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OTIS
Hot Leg
High Point Vent Test
#240100

Florida Power Corporation
Sacramento Municipal Utility District

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OTIS GAS TEST 240100:

Preliminary Results

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ABSTRACT

This is an initial report for OTIS Test 240100 using preliminary data. The test examines the effectiveness of the hot leg high point vent and of plant venting procedures, with a gas-laden primary system. Test execution is as planned. Vent actuation and associated procedures restore natural circulation and support a rapid cooldown of the primary system.

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1. INTRODUCTION

This is an initial report of OTIS Test 240100 using preliminary data. The test uses the hot leg high point vent and the associated (revised) plant procedures, adapted to OTIS, to restore natural circulation and to cooldown the primary within the specified pressure-temperature envelope. OTIS (Once-Through Integral System) is a single hot leg and single cold leg simulation of a raised-loop plant of B&W design, section 2. Adaptation of OTIS for this test related to lowered-loop plants of lesser rated power requires scaling compromises and adjustments, cf. section 3.1.

The test is initialized according to the procedure in section 3.2.1. A final initialization gas injection to the hot leg U-bend voids that region, interrupts loop flow, and triggers test initiation as planned. The loop burden of noncondensibles at initiation is approximately 30 scf; injected and recovered gas volumes indicate gas closure to roughly 10% of the total injected volume, section 3.2.3.

The operator invokes recovery procedures, based on those of SMUD, immediately upon test initiation, section 3.2.2. The loop condition measurements throughout test initialization and conduct permit extensive tracking of system interactions, section 3.2.3. The post-initialization interactions are conveniently subdivided according to sequential testing phases (sections 3.3.2 through 3.3.5): Initiation (at 312 minutes after data acquisition system activation); a constant-pressure venting and cooldown phase; a depressurization phase; and a final, low pressure cooldown and stabilization period. The cooldown proceeds at an average rate of 60F/h, with rates sometimes approaching 100F/h. The gas removal rate is greatest initially, and during the later portions of the cooldown and depressurization phase. Conditions are maintained within the specified pressure-temperature envelope throughout the venting and cooldown evolutions. The results satisfy the test objectives of demonstrating the ability of the hot leg high point vent, in conjunction with operator actions based on those of the plant operator, to vent excess noncondensibles, to restore circulation, and subsequently to cool the system while approximately maintaining the specified pressure-temperature limits.

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:

- o 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.

- o 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.

- o 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 control orifice assembly. The details of the orifice design are illustrated in Figure 2-3. Scaled leaks of 15 cm^2 and 20 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 0.034 inches in OTIS.

To preclude leakage from the loop, sealed stem valves were used where possible throughout the loop. Additionally, all instrument fittings in the reactor 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 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 head-flow curves of the plant pumps. 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 and top plenum of the reactor vessel to the external downcomer. The 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:

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

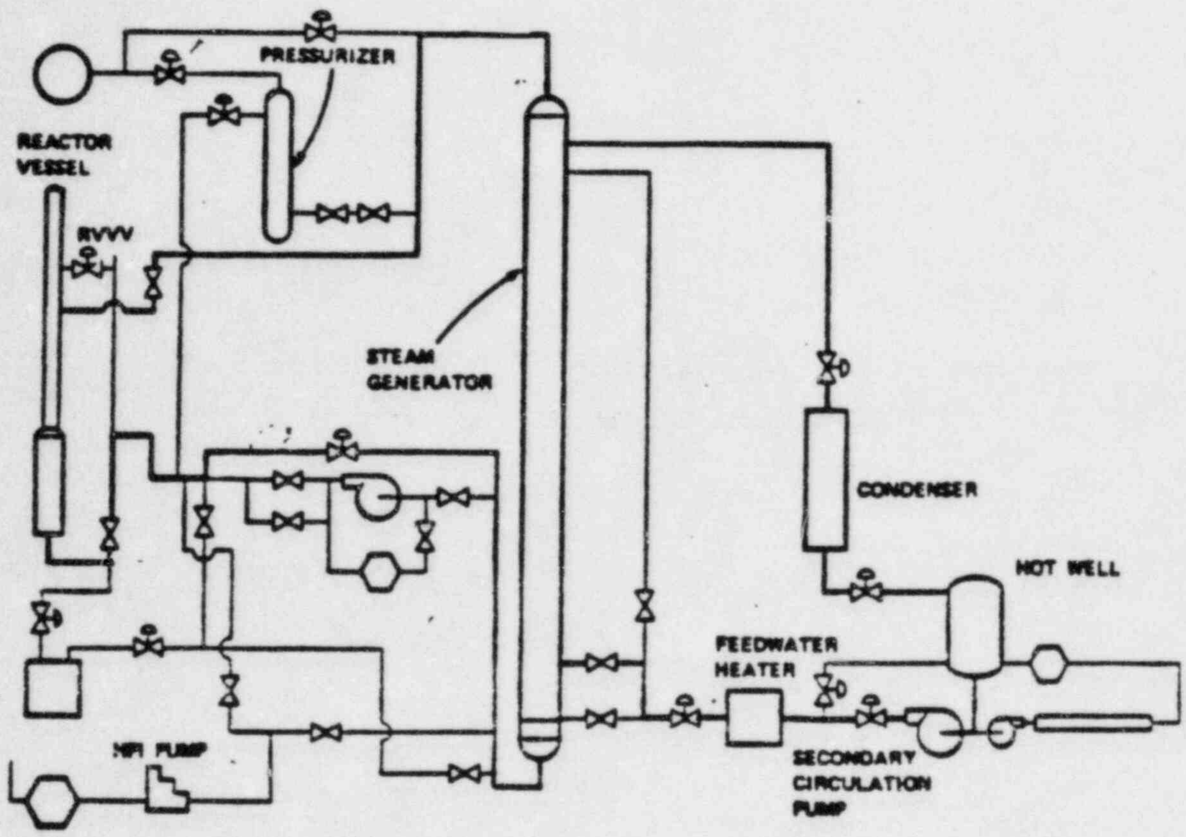


Figure 2-1. OTIS General Arrangement

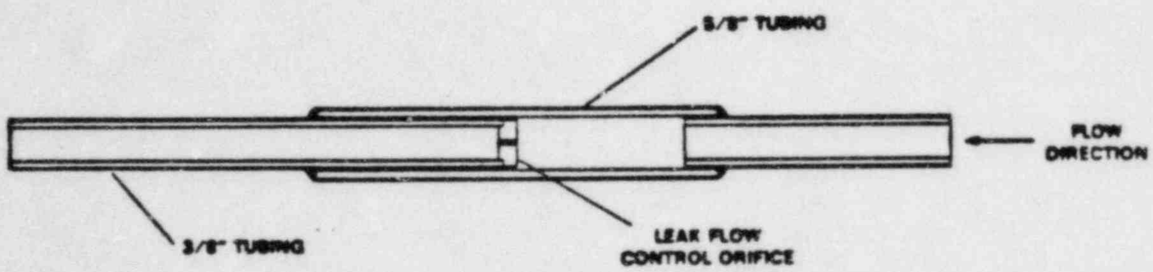


Figure 2-2 Leak Flow Control Orifice Assembly

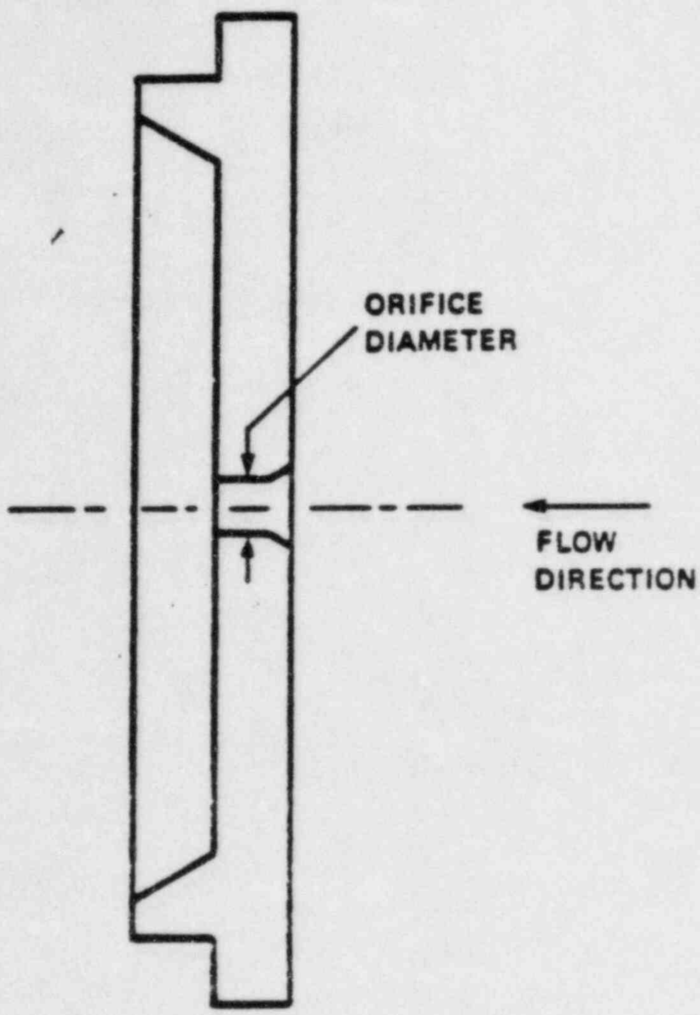


Figure 2-3 Leak Flow Control Orifice

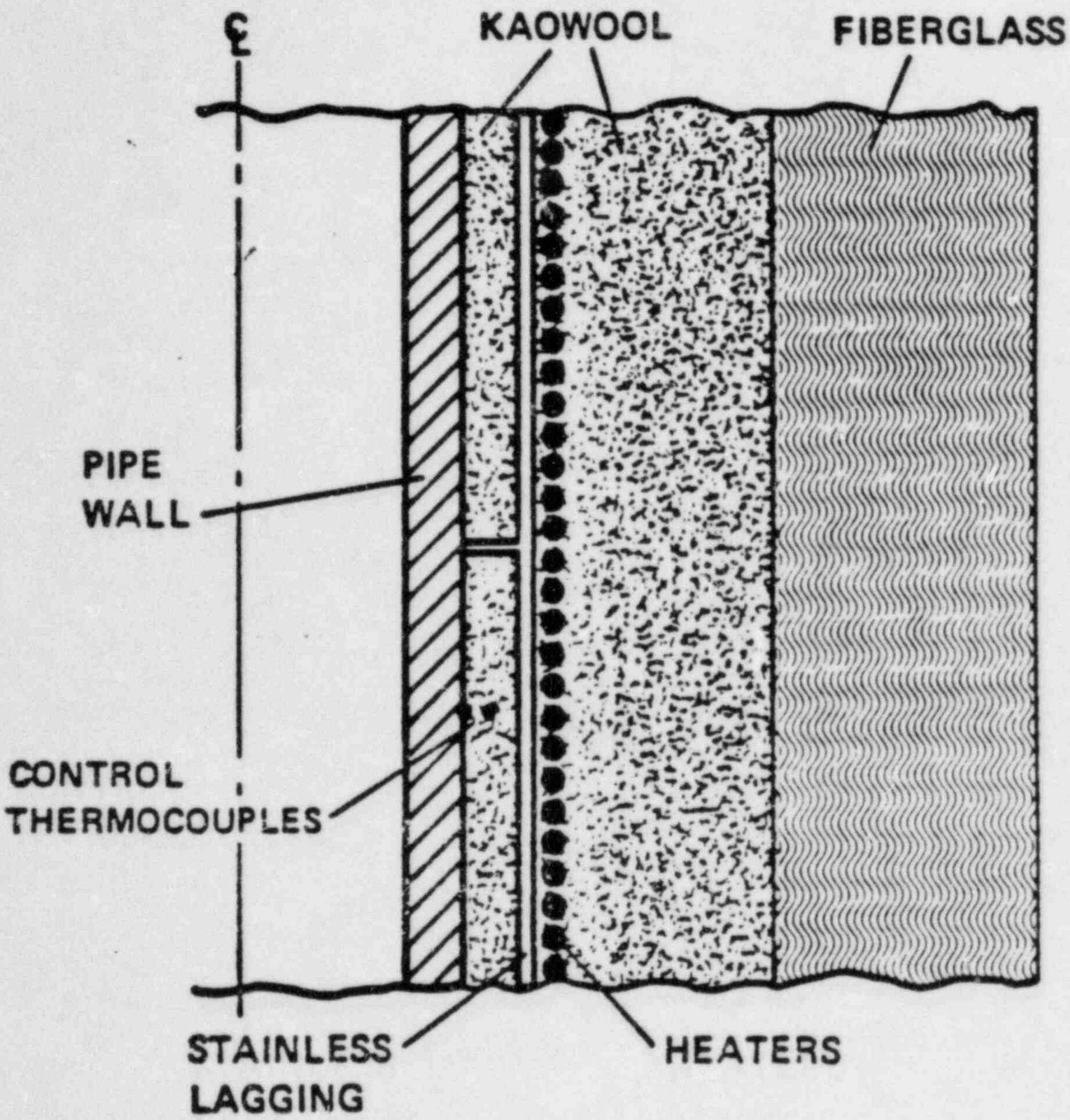


Figure 2-4 Guard Heater Concept

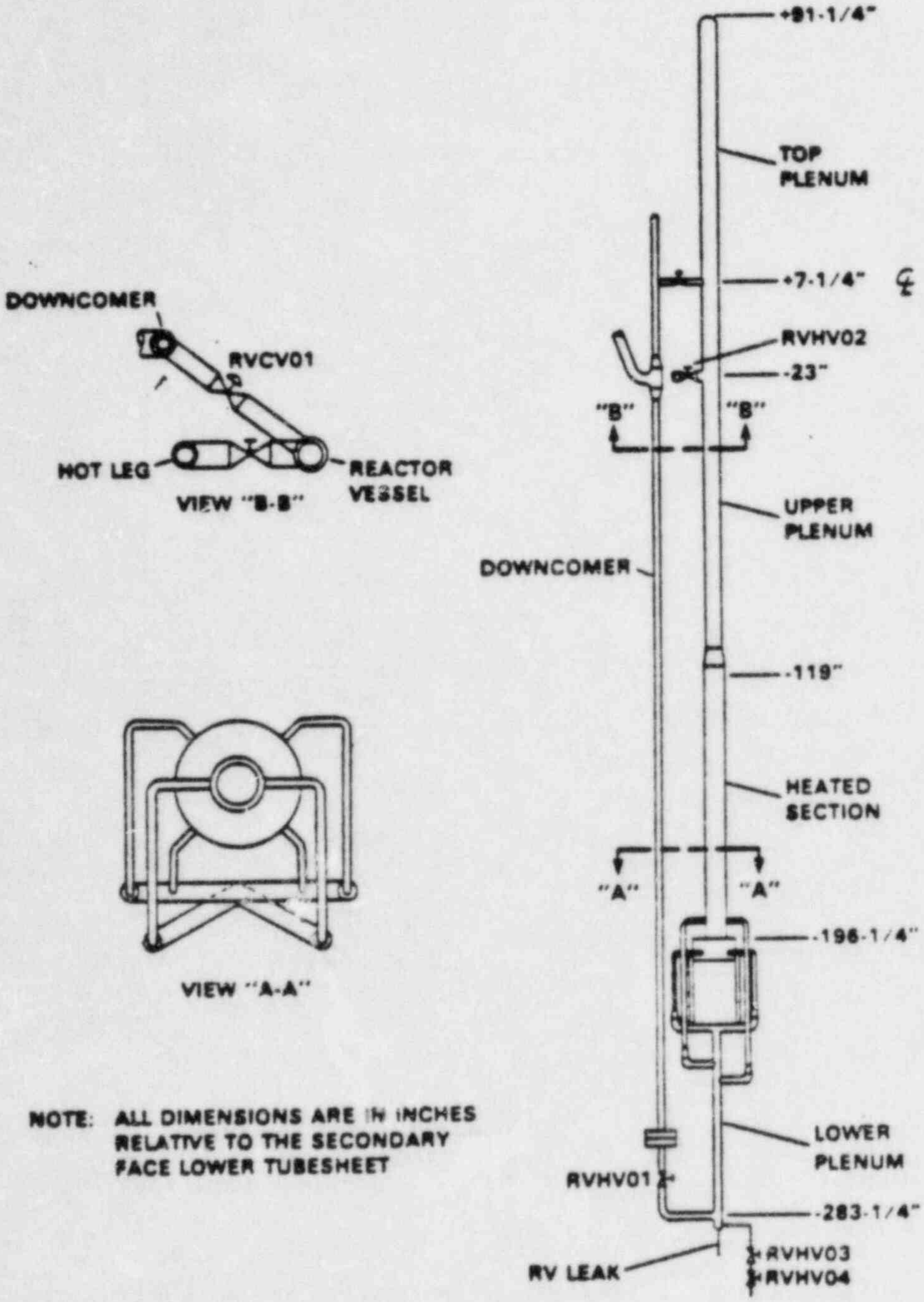


Figure 2-5. Reactor Vessel and Downcomer General Arrangement

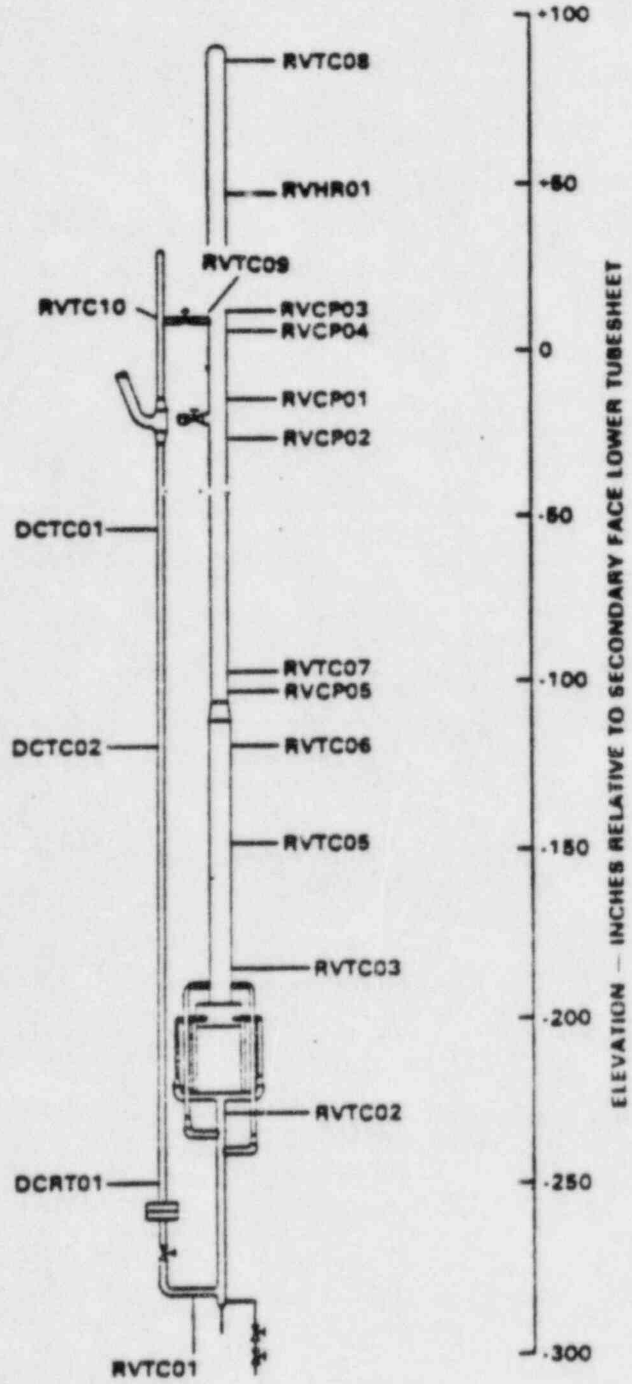


Figure 2-6. Reactor Vessel and Downcomer Instrumentation

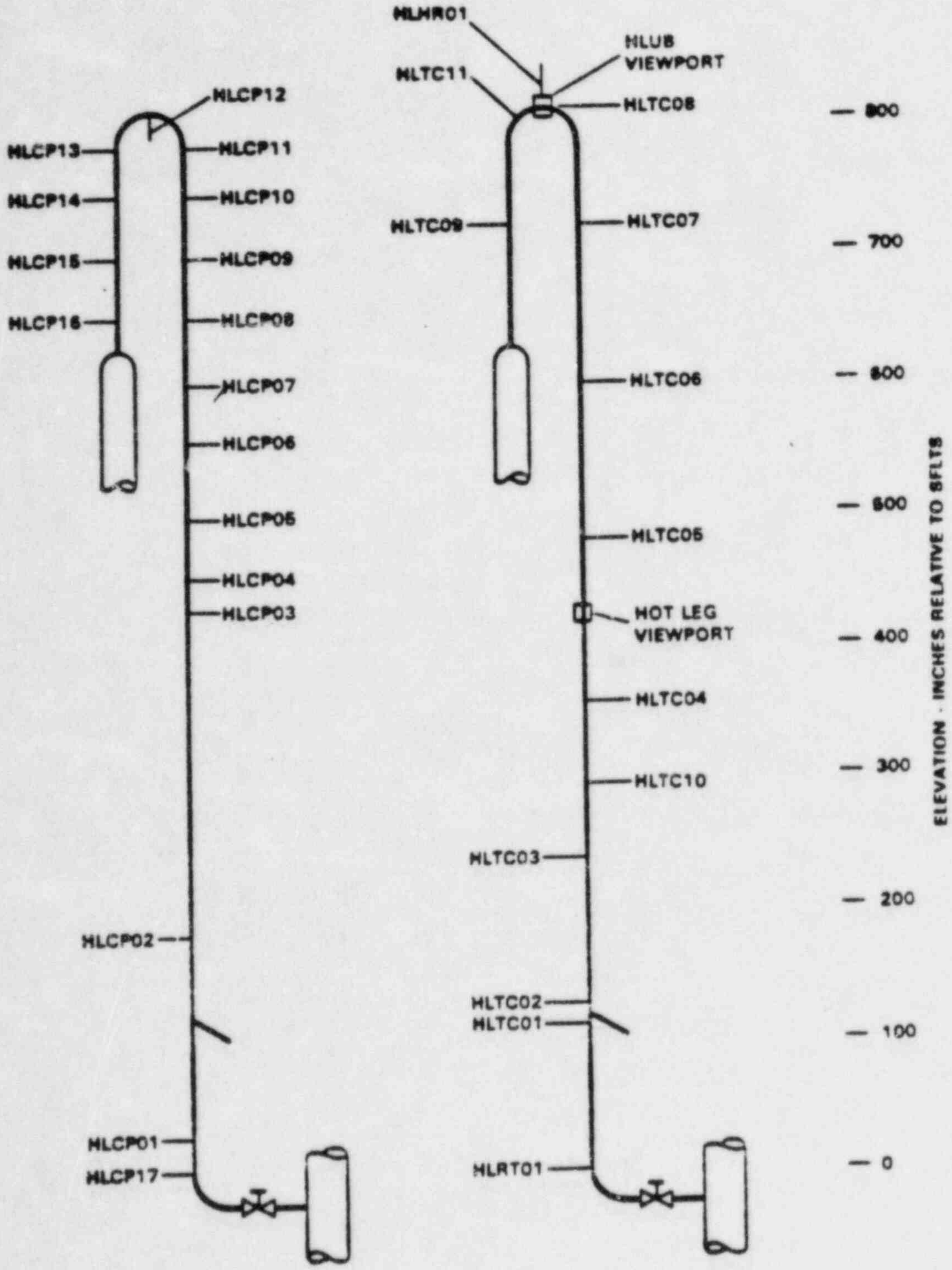


Figure 2-7. Hot Leg Instrumentation - Temperature Measurements, Conductivity Probes and Viewports

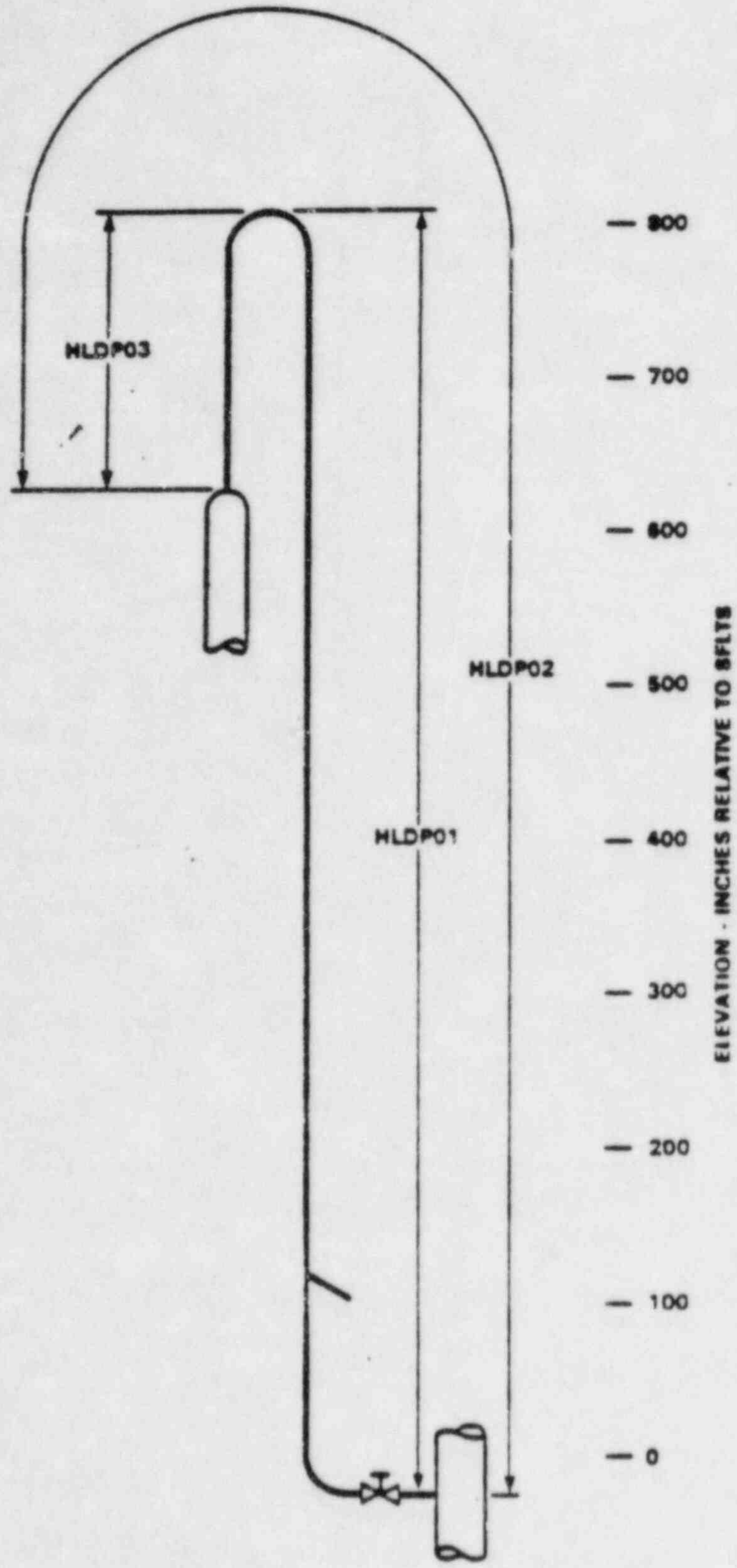


Figure 2-8. Hot Leg Instrumentation - Differential Pressure Measurements

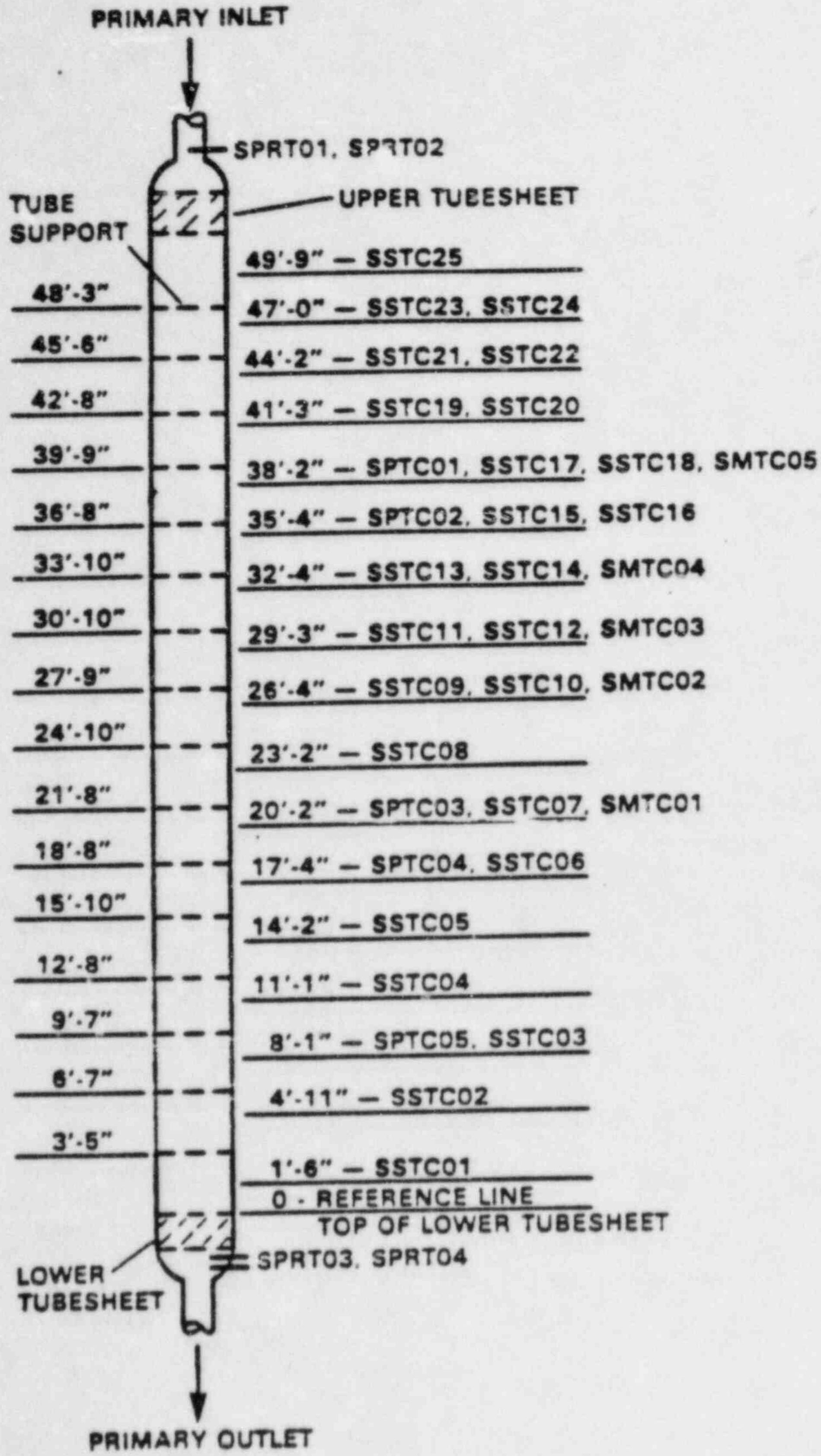


Figure 2-9. OTSG Temperature Measurements and Tube Support Plate Elevations

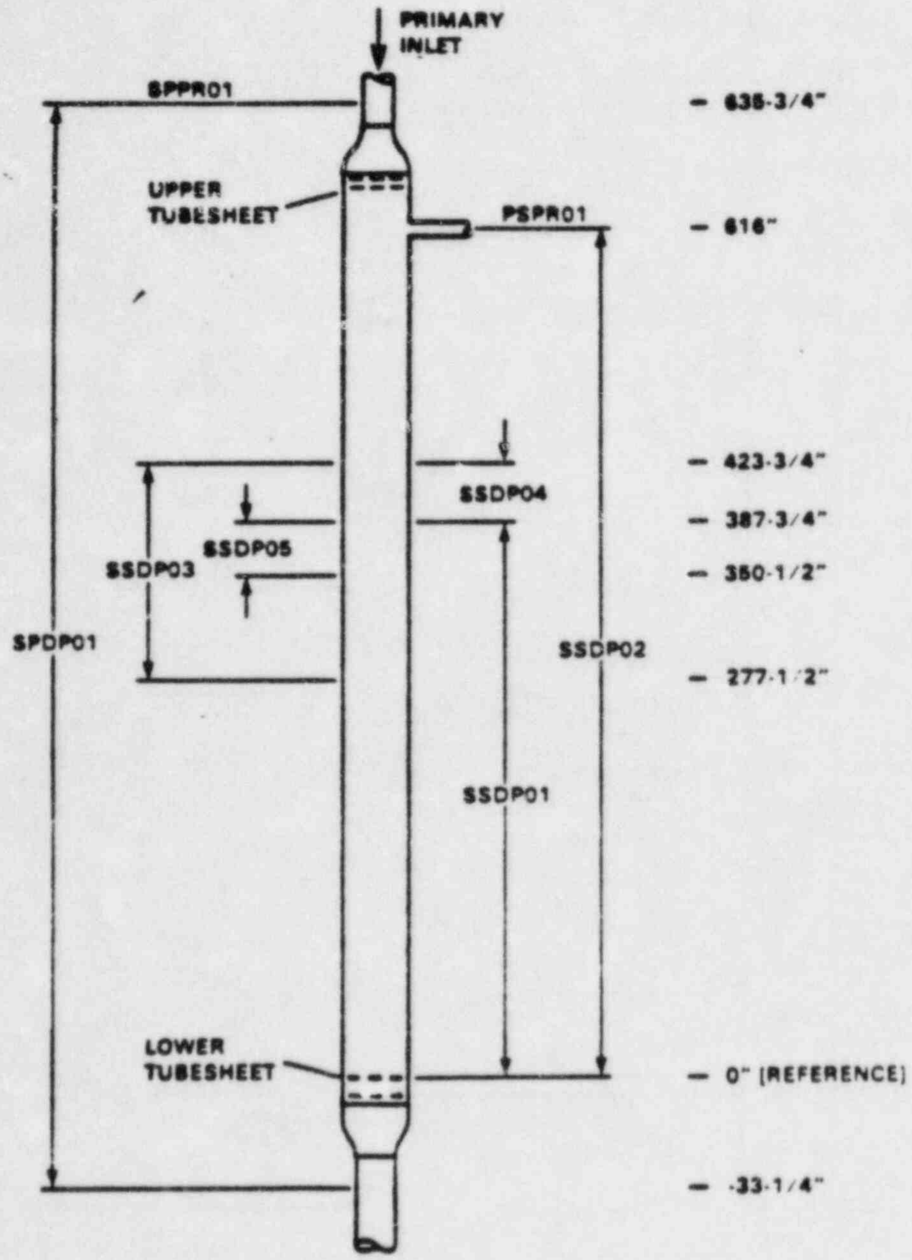


Figure 2-10. OTSG Pressure and Differential Pressure Measurements

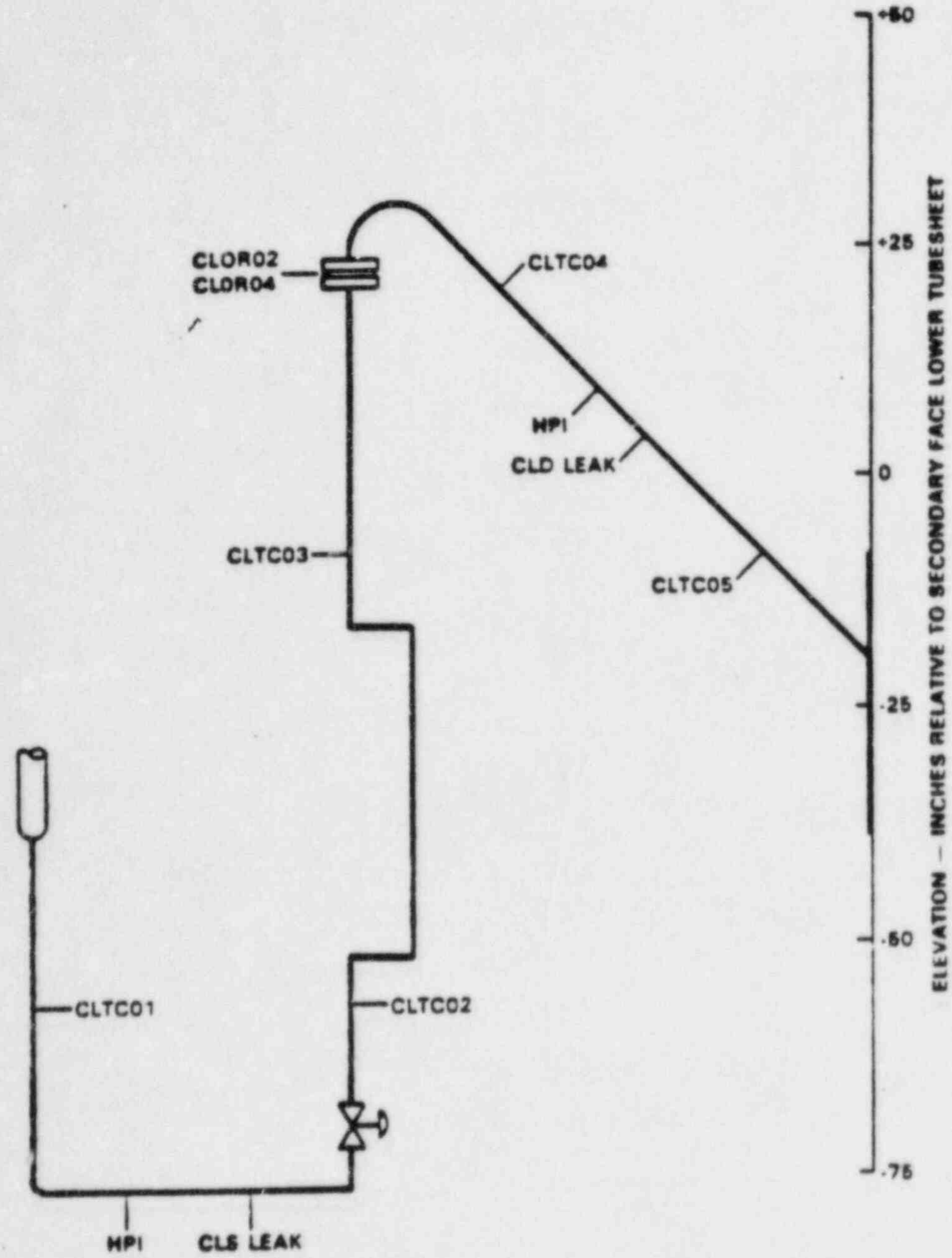


Figure 2-11. Cold Leg Piping - Temperature and Flow Measurements, Location of High Pressure Injection and Cold Leg Leaks

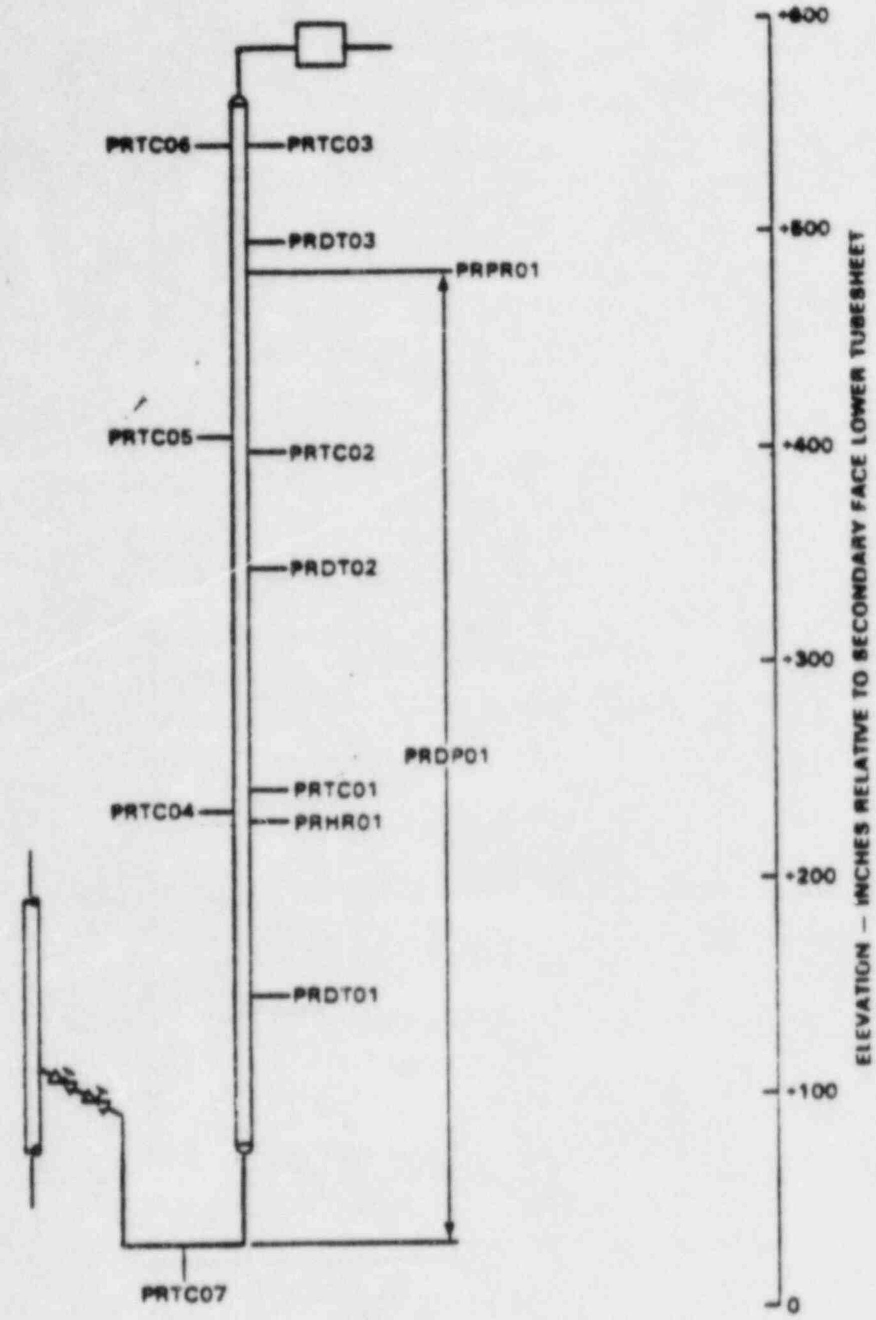


Figure 2-12. Pressurizer Instrumentation

3. TEST DESCRIPTION

3.1. Background

3.1.1. Introduction

This test applies (revised) SMUD hot leg high point venting and natural circulation cooldown procedures to OTIS. It is intended to demonstrate the ability of these procedures to cool and depressurize the primary from approximately 600F and 2000 psia initial conditions to conditions at which the DHS (Decay Heat System) would be activated, approximately 280F and 250 psia. This cooldown is to be performed with a burden of NCG (noncondensible gas) in the primary.

3.1.2. Test Description

The initial conditions assume that inadequate core cooling has occurred during a LOCA, such that significant volumes of NCG have been evolved. The operator has used HPI to cool the core and to partially refill the system, but the HLUB (Hot Leg U-Bend) and RVUH (Reactor Vessel Upper Head) remain gas filled. AFW has become available, the operator intends to restore subcooled natural circulation (SNC) to cool the primary.

The relevant SMUD procedures are:

D.5 Loss of Reactor Coolant/Reactor Coolant System Pressure

C.47 Inadequate Core Cooling

C.48 Loss of Subcooled Natural Circulation (to be revised)

Referring to these procedures, D.5 and C.47 precede the conditions at which this test is initialized, at the start of this test C.48 is instituted to regain subcooled natural circulation (SNC) and to cooldown the primary system. Only those portions of the plant procedures which are relevant to OTIS are invoked herein. Only those OTIS indications which simulate those of the plant are to be used for test control after test initiation.

It should be noted that OTIS elevations replicate those of a raised-loop plant, the model steam generator is approximately 25 feet higher relative to the centerline of the simulated core than are the corresponding SMUD components. The OTIS SG secondary level is to be raised to 10' after test initiation, rather than approximately 30' which would simulate the SMUD procedure, to partially offset this elevation difference. Also, OTIS simulates a single controlled discharge from the top of the model pressurizer. The use of this discharge path to simulate the pressurizer vent precludes simulation of the PORV in this OTIS test.

OTIS Vent Size

The size of the OTIS HLHPV (Hot Leg High Point Vent) governs its venting rate; it is thus important to the typicality of the test. Sizing the model HPV involves the OTIS general scaling factor, 1686, which was derived for a 205 fuel assembly plant (cf. Appendix A of reference 4). This scale factor obtains a model power of 21.4 kW per percent full power for simulation of a 3600 MW plant. Retaining the same model power equivalency, the plant boundary flow areas must be adjusted for plant rated power levels other than 3600 MW. The SMUD rated power level is 2772 MW, thus its boundary flow areas must be increased by 3600/2772 = 1.30 before scaling them to OTIS (using the general OTIS scaling factor, 1686). The (flow-limiting) flow area of 2 SMUD HLHPV's is 1.91 cm^2, thus the power-adjusted area to be scaled in OTIS is 1.3 x 1.9 = 2.5 cm^2. For FPC, rated power is 2544 MW and the area of 2 HLHPV's is 1.4 cm^2. The area adjustment factor is then 3600/2544 = 1.42 and the adjusted area to be scaled in OTIS is 1.4 x 1.42 = 2 cm^2. For this single HLHPV-effects test, OTIS employs a compromise vent size, which is intermediate to the two ideal areas, 2.11 cm^2/1686. This is 15% less than ideal for simulation of the SMUD vents and 6% greater than ideal for FPC. This compromise area is perceived to be adequate for the assessment of venting effects for both plants.

Nitrogen Versus Hydrogen

OTIS employs nitrogen to simulate the plant noncondensibles, predominantly hydrogen. N_2 differs from H_2 in both soluability and density. H_2 is roughly twice as soluable as N_2, the volumes of gas dissolved in the loop fluid differ by a like amount. Because only 20% of the initial loop burden of NCG is dissolved nitrogen (versus 35% using hydrogen), this solubility difference is acceptable,

The density of nitrogen is similar to that of steam, nitrogen is somewhat more dense than steam at saturated conditions below approximately 1800 psia. Hydrogen, on the other hand, is roughly one-tenth as dense as steam. This difference between the relative densities of nitrogen and steam, and that of hydrogen and steam, has little apparent impact on transport processes; such transport processes occur throughout the primary loop during natural circulation of liquid with dissolved and/or entrained NCG. Separation processes governed by buoyant forces are sensitive to relative density differences, however. With vapor at the HLUB region, the relatively dense nitrogen tends to be segregated toward the lower voided elevations and thus to the less readily vented (from the high point) than a higher noncondensible such as hydrogen. Testing with nitrogen is thus conservative by this consideration. With voiding in the upper RV, on the other hand, the relatively dense nitrogen gravitates toward the lower voided elevations and is more readily swept out of the RV upper head. The use of helium rather than nitrogen to simulate hydrogen is desirable on the basis of relative densities. But helium is much more difficult to contain than nitrogen, rendering closure on gas inventory unlikely. For this reason, nitrogen is retained as the NCG for OTIS simulation of hydrogen.

3.1.3 Initialization

Initialization obtains a hot and NCG-laden primary system. NCG additions are performed in three steps, the last of which (HLUB injection) triggers test initiation. The secondary is to be initialized at 1300 psia with a 5' level and high-elevation AFW injection. (Secondary pressure is initialized relatively high to elevate the initial primary fluid temperature at sustaining power). The primary is initially at approximately 1700 psia on pressurizer pressure control. Core power is at the sustaining level (approximately 1/2% of scaled full power, 1% = 21.4 kW). Initial pressurizer level is low, approximately 5'. During initialization, the pressurizer heaters are controlled to maintain an approximately adiabatic pressurizer. The RVVV is in automatic control with open/close setpoints of 0.25/0.125 psi.

The initialization steps are described in detail in the following section.

Saturate Primary Fluid With NCG

Add nitrogen to the primary in approximately 1 scf increments using a loop addition site other than that of the reactor vessel (to minimize gas collection in the RVUH before saturating the loop fluid). Continue this incremental injection into the loop, allowing primary system pressure to increase, until the primary liquid inventory is apparently saturated at approximately 2000 psia system pressure. Base the approach to saturation on the volume of gas injected and on the behavior of Pr level and primary pressure. The volume of nitrogen required to saturate the primary liquid inventory at the final pressure of approximately 2000 psia is 10 to 15 scf. The Pr level is expected to increase roughtly 1/2' at each addition, then to subside to its initial level with gas dissolution.

Displace RVUH Liquid With NCG

Manually close the RVVV (the internals vent valve simulation). Inject nitrogen to the reactor vessel gas addition site, to displace the RVUH liquid inventory with NCG. Approximately 30 scf of NCG are required to void the RVUH down to the RVVV elevation, inject this 30 scf in relatively large increments to minimize sweeping of the injected gas out the hot leg. Pause between injections to allow primary pressure to subside. Continue these incremental injections until the RV collapsed liquid level approaches the elevation of the RVVV (the RVVV elevation is +0.6' relative to the SGLTSUF, Steam Generator Lower Tube Sheet Upper Face). If necessary, momentarily close the cold leg throttle valve during each of these injections to minimize sweeping of NCG into the hot leg. (The cumulative loop burden of NCG will now be approximately 30 scf.)

Pressurizer level will increase by 10 to 15 feet during these injections. Modify this injection sequence as required to cause RVUH voiding without significant HLUB voiding. Following this NCG injection sequence, return the RVVV control to automatic actuation on differential pressure.

Void HLUB With NCG

Inject approximately 5 scf of nitrogen at the HLUB. Verify that the horizontal run of the HLUB is completely voided by monitoring the HLUB viewpoint. If the HLUB has not yet voided, continue NCG injections to the HLUB. After the HLUB has voided: Start a primary pressure-temperature plot, increase core power to 1% of scaled full power greater than ambient losses (1-1/2% total), and immediately initiate the test.

3.1.4. Initiation and Conduct

Test initiation immediately follows the final initialization step, the voiding of the HLUB with NCG. Test initiation begins with the restoration of SNC (Subcooled Natural Circulation). With SNC verified, cooldown as outlined. If SNC is lost during this cooldown (using the SNC verification criteria) take appropriate action to restore SNC. The system is to be cooled in this fashion until Decay Heat System cooling can be instituted, i.e., primary temperature $\leq$280F and primary pressure approximately 250 psia. The entire cooldown and depressurization is to adhere to the SMUD P-T envelope; for $T_{RCS} \leq$ 500F, this P-T envelope may be approximated by the fluid temperatures between T_{sat}-50F and T_{sat}-100F.

The automated secondary depressurization system available in OTIS may be used to perform the cooldown specified in the following sections. Throughout the test, approximate the SMUD AFW head-flow characteristics by limiting the OTIS AFW flowrate versus pressure to that given for the OTIS simulation of Davis Besse AFW (cf. the OTIS Test Specifications,[4] Figure A-6b, curve "DB"). Approximate the SMUD HPI head-flow characteristics; LPI simulation is unnecessary for this test.

The OTIS procedures herein are derived from SMUD procedures:

OTIS Procedure	Corresponding SMUD Procedure
Restore SNC	C.48 Loss of SNC
Verify SNC	C.48 and B.4 Section 6.1.2 and .3
SNC Cooldown	C.48 - Revised

Restore SNC (Procedure C.48)

1. Increase primary system pressure to the maximum pressure allowed by the P-T envelope using throttled HPI. Pressurizer heaters may be used to assist pressurization. Note: Do not exceed 2300 psia primary system pressure. The method of primary system depressurization, beyond that supplied by venting, cooldown, and adjusting HPI, is by opening the pressurizer vent, and by actuating pressurizer spray flow supplied by diverted HPI; limit this pressurizer spray flow to less than 0.01 lbm/sec.

2. Raise the SG level to approximately 10' using $\geq$1/3 gpm (0.04 lbm/s or 2% of full secondary flow) AFW flowrate.

3. Depressurize the SG secondary to obtain 100F/h secondary cooldown rate. Note: Do not exceed 100F/h primary system cooldown rate.

4. Open the HLHPV (Hot Leg High Point Vent) and keep it open.

5. Verify SNC using Section 3.2. When SNC is verified, cooldown using the procedure of section 3.3.

Verify SNC (Procedure B.4, Section 6.1.2 and 3)

The steps herein are used to verify SNC (subcooled natural circulation). If SNC can not be verified, restore SNC. When SNC is verified, cooldown. Plot T_{core}, T_{hot}, T_{cold} and $T_{sec\ sat}$ (SG secondary saturation temperature at steam pressure) versus time to perform these verification steps:

1. $T_{RCS} \geq$ 50F subcooled.
2. $(T_{Hot} - T_{Cold}) \leq$ 100F.
3. T_{Hot} and T_{Core} rise approximately 35F above T_{cold} and, after approximately 15 to 30 minutes, begin to track T_{cold}.
4. T_{Cold} remains steady or decreases slightly, and is equal to or slightly greater than $T_{sec\ sat}$.
5. T_{Cold} tracks $T_{sec\ sat}$.
6. T_{Hot} and T_{Cold} track changes in $p_{SG\ sec}$.

7. T_{Hot} and T_{Cold} are approximately equal and have similar trends.

SNC Cooldown (Procedure C.48 Revised)

1. Continue to verify SNC. If SNC is lost, restore SNC.
2. Cooldown the primary at approximately 100F/h by regulating the secondary system cooldown rate. Note: Do not exceed 100F/h primary system cooldown rate.
3. Depressurize the primary system in steps not to exceed 70 to 100 psi, to remain within the P-T envelope. The method of depressurization (beyond that provided by venting, cooldown, and adjusting HPI) is by opening the pressurizer vent, and by actuating pressurizer spray supplied by diverted HPI; limit spray flow to less than 0.01 lbm/s. Pressure control and/or repressurization is accomplished using throttled HPI as augmented by pressurizer heater actuation. Note: keep the HLPHV vent open.
4. Control pressurizer level at approximately 12 ± 5' using throttled HPI, but only as permitted within the P-T envelope.
5. Continue primary cooldown and depressurization within the P-T band until $T_{RCS} \leq 280F$ and $p_{PRI} < 250$ psia, i.e., to the DHS actuation conditions.

3.1.5. Post-Test NCG Accounting

Determine the NCG volume remaining after the completion of testing. Compare this volume and the volume collected during testing to the volume of NCG injected considering initial and final dissolved gas concentrations.

Required Instruments

The instrumentation requirements of this test correspond to those of the several OTIS tests, cf. Appendix B of the OTIS Test Specifications.[4] In addition to these measurements, the NCG-specific measurements are required, i.e., injection and collection times, amounts, and conditions.

3.2. Performance

Test initialization, conduct, and measurements are compared to their specifications in the following paragraphs.

3.2.1. Initialization

OTIS was initialized to obtain a hot and gas-laden system as specified. Approximately 3C scf of nitrogen were injected into the system prior to test initiation. Several minor adjustments were made to the specified initialization steps and conditions.

The initial SG steam pressure was reduced from 1300 psia to ~1200 psia, to reduce the initial loop temperatures; this slightly increases the time after the final (stagnating) gas injection at which the test is initiated and at which the operator invokes the plant venting procedures.

The system was initialized at 1% of scaled full power, rather than ~1/2% as specified. This was done to offset the increased losses to ambient (due to a higher than usual initialization temperature), to ensure that the SG secondary remained at pressure throughout initialization, and to maintain a substantial primary flowrate with which to distribute the gases throughout the system. Just before test initiation, core power was increased an additional 1% of scaled full power as specified; power during the test was then 2% of scaled full power (rather than 1% plus losses to ambient). This increased power increases the natural circulation flow rate (by the ratio of power levels raised to the one-third power); it also increased the primary-to-secondary temperature difference and thus raised the minimum temperature to which the primary fluid could be cooled. After the cooldown was completed, losses to ambient had decreased to roughly 0.13% of full power. At this time the available power (core less ambient losses) was ~1.9% versus ~1.4% specified, and the actual versus planned natural circulation flow rate was ~10% higher.

Initial gas additions were made to install noncondensibles in the RV upper head, rather than to first saturate the loop fluid with gas. This was done to ensure that the RV burden would be installed before the HL U-Bend voided and loop flow stalled, and was based on observations during initial injections. The technique employed was successful in establishing the desired initial gas burdens, particularly in the RV Upper Head.

Primary pressure was maintained near 1700 psia during initialization, rather than increasing to 2000 psia as initialization progressed. As with the secondary pressure adjustment, this was done to expand the time and pressure band between the final injection and test initiation. The reduced primary pressure decreases the volume of gas which can be dissolved in the primary liquid. But the total amount injected (and subsequently recovered) was 30 scf (or approximately 3 loop volumes, cf. Figures 3-3a and b). Thus the slightly reduced initial primary pressure allowed a more orderly transition from initialization to test initiation, and had no major impact on initial conditions.

The final initialization step was to inject a relatively large amount of gas into the HL U-Bend, and to verify voiding and loop flow stagnation. This test-initiating evolution was performed as planned.

3.2.2. Conduct

Test conduct was as specified. The procedures to restore SNC (subcooled natural circulation), verify SNC, and cooldown were invoked sequentially and successfully. SNC was not lost after it was first re-established.

The operator used pressurizer spray (diverted HPI) extensively to reduce primary pressure; Pr heaters were used to a lesser extent to hold pressure. The primary was cooled and depressurized well within the specified pressure-temperature band (cf. Figure 3-5). HPI was throttled such that approximately uniform cold leg and downcomer fluid temperatures were maintained, cf. Figure 3-1f and appended plot 26. Operator comments during the test are given in Table 3-2.

3.2.3. Measurements

Unavailable measurements are summarized in Table 3-3; none of these omissions hindered test interpretation. Gas accounting is summarized in Figures 3-3a and b. The maximum apparent loop burden (Figure 3-3b) is obtained by assuming all the voided regions except that of the pressurizer contain only nitrogen, and that the entire loop liquid inventory contains dissolved gas at the concentration indicated by the core-exit partial pressure. This maximum-volume estimate obtains ~40 scf at test initiation and a residual burden of ~5 scf.

The nitrogen is measured upon injection, and again as it evolves from the venting (HPV) effluent. These measurements of input and output provide a second and more reliable indication of loop NCG burden, cf Figure 3-3a. The burden at test initiation is ~30 scf (Table 3-4); the total amount collected exceeds the amount injected by approximately 3 scf (and some noncondensible gas certainly remains in the system at test termination). On the basis of the existing information, at least 30 scf of nitrogen were in the loop at the start of the test.

3.2.4. Summary

Test initialization, conduct, and measurements paralled the specifications. Adjustments to the initialization procedure were made as required to conduct the test, specifically to extend the brief period between the final initialization gas addition and test initiation. Test conduct was as specified; once initiated, natural circulation was maintained using the specified procedures. The specified pressure-temperature envelope was approximately maintained

Gas closure calculations (based on measurements of the amount of gas added and collected) indicate an uncertainty of roughly 10% of the maximum initial total burden; this maximum loop NCG volume was approximately 30 scf or 3 loop volumes. Comparison of the amount of gas injected with that recovered substantiates the ability of OTIS to contain gas.

3.3. Observations

Test observations are conveniently described according to the major test phases:

(1) Initialization, 0 to 310 minutes (DAS),

(2) Initiation, 312 minutes,

(3) Constant-Pressure Phase (to 381 minutes),

(4) Depressurization, 381 to 540 minutes, and

(5) Stabilization Phase (beyond 540 minutes).

Subsequent sections address these 5 phases. Figures 3.1 through 3.6 are extracted from the larger plot file (appended) and augment the discussions of the loop interactions.

3.3.1. Initialization Phase, 0 to 310 Minutes

The test is brought to its initial conditions over a 5 hour period. The major activities during this time are multiple gas injections, a core power increase, and a larger gas injection just preceding the initiation of the test.

The DAS (Data Acquisition System) is activated at 1451 on 26 April 1984. (This time of DAS activation establishes zero time for the several appended time-based plots). At this time the primary system is full, subcooled, and in natural circulation (Pr level is ~13'). Core power is 1% of scaled full power (1% = 21.4 kW, losses to ambient are ~1/2% power). Primary pressure is 1725 psia (Figure 3.1a), loop fluid temperatures are 565F to 585F (Figure 3.1b, saturation pressure at 585F is 1375 psia). Primary flowrate is 2.85% of full flow (1% = 0.265 lbm/s). The SG secondary pressure is 1200 psia (Tsat = 567F), secondary liquid level is ~7'; secondary feed and steam flowrates are nearly zero. The primary loop fluid is largely gas free, primary boundary systems are inactive (no leaks, HPI, etc.).

At 1505, 14 minutes after DAS activation, the RVVV is manually closed in preparation for the gas additions. The incremental gas additions begin at 1517, 26 minutes after DAS activation. This first addition consists of ~2 scf (standard cubic feet) of nitrogen injected at the bottom of the RV.

Immediately upon injection the Pr (pressurizer) level increases, then subsides (Figure 3-1c). The Pr surgeline metal temperature increases from 507F to 560F, reflecting the insurge of 565F hot leg fluid (appended plot 121). Loop flowrate perturbs by ~1/2% at and after the injection. The second injection, ~2 scf at 1525 (34 min. after DAS activation), is performed in the same manner as the first (the gas addition schedule is given in Table 3-4).

Most subsequent additions are done with the cold leg throttle valve (CLCV01) momentarily closed to reduce the transport of the injected gas out the hot leg nozzle, and thus to direct the NCG (noncondensible gas, nitrogen) to the RV upper head. These brief periods of stalled flow (Figure 3-1h) perturb system conditions generally (Figures 3-1a-g). For example, primary flowrate momentarily decreases to zero, primary pressure briefly increases in response to the decreased heat removal rate, and the SG primary fluid temperatures and SG secondary pressure similarly fluctuate.

The 5th gas addition at 71 min. (after DAS activation) begins to void the RV (reactor vessel) upper plenum (Figure 3-1c). The RV collapsed liquid level begins to decrease and the upper plenum void fraction begins to increase (Figure 3-1d); the core region and outlet plenum void fractions increase at each gas addition but subsequently subside. The Pr level begins to increase at an enhanced rate (Figure 3-1c). The cumulative gas volume in the loop is 9.43 scf (Table 3-4) which is approximately the amount needed to saturate the loop fluid at the current loop conditions.

Additions beyond the 5th gas injection correspondingly expand the RV upper plenum voided volume and continue to raise pressurizer level. Primary pressure increases with each add and is allowed to subside between injections. Also, bubbles are repeatedly observed visually at the HL viewport (35' elevation) just after these RV gas additions.

At 155 min. the RV conductivity probe just above the elevation of the RVVV begins to indicate dry. This indication follows the 10th incremental gas addition, the cumulative NCG burden is now 18.1 scf (Table 3.4). The RV conductivity probe just below the elevation of the RVVV (+0.6'), RVCP04 (appended plot 113), indicates decreased wetting at 185 min. These CP indications roughly correlate with the indicated RV collapsed liquid level (Figure 3.1c): +2.2' at 160 min., +2' at 180 min., and +0.6' at 215 min.

During this period of RV voiding, the outlet plenum and upper plenum fluid temperatures fluctuate between 580F and 605F (nearly saturation, Figure 3-1e). At 170 min., the fluid upstream of the RVVV (RVTC09) begins to cool, reaching 555F by 195 min. (Figure 3-1g); this temperature is lower than that of the RV-region liquid, which ranges from 560F to 570F (Figure 3-1e). These indications confirm the presence of a gas other than steam in the voided RV volume, i.e., of the injected nitrogen.

After the 12th gas addition at 1755 (184 min. after DAS activation), voiding is briefly observed visually at the HLUB (Hot Leg U-Bend). The cumulative NCG burden is now 20.5 scf (Table 3-4) or 2 loop volumes. At 215 minutes, the RV indicated level reaches the elevation of the RVVV (+0.6') and remains relatively constant through the subsequent gas additions (14th through 16th, Figure 3-1c). Primary pressure is similarly more stable than before but these final small additions were made without interrupting loop flow.

After both the 14th and 15th gas additions at 232 min. and 255 min., brief voiding is again visually observed at the HLUB. However the calculated HL level indicates full throughout this period -- the short duration of the HLUB voiding apparently renders it undetectable.

The 16th incremental gas addition at 273 min. raises the loop burden to 23.3 scf (Table 3-4). The RV remains voided down to the elevation of the RVVV (Figure 3-1c). In preparation for the test-initiating injection to the HLUB, core power is increased to 2% of full power beginning at 295 minutes, and control of the RVVV is returned to automatic on differential pressure at 299 minutes; the valve remains closed. In response to this power increase, primary flow increases from 3% to 4% of full flow, and the Pr (pressurizer) surgeline metal temperature increases with the insurge into the Pr. Loop fluid temperatures also change gradually with the power and flow adjustments. Core power approaches 2% of full power by 310 minutes (appended plot 19) and the loop is ready for the initiating gas addition.

At 312 minutes, 5-1/2 scf of nitrogen are injected into the HLUB, raising the total loop burden to approximately 30 scf or 3 loop volumes (Table 3-4). This injection voids the HL by ~1' upstream of the HLUB and by 3' downstream of the HLUB (Figure 3-2b). The HLUB fluid temperature abruptly decreases to 480F, then increases (Figure 3-2h). Primary loop flowrate stalls in response to the voided HLUB (Figure 3-2c). The RVVV differential pressure increases, the valve opens and the temperature of the DC (downcomer) fluid at the RVVV discharge increases from 532F to 580F (Figure 3-2j). The CL (cold leg) flowrate begins to diverge from that of the DC (downcomer) (Figure 3-2c). the decreasing loop flow impedes primary-to-secondary heat transfer, causing primary pressure to abruptly increase toward 1900 psia (Figure 3-2a). These indications of stalled flcw prompt test initiation.

3.3.2. Initiation, 312 Minutes

At test initiation, the loop burden of noncondensible gas has been raised to 30 scf with a final injection of 6-1/2 scf at the HLUB. Loop flow is stalled, core region fluid temperatures are increasing markedly, and primary pressure reaches 1900 psia by 312.4 minutes (Figures 3-2a, c, and g). At this time the test is initiated and the operator begins to use the HLHPV (HL High Point Vent) and the steam generator to regain circulation and to cooldown the system.

As mentioned at the end of the description of loop initialization, conditions are changing rapidly as the test is initiated (Figures 3-2a-j). At 312.8 minutes, the HLUB-downstream void fraction abruptly increases to 13% and persists until 315 minutes. The conductivity probe downstream of the HLUB indicates dry. Simultaneously loop flow, which had briefly returned to 3% of full flow, subsides and remains nearly stagnant until 314 minutes (Figure 3-2c). The RVVV momentarily closes but by 313 minutes the actuating DP has increased to 0.2 psi and the valve reopens at 313.2 minutes as confirmed by the RVVV downstream fluid temperature response shown on Figure 3-2j. The RVVV discharge progressively heats the downcomer fluid (Figure 3-2i). As the HL voided volume diminishes the RV voided region expands (Figure 3-2b); at 313.5 min. the RV upper plenum void fraction begins to increase from a minimum of 60% (Figure 3-2f).

At 313.6 minutes the HL High Point Vent (HPV) is opened. The initial gas venting rate over the first half hour is roughly 20 scf/hr (Figure 3-3a). At 313.8 min. the AFW flowrate increases from 0 to 3% of full secondary flowrate (Figure 3-2d. 1% = 0.0265 lbm/sec). (Both the HPV and AFW indications are in response to specified operator actions.) Secondary steam pressure begins to decrease from 1200 psia (Figure 3-2a) and the SG primary outlet temperatures begin to decrease. SG secondary level begins to increase (Figure 3-2b).

By 314 minutes liquid again reaches the HLUB spillover elevation (the HPV effluent metering system first begins to indicate liquid in the vented stream at 314.6 minutes). Loop flowrate restarts (Figure 3-2c), the relatively hot DC fluid reaches the core (Figure 3-2g) and the HL fluid temperatures increase (by 15F) sequentially with elevation as this warmer fluid passes (Figure 3-2h). AFW activation with stalled primary flow had decreased the upper-elevation wetted-tube primary fluid temperatues roughly to secondary saturation temperature; now the resurgence of loop flow reheats this fluid (the aforementioned warmer HL fluid reaches the SG at 316.5 minutes).

By 314.3 minutes the HLUB-downstream conductivity probe indicates rewetted. With the continuing discharge from the HPV and the reactivated primary-to-secondary heat transfer, primary pressure begins to decrease at 314.5 minutes (Figure 3-2a). With this pressure reduction the RV voided volume continues to expand gradually (Figure 3-2f). At 314.7 minutes the RV conductivity probe above the elevation of the RVVV indicates dry and the RVVV DP peaks at the actuation pressure. Subsequently the valve momentarily opens, the DC fluid beyond the valve briefly reheats (Figure 3-2i and j), and the DC flowrate peaks at 0% of full flow (Figure 3-2c). By 315 min. the indicated RV collapsed liquid level reaches the RVVV elevation (+0.6', Figure 3-2b), and at 315.2 min. the RVCP (conductivity probe) just below the elevation of the RVVV indicates decreased wetting.

Primary loop flowrate reaches a maximum of 6-1/2% of full flow by 315.8 min. (Figure 3-2c). The operator transfers AFW control to automatic (constant level) as the secondary level approaches the specified control point (10', Figure 3-2b) and the AFW flowrate abruptly decreases (Figure 3-2d). The primary flowrates in the wetted versus the unwetted SG tubes begin to diverge. With the continued heat transfer and decreased AFW flow the SG secondary begins to repressurize (Figure 3-2a); the SG secondary fluid temperatures increase from 575F to 585F.

3.3.3. Constant-Pressure Phase (to 381 Minutes)

Five minutes after test initiation (which occurred at 312 minutes based on DAS time) the loop is virtually liquid full, primary flow and primary-to-secondary heat transfer have been reestablished (Figures 3-4a-e). The RV collapsed liquid level remains between the elevations of the HL nozzle and the RVVV (Figure 3-4c); based on the "depressed" temperatures (vapor temperatures which are less than the saturation temperature from total pressure) in the voided region of the RV (Figure 3-4e), this volume contains significant amounts of the injected noncondensible gas. At 317 minutes the operator reduces the SG steam pressure control point to 1050 psia (Figure 3-4a). Secondary steam and feed flow begin to increase (Figure 3-2d), as does primary loop flow rate (Figure 3-2c). Primary pressure begins to decrease from 1790 psi at 318.2 minutes (Figure 3-4a). At this time the total primary fluid energy begins to decrease; the pressurizer outsurges gradually as the loop fluid contracts (Figure 3-4c), and the total primary fluid volume decreases. The operator uses the main Pr (pressurizer) heaters to slow the rate of primary pressure decrease at 320 minutes. Primary pressure is maintained roughly constant until 381 minutes (Figure 3-4a).

At 330 minutes, the operator actuates throttled HPI with the Pr level approaching 20' (Figure 3-4d), the HPI flowrate is subsequently throttled, at ~335 min. Total primary fluid mass begins to increase, primary pressure increases from ~1600 psia; Pr level begins to increase (Figure 3-4c); the RV level begins to increase from -1-1/2', the RV upper plenum void fraction begins to decrease from 95%. The introduction of cold HPI fluid abruptly decreases the CL exit fluid temperature to ~520F.

The operator initiates a series of stepwise reductions of secondary control pressure beginning at 338 minutes. Secondary pressure responds accordingly (Figure 3-4a), SG steam and feed flow increase briefly with each pressure reduction, and the primary loop fluid temperatures begin to track the decreasing secondary saturation pressure (Figure 3-4b).

3.3.4. Depressurization Phase, 381 to 540 Minutes

The operator has cooled the primary at roughly constant pressure for approximately 1 hour, from test initiation at 312 minutes until 381 minutes. Primary conditions (based on total pressure and hot leg fluid temperature) have been altered from 20F subcooled to 80F subcooled at 1750 psia (Figure 3-5). The operator now initiates primary depressurization to conform to the specified p-T envelope.

It should be noted that the indicated primary fluid subcooling (based on total primary pressure and HL or core outlet fluid temperature) is greater than the actual subcooling. The individual total primary pressure consists of the partial pressure of water vapor and the partial pressure of nitrogen. At least during the initial venting phase, and perhaps sporadically throughout the cooldown, the correspondence between the trends of apparent saturation temperature and core outlet fluid temperature indicate that the core outlet fluid was saturated, cf. Figure 3-5.

At 381 minutes a small amount of HPI is briefly diverted to provide pressurizer spray. Primary pressure begins to decrease, Pr level increases, and the RV voided volume expands (the RV liquid level decreases 1' from the RVVV elevation, Figure 3-4c). Primary flow rate decreases toward 3% of full flow and then increases, apparently in response to the momentary diversion of loop fluid to the pressurizer. This depressurization moves loop conditions from 80F subcooled at 1750 psia to ~60F subcooled at 1525 psia (Figure 3-5). Primary pressure is stabilized at 1525 psia at 388 minutes using the Pr main heaters (Figure 3-4a). The primary is held at this pressure until the continuing cooldown increases the subcooling margin to roughly 70F.

This combination of depressurization followed by cooldown at constant pressure is used repeatedly to traverse the p-T envelope (Figure 3-5). Pressurizer spray is used to depressurize, the Pr main heaters are used to maintain pressure only for the first few cooldown periods. As the sequence progresses, visual indications of gas evolution are more commonly encountered; bubbles are seen at the HL viewport (35'); brief and partial-voiding is sometimes seen at the HLUB viewport. These sightings occur shortly after a primary depressurization. The metered gas discharge rate from the HPV also increases as the depressurization -- cooldown sequence progresses. This collection rate increases to ~15 scf/hour at 475 minutes (~163 minutes after test initiation) (Figure 3-3a); at this time the primary pressure is ~600 psia and the rate of primary cooldown approaches 100F/hr.

The sequence of depressurizations and cooldowns progresses smoothly. At 442 minutes the operator transfers secondary depressurization to the automatic controller, set to obtain a 100F/hour secondary cooldown. At 455 minutes, during the depressurization from 1000 to 840 psia, the downcomer level decreases 1/2' from full and continues to evidence slight voiding for the next 3 hours (Figure 3-6c). The DC level did not decrease enough to afford a measurement of its temperature, but based on the highly subcooled temperature measured downstream of the RVVV (Figure 3-6d), the DC void is apparently nitrogen gas.

3.3.5. Stabilization Phase (Beyond 540 Minutes)

The SG secondary approaches its minimum pressure (approximately 30 psia) at 540 minutes, 228 minutes after test initiation (Figure 3-1a). The primary cooldown rate begins to diminish correspondingly (Figure 3-1b). The DC level indicates full, and the RV level slowly increases toward the elevation of the RVVV (Figure 3-1c). At 590 minutes, the RV conductivity probe above the HL nozzle rewets.

Primary pressure and temperature are maintained within or just below the specified band as the cooldown diminishes (Figure 3-5). The cooldown is completed at 600 minutes, 388 minutes after test initiation. Pressure and HL fluid temperature are 180 psia and 380F. The average cooldown rate was roughly 1F per minute (Figure 3-1b).

At 690 minutes the HPI flow rate is increased to raise the Pr level. The test is completed at 700 minutes. The final burden of noncondensibles is less than 5 scf (Figures 3-3a and b), roughly 30 scf have been discharged from the loop and recovered.

3.4. Conclusion

OTIS Test 240100 exercises the HLHPV with a burden of NCG in the primary system. Plant procedures modified to apply to OTIS are used. The OTIS HLHPV size is intermediate to the ideal scaled area to simulate the SMUD and FPC HL HIgh Point Vents.

The test is initialized in the manner specified. After 6 hours of injections, ~6 scf of nitrogen are added to the HL U Bend, bringing the total gas burden to ~30 scf. HLUB voiding and primary flow interruption are verified and the test is initiated. The operator employs the adapted plant procedures to restore natural circulation and to cooldown the primary. The specified p-T envelope is approximately adhered to while maintaining an average cooldown rate of 60F/hour. Measurements are sufficient to explore major loop interactions, gas closure is obtained to within approximately 10% of the injected volume. This test meets its objective.

Table 3-1. Initial Conditions

The adjustments of the specified intial conditions are addressed in section 3.2.2 and are appropriate to the test.

	Specified	Actual
SG Secondary Pressure (psia)	1300	1200
SG Secondary Liquid Level (ft)	5	5
High-Elevation AFW Injection	yes	yes
Primary System Pressure (psia)	1700 to 2000	1700
Core Power (% of full power, 1% = 21.4 kW)	1-1/2	2
Pressurizer liquid level (ft)	5	13
RVVV in automatic control, setpoints 0.25/0.125 psi	yes	yes
	(note the pressure difference)	

Nitrogen injected to displace the RV Upper Head Liquid, to apparently saturate the loop liquid with NCG at 2000 psia, and finally to void the HLUB.

Table 3-2. Operator Comments

TIME	COMMENT
14:51	START DATA SAVE FOR RUN 240100
15:05	CLOSED RVVV MANUAL FROM AUTO CLOSED
15:16:45	FIRST GAS ADDITION MADE 1.98 SCF ADDED AT RV
15:24:55	SECOND GAS ADDITION MADE 2.23 SCF ADDED AT RV
15:35:20	THIRD GAS ADDITION MADE 2.01 SCF ADDED AT RV WITH STALLED FLOW (CLOSED CLCV01)
15:37	OPENED CLCV01, FLOW STARTED
15:46	CLCV01 CLOSED TO STALL FLOW
15:47:20	FOURTH GAS ADDITION MADE 2.27 SCF ADDED AT RV
15:49	OPENING CLCV01 FLOW STARTED
16:01	CLOSED CLCV01 TO STALL FLOW
16:01:55	FIFTH GAS ADDITION MADE 2.02 SCF ADDED AT RV
16:03	OPENING CLCV01 TO START FLOW
16:13	CLOSING CLCV01 TO STALL FLOW
16:13:46	SIXTH GAS ADDITION MADE 2.04 SCF ADDED AT RV
16:14	OPENING CLCV01 TO START FLOW
16:24	CLOSING CLCV01 TO STALL FLOW
16:24:46	SEVENTH GAS ADDITION MADE 2.01 SCF ADDED AT RV
16:26	OPENED CLCV01 TO START FLOW
16:37	CLOSING CLCV01 TO STALL FLOW
16:38:20	EIGHTH GAS ADDITION MADE 2.07 SCF ADDED AT RV
16:39	OPENING CLCV01 TO START FLOW
16:59	CLOSING CLCV01 TO STALL FLOW
17:00:25	NINTH GAS ADDITION MADE 2.30 SCF ADDED AT RV
17:02	OPENING CLCV01 TO START FLOW
17:14:30	CLOSING CLCV01 TO STALL FLOW
17:14:50	TENTH GAS ADDITION MADE 2.28 SCF ADDED AT RV
17:16	CLCV01 OPENED TO START FLOW
17:23	CLCV01 OPENED ALL THE WAY (100 %)
17:31:05	ELEVENTH GAS ADDITION MADE 2.17 SCF ADDED AT RV
17:54:42	TWELEVTH GAS ADDITION MADE 1.09 SCF ADDED AT RV
18:25	CLCV01 CLOSED, ADDITION 13 OF 1.08 SCF AT RV
18:27	OPENING CLCV01 TO REGAIN FLOW
18:42:40	FOURTEENTH GAS ADDITION MADE 1.02 SCF ADDED AT RV
19:06:25	FIFTEENTH GAS ADDITION MADE 1.08 SCF ADDED AT RV
19:23:46	SIXTEENTH GAS ADDITION MADE 1.41 SCF ADDED AT RV
19:46	STARTING TO INCREASE CORE POWER TO 42.6 KW
19:50	RVVV TO AUTO, VALVE CLOSED
19:54	CONTINUE TO INCREASE CORE POWER
19:58	DCDP01 OUT OF SERVICE
20:05	ADDED ABOUT 10 SCF HLUB , OPENED CLCV01 , VERIFIED STALLED FLOW
	HPV OPEN
	AFW ON
20:07	SFCV03 TO AUTO AS SG LEVEL REACHES 10 FT
20:08	REDUCING STM PRESSURE TO 1050 PSIA
20:11	PRESSURIZER MAIN HTRS ON
20:18	SWITCHED FROM NORTH TANK TO SOUTH ACCUMULATING TANK MANUALLY THROTTLED HPI INJECTION

Table 3-2. Operator Comments (Cont'd)

20:22	RVVV CYCLED (CLOSED AT THIS TIME)
20:23	CLDP02 AND DCDP01 OUT OF SERVICE
20:30	LOWERED SEC STEAM PRESSURE 20 PSI
20:32	DCDP01 AND CLDP02 BACK IN SERVICE
20:33	DCDP01 OUT OF SERVICE
	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:34	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:39	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:40	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:43	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:48	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:51	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:56	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
20:58	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:03	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:20	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:22	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:25	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:27	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:28	PRESSURIZER SPRAY ON
21:34	PRESSURIZER SPRAY OFF
	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:37	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:38	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:42	DCDP01 BACK IN SERVICE
21:43	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:44	DCDP01 OUT OF SERVICE
21:47	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:48	PRESSURIZER SPRAY ON
21:51	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:54	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:55	SPRAY OFF
21:57	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
21:59	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
22:00	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
22:02	PRESSURIZER SPRAY ON
22:04	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
22:07	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
22:08	SPRAY OFF
22:09	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
22:10	LOWERED SEC STEAM PRESSURE ABOUT 20 PSI
22:13	LOWERING SEC STEAM PRESSURE VIA RAMP CONTROL ABOUT 100 DEG/HR COOL DOWN
22:22	PRESSURIZER SPRAY
22:29	PRESSURIZER SPRAY OFF
22:30	SWITCH FROM SOUTH TO NORTH ACCUMULATING TANKS

Table 3-2. Operator Comments (Cont'd)

22:31	PRESSURIZER SPRAY IS ON
22:36	SPRAY OFF
22:37	PRESSURIZER MAIN HTRS OFF
22:40	PRESSURIZER SPRAY ON
22:43	THROTTLING BACK ON HPI
22:45	SPRAY OFF
22:46	SWITCHING TO NORTH TANK
22:50	OPENED HIGH STEAM HAND VALVE
	SET PSDP03/04 AND PSOR03/04 TO READ
22:53	PRESSURIZER SPRAY IS ON
23:01	PRESSURIZER SPRAY OFF
23:09	PRESSURIZER SPRAY ON
23:13	PRESSURIZER SPRAY OFF
23:16	OPENED SOUTH TANK
	PRESSURIZER SPRAY ON
23:20	DRAINING NORTH TANK IN
23:25	CLOSED NORTH TANK DRAW VALVE
23:26	PRESSURIZER SPRAY ON
23:34	PRESSURIZER SPRAY OFF
23:42	PRESSURIZER SPRAY ON
23:54	PRESSURIZER SPRAY OFF
00:00	NORTH TANK FILL OPEN
00:01	SOUTH TANK FILL CLOSED
00:08	DRAINING SOUTH TANK
01:45	CONTINUING TO THROTTLE HPI AT A VERY LOW FLOW RATE WHICH DOES NOT INDICATE ON OTIS DISPLAY
02:21	INCREASED HPI TO RAISE PRESSURIZER LEVEL
02:45	HPV CLOSED
	STOPPED HPI
	RV CORE TEMP APPEARS TO HAVE BEEN STALLED AT 300 DEG STOP DATA SAVE

HPV LEAK WT = 297 LBM ELLIOT TANK USAGE = 57 GAL

Table 3-3. Unavailable Measurements

SUMMARY OF VARIABLES DISCARDED ON INPUT, TEST240100

NO.	VTAB	SYSTEM	INST.	ELEVATION	DESCRIPTION
1	155HLTC06	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	53SSTC13	22SGS	2FTC	32.30	SG SECOND.FLUID TEMP (F)
20	79SMTC02	22SGS	25MTC	26.30	SG SECOND. METAL TC (F)
21	76SMTC06	22SGS	25MTC	44.20	SG SECOND. METAL TC (F)
22	289SSCP20	22SGS	32RCP	0.00	SG SECOND. UP.WET.CP (REF. FT)
23	344V1TC03	34CLD	2FTC	-999.00	CLD LEAK FLUID TEMP (F)

Table 3-4. Gas Additions

Addition number	Clock time	DAS time (min)	Gas Volume (scf) Added	Gas Volume (scf) Cumulative
				0
1	1517	26	1.82	1.82
2	1525	34	2.03	3.85
3	1535	44	1.80	5.65
4	1547	56	1.95	7.60
5	1602	71	1.83	9.43
6	1614	83	1.79	11.2
7	1625	94	1.72	12.9
8	1638	107	1.76	14.7
9	1700	129	1.68	16.4
10	1715	144	1.70	18.1
11	1731	160	1.63	19.7
12	1755	184	0.83	20.5
13	1825	214	0.74	21.3
14	1843	232	0.89	22.2
15	1906	255	0.84	23.0
16	1924	273	0.31	23.3
17	<2005	<314	6.44	29.8

Figure 3-1a. Primary and Secondary Pressures

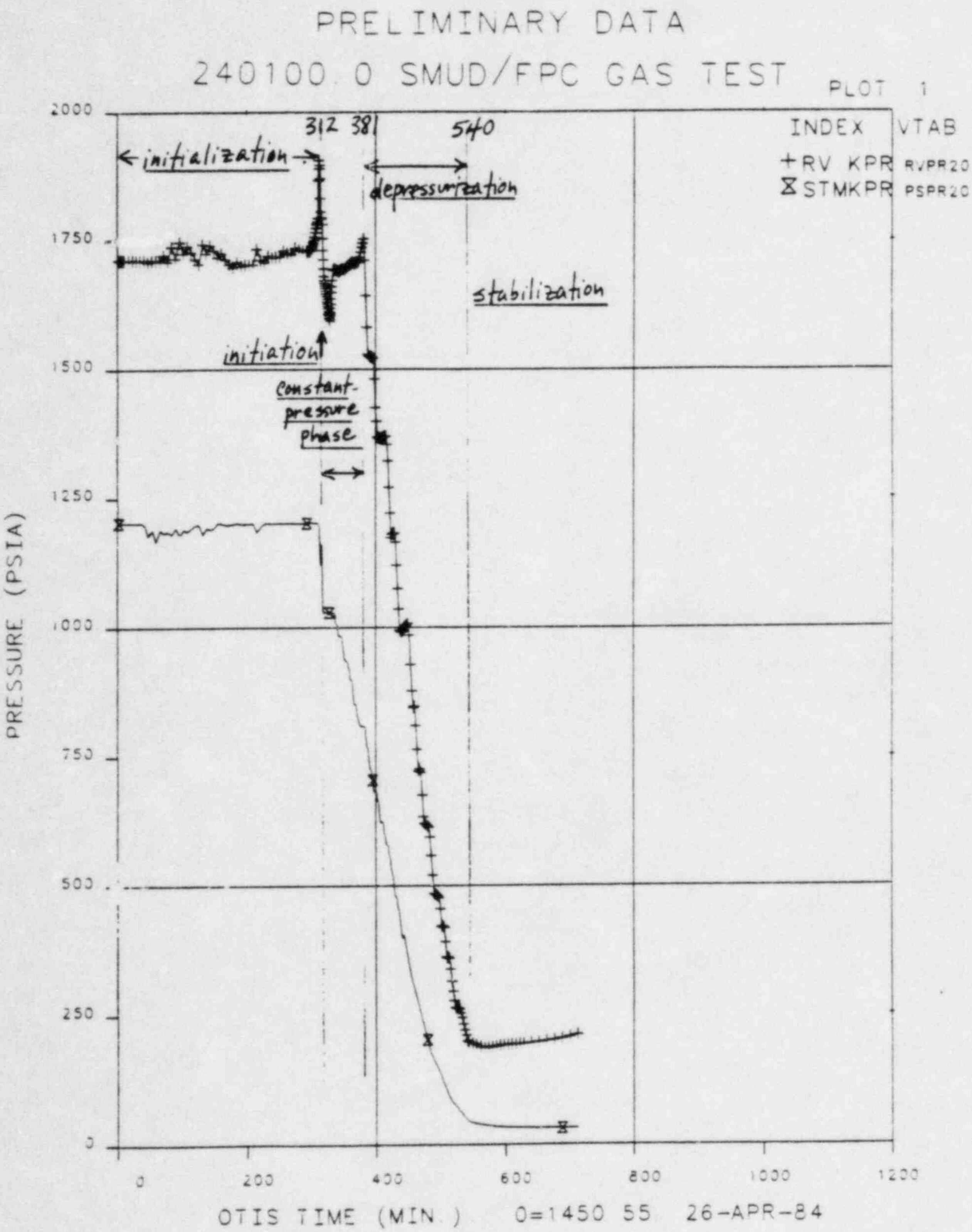


Figure 3-1b. Average Fluid Temperatures

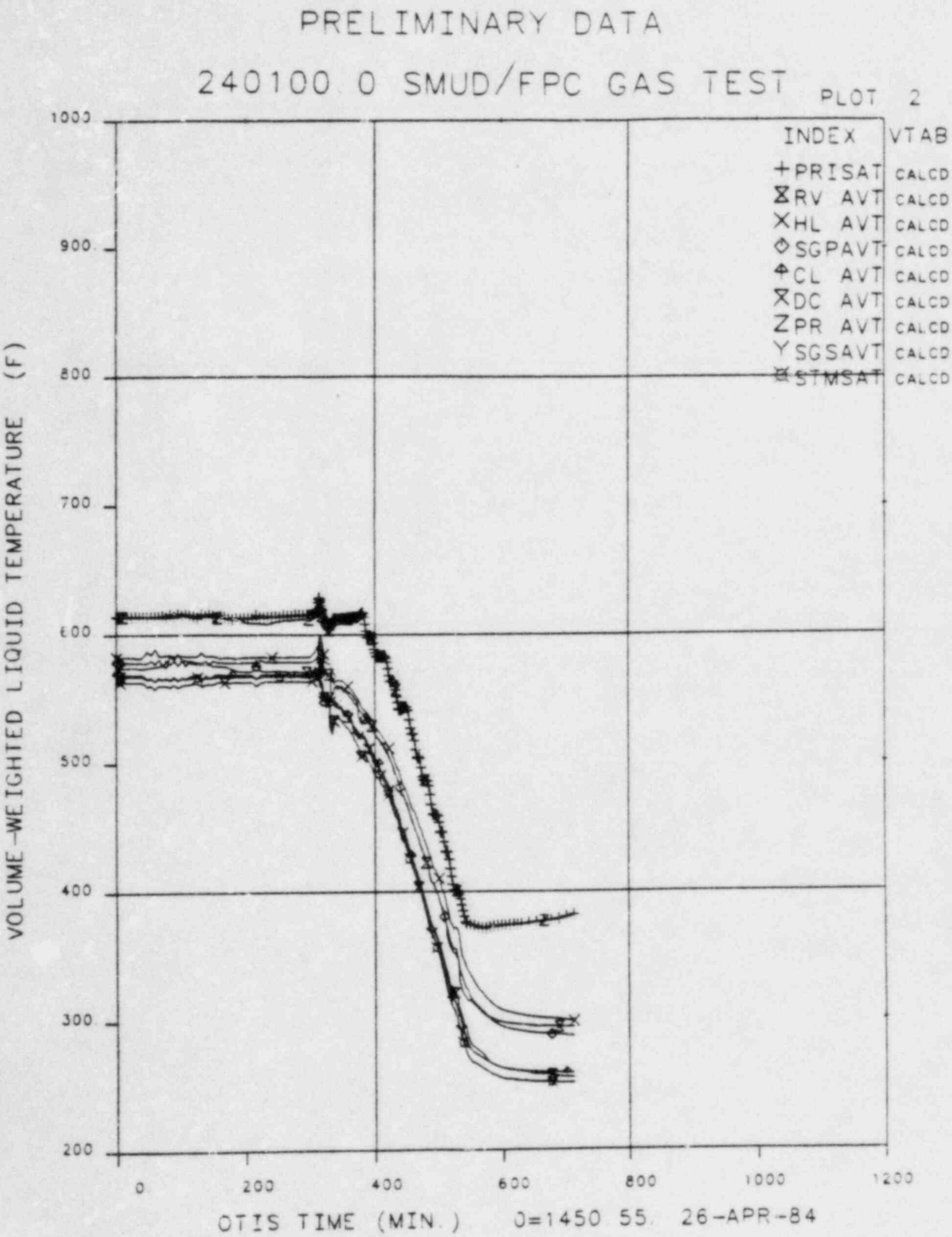


Figure 3-1c. Collapsed Liquid Levels

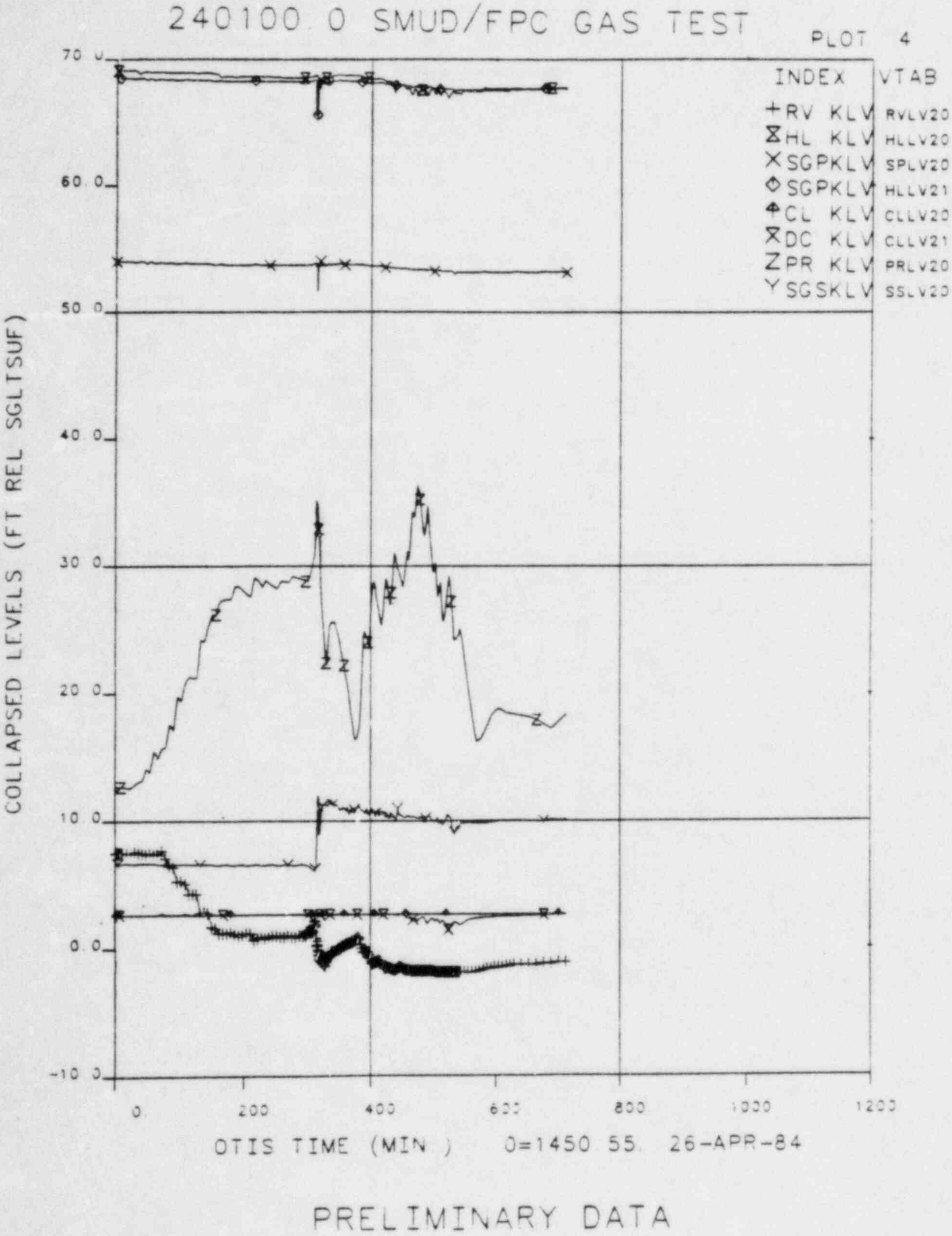
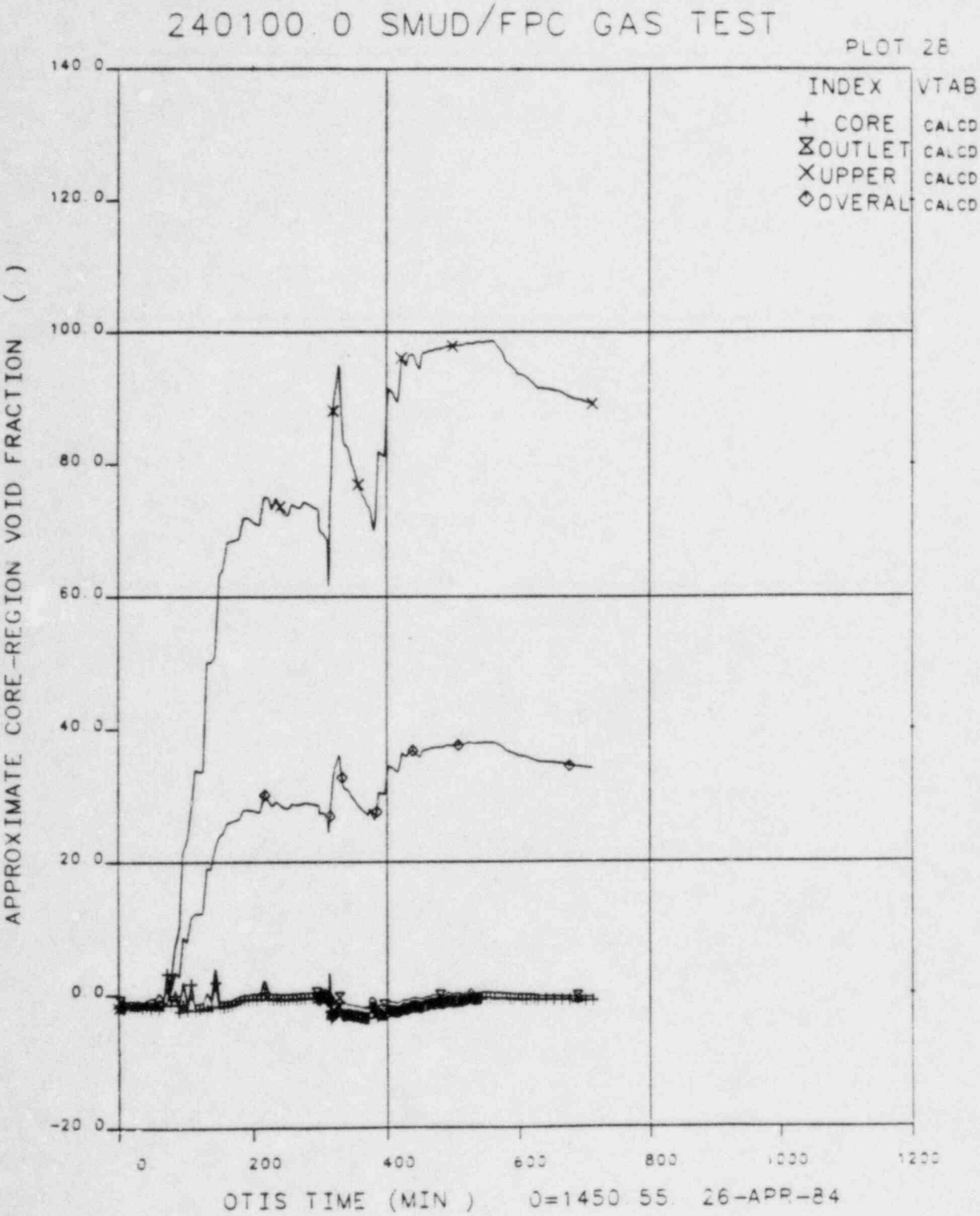
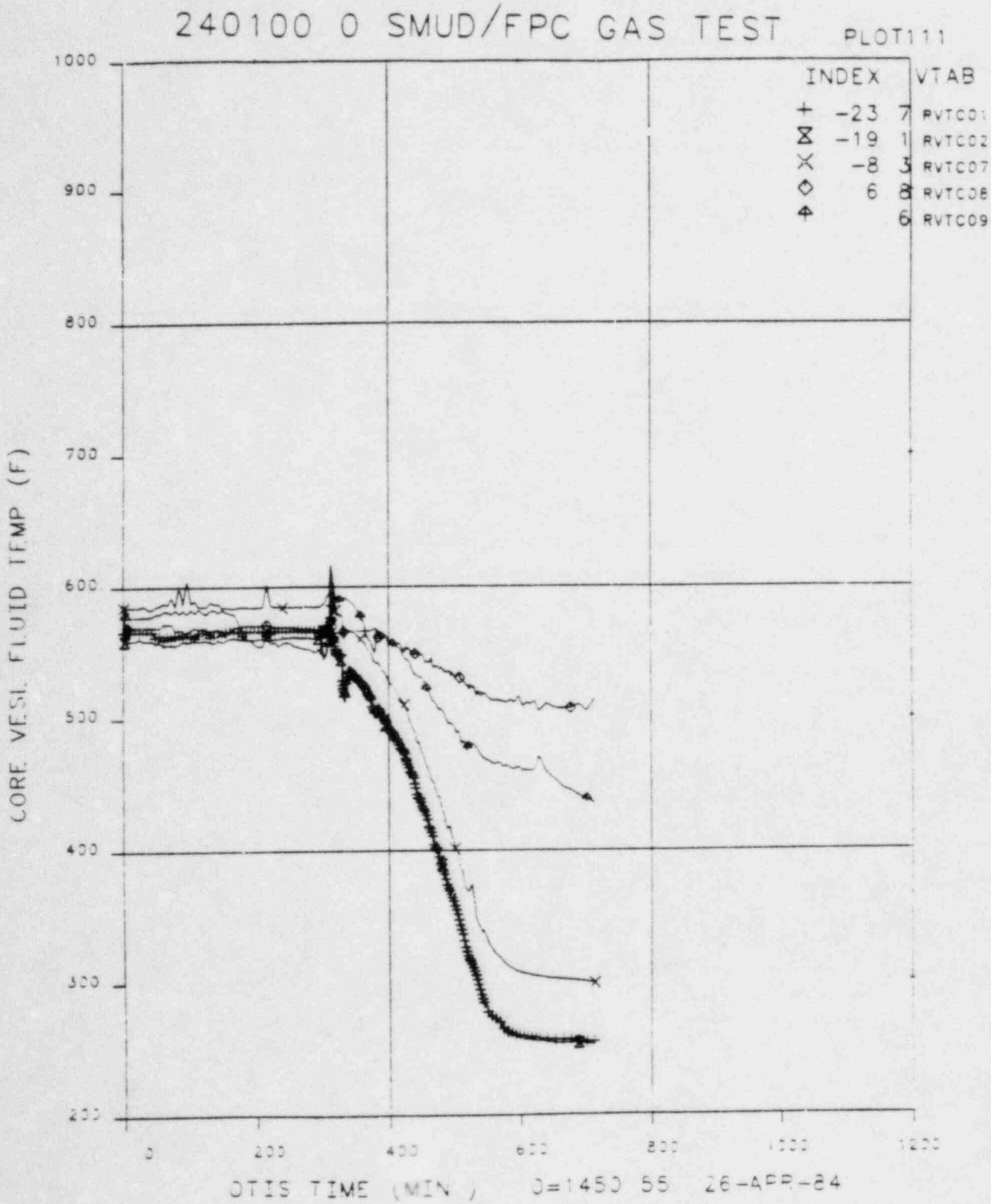


Figure 3-1d. Approximate Reactor Vessel Void Fractions



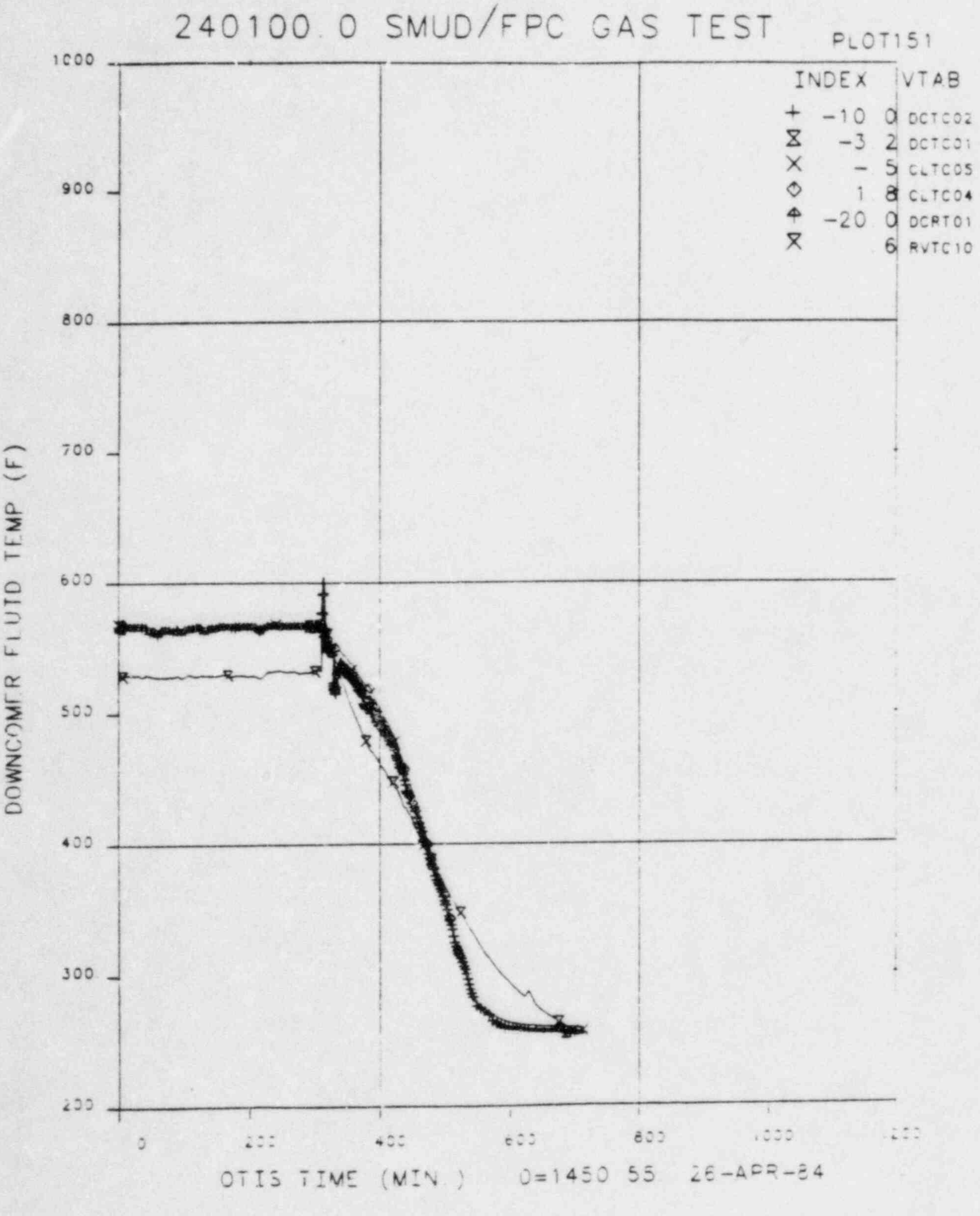
PRELIMINARY DATA

Figure 3-1e. Reactor Vessel Fluid Temperatures



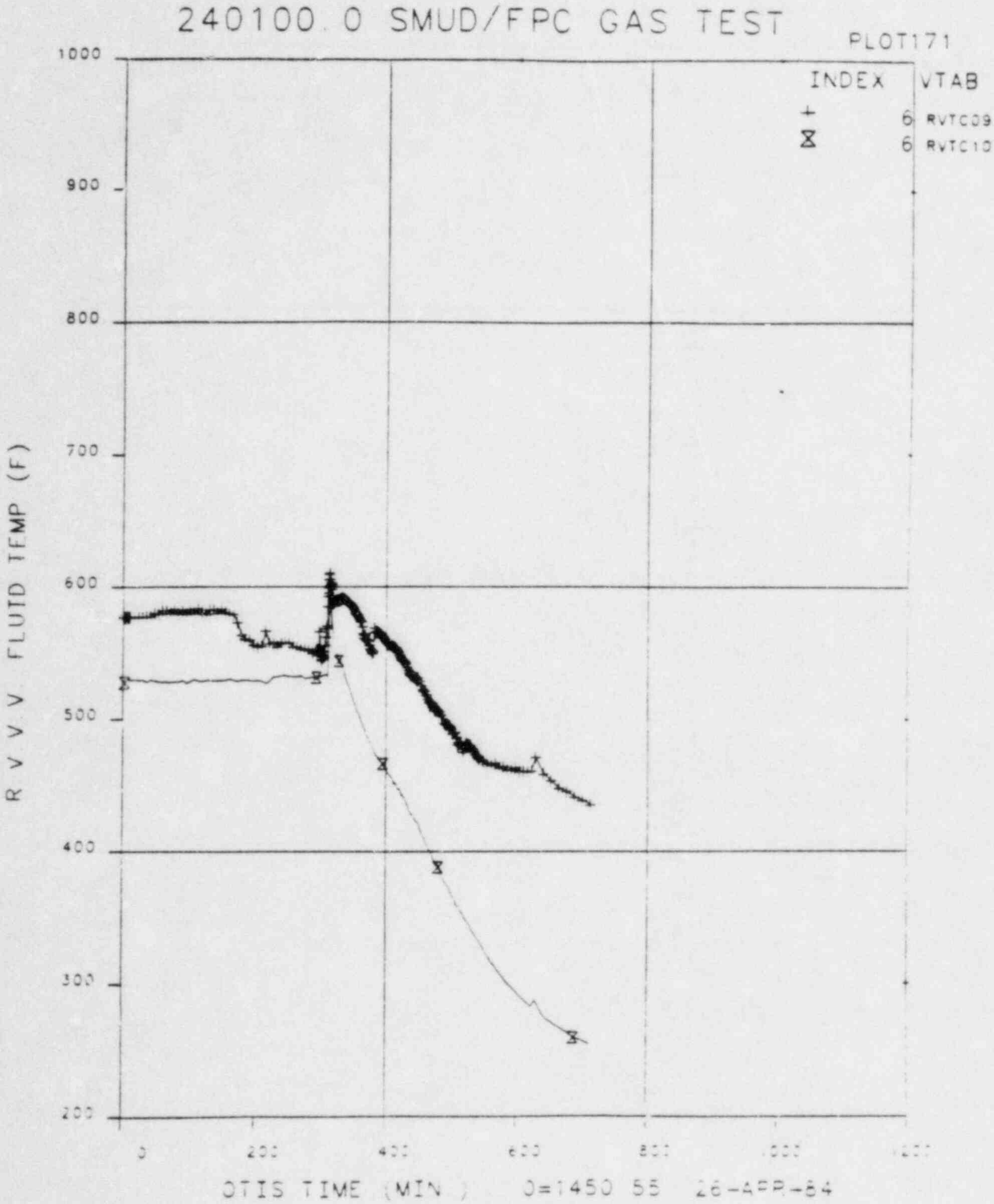
PRELIMINARY DATA

Figure 3-1f. Downcomer Fluid Temperatures



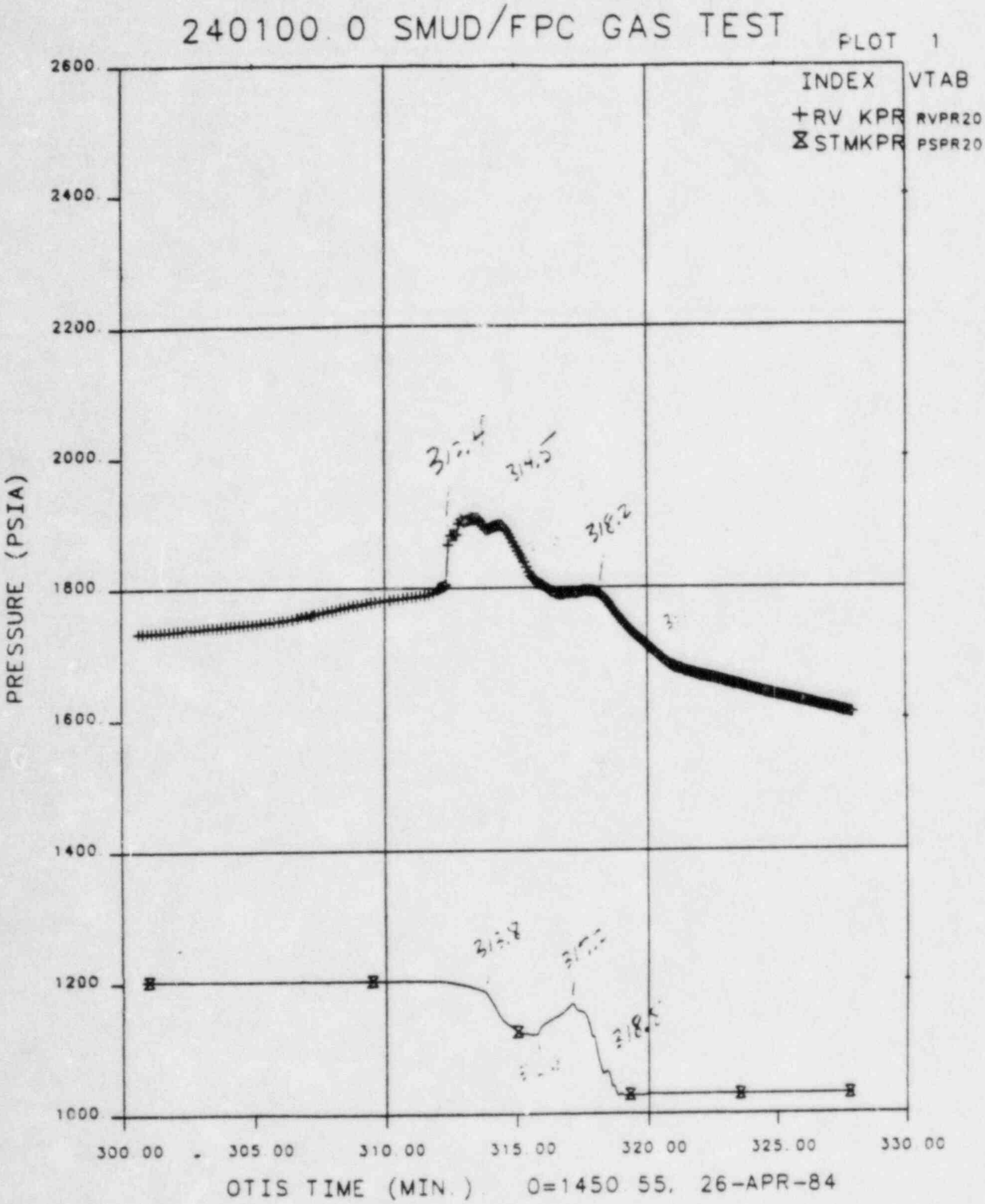
PRELIMINARY DATA

Figure 3-1g. RVVV Fluid Temperatures



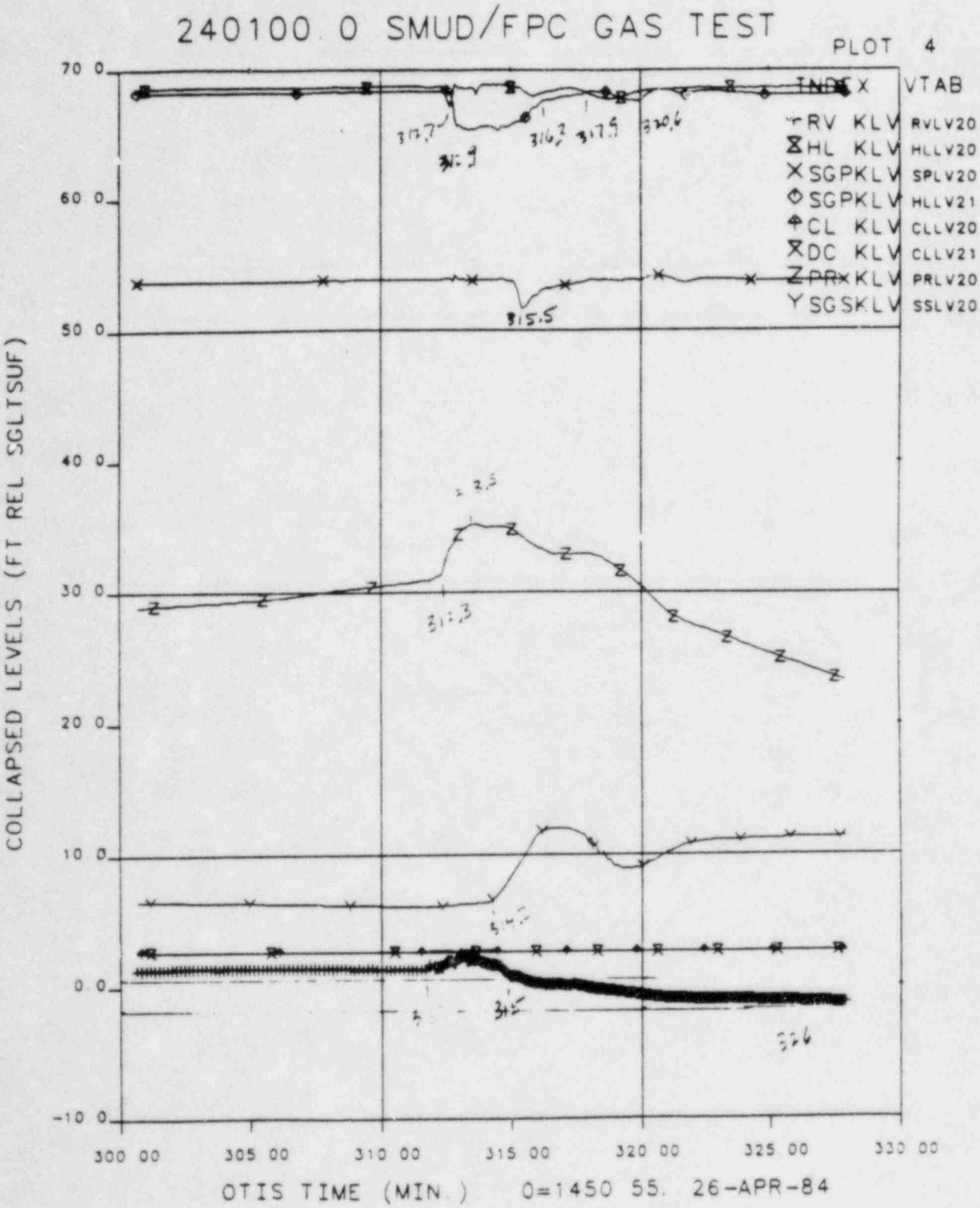
PRELIMINARY DATA

Figure 3-2a. Primary and Secondary Pressures



PRELIMINARY DATA

Figure 3-2b. Collapsed Liquid Tends



PRELIMINARY DATA

Figure 3-2c. Primary Flowrates

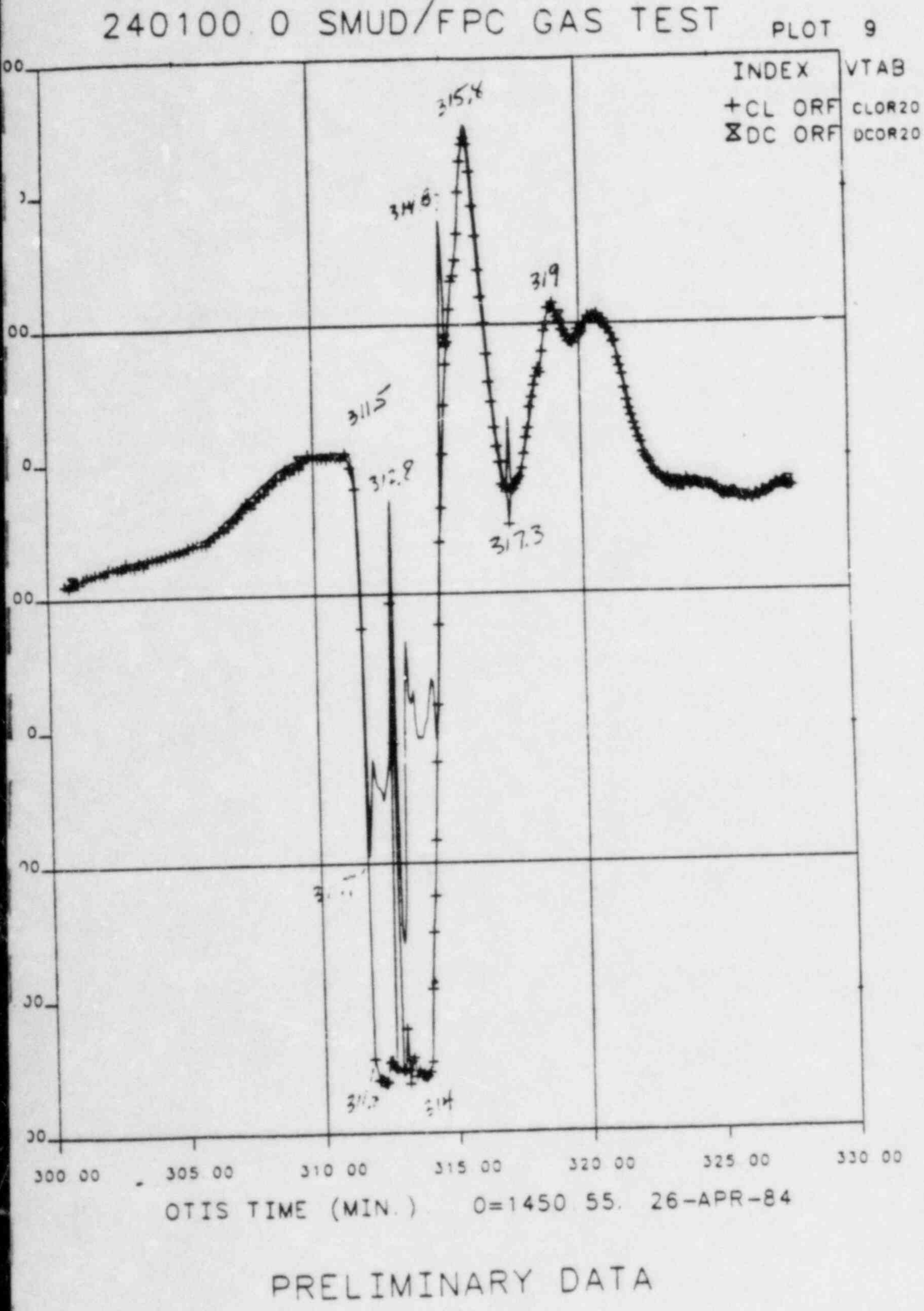
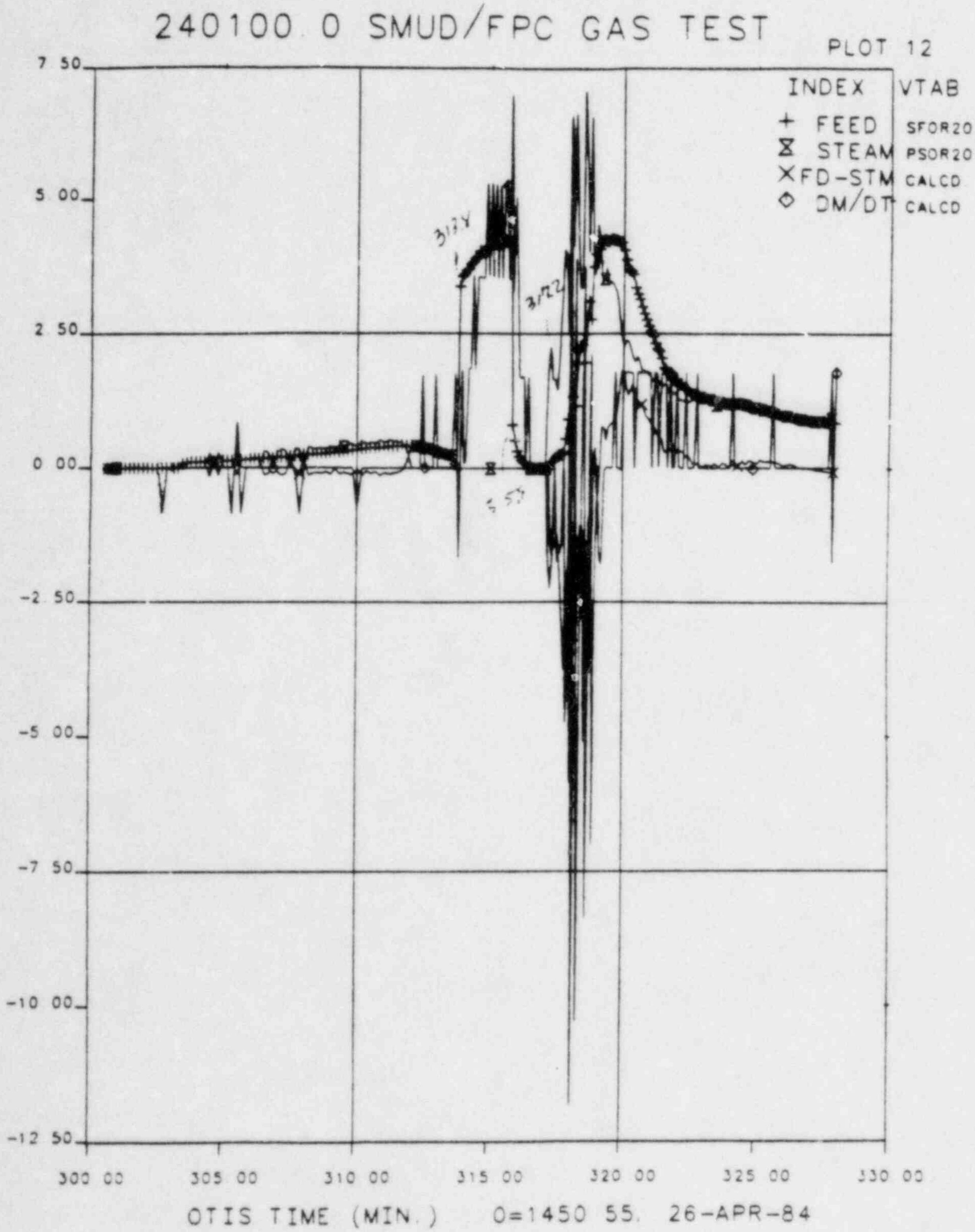
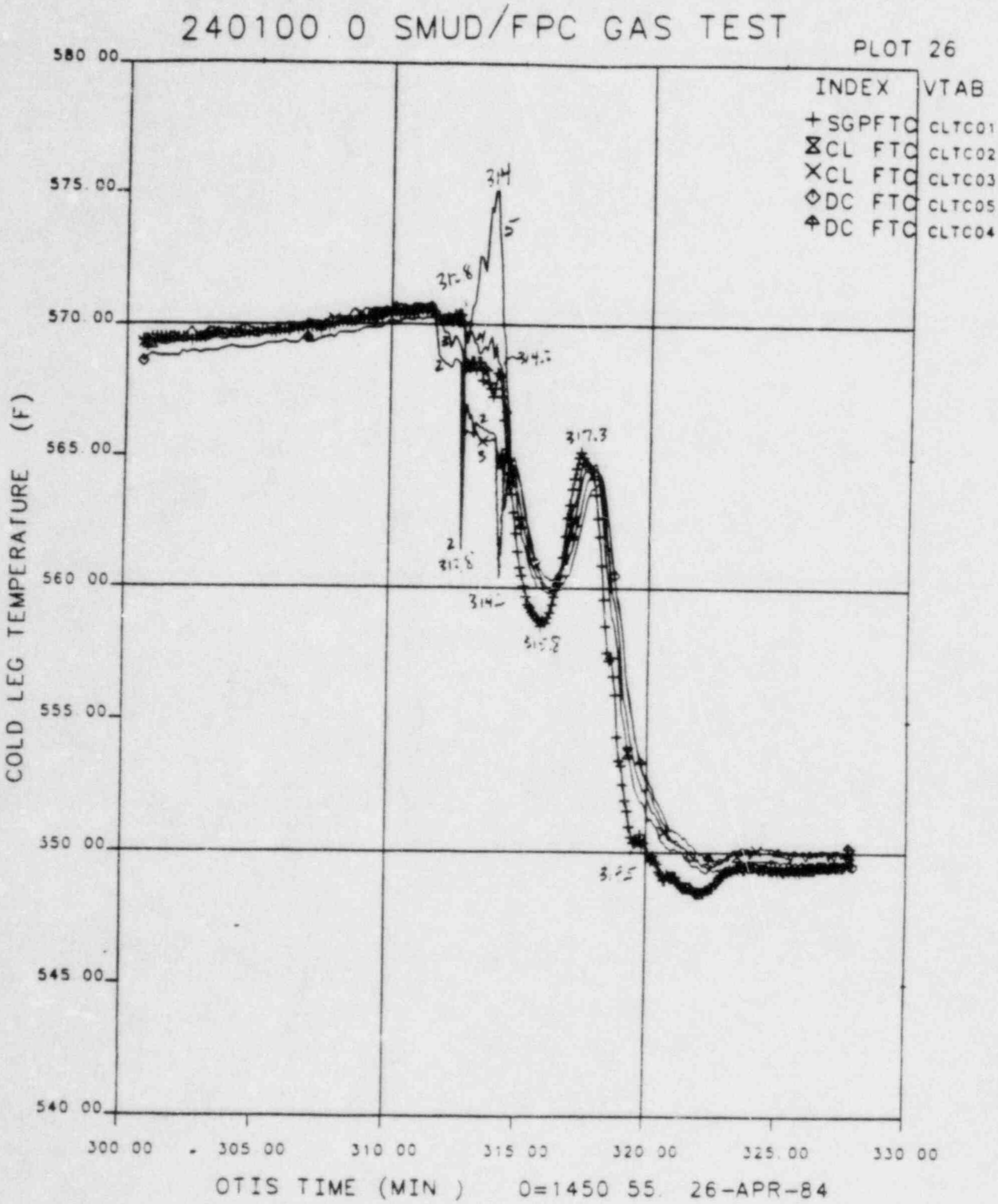


Figure 3-2d. Secondary Flowrates



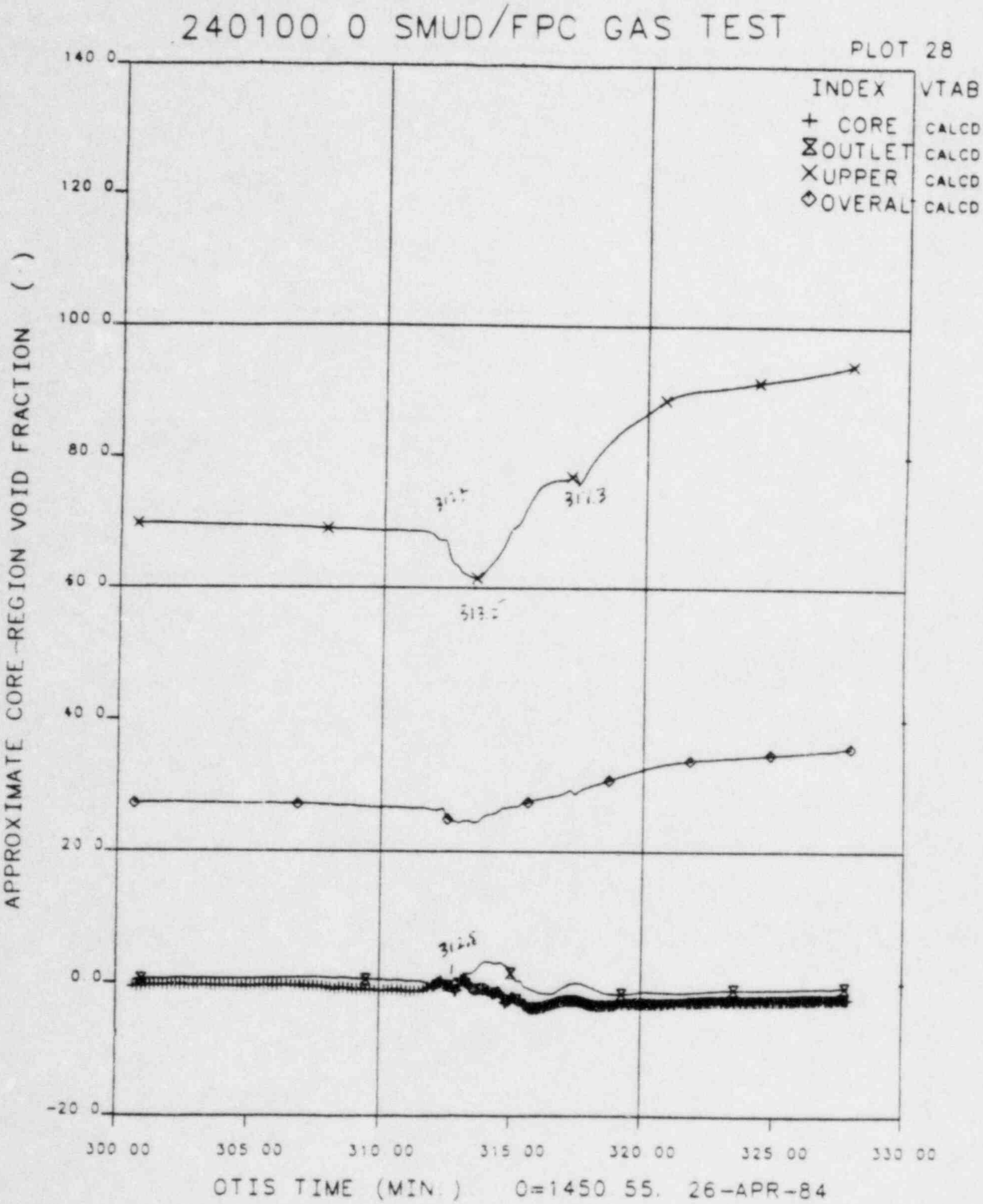
PRELIMINARY DATA

Figure 3-2e. Cold Leg Fluid Temperatures



PRELIMINARY DATA

Figure 3-2f. Approximate RV Void Fractions



PRELIMINARY DATA

Figure 3-2g. RV Fluid Temperatures

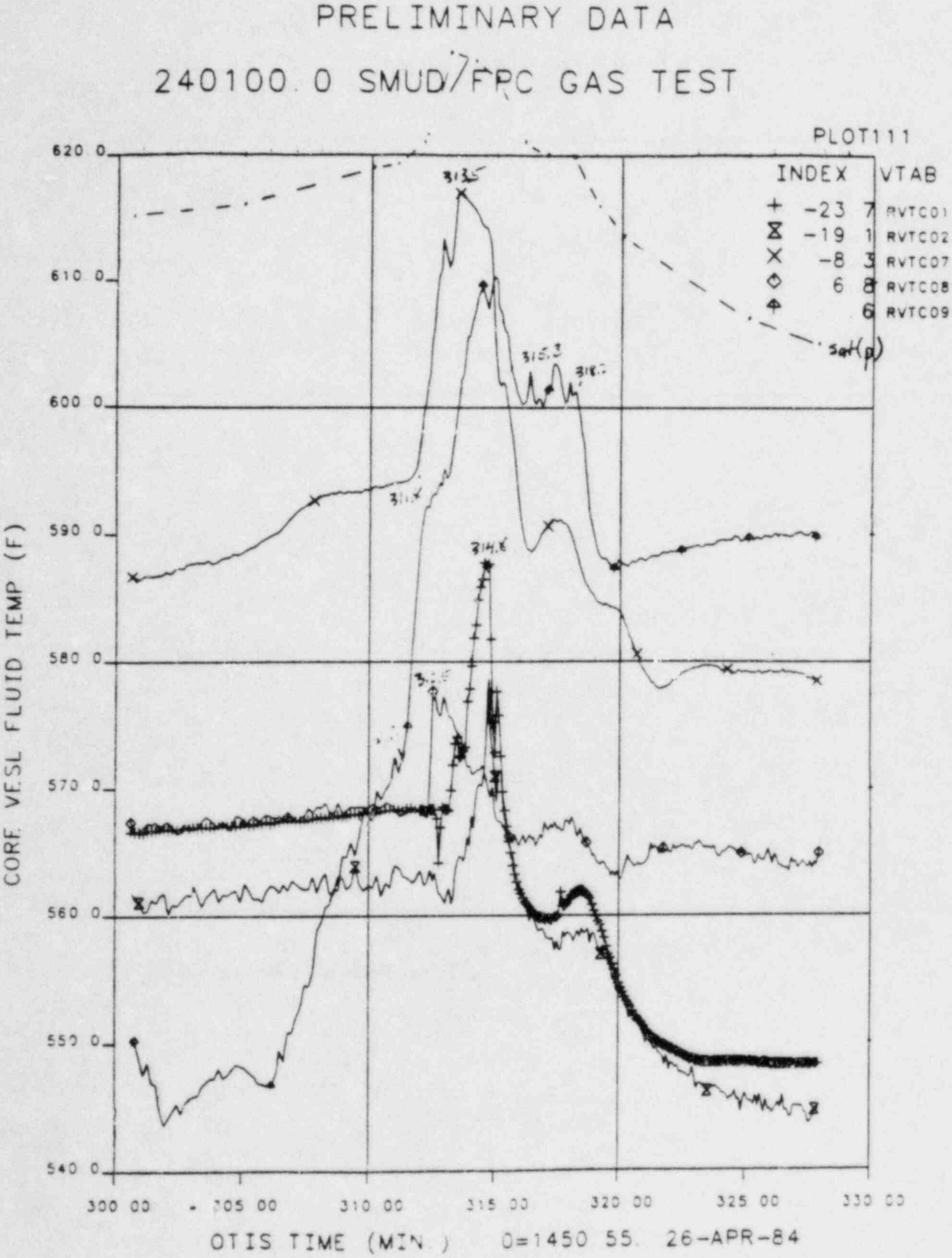


Figure 3-2h. Hot Leg Fluid Temperatures

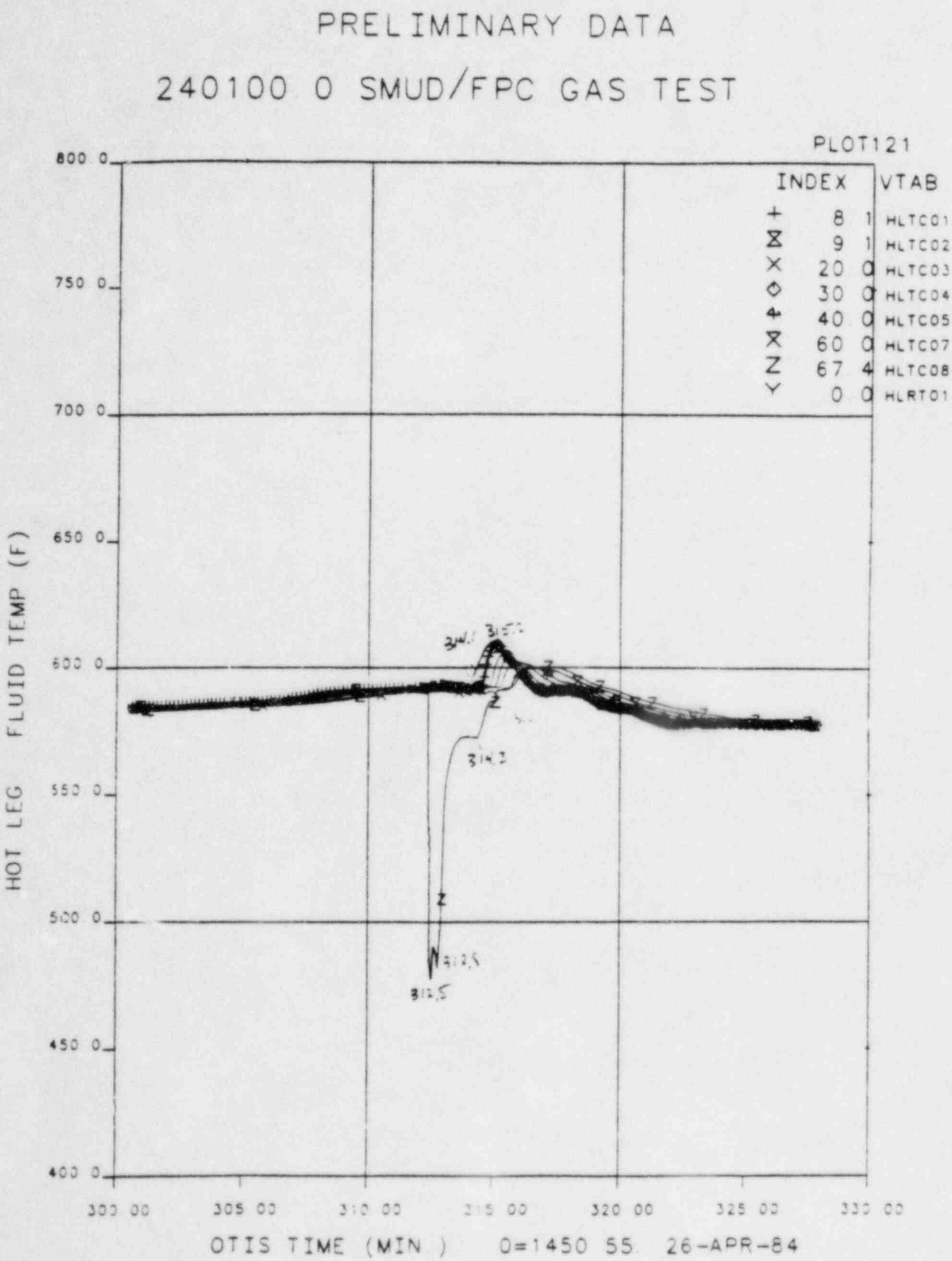


Figure 3-2i. Downcomer Fluid Temperatures

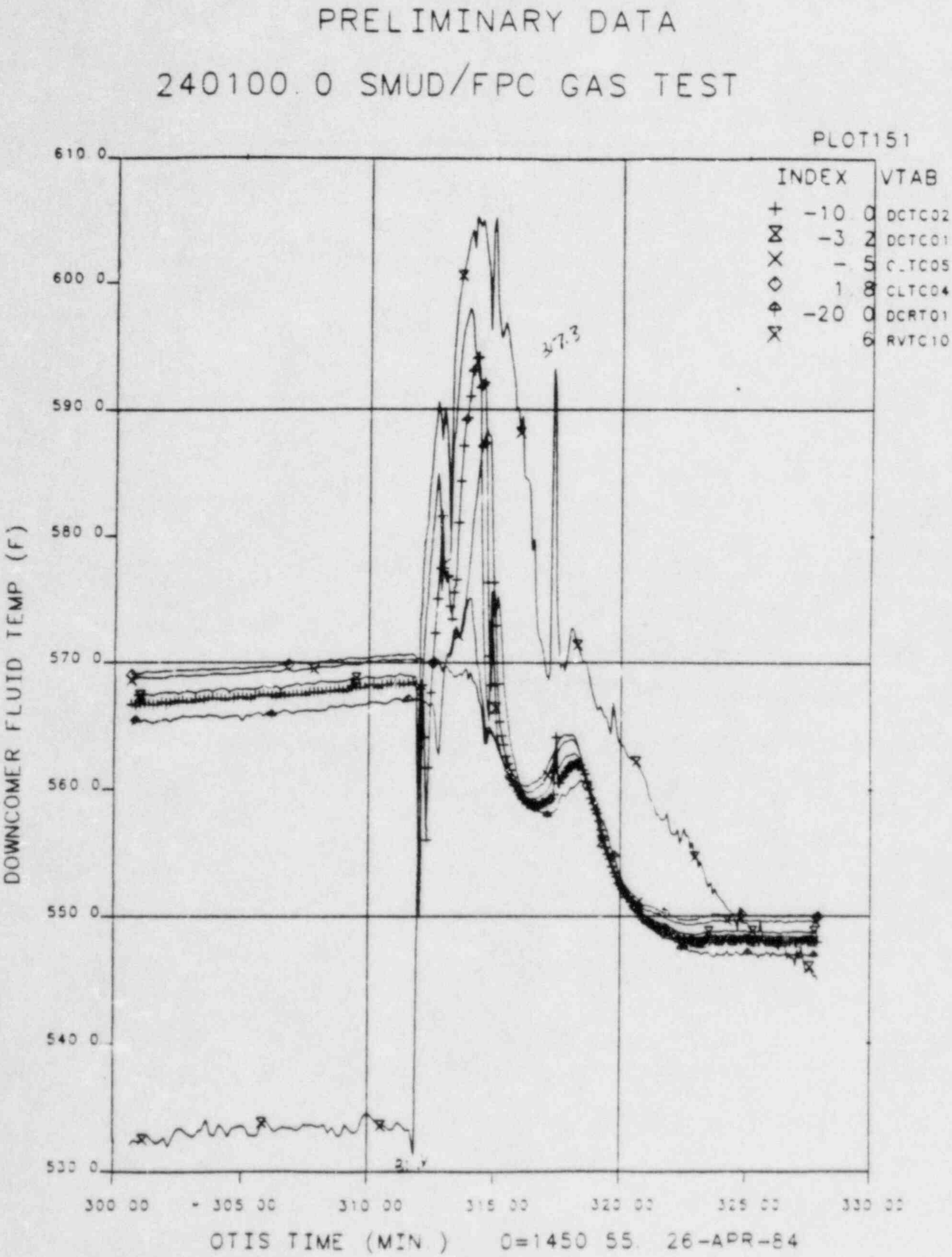
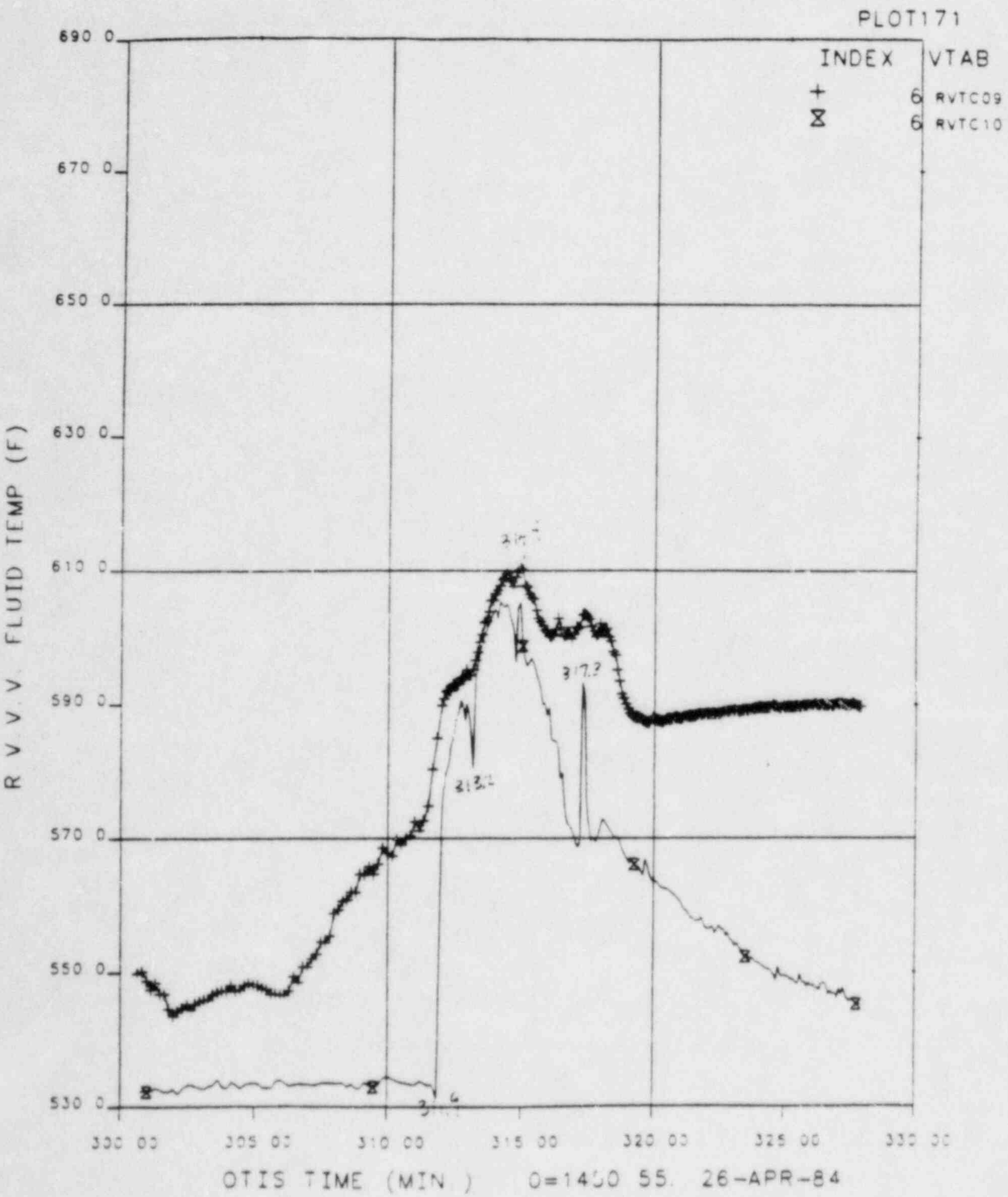
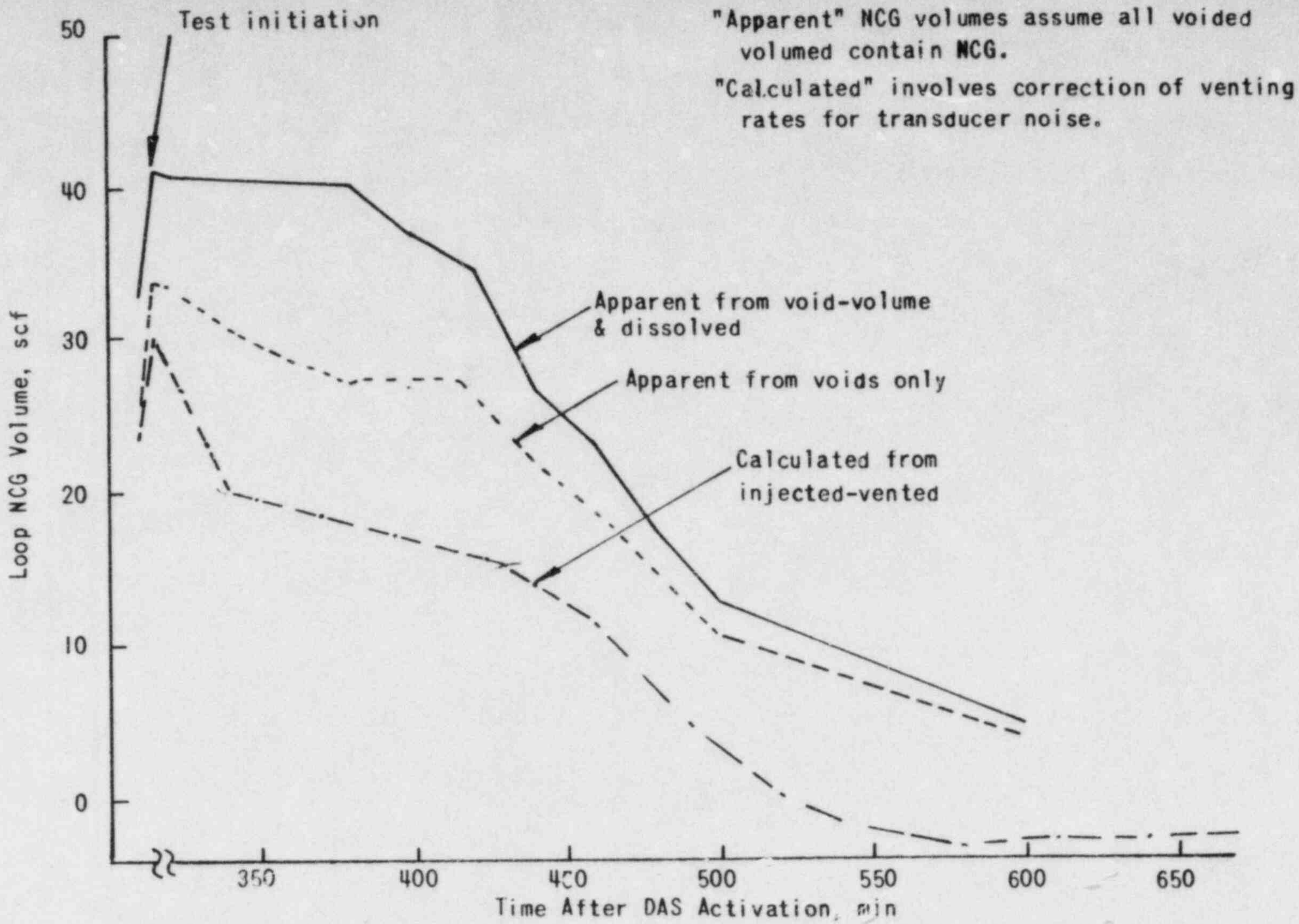


Figure 3.2j. RVVV Fluid Temperatures

PRELIMINARY DATA

240100 0 SMUD/FPC GAS TEST





Time After DAS Activation, min

Fig 3-2a

3-43

Figure 3-4a. Primary and Secondary Pressures

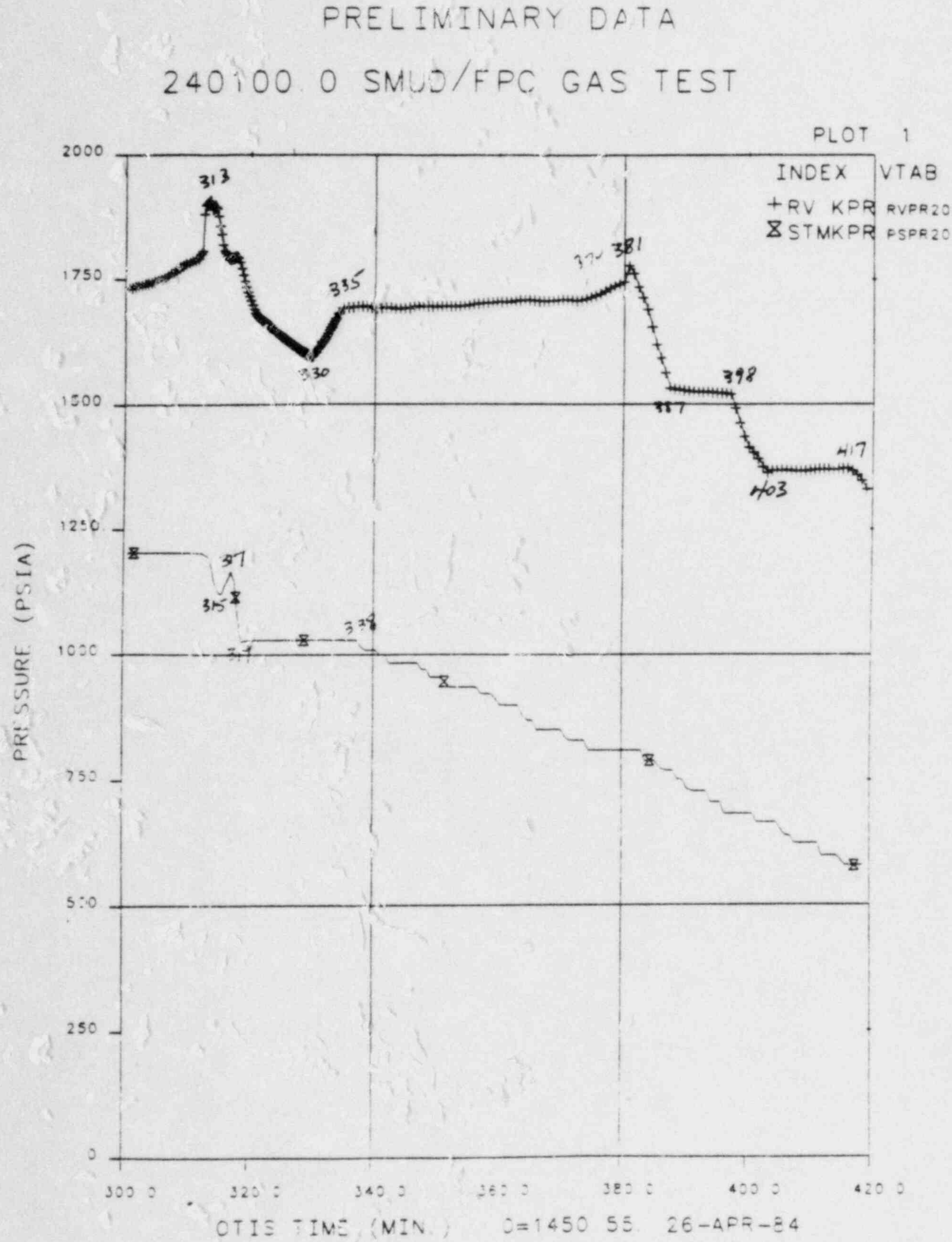


Figure 3-4b. Average Fluid Temperatures

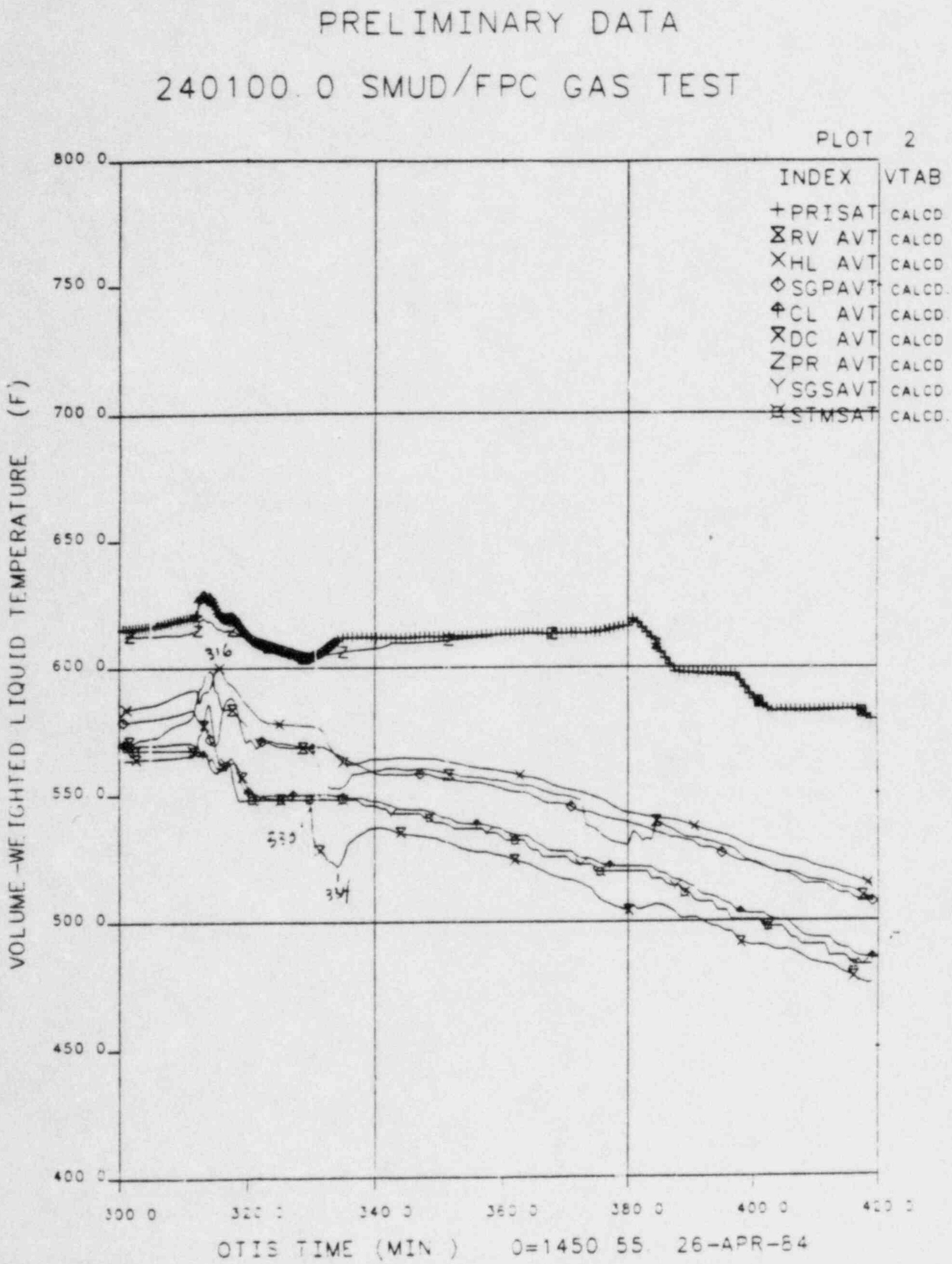


Figure 3-4c. Collapsed Liquid Tends

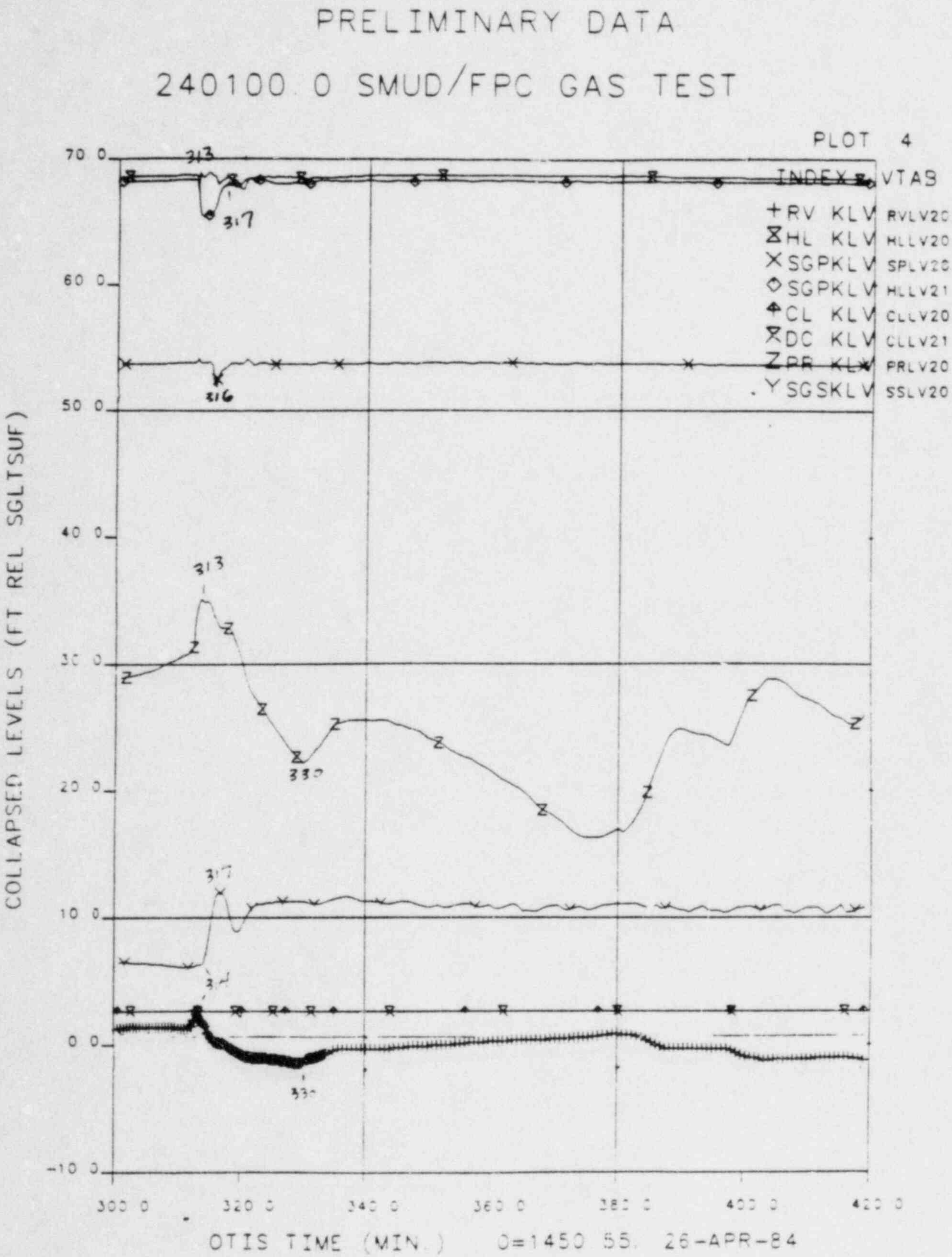


Figure 3-4d. Primary Boundary Flowrates

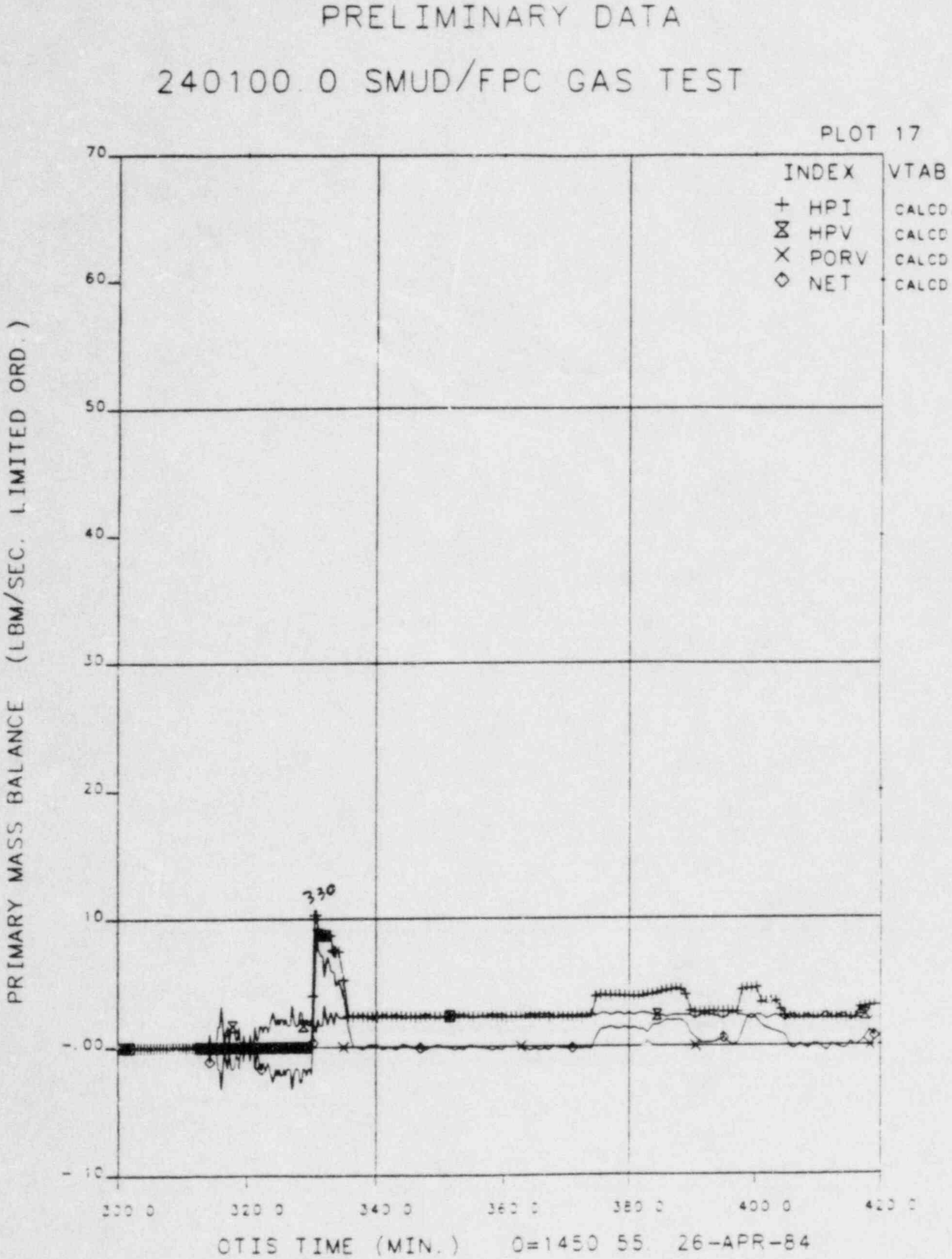


Figure 3-4e. RV Fluid Temperatures

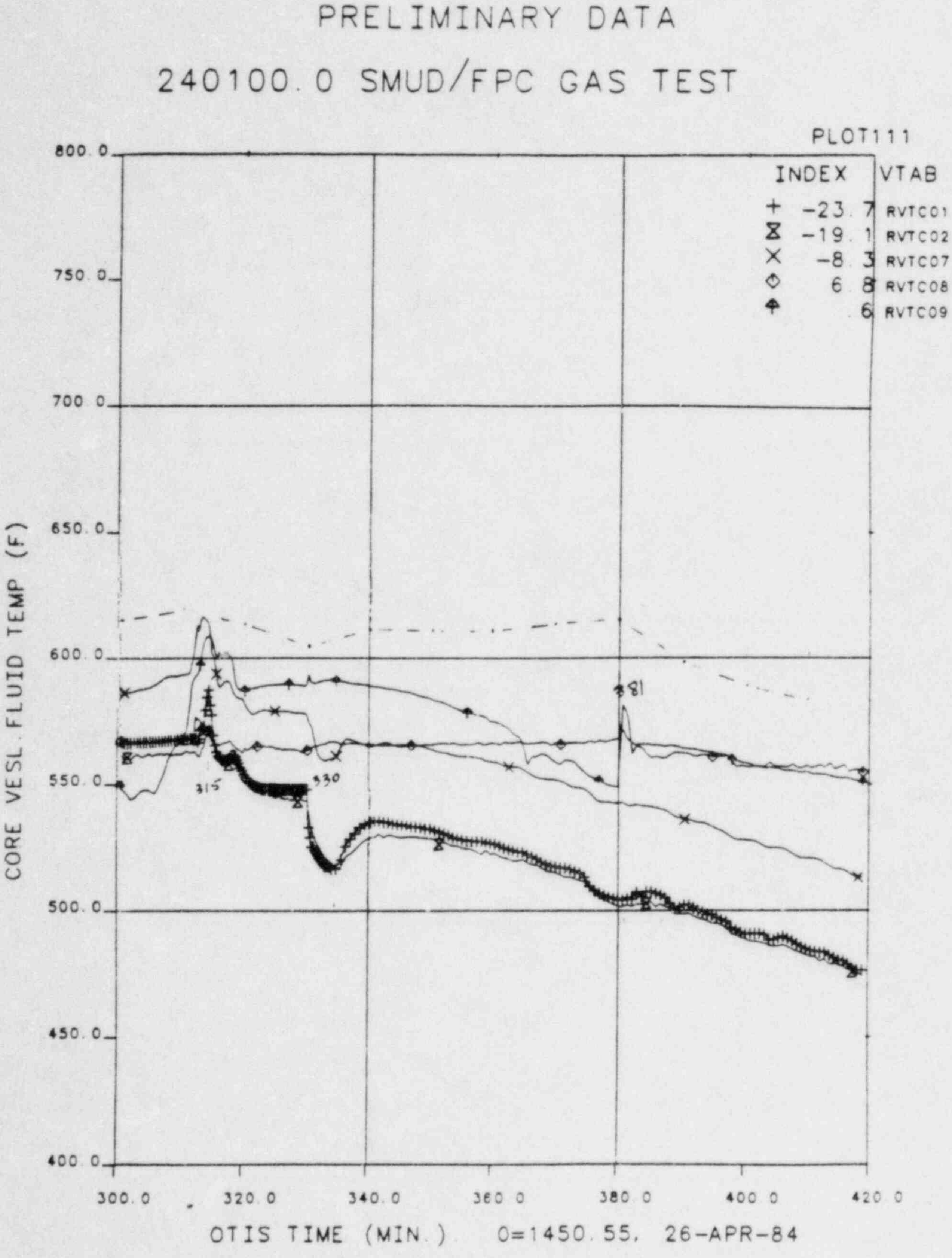


Figure 3-5. Primary Pressure - Temperature Trends

P-T envelope from SMUD procs (Encl. 8.1 of B.4-21)
Test 240100 conditions from Pzr pressure (PRPR20)
and HL fluid temperature (HLTC07 at 60').
Circled numbers indicate times (min.) after test initiation (0=312 min after DAS activation at 1451, 26 April 1984.)

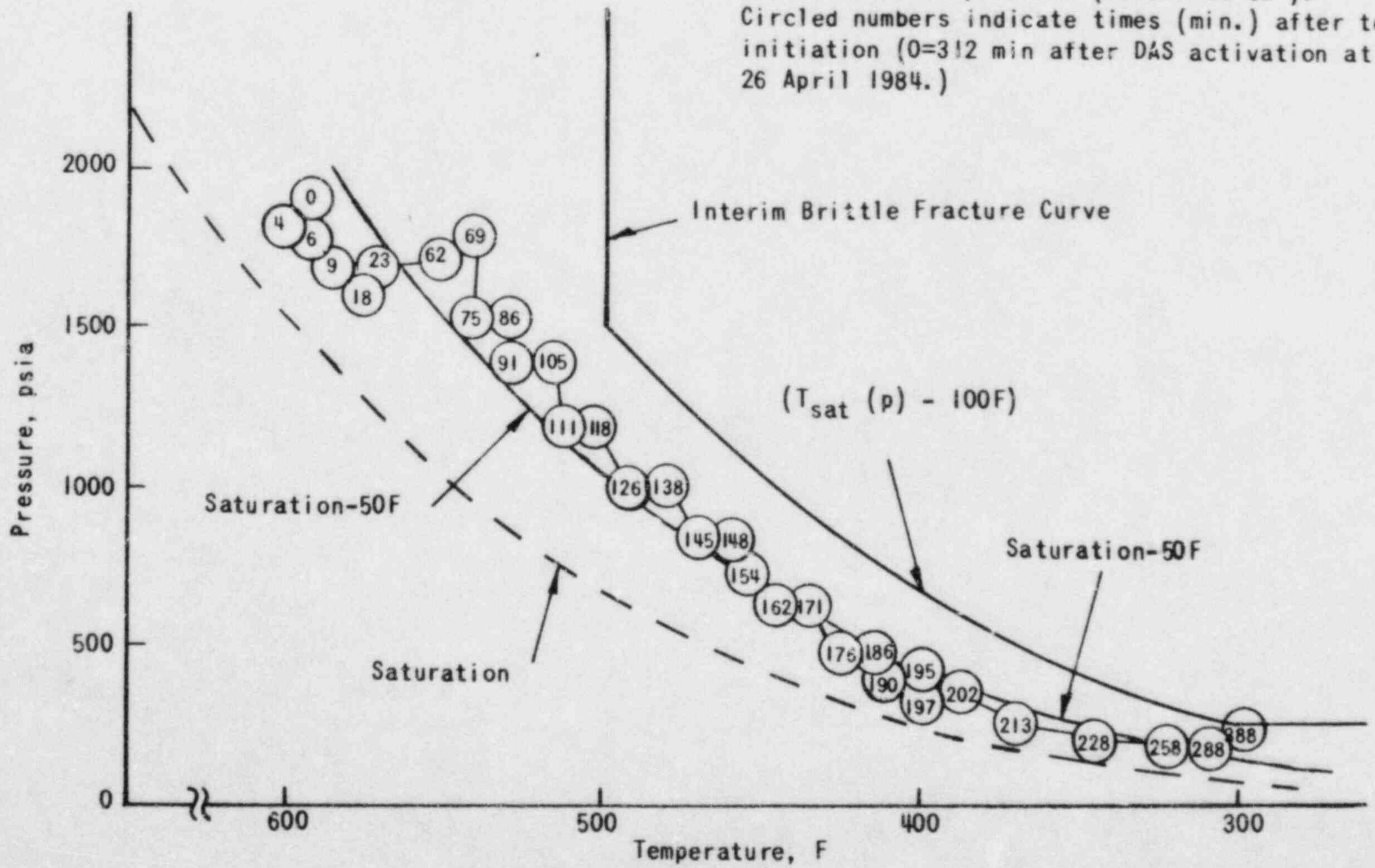


Figure 3-6a. Primary and Secondary Pressures

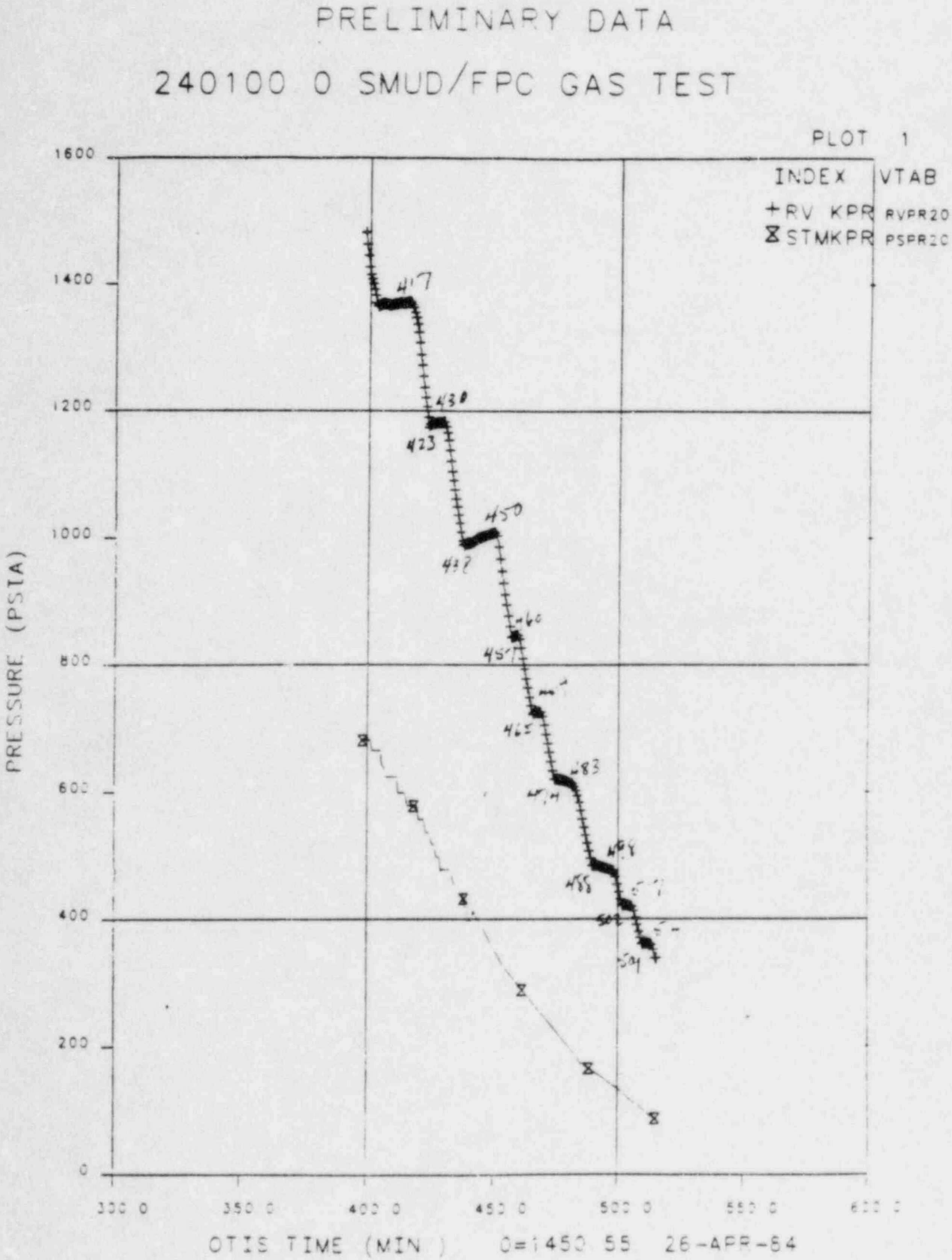


Figure 3-6b. Average Fluid Temperatures

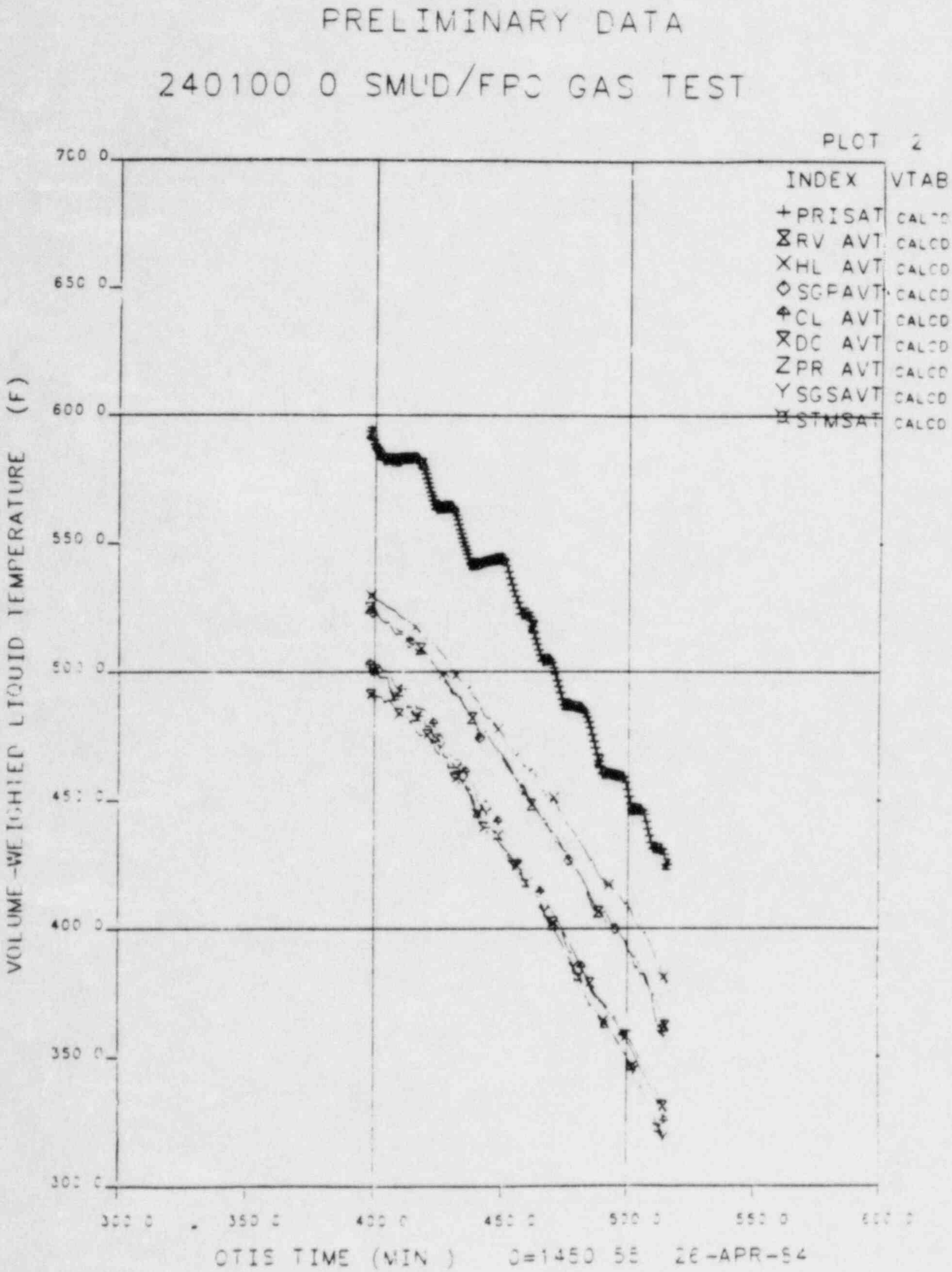


Figure 3-6c. Collapsed Liquid Tends

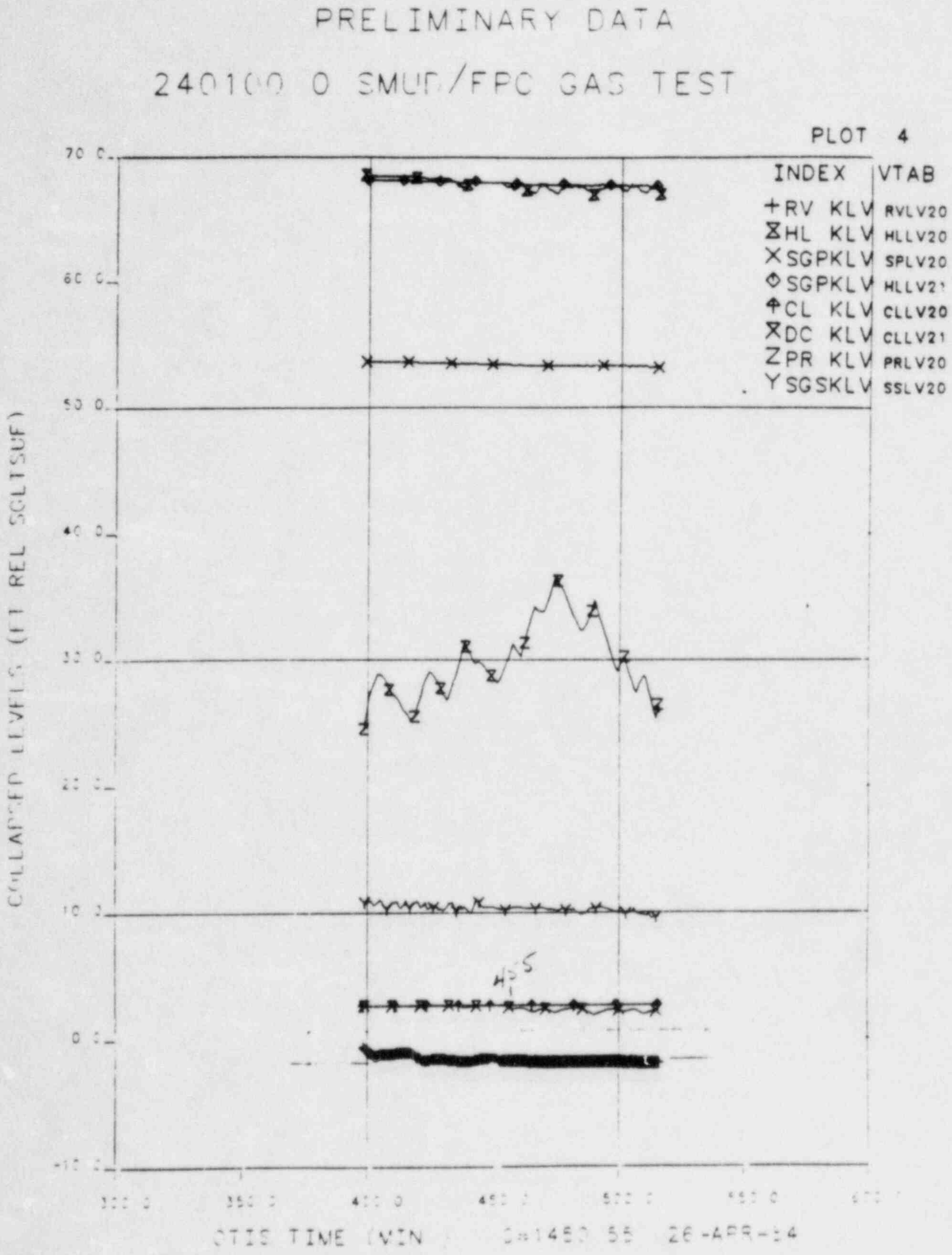
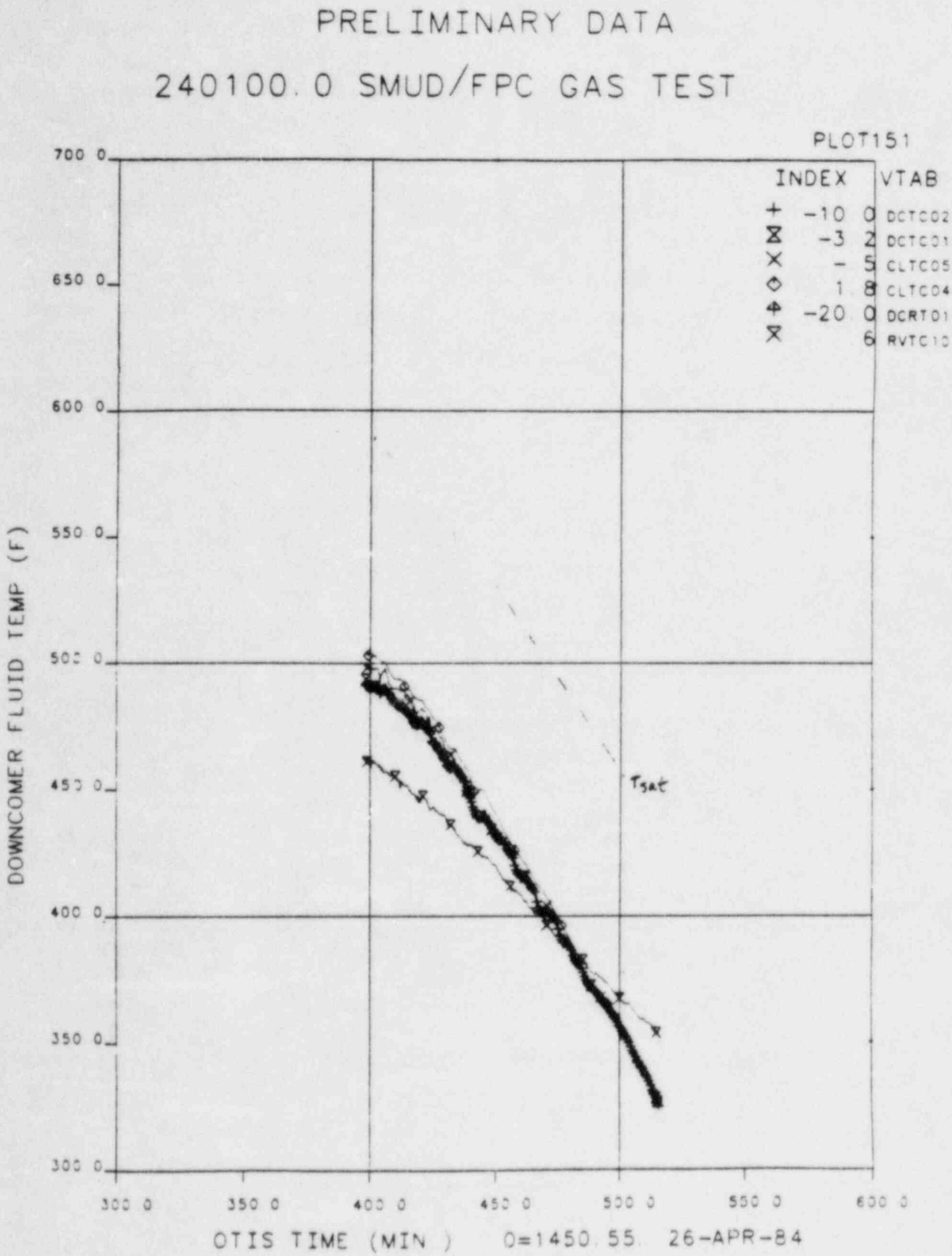


Figure 3-6d. Downcomer Fluid Temperatures



4. SUMMARY

Test initialization, measurements, and conduct were appropriate to the test objectives. The results of this test indicate that HL high point venting is effective in removing NCG; it thus permits a controlled natural circulation cooldown while maintaining primary fluid conditions approximately within the specified pressure-temperature envelope. The gas in the HL U-Bend region was quickly removed by opening the vent. OTIS was then cooled at 60F/hr using (revised) plant procedures adapted to the model.

5. REFERENCES

1. "OTIS HLHPV Test," B&W Document No. 86-1149137-00.

2. "OTIS Non-Condensible Gas test," ARC Technical Procedure ARC-TP-626 Revision 1.

3. "OTIS Design Requirements," B&W Document No. 51-1149127-00.

4. "OTIS Test Specifications," B&W Document No. 86-1149120-03.

APPENDIX - DATA PLOTS

Page

1.0 INTRODUCTION. 1

2.0 DATA REDUCTION TECHNIQUES 3

3.0 PLOT DIRECTORY. 40

4.0 OTIS TEST FACILITY INSTRUMENTATION. 51

---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 flow rate, 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

= $(157.4 \times 10^6$ 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

= $(16.1 \times 10^6$ lbm/hr$)/(1685.6 \times 3600$ 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 lbm/ft^3)/(7.481 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. Lowest Steam Volume, No Liquid

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. Intermediate Steam-Region Volume

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. Highest Steam-Region Volume

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.

Summary

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, x 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

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)

$$M_v = V_v \, X \rho_v.$$

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

$$M_v = V_v \, X \rho_v$$

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

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

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

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

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:

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

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):

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

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

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

(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 ($\Delta m/\Delta t$):

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

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 ENERGY: Total Primary System Fluid Energy

2.7.2.1 Indicated

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 $(\rho C_p)_{metal} = 60\ (B/ft^3F)$. The total primary contribution due to low metal is then the sum over the primary components:

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

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:

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

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:

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

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

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

<u>RVHPV</u>: 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:

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

<u>PORV</u>: 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: $q_{pri-to-sec} + q_{SG\ metal} = q_{steam-feed} + q_{sec\ fluid\ storage} + q_{SG\ to\ ambient}$

where $q_{pri-to-sec}$ 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^{3}F 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.

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

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

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

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

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

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

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

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 <u>Summary Of Net Primary Fluid Energy Rate Of Change - $\dot{e}_{net}$</u>

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)

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

where

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

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

and

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

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 T_{sat} 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:

$$\dot{v}_{HPI} = \frac{\dot{m}_{leak}}{\rho_{leak}} + \frac{\dot{m}_{HPI} - \dot{m}_{leak}}{\bar{\rho}_1}$$

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 ($\bar{\rho}_1$).

<u>$\dot{v}_{leak}$</u>: 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 $\dot{v}_v$.

$\underline{\dot{v}_{core}}$: 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.

$\underline{\dot{v}_{HPI}}$: 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.

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

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:

$$0 \leq X \leq 1.$$

$\underline{\dot{v}_P}$: 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, $\dot{v}_{\Delta\rho}$.

$\underline{\dot{v}_{\Delta P}}$: 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

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

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

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

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

$\dot{v}_l$ 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

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

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

$\dot{v}_{\Delta\rho}$: 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:

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

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 ($BTU/hrft^2F$) 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.

2.9 Subroutine Natural

In this section the single-phase natural circulation ca ulations are described. The calculations are used to generate four different p 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

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

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

therefore

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

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 $\rho = \rho(T,P)$

2.9.2 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 flowrates 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.

3.0 PLOT DIRECTORY

The plots indexed herein are the primary method of presentation of test results. There are two major types of p'ots: (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.

3.1 TIME-BASED PLOTS

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

Basic Plots, Plots 1-30

PLOT NUMBER	ORDINATE	DISCUSSION
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.

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.

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.

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.

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 Leq Conductivity	High conductivity indicates wet, low indicates dry.
124	Hot Leq 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.

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

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

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

160-Series Plots, Pressurizer

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

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

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

PLOT NUMBER	ORDINATE	DISCUSSION
181	HPI Turbine Meter Flow Rate (lbm/sec)	

190-Series Plots, Secondary System

PLOT NUMBER	ORDINATE	DISCUSSION
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

PLOT NUMBER	ORDINATE	DISCUSSION
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	

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 br ry condition that the first derivatives are 0 at .nd 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.

TABLE 3.1

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

Plot Number	Variable	Appendix Discussion In Paragraph ...
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

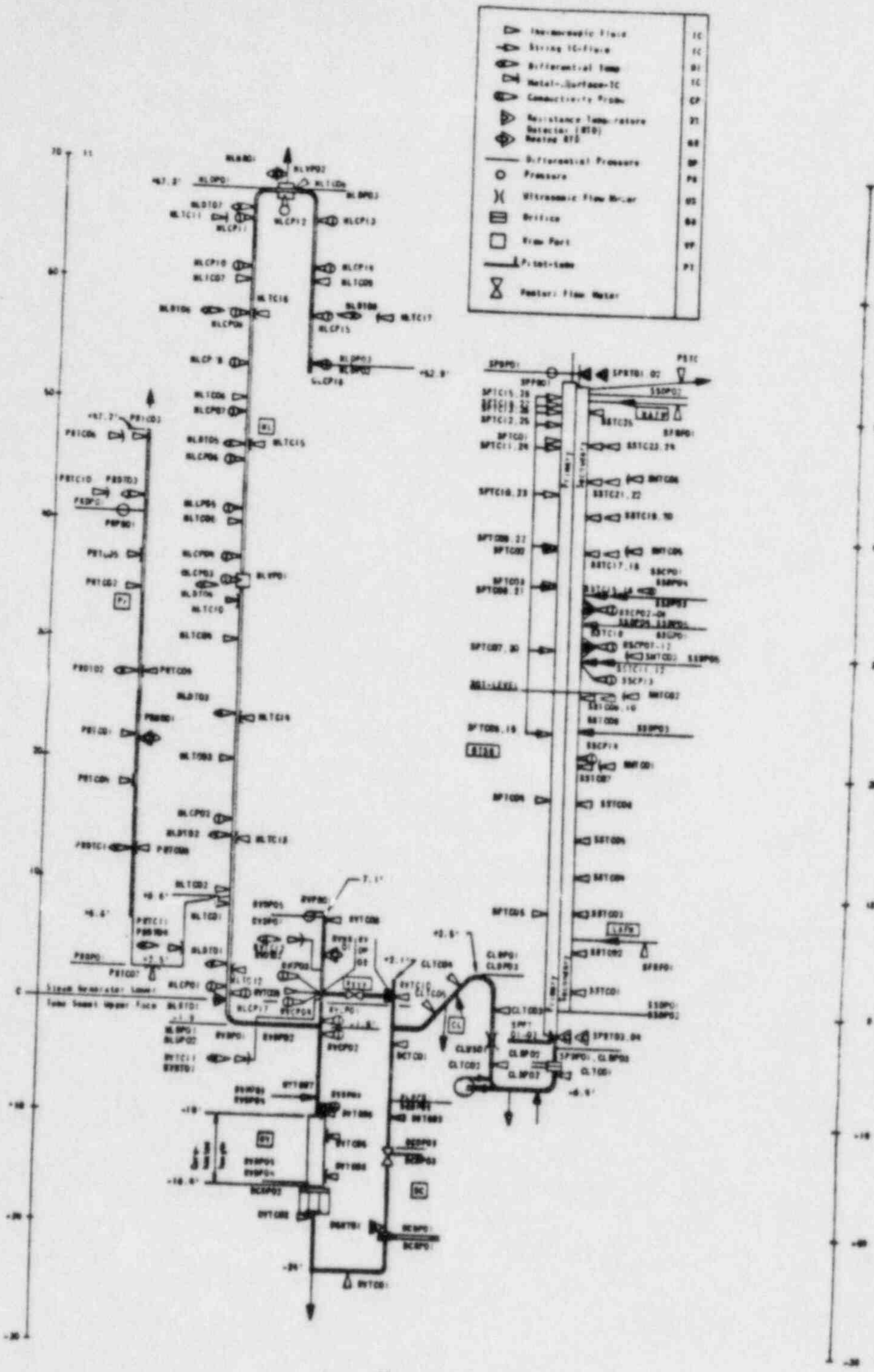
TABLE 4.2 INSTRUMENT ABBREVIATIONS

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 OTIS INSTRUMENTS



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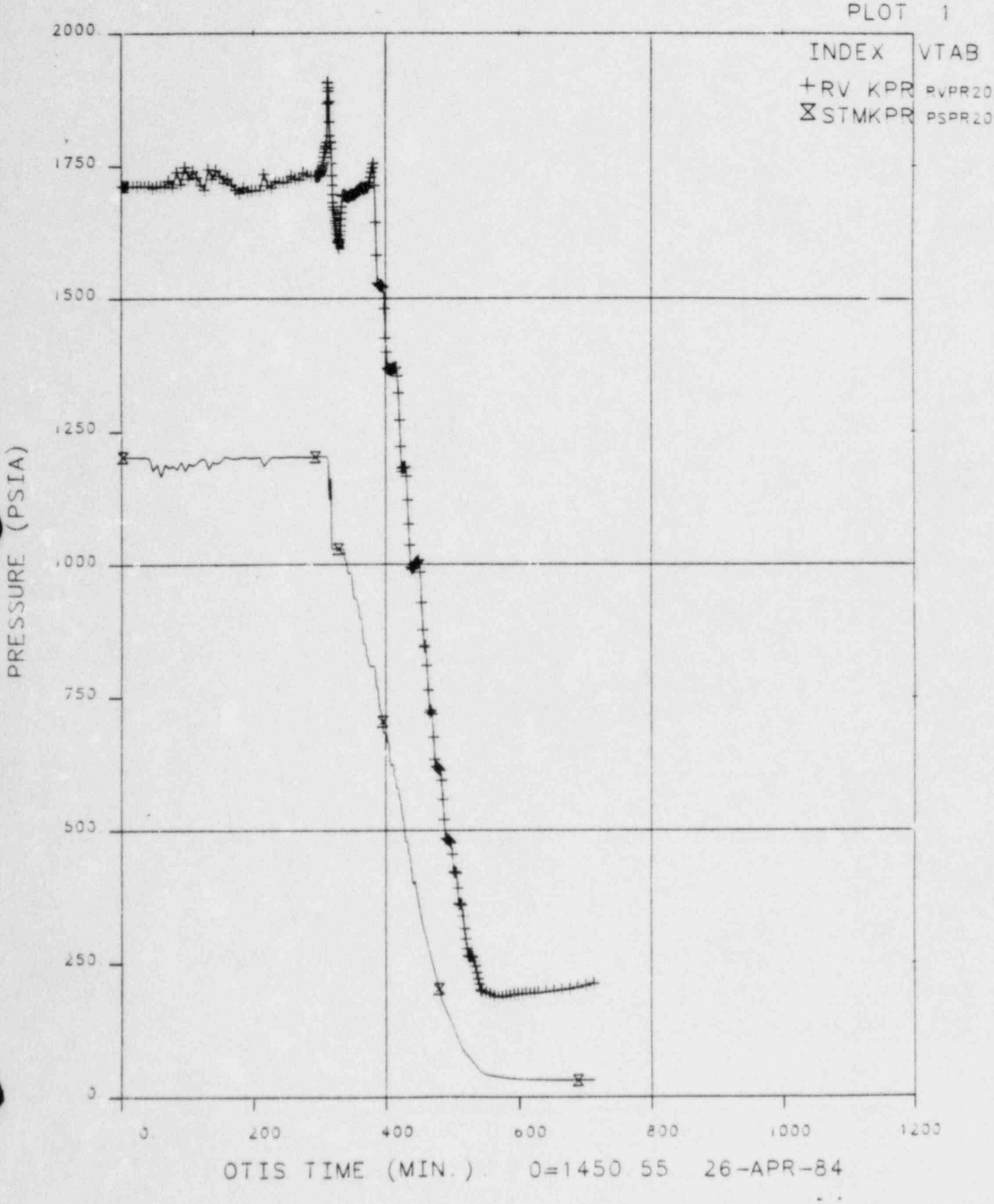

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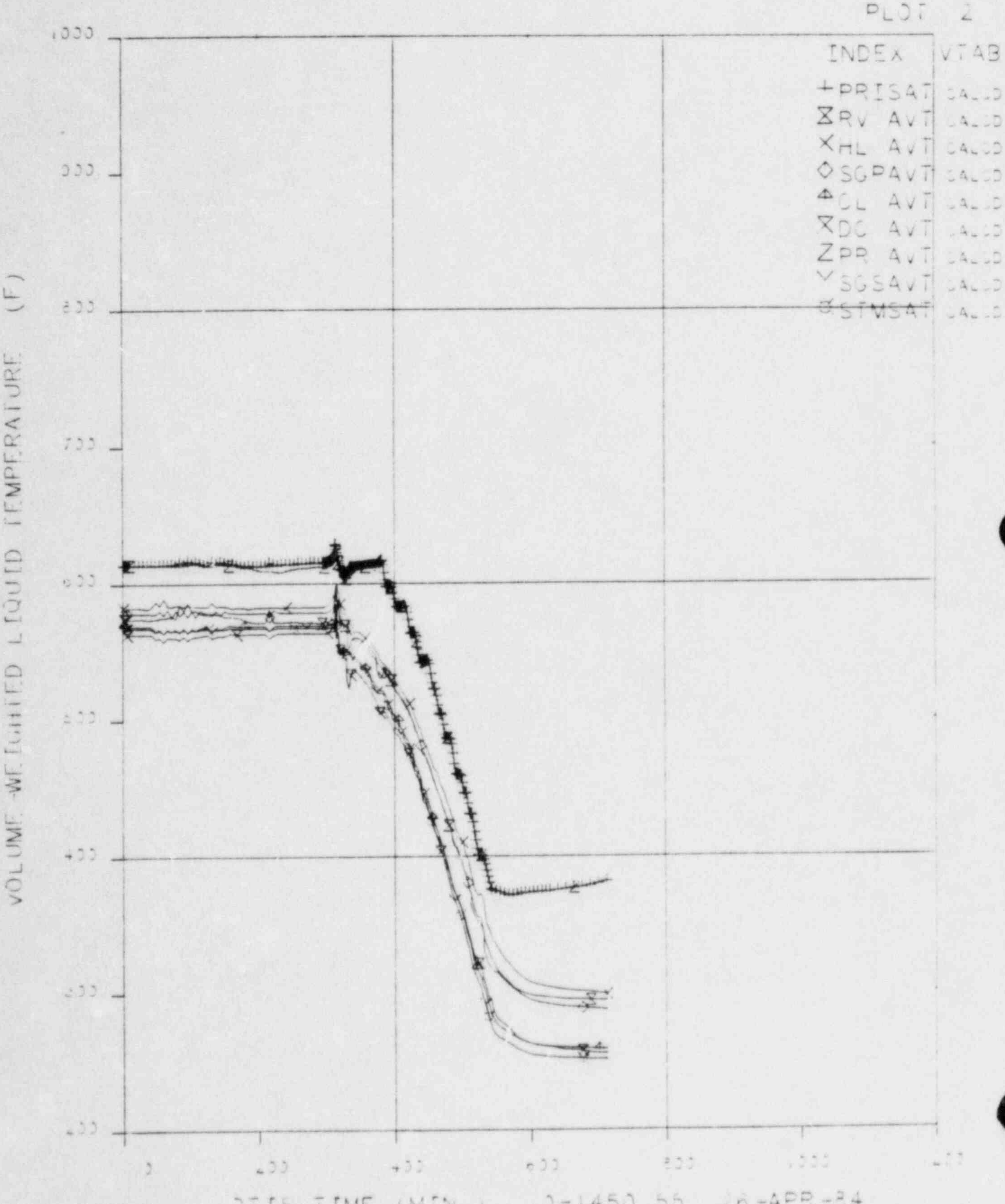

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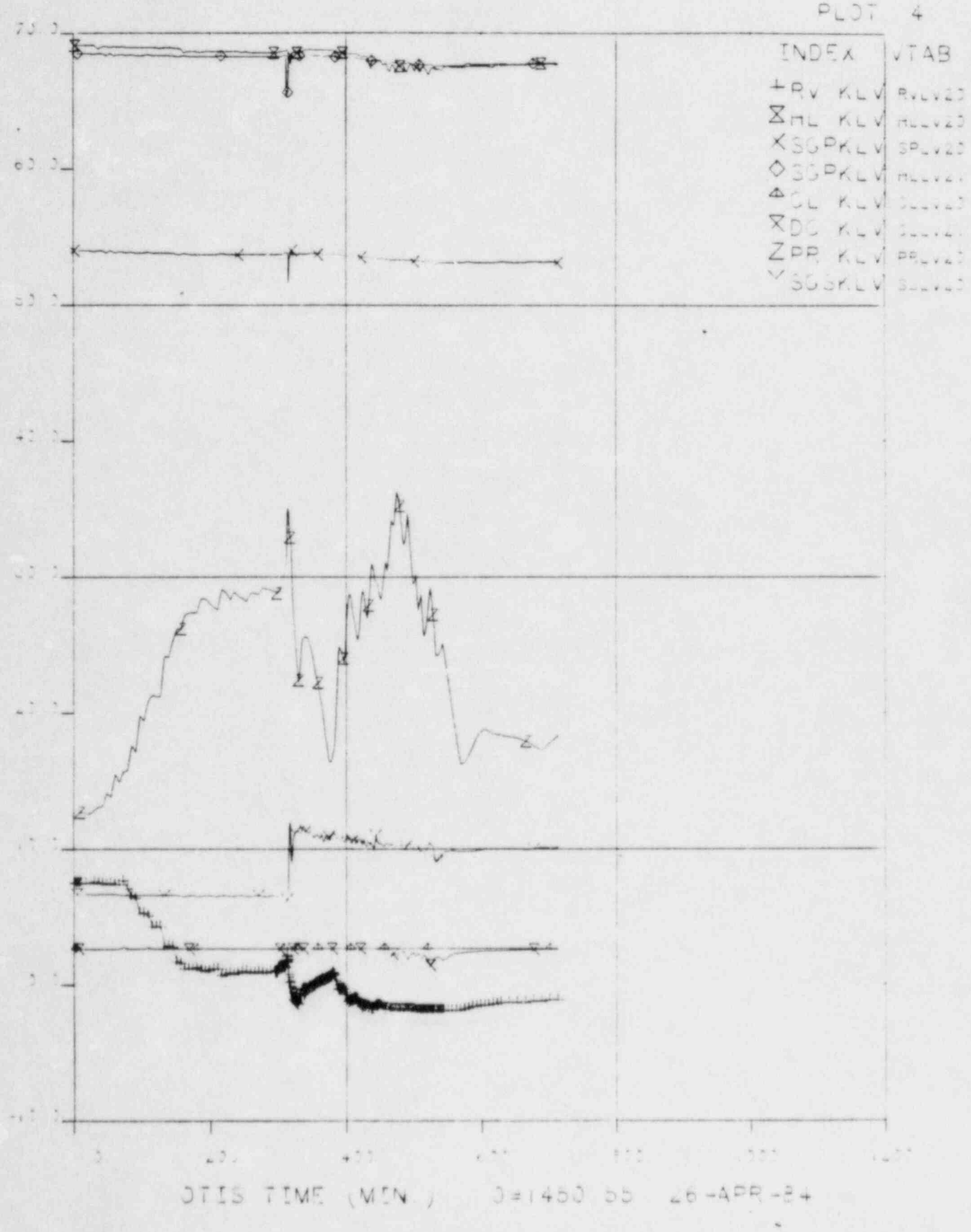

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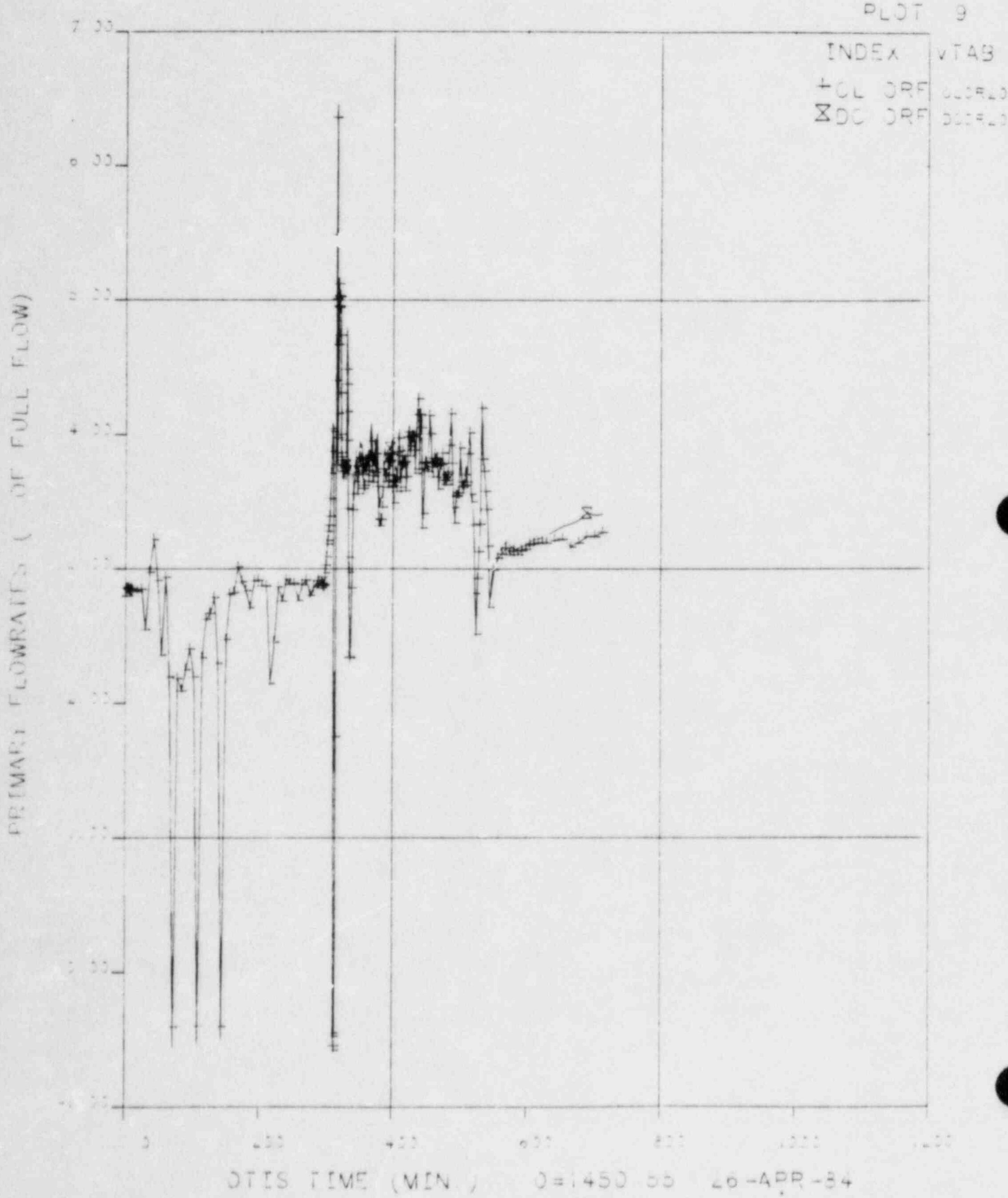

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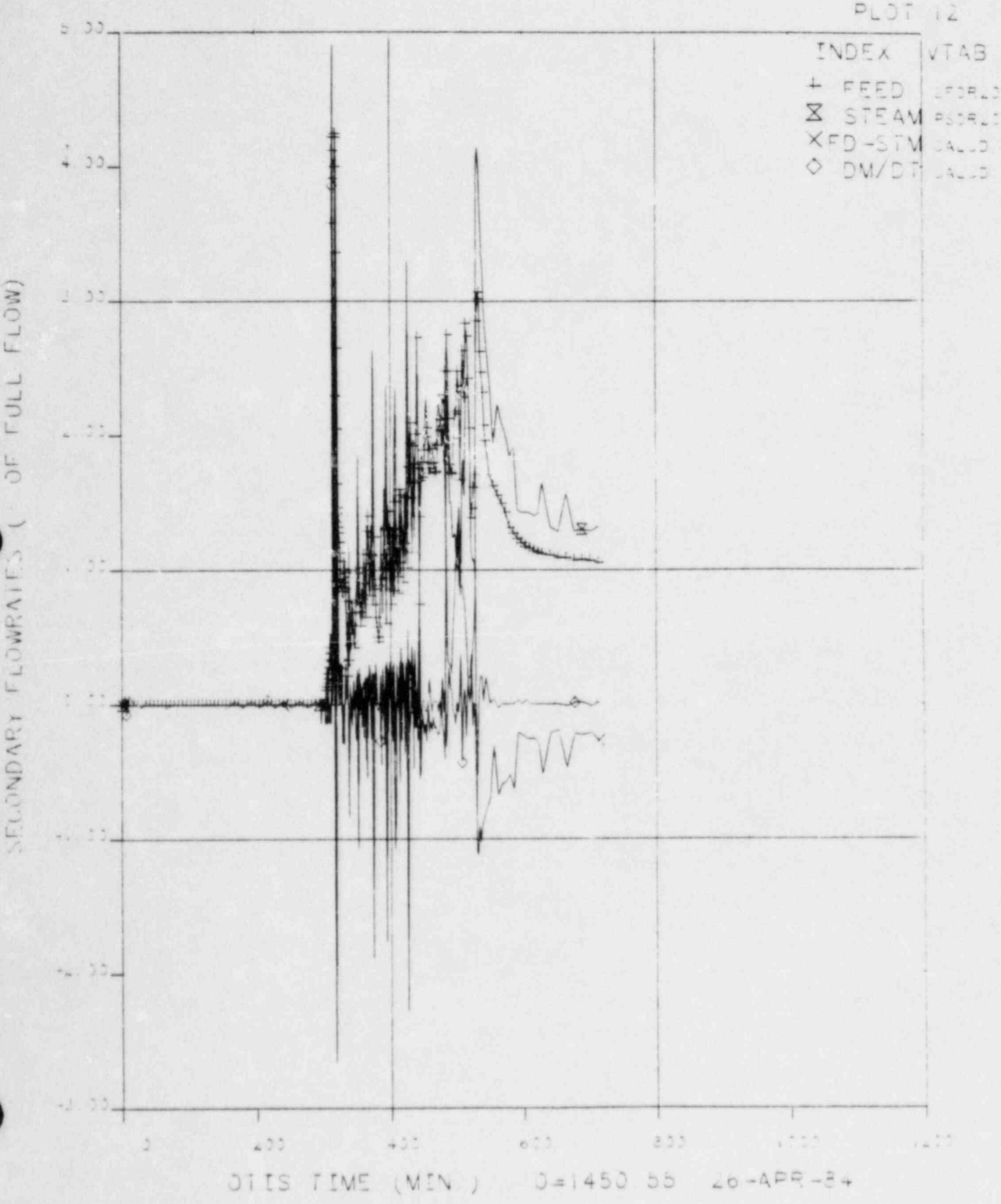

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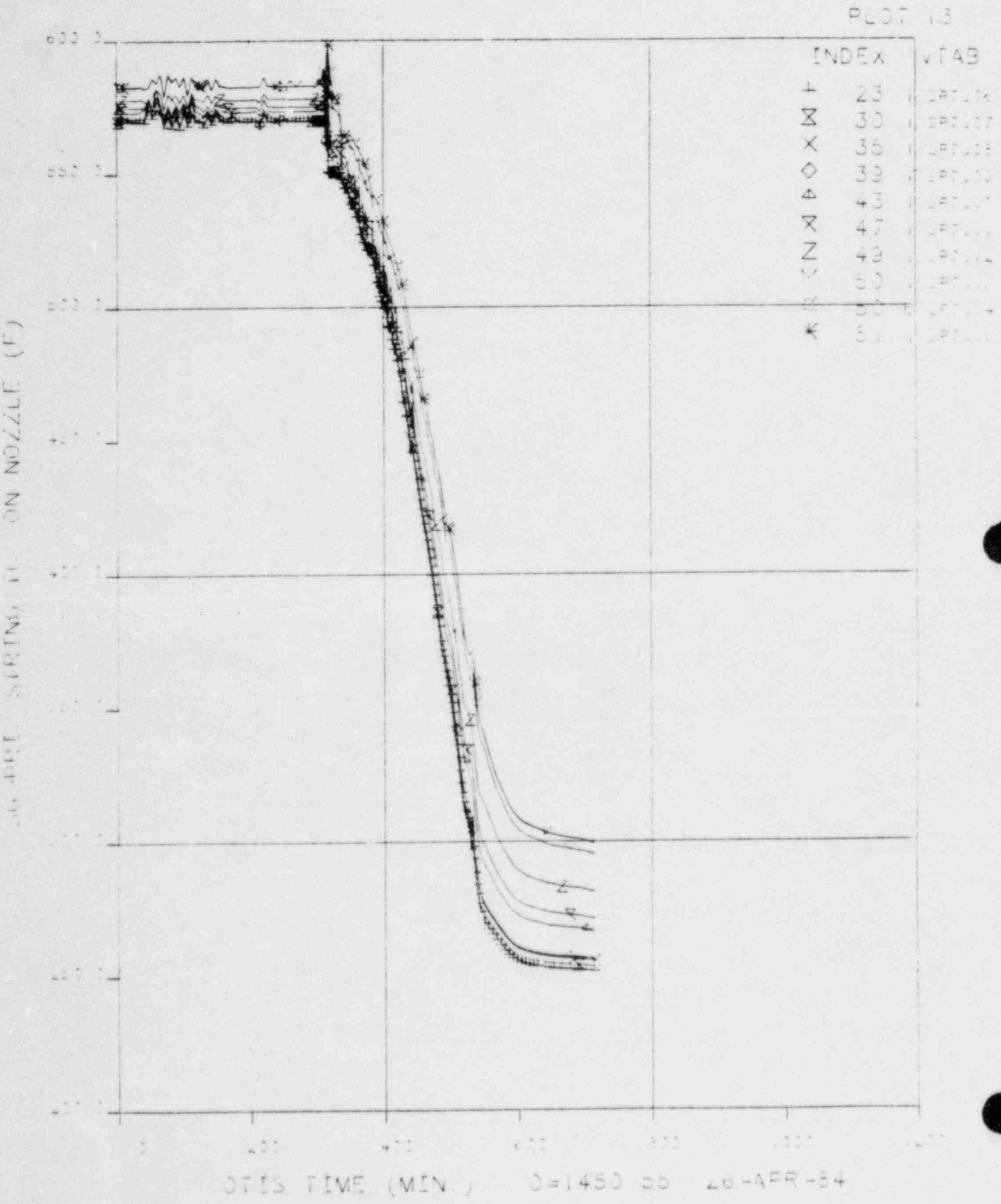

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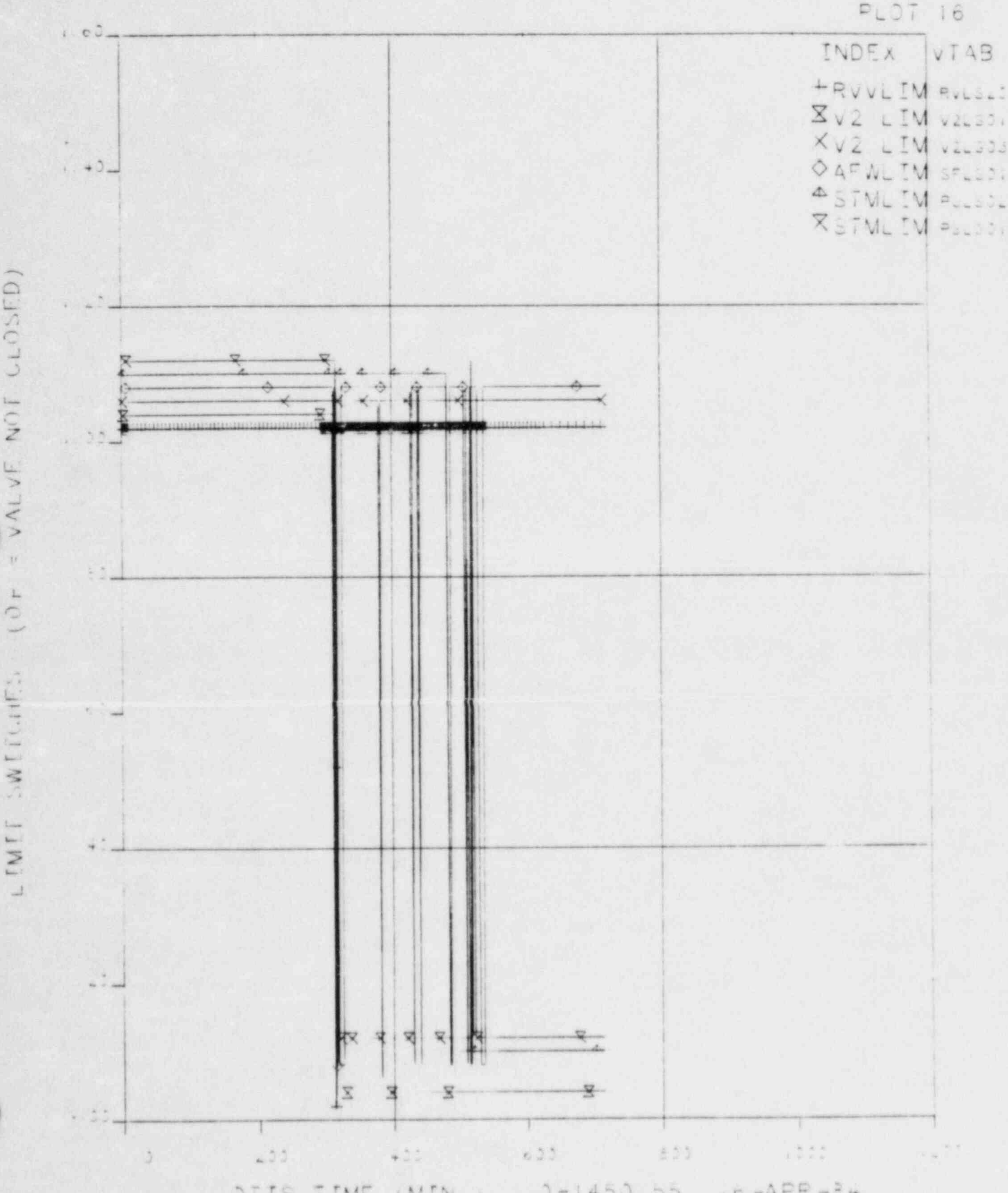

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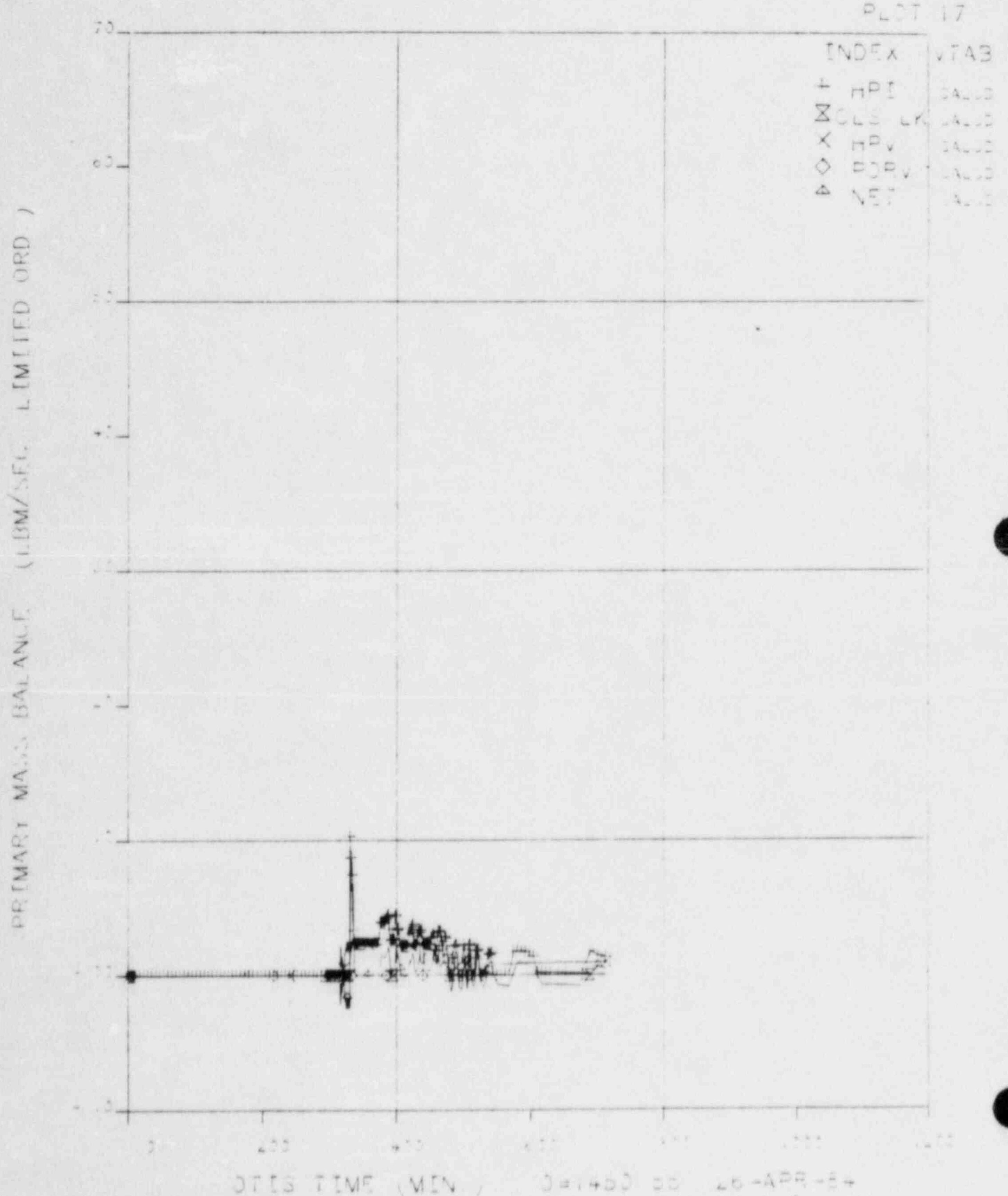

A-62

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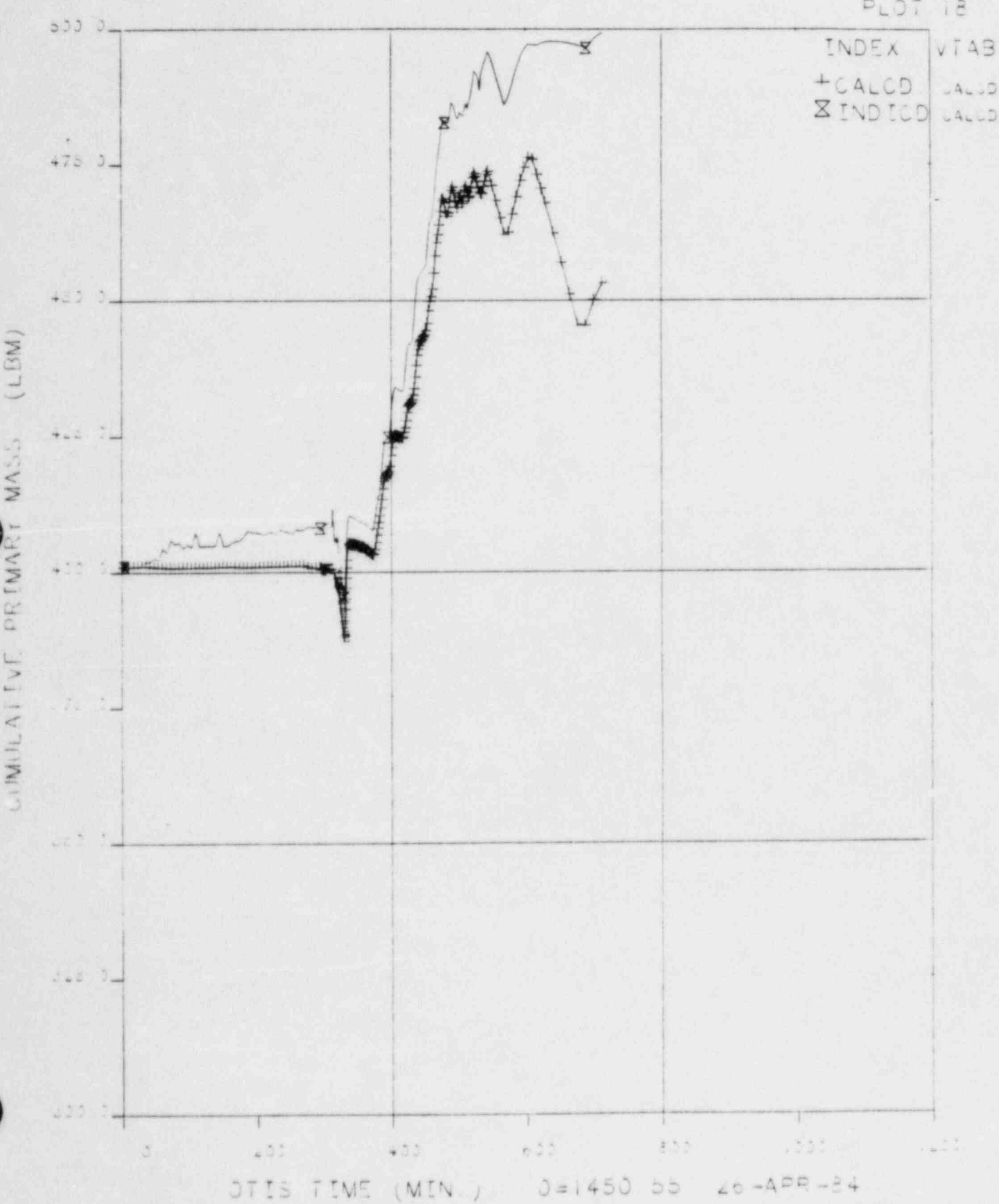

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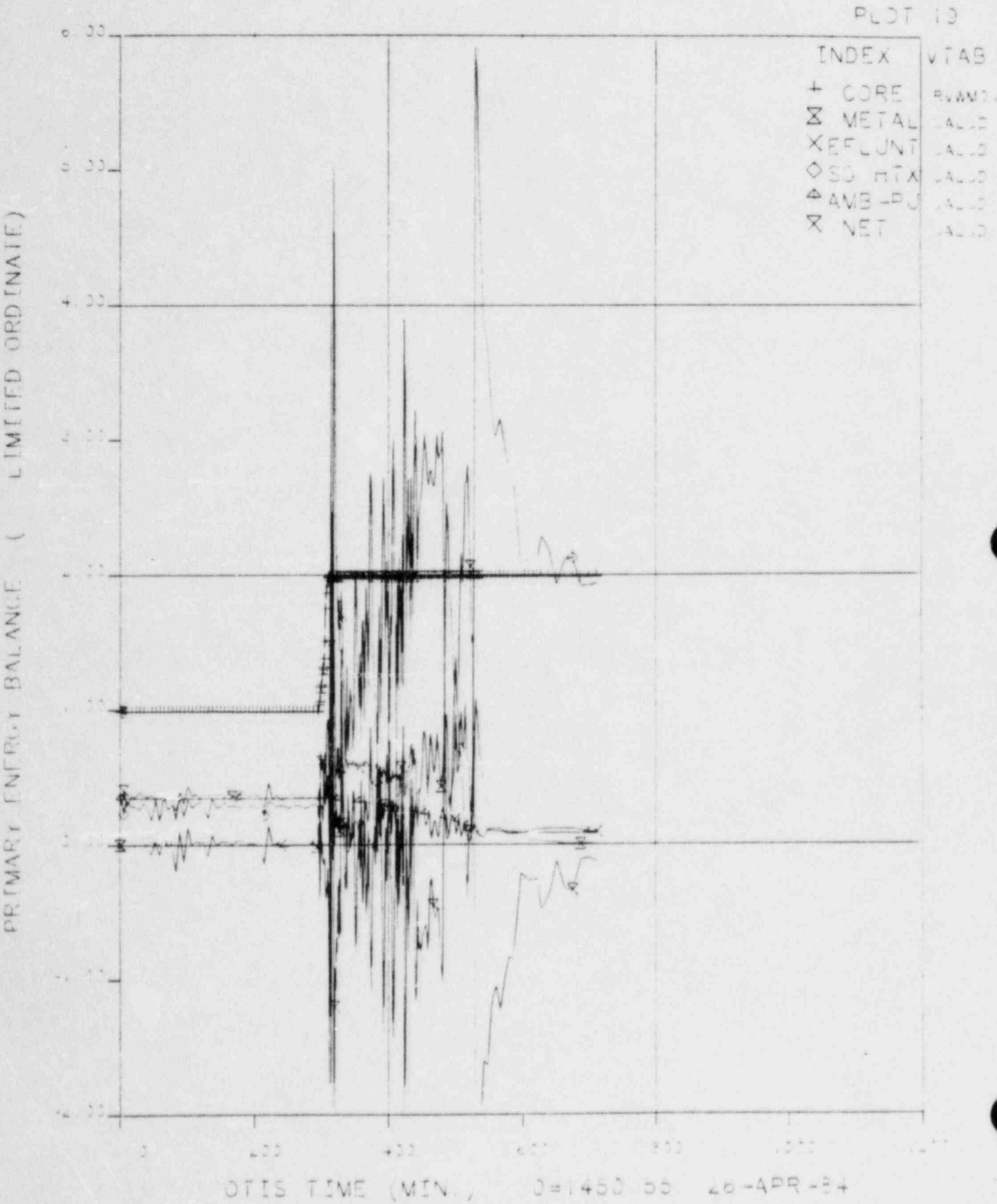

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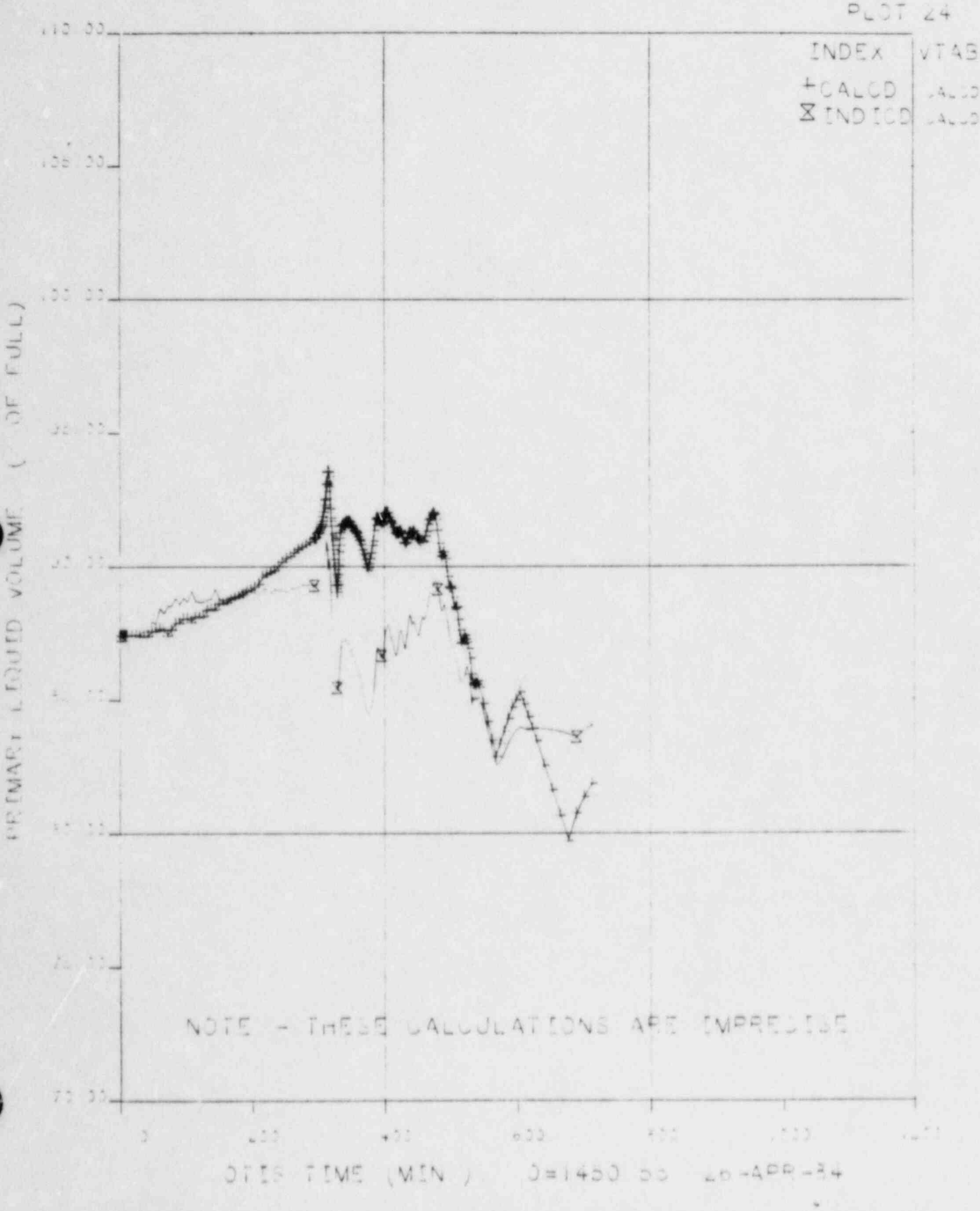

PRELIMINARY DATA

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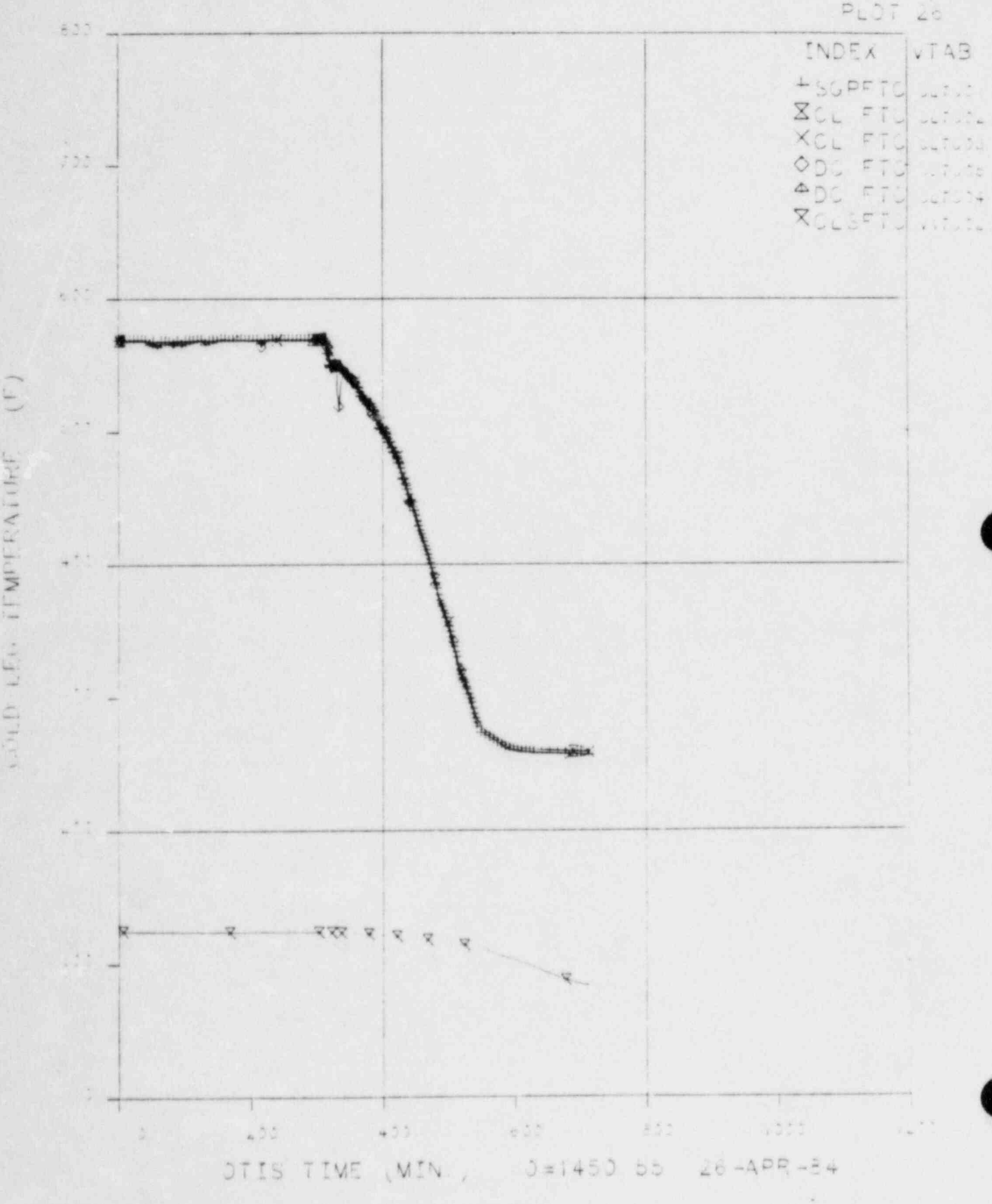
PLOT 26



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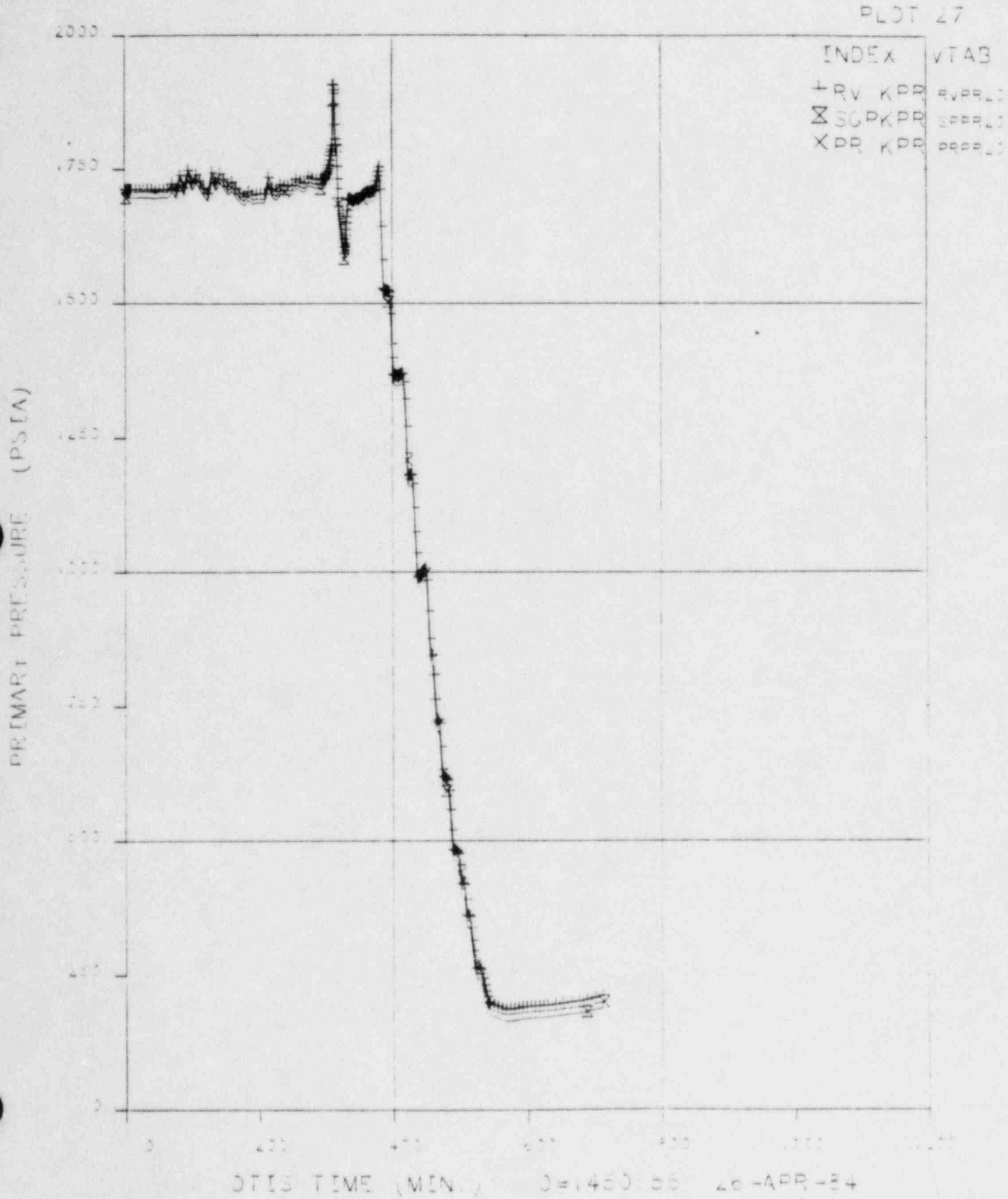

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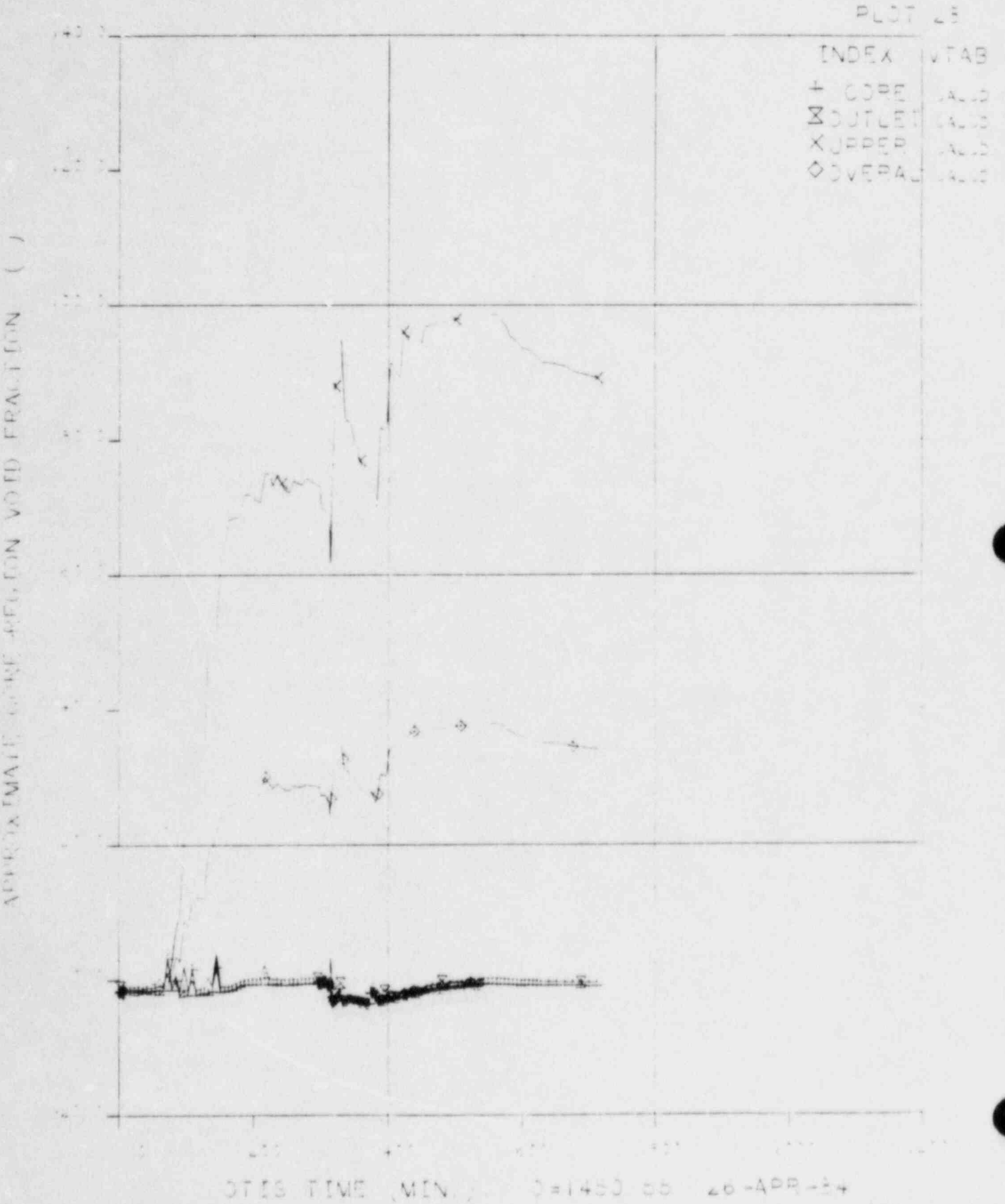

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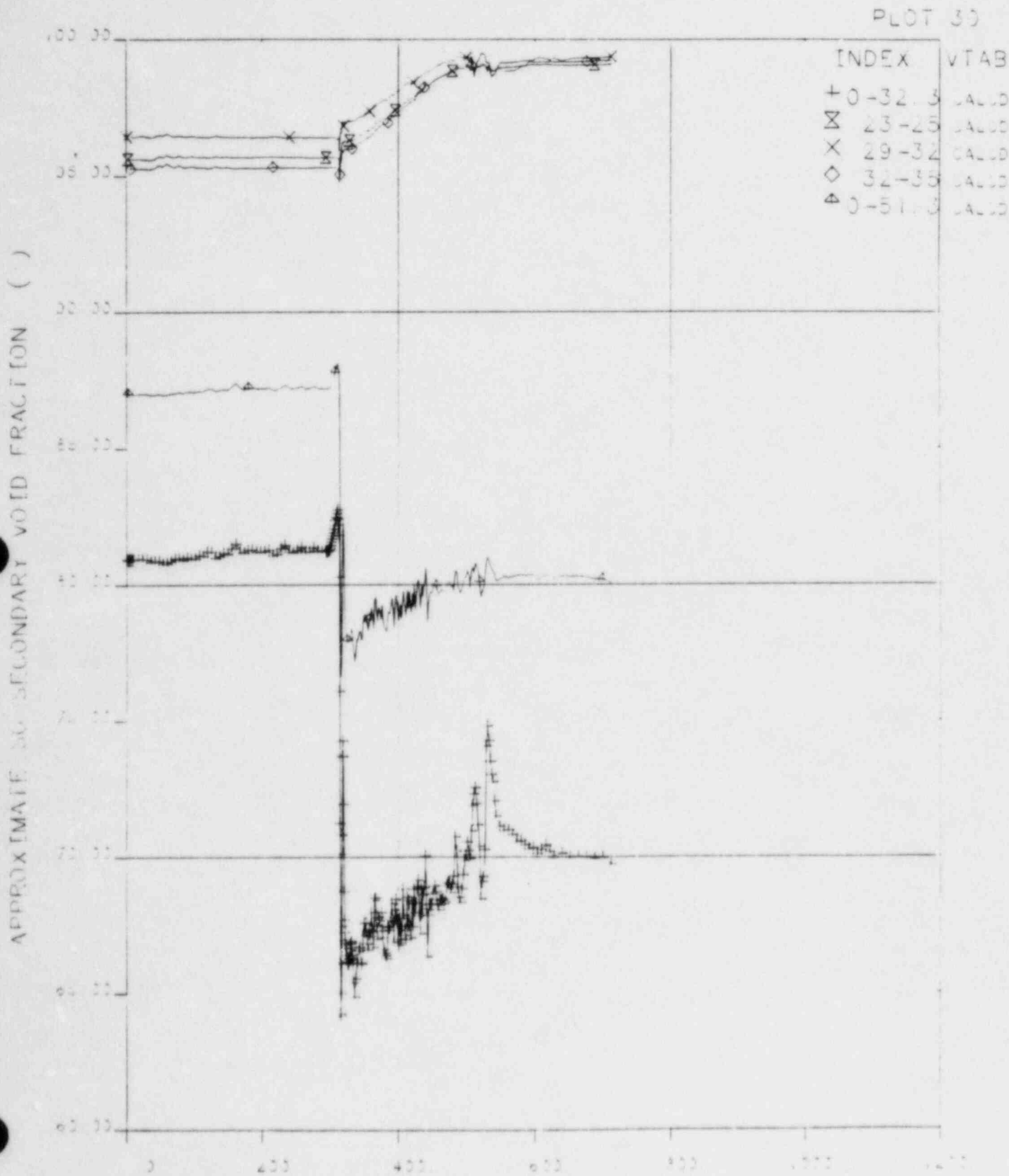

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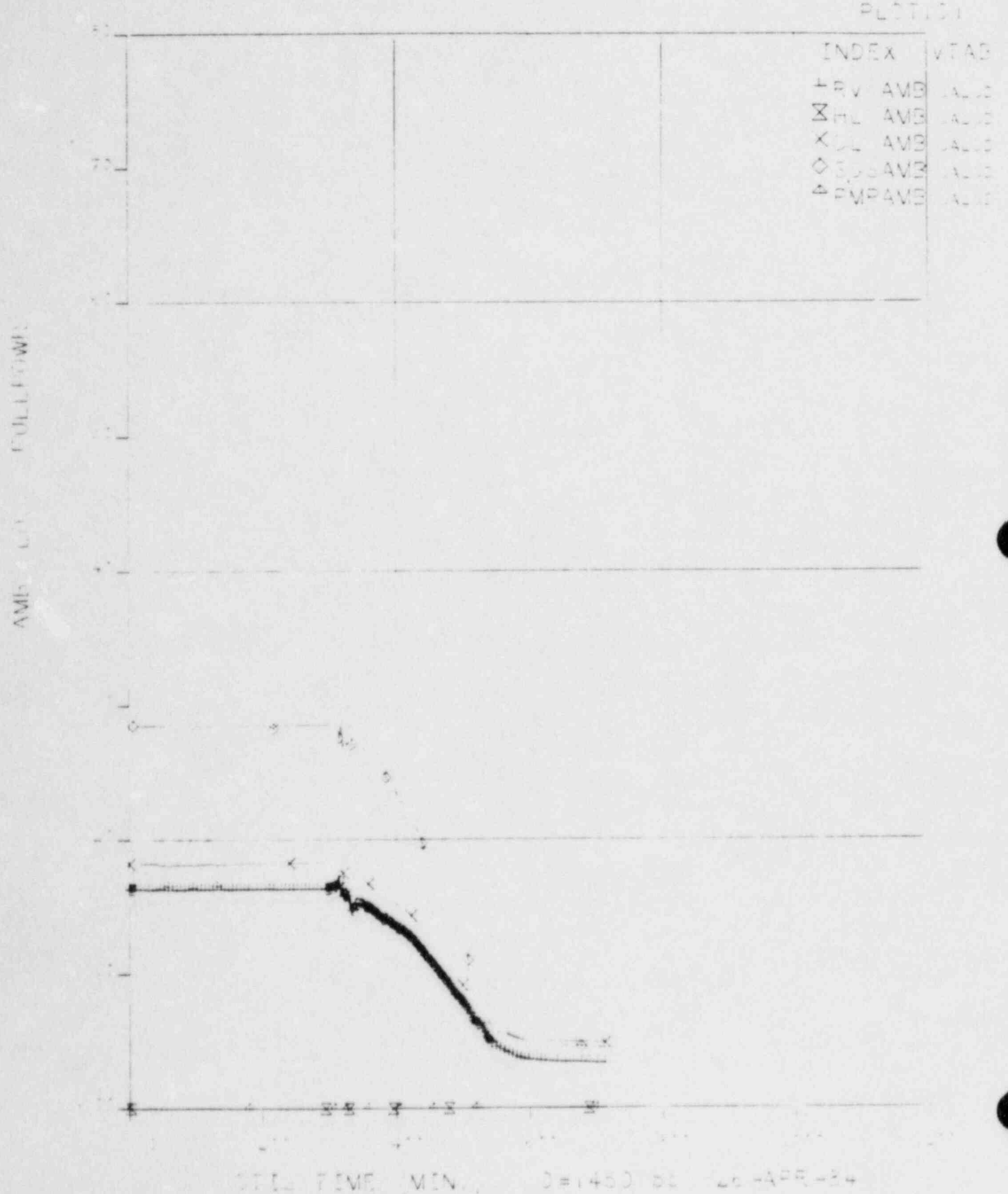

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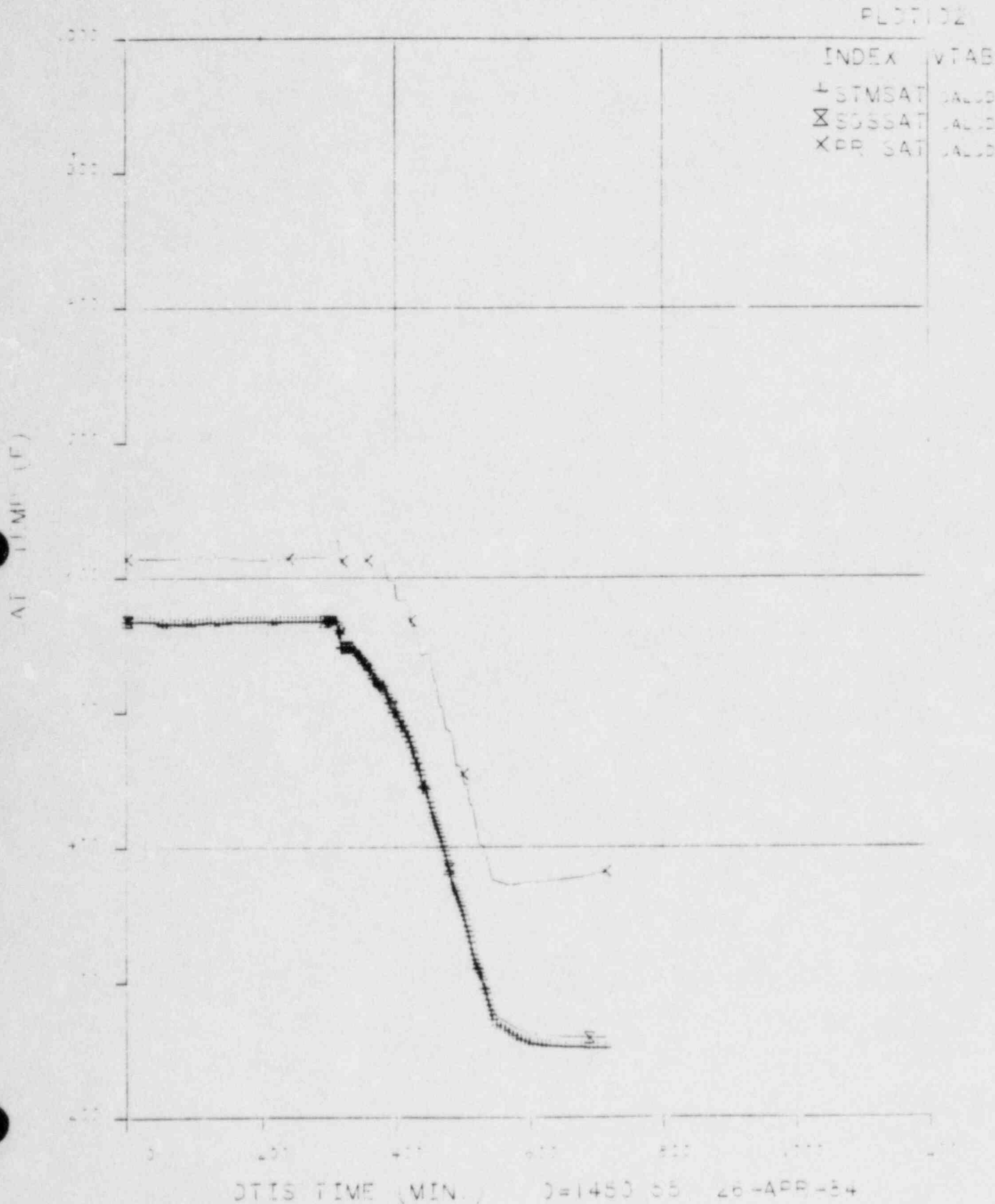

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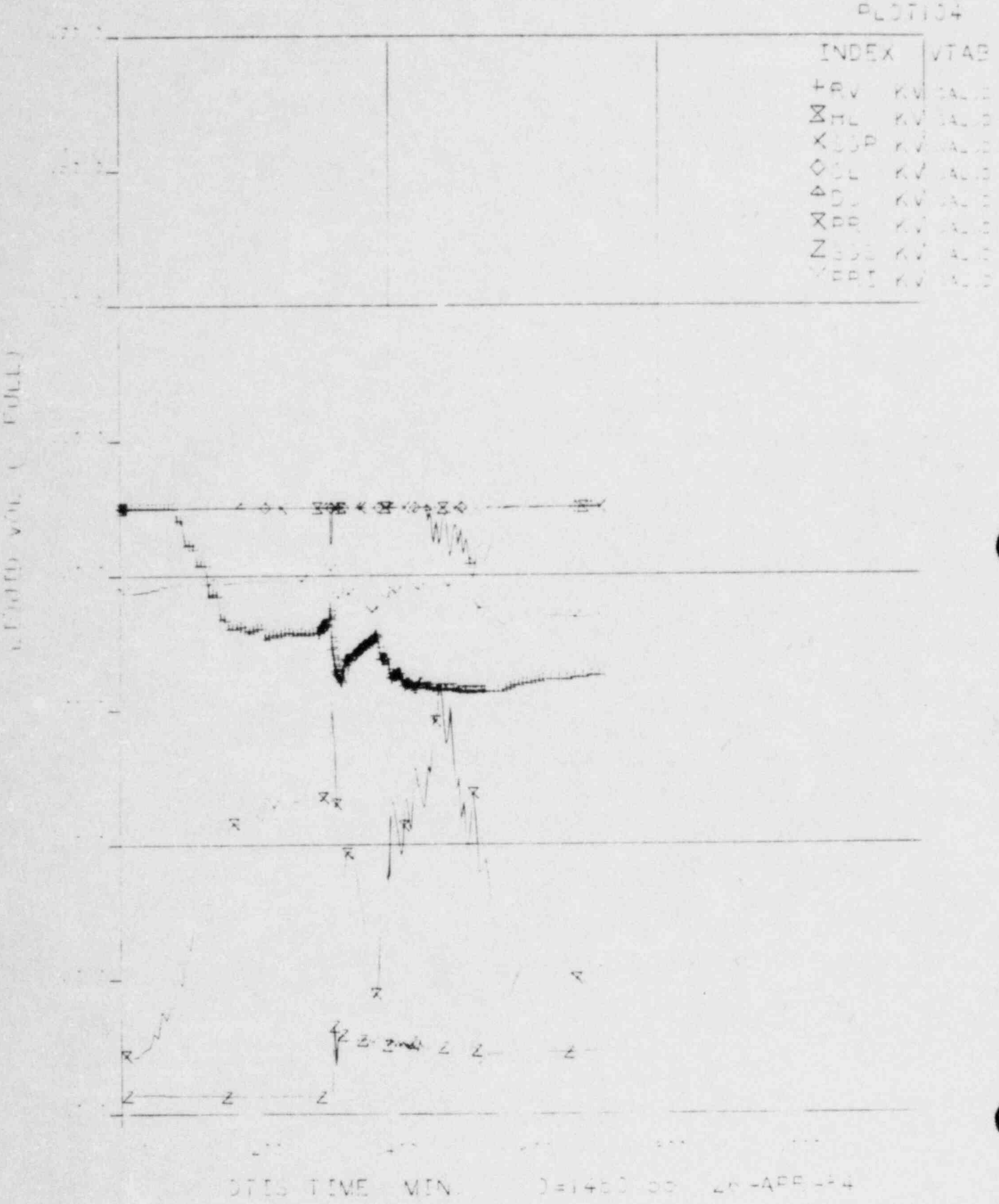
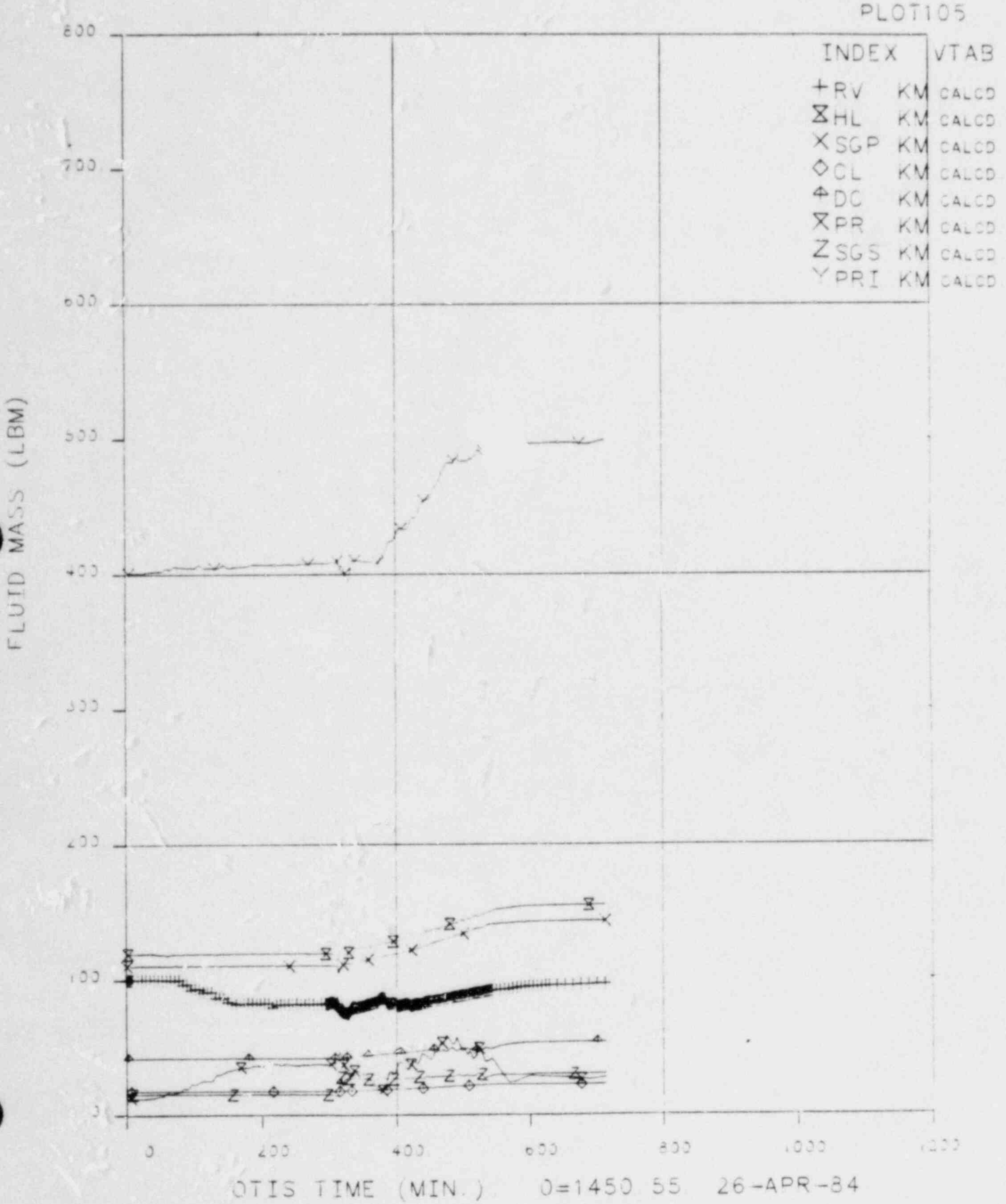


PRELIMINARY DATA

PRELIMINARY DATA

0100.0 SMUD/FPC GAS TEST



PRELIMINARY DATA

PRELIMINARY DATA

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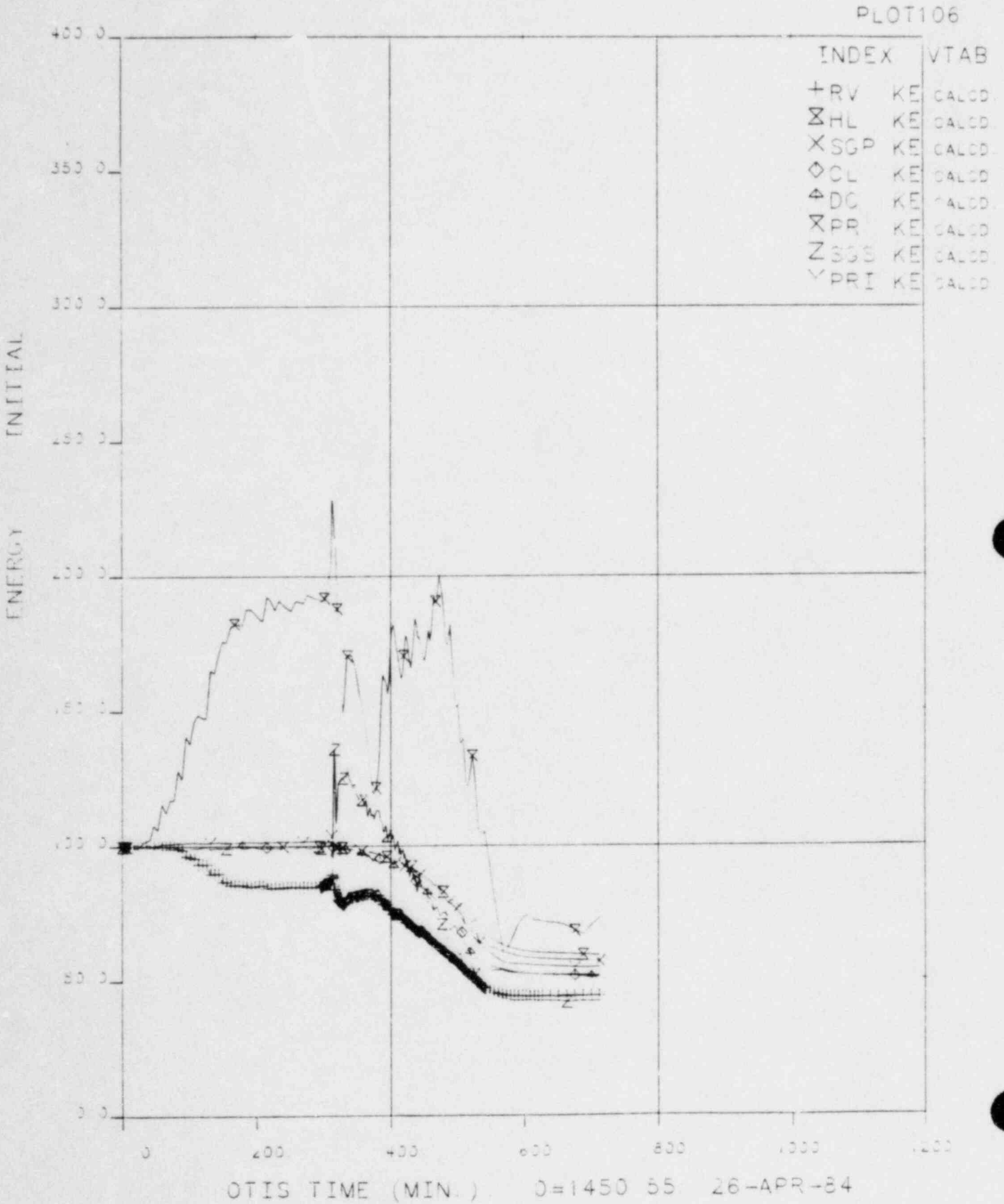

PRELIMINARY DATA

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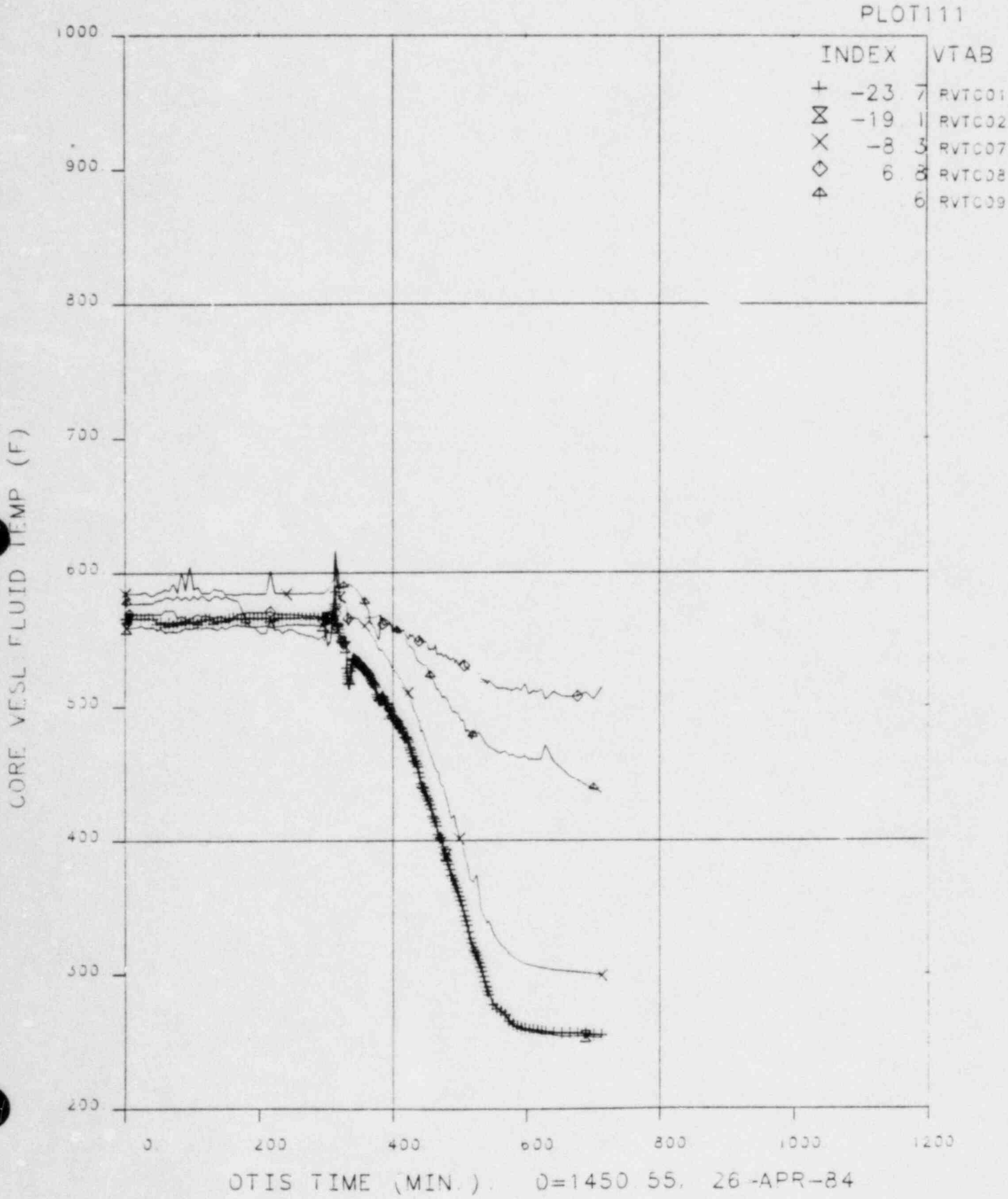

PRELIMINARY DATA

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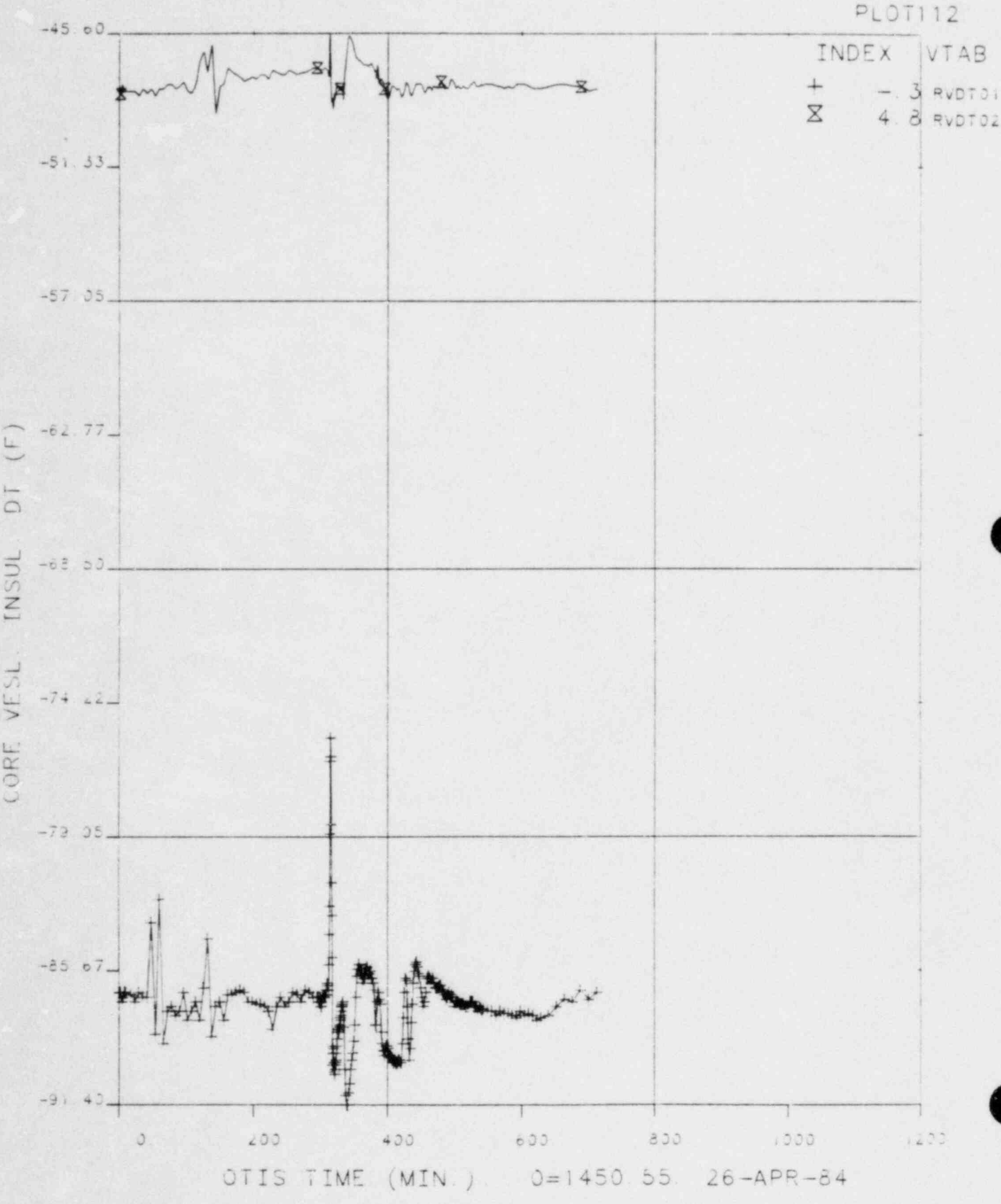

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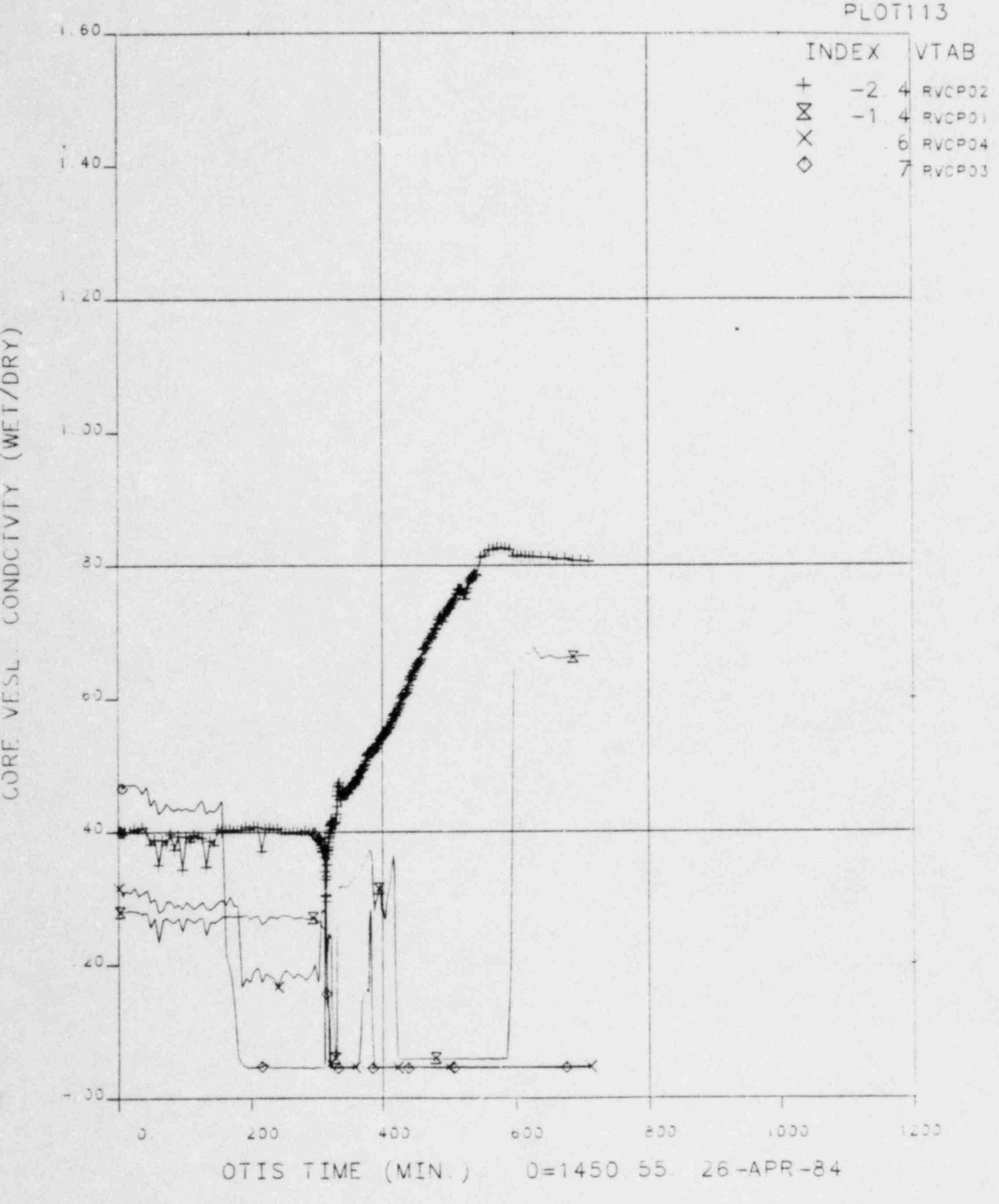

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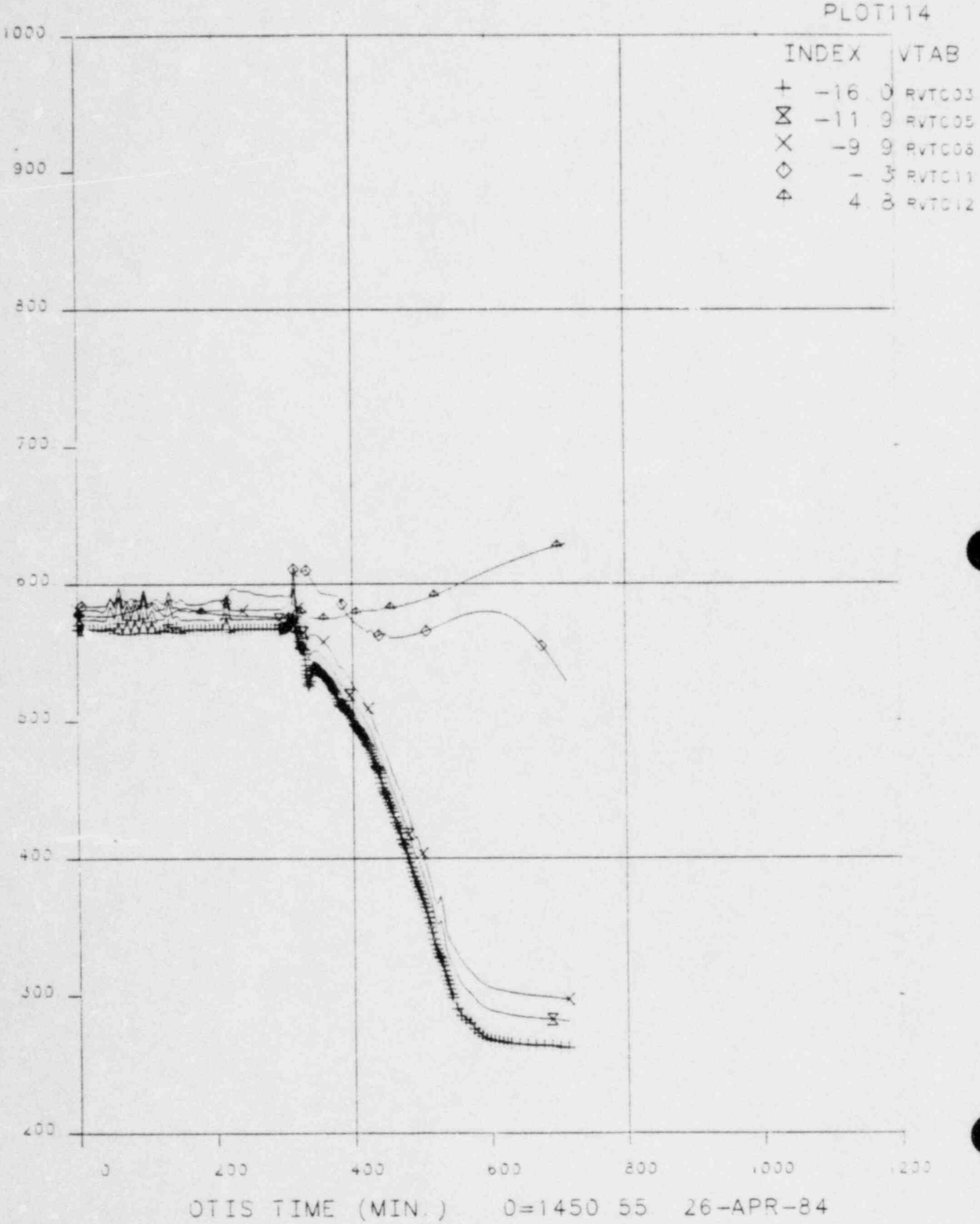

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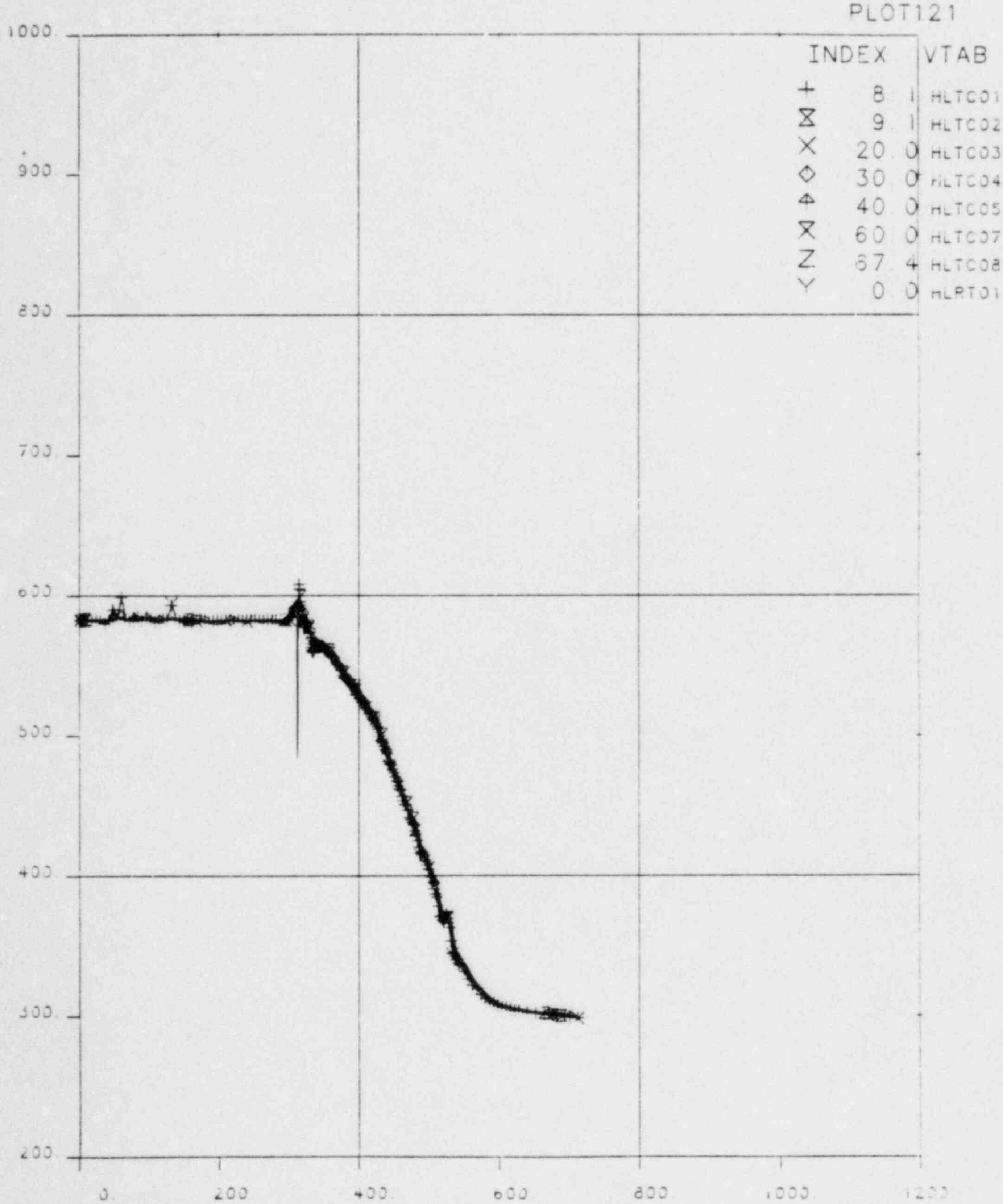

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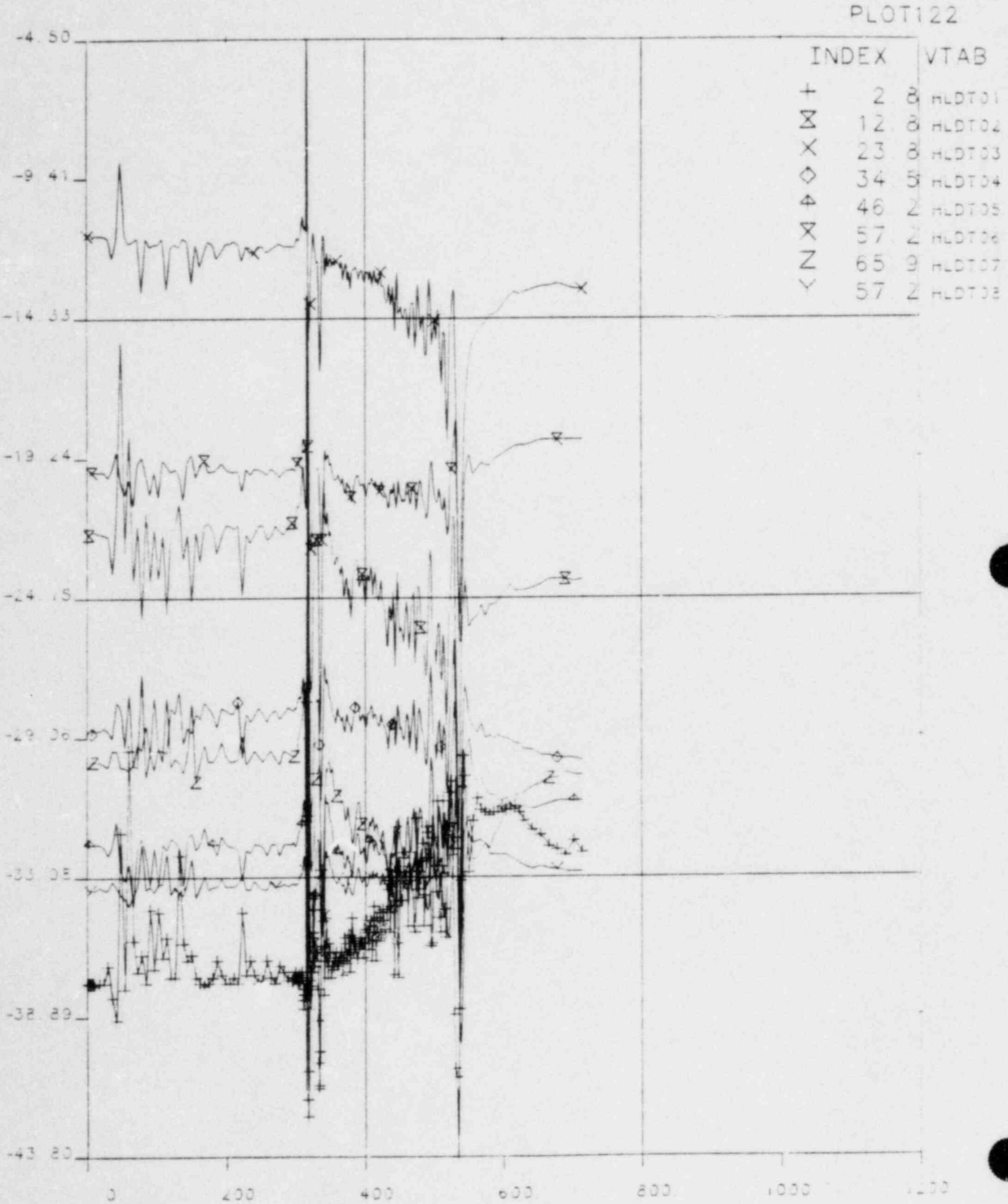

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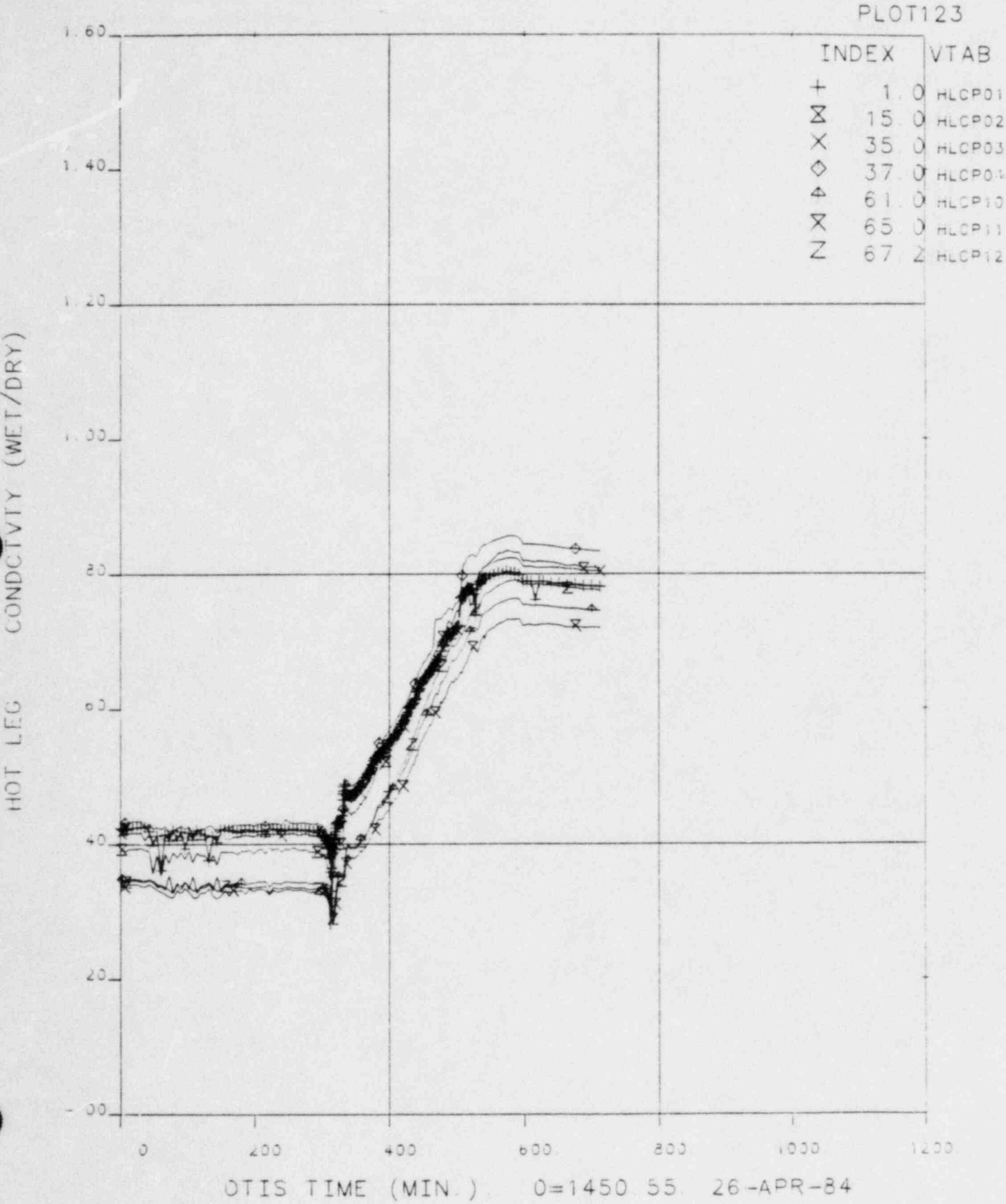

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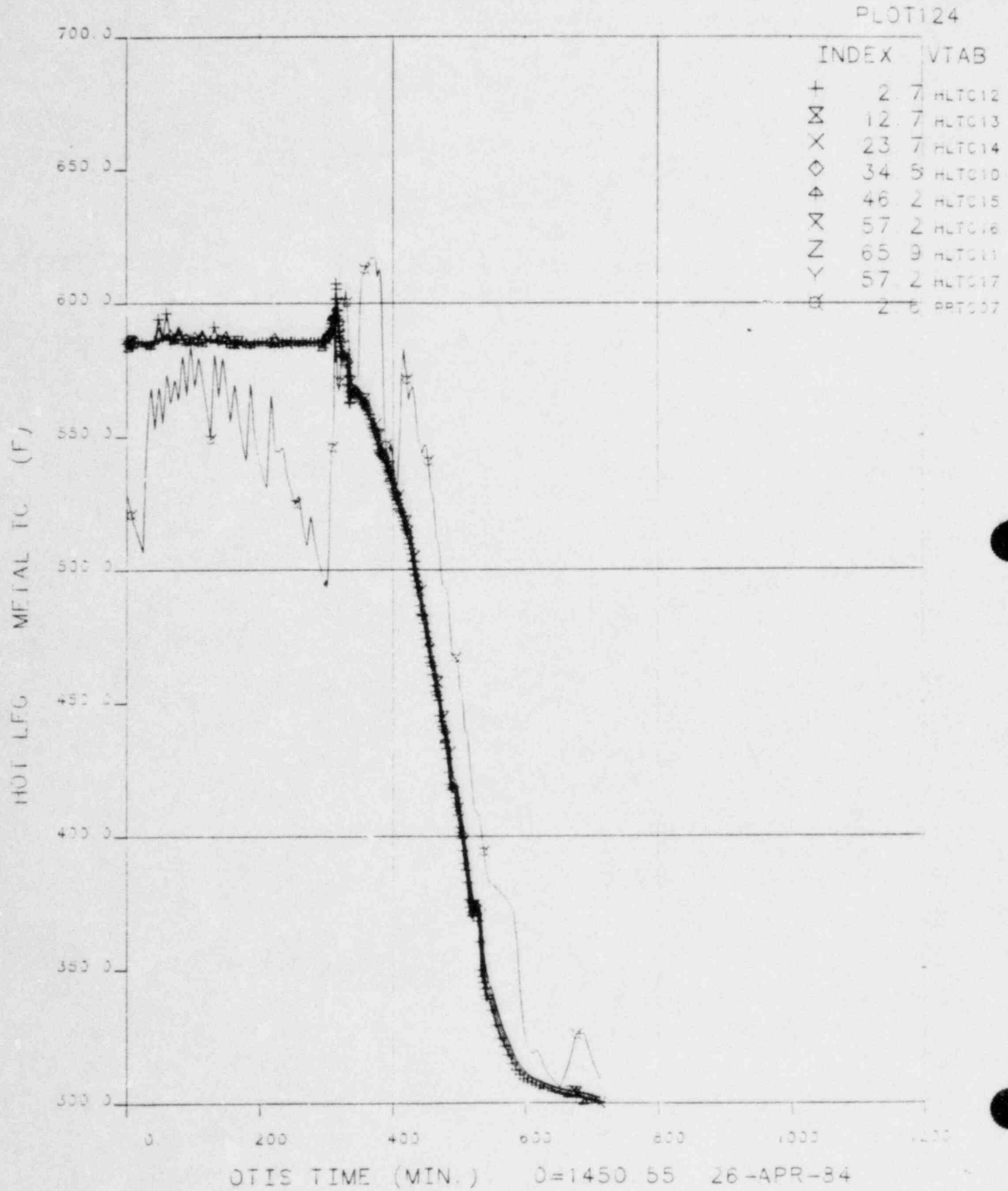

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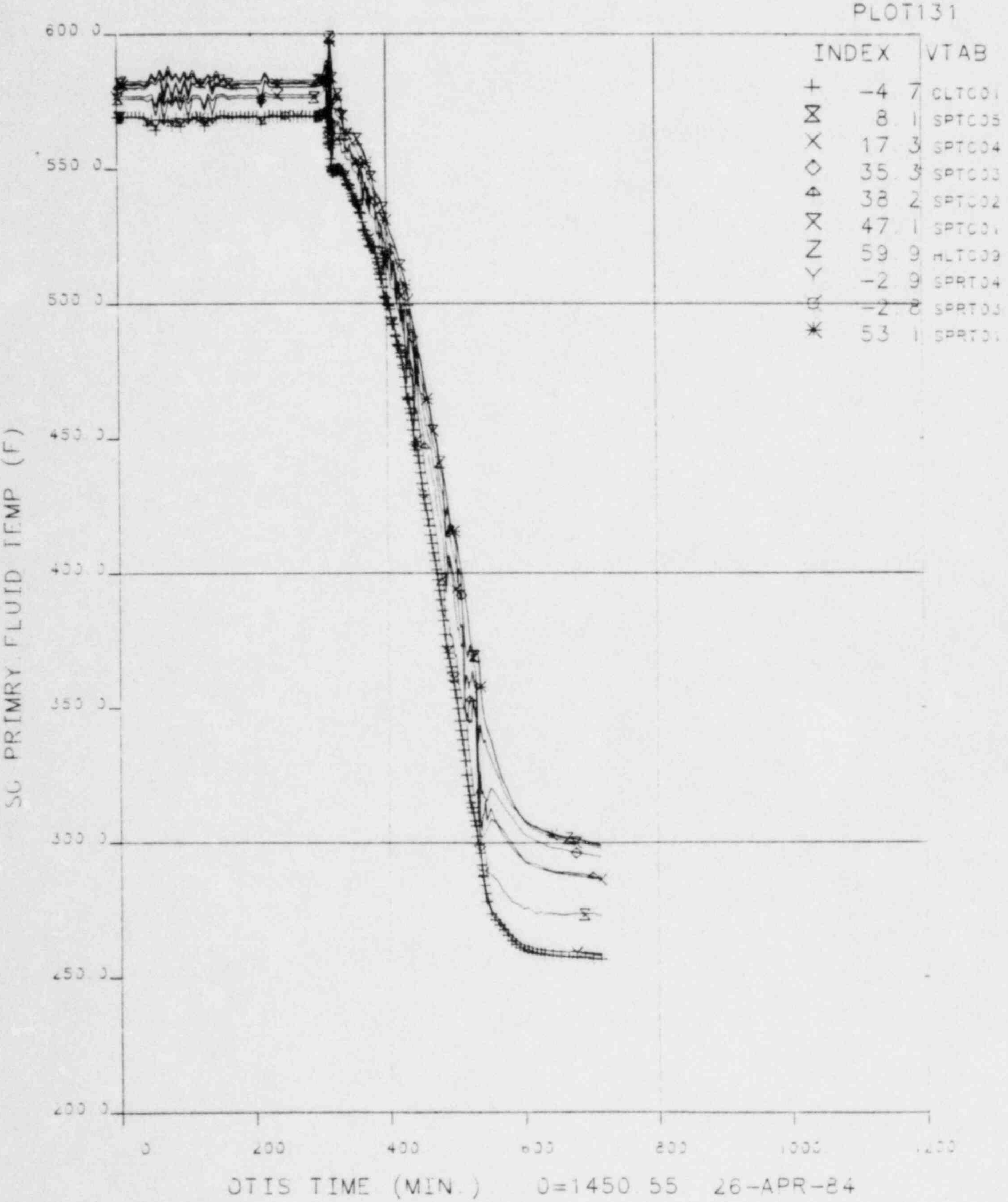

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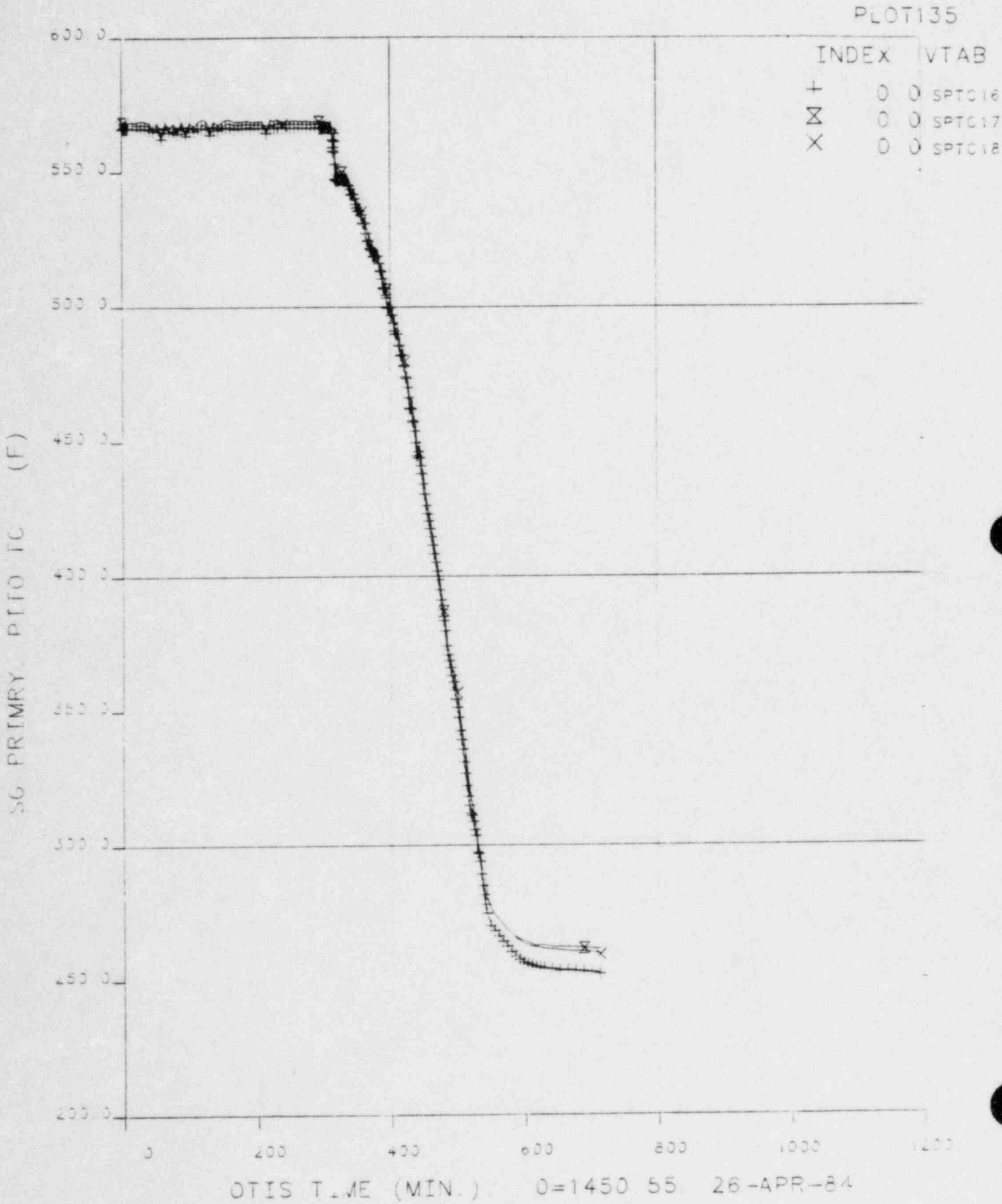

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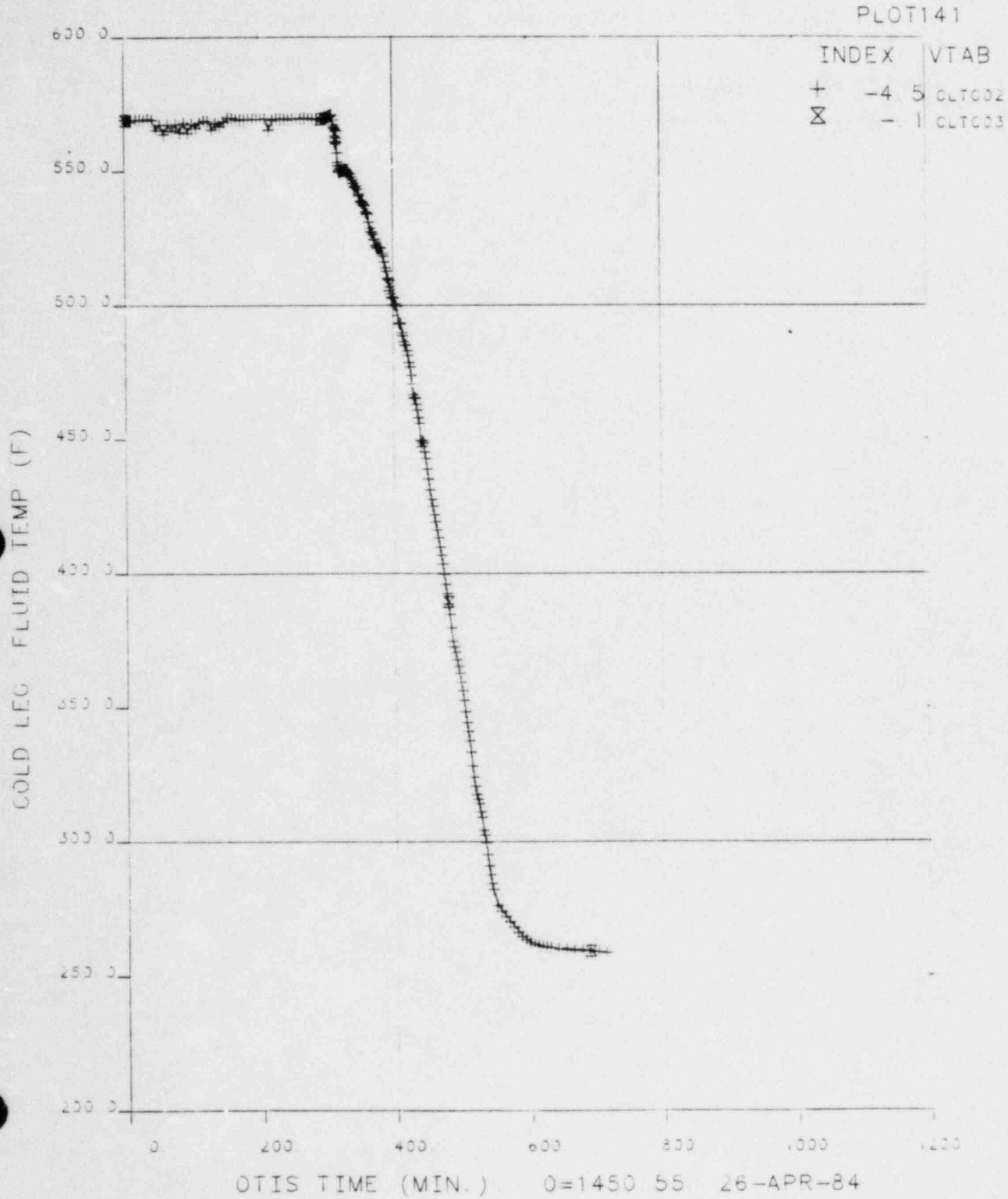

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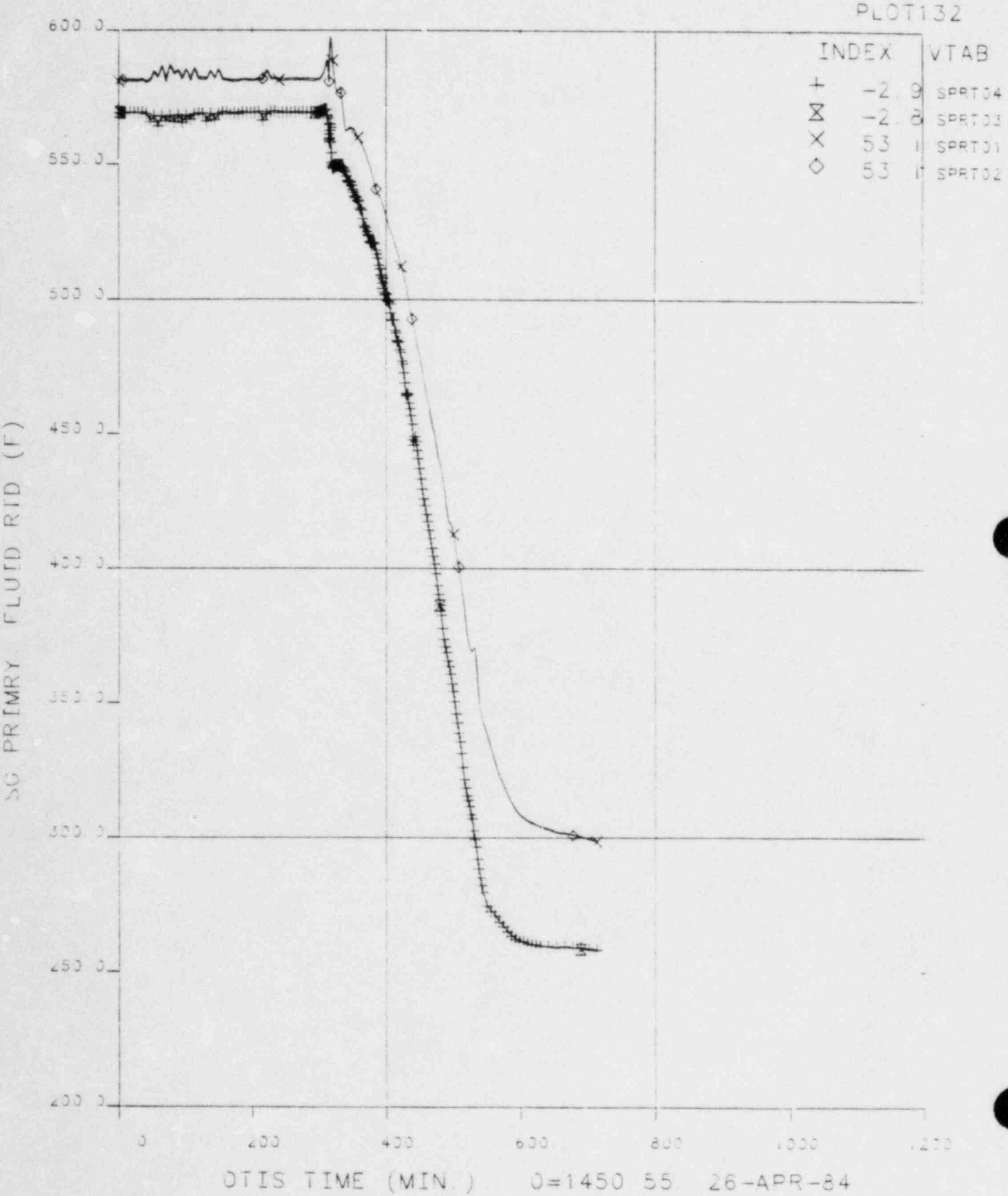

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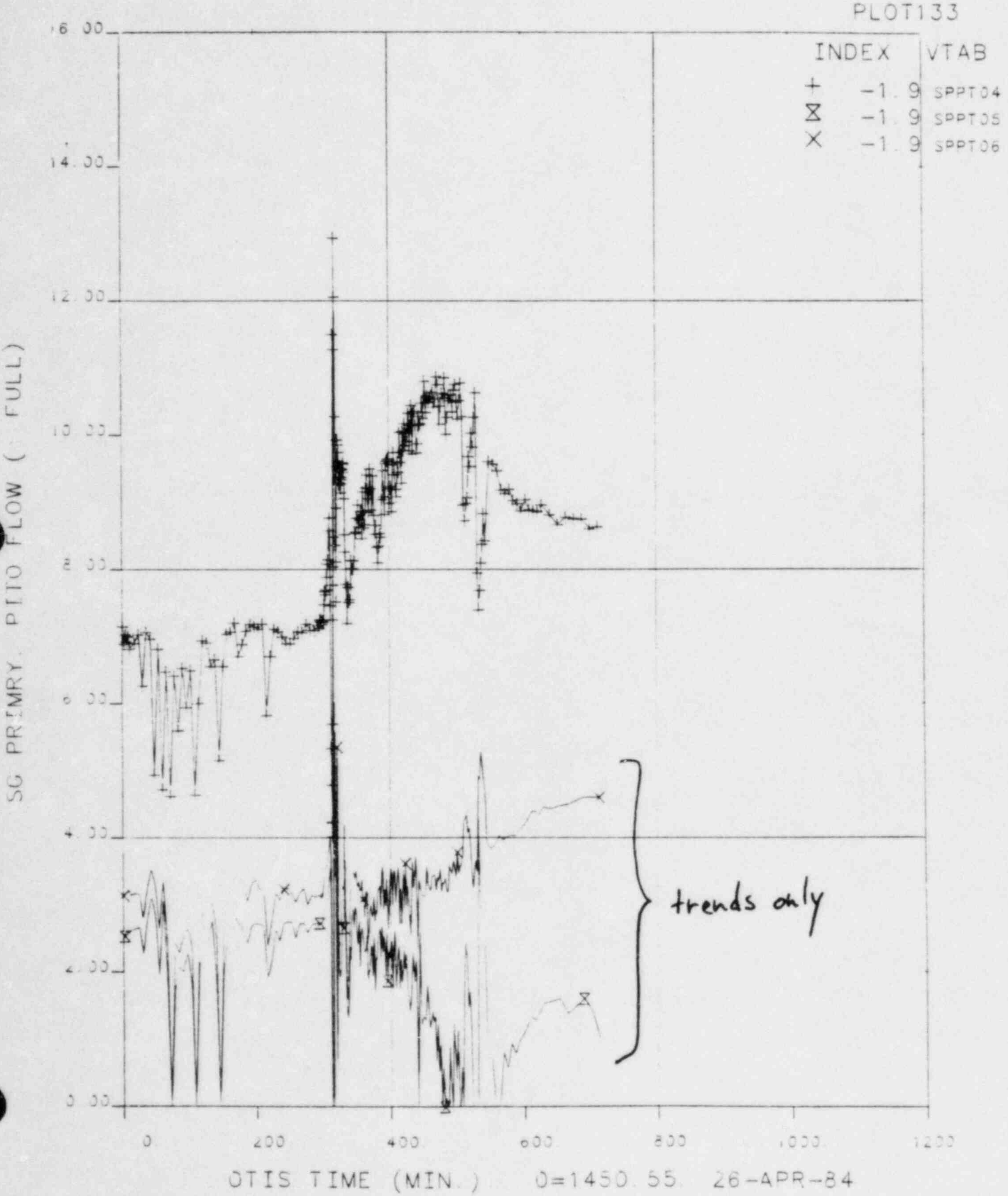

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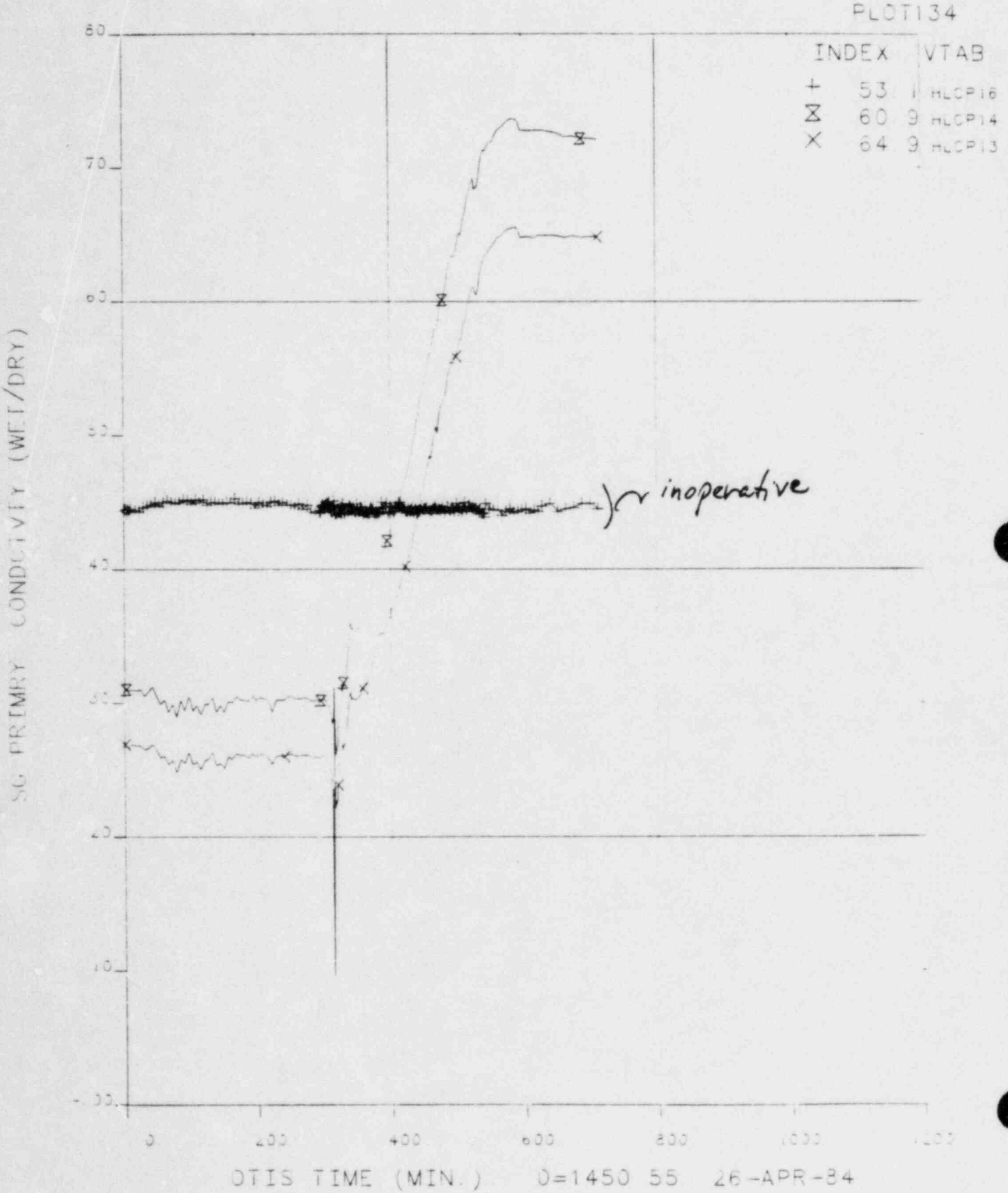

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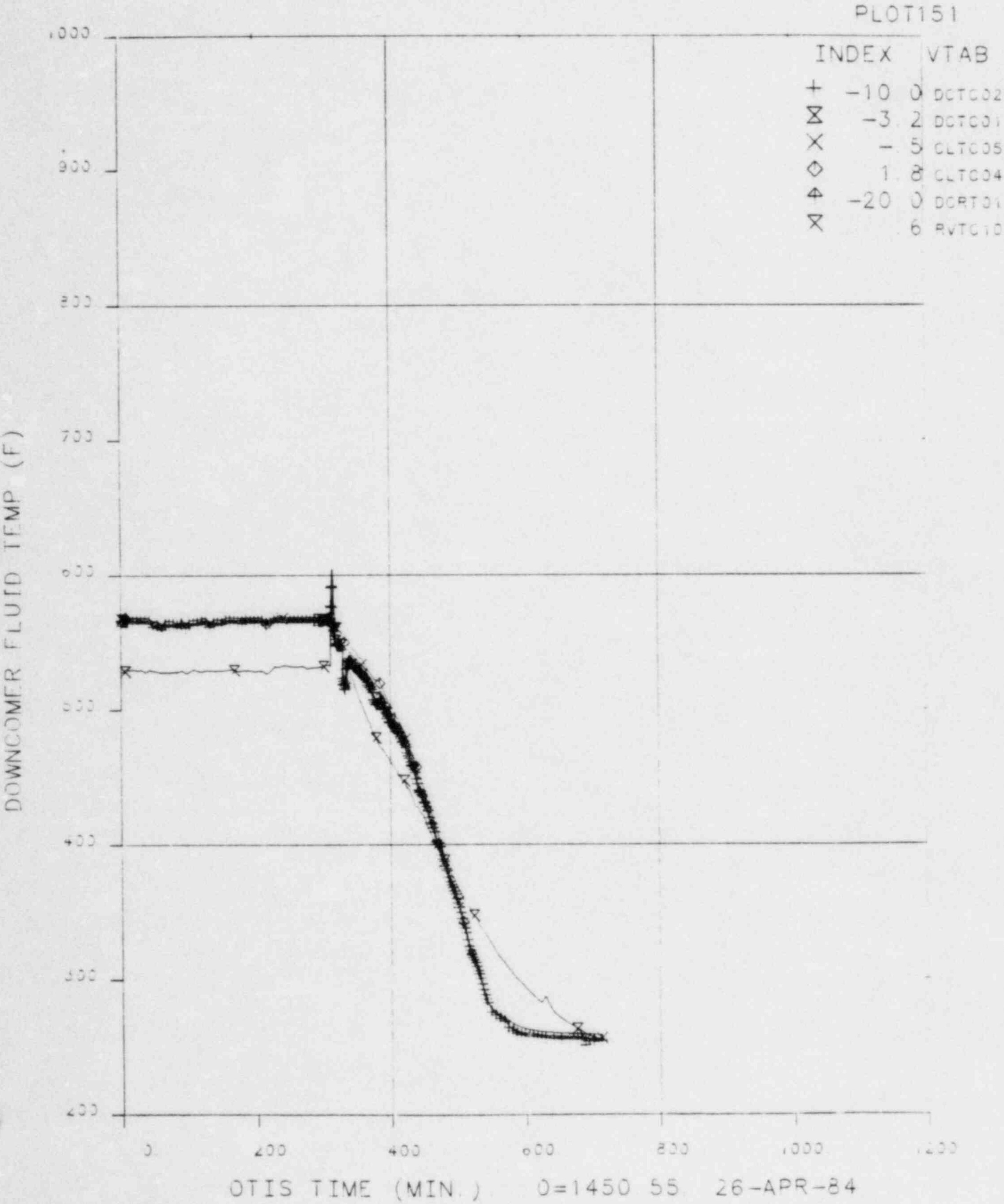

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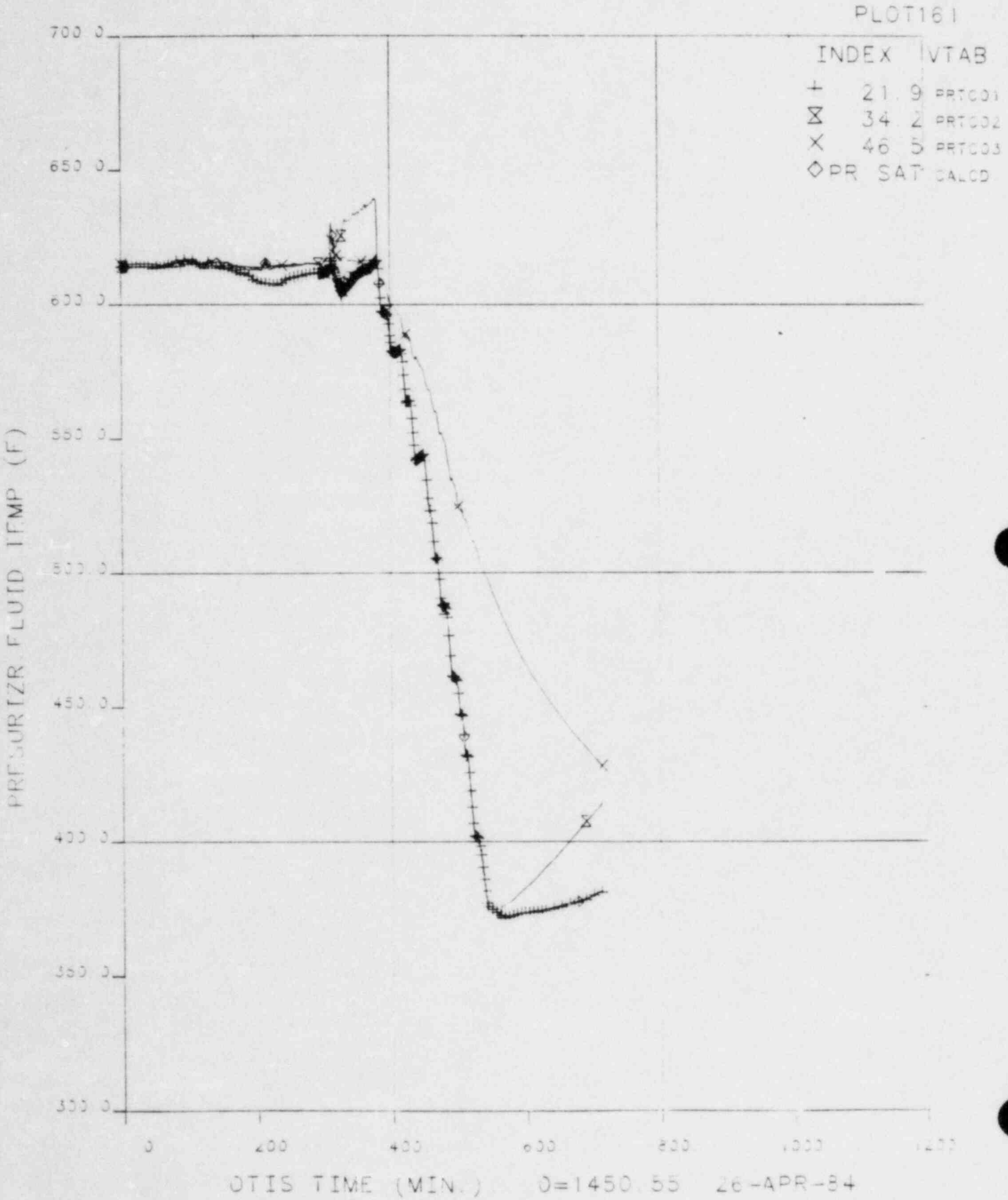

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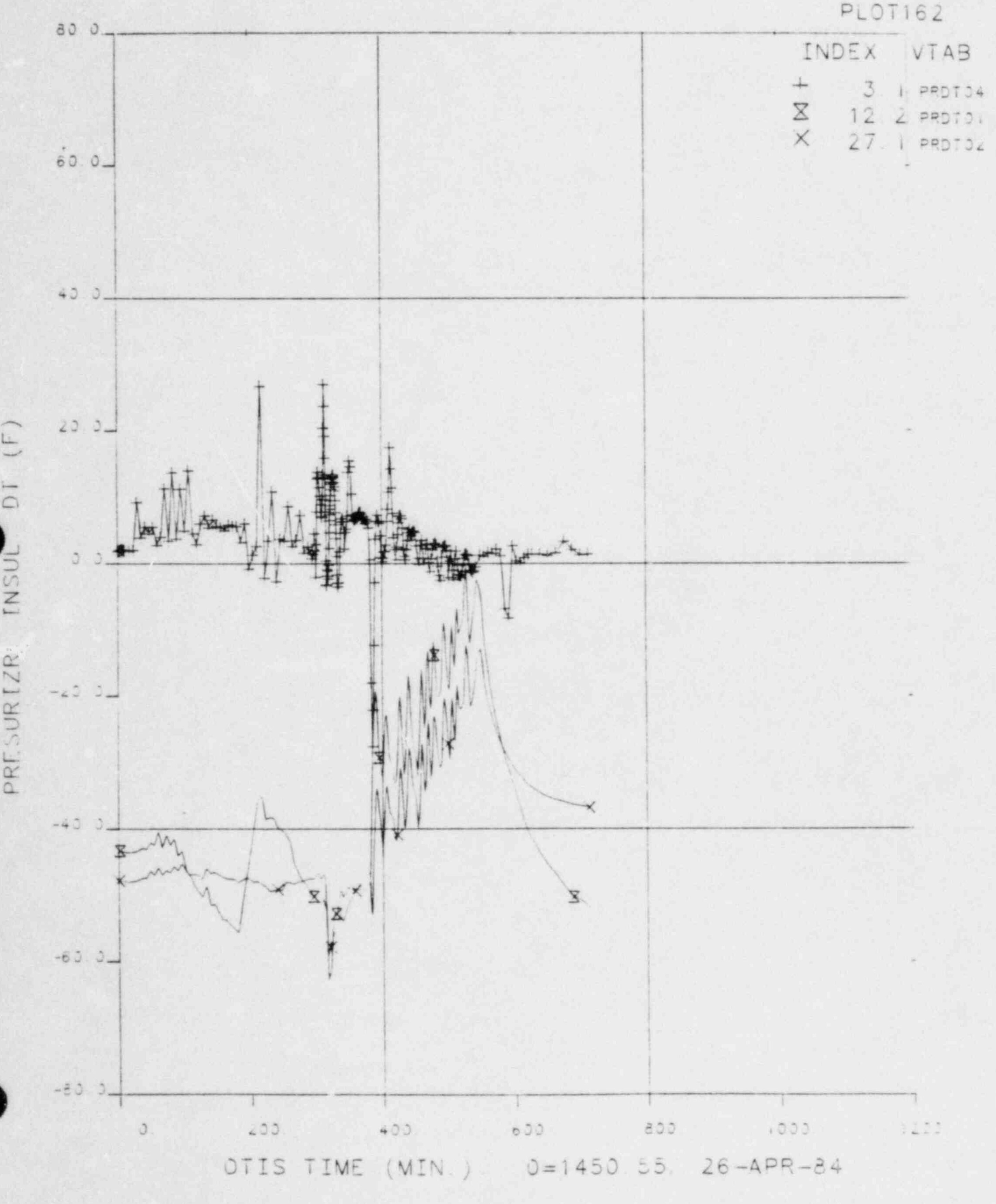

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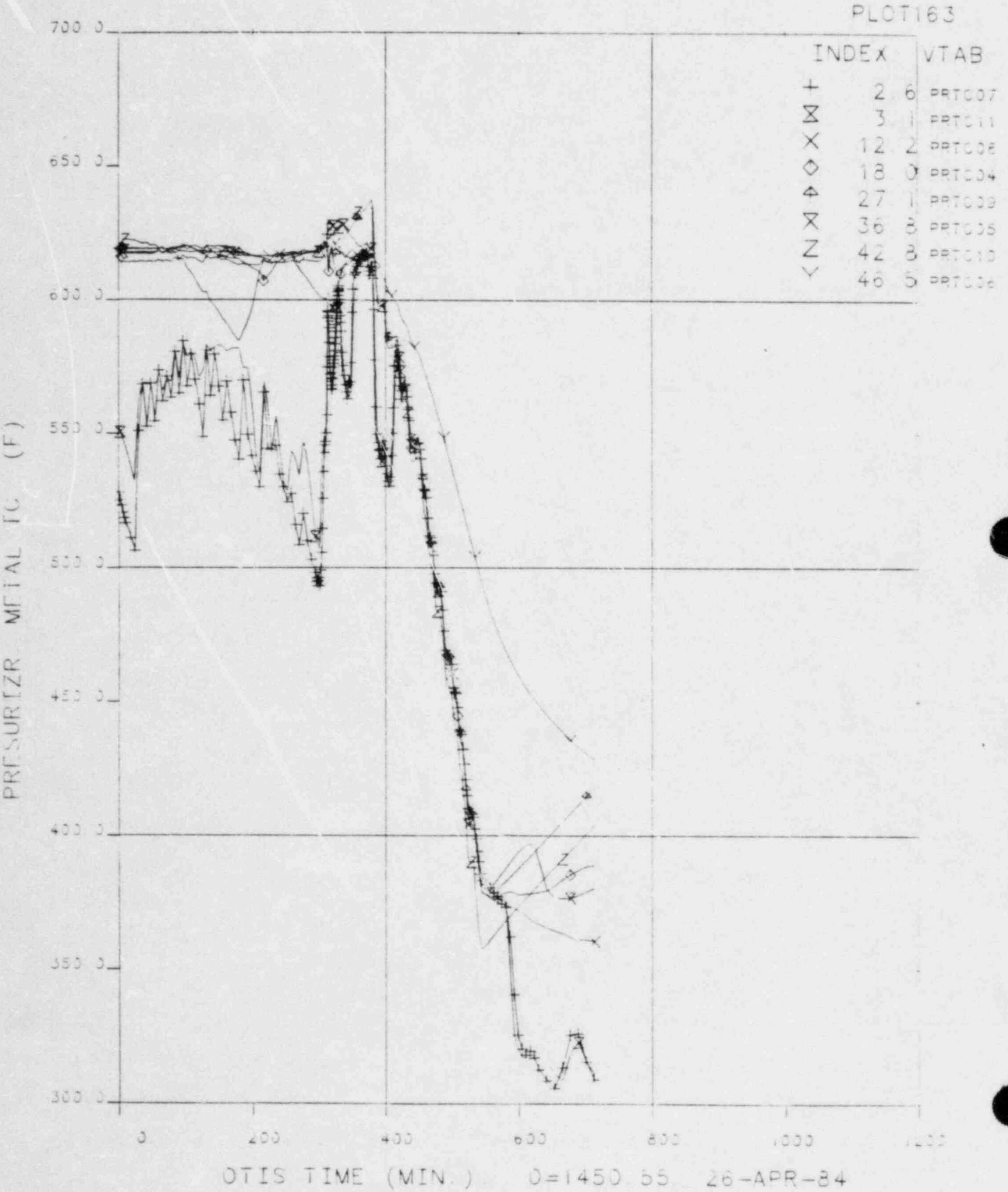

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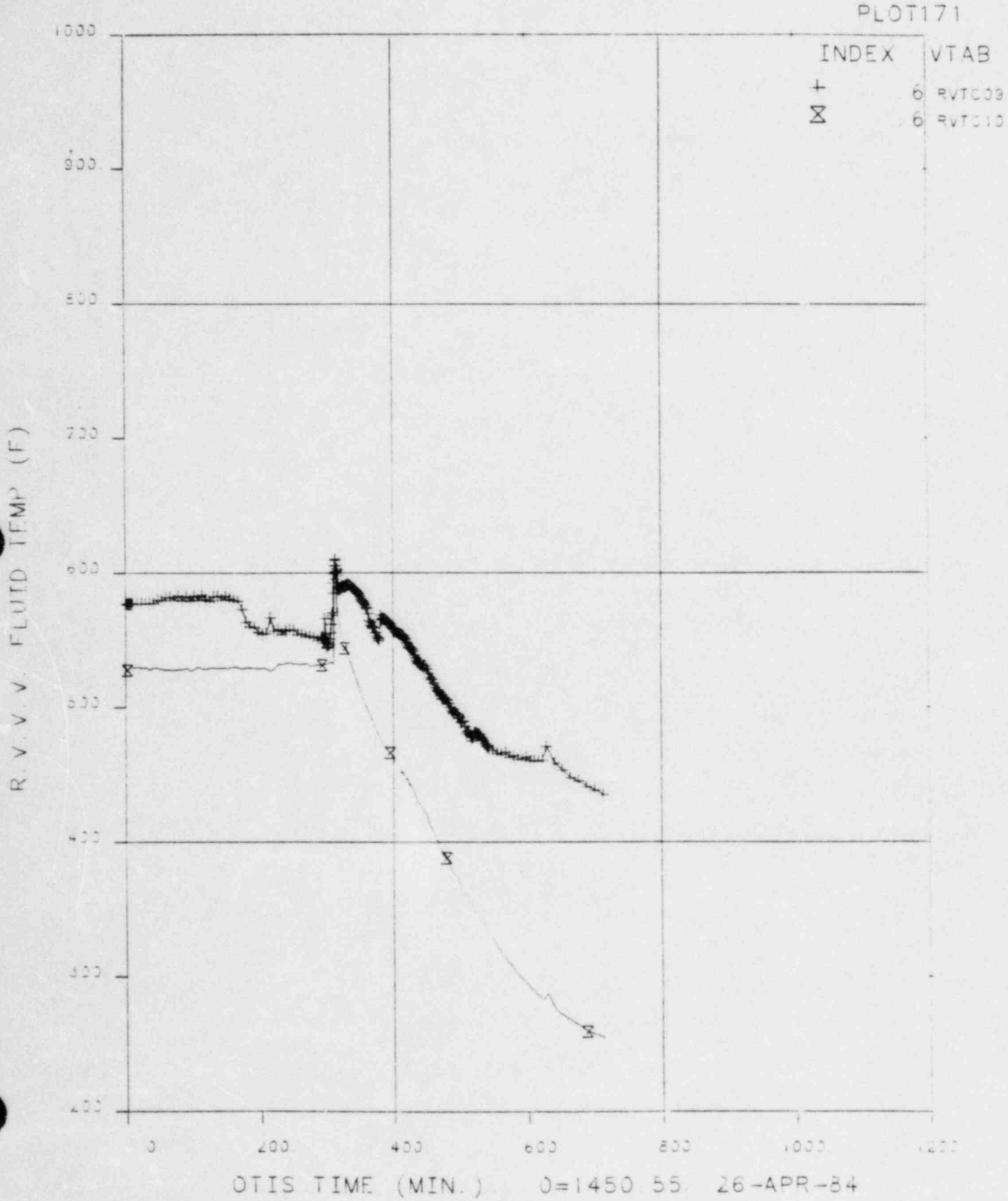

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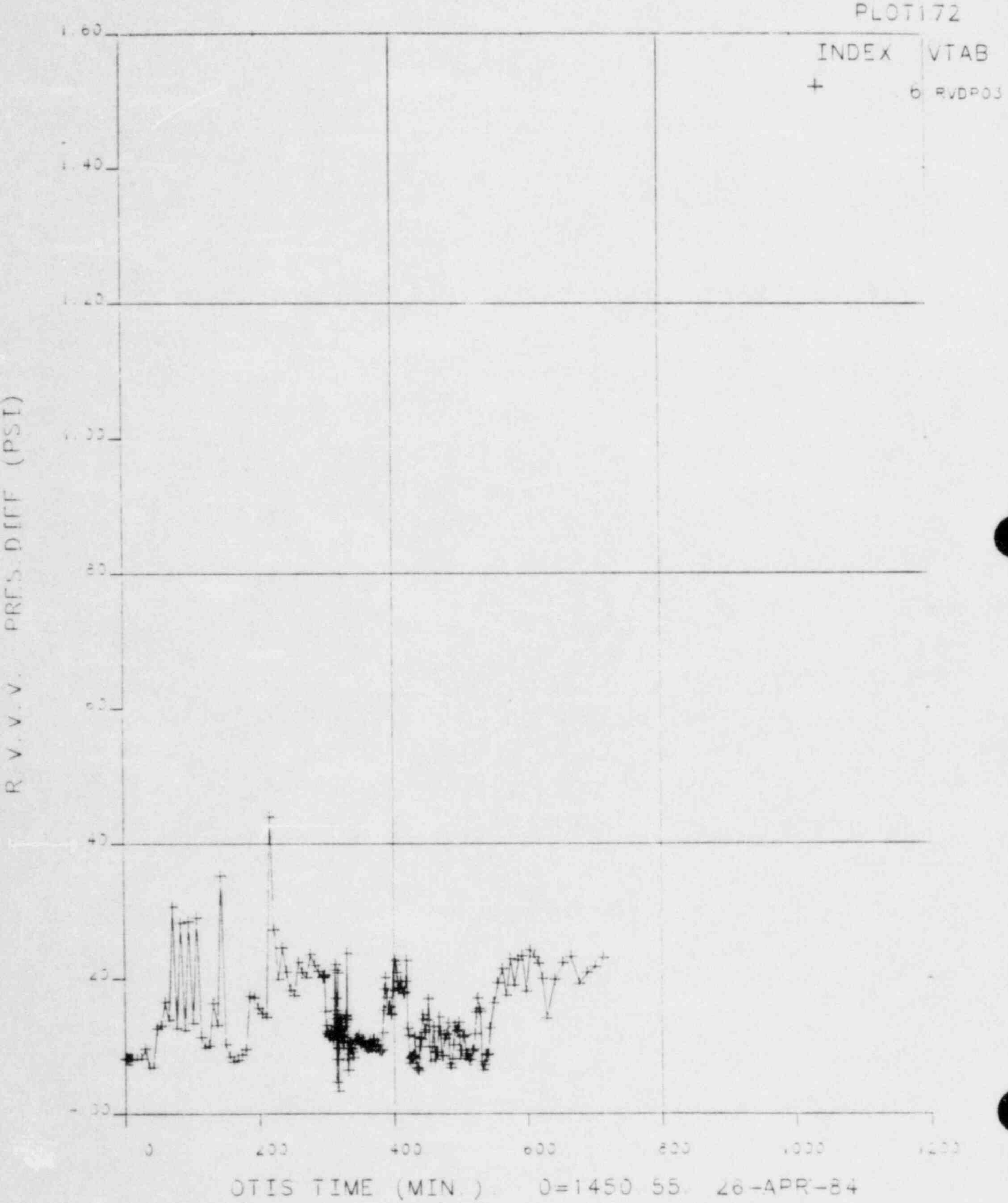

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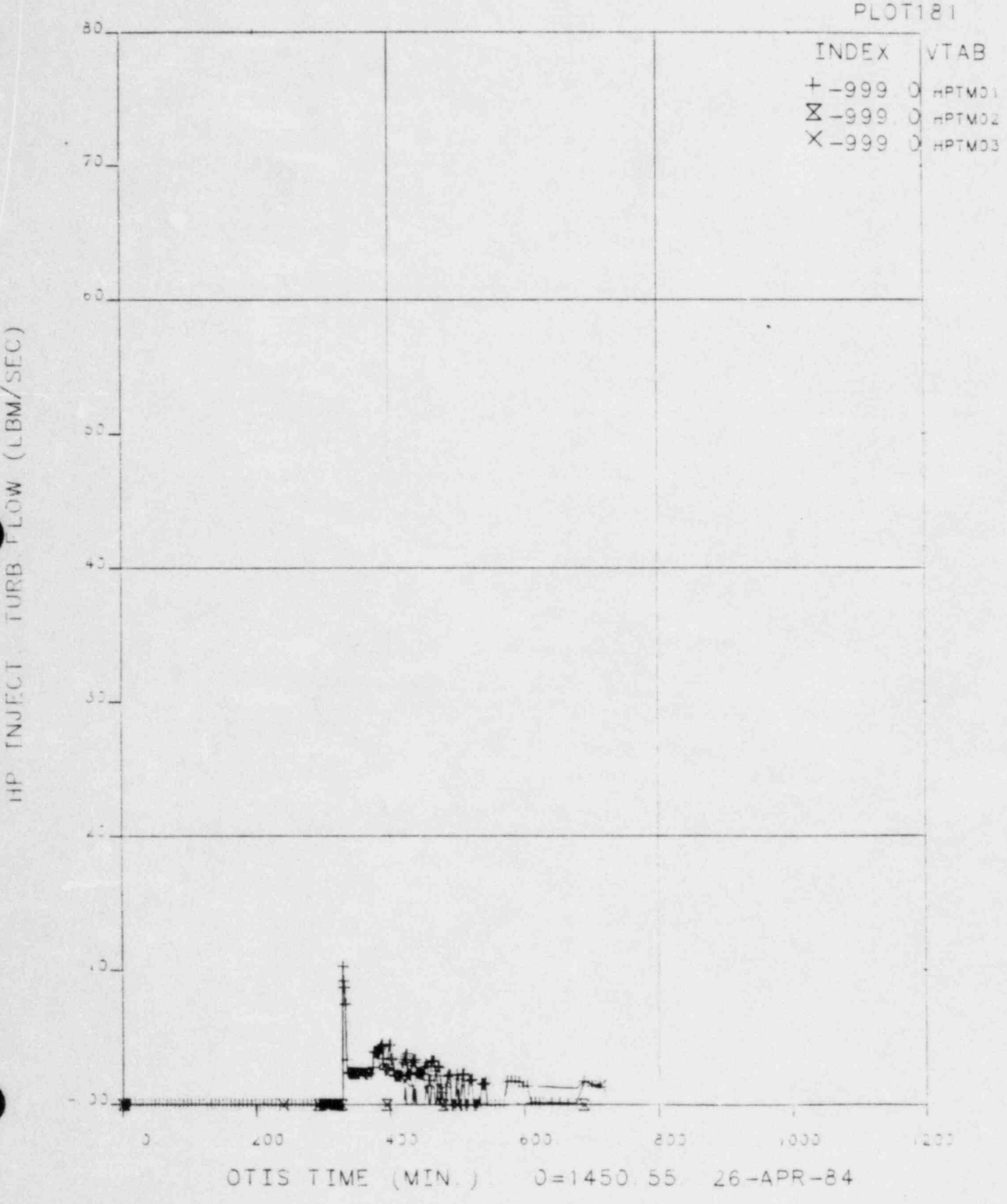

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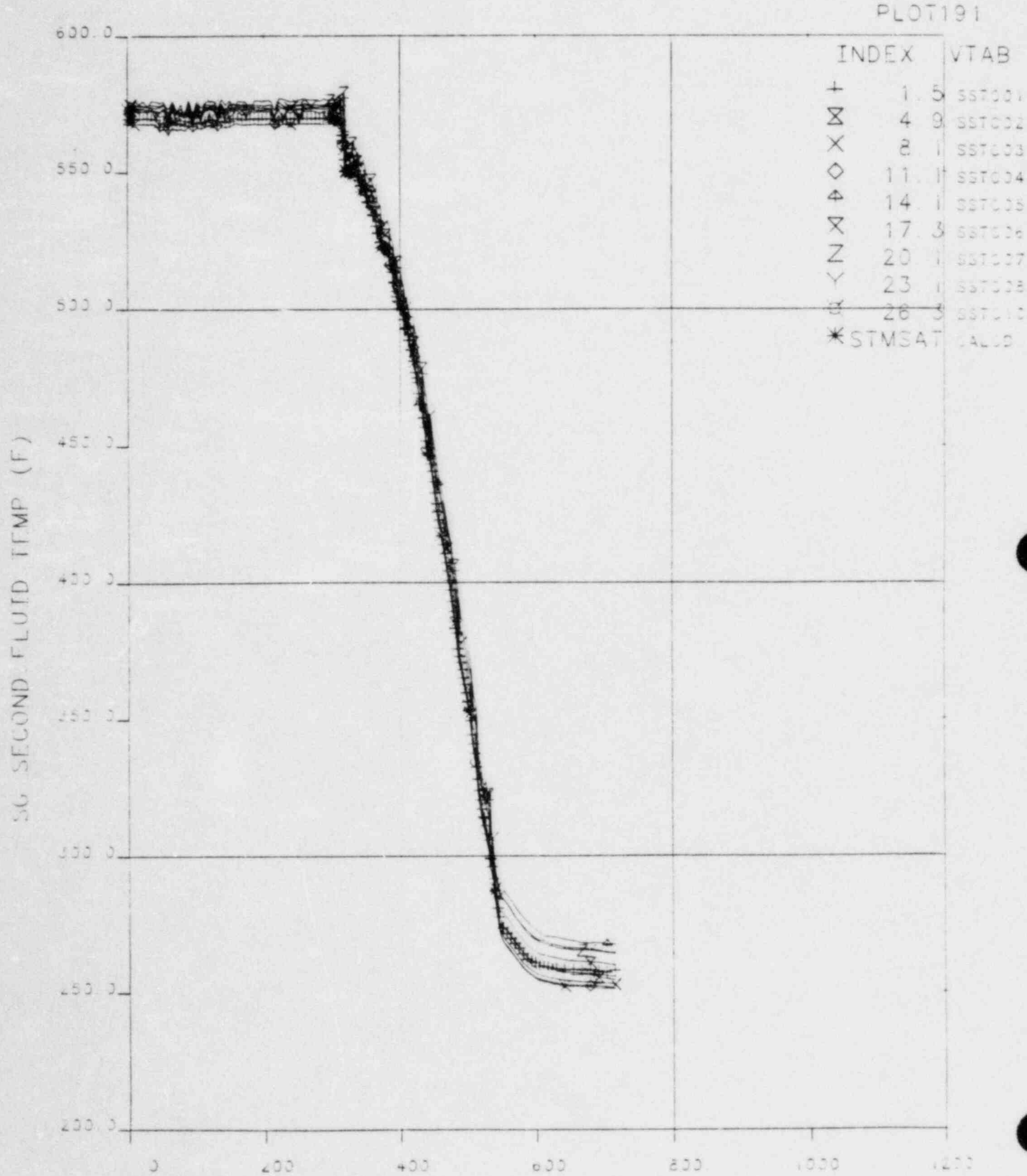

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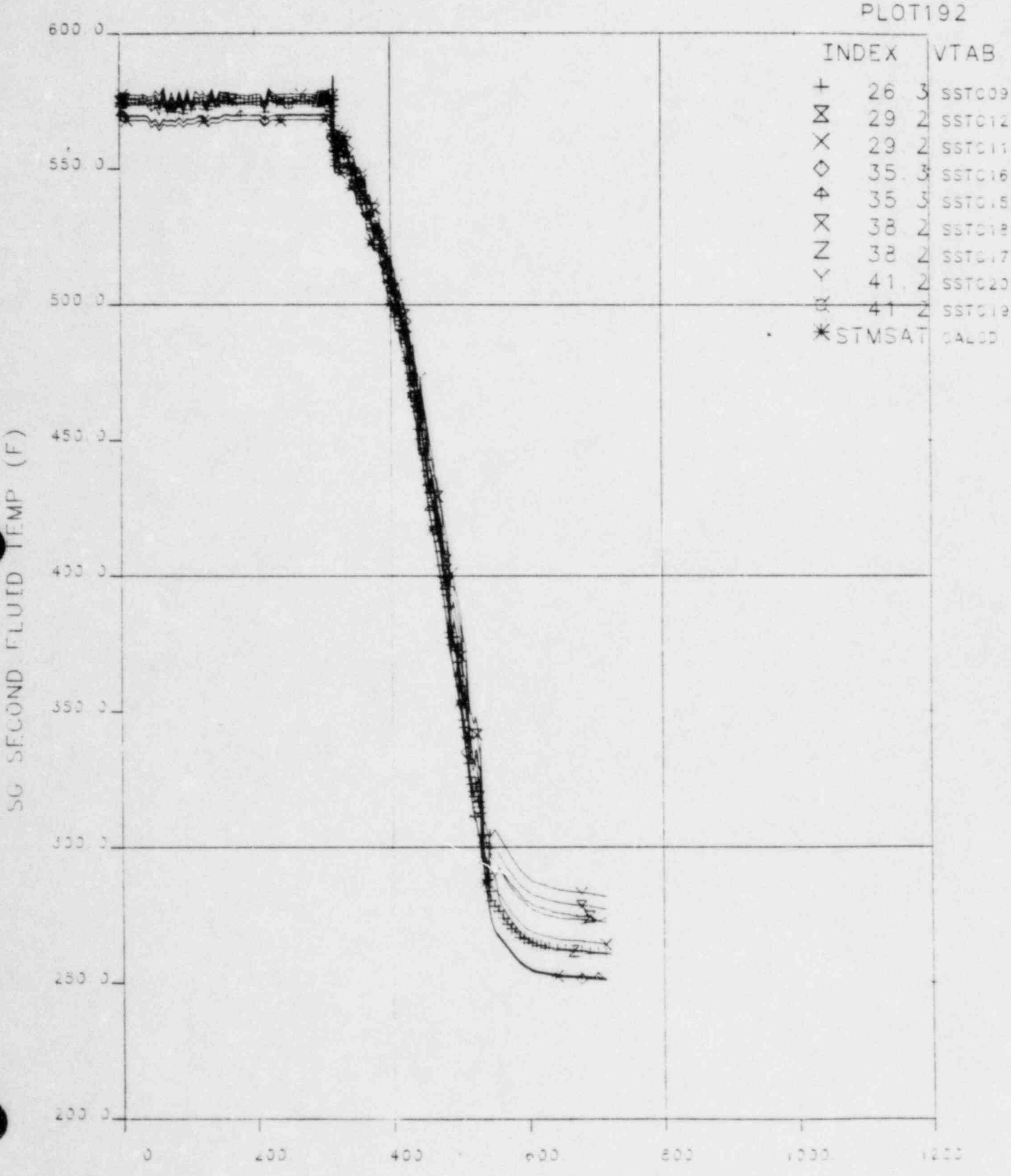

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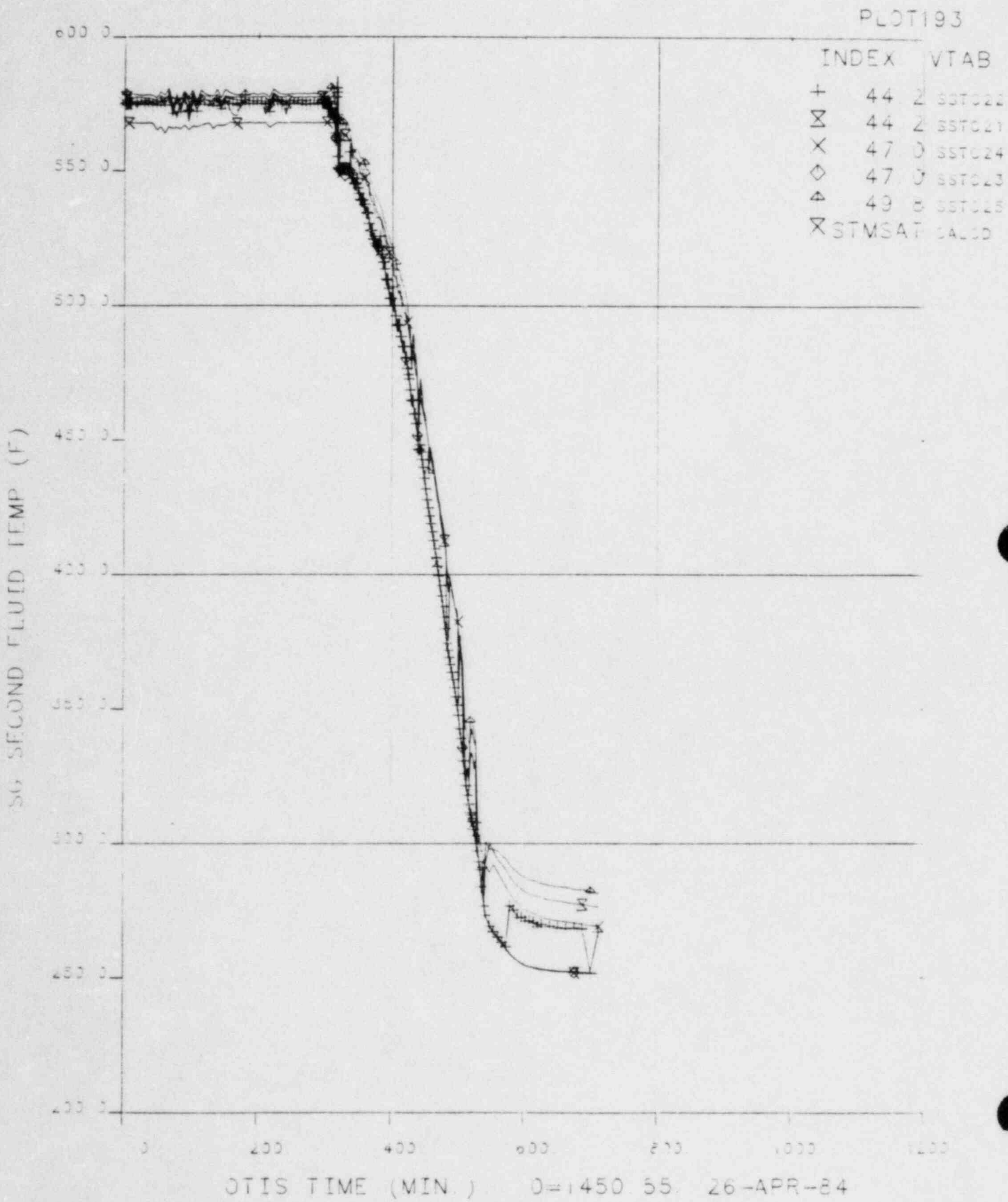

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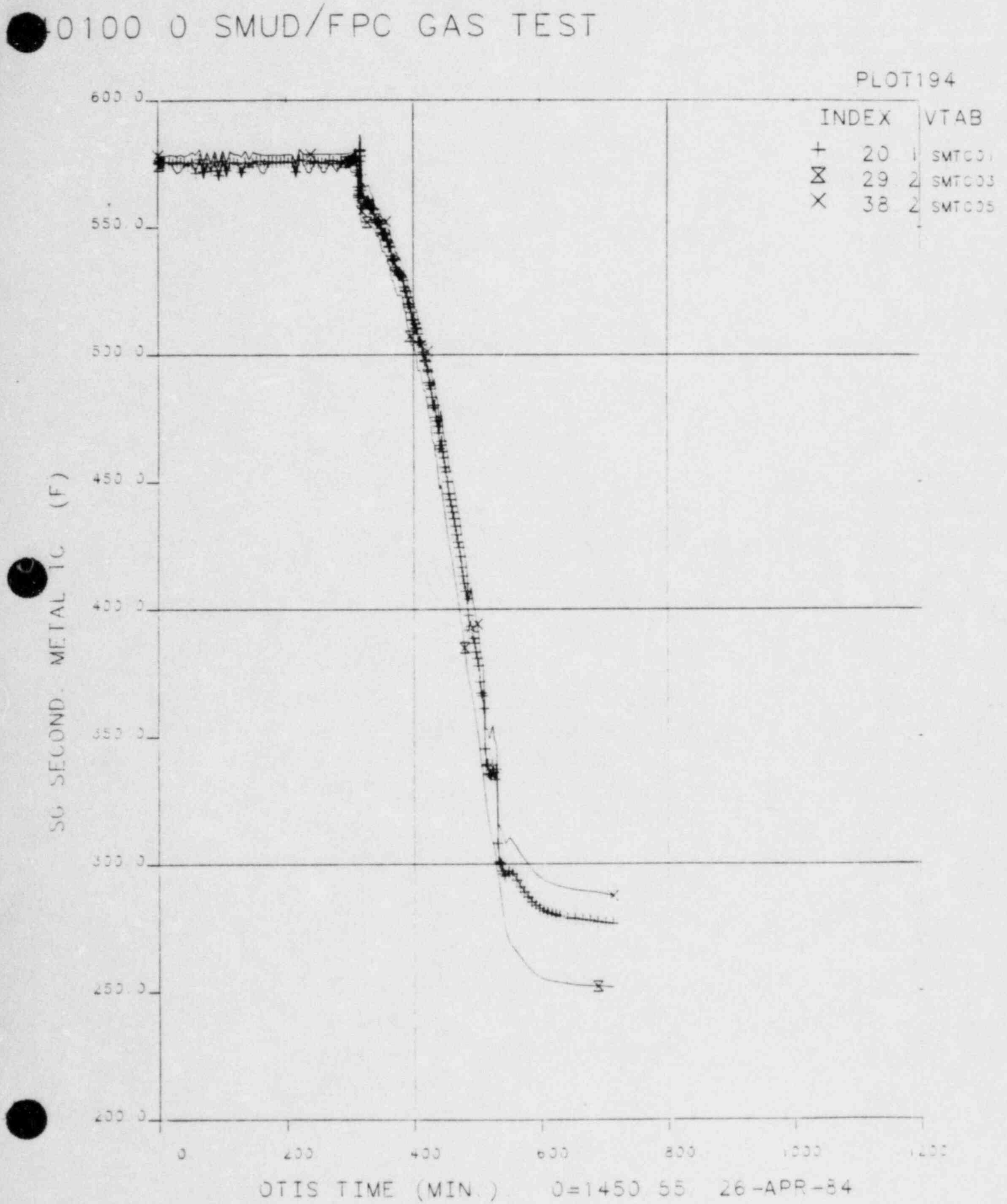

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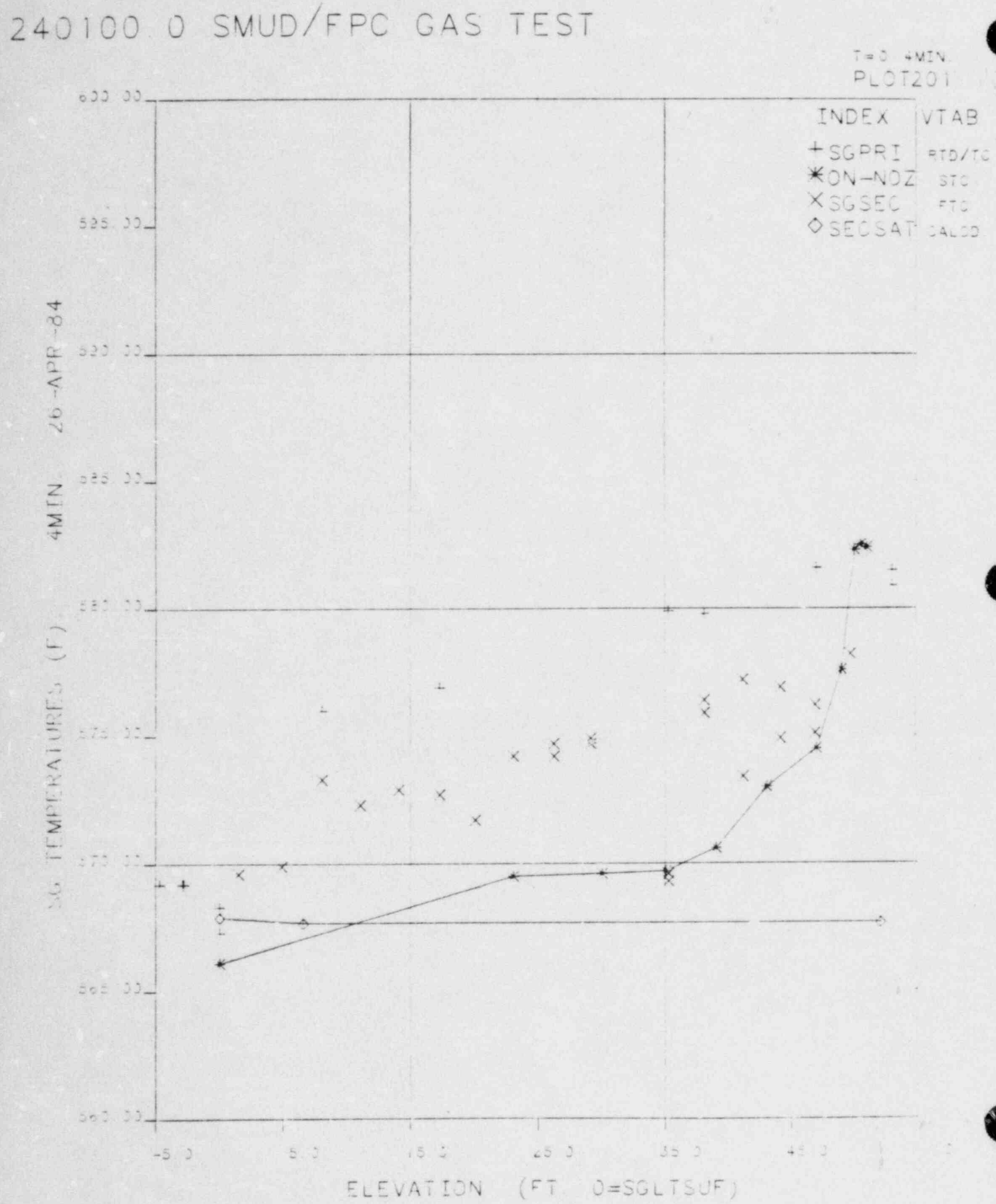

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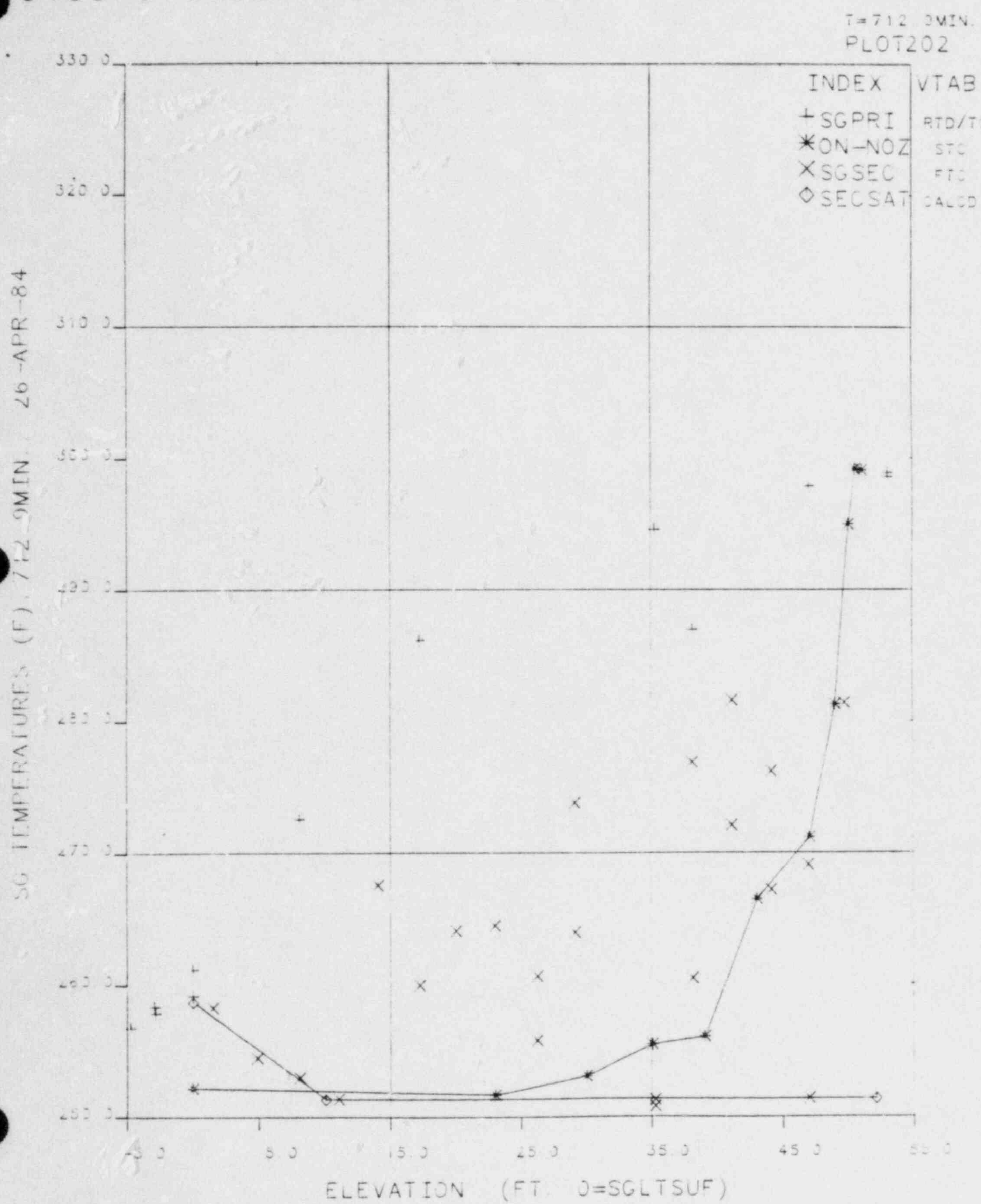

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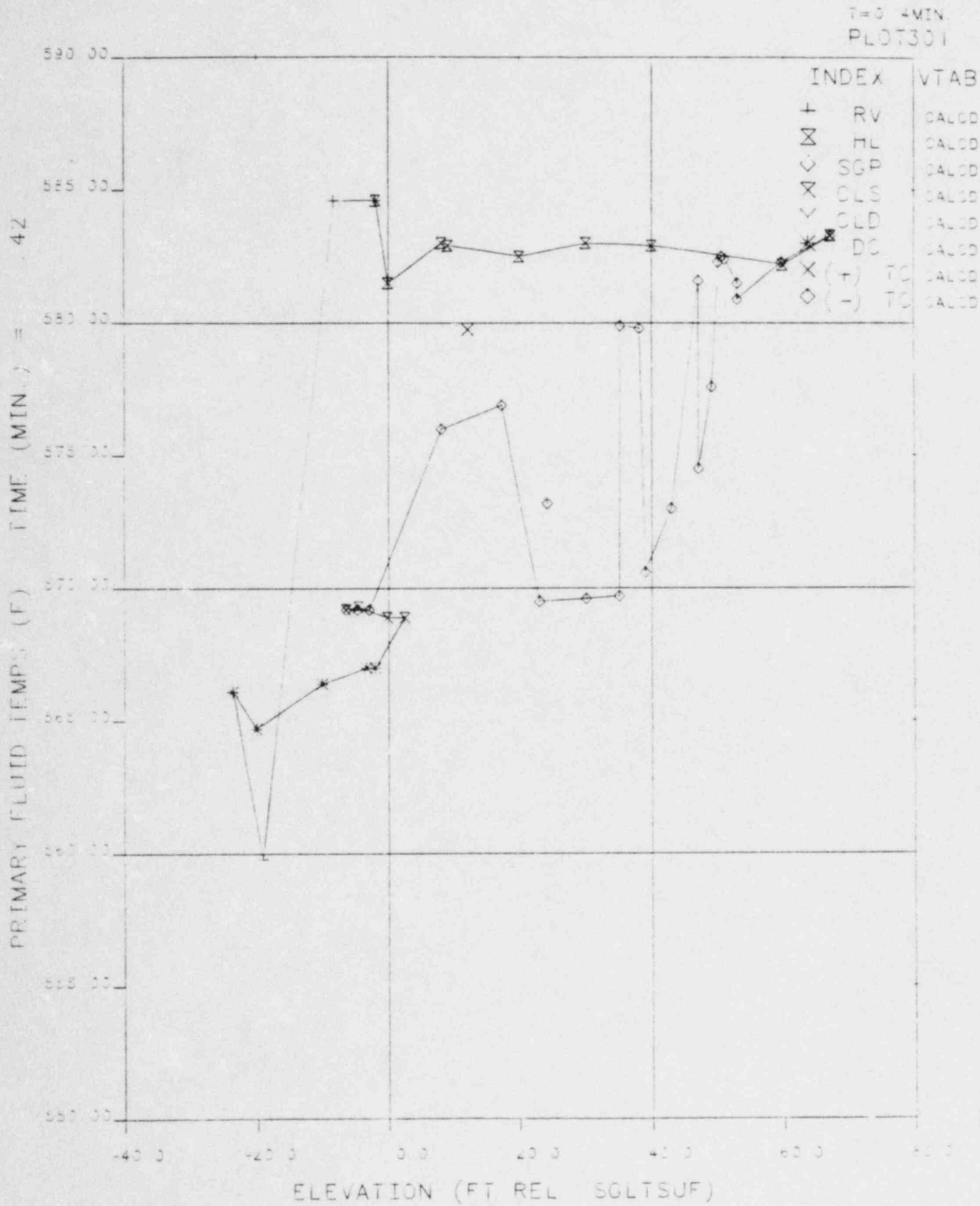

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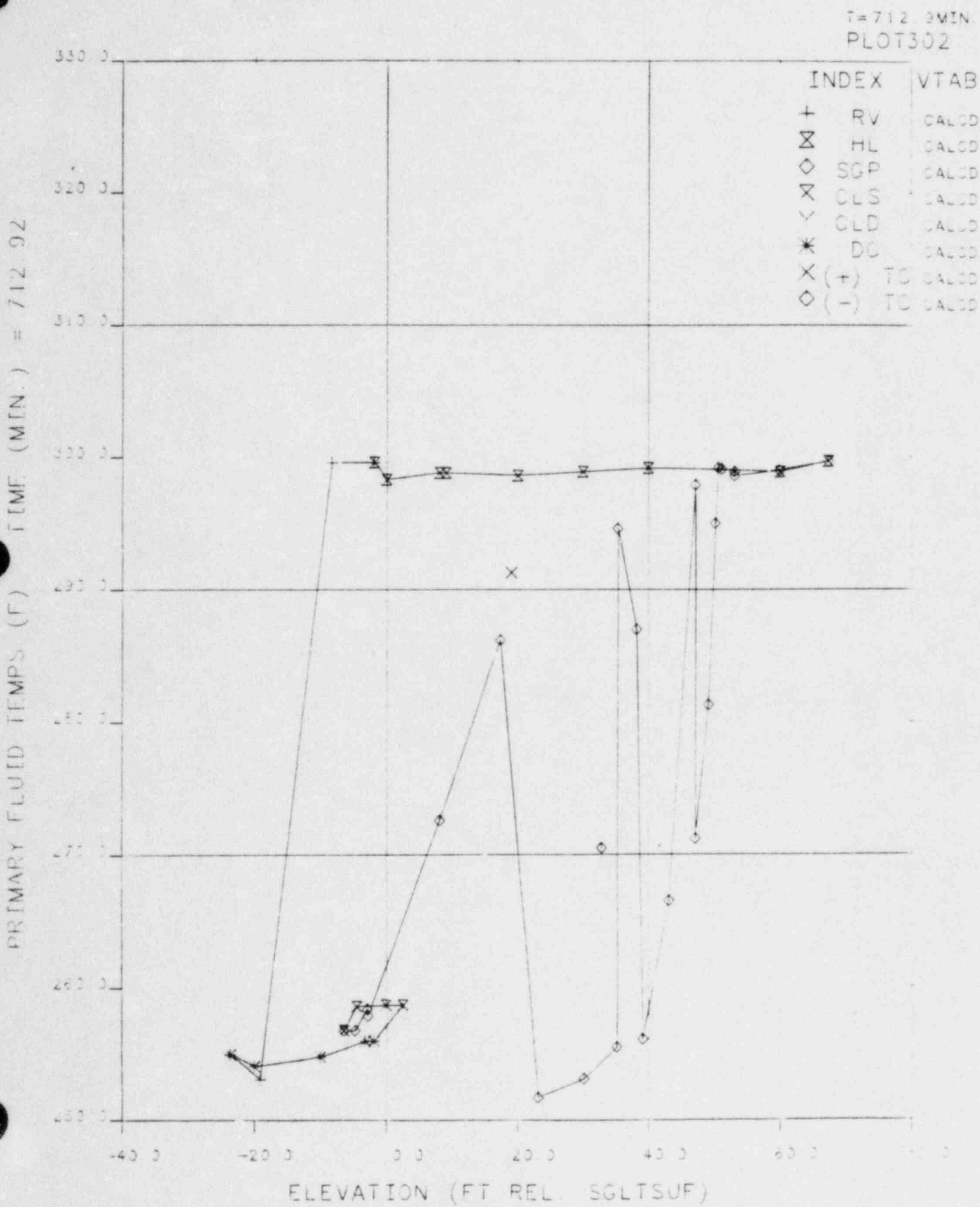

PRELIMINARY DATA

INDEX	INPUT	VTAG	SYSTEM	INST	ELEV	DESCRIPTION
1	61	61RVTC01	1RV	2FTC	-23.70	CORE VESL.FLUID TEMP (F)
2	62	62RVTC02	1RV	2FTC	-19.10	CORE VESL.FLUID TEMP (F)
3	86	86RVTC07	1RV	2FTC	-6.30	CORE VESL.FLUID TEMP (F)
4	67	67RVTC08	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	90RVPW01	1RV	7 C	-13.2	CORE VESL. POWER (FULLPWR
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	63	63RVTC03	1RV	25MTC	-16.00	CORE VESL. METAL TC (F)
18	64	64RVTC05	1RV	25MTC	-11.90	CORE VESL. METAL TC (F)
19	65	65RVTC06	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	30RPR	7.10	CORE VESL. CORRD.PR (PSIA)
23	288	288RVLV20	1RV	31RLV	-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	2.80	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	.30	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	31RLV	-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	38.20	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	53.00	SG PRIMRY. COR.LVLDP (PSI)
75	166	166HLDT04	3SGP	10 DT	57.20	SG PRIMRY. INSUL. DT (F)
76	39	39SPPT04	3SGP	14PTD	-1.90	SG PRIMRY. PITO FLOW (% FULL)
77	40	40SPPT05	3SGP	14PTD	-1.90	SG PRIMRY. PITO FLOW (% FULL)
78	41	41SPPT06	3SGP	14PTD	-1.90	SG PRIMRY. PITO FLOW (% FULL)
79	273	273HLCP16	3SGP	16 CP	53.10	SG PRIMRY. CONDCTVITY (WET/DRY)
80	272	272HLCP15	3SGP	16 CP	56.90	SG PRIMRY. CONDCTVITY (WET/DRY)
81	271	271HLCP14	3SGP	16 CP	60.90	SG PRIMRY. CONDCTVITY (WET/DRY)
82	270	270HLCP13	3SGP	16 CP	64.90	SG PRIMRY. CONDCTVITY (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	37.10	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	35	35SPTC28	3SGP	21STC	51.10	SG PRIMRY. STRING TC (F)
102	209	209HLTC17	3SGP	25MTC	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	279SPPP20	3SGP	30KPP	53.10	SG PRIMRY. CORRD.PR (PSIA)
107	284	284SPLV20	3SGP	31KLV	-2.50	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	276	276CLCR20	4CL	6DPF	-999.00	COLD LEG HEAD-FLOW (FULLFLOW
112	328	328CLLV20	4CL	31KLV	-2.40	COLD LEG COLLD.LVL (REF. FT)
113	126	126DCTC02	5DC	2FTC	-10.00	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	228	228DCCP20	5DC	6DPF	-999.00	DOWNCOMER HEAD-FLOW (FULLFLOW
119	329	329CLLV21	5DC	31KLV	-6.20	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	46.90	PRESURIZR.FLUID TEMP (F)
123	338	338PRDT04	6PR	10 DT	3.10	PRESURIZR. INSUL. DT (F)
124	101	101PRDT01	6PR	10 DT	12.20	PRESURIZR. INSUL. DT (F)
125	102	102PRDT02	6PR	10 DT	27.10	PRESURIZR. INSUL. DT (F)
126	103	103PRDT03	6PR	10 DT	42.40	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	12.00	PRESURIZR. METAL TC (F)
130	107	107PRTC04	6PR	25MTC	18.00	PRESURIZR. METAL TC (F)
131	211	211PRTC09	6PR	25MTC	27.10	PRESURIZR. METAL TC (F)
132	108	108PRTC05	6PR	25MTC	36.30	PRESURIZR. METAL TC (F)

133	227	227PRTC10	6PR	26AI	42.60	PRESURIZR. METAL TC (F)
134	109	109PRTC06	6PR	26MI	46.50	PRESURIZR. METAL TC (F)
135	280	280PRPR20	6PR	30RP	40.50	PRESURIZR. CURRD.PR (PSIA)
136	283	283PRLV20	6PR	31RL	2.50	PRESURIZR. COLLD.LVL (REF. FT)
137	66	66RVTC09	7RVV	2FI	.60	R.V.V.V. FLUID TEMP (F)
138	69	69RVTC10	7RVV	2FI	.60	R.V.V.V. FLUID TEMP (F)
139	95	95RVLPC3	7RVV	6LP	.60	R.V.V.V. PRES.DIFF (PSI)
140	229	229RVLS20	7RVV	26LI	.60	R.V.V.V. LIMIT SW. (O=OPEN)
141	323	323RVLS01	7RVV	24EI	.60	R.V.V.V. MISCELLAN (VARIOUS)
142	324	324RVLS06	7RVV	24EI	.60	R.V.V.V. MISCELLAN (VARIOUS)
143	319	319RVRF20	7RVV	32RO	.60	R.V.V.V. CALC.FLOW (% FULL)
144	113	113HPTC01	10HPI	2FI	-999.00	HP INJECT.FLUID TEMP (F)
145	222	222HPTM01	10HPI	13TM	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
146	223	223HPTM02	10HPI	13TM	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
147	224	224HPTM03	10HPI	13TM	-999.00	HP INJECT. TURB.FLOW (LBM/SEC)
148	218	218HPAC01	10HPI	14AC	-999.00	HP INJECT. ACCD.FLOW (LBM)
149	219	219V1AC01	11V1	14AC	-999.00	1-PH VENT. ACCD.FLOW (LBM)
150	230	230V1LS01	11V1	26LI	-999.00	1-PH VENT. LIMIT SW. (O=OPEN)
151	231	231V1LS02	11V1	26LI	-999.00	1-PH VENT. LIMIT SW. (O=OPEN)
152	232	232V1LS03	11V1	26LI	-999.00	1-PH VENT. LIMIT SW. (O=OPEN)
153	317	317V1RF20	11V1	30FL	-999.00	1-PH VENT. CALD.FLOW (LBM/SEC)
154	220	220V2AC01	12V2	14AC	-999.00	2-PH VENT. ACCD.FLOW (LBM)
155	221	221V2AC02	12V2	14AC	-999.00	2-PH VENT. ACCD.FLOW (LBM)
156	233	233V2LS01	12V2	26LI	-999.00	2-PH VENT. LIMIT SW. (O=OPEN)
157	234	234V2LS03	12V2	26LI	-999.00	2-PH VENT. LIMIT SW. (O=OPEN)
158	318	318V2RF20	12V2	30FL	-999.00	2-PH VENT. CALD.FLOW (LBM/SEC)
159	198	198FPRTC3	21AFW	3RT	-999.00	AUX. FEED FLUID RTD (F)
160	345	345SFLS01	21AFW	26LI	-999.00	AUX. FEED LIMIT SW. (O=OPEN)
161	346	346SFLS02	21AFW	26LI	-999.00	AUX. FEED LIMIT SW. (O=OPEN)
162	294	294SFCR20	21AFW	33RC	-999.00	AUX. FEED CALC.FLOW (% FULL)
163	295	295SFFF01	21AFW	34AV	-999.00	AUX. FEED AVG. TEMP (F)
164	65	65SSTC01	22SGS	2FI	1.50	SG SECOND.FLUID TEMP (F)
165	64	64SSTC02	22SGS	2FI	4.90	SG SECOND.FLUID TEMP (F)
166	63	63SSTC03	22SGS	2FI	8.10	SG SECOND.FLUID TEMP (F)
167	62	62SSTC04	22SGS	2FI	11.10	SG SECOND.FLUID TEMP (F)
168	61	61SSTC05	22SGS	2FI	14.10	SG SECOND.FLUID TEMP (F)
169	60	60SSTC06	22SGS	2FI	17.30	SG SECOND.FLUID TEMP (F)
170	59	59SSTC07	22SGS	2FI	20.10	SG SECOND.FLUID TEMP (F)
171	58	58SSTC08	22SGS	2FI	23.10	SG SECOND.FLUID TEMP (F)
172	56	56SSTC10	22SGS	2FI	26.30	SG SECOND.FLUID TEMP (F)
173	57	57SSTC09	22SGS	2FI	26.30	SG SECOND.FLUID TEMP (F)
174	54	54SSTC12	22SGS	2FI	29.20	SG SECOND.FLUID TEMP (F)
175	55	55SSTC11	22SGS	2FI	29.20	SG SECOND.FLUID TEMP (F)
176	53	53SSTC13	22SGS	2FI	32.30	SG SECOND.FLUID TEMP (F)
177	51	51SSTC16	22SGS	2FI	35.30	SG SECOND.FLUID TEMP (F)
178	52	52SSTC15	22SGS	2FI	35.30	SG SECOND.FLUID TEMP (F)
179	49	49SSTC18	22SGS	2FI	38.20	SG SECOND.FLUID TEMP (F)
180	50	50SSTC17	22SGS	2FI	38.20	SG SECOND.FLUID TEMP (F)