.

CLS or CLD Leak: The leak h and ρ are found at system pressure and leak temperature (using ZZTP), i.e., $h=f(P,T_{leak})$, $\rho=f(P,T_{leak})$. If P and T_{leak} are close to saturation the properties are set to those for saturated liquid.

HLHPV: The HLHPV discharge involves a deliberate estimate of state. A state indicator (KEYPHAS) is set to zero, then perturbed based on several indications of state. The final value of KEYPHAS, i.e., the aggregate of several state checks, is used to choose between phases.

Saturation Temperature: If the HLHPV fluid temperature is more than 2F subcooled, KEYPHAS is set to -1; if the temperature indicates more than 2F superheated, KEYPHAS is set to +1.

Hot Leg (upstream) Liquid Volume: If the HL volume is 100% full, KEYPHAS is reduced by 1; if the volume indicates less than or equal to 98% full, KEYPHAS is increased by 1.

HLHPV flowrate: If the current HPV indicated mass flowrate is more than 2.5 times the "base" rate, KEYPHAS is set to -2 (i.e., the previous T and V-liquid checks are over-ridden and saturated liquid discharge is used). The base is established at the first instance of HLHPV flow greater than 0.0012 lbm/s (this minimum flowrate to distinguish flow from noise is based on data observations). Subsequent HPV flowrates greater than 0.0012 either update the base, or trigger KEYPHAS=-2 if they are greater than 2.5 times the current base ("2.5" was established by reviewing data and consulting critical flow relations, but it is unfortunately not unequivocal).

Following the KEYPHAS setting just outlined, KEYPHAS is tested to flag state: KEYPHAS<0 obtains saturated or subcooled liquid, KEYPHAS>0 obtains saturated or superheated vapor (if P-system and T-HLHPV obtained a state in agreement with the KEYPHAS state check, the P-T properties are retained). Once the HLHPV enthalpy is determined, the HLHPV energy transfer is then

$$q_{HLHPV} = C \dot{m}_{HLHPV} h, (\% \text{ full power})$$

RVHPV: The reactor vessel high point-vent involves a state determination which is identical to that described for the HLHPV with the exception that conditions in the RV plenum are used. The energy transfer is then:

$$Q_{RVHPV} = C \dot{m}_{RVHPV} h, (\% \text{ full power})$$

PORV: The PORV discharge involves a state determination similar to that just described for the HPV. The PORV setting of KEYPHAS based on temperature is the same, i.e. 2F subcooled obtains KEYPHAS=-1 and 2F superheated yields +1. The PORV level test is done on the pressurizer. If the Pr is more than 98% full (of liquid), KEYPHAS is reduced by 1; if the Pr liquid inventory is less than or equal to 98%, KEYPHAS is increased by 1. The PORV uses no base-flow check. Instead, if the previous two state tests obtain KEYPHAS=0 (no net state determination), and if the STP routine returned its flag=0 (indicated conditions approximately at saturation), then the vapor state is imposed by setting KEYPHAS=+1.

PORV-fluid properties are set based on KEYPHAS as with the HPV; again, if p-T results are confirmed by the indicated state, then subcooled or superheated properties are used.

HPI:

The HPI energy contribution is determined using the HPI fluid enthalpy at system pressure and HPI fluid temperature.

2.7.2.2.1.4 q_{SG}:

"q_{SG}" is the energy tranfer rate across the SG tubes, from the primary to the secondary system. Early attempts to calculate q_{SG} from $\dot{m}_{pri}\ \Delta h_{SG}$ were thwarted by primary flow determination - it is inaccurate at low flowrates, and is sometimes adversely affected by voiding and/or HPI backflow at the flow metering device. For this reason, q_{SG} relies on the secondary energy balance:

SG Secondary: $\dot{e}_{in} = \dot{e}_{out} + \dot{e}_{storage}$

or: $q_{pri\text{-}to\text{-}sec} + q_{SG\ metal} = q_{steam\text{-}feed} + q_{sec\ fluid\ storage} +$
$q_{SG\ to\ ambient}$

where $q_{pri\text{-}to\text{-}sec}$ is the sought-after q_{SG}.

$q_{SG\ Metal}$: The qSG-metal calculation is exactly analogous to that used to calculate the primary metal contribution to net primary $\dot{e}$. Again the calculation is performed for "high" and "low" metal (that adjacent to vapor and assumed to respond to T_{sat}, and that adjacent to liquid and assumed to respond to volume-weighted liquid average temperature). The approximation $(\rho Cp)_{metal} = 60$ B/ft^3F is again employed, also the metal fractions in the two region are apportioned as the current liquid volume. Unlike the primary metal calculation, no quenching term is estimated for the SG secondary.

$q_{steam\text{-}feed}$: The energy contribution of steam and feed flow are calculated from

$$q_{steam\text{-}feed} = 0.02653\ (\dot{m}_{steam}\ h_{steam} - \dot{m}_{feed}\ h_{feed})\ C$$

where 0.02653 converts steam and feed mass flowrate from % full (secondary) flow to (lbm/sec), and C is the usual conversion from (B/S) to % full power. Steam and feed flowrates ($\dot{m}$) are indicated, the stream enthalpies are taken at secondary steam pressure and the stream temperatures. (Because of heat loss impact in the steam outlet piping upstream of the steam temperature measurement, steam temperature is taken at the highest SG secondary temperature.

$q_{\text{sec fluid storage}}$: The energy contribution of SG secondary stored fluid energy is determined by differencing the total stored SG fluid energy at successive times:

$$q_{\text{sec fluid storage}} = C \left[\frac{E(t) - E(t-\Delta t)}{\Delta t}\right], \text{ \% full power}$$

The stored fluid energy (E) is taken from indications:

$$E = E_l + E_v$$
$$= M_l \bar{h}_l + V_v \rho_v \bar{h}_v$$

where M = Total liquid mass (in the SG secondary),

$\bar{h}_l$, $\bar{h}_v$ = volume-weighted average liquid or vapor enthalpy,

V_v = Vapor volume, and

ρ_v = vapor density.

$q_{\text{SG to ambient}}$: The SG secondary energy loss to ambient, qSG to ambient, is estimated at the current SG average secondary fluid temperature using previously obtained SG heat loss data (calculation in subroutine CLOSURE). For the SG secondary the heat loss to ambient is

$$q_{\text{SG to ambient}} = \frac{1}{21.4} (0.0159)(\bar{T} - 206)$$

where $\bar{T}$ for the SG secondary is the average of all SG secondary temperatures.

2.7.2.2.1.5 q_{ambient}:

Primary heat loses are calculated from earlier heat loss data, similarly to the previously-noted SG secondary calculation. The primary is considered in three regions for this purpose - reactor vessel (RV), hot leg (HL), and cold leg (CL). The respective equations are:

RV: $q_{amb} = (1/21.4)(0.0107)(\bar{T} - 200)$

HL: $q_{amb} = (1/21.4)(0.0142)(\bar{T} - 296)$

CL: $q_{amb} = (1/21.4)(0.00884)(\bar{T} - 144)$

Calculations are performed in CLOSURE, each obtains units of % full power. The 3 regions used regional bounding RTD indications to set $\overline{T}$, as was done for the heat loss fits. The HL heat loss is set to zero when the HL guard heaters are energized, as signalled by a HL insulation temperature difference less than zero.

2.7.2.2.1.6 Summary Of Net Primary Fluid Energy Rate Of Change - $\dot{e}_{net}$

The initial equation for "calculated" net primary system fluid energy rate of change was:

$$\dot{e}_{net} = q_{core} + q_{primary\ metal} - q_{leak\text{-}HPI} - q_{SG} - q_{ambient}$$

It is instructive to tabulate the relations for these components of $\dot{e}_{net}$ which have been described in the preceding pages:

q_{core} from indication. (1)

$$q_{primary\ metal} = q_{low} + q_{high} + q_{quench} \quad (2)$$

where

$$q_{low} = \sum_{components} 60 \left(\frac{V_{li}}{V_i}\right) V_{mi} \left[\frac{\overline{T}_{li}(t-\Delta t) - \overline{T}_{li}(t)}{\Delta t}\right] C \quad (2a)$$

$$q_{high} = \sum_{components} 60 \left(\frac{V_{vi}}{V_i}\right) V_{mi} \left[\frac{T_{sat}(t-\Delta t) - T_{sat}(t)}{\Delta t}\right] C \quad (2b)$$

and

$$q_{quench} = \sum_{components} 60 \left[\frac{V_{li}(t) - V_{li}(t-\Delta t)}{V_i\ \Delta t}\right] V_{mi} (T_{sat} - \overline{T}_{li}) C \quad (2c)$$

where Equation (2c) is only used during refill, i.e., when $V_{li}(t) > V_{li}(t-\Delta t)$

Each of the components of q_{metal}, viz. q_{low}, q_{high}, and q_{quench}, tie directly to indications (or are assigned constants, such as component metal volume V_{mi}, fluid volume V_i, and the conversion to % full power, C). The volume-weighted liquid average temperatures were obtained (subroutine PROPS) from observed fluid temperatures, observed levels, and component volume-versus-elevation, V(z). Saturation temperature Tsat of course was defined at indicated system temperature. Thus no empiricism was used to define q_{metal}, rather independent indications and several assumptions (already described) were used.

The next component of $\dot{e}_{net}$ was $q_{leak-HPI}$

$$q_{leak-HPI} = \sum_{discharges} q_{discharge} - q_{HPI} \tag{3}$$

where, in general,

$$q_{discharge} = C\,\dot{m}_{discharge}\,h_{discharge}.$$

Discharge mass flowrate ($\dot{m}_{discharge}$) was indicated (or was obtained directly from indicated accumulated flow measurements). But the discharge fluid enthalpy ($h_{discharge}$) invoked a number of tests and assumptions regarding discharged fluid state.

The q_{SG} component was quite involved:

$$q_{SG} = q_{steam-feed} + q_{sec\ fluid\ storage} + q_{SG\ to\ ambient} - q_{SG\ metal} \tag{4}$$

$q_{steam-feed}$: required indicated steam and feed mass flowrates, and stream temperatures combined with secondary pressure.

$q_{secy\ fluid\ storage}$: used levels and V(z) to get volumes, and sensed temperatures and SG pressure to find h and $\rho = f(p,T)$.

$q_{SG\ to\ ambient}$: used earlier heat loss data and current SG secondary fluid temperatures.

$q_{SG\ metal}$: like the primary metal, used current fluid volume and fluid temperatures plus several approximations (and ignores metal time delay).

2.7.3 VOLUME

Like the preceding mass and energy comparisons, the rate of change of primary liquid (and vapor) volume is calculated, summed in time, and compared to indicated total primary liquid volume.

2.7.3.1 Indicated

Indicated liquid volume is the sum of the component liquid volumes:

$$V_l = \sum_{\substack{\text{primary} \\ \text{components}}} V_{li}$$

where V_{li} = Component liquid volume, from component liquid level and volume-versus-elevation, V(z).

2.7.3.2 Calculated

Calculated liquid volume is the preceding calculated volume plus the time-incremental contributions:

$$V_l(t) = \left[V_l(t-\Delta t) + \dot{v}_{lnet}\,\Delta t\right]\left(\frac{100}{V}\right) \text{, \% full}$$

where $\dot{v}_{lnet}$ (ft^3/s) is the sum of the calculated primary liquid volume rate of change,

and V = Total primary system fluid volume.

2.7.3.2.1 $\dot{v}_l$-net (liquid)

$$\dot{v}_{lnet} = \dot{v}_{HPI} - \dot{v}_{leak} - \dot{v}_{\Delta\rho} - \dot{v}_{steam} + \dot{v}_{\Delta P}$$

where the components, to be discussed next, are:

$\dot{v}_{HPI}$ = $\dot{v}_l$ due to HPI,

$\dot{v}_{leak}$ = $\dot{v}_l$ discharged (leaks + HPV + PORV),

$\dot{v}_{\Delta\rho}$ = $\dot{v}_l$ due to liquid thermal expansion/contraction,

$\dot{v}_{steam}$ = $\dot{v}_l$ due to steam generation, and

$\dot{v}_{\Delta P}$ = $\dot{v}_l$ due to primary pressure effects.

$\dot{v}_{HPI}$: The primary liquid volume change due to HPI is considered in two components, that HPI mass flowrate less than or equal to liquid-region leak flow, and that HPI in excess of leak flow. When HPI is less than liquid-region leak flow,

$$\dot{v}_{HPI} = \frac{\dot{m}_{HPI}}{\rho_{leak}}$$

where ρ_{leak} is the density of the liquid region leak fluid. The assumption here is that leak-HPI cooling or heating are felt in primary liquid average temperature (which is introduced in the $\dot{v}_{\Delta\rho}$-term) but that the steady-state leak-HPI mass exchange without primary fluid temperature change (e.g., with core heating offsetting HPI cooling) has no net impact on primary liquid volume.

When HPI mass flowrate exceeds leak flow, $\dot{v}_{HPI}$ is calculated using:

$$\dot{v}_{HPI} = \frac{\dot{m}_{leak}}{\rho_{leak}} + \frac{\dot{m}_{HPI} - \dot{m}_{leak}}{\bar{\rho}_l}$$

Here the first term invokes the assumption just described, the second term similarly obtains no heating/cooling effect of HPI in excess of leak flow (reserving that for the $\dot{v}_{\Delta\rho}$ term) by introducing the excess HPI mass flowrate at system average liquid density ($\bar{\rho}_l$).

$\dot{v}$ leak: The aggregate discharge of primary liquid from leaks (CLS or CLD), HPV, and PORV are grouped under $\dot{v}_{leak}$. As described in the previous section regarding primary energy balance, the various discharge calculations involve tests for discharge fluid temperature and for effluent state. These identical determinations are used to assign each discharge stream to the liquid-or vapor-change category. For each stream determined to be liquid, the stream fluid density is used to find the liquid volume effect:

$$\dot{v}_{leak} = \dot{m}_{leak}/\rho_{leak}$$

(Recall that the CLS is limited to subcooled and saturated liquid; the remaining discharges may affect either the liquid or vapor volume change).

$\dot{v}_{\Delta\rho}$: The effect of primary liquid inventory contraction and expansion on liquid volume is estimated using:

$$\dot{v}_{\Delta\rho} = \sum_{\text{components}} V_{1i} \left[1 - \frac{\bar{\rho}_1 (t-\Delta t)}{\bar{\rho}_1(t)}\right]\frac{1}{\Delta t}$$

where V_{1i} is the liquid volume in component i, and $\bar{\rho}_1$ is the volume-weighted average liquid density in that component.

$\dot{v}_{steam}$: The effect of vapor generation and/or condensation on liquid volume is calculated using:

$$\dot{v}_{steam} = \frac{\rho_g}{\rho_f}\left[\dot{v}_{v_{core}} - \dot{v}_{v_{HPI}} - \dot{v}_{v_{BCM}} - \dot{v}_{v_{amb}} - \dot{v}_{v_{metal}}\right]$$

where the components of $\dot{v}_v$ are described subsequently,

$\dot{v}_{\Delta P}$: The effect of pressure on near saturated liquid and vapor is determined using:

$$\dot{v}_{1\Delta P} = \dot{v}_1 \frac{\Delta P}{\Delta t} - \frac{\rho_g}{\rho_f} \dot{v}_v \frac{\Delta P}{\Delta t}$$

where

$$\dot{v}_1 \frac{\Delta P}{\Delta t} = M_{1\sim f} \frac{\Delta P}{\Delta t} \left.\frac{\partial v_f}{\partial P}\right|_h \qquad \left.\frac{\partial v_f}{\partial P}\right|_h = v_f \left[\frac{T_{sat}\, v_{fg}\, \beta_f\, 144}{h_{fg}\, 778.2} - K_f\right]$$

$$\beta_f = - \frac{1}{v_f} \left.\frac{\partial v_f}{\partial T}\right|_P ,$$ the coefficient of volume expansivity ($°R^{-1}$)

$$K_f = - \frac{1}{v_f} \left.\frac{\partial v_f}{\partial P}\right|_T ,$$ the coefficient of isothermal compressibility (in^2/lbf)

$M_{1\sim f}$ denotes the mass of liquid which is near saturation

$\dot{v}_v$ is the corresponding contribution for pressure effects on the near-saturated vapor volume

The factors 144 and 778.2 convert ft^2 to in^2 and Btu to ft-lbf respectively.

2.7.3.2.2 Vapor Volume

Vapor volume change is calculated for display, and for use with liquid volume change to predict pressure (described subsequently). Net vapor volume change ($\dot{v}_v$) is considered in its several constituents:

$$\dot{v}_v = \dot{v}_{core} - \dot{v}_{HPI} - \dot{v}_{leak} - \dot{v}_{BCM} - \dot{v}_{amb} - \dot{v}_p$$

where $\dot{v}_p = \dot{v}_{\Delta P} - \dot{v}_{metal} - \dot{v}_{\Delta\rho}$

the pressure-responsive components of $\dot{v}_v$.

$\dot{v}_{core}$: Core vapor production is calculated using

$$\dot{v}_{core} = \left[\frac{q_{core}}{C} - 0.259\ \dot{m}_{DC}\ (h_f - h_{in})\right] \frac{v_g}{h_{fg}}$$

where C converts q_{core} (% fp) to (B/S), 0.259 converts DC flowrate ($\dot{m}_{DC}$) from % full flow to (lbm/s),

and the units of $\dot{v}_{core}$ (as usual for $\dot{v}$) are (ft^3/sec).

Core inlet fluid enthalpy is calculated at the temperature indicated by RVTC02, it is limited to h_f or less. If the core outlet fluid is subcooled (based on RVTC07), core vapor generation is nulled.

$\dot{v}_{HPI}$: The role of cold HPI fluid in vapor condensation is introduced into the HPI term, $\dot{v}_{HPI}$. Two components of HPI are considered: (1) HPI "AWAY" is assumed to heat to leak fluid enthalpy by steam condensation, and (2) HPI "COND" is assumed to heat to the upper downcomer fluid temperature, also by vapor condensation. The "AWAY" component is taken to be the single-phase leak flowrate (CLS or CLD). If CL loop flow indicates reverse flow, the current SG primary liquid inventory change is converted to a mass flowrate (HPI2SGP) and added to the "AWAY" component:

$$HPI2SGP = (M_{SG}(t) - M_{SG}(t - \Delta t))/\Delta t$$

The "AWAY" term is limited to the range:

$$0 \leq AWAY \leq \dot{m}_{HPI}$$

and its contribution is:

$$\dot{v}_{HPI\,AWAY} = \frac{\dot{m}_{AWAY}\,(h_{leak} - h_{HPI})}{\rho_g\ h_{fg}}$$

The HPI-"COND" component is set equal to the excess of HPI:

$$HPICOND = \dot{m}_{HPI} - \dot{m}_{AWAY}$$

and constrained to be greater than or equal to zero. Its $\dot{v}$ contribution is taken over the heatup from HPI enthalpy to that at the upper DC fluid temperature, DCTC01:

$$\dot{v}_{HPI\ COND} = \frac{\dot{m}_{COND}\ (H_{DCTC01} - h_{HPI})}{\rho_g\ h_{fg}}$$

Then the $\dot{v}$ effects are the sum:

$$\dot{v}_{HPI} = \dot{v}_{HPI\ AWAY} + \dot{v}_{HPI\ COND}$$

(Note the differing assumptions regarding HPI heating used to get the $\dot{v}_l$ effects of HPI, versus those used here for the $\dot{v}_v$ effects). When the DC is approximately filled (collapsed level above 1.5'), $\dot{v}_{vHPI}$ is limited to no more than $\dot{v}_{vcore}$.

$\underline{\dot{v}_{BCM}}$:

The primary vapor volume impact of the SG boiler condenser mode is activated when the SG primary collapsed liquid level is within 3' of the secondary, and when the SG primary level is within the SG with AFW active.

Then this contribution is:

$$\dot{v}_{BCM} = \frac{q_{SG}\ v_g}{C\ h_{fg}}\ ,\ ft^3/s$$

where C converts q_{SG} from % fp to (B/S),
and the calculation of q_{SG}, primary-to-secondary energy transfer rate, has been described previously in the energy section.

$\dot{v}_{amb}$:

System heat losses to ambient are assumed to condense primary vapor in linear proportion to the vapor length exposed to these losses. The two primary components for which this condensation mechanism is calculated are the SGP and RV. The calculation of their heat losses to ambient (q_{SGamb} and q_{RVamb}) has been described in the energy section. Then:

$$\dot{v}_{amb} = (X_{SG}\, q_{SGamb} + X_{RV}\, q_{RVamb})\, v_g / C\, h_{fg}$$

where X_{SG} and X_{RV} are the fractional SG and RV lengths in vapor:

$$X_{SG} = 1 - \frac{Z_{SGP}}{52}$$

and

$$X_{RV} = 1 - \left(\frac{Z_{RV} + 24}{31}\right)$$

where both are limited to the range:

$0 \leq X \leq 1.$

$\dot{v}_p$: Pressure effects on $\dot{v}$ are considered in three forms: (1) Pressure effects on near-saturated liquid and vapor; (2) condensation of vapor on metal with pressurization, $\dot{v}_{metal}$; and (3) compression effects on $\dot{v}$ through bulk vapor density, $\dot{v}_{\Delta\rho}$.

$\dot{v}_{\Delta P}$: The effect of pressure on the volume of vapor is determined using:

$$\dot{v}_{v\Delta P} = M_{v\sim g} \frac{\Delta P}{\Delta t} \left.\frac{\partial v_g}{\partial P}\right|_h - \frac{\rho_f}{\rho_g} \dot{v}_1 \frac{\Delta P}{\Delta t}$$

where

$$\left.\frac{\partial v_g}{\partial P}\right|_h = v_g \left[\frac{T_{sat}\, v_{fg}\, \beta_g}{h_{fg}} \frac{144}{778.2} - K_g\right]$$

$$\beta_g = -\frac{1}{v_g} \left.\frac{\partial v_g}{\partial T}\right|_P$$, the coefficient of volume expansivity ($°R^{-1}$)

$$K_g = -\frac{1}{v_g} \left.\frac{\partial v_g}{\partial P}\right|_T$$, the coefficient of isothermal compressibility (in^2/lbf)

$M_{v\sim g}$ denotes the mass of vapor which is near saturation

$\dot{v}_1$ is the corresponding contribution for pressure effects on the near-saturated liquid volume

The factors 144 and 778.2 convert ft^2 to in^2 and Btu to ft-lbf respectively

$\underline{\dot{v}_{metal}}$: As pressurization raises saturation temperature, vapor is condensed on the bounding metal to elevate its stored energy correspondingly. The usual assumption is made that the metal is without time lag, that the metal is adequately characterized by $(\rho Cp)_{metal} = 60$ (B/ft^3F), and that the volume of metal surrounding vapor equals the volume of vapor (the system total fluid and metal volumes are approximately equal). Then:

$$\dot{v}_{metal} = \frac{[T_{sat}(t) - T_{sat}(t-\Delta t)]\ V_v\ 60}{\rho_g\ h_{fg}\ \Delta t}\ ,\ ft^3/s.$$

$\underline{\dot{v}_{\Delta\rho}}$: Bulk vapor density change effects on $\dot{v}$ are:

$$\dot{v}_{\Delta\rho} = \frac{V_v}{\Delta t}\left[\frac{\rho_g(t)}{\rho_g\ (t-\Delta t)} - 1\right]$$

where V_v = Primary vapor volume.

2.7.4 PRESSURE

The calculated total primary liquid and vapor volume change are assessed to calculate pressure, the calculated pressure rate of change is compared to the indicated pressure change. For this purpose the liquid and vapor $\dot{v}$'s are sub-calculated without pressure effects. Label these volume changes without pressure effects using primes ('). Then

Liquid With Pressure Effects:

$$\dot{v}_1 = \dot{v}_{HPI} - \dot{v}_{leak} - \dot{v}_{\Delta\rho} - \dot{v}_{steam} + \dot{v}_{\Delta P}$$

where

$$\dot{v}_{steam} = \frac{\rho_g}{\rho_f}\left(\dot{v}_{v_{core}} - \dot{v}_{v_{HPI}} - \dot{v}_{v_{BCM}} - \dot{v}_{v_{amb}} - \dot{v}_{v_{metal}}\right)$$

Liquid Without Pressure Effects:

$$\dot{v}_l' = \dot{v}_l - \dot{v}_{\Delta P} - \frac{\rho_g}{\rho_f} \dot{v}_v \text{ metal}$$

Vapor With Pressure Effects

$$\dot{v}_v = \dot{v}_{core} - \dot{v}_{HPI} - \dot{v}_{leak} - \dot{v}_{BCM} - \dot{v}_{amb} + \dot{v}_P$$

where

$$\dot{v}_P = \dot{v}_{\Delta P} - \dot{v}_{metal} - \dot{v}_{\Delta \rho}$$

Vapor Without Pressure Effects:

$$\dot{v}_v' = \dot{v}_v - \dot{v}_P$$

To calculate the system pressure change compatible with the liquid and vapor volume changes calculated, a pressure is chosen iteratively. At this pressure, the pressure-dependent terms of $\dot{v}_v$ and $\dot{v}_l$ are determined, added to $\dot{v}_v'$ and $\dot{v}_l'$, and the sum (i.e., the total liquid and vapor volume change) is compared to zero. Convergence is signalled when the total volume change rate at the calculated pressure is less than $\pm 10^{-6}$ ft^3/sec, or when the iteratively-set maximum and minimum pressure change rates differ by less than 10^{-3} psi/sec. Iteration is greatly accelerated by chosing the successive estimates of dP/dt based on the straight line fit of the last two results. The first two sets of $\dot{v}$ versus dP/dt are available from $(\dot{v}_l' + \dot{v}_v')$ at dP/dt = 0 and $(\dot{v}_l + \dot{v}_v)$ at dP/dt indicated. The calculated dP/dt is limited only such that calculated P

$$P_{calc}(t) = P_{indicated}(t-\Delta t) + \Delta t \left(\frac{\Delta P}{\Delta t}\right)_{calc}$$

lies within the range $0 \leq p \leq 3000$ psia.

2.8 Subroutine SGHTRAN

Indications of SG performance are obtained by determining the SG local heat transfer coefficients and the SG linear heat rate. This subroutine performs the intermediate calculations necessary and determines the SG linear heat rate and the SG local heat transfer coefficients as explained in the following sections.

2.8.1 Steam Generator Temperature Profiles

The actual temperature locations vary depending on the tube and the axial elevation. To perform the calculations in this subroutine the steam generator temperatures must first be assigned to one or more of four categories:

1. On-nozzle SG primary temperatures - these consist of the fluid inlet and outlet RTD's (Resistance Temperature Detectors) and the string thermocouples located in the SG tube which is adjacent to the minimum AFW nozzle.

2. Off-nozzle SG primary temperatures - these consist of the fluid inlet and outlet RTD's and the string thermocouples located in the SG tube which is located in the SG tube which is 180° away from the on-nozzle tube (on the opposite side on the periphery of the steam generator).

3. Composite SG primary temperatures - these consist of various primary thermocouples located within different tubes at various axial locations including the string TCs and the SG primary inlet and outlet RTDs.

4. Composite SG secondary temperatures - these consist of all the SG secondary temperature indications from the various axial and radial thermocouple locations (they are not segregated into "wetted" and "unwetted" categories based on their lateral position within the SG).

It should be noted that in order to define the axial temperature distribution within the on-nozzle and off-nozzle SG tubes, the SG primary fluid thermocouple at 8.1 ft (SPTC05) is included (the lowest elevation for the string TC is 23.1 ft).

2.8.2 Curve Fitting of the Steam Generator Temperature Profiles

The four types of SG temperature profiles are curve-fit for plotting and local analyses. Because standard curve-fitting logic requires ordered and single-valued functions, the supplied temperature indications within each category are ordered by elevation (Subroutine ORDERIT), and are condensed to a single average temperature at one elevation when several indications are within 1/4 foot of elevation of each other. Fitting is performed by a standard package supplying modified spline fits.

The boundary conditions imposed on the curve-fit differ between the Primary and Secondary profiles. Because the Primary profiles contain end points (the RTD's) beyond the region of active heat transfer, the imposed Primary boundary condition is no heat transfer, i.e., zero first derivatives, dT/dz = 0, at both ends. Secondary temperatures do not delineate the extremes of SG elevation, however. Thus zero second derivations (constant dT/dz) are imposed at the end points of the Secondary temperatures, local analyses are performed only within the extremes of the elevations of the supplied SG Secondary temperatures (extrapolation of spline-like curve fits is not defensible).

These curve-fit SG temperature profiles are limited by the axial density of the temperature measurements. This limitation may be observed by examining a SG primary fluid temperature curve-fit just below the elevation of Secondary dryout. The curve-fit primary profile drops sharply at this elevation. The actual profile is likely to extend to lower elevations before beginning its rapid decrease, corresponding to augmented Primary-to-Secondary heat transfer over the Secondary boiling length.

2.8.3 Steam Generator Linear Heat Rates

SG linear heat rate is the heat transferred per unit axial distance. It is evaluated for each of the SG Primary temperature categories: On-Nozzle, Off-Nozzle, and Primary composite. The curve-fit SG Primary temperature profiles are evaluated at multiple axial increments, these extracted temperatures and SG Primary pressure are used to obtain local SG Primary fluid specific enthalpy (using property Subroutine STP). Adjacent enthalpies are differenced; linear heat rate is then the product of these local fluid enthalpy differences and primary flowrate, divided by the length of the axial increment. Evaluations are performed only over the range of elevation subtended by the available SG Secondary temperatures, as previously mentioned; to accommodate the total energy transfer to the Primary fluid within the SG, the linear heat rate calculations at the top and bottom increments are modified to use the SG Primary Inlet and Outlet (RTD) temperatures, their increment lengths are correspondingly modified. Linear heat rates are expressed in the customary units of Kw/ft, i.e. heat transferred per unit axial distance.

The Primary flowrate used to calculate SG linear heat rate is total Primary System flowrate from the Cold Leg Orifice indication, distributed uniformly through the 19 SG tubes; the SG linear heat rate is not modified to account for any estimate or observation of flow maldistribution through the various SG tubes.

The method used to determine the linear heat rates is only valid when single phase liquid conditions exist in the SG primary, i.e., the fluid enthalpy is obtained from the fluid temperature and pressure which is indeterminate when the fluid becomes a two-phase mixture.

2.8.4 Steam Generator Local Heat Transfer Coefficients

Local SG heat transfer coefficients (htc) are obtained from local linear heat rate and local Primary-to-Secondary temperature differences. Local temperature differences are obtained by evaluating the appropriate curve-fit SG temperature profiles and differencing the results. Calculated htc's are limited to positive values, i.e. when local linear heat rate and local Primary-to-Secondary temperature difference differ in sign, htc is set to zero. Local htc's (BTU/hrft^{2}F) are expressed as base-ten logarithms for plotting and for ease of comparison; log-htc is limited to 0 or greater, plotted log-htc is limited to 1 or greater. Local htc is conceptually the SG Secondary convective heat transfer coefficient, its variations during testing commonly reflect Secondary phenomena (boiling, superheat, AFW effects, and so on). It should be noted, however, that the log-htc calculations just defined use a Primary-fluid to Secondary-fluid temperature difference. The htc is thus a series-composite of the convective htc within the SG tube, conduction through the tube wall, and heat transfer from the tube to to Secondary, i.e., an overall heat transfer coefficient.

Since the steam generator local heat transfer coefficients are determined using the local linear heat rate, they are also valid only when the primary fluid is a single phase liquid as explained in Section 2.8.3.

For a closed continuous loop with a distributed temperature field the natural circulation can be evaluated by:

$$\dot{m}_{NC,L} = \left[\frac{2\bar{\rho}A_R^2\, g\, (\rho_C-\rho_H)(Z_C-Z_H)}{Eu,L}\right]^{\frac{1}{2}}$$

where,

- $\bar{\rho}$ = average density
- ρ_H = density of hot thermal center
- ρ_C = density of cold thermal center
- Z_H = elevation of hot thermal center
- Z_C = elevation of cold thermal center
- Eu,L = loop Euler number
- A_R = reference area

The thermal center densities and elevations are defined as follows:

$$\rho_H = \int \rho_i\, dz_i / \int dz_i \qquad Z_C = \int Z_d\, d\rho_d / \int d\rho_d$$
$$\rho_C = \int \rho_d\, dz_d / \int dz_d$$
$$Z_H = \int z_i\, d\rho_i / \int d\rho_i$$

where the subscripts i and d mean increase and decrease.

That is, the hot thermal center density is equal to the elevation weighted density increase whereas, the hot thermal center is the average elevation of the increasing densities.

For discretized data the integrals are evaluated as:

$$\rho_H = \Sigma \rho_i\, \Delta Z_i / \Sigma\, \Delta Z_i \qquad Z_H = \Sigma\, Z_i\, \Delta\rho_i / \Sigma\, \Delta\rho_i$$

$$\rho_C = \Sigma \rho_d\, \Delta Z_d / \Sigma\, \Delta Z_d \qquad Z_C = \Sigma\, Z_d\, \Delta\rho_d / \Sigma\, \Delta\rho_d$$

and $\bar{\rho} = \Sigma\, \rho\Delta Z / \Sigma\, \Delta Z$
where $\rho = \rho(T,P)$

2.9 Subroutine Natural

In this section the single-phase natural circulation calculations are described. The calculations are used to generate four different plot types. The first type shows temperature versus elevation for a given time. The second type displays the calculated and indicated flowrates versus time. In the third type the thermal center locations are plotted versus time. In the fourth type the natural circulation driving head versus time is displayed. Following a discussion of the natural circulation equations and their solution, a brief description of the input and output formats is given.

2.9.1 Program Description

The single-phase natural circulation equation can be derived from the equation of motion:

$$\rho \frac{Dv}{Dt} = - \nabla P - [\nabla \cdot \tau] + \rho g$$

Assuming that natural circulation is a quasi-steady state then

$$\frac{Dv}{Dt} = 0$$

If it is further assumed that the viscous force term can be approximated by

$$- [\nabla \cdot \tau] = \frac{Eu}{\Delta z} \frac{\dot{m}^2}{2\bar{\rho}A^2}$$

and the pressure gradient is dominated by the gravity term:

$$\nabla P = \bar{\rho}\, g$$

and the density can be approximated by the first order expression

$\rho = \bar{\rho} + \Delta\rho$ then:

$$0 = - \bar{\rho}g + \frac{Eu}{\Delta z} \frac{\dot{m}^2}{2\bar{\rho}A^2} + g(\bar{\rho} + \Delta\rho)$$

therefore

$$\dot{m}_{NC} = \left(\frac{2\, \bar{\rho} g\, A^2\, \Delta\rho\, \Delta z}{Eu}\right)^{\frac{1}{2}}$$

3.0 PLOT DIRECTORY

The plots indexed herein are the primary method of presentation of test results. There are two major types of plots: (1) Time-based plots (Section 3.1), and (2) Elevation-based plots (Section 3.2). Plots are futher categorized by the types plotted variables:

Range of Plot Numbers	Type of Plot
Time-Based Plots, Section B.1	
1-30	Basic
100-109	Calculated Conditions
110-119	Core Vessel
120-129	Hot Leg
130-139	SG Primary
140-149	Cold Leg
150-159	Downcomer
160-169	Pressurizer
170-179	Reactor Vessel Vent Valve
180-189	Primary Boundary
190-199	Secondary System
320-329	Natural Circulation
Elevation-Based Plots (indexed by time), Section B.2	
200-219	SG Temperatures
220-239	SG Temperatures and Trends
240-259	SG Linear Heat Rates
260-279	SG Heat Transfer Coefficients
300-319	Primary Fluid Temperatures

Throughout these plots, supplied variables have their alpha-numeric instrument descriptor entered under "VTAB", calculated variables contain the VTAB-entry "CALCD." These calculations have been outlined in Section 2, instruments are located in Section 4.

2.9.2 Input - Output

The input to subroutine NATURAL consists of the recorded temperatures at various elevations around the loop along with the loop pressure. The temperature-pressure data is converted by way of water property routines to local densities. The densities are averaged as described in the preceding section to obtain the natural circulation flow, thermal center values and location as well as the natural circulation driving head ($\Delta\rho$). The output consists of the plotted results. The first set of plots shows the input temperatures at a given time versus the instrument elevation. The second and third series of plots shows the computed natural circulation flowrate versus time and the thermal center densities and elevations used in the flowrate calculation respectively. The last plot series shows the natural circulation driving head ($\Delta\rho$) versus time.

PLOT NUMBER	ORDINATE	DISCUSSION
Basic Plots, Plots 1-30		
13	SG-Primary String Thermocouple (TC) Temperatures, On-Nozzle (F).	The temperature indicted by each of the 10 TC's is indicated; their elevations (ft. relative to SGLTSUF) are given under "INDEX." "On-Nozzle" denotes the SG tube directly in front of the minimum-wetting AFW nozzle.
14	SG-Primary String TC Temperatures (F), Opposite Nozzle	The temperatures analogous to Plot 13 are given for the string in the SG tube which is directly opposite (and across the tube bundle) from the minimum-wetting AFW nozzle.
15	System Energy Transfer (% Full Power)	Energy transfer is shown for the Core, Primary, SG Primary Out, and SG Secondary Out. Core power is taken directly from the wattmeter. "Primary" power is Core Power less losses to ambient. SG Primary power-out is SG Primary flow times SG inlet minus outlet fluid specific energy. SG Secondary power out is steam minus feed convected energy, plus SG Secondary heat losses to ambient.
16	Limit Switches	
17	Primary Mass Balance (lbm/s)	Primary mass rate of charge due to HPI and discharges, and net primary system mass rate of charge. Discharge sites are keyed to limit switch actuations. The ordinate is limited to -0.1 to +0.7 lbm/sec.
18	Cumulative Primary Mass (lbm)	Calculated and apparent (indicated) Primary System fluid mass.
19	Primary Energy Balance (% of full power)	Primary system energy rate of change due to: core, all discharges minus HPI (EFLUNT); and all Primary ambient losses (AMB-PU). The net of these energy change sources is also shown. The ordinate is limited to -2 to +6% of full power, 1% = 21.4 kw).
20	Total Primary Fluid Energy (% of Initial Total Energy	Calculated and indicated total Primary fluid energy, normalized to initial total fluid energy.
21	Primary Fluid Average Specific Energy (Btu/lbm)	Calculated and indicated Primary fluid average specific energy.

3.1 TIME-BASED PLOTS

Time on the abcissa is displayed in minutes after the start of testing.

PLOT NUMBER	ORDINATE	DISCUSSION
Basic Plots, Plots 1-30		
1	Pressure (psia), Primary and Secondary.	
2	Fluid Temperature (Volume Weighted, F)	Volume-weighted fluid temperatures are shown for each primary component (RV, HL, SGP, CL, DC, and PR) and the SG Secondary (SGS). Primary and Secondary (steam) saturation temperatures are also shown.
4	Collapsed Levels (feet relative to the SG Lower Tube Sheet Upper - Secondary Face).	Fully-corrected collapsed levels are shown for each instrumented component. "Collapsed" level indicates the equivalent all-liquid level. Two levels are indexed "SGPKLV"; variable-index (VTAB) SPLV20 is the Primary level in the SG, while HLLV21 indicates the sum of the SG Primary level plus that in the HL stub downstream of the HL U-Bend (HLUB).
8	SG Secondary Level (ft.)	The collapsed and auctioneered-CP SG Secondary levels are shown. "Auctioneering" obtains the highest CP (Conductivity Probe) elevation at and below which the remaining CP's are wetted. Note the testpoints in which Secondary CP's were not calibrated (shown in the Instrument Status Table). The collapsed-level maximum instrument sensitivity and the minimum CP spacing are both frequently visible in this plot.
9	Primary Flowrates (% of Full Flow)	CL and DC Orifice flow is shown. Note the calibration limitations of the CL orifice (cf. the Instrument Status Table). The conversion from % (scaled) full flow is: 1% Full Flow = 0.259 lbm/sec.
12	Secondary Flowrate (% of Full Flow)	The two direct variables are feed flow and steam flow (auctioneered between the high-flow and low-flow steam and feed circuits as appropriate). The two indirect variables are "FD-STM" and "DM/DT." FD-STM is the difference of feed and steam flow already plotted. DM/DT is the SG Secondary fluid mass difference over each time increment, divided by the duration of each increment. (DM/DT at time zero is nulled). The conversion for secondary flow is: 1% (scaled) Full Flow = 0.0265 lbm/sec.

Component-Oriented Plots, Plots 100-199

100-Series Plots, Calculated Conditions

PLOT NUMBER	ORDINATE	DISCUSSION
101	Ambient Heat Losses (% of Full Power)	Losses to ambient are shown for the RV, HL, CL and SGS. RV, HL, CL, and SGS losses are determined as functions of component average temperature. HL losses are nulled when the HL Guard Heaters are energized. The conversion factor is 1% (scaled) full power = 21.4 kw.
102	Saturation Temperature (F).	Saturation temperatures are shown for secondary steam, "SGS", and for the Pressurizer. "STMSAT" is saturation temperature at steam pressure. "SGSSAT" is saturation temperature at steam pressure plus the pressure of the current liquid column in the SG Secondary (i.e., it is approximately the (maximum) SGS saturation temperature, at the bottom of the generator). "PR SAT" is the saturation temperature at the Pressurizer pressure.
103	DM/DT lbm/sec	
104	(Component) Liquid Volume (% of Full)	Component fractional liquid volumes are shown for the RV, HL, SGP (including HL stub to HLUB), CL, DC, PR, SGS (Secondary), and Primary total (PRI). Each volume reflects the collapsed level (Plot 4) converted using approximate component volume versus (heated) elevation. The Primary total volume represents the sum of the primary component fluid volumes, normalized to the total primary volume.
105	Component Fluid Mass (lbm/sec)	
106	Component Energy (% of Initial Energy).	Component Energy normalized to initial energy is shown for the RV, HL, SGP (including HL stub), CL, DC, PR, SGS (Secondary), and PRI (Primary Total). For each component, energy is taken as liquid mass times liquid specific energy, plus vapor mass times vapor specific energy. "PRI" is the sum of the primary component energies, normalized to time-zero content.

PLOT NUMBER	ORDINATE	DISCUSSION
Basic Plots, Plots 1-30		
22	Primary Liquid DVOL/DT (ft^3/min)	Primary liquid volume rate of change due to: HPI; all liquid-state discharges (DISCH); liquid density effects (DVDRHO); and steam generation (2 STEAM). The net of these liquid volume change sources is also shown. The ordinate is limited to -0.2 to +0.6 ft^3/min.
23	Primary Vapor Volume Change (ft^3/min)	Primary vapor volume change rate due to: steam generation in the core (CORE); condensation by HPI fluid (HPICON); vapor-region discharges (DISCH); boiler-condenser mode condensation in the SG (BCM); condensation due to heat losses to ambient (AMBCON); and pressurization effects (DPRESS). The net of these vapor volume change sources is also shown.
24	Primary Liquid Volume (% of total Primary Volume)	Calculated and indicated Primary system liquid volumes are shown.
25	Primary Pressure Change (psi/min)	Calculated and indicated Primary system pressurization rates are shown.
26	Cold Leg Fluid Temperatures (F)	Cold Leg fluid temperatures, CLTC01-05, are shown. (CLTC01 has been combined with the SG Primary fluid temperatures, and CLTC04 and 5 with the Downcomer fluid temperatures, to perform fluid-volume weighted property calculations in subroutine PROPS).
27	Pressure (psia) Primary Loop	The RV, SG primary and the PR pressure are shown.
28	Approximate Core-Region Void Fractions	Approximate voided length in the RV (based on level ΔP's without flow corrections) expressed as a percent of the total length of the component.
29	Approximate Hot Leg Void Fraction	Implied voided length in the HL (based on level ΔP's without flow corrections) expressed as a percent of the total length of the component. Note the RV-to-SG void fraction becomes negative when the HL level is greater than the SG pressure tap elevation, about 53 ft, due to the locations of the pressure taps and the liquid level difference in the upstream and downstream portion of the U-bend.
30	Approximate Steam Generator Secondary Void Fraction	Implied voided length steam in the SG secondary (based on level ΔP's without flow corrections) expressed as a percent of the total length of the component.

130-Series Plots, SG Primary

PLOT NUMBER	ORDINATE	DISCUSSION
133		VTAB SPPT04 samples the on-nozzle tube containing a TC string, SPPT05 samples of off-nozzle tube containing a string TC, and SPPT06 samples a tube without a string TC. The conversion of Primary flow is: 1% scaled full flow = 0.259 lbm/sec.
134	SG Primary Conductivity	High conductivity indicates wet, low indicates dry.
135	SG Primary Pitot Temperature	

140-Series Plots, Cold Leg

PLOT NUMBER	ORDINATE	DISCUSSION
141	Cold Leg Fluid Thermocouple Temperature (F)	The available CL temperatures are shown, and are indexed by elevation (ft relative to SG LTSUF). Note that the VTAB numbering indicates the occurrence of the TCs, proceeding from the SG outlet to the CL nozzle: CLTC01 is at the CL lowpoint, CLTC02 and 03 move up the CL from the lowpoint to the spillover (SO), and CLTC04 and 05 are in the sloping run toward the nozzle.

150-Series Plots, Downcomer

PLOT NUMBER	ORDINATE	DISCUSSION
151	Downcomer Fluid Temperature (F)	The available DC fluid temperatures are shown, and indexed by elevation.

160-Series Plots, Pressurizer

PLOT NUMBER	ORDINATE	DISCUSSION
161	Pressurizer Fluid Temperatures (F)	The available PR fluid temperatures are shown and indexed by elevation (ft relative to the SG LTSUF). Saturation temperature at PR pressure is also shown.
162	Pressurizer Insulation DT (F)	The available PR and surge line insulation DT's are shown and indexed by elevation (ft relative to the SG LTSUF).
163	Pressurizer Metal Temperature (F)	The available PR and surge line metal temperatures are shown and indexed by elevation (ft relative to the SG LTSUF).

170-Series Plots, Reactor Vessel Vent Valve

PLOT NUMBER	ORDINATE	DISCUSSION
171	Reactor Vessel Vent Valve (RVVV) Fluid Temperature (F)	The fluid TC temperatures bracketing the RVVV are shown (RVTC09 upstream and RVTC10 downstream).

110-Series Plots, Core Vessel

PLOT NUMBER	ORDINATE	DISCUSSION
111	Core Vessel Fluid Temperatures (F)	Available core fluid temperature indications are shown; they are indexed in feet relative to the SG LTSUF.
112	Core Vessel Insulation DT (F)	Available core vessel insulation DT's are shown; they are indexed in feet relative to the SG LTSUF.
113	Core Vessel Conductivity	High conductivity indicates wet, low indicates dry.
114	Core Vessel Metal Temperatures (F)	Available core vessel metal temperatures are shown, and indexed by elevation above the SG LTSUF.

120-Series Plots, Hot Leg

PLOT NUMBER	ORDINATE	DISCUSSION
121	Hog Leg Fluid Temperature (F)	The hot leg fluid temperatures are shown, from the HL Nozzle to the HLUB, indexed by feet relative to the SG LTSUF.
122	Hot Leg Insulation DT (F)	The hot leg insulation DT's are shown from the HL nozzle to the SG inlet, indexed by feet relative to the SG LTSUF.
123	Hot Leg Conductivity	High conductivity indicates wet, low indicates dry.
124	Hot Leg Metal Temperatures (F)	The hot leg metal temperatures are shown, from the HL nozzle to the HLUB indexed by feet relative to the SG LTSUF. The pressurizer surge line metal temperature, at the low point of the surge line, is also shown.

130-Series Plots, SG Primary

PLOT NUMBER	ORDINATE	DISCUSSION
131	SG Primary Fluid Temperatures (F)	The SG primary fluid temperatures (but not the string TCs), and the HL temperatures downstream of the HLUB, are shown and indexed in feet relative to the SG LTSUF.
132	SG Primary Fluid Resistance Temperature Detector (RTD)	The 4 SG primary inlet and outlet RTDs are shown, and indexed in feet relative to the SG LTSUF.
133	SG Primary Pitot Tube Flow (% Full Flow)	The flow indicated by the SG Primary Pitot Tubes is shown. Individual tube indications are multiplied by 19 to include all tubes, and by 0.847 to approximately correct for the tube flow profile sampled by the Pitot tube. No correction is made for SG tube resistance differences due to the instrumentation.

3.2 ELEVATION-BASED PLOTS

Elevation on the abcissa is displayed in feet relative to the SG Lower Tube Sheet Upper Secondary Face (SG LTSUF). Plots commonly extend from -5 to +55 feet, to encompass the SG-bracketing primary fluid RTDs.

Elevation-based plots are made at selected times, the time of each plot is printed on the plot, directly above the plot number.

SG Heat Transfer Plots 200-299

PLOT NUMBER	ORDINATE	DISCUSSION
200-Series Plots	SG Temperatures at Time...Date... (F)	Five types of SG temperatures are shown: SGPRI (Primary) RTD/Fluid TC, OFFNOZ String TC, ON-Nozzle String TC's, SEC, and Saturation. The SGPRI RTD/TC include all the SG Primary temperature measurements other than the String TC. The OFFNOZ and ON-NOZ String TC's indicate all the temperatures of Plots 13 and 14. The SGSEC points include all the secondary fluid temperature indications. The SECSAT plot shows SG secondary fluid saturation temperature corrected for level. The point at elevation 0 is saturation at steam pressure plus the pressure of the current liquid column. The middle and Z=52 ft points are saturation at steam pressure; the middle point is plotted at the elevation of the current collapsed secondary level. Only these saturation temperatures, and those of the String TC's, are connected (by straight lines between points).
220-Series Plots	SG Temperatures and Trends (F) at Time..., Date...	Temperatures and Trends are shown from ON-NOZ (On-Nozzle STC), OFF NOZ (Off-Nozzle STC), ALL PRI, and ALL SEC. The On-Nozzle and Off-Nozzle plots include the String TC's (Plots 13 and 14) plus the bounding SG Primary fluid RTD's, plus the SG Primary fluid TC at 8.1 feet (this TC is needed to define the STC profiles). The ALL PRI plot includes primary fluid temperatures from TC's, String TC's, and bounding RTD's. The ALL SEC plot includes all secondary fluid TC indications. Other than the String TC's, no allowance is made for TC position within the SG tube bundle. Modified splines are used to curve-fit these temperatures for analyses. The measured temperatures are used, except that measurements near one elevation are collapsed to a single temperature and elevation. The 3 primary spline fits use the boundary condition that the first derivatives are 0 at the end points, the

SG Heat Transfer Plots 200-299

PLOT NUMBER	ORDINATE	DISCUSSION
220-Series Plots		ALL SEC fit uses 0 second derivatives at the end points. These curves fits are limited by the density of temperature measurements, cf. Section 2.
240-Series Plots	SG Linear Heat Rate (kw/ft)	The SG Primary Linear Heat Transfer Rates are shown for the 3 groups of SG primary temperatures of the previous plots: ON-Nozzle, OFF-Nozzle, and All Primary (temperatures). The curve-fit temperature profiles (of the previous plots) are used to obtain specific energy change with elevation, calculated SG primary total flow is introduced to calculate incremental linear heat rate (no allowance is made for flow redistribution among the SG Primary tubes).
260-Series Plots	Log-htc	LOG_{10}-htc (heat transfer coefficient) is plotted for the 3 temperature groupings of the 2 previous plots: ON-Nozzle String TC's, OFF-Nozzle String TC's, and All Primary temperatures. htc is calculated using the incremental q of the preceding plot, and the local primary-to-secondary temperature difference from the curve fits of the preceding plot. Heat transfer coefficients less than 10 are shown as log-htc = 1.

Natural Circulation Plots, Plots 300+

PLOT NUMBER	ORDINATE	DISCUSSION
300-Series Plots	Primary Fluid Temperatures (F)	Each Primary Loop fluid temperature versus elevation is plotted and keyed to its Primary component. Thermal centers are also shown.

170-Series Plots, Reactor Vessel Vent Valve

PLOT NUMBER	ORDINATE	DISCUSSION
172	RVVV Pressure Difference (psi)	
173	RVVV Miscellaneous	The open/close actuation of the RVVV limit switch is shown.
174	RVVV Calculated Flowrate (% of full flow)	The plotted variable (RVRF20) is the indicated Downcomer flowrate minus the indicated Cold Leg flowrate (cf. Plot 321).

180-Series Plots, Primary Boundary

181	HPI Turbine Meter Flow Rate (lbm/sec)	

190-Series Plots, Secondary System

191-193	SG Secondary Fluid Temperatures (F)	The available SG Secondary fluid temperatures are shown, as well as SG Secondary saturation temperature at steam pressure. Fluid TCs are indexed by elevation (ft relative to the SG LTSUF). For plotting clarity, only the lowest 9 TCs are shown in Plot 191, the next 9 in 192, and so forth, until all are displayed (usually 3 plots).
194	SG Metal Temperature (F)	The available SG Secondary Metal temperatures are shown, and indexed by elevation (ft relative to the SG LTSUF).

320-Series Plots, Natural Circulation

321	RVVV Flowrates	Predicted and indicated RVVV flowrates.
322	Loop Flowrates	Predicted and indicated loop flowrates.
323	Thermal Centers	Heating and cooling (normalized) densities and elevations versus time.
324	Natural Circulation Driving Force	

TABLE 3.1

CROSS REFERENCE OF PLOTTING VARIABLES (SECTION 3)
TO THE SECTION 2 DISCUSSION OF THEIR CALCULATION

Plot Number	Variable	Appendix Discussion In Paragrapn ...
2	Volume-Weighted Fluid Temperatures	2.5.1
4	Collapsed Levels	2.4.4
9	Primary Flowrates	2.4.3
12	Secondary Flowrates, Feed-Steam and	2.5.6
	dm/dt	2.6.2
17	Primary Mass Change Sources	2.7.1
18	Cumulative Primary Mass	2.7.1
19	Primary Energy Change Sources	2.7.2
20	Total Primary Fluid Energy	2.7.2
22	Primary Liquid Volume Change Sources	2.7.3
23	Primary Vapor Volume Change Sources	2.7.3
24	Primary Liquid Volume	2.7.3
25	Primary Pressure Change	2.7.4
191-3	SG Secondary Fluid TC, Steam Saturation	2.5.6
101	Heat Losses to Ambient	2.6.4
102	Saturation Temperatures	2.5.6
103	Component Liquid Volumes	2.6.1
107	Component Fluid Energy	2.6.6
200+	SG Temperature Profiles, Secondary Saturation	2.8.1
220+	SG Temperatures and Trends	2.8.2
240+	SG Linear Heat Rate	2.8.3
260+	Log-htc	2.8.4
301+	Loop Fluid Temperature Profiles	2.9
321, 322	Predicted and Indicated Flowrates	2.9
323	Thermal Centers	2.9
324	Natural Circulation Driving Force	2.9

4.0 OTIS TEST FACILITY INSTRUMENTATION

The relative location of the OTIS Test Facility Instrumentation is shown on Figure 4-1. Instrument designations consist of two, two-letter groups and a number group. The first two letter group identifies the loop component or subsystem in which the instrument is installed. For example, RV notes that the instrument is located in the reactor vessel. The second two letter group defines the instrument type, such as TC for a thermocouple or CP for a conductivity probe. The two number group indicates that the instrument is used for test data and also the sequential instrument number of that type in a component.

Table 4.1 provides a listing of loop component abbreviations and Table 4.2 provides a listing of instrument abbreviations which are used to identify the instrumentation shown on Figure 4-1.

As an example of the instrument designation a test data thermocouple (number 8) in the reactor vessel would be:

RVTC08

RV - Reactor Vessel

TC - Thermocouple

08 - Test data sequential number

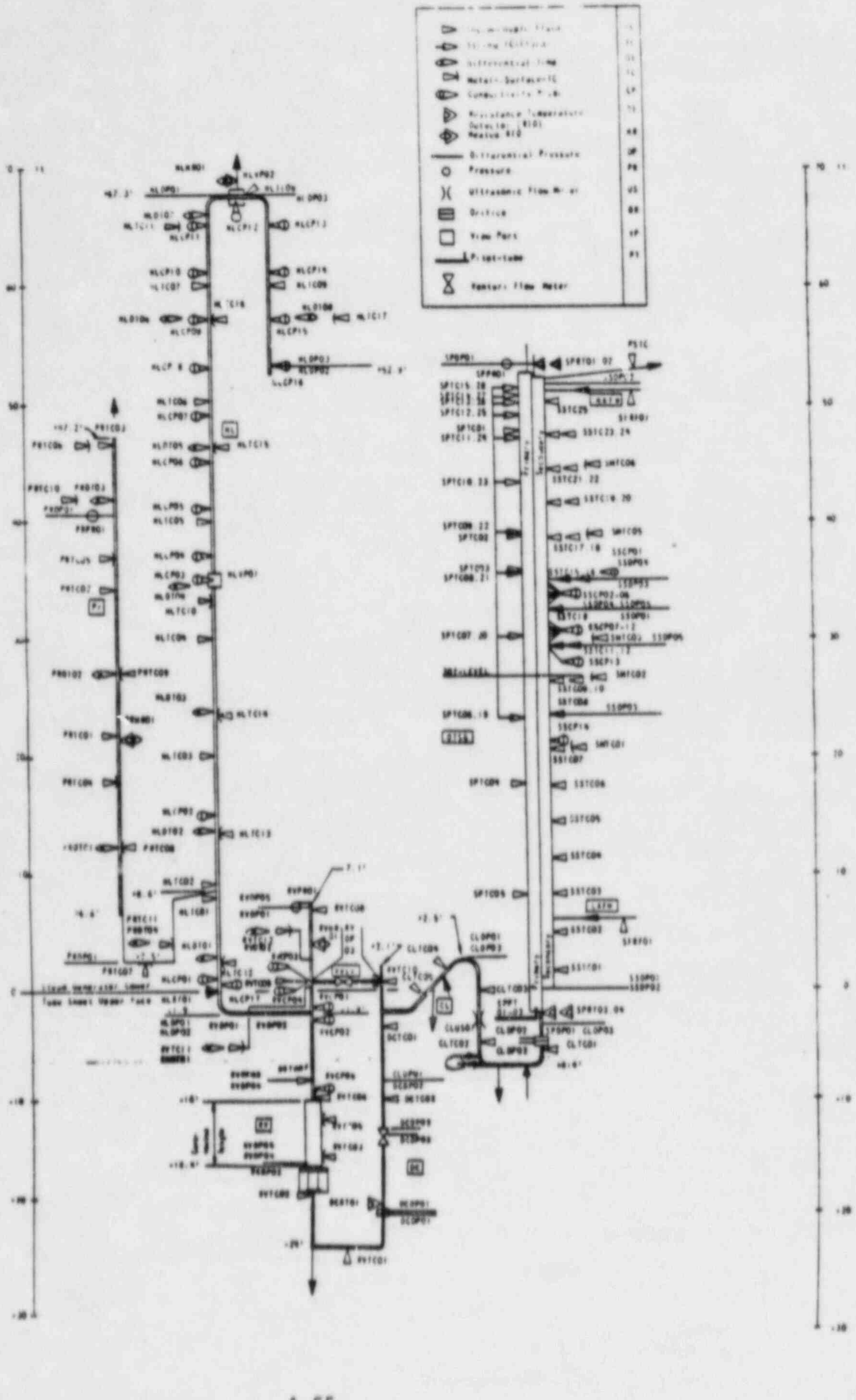
TABLE 4.2 INSTRUMENT ABBREVIATIONS

Instrument or Hardware	Abbreviation
Thermocouple	TC
Resistance Temperature Detector	RT
Differential Temperature	DT
Pressure	PR
Differential Pressure	DP
Orifice	OR
Ultrasonic Flow Meter	US
Pitot Tube	PT
Conductivity Probe	CP
Heated RTD	HR
View Port	VP

TABLE 4.1 LOOP COMPONENT ABBREVIATIONS

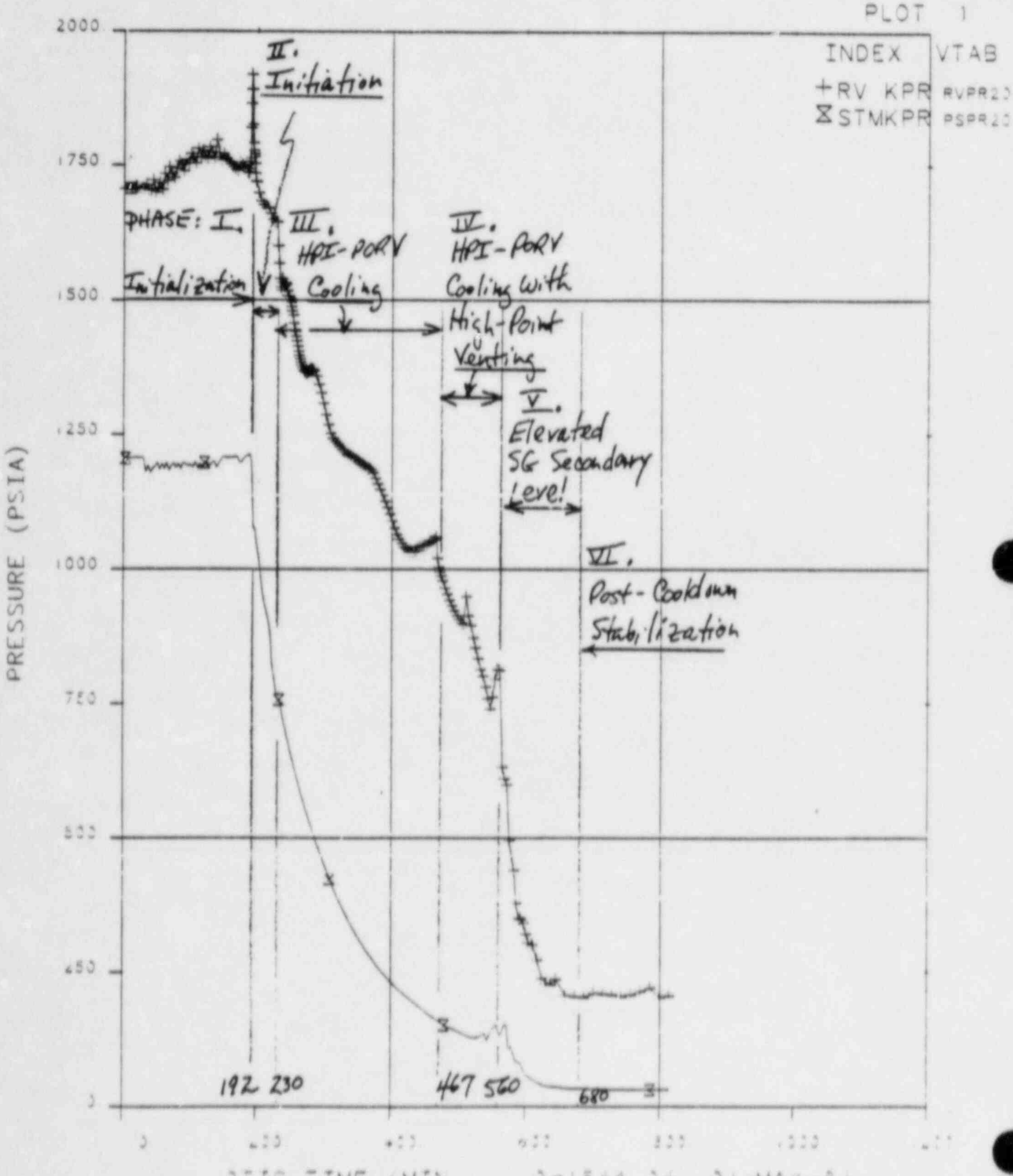
Loop Component	Abbreviation
Steam Generator - Primary	SP
Steam Generator - Secondary	SS
Steam Generator - Metal	SM
Reactor Vessel	RV
Downcomer	DC
Pressurizer	PR
Cold Leg	CL
Hot Leg	HL
HPI	HP
Secondary Forced Circulation	SF
Steam Piping	PS
Feedwater Piping	FP

Figure 4-1 LOCATION OF [illegible] INSTRUMENTS



PRELIMINARY DATA

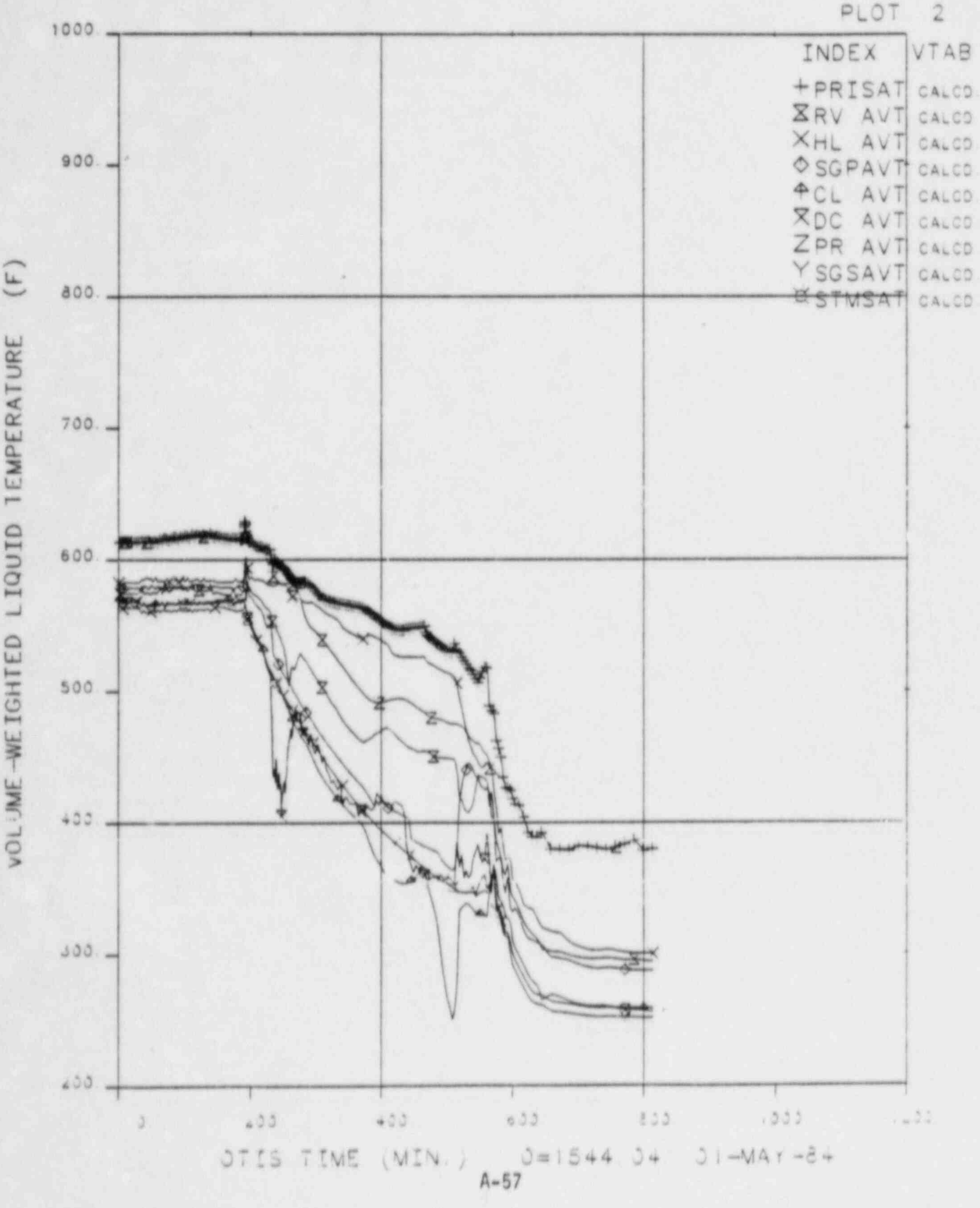
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

40200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

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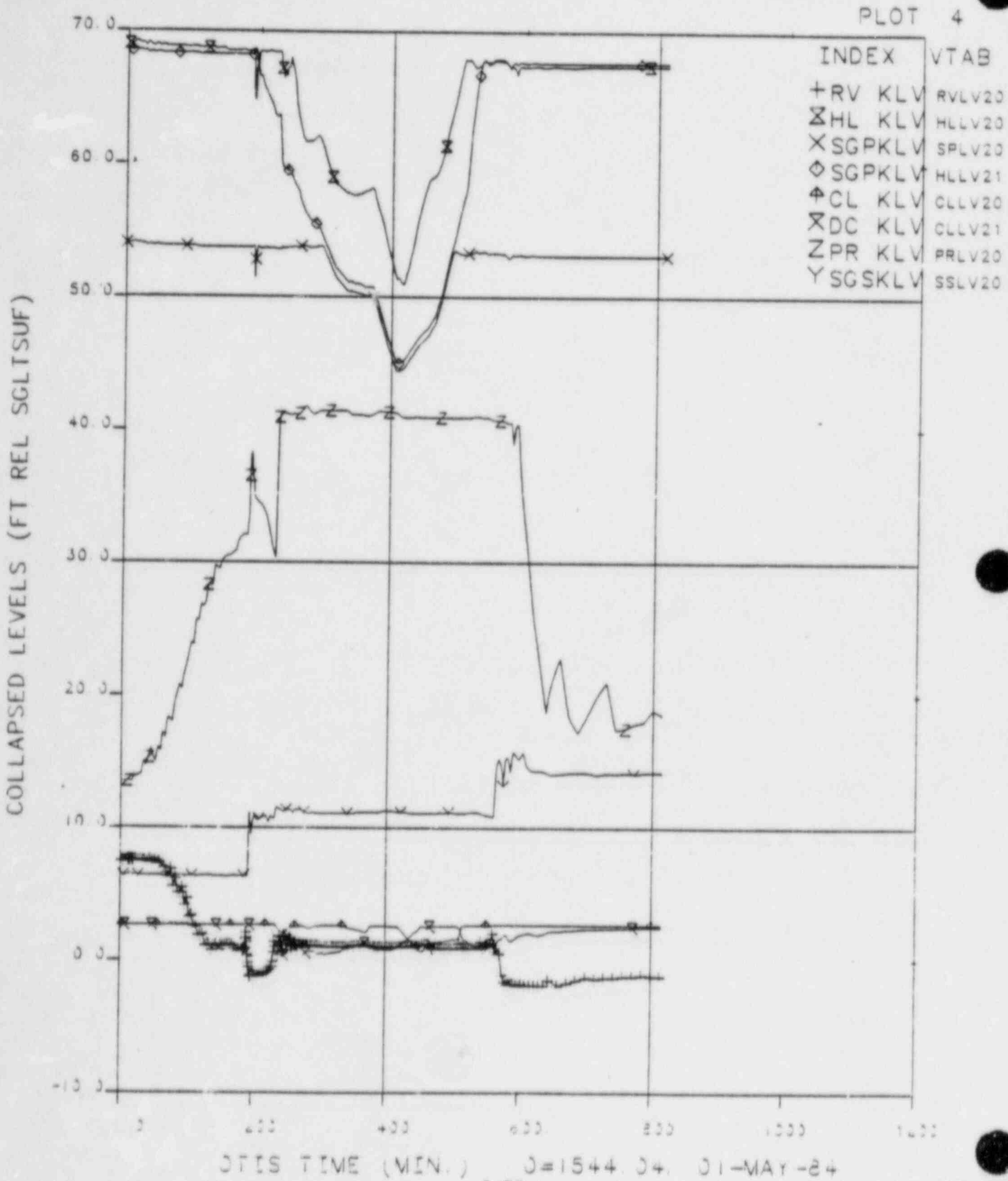

PRELIMINARY DATA

PRELIMINARY DATA

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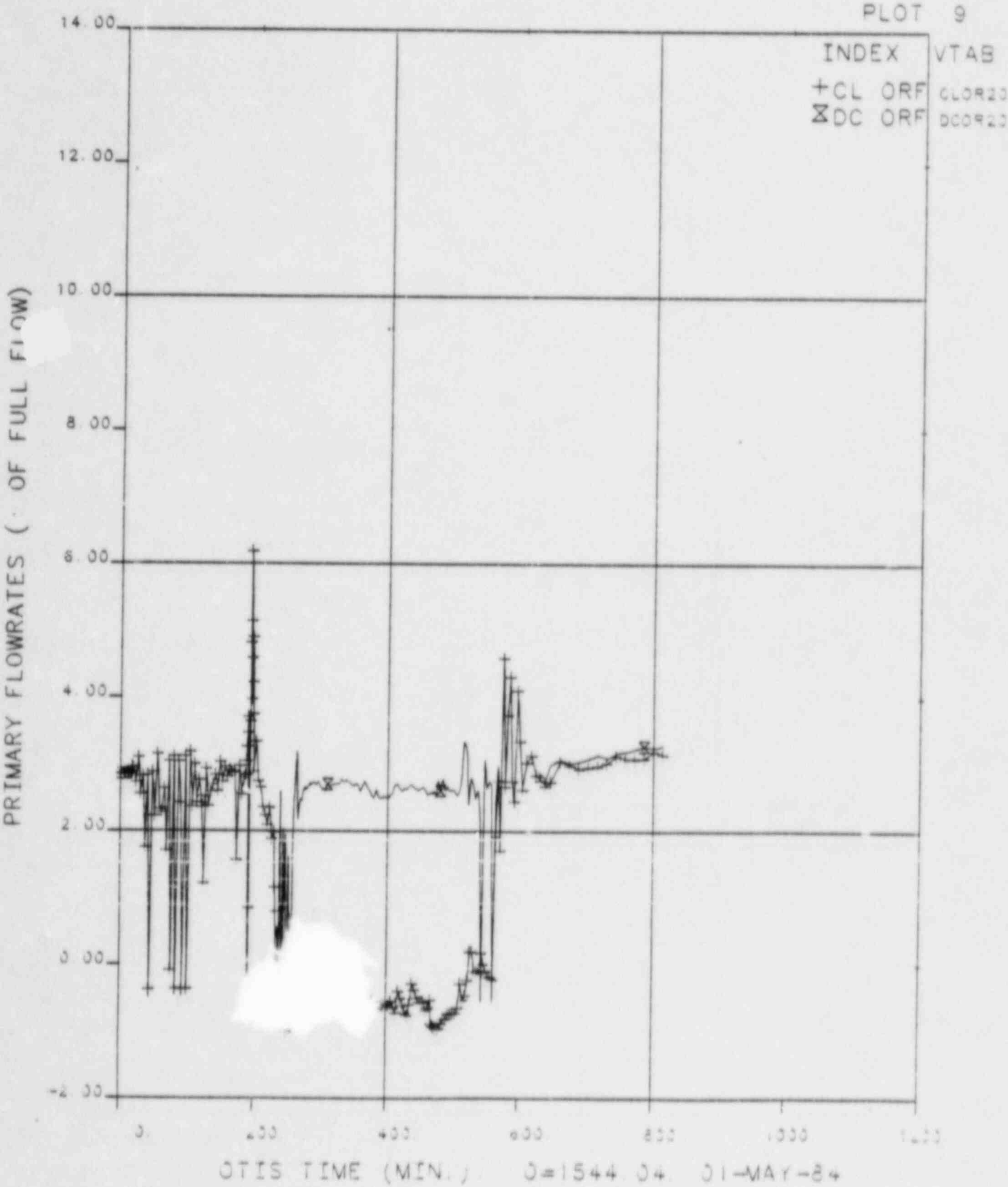
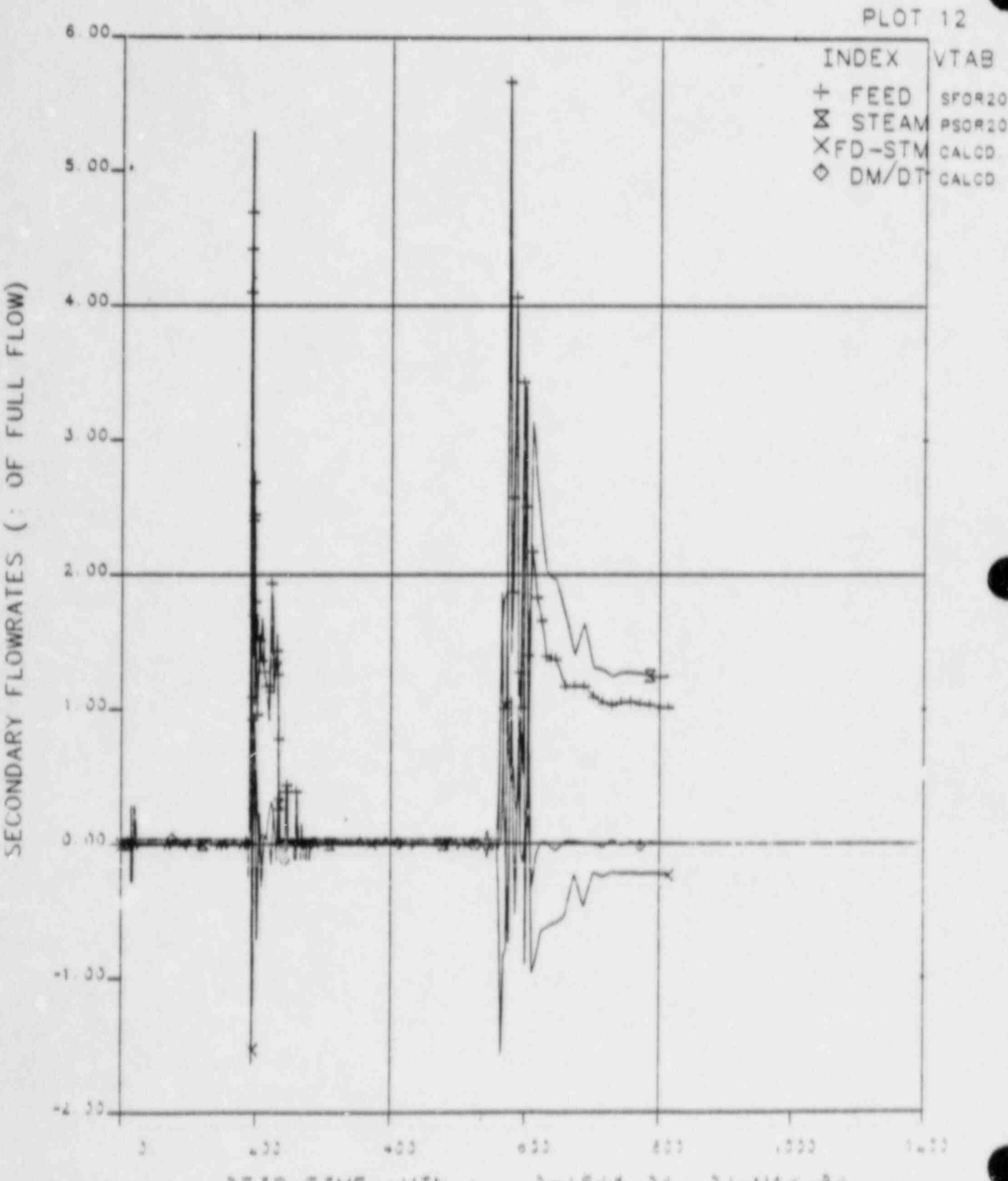


PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)

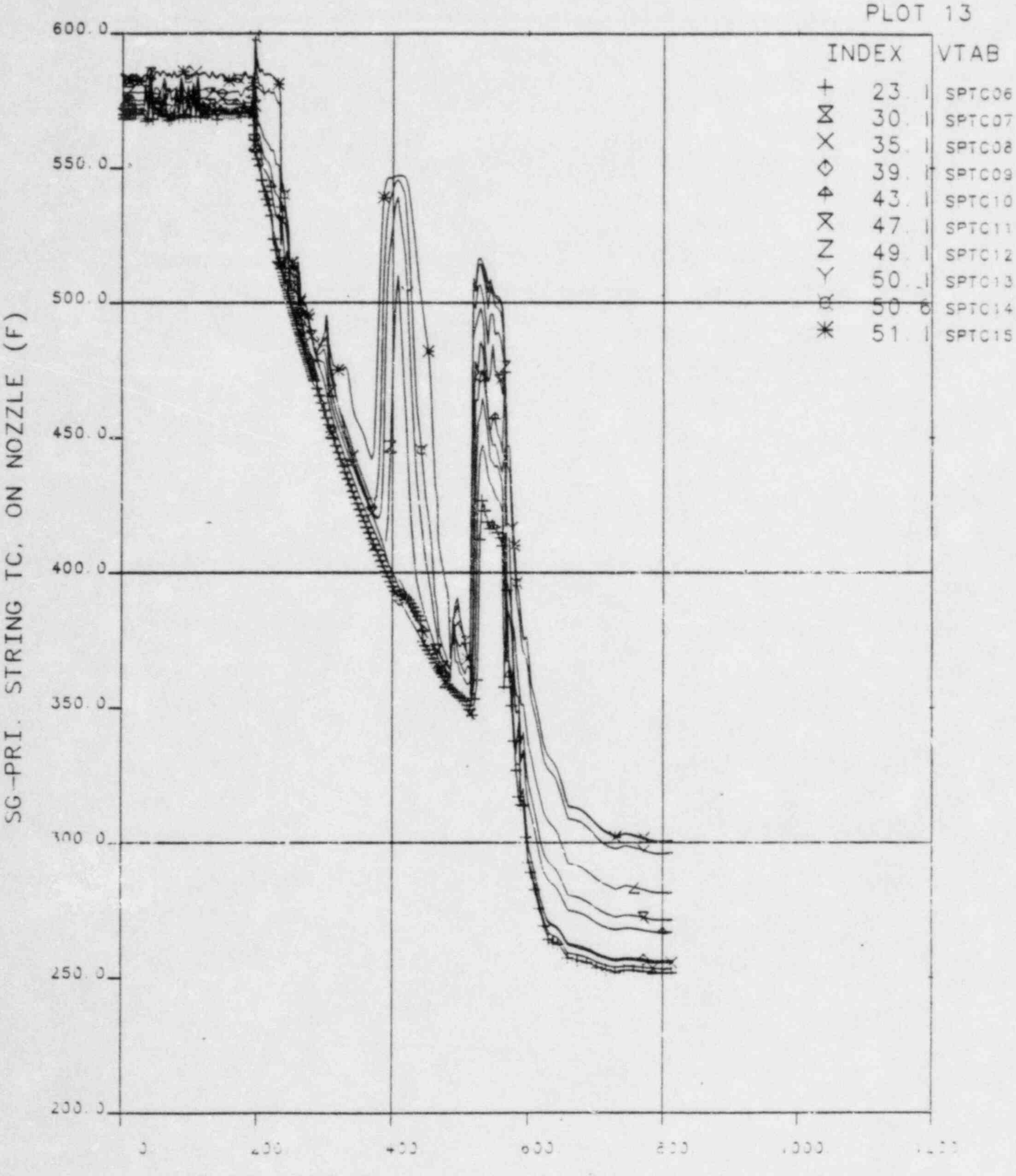


A-60

PRELIMINARY DATA

PRELIMINARY DATA

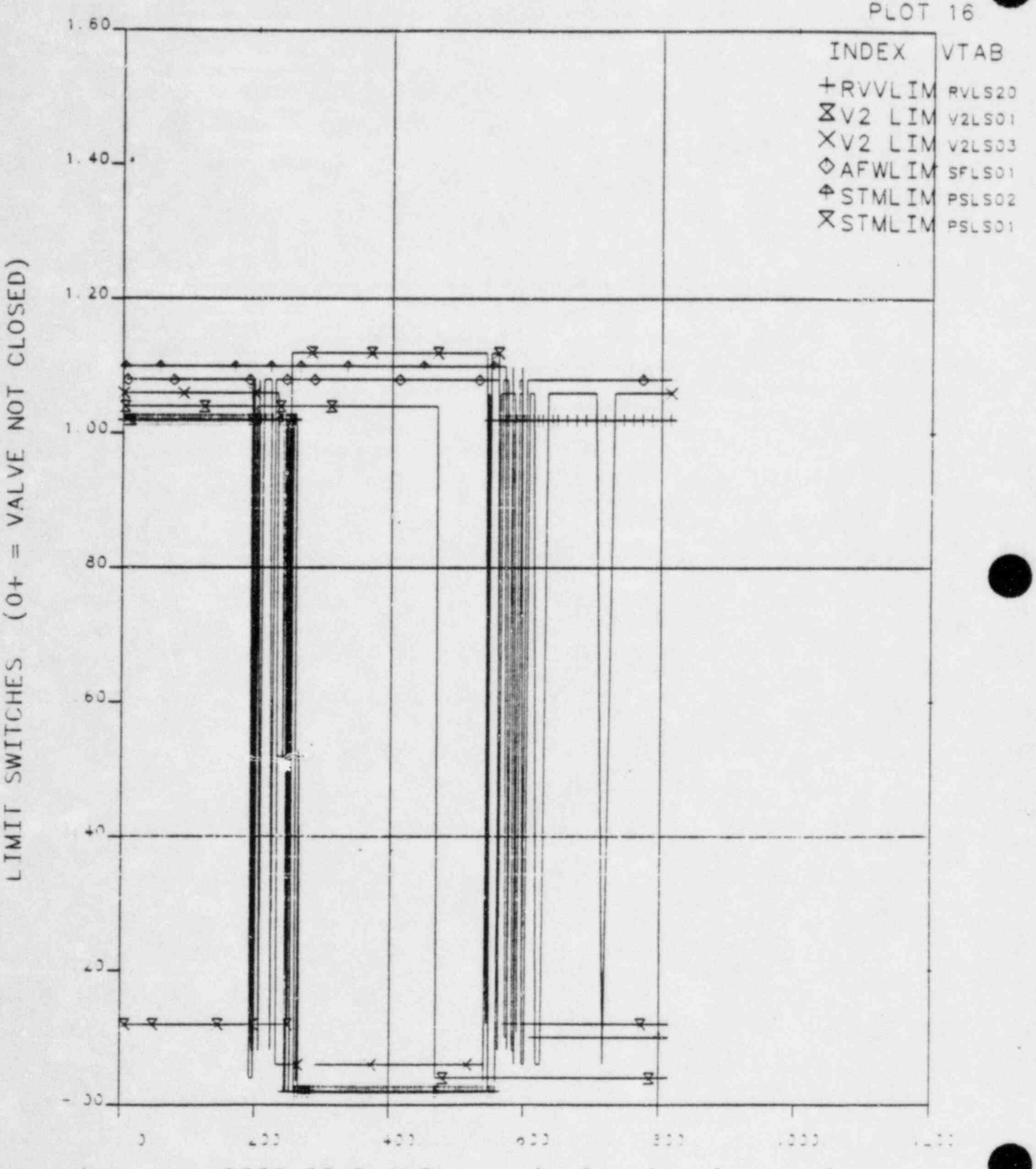
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

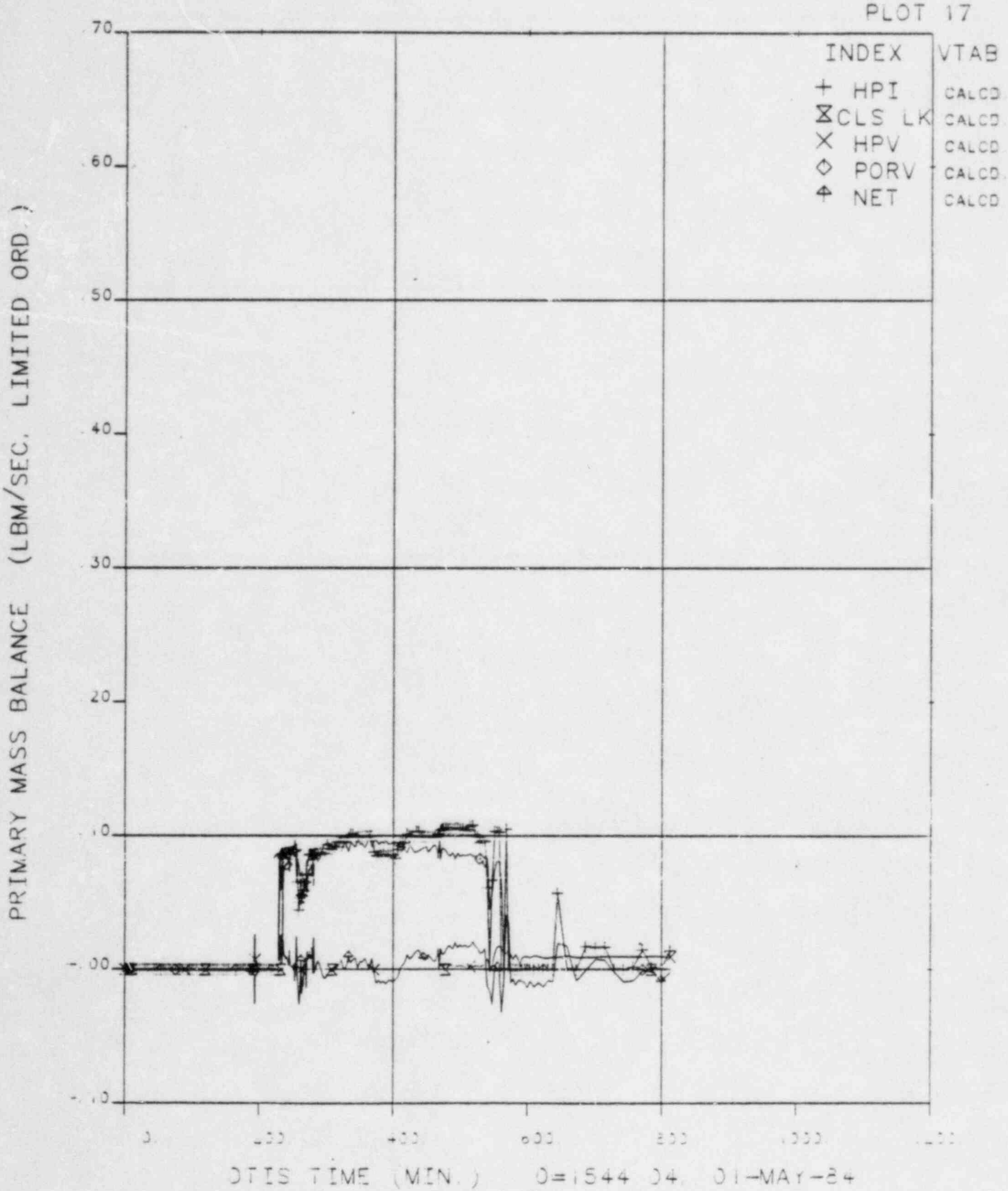
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

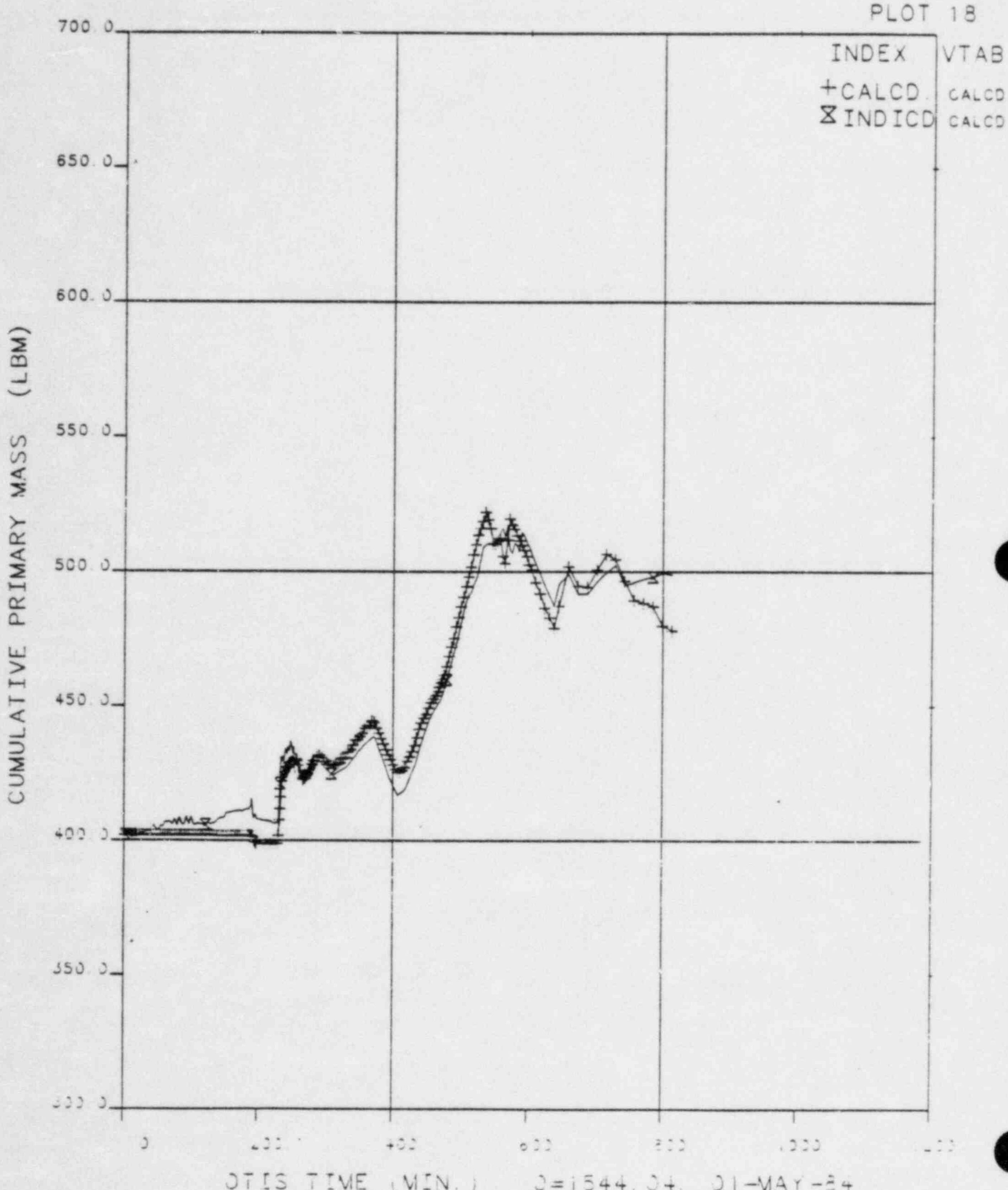
840200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

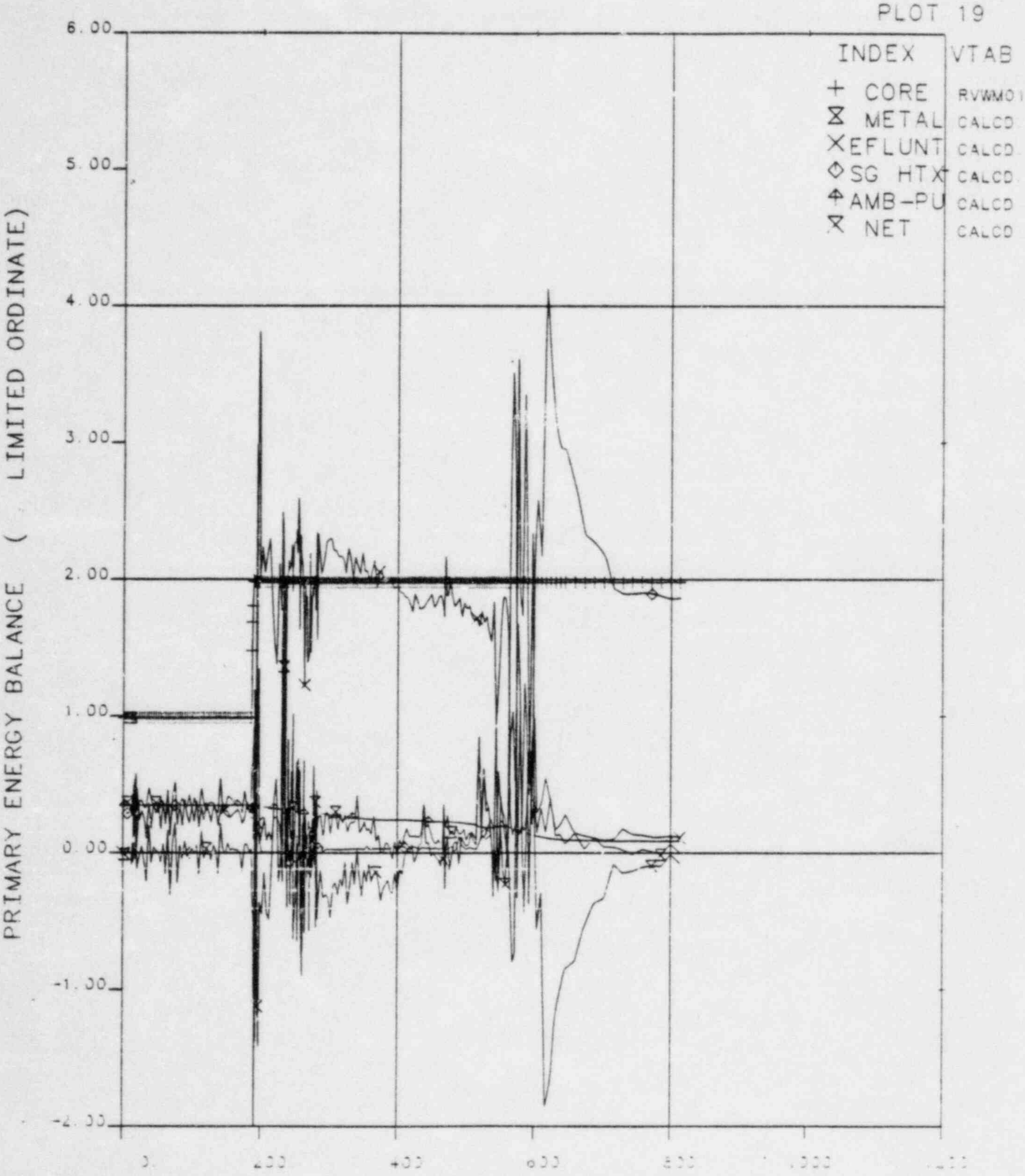
PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

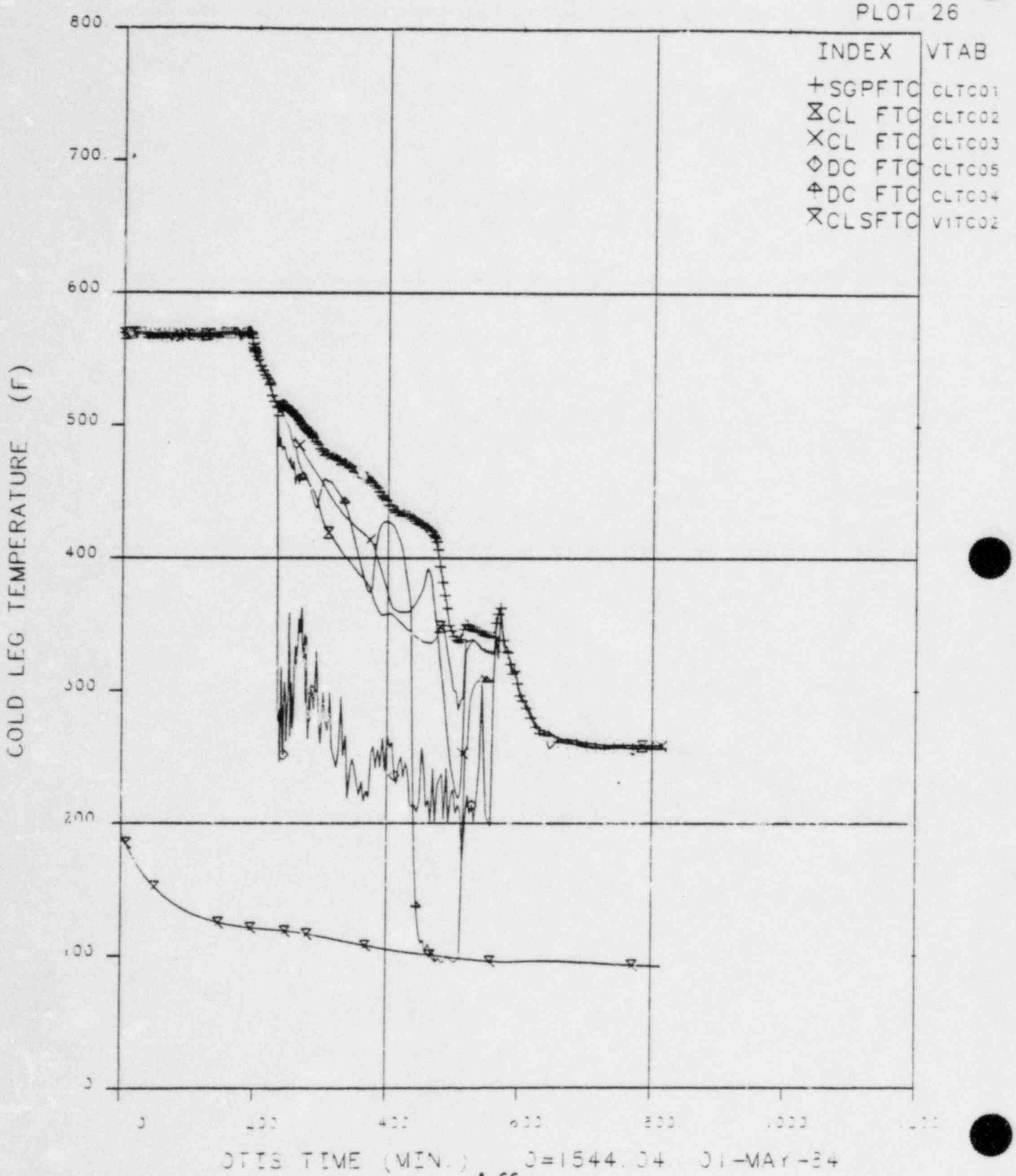
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

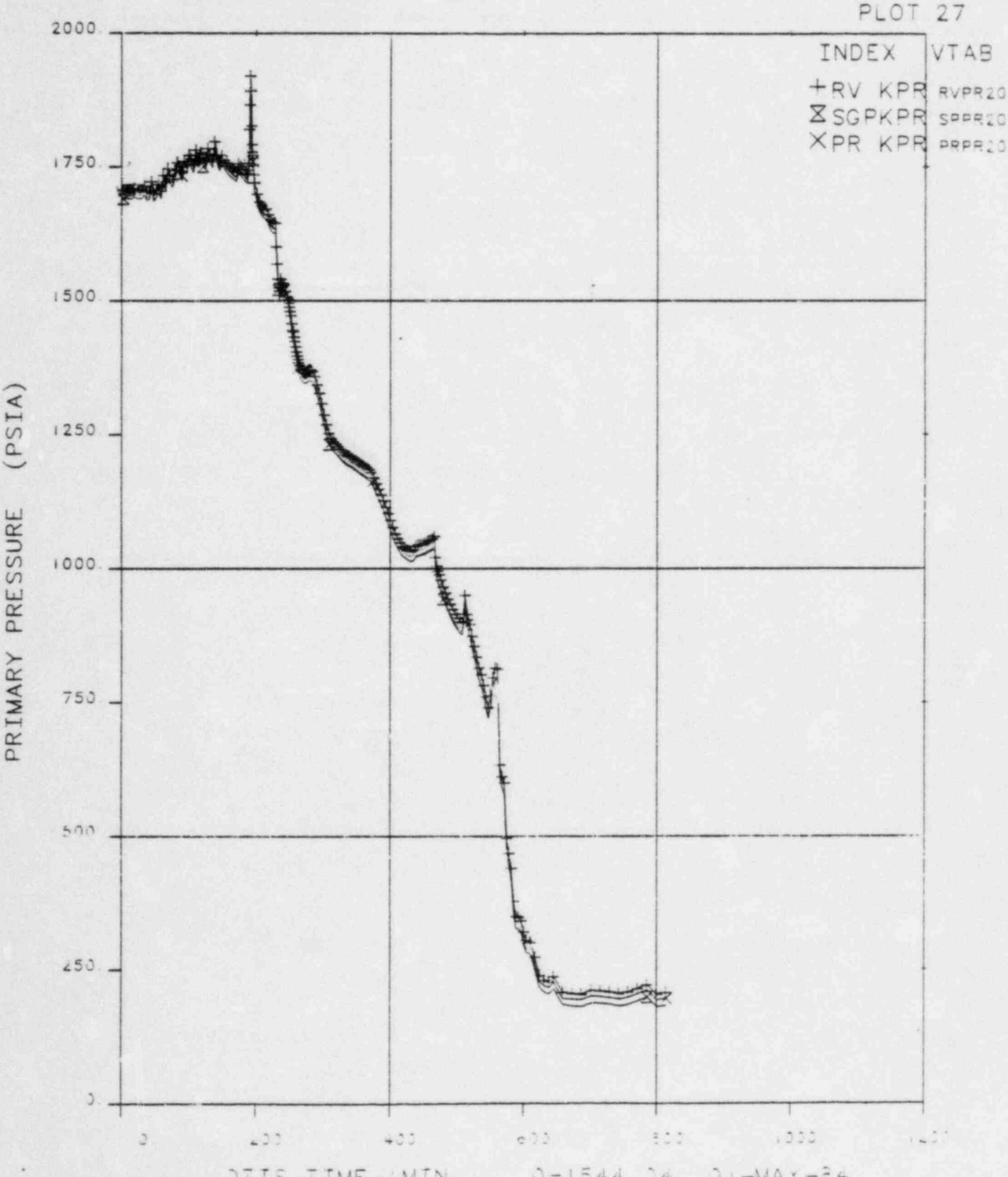
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

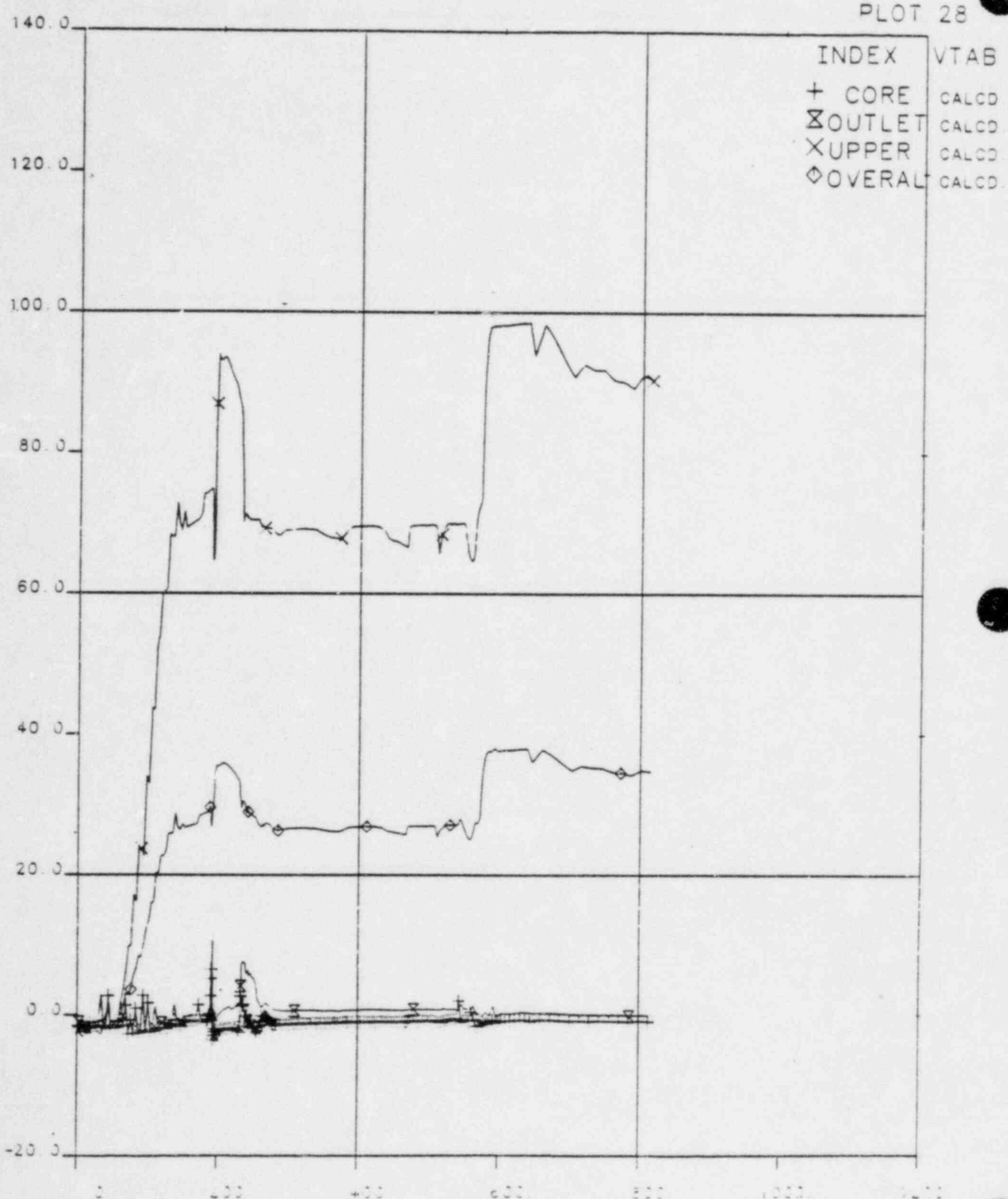
40200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



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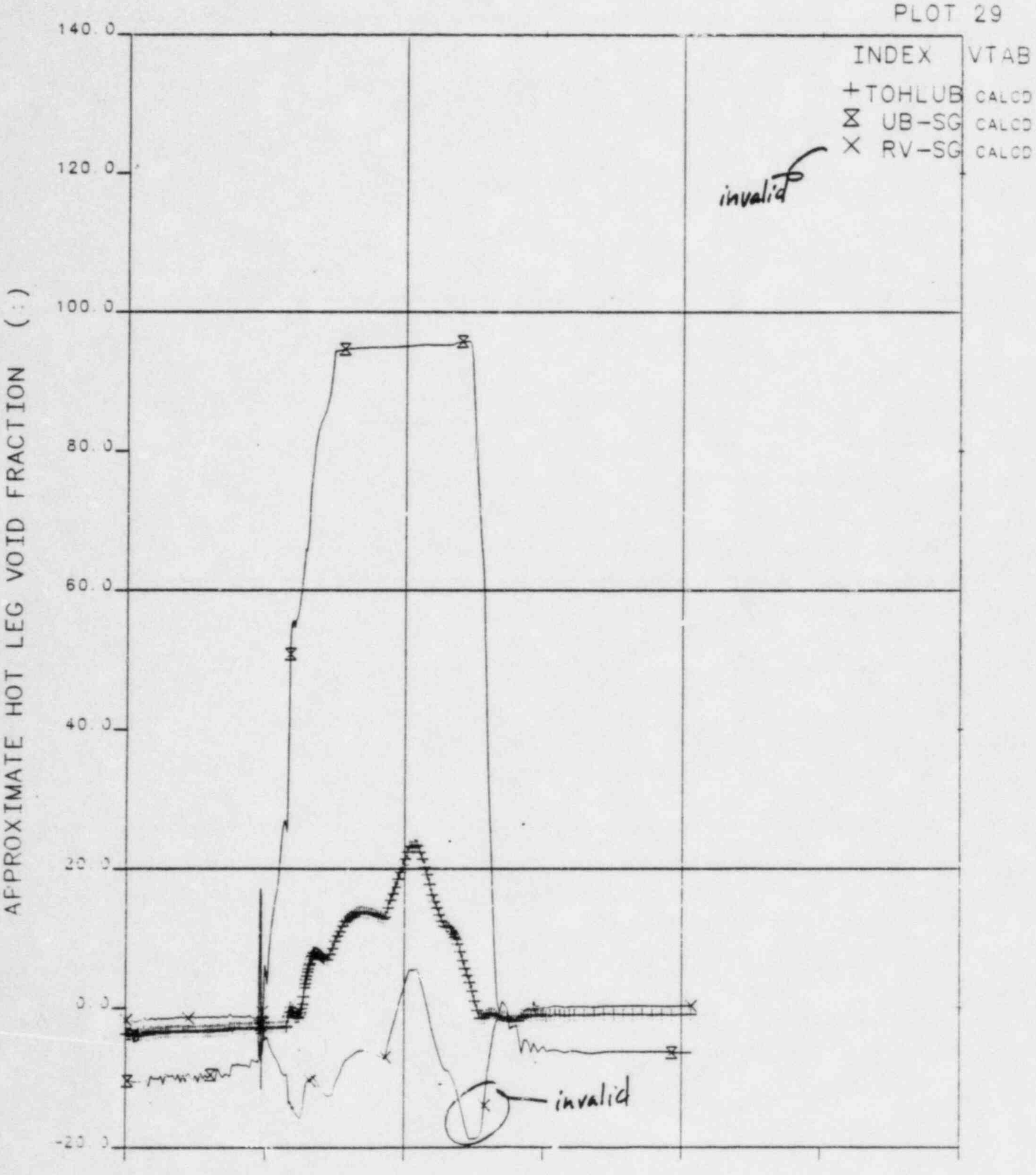
PRELIMINARY DATA

PRELIMINARY DATA

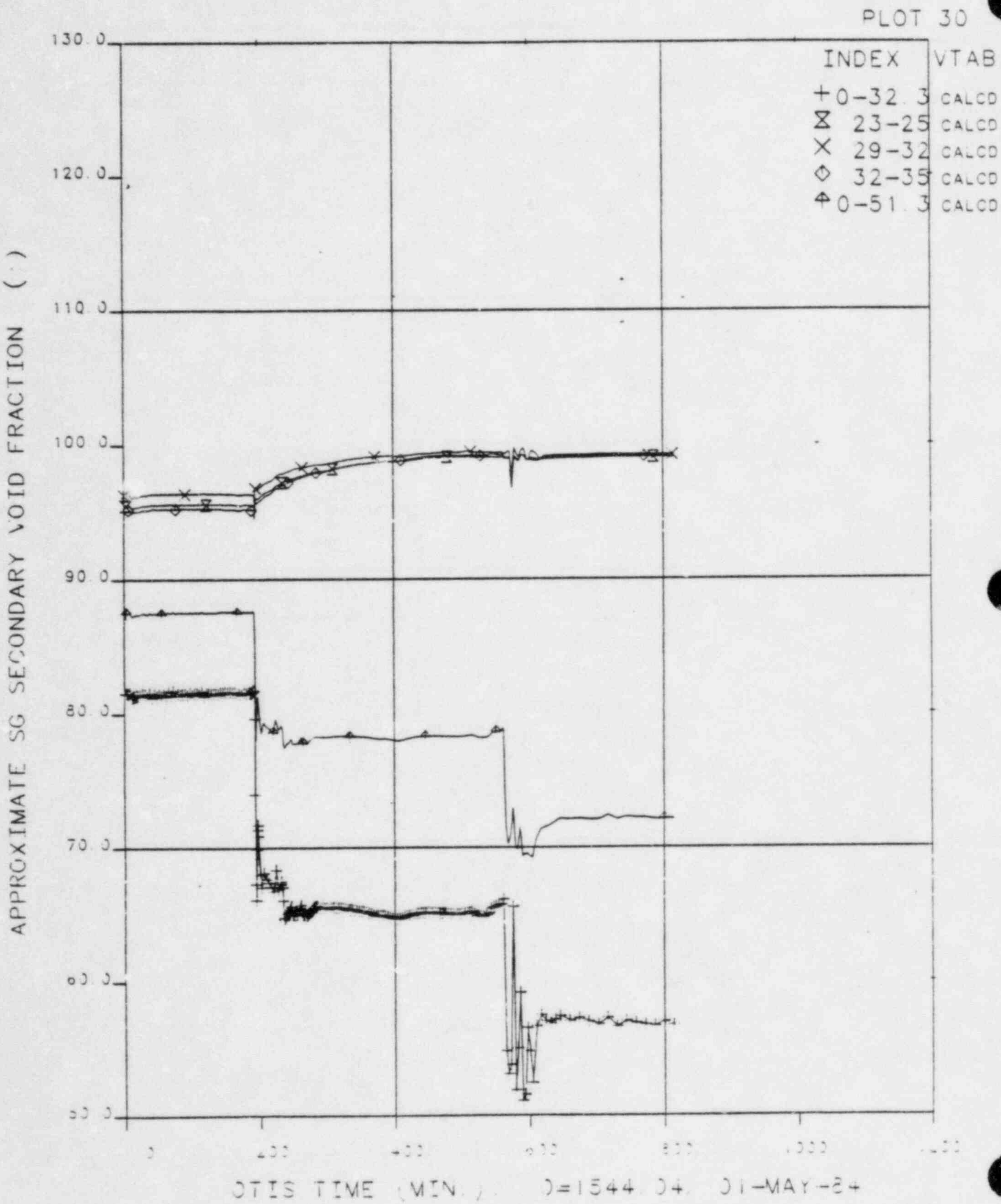
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

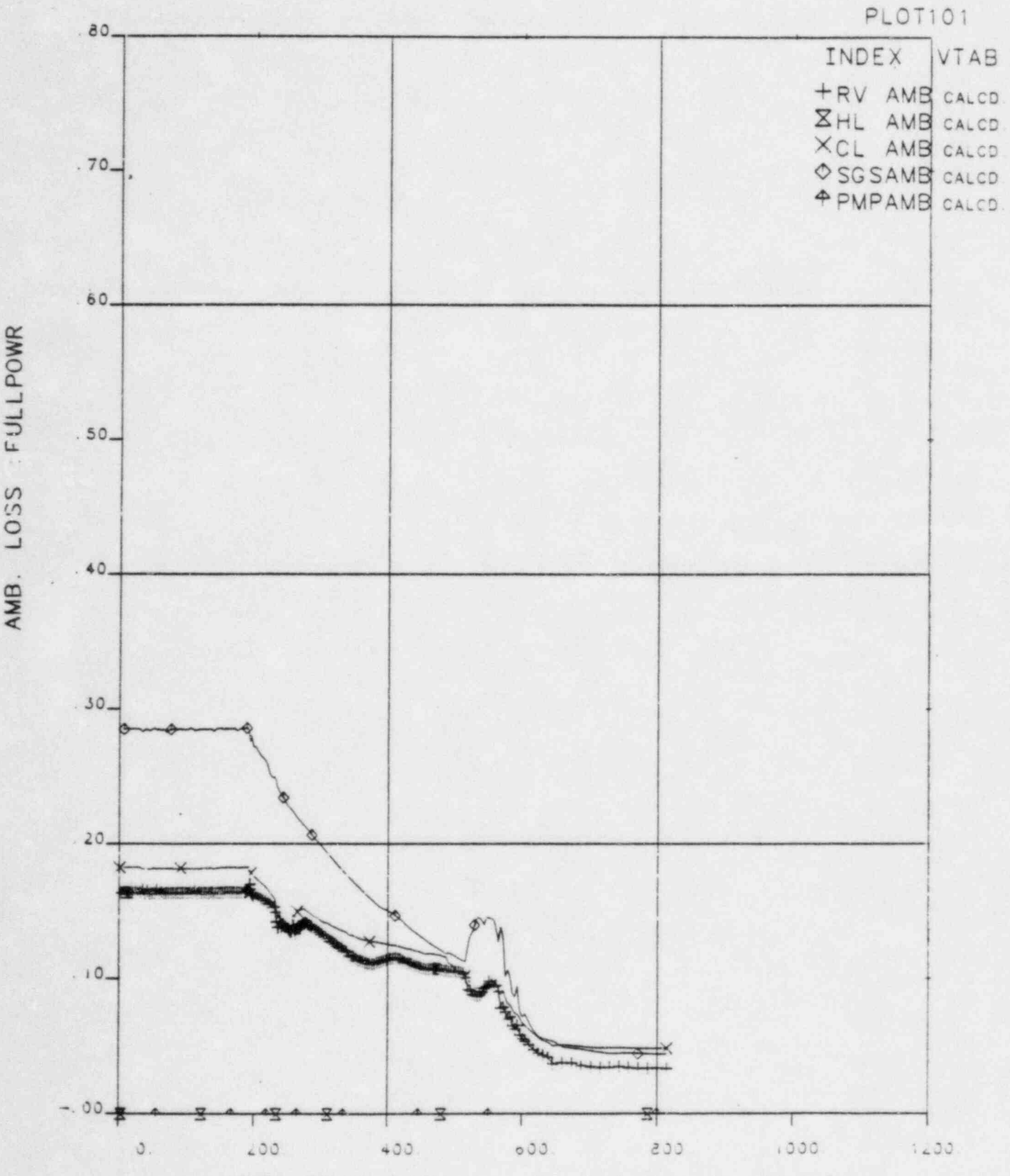
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

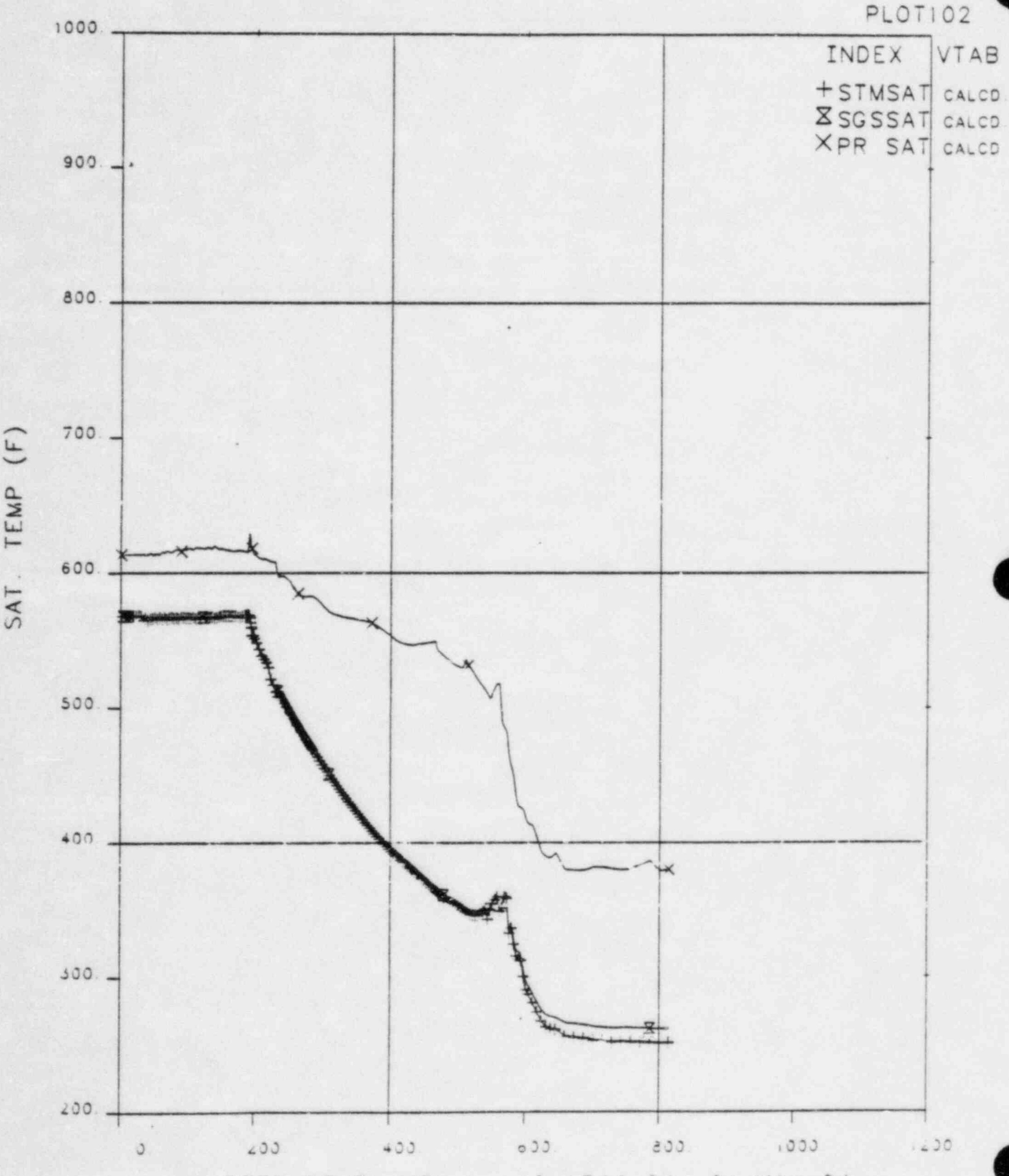
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

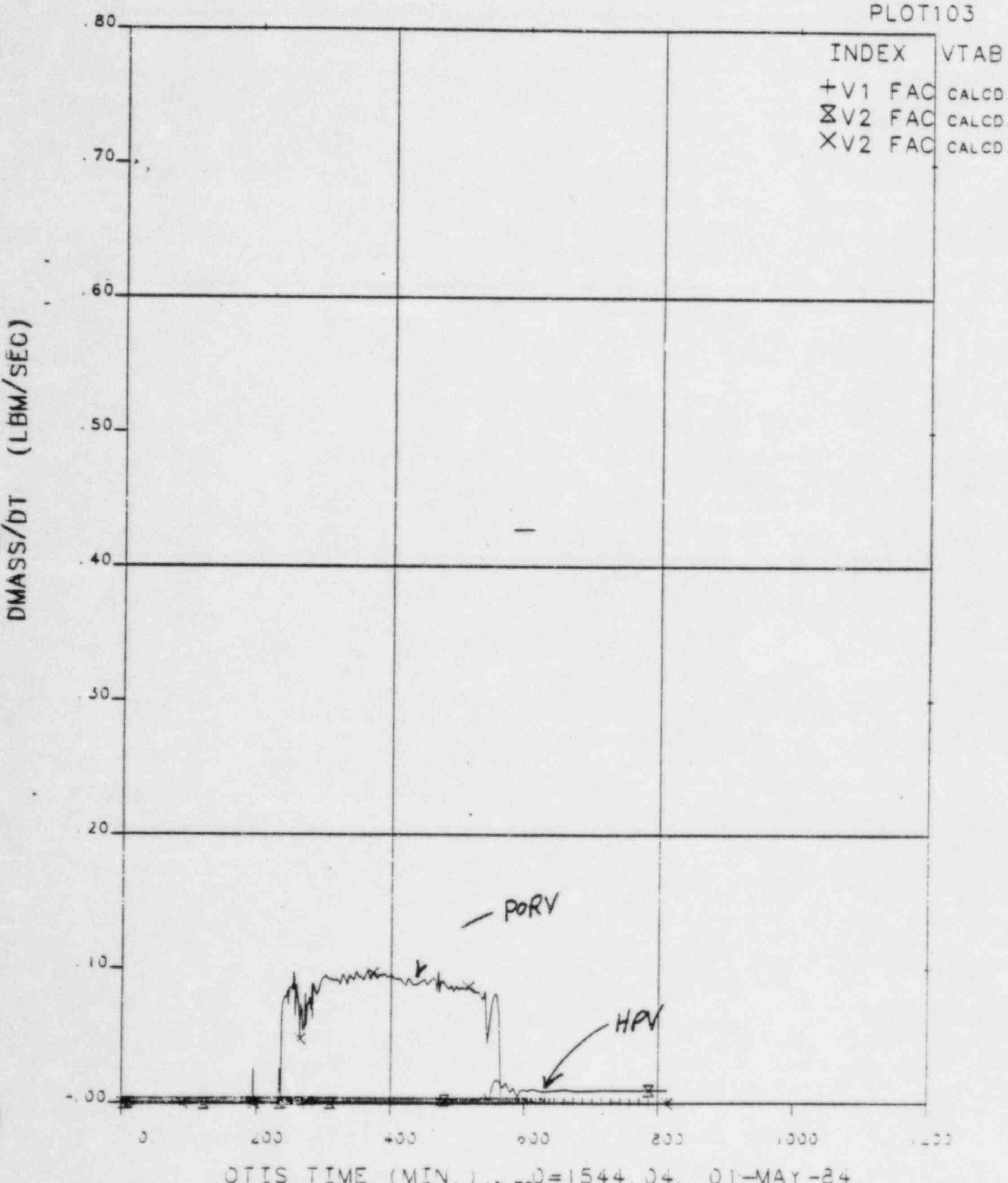
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

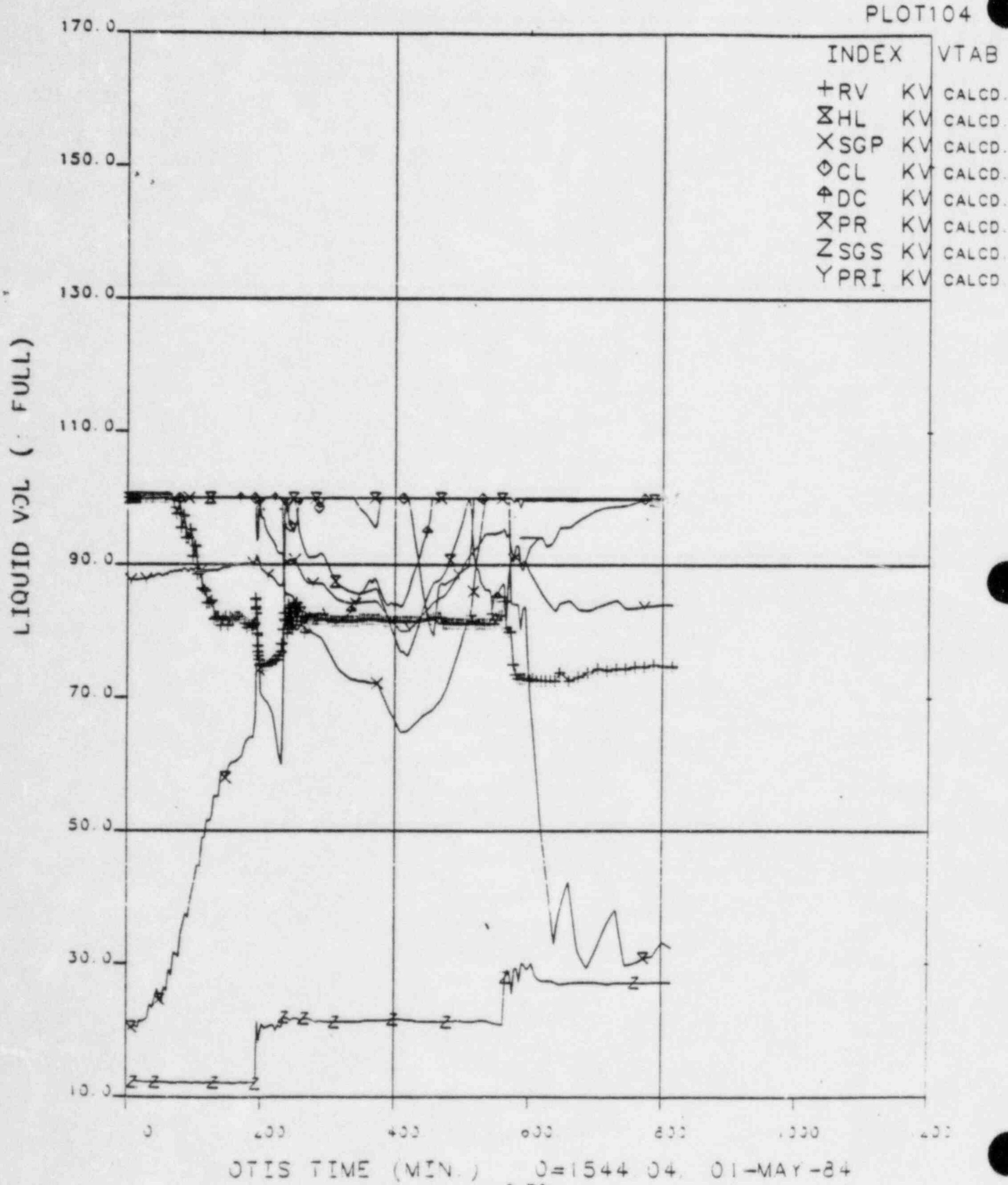
840200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

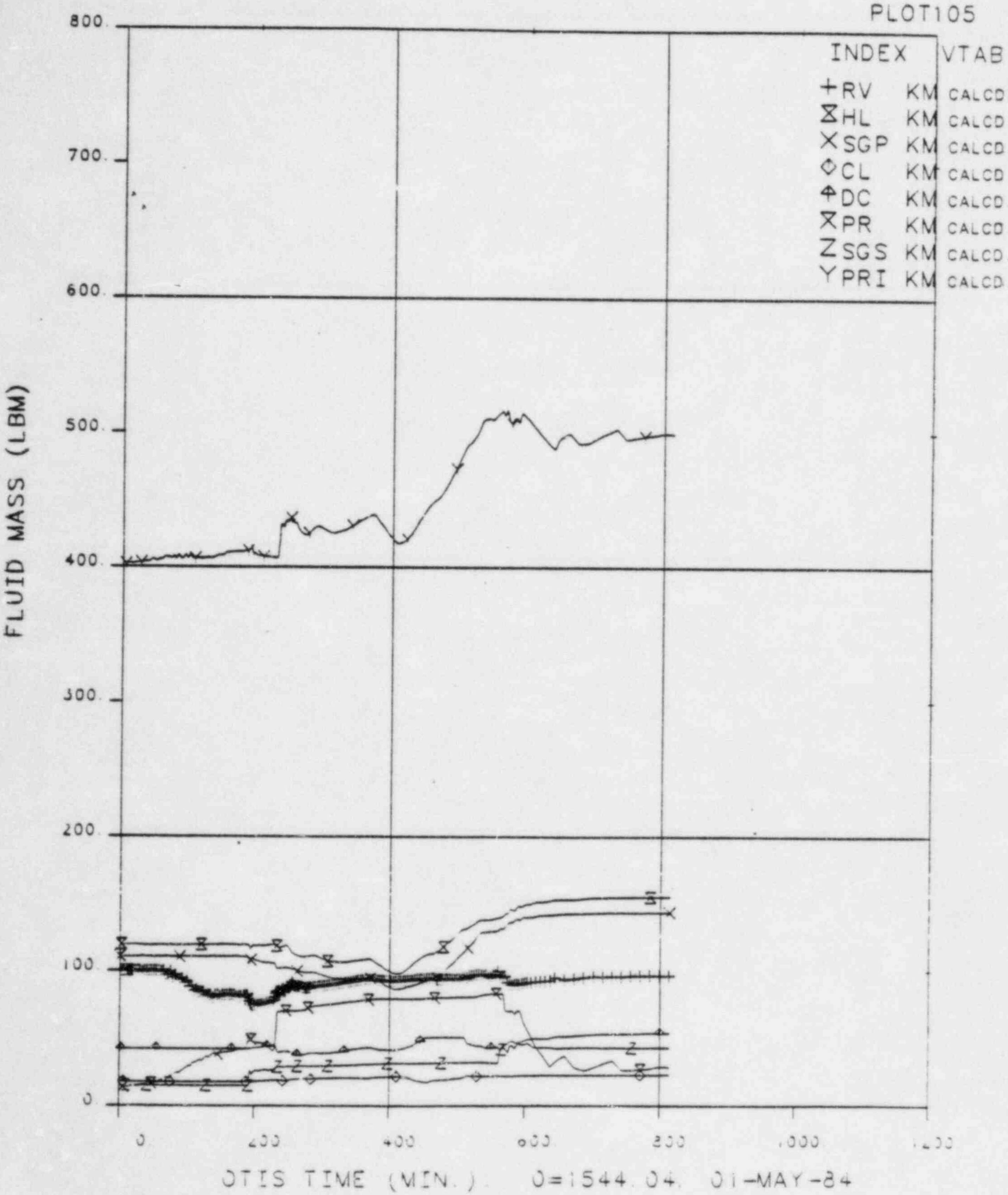
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

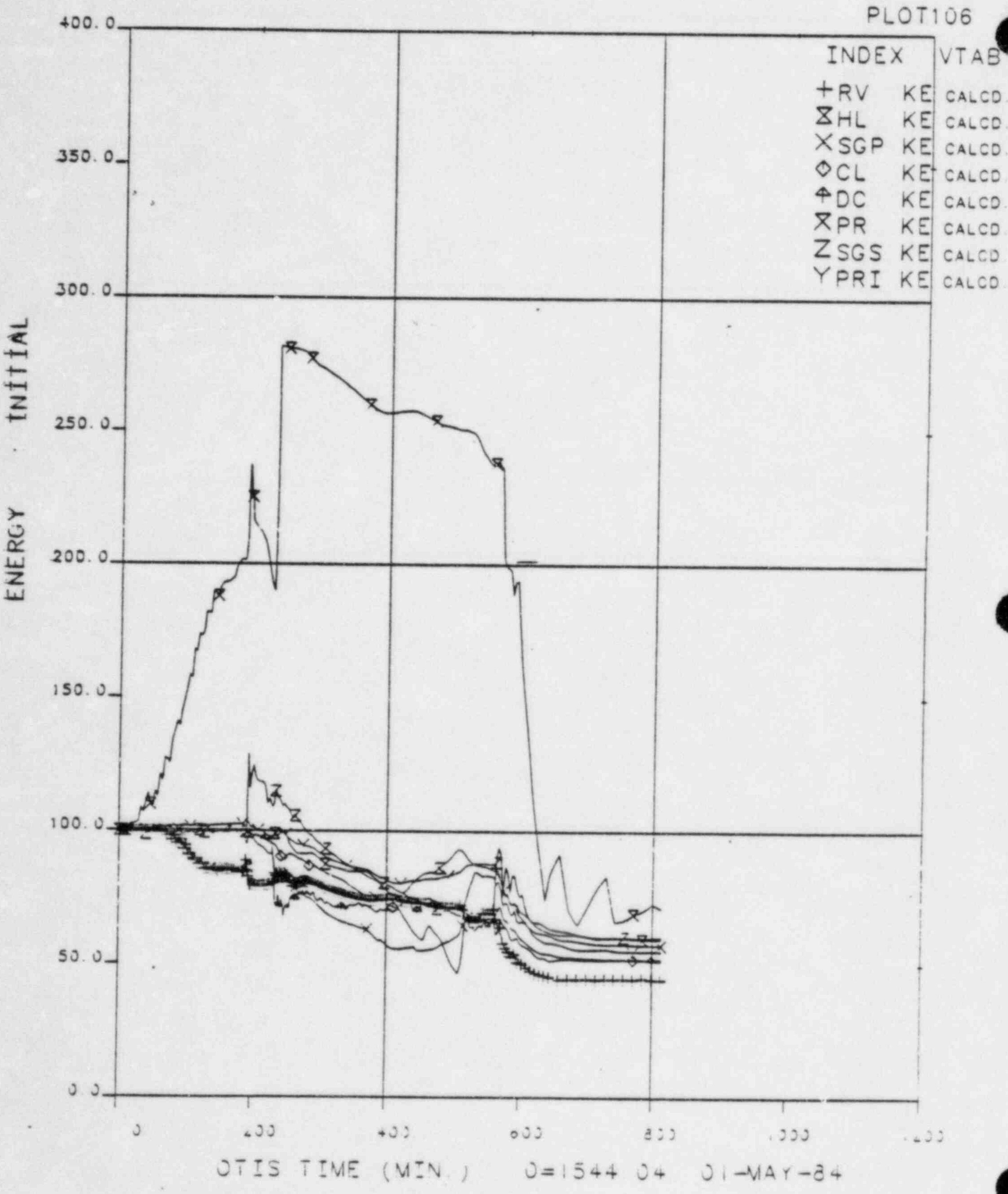
PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

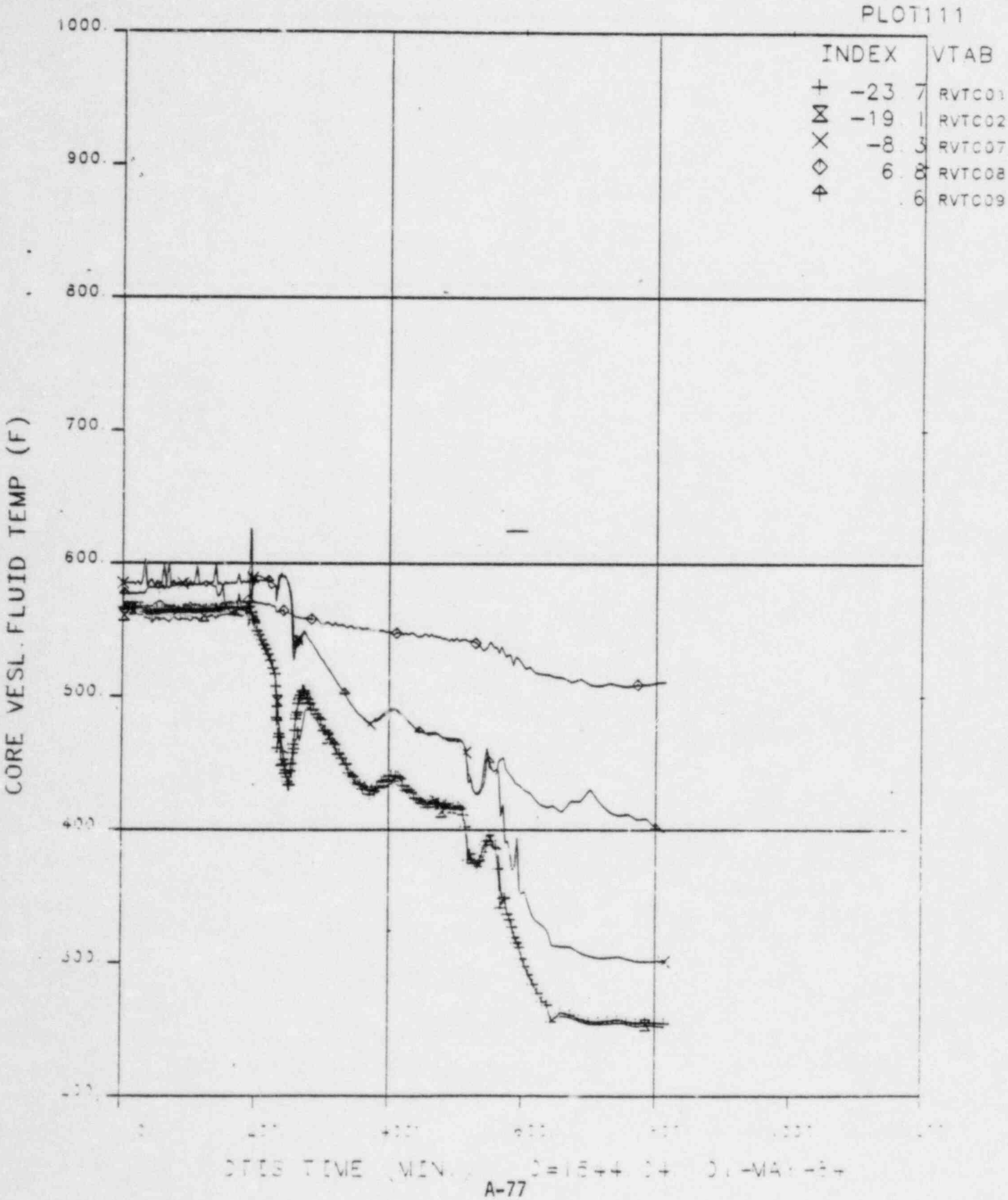
0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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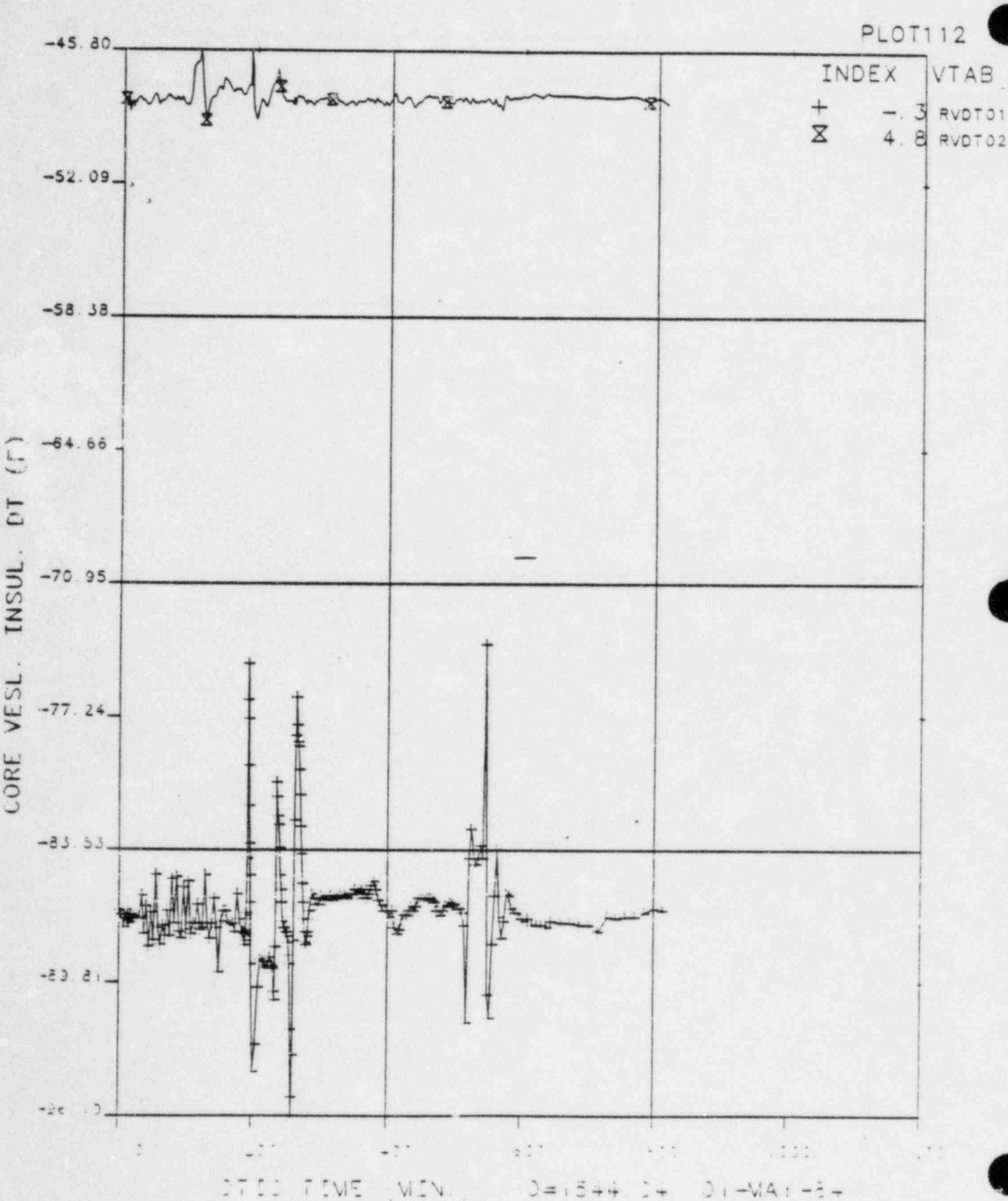
240200.0 FPC GAS TEST (W/ FEED & BLEED)



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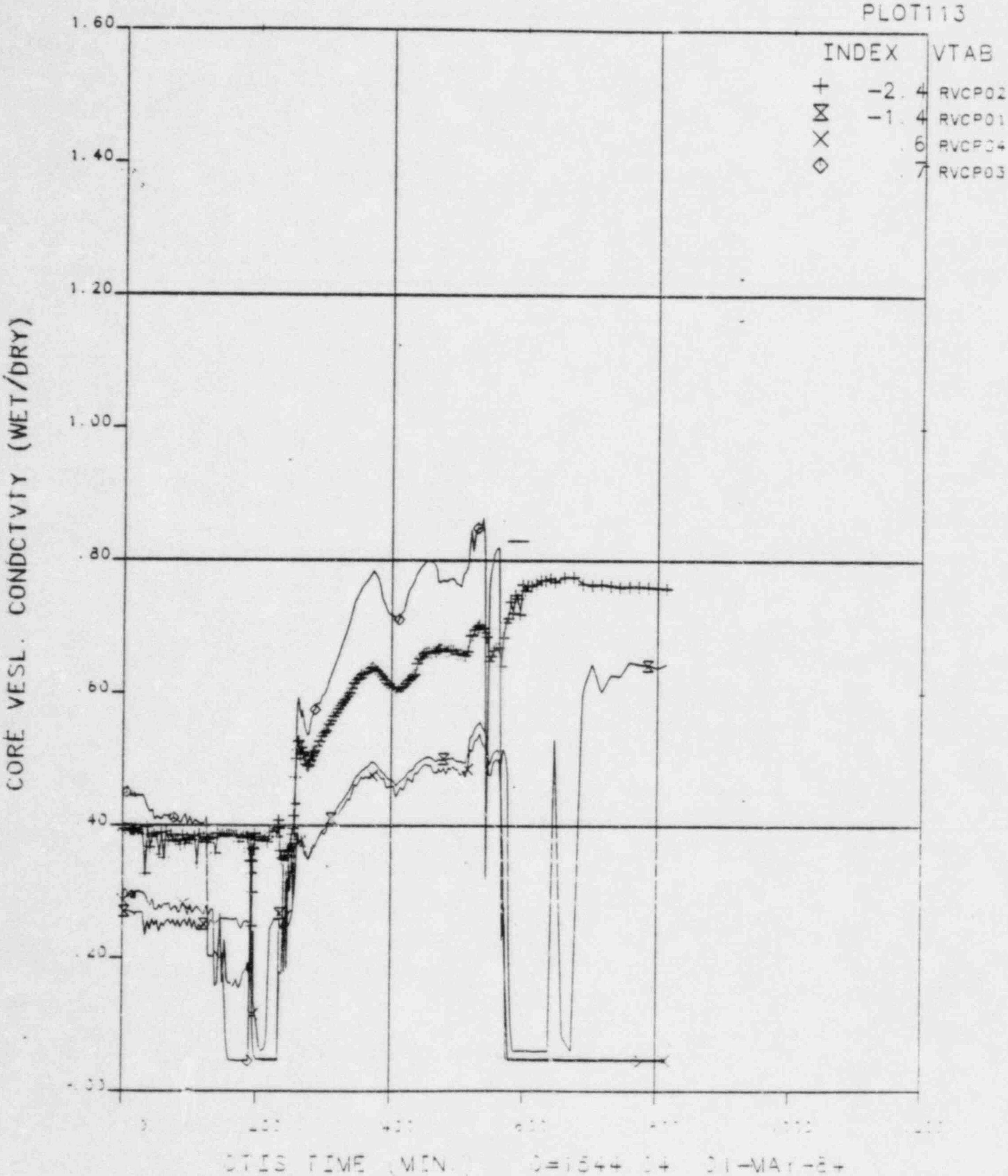
PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)

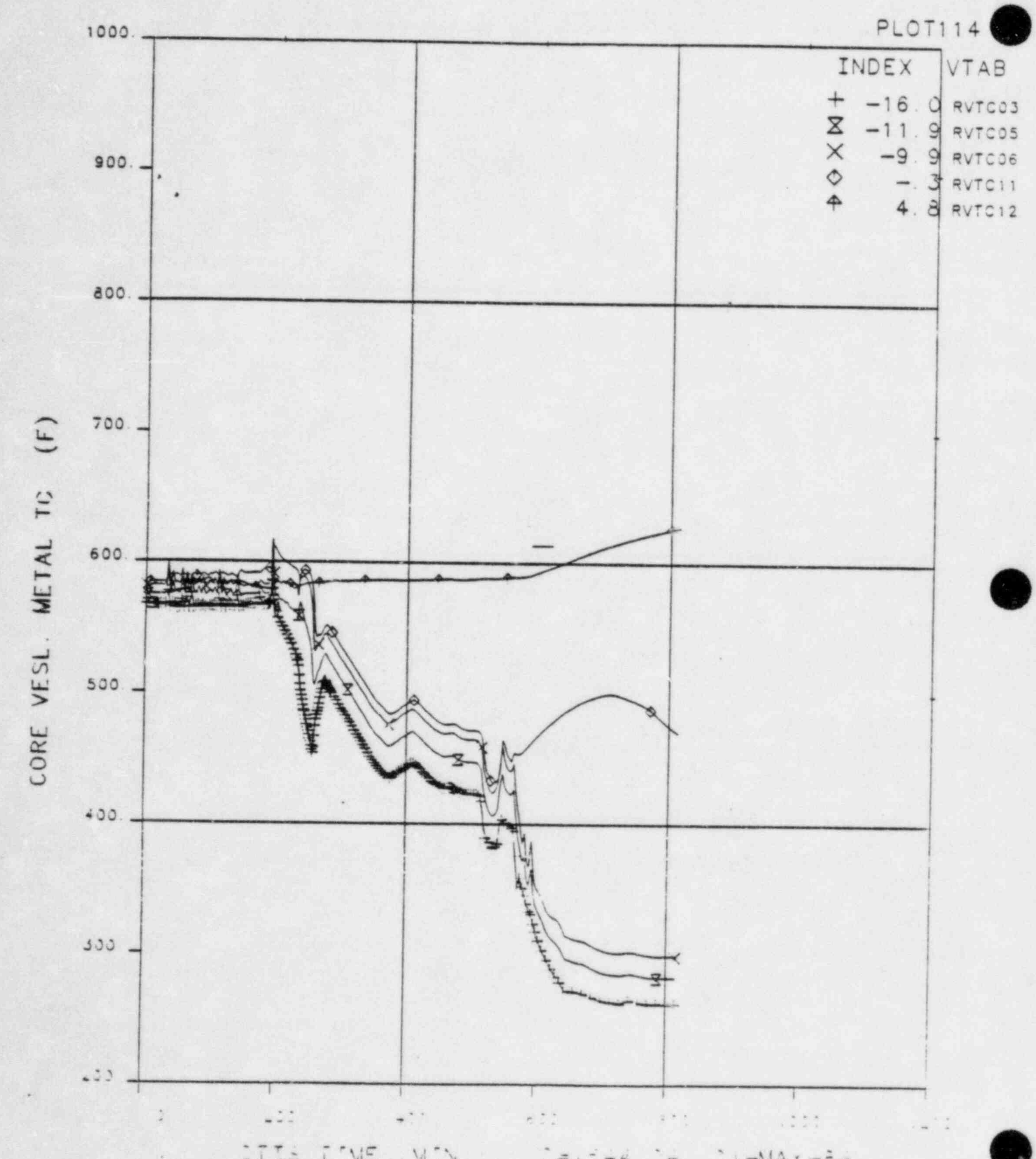


A-79

PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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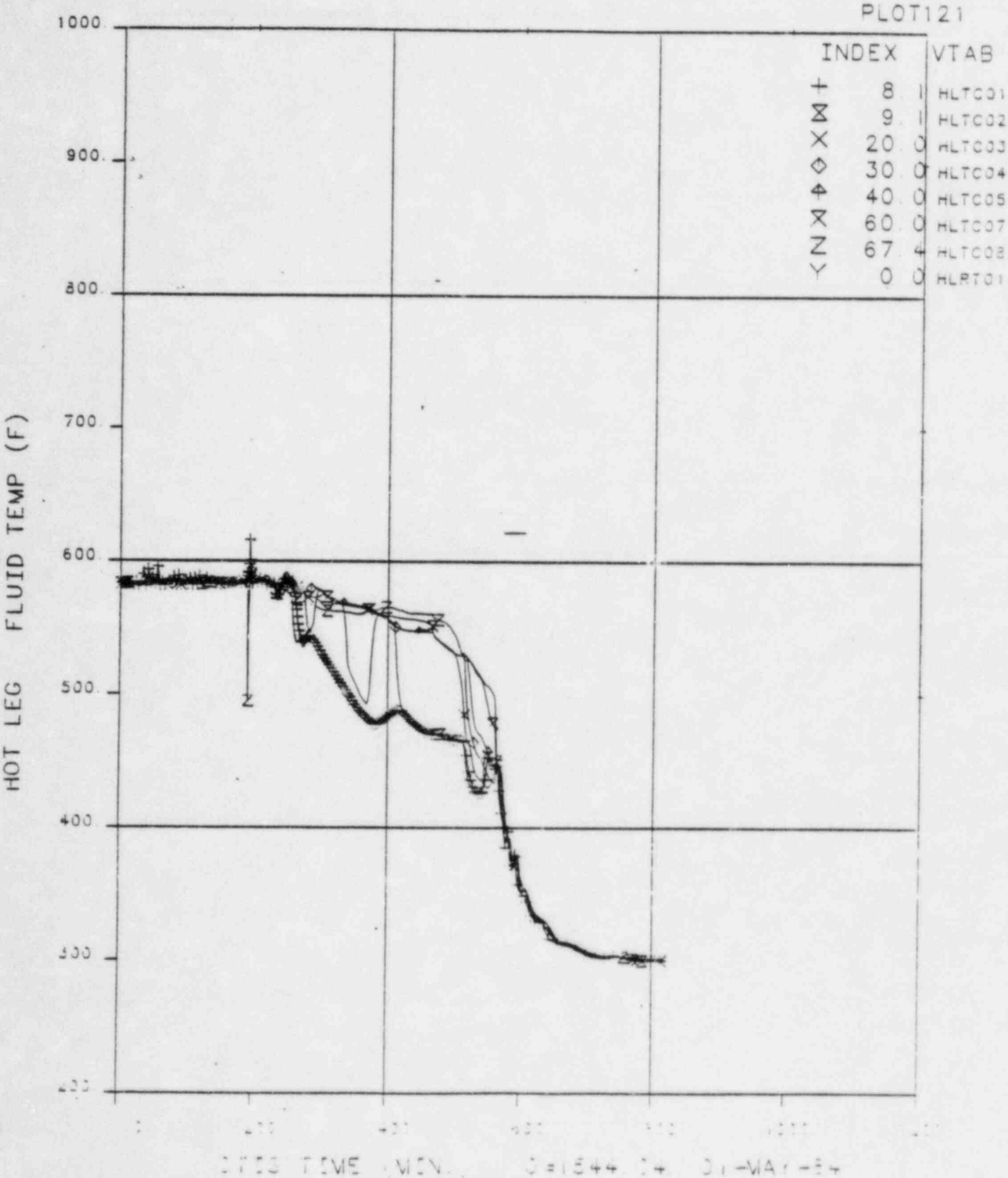
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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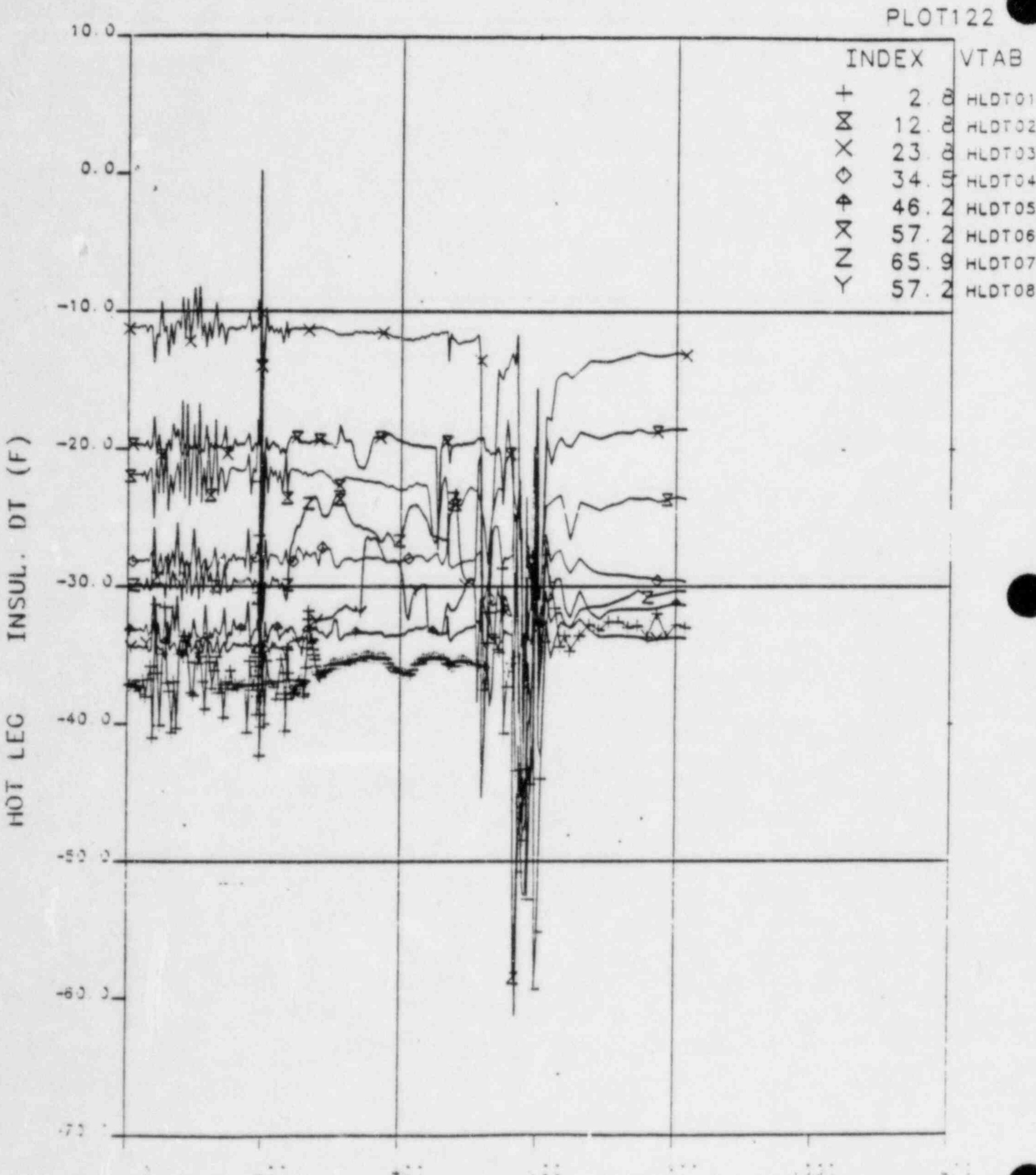
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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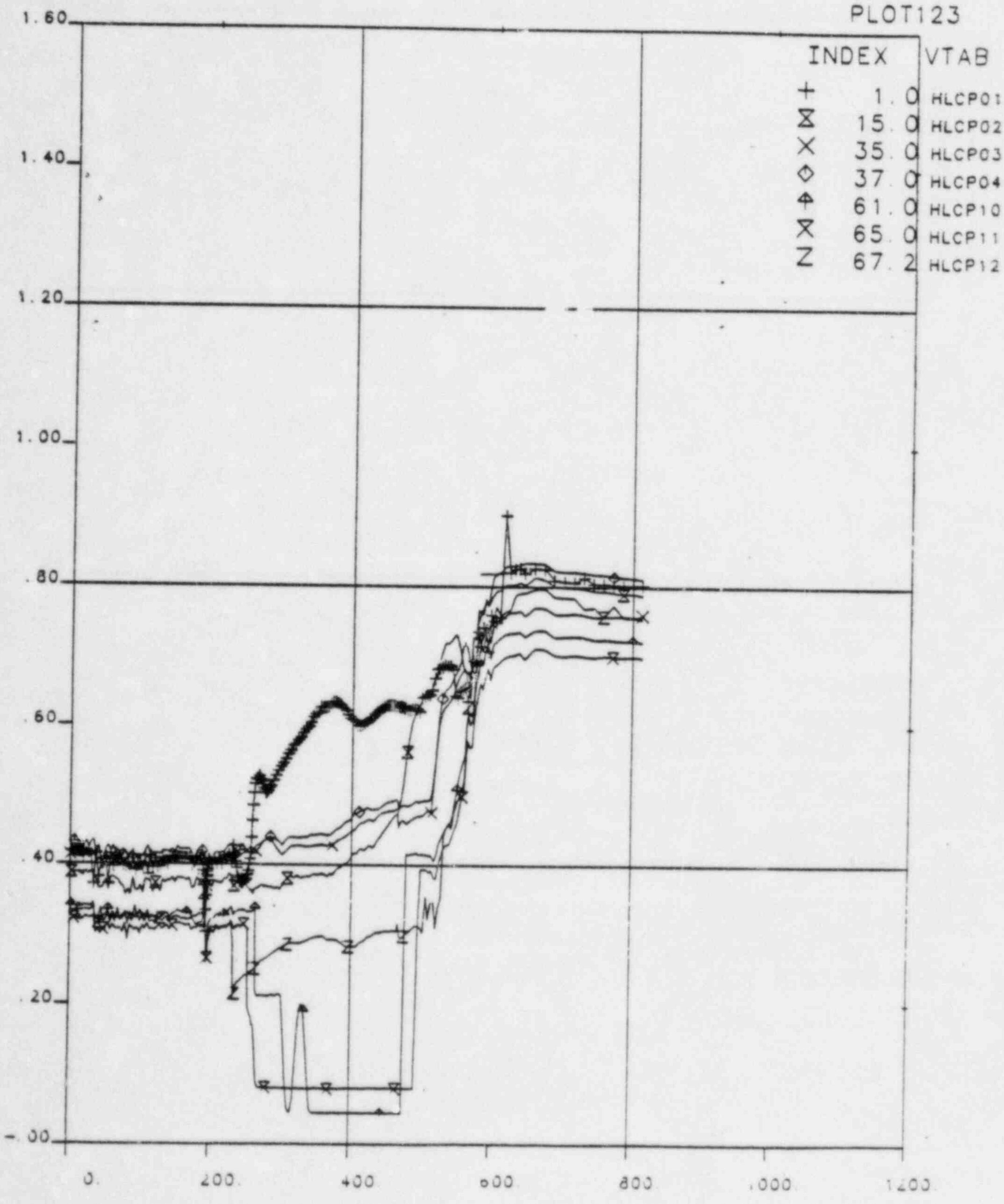
240200.0 FPC GAS TEST (W/ FEED & BLEED)



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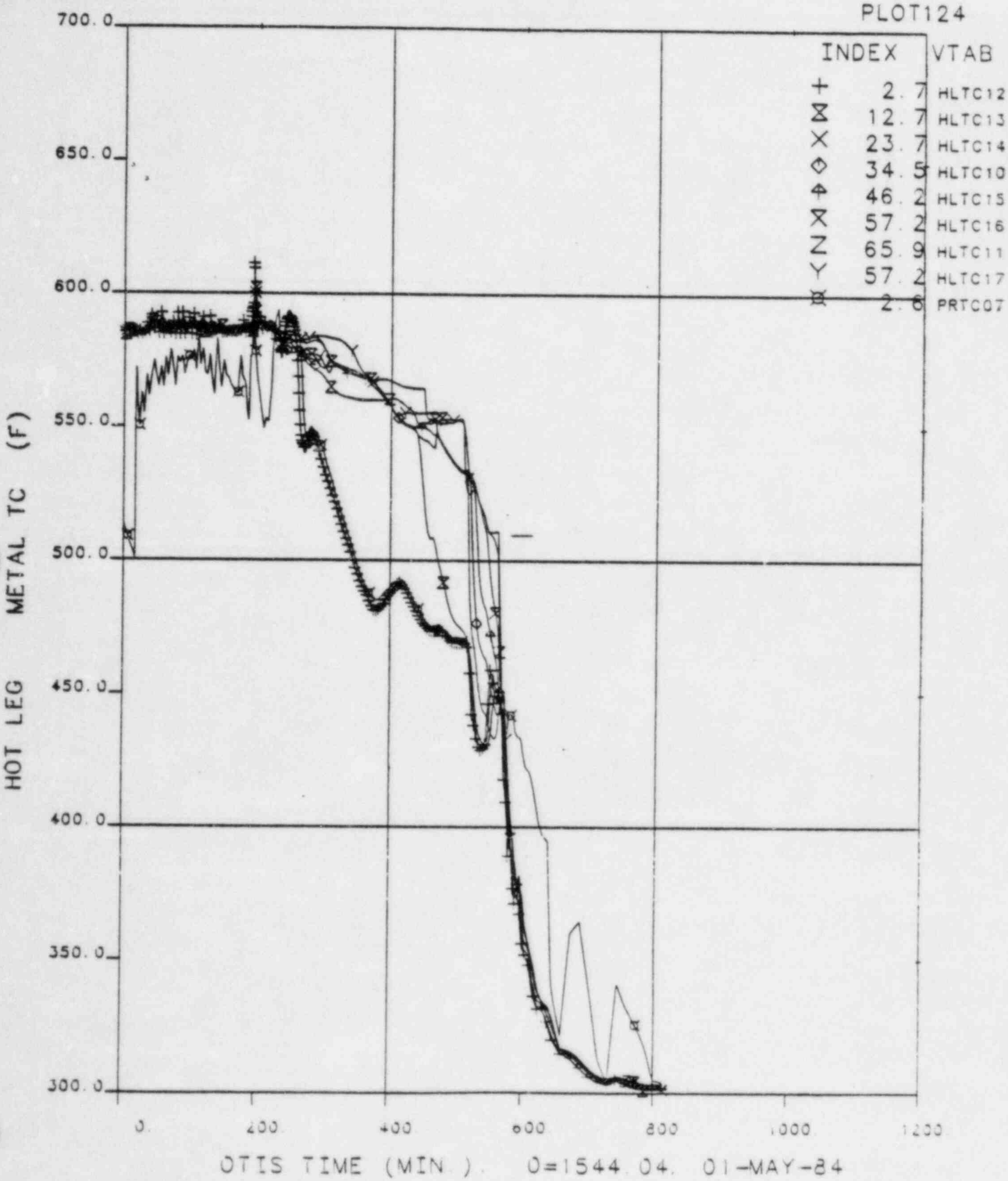
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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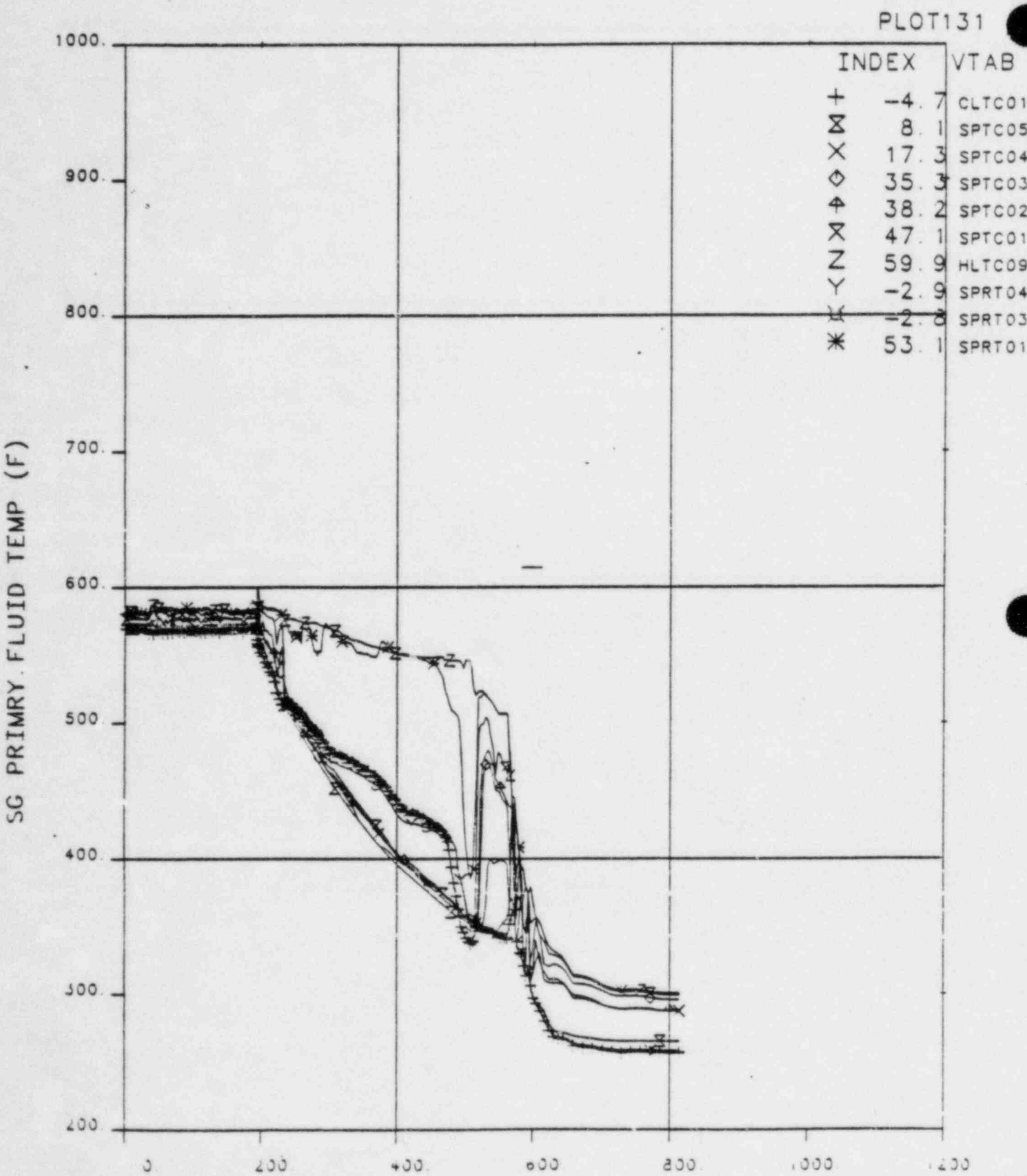
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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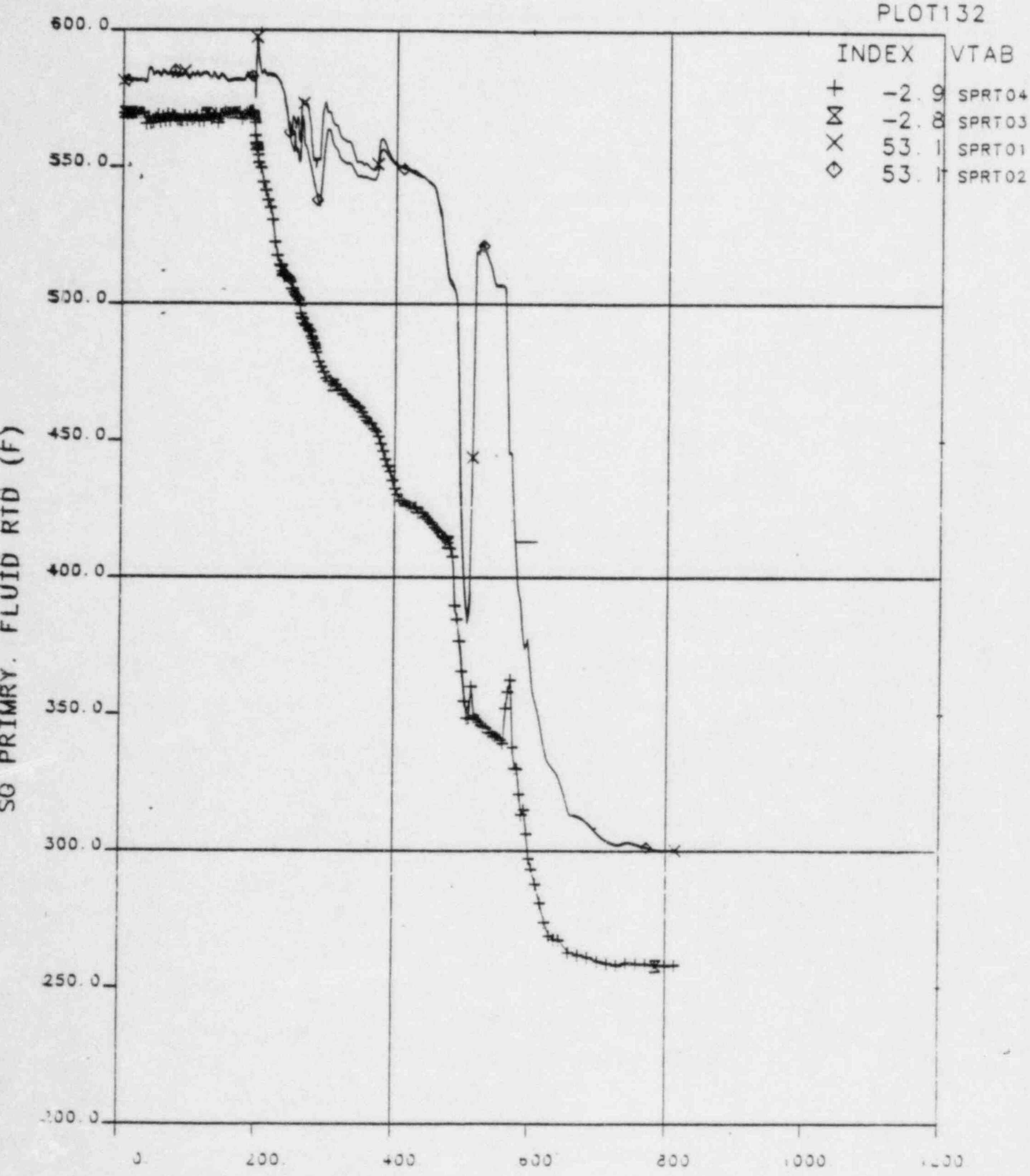
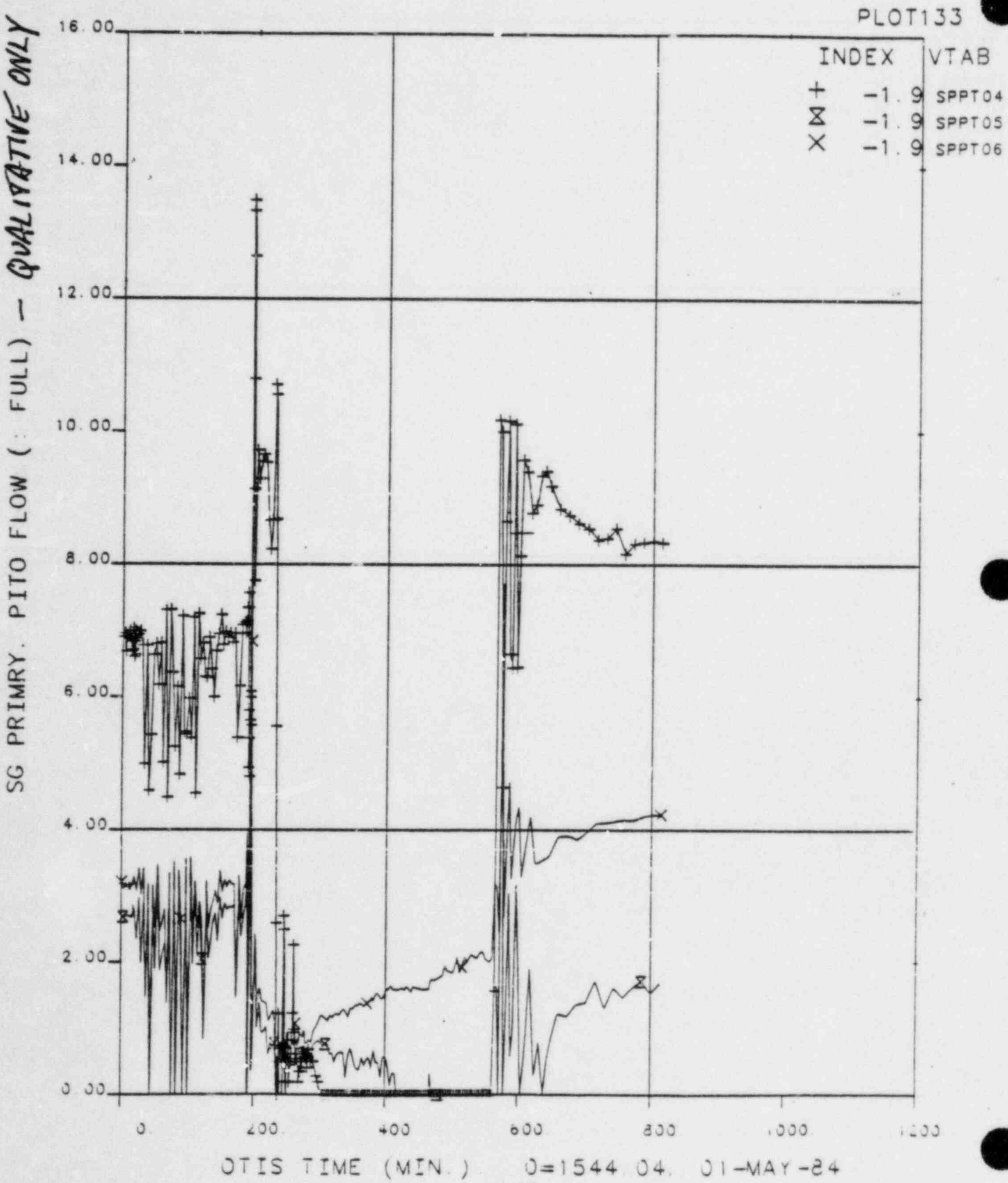
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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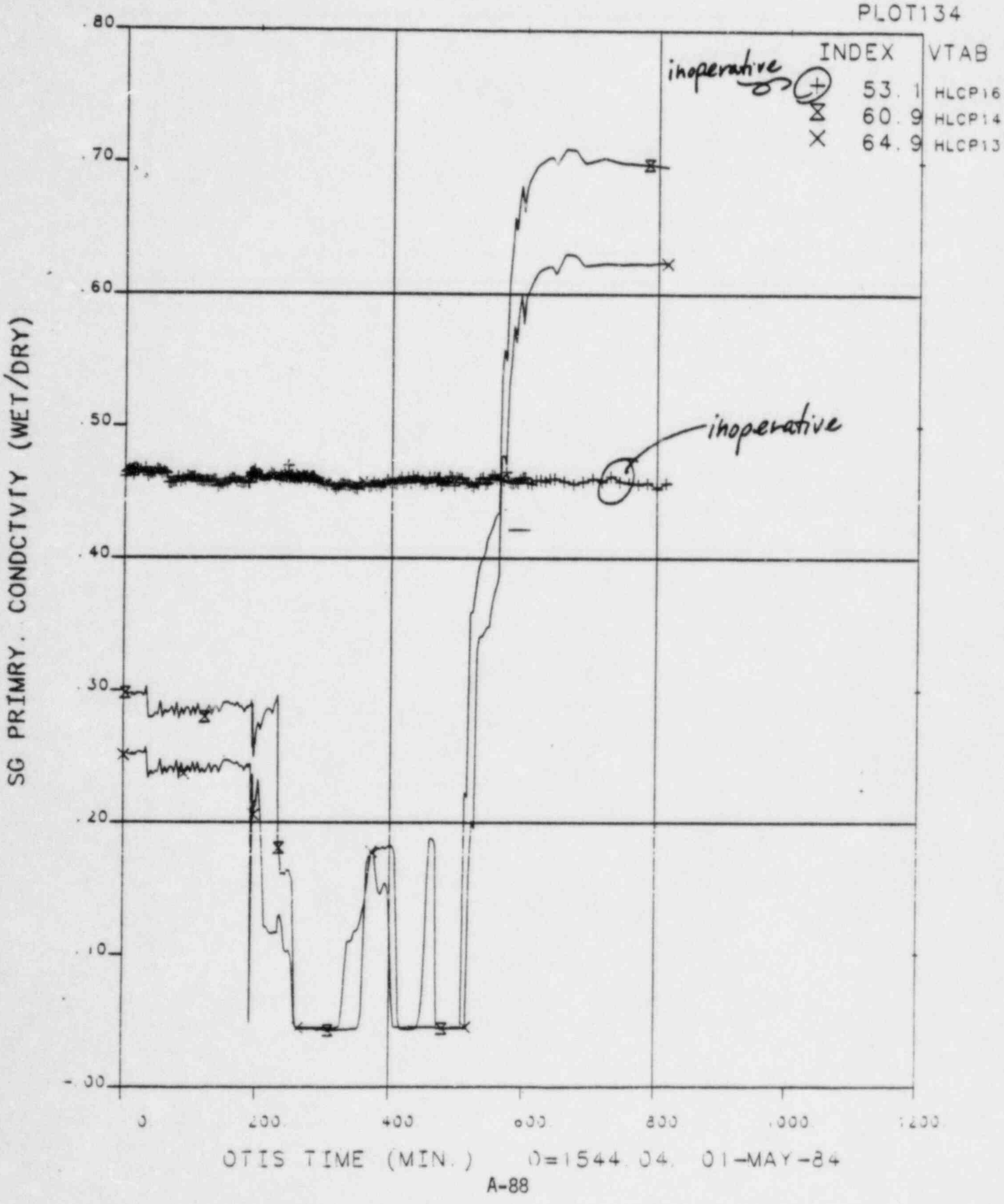
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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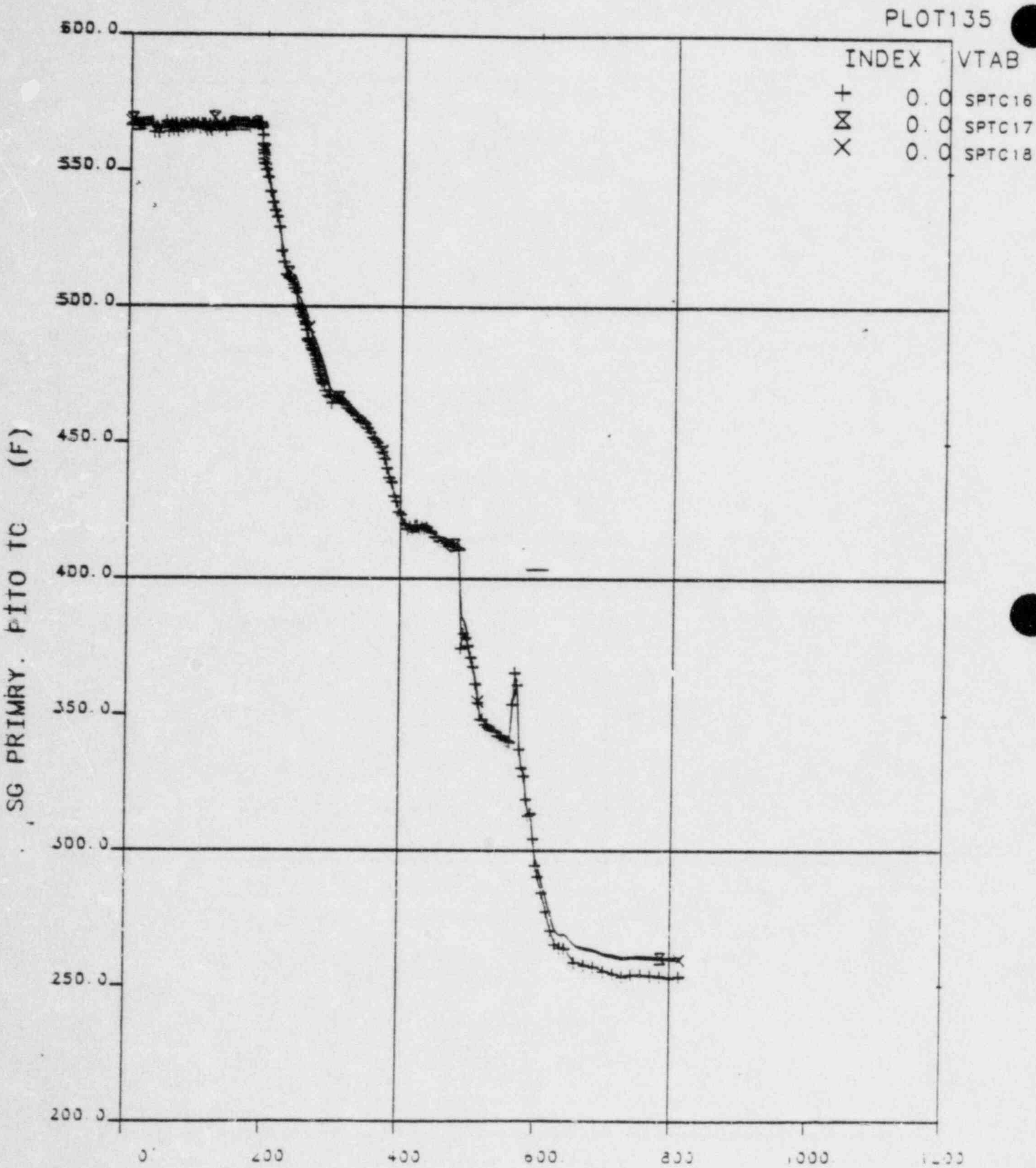
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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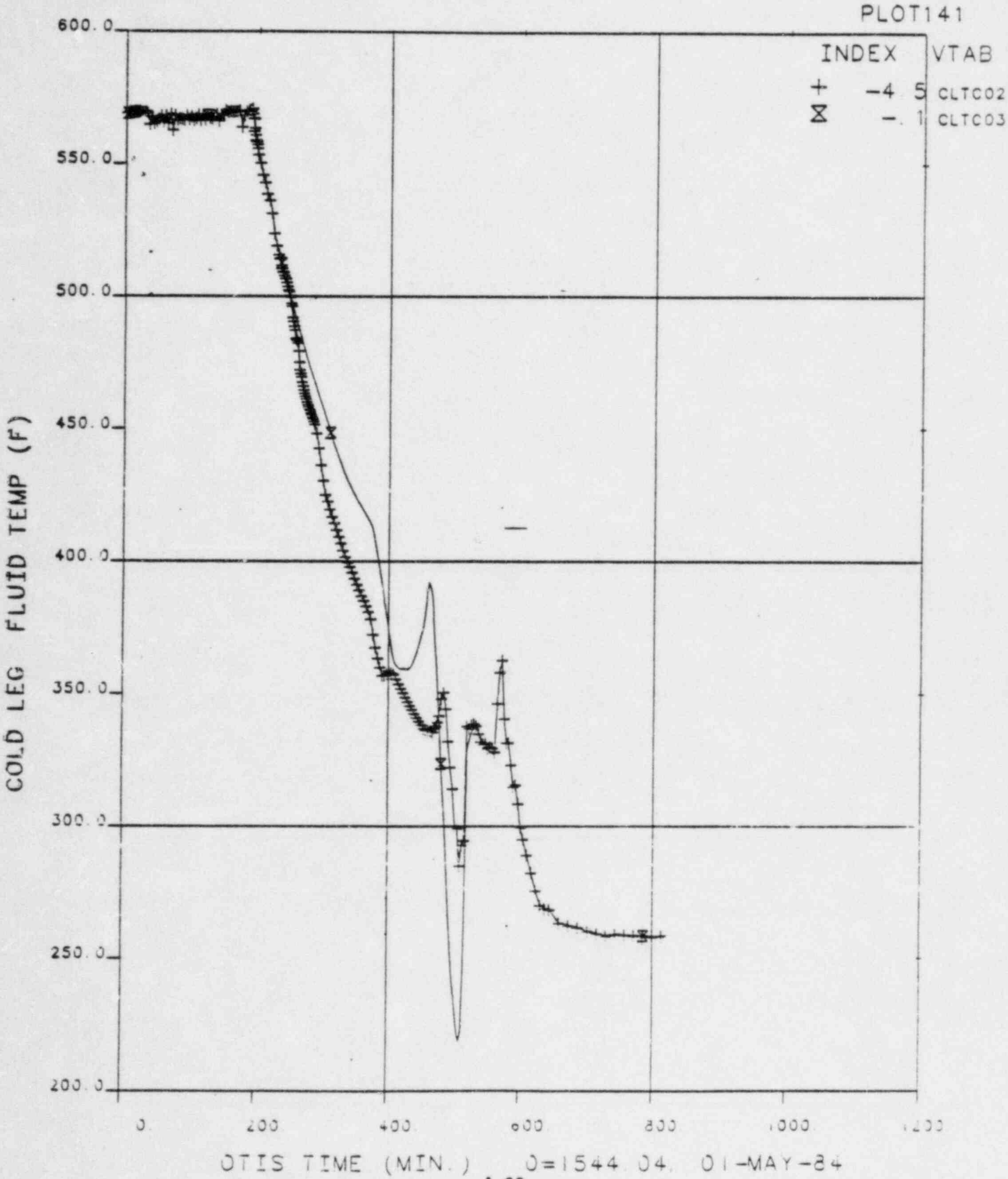

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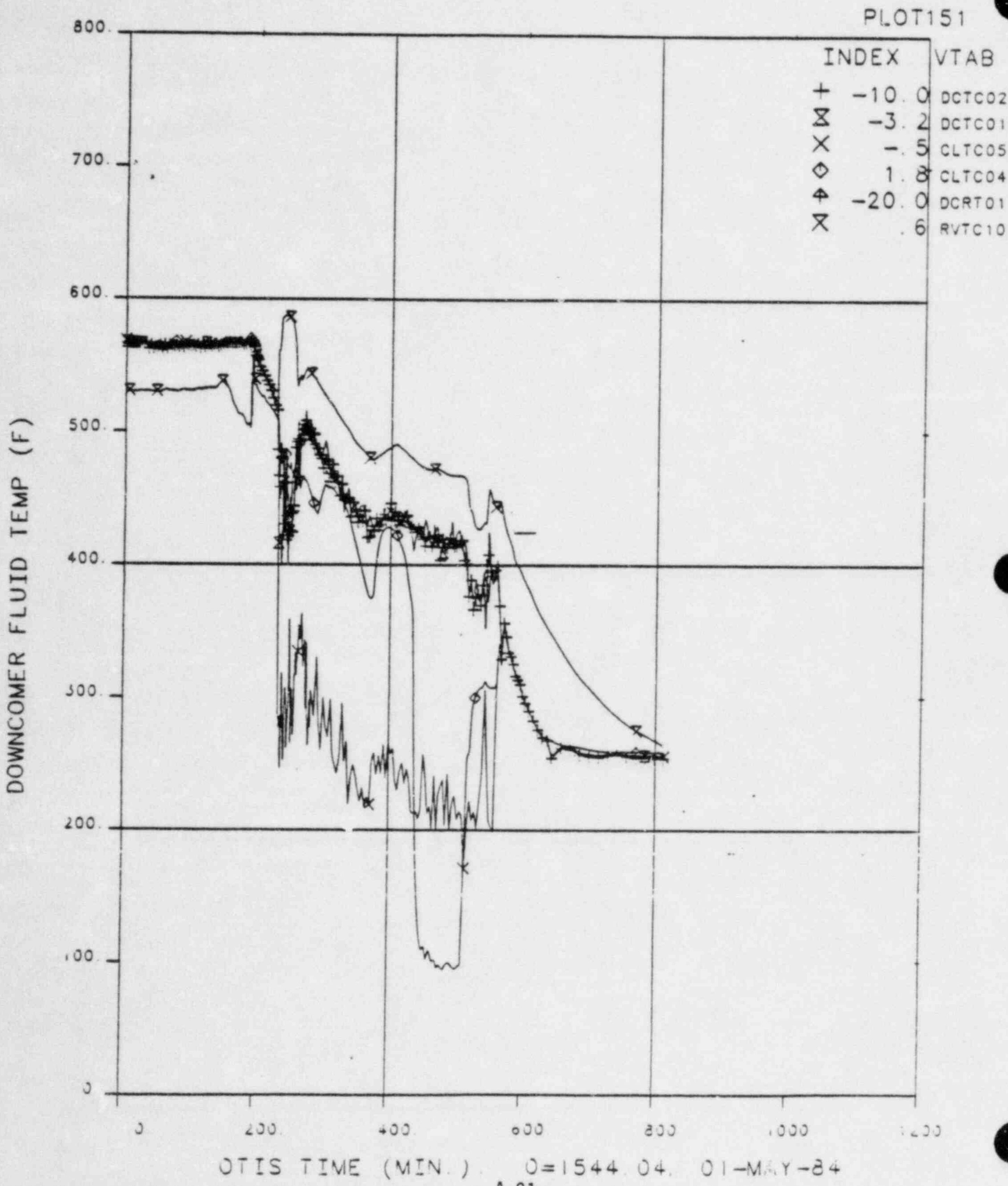

PRELIMINARY DATA

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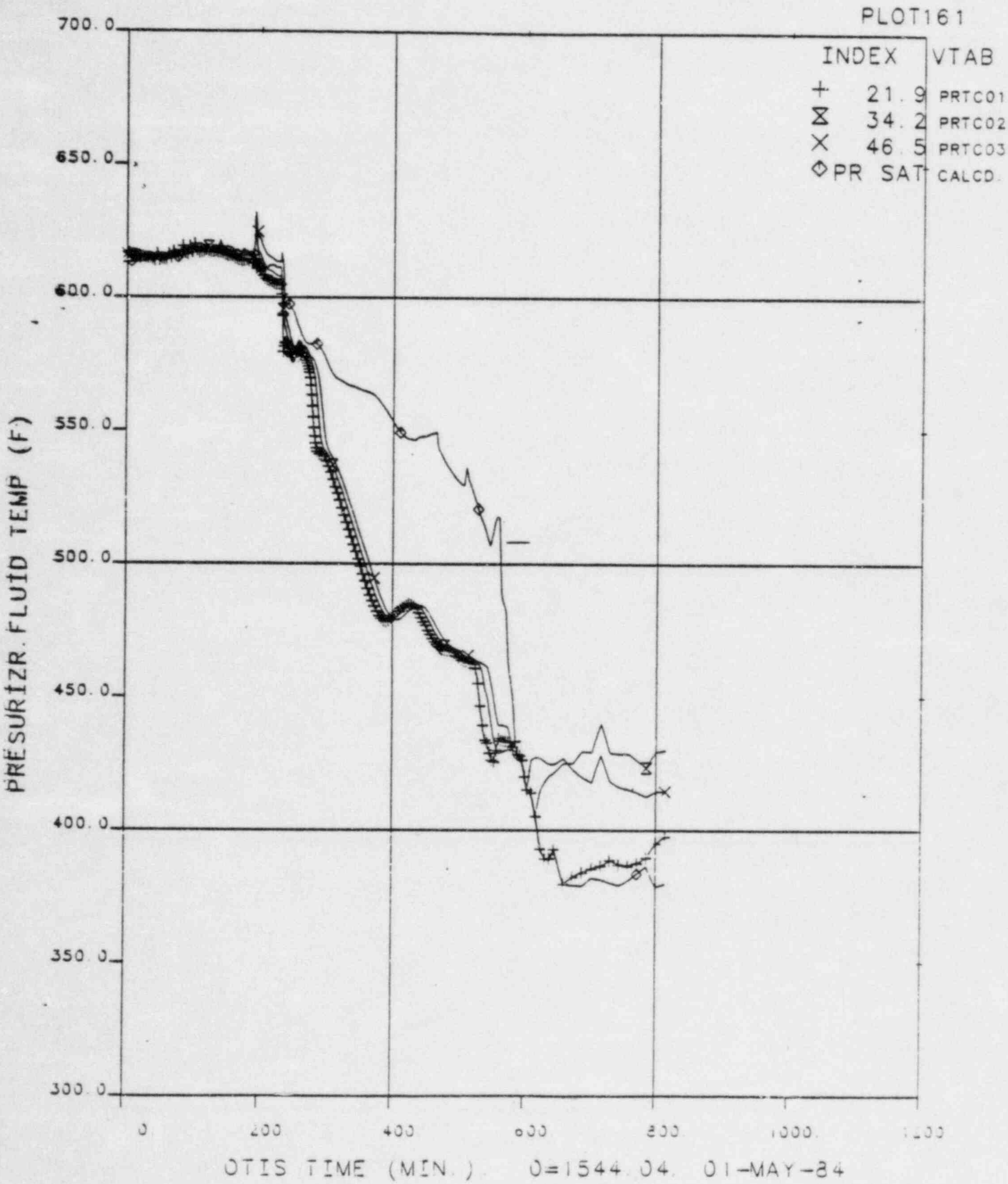
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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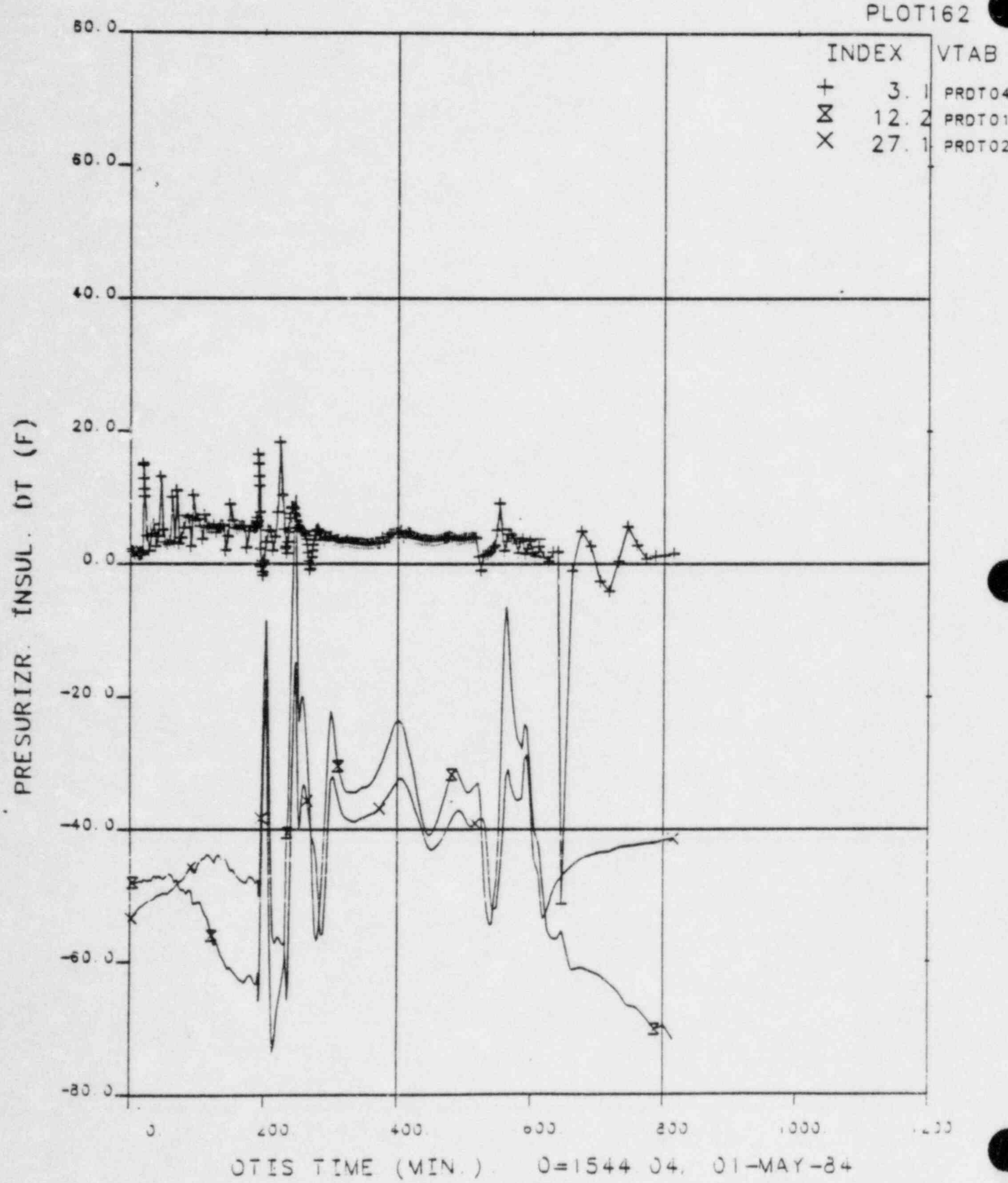
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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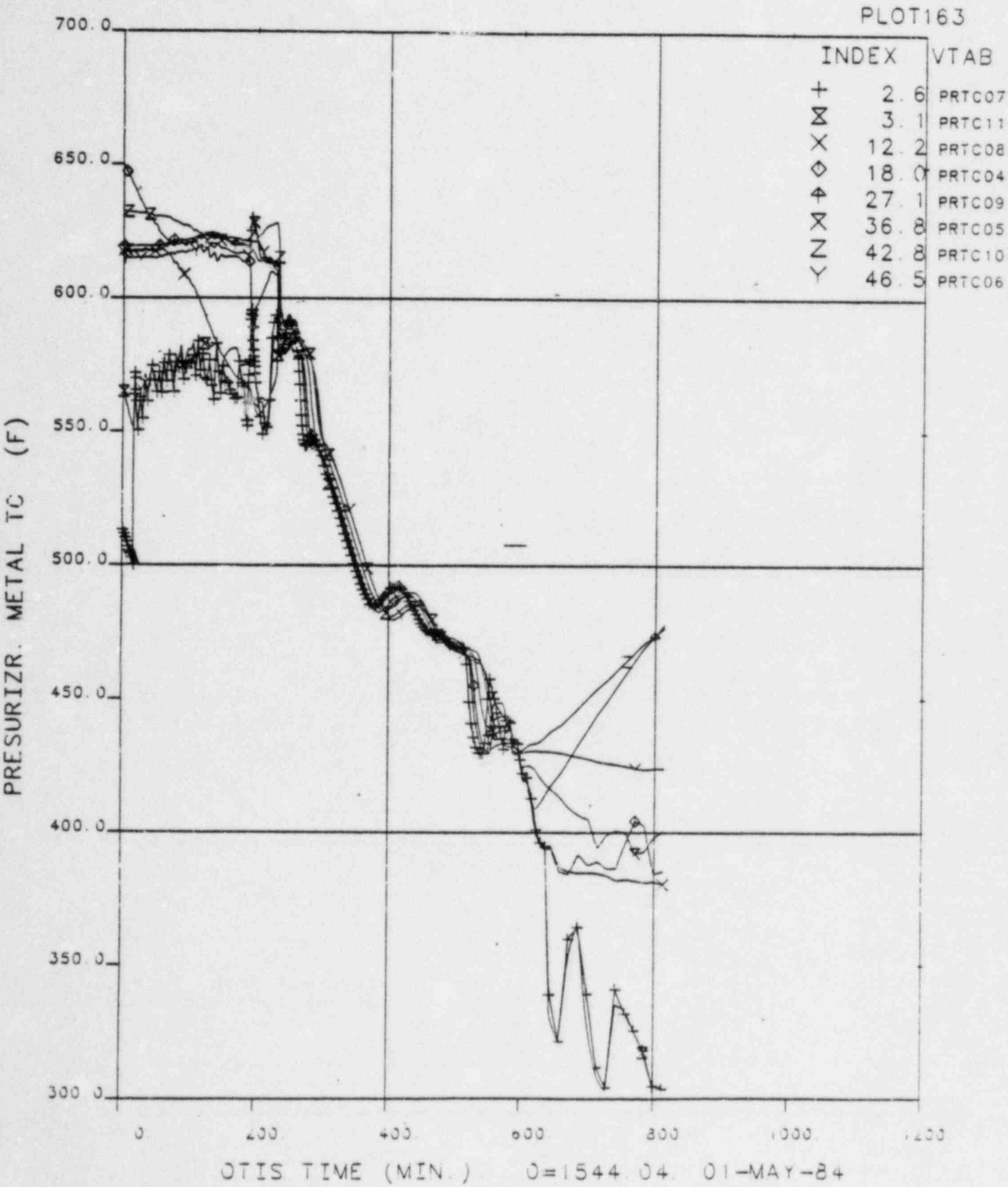
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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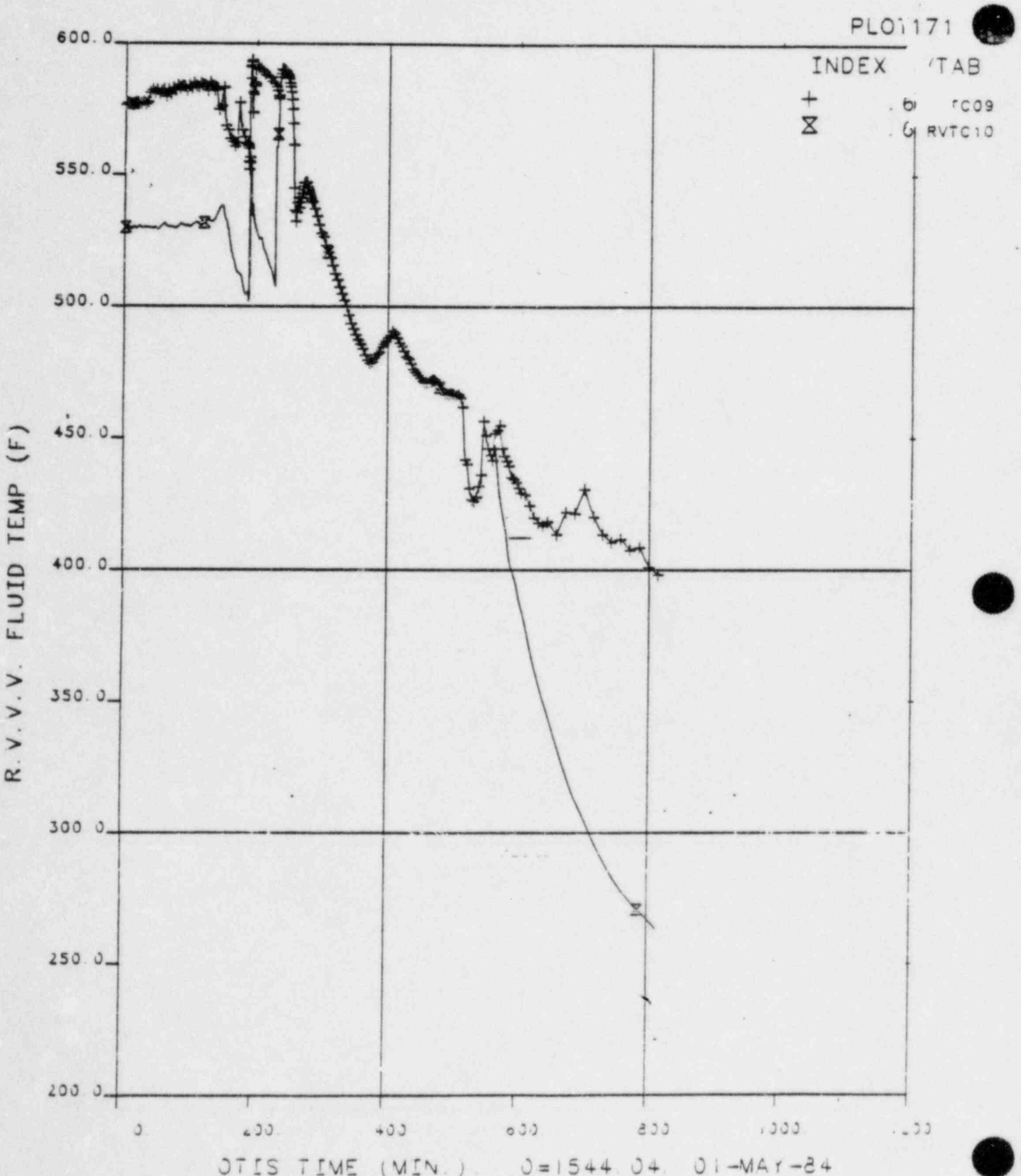
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

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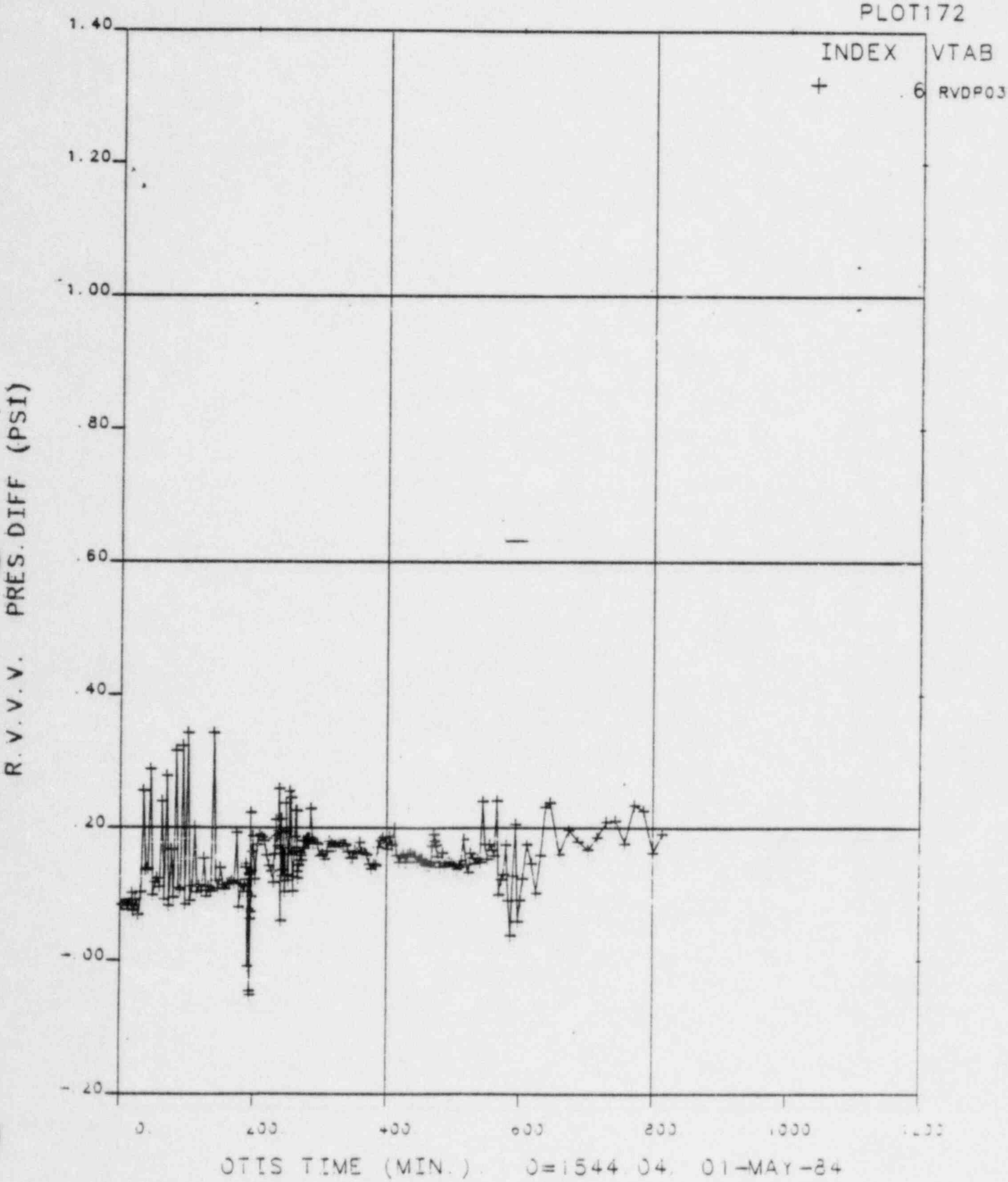
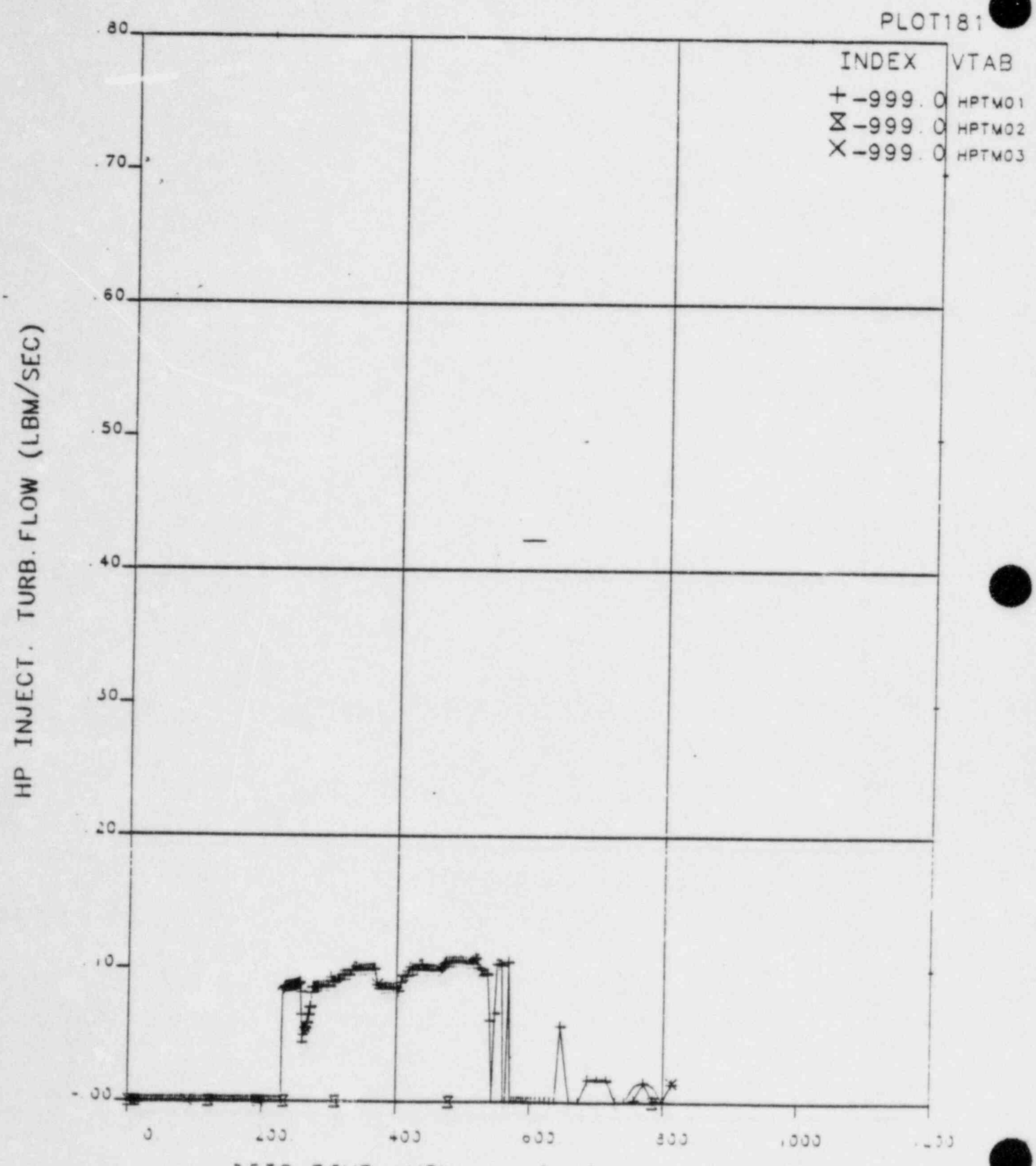
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



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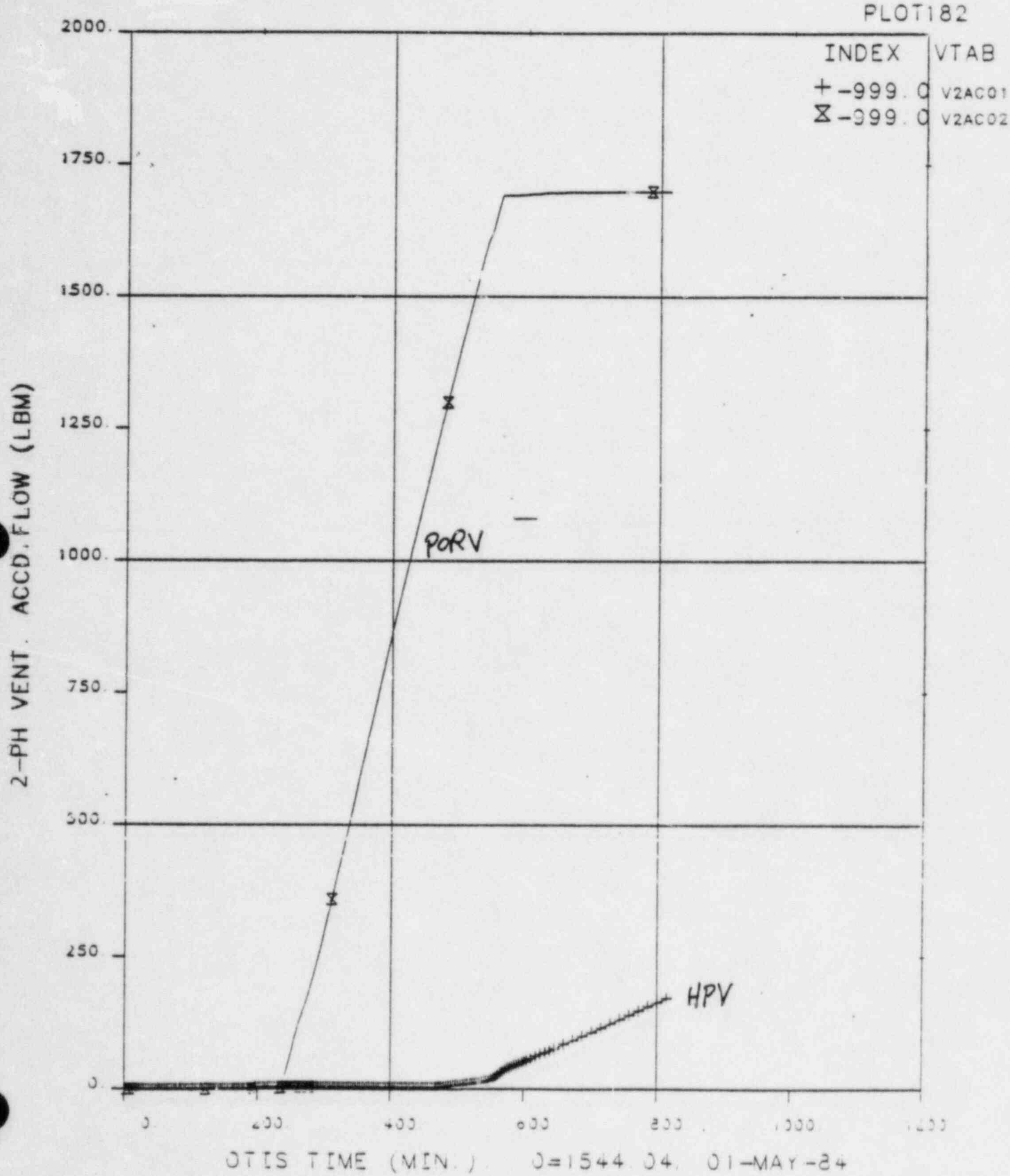
PRELIMINARY DATA

PRELIMINARY DATA

40200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

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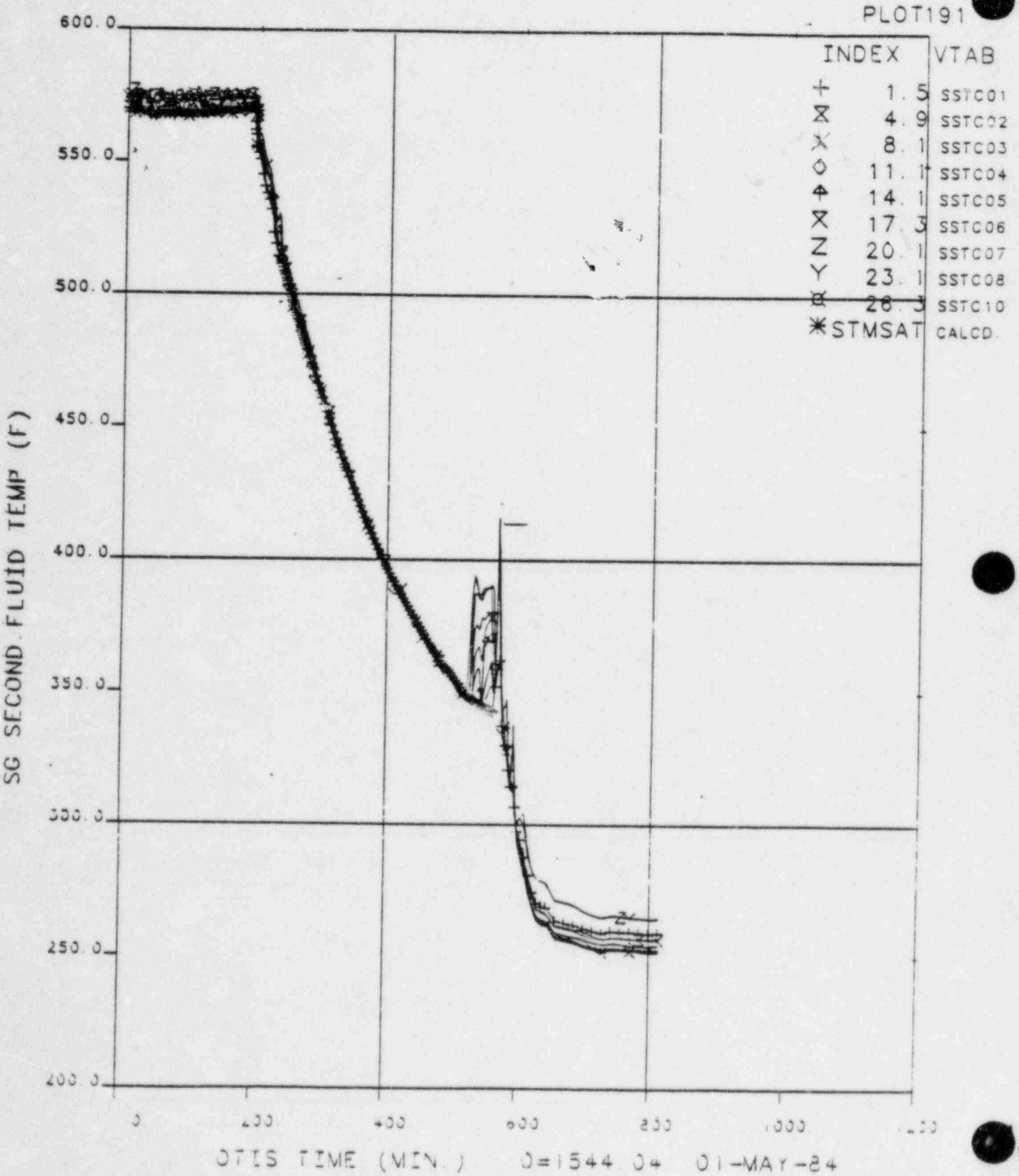
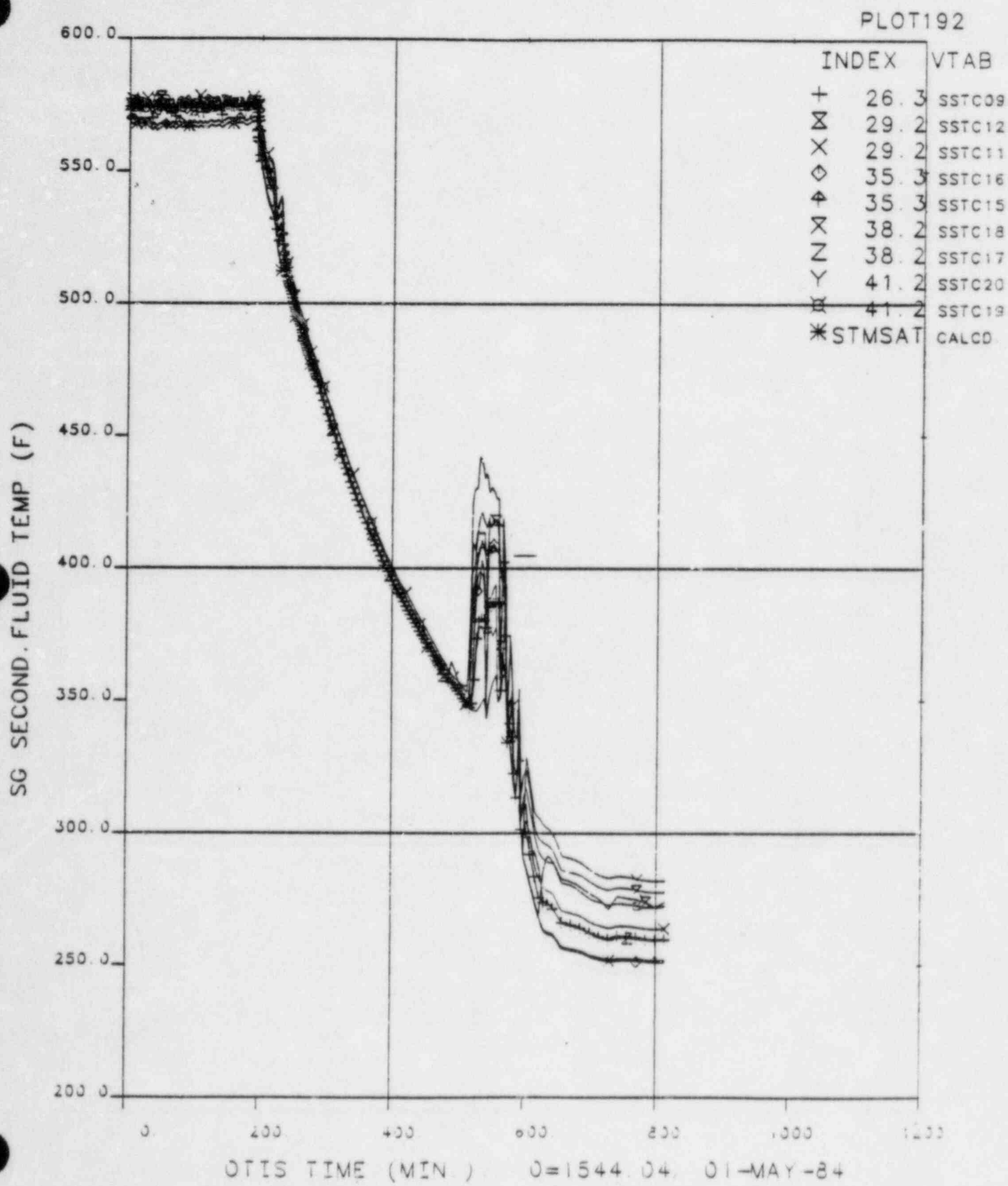


PRELIMINARY DATA

PRELIMINARY DATA

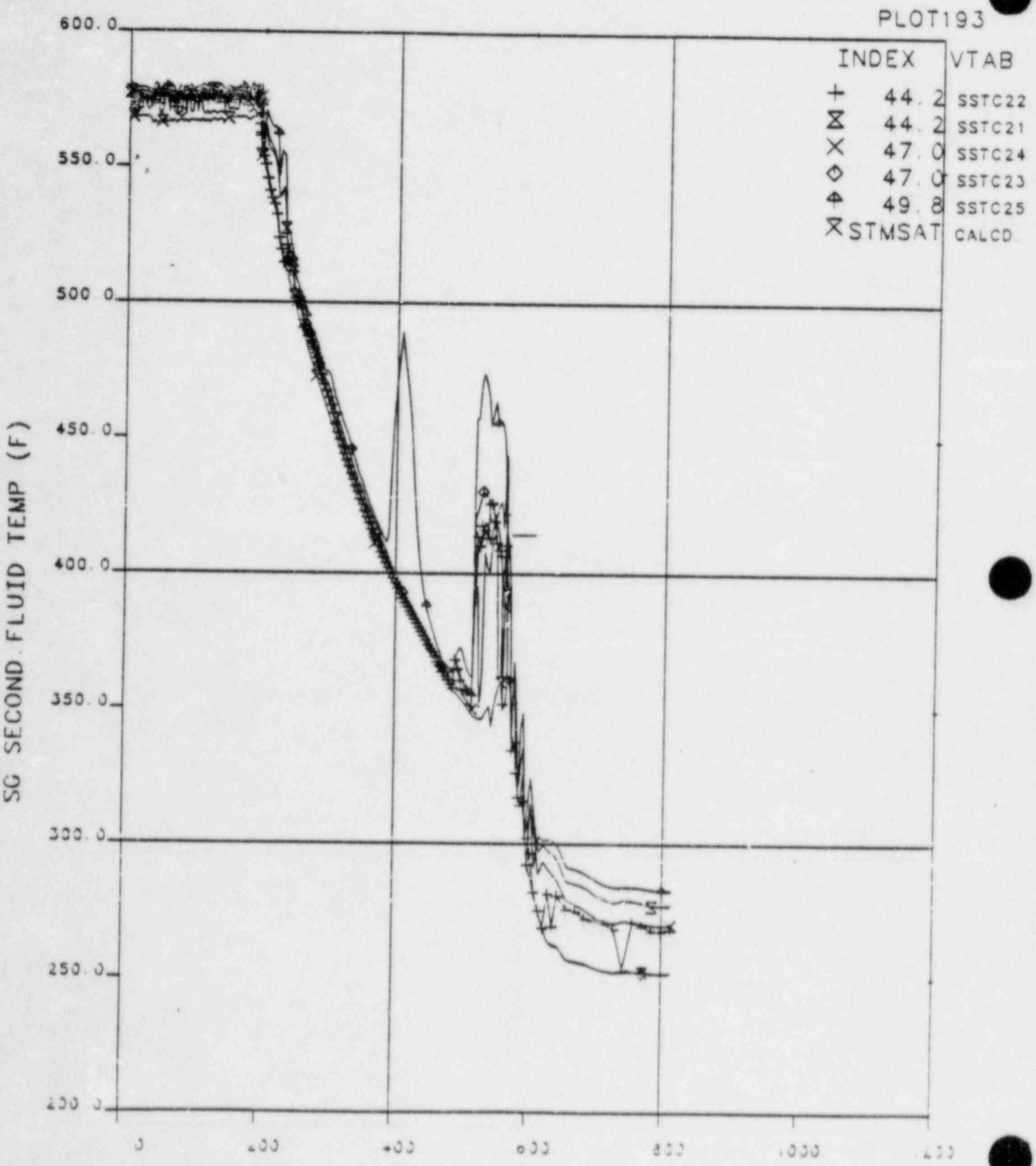
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



A-101

PRELIMINARY DATA

PRELIMINARY DATA

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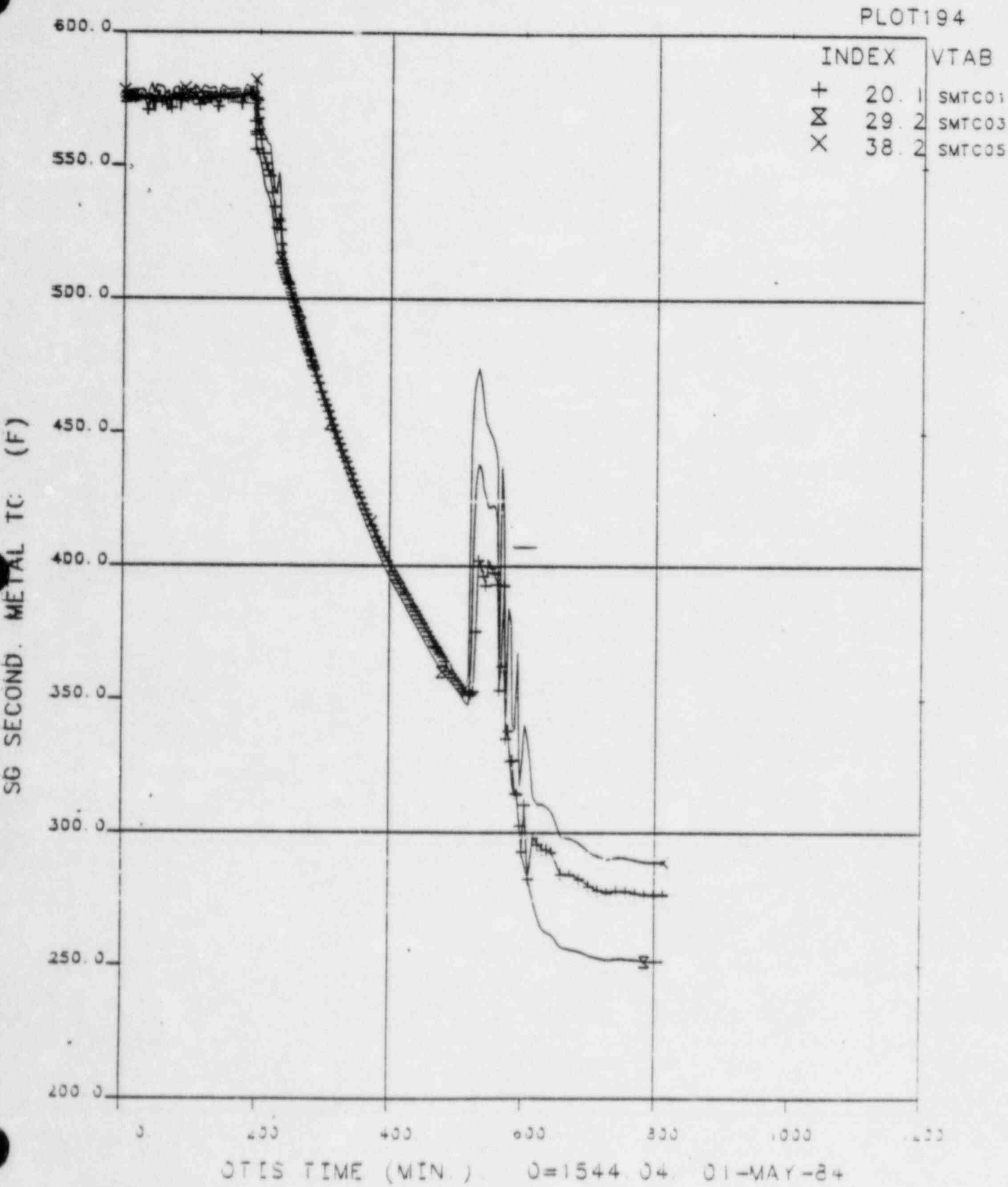

A-102

PRELIMINARY DATA

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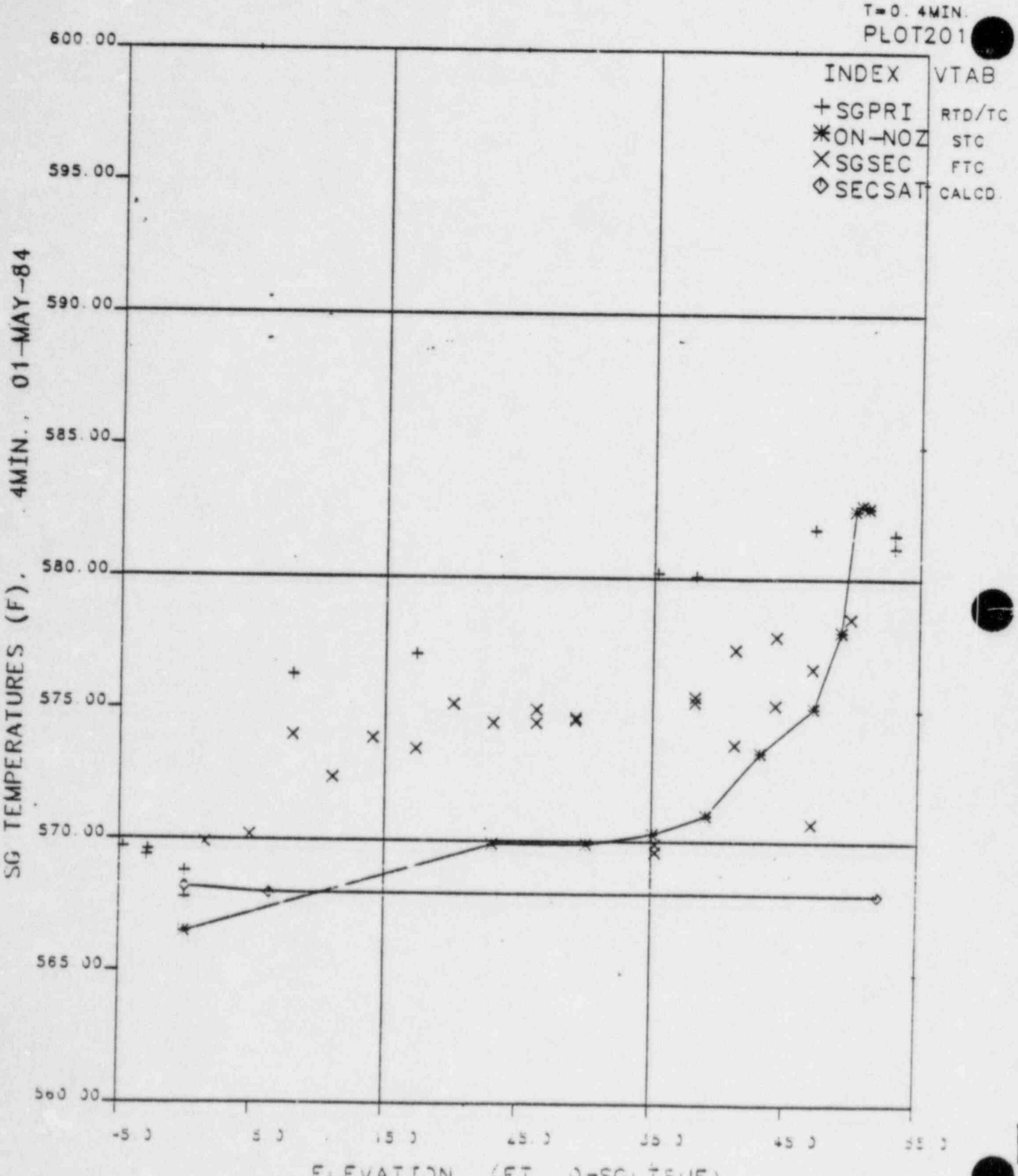
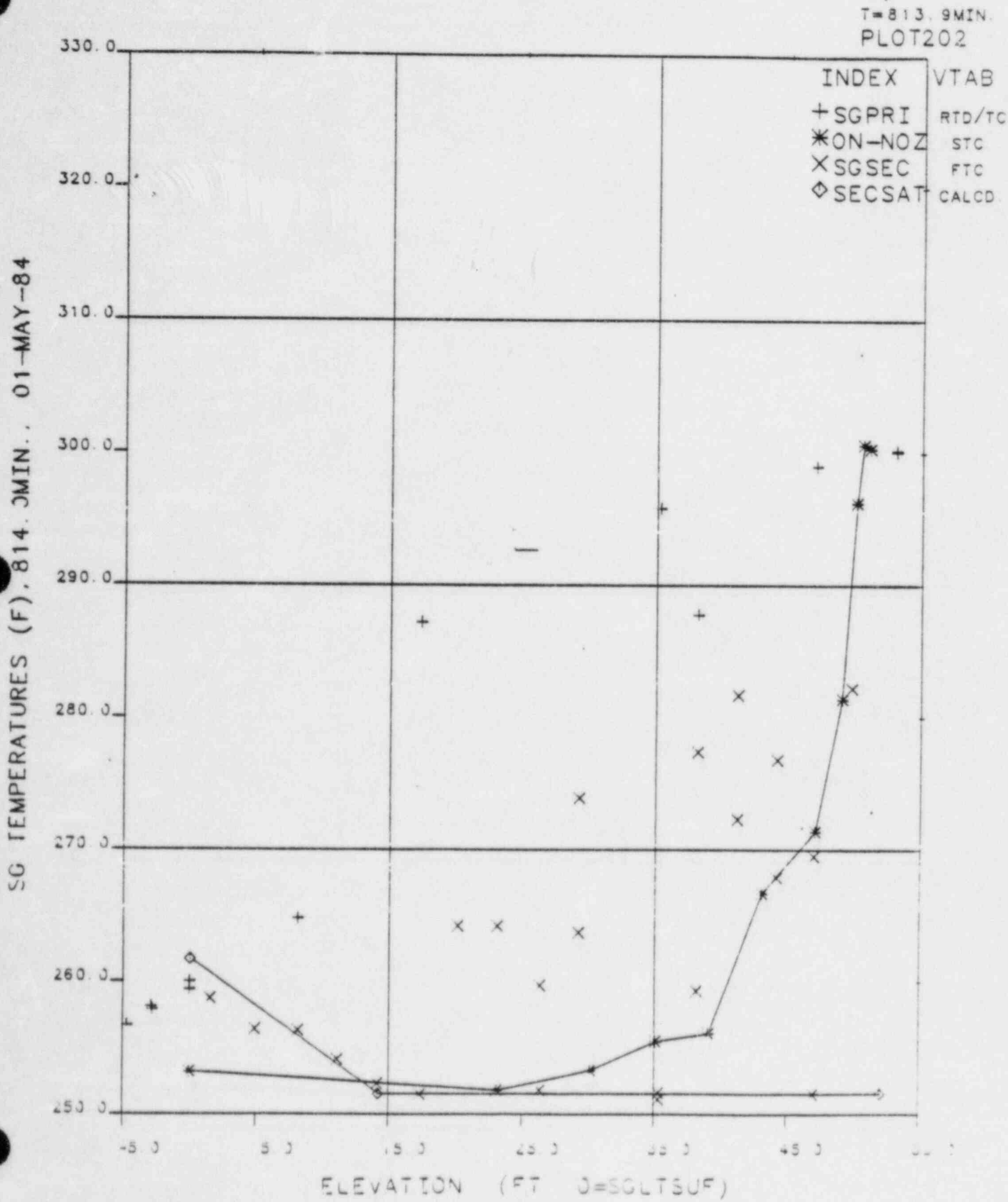


PRELIMINARY DATA

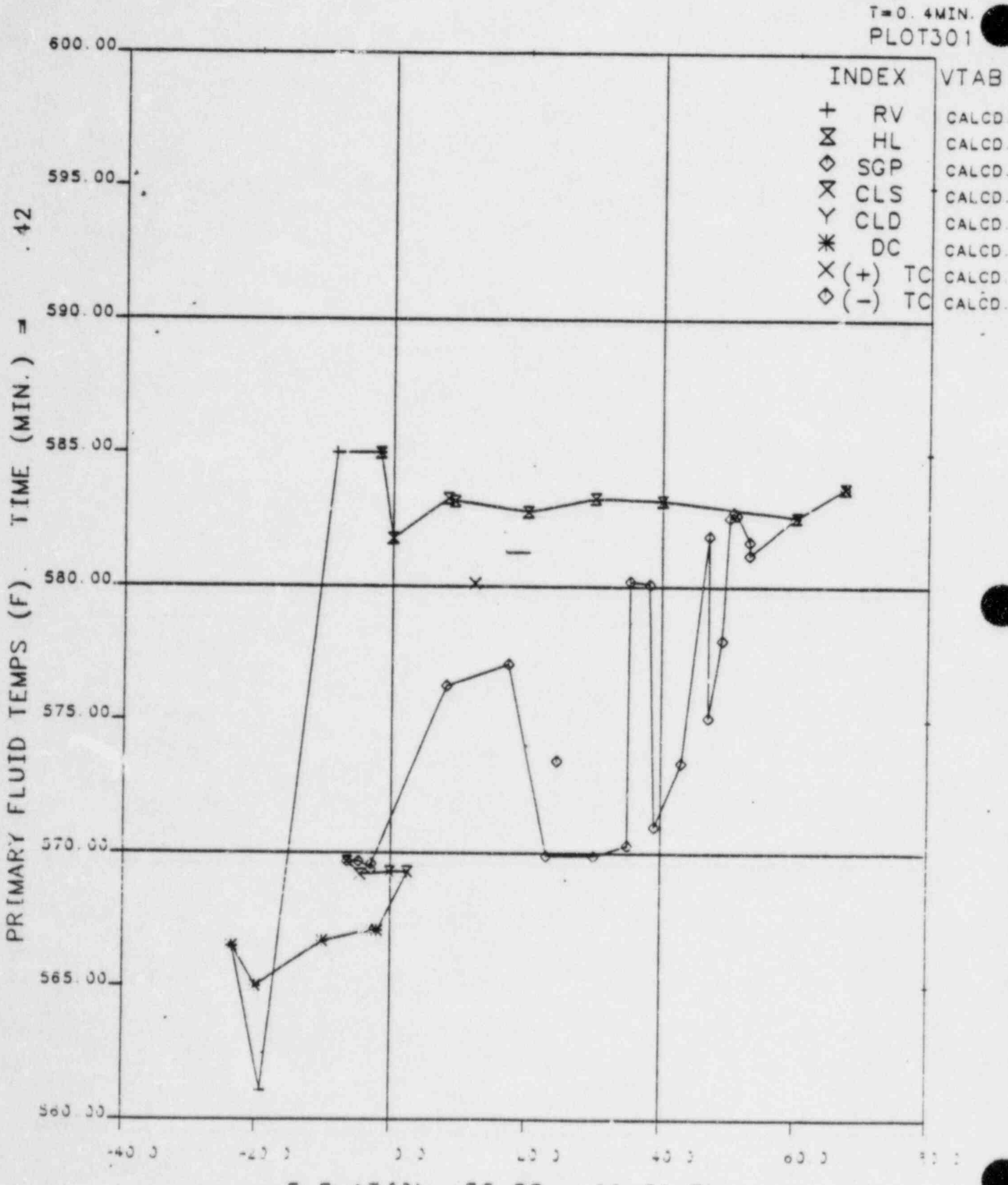
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)

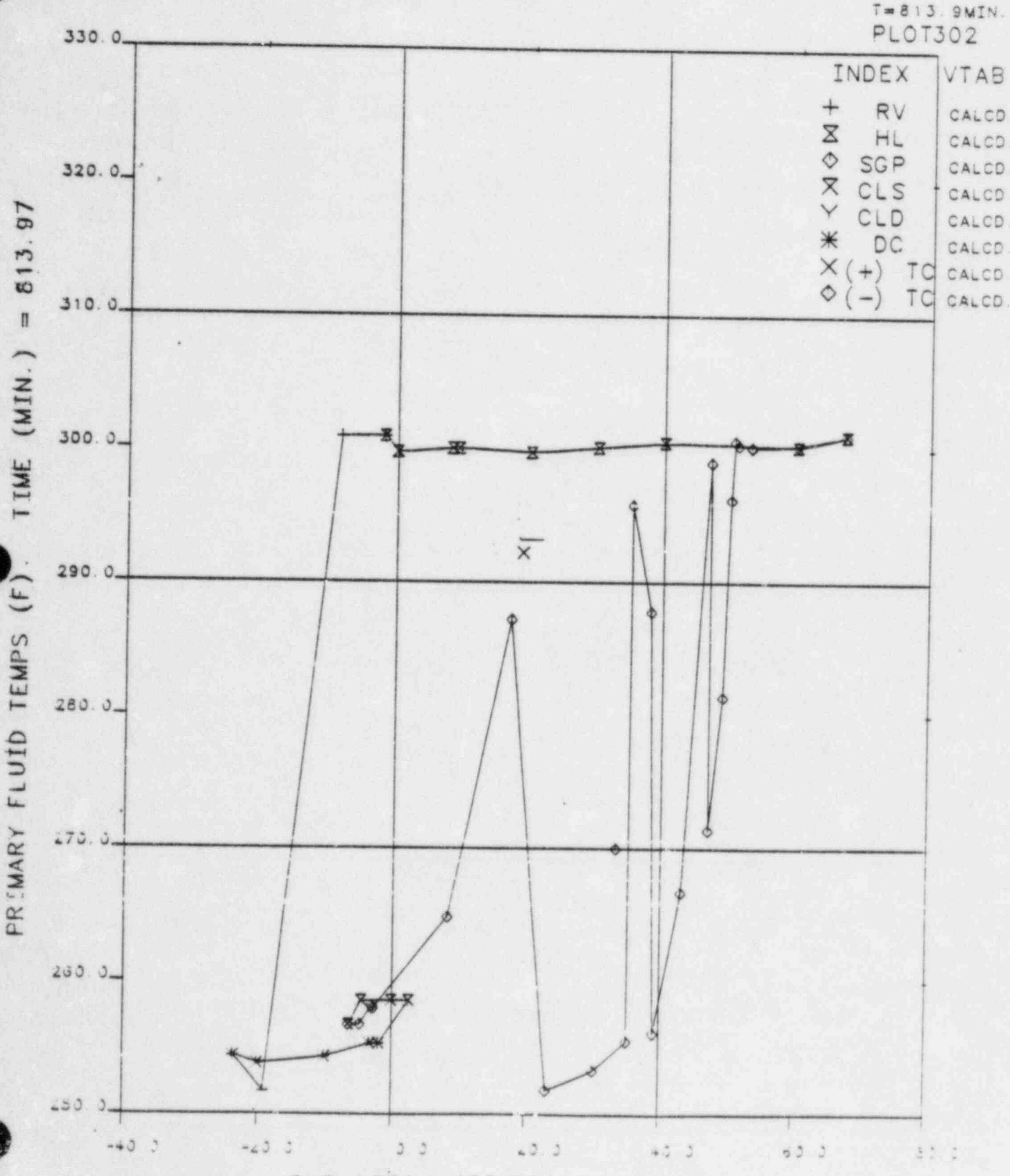


A-105

PRELIMINARY DATA

PRELIMINARY DATA

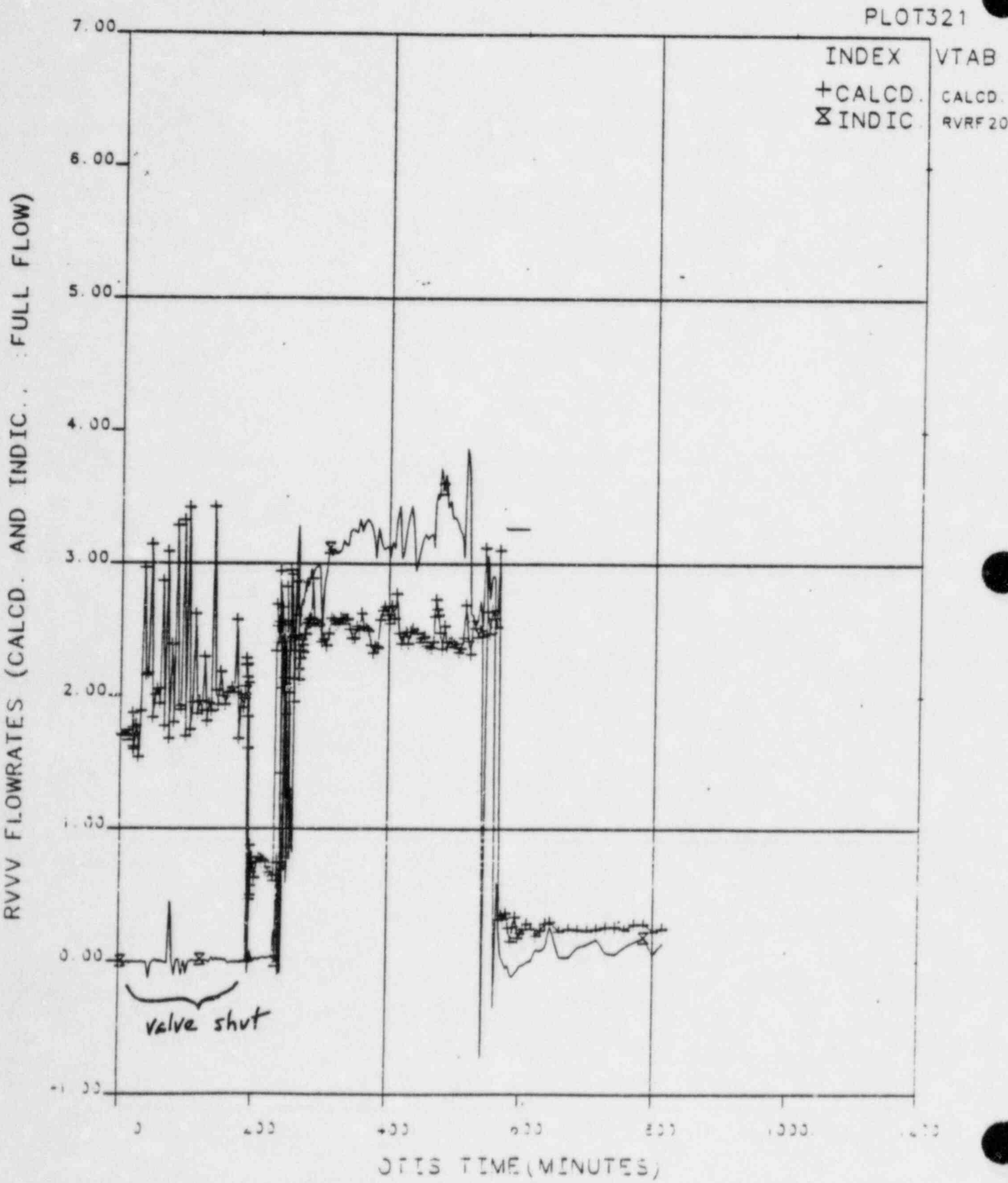
240200.0 FPC GAS TEST (W/ FEED & BLEED)



PRELIMINARY DATA

PRELIMINARY DATA

240200.0 FPC GAS TEST (W/ FEED & BLEED)



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PRELIMINARY DATA

INDEX	INPUT	VTAB	SYSTEM	INST	ELEV	DESCRIPTION
1	81	81RVTC01	1RV	2FTC	-23.70	CORE VESL.FLUID TEMP (F)
2	82	82RVTC02	1RV	2FTC	-19.10	CORE VESL.FLUID TEMP (F)
3	86	86RVTC07	1RV	2FTC	-6.30	CORE VESL.FLUID TEMP (F)
4	87	87RVTC08	1RV	2FTC	6.80	CORE VESL.FLUID TEMP (F)
5	97	97RVLV04	1RV	4LDP	-16.10	CORE VESL. COR.LVLDP (PSI)
6	99	99RVLV05	1RV	4LDP	-16.10	CORE VESL. COR.LVLDP (PSI)
7	94	94RVLV02	1RV	4LDP	-8.10	CORE VESL. COR.LVLDP (PSI)
8	92	92RVLV01	1RV	4LDP	-1.90	CORE VESL. COR.LVLDP (PSI)
9	90	90RVPM01	1RV	7 C	-13.20	CORE VESL. POWER (FULLPOWR
10	339	339RVDT01	1RV	10 DT	-.33	CORE VESL. INSUL. DT (F)
11	340	340RVDT02	1RV	10 DT	4.83	CORE VESL. INSUL. DT (F)
12	254	254RVCP02	1RV	16 CP	-2.40	CORE VESL. CONDCTVTY (WET/DRY)
13	253	253RVCP01	1RV	16 CP	-1.40	CORE VESL. CONDCTVTY (WET/DRY)
14	256	256RVCP04	1RV	16 CP	.60	CORE VESL. CONDCTVTY (WET/DRY)
15	255	255RVCP03	1RV	16 CP	.70	CORE VESL. CONDCTVTY (WET/DRY)
16	257	257RVCP05	1RV	23RCP	-8.90	CORE VESL. REF. C.P.
17	83	83RVTC03	1RV	25MTC	-16.00	CORE VESL. METAL TC (F)
18	84	84RVTC05	1RV	25MTC	-11.90	CORE VESL. METAL TC (F)
19	85	85RVTC06	1RV	25MTC	-9.90	CORE VESL. METAL TC (F)
20	341	341RVTC11	1RV	25MTC	-.33	CORE VESL. METAL TC (F)
21	342	342RVTC12	1RV	25MTC	4.83	CORE VESL. METAL TC (F)
22	281	281RVPR20	1RV	30KPR	7.10	CORE VESL. CORRD.PR (PSIA)
23	288	288RVLV20	1RV	31KLV	-16.10	CORE VESL. COLLD.LVL (REF. FT)
24	150	150HLTC01	2HL	2FTC	8.10	HOT LEG FLUID TEMP (F)
25	151	151HLTC02	2HL	2FTC	9.10	HOT LEG FLUID TEMP (F)
26	152	152HLTC03	2HL	2FTC	20.00	HOT LEG FLUID TEMP (F)
27	153	153HLTC04	2HL	2FTC	30.00	HOT LEG FLUID TEMP (F)
28	154	154HLTC05	2HL	2FTC	40.00	HOT LEG FLUID TEMP (F)
29	155	155HLTC06	2HL	2FTC	50.00	HOT LEG FLUID TEMP (F)
30	156	156HLTC07	2HL	2FTC	60.00	HOT LEG FLUID TEMP (F)
31	157	157HLTC08	2HL	2FTC	67.40	HOT LEG FLUID TEMP (F)
32	149	149HLRT01	2HL	3RTD	0.00	HOT LEG FLUID RTD (F)
33	168	168HLLV01	2HL	4LDP	-1.90	HOT LEG COR.LVLDP (PSI)
34	170	170HLLV02	2HL	4LDP	-1.90	HOT LEG COR.LVLDP (PSI)
35	159	159HLDT01	2HL	10 DT	2.60	HOT LEG INSUL. DT (F)
36	160	160HLDT02	2HL	10 DT	12.80	HOT LEG INSUL. DT (F)
37	161	161HLDT03	2HL	10 DT	23.60	HOT LEG INSUL. DT (F)
38	162	162HLDT04	2HL	10 DT	34.50	HOT LEG INSUL. DT (F)
39	163	163HLDT05	2HL	10 DT	46.20	HOT LEG INSUL. DT (F)
40	164	164HLDT06	2HL	10 DT	57.20	HOT LEG INSUL. DT (F)
41	165	165HLDT07	2HL	10 DT	65.90	HOT LEG INSUL. DT (F)
42	258	258HLCP01	2HL	16 CP	1.00	HOT LEG CONDCTVTY (WET/DRY)
43	259	259HLCP02	2HL	16 CP	15.00	HOT LEG CONDCTVTY (WET/DRY)
44	260	260HLCP03	2HL	16 CP	35.00	HOT LEG CONDCTVTY (WET/DRY)
45	261	261HLCP04	2HL	16 CP	37.00	HOT LEG CONDCTVTY (WET/DRY)
46	262	262HLCP05	2HL	16 CP	41.00	HOT LEG CONDCTVTY (WET/DRY)
47	263	263HLCP06	2HL	16 CP	45.00	HOT LEG CONDCTVTY (WET/DRY)
48	264	264HLCP07	2HL	16 CP	49.00	HOT LEG CONDCTVTY (WET/DRY)
49	265	265HLCP08	2HL	16 CP	53.00	HOT LEG CONDCTVTY (WET/DRY)
50	266	266HLCP09	2HL	16 CP	57.00	HOT LEG CONDCTVTY (WET/DRY)
51	267	267HLCP10	2HL	16 CP	61.00	HOT LEG CONDCTVTY (WET/DRY)
52	268	268HLCP11	2HL	16 CP	65.00	HOT LEG CONDCTVTY (WET/DRY)
53	269	269HLCP12	2HL	16 CP	67.20	HOT LEG CONDCTVTY (WET/DRY)
54	274	274HLCP17	2HL	23RCP	.50	HOT LEG REF. C.P.
55	204	204HLTC12	2HL	25MTC	2.70	HOT LEG METAL TC (F)
56	205	205HLTC13	2HL	25MTC	12.70	HOT LEG METAL TC (F)
57	206	206HLTC14	2HL	25MTC	23.70	HOT LEG METAL TC (F)
58	326	326HLTC10	2HL	25MTC	34.50	HOT LEG METAL TC (F)
59	207	207HLTC15	2HL	25MTC	46.20	HOT LEG METAL TC (F)
60	208	208HLTC16	2HL	25MTC	57.20	HOT LEG METAL TC (F)
61	327	327HLTC11	2HL	25MTC	65.90	HOT LEG METAL TC (F)
62	286	286HLLV20	2HL	31KLV	-1.90	HOT LEG COLLD.LVL (REF. FT)
63	114	114CLTC01	3SGP	2FTC	-4.70	SG PRIMRY.FLUID TEMP (F)
64	12	12SPTC05	3SGP	2FTC	8.10	SG PRIMRY.FLUID TEMP (F)
65	11	11SPTC04	3SGP	2FTC	17.30	SG PRIMRY.FLUID TEMP (F)
66	10	10SPTC03	3SGP	2FTC	35.30	SG PRIMRY.FLUID TEMP (F)
67	9	9SPTC02	3SGP	2FTC	36.20	SG PRIMRY.FLUID TEMP (F)
68	8	8SPTC01	3SGP	2FTC	47.10	SG PRIMRY.FLUID TEMP (F)
69	158	158HLTC09	3SGP	2FTC	59.90	SG PRIMRY.FLUID TEMP (F)
70	7	7SPRTC4	3SGP	3RTD	-2.90	SG PRIMRY. FLUID RTD (F)

71	6	6SPRT03	3SGP	3RTD	-2.80	SG PRIMRY: FLUID RTD (F)
72	4	4SPRT01	3SGP	3RTD	53.10	SG PRIMRY: FLUID RTD (F)
73	5	5SPRT02	3SGP	3RTD	53.10	SG PRIMRY: FLUID RTD (F)
74	172	172HLLV03	3SGP	4LDP	55.00	SG PRIMRY: COR.LVLDP (PSI)
75	166	166HLDT04	3SGP	10 DT	57.20	SG PRIMRY: INSUL. DT (F)
76	39	39SPPT04	3SGP	14PTO	-1.90	SG PRIMRY: PITO FLOW (% FULL)
77	40	40SPPT05	3SGP	14PTO	-1.90	SG PRIMRY: PITO FLOW (% FULL)
78	41	41SPPT06	3SGP	14PTO	-1.90	SG PRIMRY: PITO FLOW (% FULL)
79	273	273HLCP16	3SGP	16 CP	53.10	SG PRIMRY: CONDCTIVTY (WET/DRY)
80	272	272HLCP15	3SGP	16 CP	56.90	SG PRIMRY: CONDCTIVTY (WET/DRY)
81	271	271HLCP14	3SGP	16 CP	60.90	SG PRIMRY: CONDCTIVTY (WET/DRY)
82	270	270HLCP13	3SGP	16 CP	64.90	SG PRIMRY: CONDCTIVTY (WET/DRY)
83	13	13SPTC06	3SGP	21STC	23.10	SG PRIMRY: STRING TC (F)
84	26	26SPTC19	3SGP	21STC	23.10	SG PRIMRY: STRING TC (F)
85	14	14SPTC07	3SGP	21STC	30.10	SG PRIMRY: STRING TC (F)
86	27	27SPTC20	3SGP	21STC	30.10	SG PRIMRY: STRING TC (F)
87	15	15SPTC08	3SGP	21STC	35.10	SG PRIMRY: STRING TC (F)
88	28	28SPTC21	3SGP	21STC	35.10	SG PRIMRY: STRING TC (F)
89	16	16SPTC09	3SGP	21STC	39.10	SG PRIMRY: STRING TC (F)
90	29	29SPTC22	3SGP	21STC	39.10	SG PRIMRY: STRING TC (F)
91	17	17SPTC10	3SGP	21STC	43.10	SG PRIMRY: STRING TC (F)
92	30	30SPTC23	3SGP	21STC	43.10	SG PRIMRY: STRING TC (F)
93	18	18SPTC11	3SGP	21STC	47.10	SG PRIMRY: STRING TC (F)
94	31	31SPTC24	3SGP	21STC	47.10	SG PRIMRY: STRING TC (F)
95	19	19SPTC12	3SGP	21STC	49.10	SG PRIMRY: STRING TC (F)
96	32	32SPTC25	3SGP	21STC	49.10	SG PRIMRY: STRING TC (F)
97	20	20SPTC13	3SGP	21STC	50.10	SG PRIMRY: STRING TC (F)
98	33	33SPTC26	3SGP	21STC	50.10	SG PRIMRY: STRING TC (F)
99	21	21SPTC14	3SGP	21STC	50.60	SG PRIMRY: STRING TC (F)
100	22	22SPTC15	3SGP	21STC	51.10	SG PRIMRY: STRING TC (F)
101	38	38SPTC28	3SGP	21STC	51.10	SG PRIMRY: STRING TC (F)
102	209	209HLTC17	3SGP	25PTC	57.20	SG PRIMRY: METAL TC (F)
103	330	330SPTC16	3SGP	26PTC	0.00	SG PRIMRY: PITO TC (F)
104	331	331SPTC17	3SGP	26PTC	0.00	SG PRIMRY: PITO TC (F)
105	332	332SPTC18	3SGP	26PTC	0.00	SG PRIMRY: PITO TC (F)
106	279	279SPPR20	3SGP	30KPR	53.10	SG PRIMRY: CORRD.PR (PSIA)
107	264	264SPLV20	3SGP	31KLV	-2.90	SG PRIMRY: COLLD.LVL (REF: FT)
108	287	287HLLV21	3SGP	31KLV	53.00	SG PRIMRY: COLLD.LVL (REF: FT)
109	115	115CLTC02	4CL	2FTC	-4.50	COLD LEG FLUID TEMP (F)
110	116	116CLTC03	4CL	2FTC	-.10	COLD LEG FLUID TEMP (F)
111	278	278CLCR20	4CL	60PF	-999.00	COLD LEG HEAD-FLOW (FULLFLOW
112	328	328CLLV20	4CL	31KLV	-2.80	COLD LEG COLLD.LVL (REF: FT)
113	126	126DCTC02	5DC	2FTC	-10.30	DOWNCOMER FLUID TEMP (F)
114	125	125DCTC01	5DC	2FTC	-3.20	DOWNCOMER FLUID TEMP (F)
115	118	118CLTC05	5DC	2FTC	-.50	DOWNCOMER FLUID TEMP (F)
116	117	117CLTC04	5DC	2FTC	1.60	DOWNCOMER FLUID TEMP (F)
117	127	127DCRTD1	5DC	3RTD	-20.00	DOWNCOMER FLUID RTD (F)
118	326	326DCCR20	5DC	60KF	-999.00	DOWNCOMER HEAD-FLOW (FULLFLOW
119	329	329CLLV21	5DC	31KLV	-8.20	DOWNCOMER COLLD.LVL (REF: FT)
120	104	104PRTC01	6PR	2FTC	21.90	PRESURIZR.FLUID TEMP (F)
121	105	105PRTC02	6PR	2FTC	34.20	PRESURIZR:FLUID TEMP (F)
122	106	106PRTC03	6PR	2FTC	40.50	PRESURIZR:FLUID TEMP (F)
123	336	336PRCT04	6PR	10 DT	3.10	PRESURIZR: INSUL. DT (F)
124	101	101PRDTC1	6PR	10 DT	12.20	PRESURIZR: INSUL. DT (F)
125	102	102PRDTC2	6PR	10 DT	27.10	PRESURIZR: INSUL. DT (F)
126	103	103PRDTC3	6PR	10 DT	42.80	PRESURIZR: INSUL. DT (F)
127	325	325PRTC07	6PR	25MTC	2.60	PRESURIZR: METAL TC (F)
128	34	34PRTC11	6PR	25MTC	3.10	PRESURIZR: METAL TC (F)
129	210	210PRTC08	6PR	25MTC	12.20	PRESURIZR: METAL TC (F)
130	107	107PRTC04	6PR	25FTC	18.00	PRESURIZR: METAL TC (F)
131	211	211PRTC09	6PR	25MTC	27.10	PRESURIZR: METAL TC (F)
132	108	108PRTC05	6PR	25MTC	36.90	PRESURIZR: METAL TC (F)

133	227	227PRTC10	6PR	25MTC	42.60	PRESURIZR. METAL TC (F)
134	109	109PPTC06	6PR	25MTC	46.50	PRESURIZR. METAL TC (F)
135	280	280PRPR2C	6PR	30KPA	40.50	PRESURIZR. CORRD.PF (PSIA)
136	283	283PRLV2C	6PR	31KLV	2.50	PRESURIZR. COLLO.LVL (REF. FT)
137	68	68RVTC05	7RVV	2FTC	.00	R.V.V.V. FLUID TEMP (F)
138	69	69RVTC10	7RVV	2FTC	.00	R.V.V.V. FLUID TEMP (F)
139	95	95RVDPL3	7RVV	6DP	.00	R.V.V.V. PRES.DIFF (PSI)
140	229	229RVLS20	7RVV	26LIM	.00	R.V.V.V. LIMIT SW. (0=OPEN)
141	323	323RVLSC1	7RVV	24ETC	.00	R.V.V.V. MISCELLAN (VARIOUS)
142	324	324RVLSC6	7RVV	24ETC	.00	R.V.V.V. MISCELLAN (VARIOUS)
143	319	319RVRF2C	7RVV	33KCV	.00	R.V.V.V. CALC.FLOW (1 FULL)
144	113	113HPTC01	10HPI	2FTC	-999.00	HP INJECT.FLUID TEMP (F)
145	222	222HPTMC1	10HPI	13TMF	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
146	223	223HPTMC2	10HPI	13TMF	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
147	224	224HPTMC3	10HPI	13TMF	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
148	218	218HPACC1	10HPI	19ACC	-999.00	HP INJECT. ACCD.FLOW (LBM)
149	219	219V1ACC1	11V1	19ACC	-999.00	1-PH VENT. ACCD.FLOW (LBM)
150	230	230V1LSC1	11V1	26LIM	-999.00	1-PH VENT. LIMIT SW. (0=OPEN)
151	231	231V1LSO2	11V1	26LIM	-999.00	1-PH VENT. LIMIT SW. (0=OPEN)
152	232	232V1LSO3	11V1	26LIM	-999.00	1-PH VENT. LIMIT SW. (0=OPEN)
153	317	317V1PF2C	11V1	36FLO	-999.00	1-PH VENT. CALD.FLOW (LBM/SEC)
154	220	220V2ACC1	12V2	19ACC	-999.00	2-PH VENT. ACCD.FLOW (LBM)
155	221	221V2ACC2	12V2	19ACC	-999.00	2-PH VENT. ACCD.FLOW (LBM)
156	233	233V2LSC1	12V2	26LIM	-999.00	2-PH VENT. LIMIT SW. (0=OPEN)
157	234	234V2LSO3	12V2	26LIM	-999.00	2-PH VENT. LIMIT SW. (0=OPEN)
158	318	318V2PF2C	12V2	36FLO	-999.00	2-PH VENT. CALD.FLOW (LBM/SEC)
159	196	196FPFTC3	21AFW	3RTD	-999.00	AUX. FEED FLUID RTD (F)
160	345	345SFLSO1	21AFW	26LIM	-999.00	AUX. FEED LIMIT SW. (0=OPEN)
161	346	346SFLSC2	21AFW	26LIM	-999.00	AUX. FEED LIMIT SW. (0=OPEN)
162	294	294SFDK20	21AFW	33KCV	-999.00	AUX. FEED CALC.FLOW (1 FULL)
163	295	295SFFFU1	21AFW	34AVT	-999.00	AUX. FEED AVG. TEMP (F)
164	65	65SSITC01	22SGS	2FTC	1.50	SG SECOND.FLUID TEMP (F)
165	64	64SSITC02	22SGS	2FTC	4.90	SG SECOND.FLUID TEMP (F)
166	63	63SSITC03	22SGS	2FTC	8.10	SG SECOND.FLUID TEMP (F)
167	62	62SSITC04	22SGS	2FTC	11.10	SG SECOND.FLUID TEMP (F)
168	61	61SSITC05	22SGS	2FTC	14.10	SG SECOND.FLUID TEMP (F)
169	60	60SSITC06	22SGS	2FTC	17.30	SG SECOND.FLUID TEMP (F)
170	59	59SSITC07	22SGS	2FTC	20.10	SG SECOND.FLUID TEMP (F)
171	58	58SSITC08	22SGS	2FTC	23.10	SG SECOND.FLUID TEMP (F)
172	55	55SSITC10	22SGS	2FTC	26.30	SG SECOND.FLUID TEMP (F)
173	57	57SSITC09	22SGS	2FTC	26.30	SG SECOND.FLUID TEMP (F)
174	54	54SSITC12	22SGS	2FTC	29.20	SG SECOND.FLUID TEMP (F)
175	53	53SSITC11	22SGS	2FTC	29.30	SG SECOND.FLUID TEMP (F)
176	53	53SSITC13	22SGS	2FTC	32.30	SG SECOND.FLUID TEMP (F)
177	51	51SSITC14	22SGS	2FTC	35.30	SG SECOND.FLUID TEMP (F)
178	52	52SSITC15	22SGS	2FTC	35.30	SG SECOND.FLUID TEMP (F)
179	49	49SSITC16	22SGS	2FTC	38.20	SG SECOND.FLUID TEMP (F)
180	50	50SSITC17	22SGS	2FTC	38.20	SG SECOND.FLUID TEMP (F)