NUREG/CR-1154
GEAP-21304-18
NRC-2
NRC-EPRI-GE Cooperative
Research and Development Report
July 1980
DRF E00-5

BWR BLOWDOWN/EMERGENCY CORE COOLING EIGHTEENTH QUARTERLY PROGRESS REPORT
APRIL 1 — JUNE 30, 1980

W. S. Hwang

Approved:
G. W. Burnette, Program Manager
BWR BD/ECC Program

Approved:
G. L. Sozzi, Manager
LOCA Systems Technology

Approved:
G. E. Dix, Manager
Safety and Thermal Hydraulic Technology

Approved:
J. E. Wood, Manager
Core Methods & Analysis

Prepared for the
United States Nuclear Regulatory Commission and
Electric Power Research Institute
Under Contract NRC-04-76-215

Printed in the United States of America

GENERAL ELECTRIC

NUCLEAR ENGINEERING DIVISION • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

8105280459

LEGAL NOTICE

CONTENTS

APPENDICES

ABSTRACT

Blowdown/Emergency Core Cooling work completed in the second quarter of (April 1 to June 30) of 1980 is summarized. During this quarter efforts to improve flow measurements with the turbine flow meter and drag disc flow meter were made. Five separate effects (boil-off) tests were conducted in TLTA and data evaluation of these tests is continuing. Significant efforts to evaluate the test data of the previously completed large break integral system tests were carried out. Many test reports including large break, small break, and separate effects (boil-off) tests were issued and some data are included herein.

1. INTRODUCTION

1.1 GENERAL

A major requirement in the design of power reactor systems is the limitation of fuel cladding temperatures below specified values during both normal operation and an unlikely, but postulated, loss-of-coolant-accident (LOCA). To meet this design requirement it is necessary to be able to predict system performance during a LOCA. Since this type of information is not obtainable from tests on actual reactors, scaled system test programs are used to provide basic system performance information. The BWR Blowdown/Emergency Core Cooling (BD/ECC) Program[1] extends the scope of the BWR Blowdown Heat Transfer (BDHT) Program to include ECC system operation. Results from the BD/ECC Program will provide a basis for evaluating BWR system phenomena throughout the entire LOCA transient from break initiation to core reflood.

1.2 PROGRAM OBJECTIVES

The BWR BD/ECC Program charter is to conduct an experimental program, jointly funded by the U.S. Nuclear Regulatory Commission (USNRC), Electric Power Research Institute (EPRI), and General Electric (GE), to obtain information on transient heat transfer following an unlikely, but postulated rupture of a steam line or recirculation line in a boiling water reactor (BWR). This program will:

1. obtain and evaluate basic BD/ECC data from test system configurations which have calculated performance characteristics similar to a BWR with 8x8 fuel bundles during a hypothetical LOCA; and
2. determine the degree to which models for the BWR system and fuel bundles describe the observed phenomena and, as necessary, develop improved models which are generally useful in improved LOCA analysis methods.

Requirements of the BWR BD/ECC Program include use of a test apparatus which will provide LOCA test conditions representative of the environment expected in the postulated BWR LOCA. The scaling and design objectives are to provide a test apparatus for investigating, on a real time basis, the expected BWR fuel thermal-hydraulic response, using an electrically heated, full-sized, full-power test bundle.

1.3 ORGANIZATION OF THE PROGRAM

The BD/ECC Program contract was executed in December 1975. The total BD/ECC Program work scope is shown in Appendix A. A report schedule is contained in Appendix B.

1.4 STATUS OF THE PROGRAM

A number of the completed and reported major milestones are presented below. Appendix B indexes the significant publications pertaining to these milestones.

1. Formulation of program plan[1] and 8x8 BDHT test plan[2] (Task AA).*
2. An evaluation of electric heaters for use in the BD/ECC Program (Task BB).
3. Issuance of report on the transient thermal-hydraulic model, MAYU04.[3]
4. Distribution of facility description report[4] for the BD/ECC 1A phase.

---

*See Appendix A for task description.

5. Issuance of revised BD/ECC 1A test plan.[5]

6. 64-Rod Bundle Test Topical Report completed.[6]

During the second quarter of 1980, five boil-off tests were successfully executed. The test data of several large break, small break and boil-off tests were reported. BD/ECC 1A phase testing will be completed soon. The TLTA configuration for BD/ECC 1B has not been agreed upon, as yet, so additional experimental work cannot be planned pending this important decision by the program sponsors.

2. PROGRAM PLANNING AND ADMINISTRATION

A Program Management Group (PMG) meeting was held in San Jose on 14–15 April 1980. In addition to administrative matters, a number of technical items were reviewed including small break test results, large break test results, and planning for the separate effects (boil-off) tests. Advantages and disadvantages of various facility options which might be used under a contemplated program modification were also reviewed.

A number of significant agreements were reached by the PMG including: (1) agreement to review facility options with respective sponsoring managements concerning interest and next actions on a multibundle facility or other facility options; (2) agreement to delete the Non-Jet Pump and Alternate Power Shape Tests in favor of higher priority tests; (3) agreement on the balance of large break tests in the current test phase as: (a) peak power, average ECC and (b) average power, average ECC*; and (4) agreement on a series of separate effects (boil-off) tests to be completed.

A significant milestone will be met in August: completion of the BD/ECC 1A large break test series. The TLTA configuration for BD/ECC 1B has not been agreed upon as yet, so additional experimental work cannot be planned pending this important decision by the program sponsors.

---

*These tests will be executed with the improved, direct measurements of break flows.

3. EXPERIMENTAL WORK

3.1 BD/ECC 1A TESTING

The planned series of five separate effects boil-off tests were successfully completed in the TLTA. The objective of these separate effects tests was to evaluate bundle heatup at constant power and system pressure as the mixture level slowly uncovered the bundle. The system pressure and power levels for each test were steady but varied from test to test. Evaluation of preliminary results indicates that the test conditions were satisfactorily met. Data evaluation is continuing.

4. ANALYTICAL EFFORT

4.1 BD/ECC-1A DATA EVALUATIONS

The status of analysis effort on TLTA test data was reviewed in the April 14-15 PMG meeting. The status of data verification for each test was reviewed with the PMG, and the priority of issuing the data reports was set by the PMG. Highlights of large and small break tests were presented and presentation materials are included in Appendix C. The test results are summarized below.

4.1.1 Highlights of the Large Break Reference Test

The main points discussed on the reference test (6422/R3, average power, average ECC rate) were:

1. Realistic bundle power simulation in TLTA 5A contributes to lower peak cladding temperatures (PCT). The maximum PCT is less than 700°F (see Figure C-1).
2. Improved simulation of the bypass flow path coupled with counter current flow limiting (CCFL) at the side entry orifice (SEO) allows the bundle to reflood with two-phase mixture prior to refilling the lower plenum (see Figure C-2).
3. CCFL breaks down at the upper tie plate after the bypass region refills (see Figure C-3). This further contributes to reflooding the bundle (see Figure C-2).
4. The lower plenum partially refills. At the end of the test (~400 seconds) the lower plenum level (Figure C-2) is just above the jet pump exit and the ECC fluid that drains through the bundle is discharged out the jet pumps.

4.1.2 Highlights of Small Break Test 2

1. The system pressure remains high until the automatic depressurization system (ADS) is activated (Figure C-4).
2. The mixture levels as shown in Figure C-5 indicate the bundle was covered with two-phase mixture for the entire transient, while a two-phase mixture level was seen in the lower plenum and bypass after the ADS initiation. The fast system depressurization due to the activation of ADS resulted in flashing and high vapor generation which led to the occurrence of the CCFL at the SEO. This CCFL phenomena at the SEO prevents the bundle mass inventory from draining into the lower plenum and, hence, maintains a low void fraction in the bundle during the entire transient.
3. No heatup occurred throughout the bundle for the entire transient (see Figures C-6 and C-7).

4.2 TEST DATA REPORT

Significant efforts were performed during this quarter to verify, analyze, and issue data reports. The major accomplishments are summarized below.

4.2.1 Large Break Tests

1. The large break reference test in TLTA 5A (No. 6422/Run 3) was verified and issued. (Appendix D).
2. The data report for the peak power, low flow — high temperature ECC test (6423/Run 3) was nearly completed and will be issued shortly.

3. An analytical effort has been underway to evaluate bundle heat transfer coefficients and local conditions in the 8×8 bundle, based on available BD/ECC 1A test results. The scope of this effort is summarized in Appendix E.

4.2.2 Small Break Tests

1. The data report for the first TLTA small break test (6431/Run 1) was completed and issued (Appendix F).
2. The data report for the second TLTA small break test (6432/Run 1) was completed and issued (Appendix G).

4.2.3 Separate Effects Tests

A preliminary report on the separate effects (boil-off) test was completed and some data are included in Appendix H. The system responses were as expected; there was no indication of new phenomena.

5. TWO-LOOP TEST APPARATUS

5.1 TEST SECTION DESIGN AND FABRICATION

Changeover of the facility from small break to large break configuration was started. Setup for the boil-off tests was also completed. Periodic recalibration of instruments was completed, the safety valves were retested, and other needed facility maintenance was performed.

The modified turbine meters and drag discs for use in the large break blowdown lines were installed. These units have been modified by Measurements Incorporated, Idaho Falls, Idaho, to include:

- new turbine rotors for different ranges
- increased target sizes on both drag discs
- new RF-type turbine meter sensors and preamplifier electronics
- modified readouts for the turbine meters

An adiabatic blowdown transient (zero bundle power and no ECC injection) was used to check the blowdown flow measurement system. Preliminary results showed that the drag discs and turbine meters performed satisfactorily. A transducer added to measure the level in the suppression tank performed successfully after the initial blowdown transient was completed. Detailed data processing has been in progress to compare these blowdown flow measurements with those calculated using the rate of change of the mass inventory within the pressure vessel.

Some shakedown tests were conducted to confirm the operation of these devices. All units operated satisfactorily in a test in which the system depressurized from full pressure and temperature conditions but with low bundle (~300 kw). Output from the turbine meters was not affected by SCR noise associated with bundle power supply, so apparently this problem has also been solved.

Preparations for the next test matrix were complete. All testing with the current facility configuration is scheduled for completion during August.

6. REFERENCES

1. R. J. Muzzy, *Preliminary BWR Blowdown/Emergency Core Cooling Program Plan*, General Electric Company, June 1976 (GEAP-21255).

2. J. P. Walker, *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Blowdown Heat Transfer Test Plan*, General Electric Company, September 1976 (GEAP-21333).

3. W. C. Punches, *MAYU04 — A Method to Evaluate Transient Thermal Hydraulic Conditions in Rod Bundles*, General Electric Company, March 1977 (GEAP-23517).

4. W. J. Letzring, Editor, *BWR Blowdown/Emergency Core Cooling Program Preliminary Facility Description Report for the BD/ECC1A Test Phase*, General Electric Company, December 1977 (GEAP-23592).

5. J. C. Wood and A. F. Morrison, *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Core Spray Interaction (BD/ECC1A) Test Plan*, General Electric Company, February 1978 (GEAP-NUREG-21638A).

6. W. S. Hwang and B. Schneidman, eds., *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Blowdown Heat Transfer (8×8 BDHT) Final Report*, General Electric Company, September 1978 (GEAP-NUREG-23977).

APPENDIX A

WORK SCOPE FOR BD/ECC PROGRAM — CONTRACT NO. NRC-04-76-215

PURPOSE

OVERALL PURPOSE

The purposes of the EPRI/NRC/GE Integral Blowdown/Emergency Core Cooling, BD/ECC, test program are to:

1. obtain and evaluate basic BD/ECC data from test system configurations which have calculated performance characteristics similar to a BWR with 8x8 fuel bundles during a hypothetical LOCA; and
2. determine the degree to which models for BWR system and fuel bundles describe the observed phenomena, and as necessary, develop improved models which are generally useful in improved LOCA analysis methods.

SPECIFIC OBJECTIVES

The specific objectives of the integral BD/ECC interaction test program are:

1. **Scaling Analysis:** evaluate and document the scaling basis of the TLTA in the configurations selected for BD/ECC interaction tests as compared to reference BWR designs.
2. **7x7 Counter-Current-Flow-Limited (CCFL) Flooding Characteristics:** conduct CCFL flooding characteristic tests of the present TLTA bundle geometry to establish the need, or lack thereof, to modify the present test apparatus design for the initial BD/ECC interaction experiments.
3. **8x8 Blowdown Heat Transfer Tests:** conduct 8x8 BDHT tests for comparison with 7x7 BDHT data and to serve as a BDHT baseline for BD/ECC interaction experiments.
4. **BD/ECC Interaction Tests:** evaluate system response and heat transfer, and evaluate effectiveness of ECC during the blowdown period, and the period extending well beyond the initial flow coastdown and lower plenum "flashing" periods of the calculated BWR-LOCA in one or more system configurations.
5. **Alternate Power Shape BD/ECC:** determine the effects of axial power shape on the system response and bundle heat transfer behavior during the calculated BWR LOCA.
6. **Non-Jet Pump Plant BD/ECC:** investigate the ECC interaction with the system during blowdown in a representative non-jet pump test system configuration.
7. **Reporting of Data:** report all data (including pertinent error bands) in conventional parametric form suitable for correlation by others.
8. **Model Development:** develop, verify, and document an improved bundle thermal-hydraulic model that can be incorporated into analyses of BWR LOCA's.
9. **Application of Data:** specify how General Electric intends to use the data to qualify the degree of conservativeness of BWR LOCA evaluation models.

SCOPE

Task AA — Program Planning and Administration

1. General Electric will prepare a Preliminary BD/ECC Program Plan that elaborates on the means for meeting the program objectives. The program plan will include, but not be limited to: (a) BWR configurations and LOCA conditions to be tested; (b) test parameters and their ranges; (c) updated conceptual designs and testing strategies; (d) an outline of model development and verification activities; and (e) the method of relating previous 7x7 rod bundle data to the 8x8 rod bundle data. Sufficient discussion of the above items will be included to substantiate the basis for the preliminary program plan. The program plan will also include an updated schedule, a proposed data verification and reporting plan, and the planned utilization of data by General Electric to assess current BWR LOCA evaluation methods.

   The preliminary program plan will be provided for EPRI and NRC review, comment, and approval on an agreed upon time schedule. If comments are not supplied to General Electric by NRC or EPRI within the agreed schedule, General Electric may proceed as proposed.

2. Following mutual agreement on the results from Task AA-1 and on the appropriate phase of Tasks BB and CC-1, General Electric will prepare a detailed test plan for each major testing phase. Each detailed test plan will include the test objectives, test phase description, test matrices, parameter ranges and reasons for selection, test execution plan, planned utilization of the data, and the planned schedule for completing that phase.

   The preliminary test plans will be provided for EPRI and NRC review, comment, and approval on an agreed upon time schedule. If comments are not supplied to General Electric by EPRI or NRC with the agreed schedule, General Electric may proceed as proposed.

Task BB — Heater Evaluation

1. Perform appropriate analysis relating electrical heater performance to predicted nuclear fuel rod temperature performance during an ECC transient. This analysis will describe the method of programming initial and decaying electrical power to produce representative BWR LOCA thermal response and will describe how differences in thermal properties are accounted for in the electrical simulations.

2. Evaluate the need for tests to demonstrate the validity of the above analyses. The heater evaluation including documentation of the above item will be provided for EPRI and NRC review, comment, and approval on an agreed upon time schedule. If comments are not supplied to General Electric for EPRI or NRC within the agreed schedule, General Electric may proceed as proposed.

Task CC — Test Facility Design and Fabrication

1. Scaling and design analyses to define each system configuration will be performed and documented. Particular attention will be given to attaining a real-time simulation of calculated BWR system and fuel bundle thermal-hydraulic LOCA response.

   Design trade-off and scaling compromise studies will be performed to establish the final scaling basis to be used for design and operation of each configuration. Appropriate analytical methods including, but not necessarily limited to, those used for BWR performance analyses will be applied to obtain best estimate performance predictions of the BWR reference plants and the test system configurations. These pre-test predictions will include time to boiling transition (BT), lower plenum flashing effects, post-BT heat transfer, and response to ECCS operation. Differences in anticipated dynamic response of the test apparatus as compared to a BWR will be identified by appropriate analysis. Measurement requirements to obtain program objectives, including type, number, location, and accuracy of instruments will be specified, and an instrumentation plan to meet these requirements will be developed. A preliminary Facility Description including documentation of the above items, presenting the technical basis for the preliminary design, will be provided for EPRI and NRC review; comment, and approval on an agreed upon time schedule. If comments are not supplied to General Electric by EPRI or NRC within the agreed schedule, General Electric may proceed as proposed.

2. Upon resolution of comments, if any, the contractor shall provide a revised Facility Description as necessary.

   The final design and procurement of necessary material for each configuration will be completed, and the system will be prepared for calibration testing.

Task DD — Test Section Design and Fabrication

Upon completion of Task BB and an evaluation of the BDHT test section counter-current-flow-limiting (CCFL) characteristics, General Electric will complete the design, procurement, and assembly of the 8x8 rod test sections for BD/ECC testing. The test section designs will be documented in the appropriate Facility Description reports.

Task EE — System Startup Tests

Upon assembly of each configuration, conduct performance and flow calibration tests. Perform hydrostatic, hydrodynamic, and transient startup tests for each configuration to establish system operational characteristics including adequacy of heater and instrumentation response. Conduct steady-state and/or transient separate effects tests necessary to provide the basis for interpretation of BD/ECC experimental results.

Task FF — BD/ECC Interaction Tests

For each configuration, perform tests as detailed Tasks AA-2 and CC-2.

Task GG — Data Evaluation and Model Development

1. Analyze and document the as-built system performance characteristics based on system startup tests. Evaluate the test apparatus design for meeting program objectives on the basis of system startup performance tests. Determine what, if any, minor modification and/or adjustments should be made on the test facility, and update the predictions of system response as appropriate.

2. Upon completion of a specified test series, reduce, evaluate, and report the experimental data. Provide the experimental basis for confirming or modifying the assumptions and models used in LOCA evaluations such as the onset of boiling transition (BT), the subsequent heat transfer rates, effects of lower plenum flashing on core thermal response, and the effects of ECC on core and system response. Document the data obtained, the storage format and how it can be accessed by others.

3. As appropriate, develop and document improved analytical models, which can be incorporated into best estimate analyses of BWR LOCA's. This will include, but not be limited to, the development of a self-standing transient thermal-hydraulic model for the prediction of local thermodynamic parameters in rod bundles during LOCA's. These local parameters are necessary for the phenomenological understanding and correlation of local heat transfer coefficients. Values for local heat transfer coefficients are desired which may be expressed as a function of local conditions such as temperature differences, flowrates, pressure, and quality.

4. Indicate how the data obtained can be used to assess current BWR LOCA evaluation models, including a quantitive determination of safety margins.

APPENDIX B

BD/ECC PROGRAM REPORTS

B.1 LIST OF REPORTS PREPARED AS PART OF THE BWR BD/ECC PROGRAM DOCUMENTATION

Report No./Type	Title/Author(s)	Principal Contents
GEAP-21207 Informal	BWR 8x8 Fuel Rod Simulation Using Electrical Heaters, J. P. Dougherty, R. J. Muzzy, March 1976.	Analysis of electrical heaters to simulate nuclear fuel rods
GEAP-21304-1 Quarterly	BWR Blowdown/Emergency Core Cooling First Quarterly Progress Report, January 1 — March 31, 1976.	
GEAP-21255 Topical Report	Preliminary BWR Blowdown/Emergency Core Cooling Program Plan, R. J. Muzzy, June 1976.	Design consideration leading to various test configurations. Test parameters and ranges. Test strategy.
GEAP-21304-2 Quarterly	BWR Blowdown/Emergency Core Cooling Second Quarterly Progress Report, April 1 — June 30, 1976.	
GEAP-21333 Topical Report	64-Rod Bundle BDHT Test Plan, J. P. Walker, September 1976.	Test matrix and test strategy for 8x8 plan.
GEAP-21304-3 Quarterly	BWR Blowdown/Emergency Core Cooling Third Quarterly Progress Report, July 1 — September 30, 1976.	
GEAP-21304-4 Quarterly	BWR Blowdown/Emergency Core Cooling Fourth Quarterly Progress Report, October 1 — December 31, 1976.	
GEAP-21304-5 Quarterly	BWR Blowdown/Emergency Core Cooling Fifth Quarterly Progress Report, January 1 — March 31, 1977.	
GEAP-21304-6 Quarterly	BWR Blowdown/Emergency Core Cooling Sixth Quarterly Progress Report, April 1 — June 30, 1977.	
GEAP-21304-7 Quarterly	BWR Blowdown/Emergency Core Cooling Seventh Quarterly Progress Report, July 1 — September 30, 1977.	

B.1 LIST OF REPORTS PREPARED AS PART OF THE BWR BD/ECC PROGRAM DOCUMENTATION (Continued)

Report No./Type	Title/Author(s)	Principal Contents
NEDG-NUREG-23732	TLTA Components CCFL Tests D. D. Jones, December 1977.	Results of CCFL testing of TLTA-1 and -3 core inlets and TLTA jet pump. Results of single phase liquid pressure drops across TLTA-3 core inlet and single phase reverse flow steam pressure drops across TLTA jet pumps.
GEAP-23592	BWR Blowdown/Emergency Core Cooling Program Preliminary Facility Description Report for the BD/ECC-1A Test Phase. W. J. Letzring, editor, December 1977.	Detailed description of TLTA configuration for BD/ECC-1A.
GEAP-NUREG-21304-8	BD/ECC 8th Quarterly Progress Report October 1 — December 31, 1977.	
GEAP-NUREG 21304-9	BD/ECC 9th Quarterly Progress Report January 1 — March 30, 1978.	
GEAP-NUREG-21638A	BWR Blowdown/Emergency Core Cooling Program 64-Rod Bundle Core Spray Interaction (BD/ECC1A) Test Plan, J. C. Wood and A. F. Morrison, February 1978.	Test matrix and test strategy for BD/ECC1A phase.
GEAP-21304-10 Quarterly	BWR Blowdown/Emergency Core Cooling Tenth Quarterly Progress Report April 1 — June 30, 1978.	
GEAP-21364-11 Quarterly	BWR Blowdown/Emergency Core Cooling Eleventh Quarterly Progress Report July 1 — September 30, 1978.	
GEAP-NUREG-23977	64-Rod Bundle Blowdown Heat Transfer (8x8) Final Report September, 1978.	Topical report covering blowdown heat transfer without ECC injection.
GEAP-NUREG-21304-12	BWR Blowdown/Emergency Core Cooling Twelfth Quarterly Progress Report October 1 — December 31, 1978.	
GEAP-NUREG-21304-13	BWR Blowdown/Emergency Core Cooling Thirteenth Quarterly Progress Report January 1 — March 31, 1979.	

GEAP-NUREG-21304-14	BWR Blowdown/Emergency Core Cooling Fourteenth Quarterly Progress Report April 1 — June 30, 1979.
GEAP-NUREG-21304-15	BWR Blowdown/Emergency Core Cooling Fifteenth Quarterly Progress Report July 1 — September 30, 1979.
GEAP-NUREG-21304-16	BWR Blowdown/Emergency Core Cooling Sixteenth Quarterly Progress Report October 1 — December 31, 1979.
GEAP-NUREG 21304-17	BWR Blowdown/Emergency Core Cooling Seventeenth Quarterly Progress Report January 1 — March 31, 1980

B.2 LIST OF REPORTS PLANNED AS PART OF BWR BD/ECC PROGRAM DOCUMENTATION

Title	Principal Contents	Scheduled Date*
BD/ECC1B Test Plan	Preliminary plan and test strategy for BD/ECC1B testing	
BD/ECC1B Facility Description	Detailed description of TLTA configuration for BD/ECC1B	
BD/ECC1A Final Report	Results from BD/ECC1A testing	
Final BD/ECC Report	Summary and Conclusions from BD/ECC program	

---

* Major revision of program is currently under consideration by the program sponsors

APPENDIX C

HIGHLIGHTS OF THE LARGE BREAK REFERENCE TEST AND SMALL BREAK TEST NO. 2

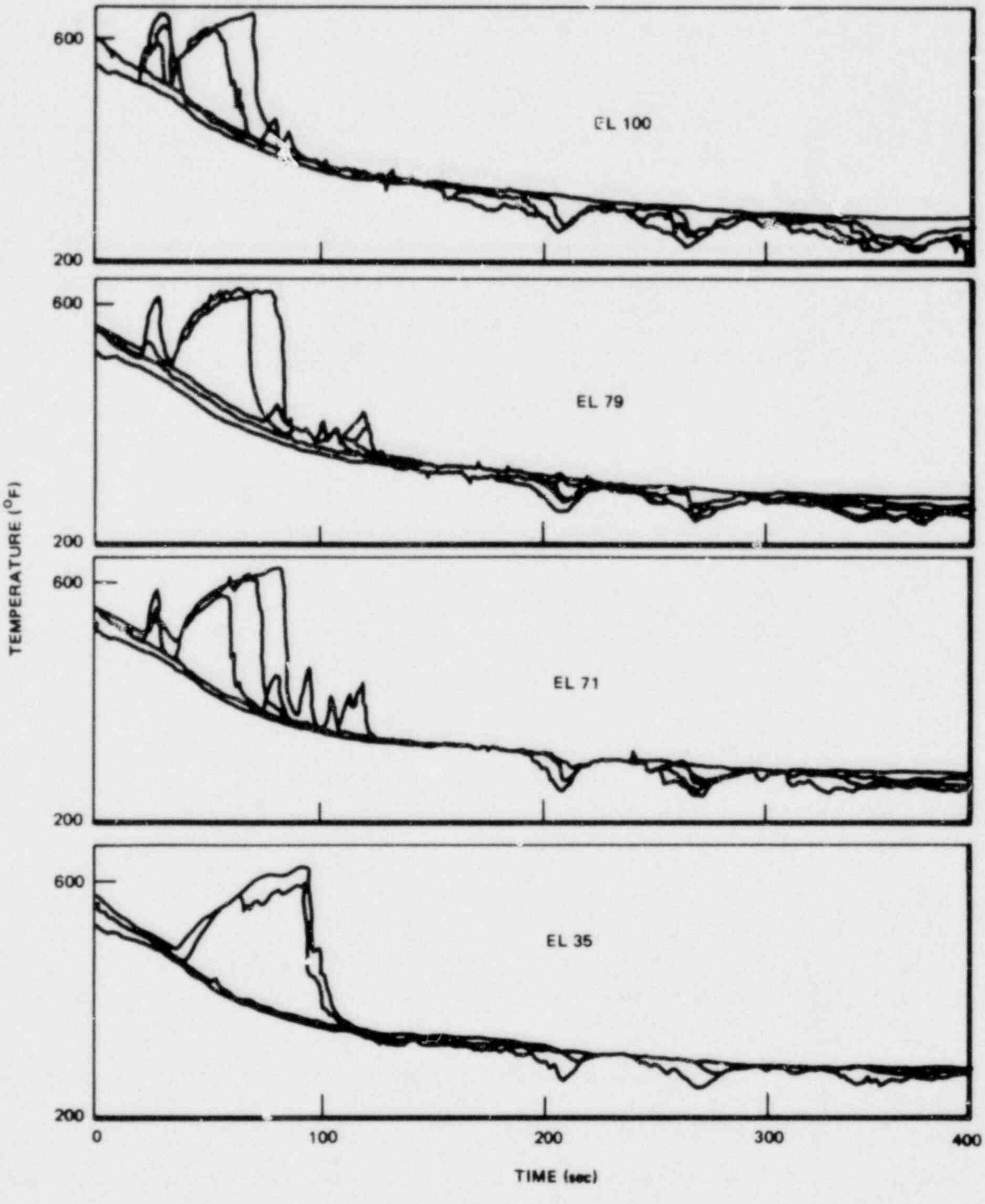


Figure C-1. Bundle Temperature Response at Selected Elevations of TLTA Reference Test (6422 Run 3, Average Power, Average ECC Rate)

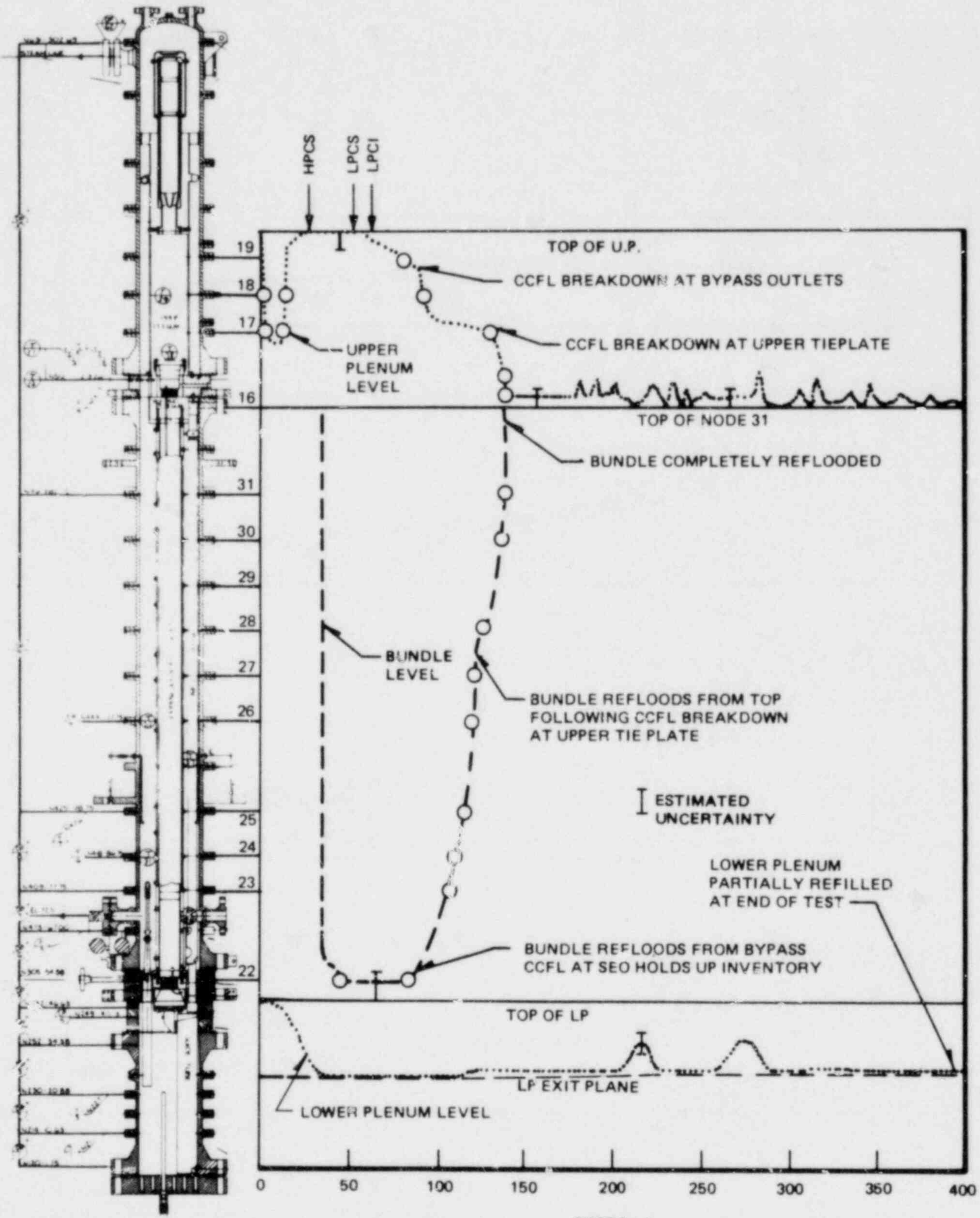


Figure C-2. Mixture Levels Along the Bundle Path: TLTA 5A Reference Test (6422 Run 3 Average Power Average ECC Rate)

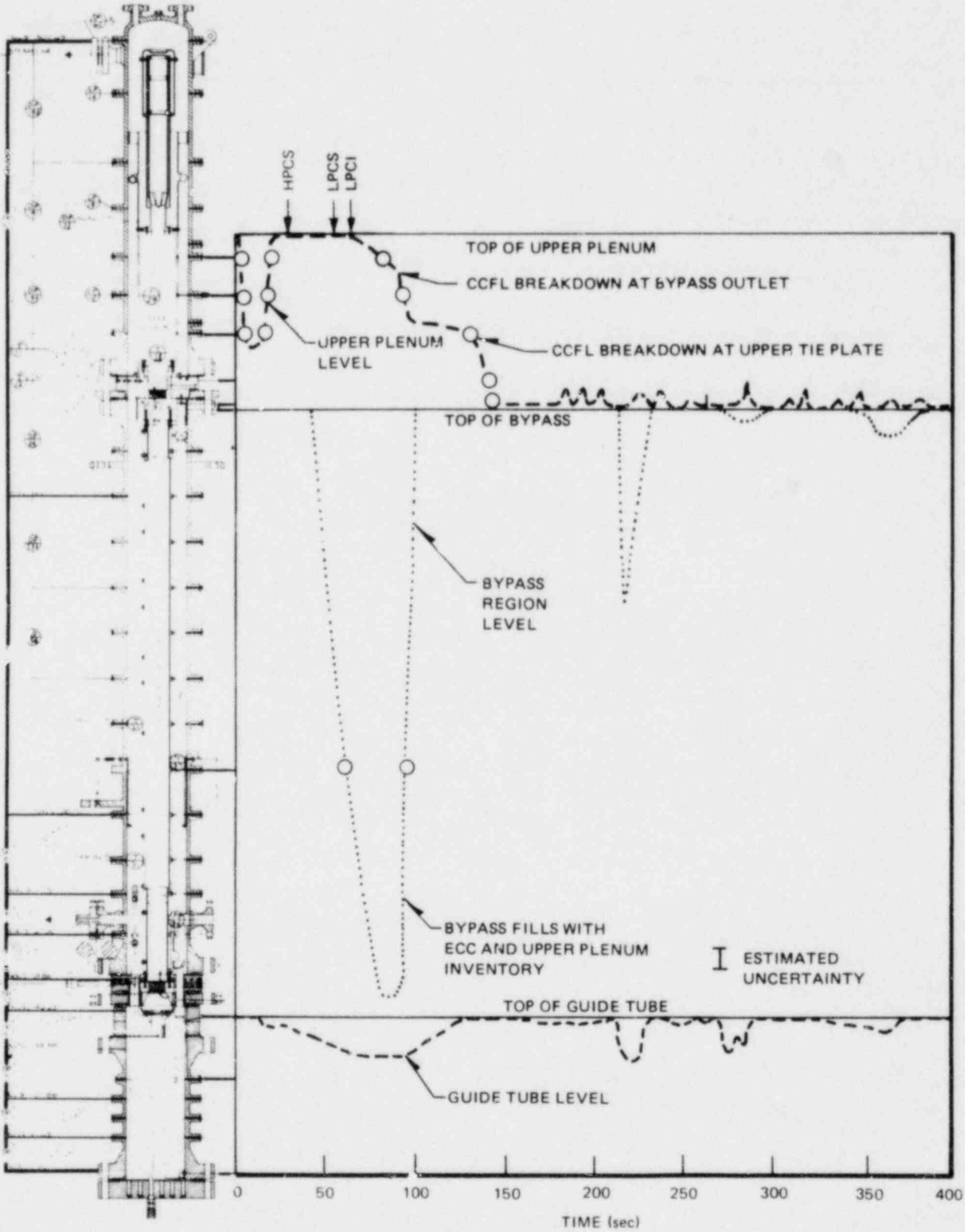


Figure C-3. Mixture Levels Along the Bypass Path: TLTA 5A Reference Test (6422 Run 3 Average Power, Average ECC Rate)

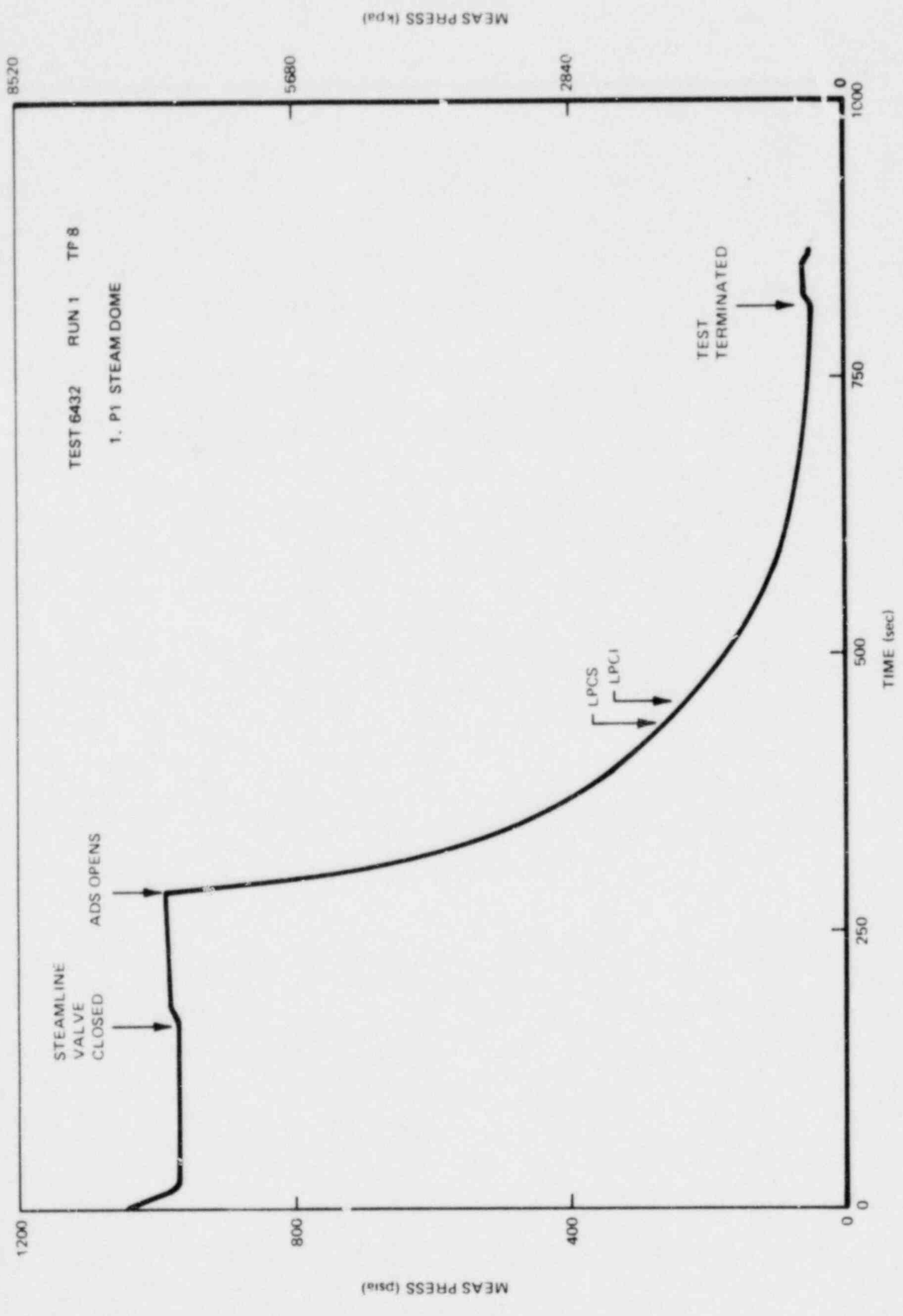


Figure C-4. System Pressure, Small Break Test II

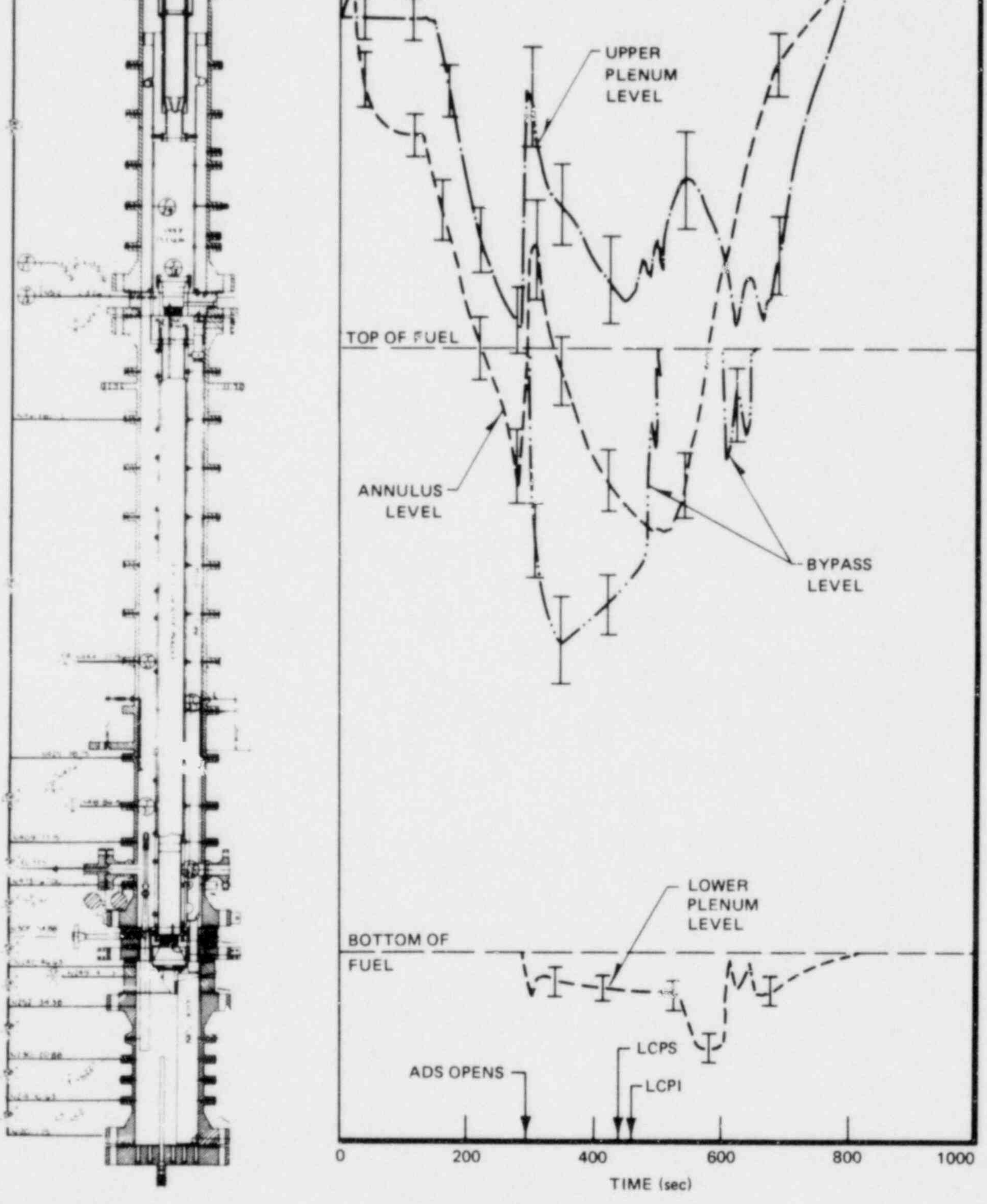


Figure C-5. Mixture Level (6432/R1), Small Break Test II

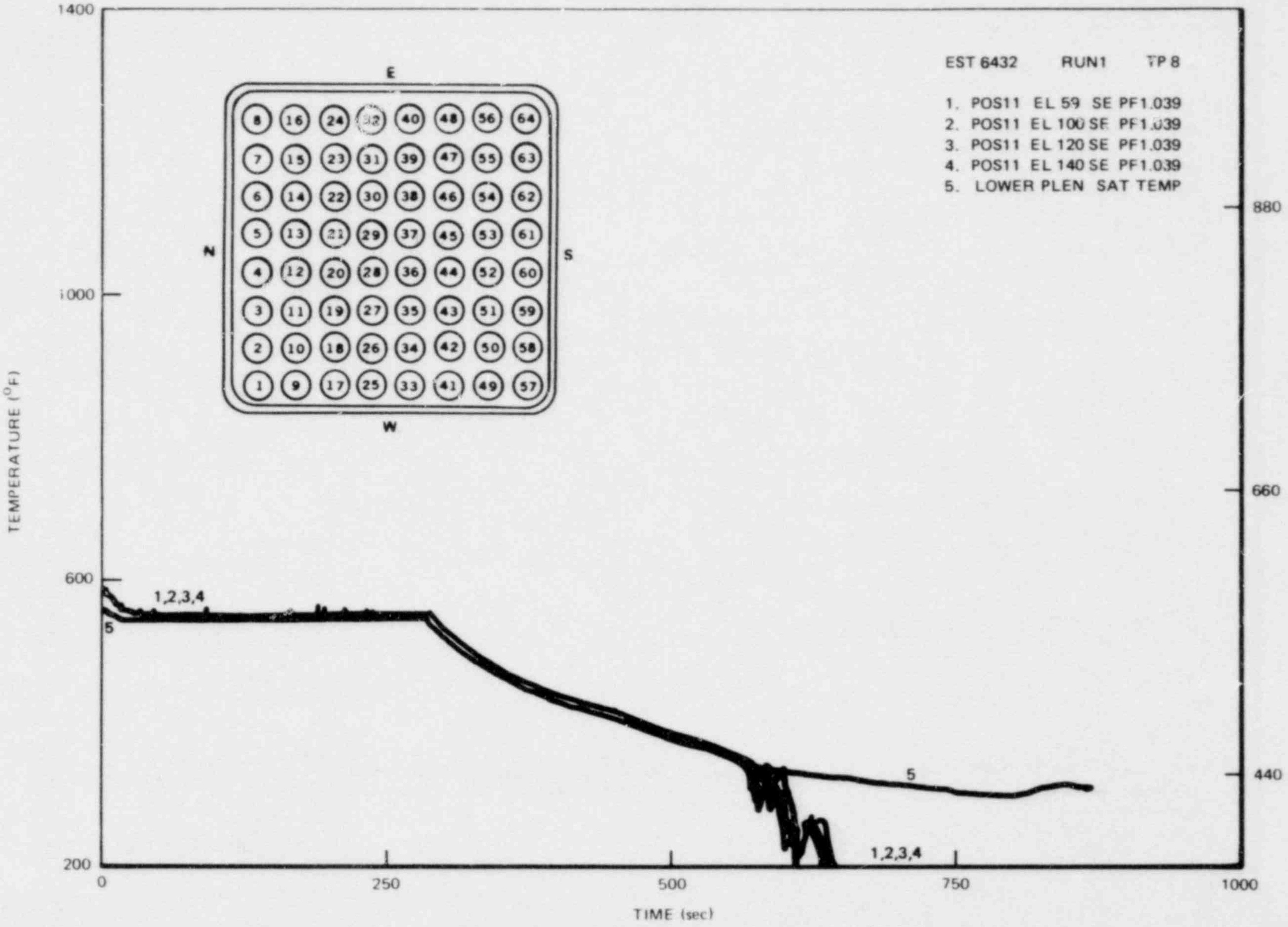


Figure C-6. Rod Cladding Temperature, Small Break Test II

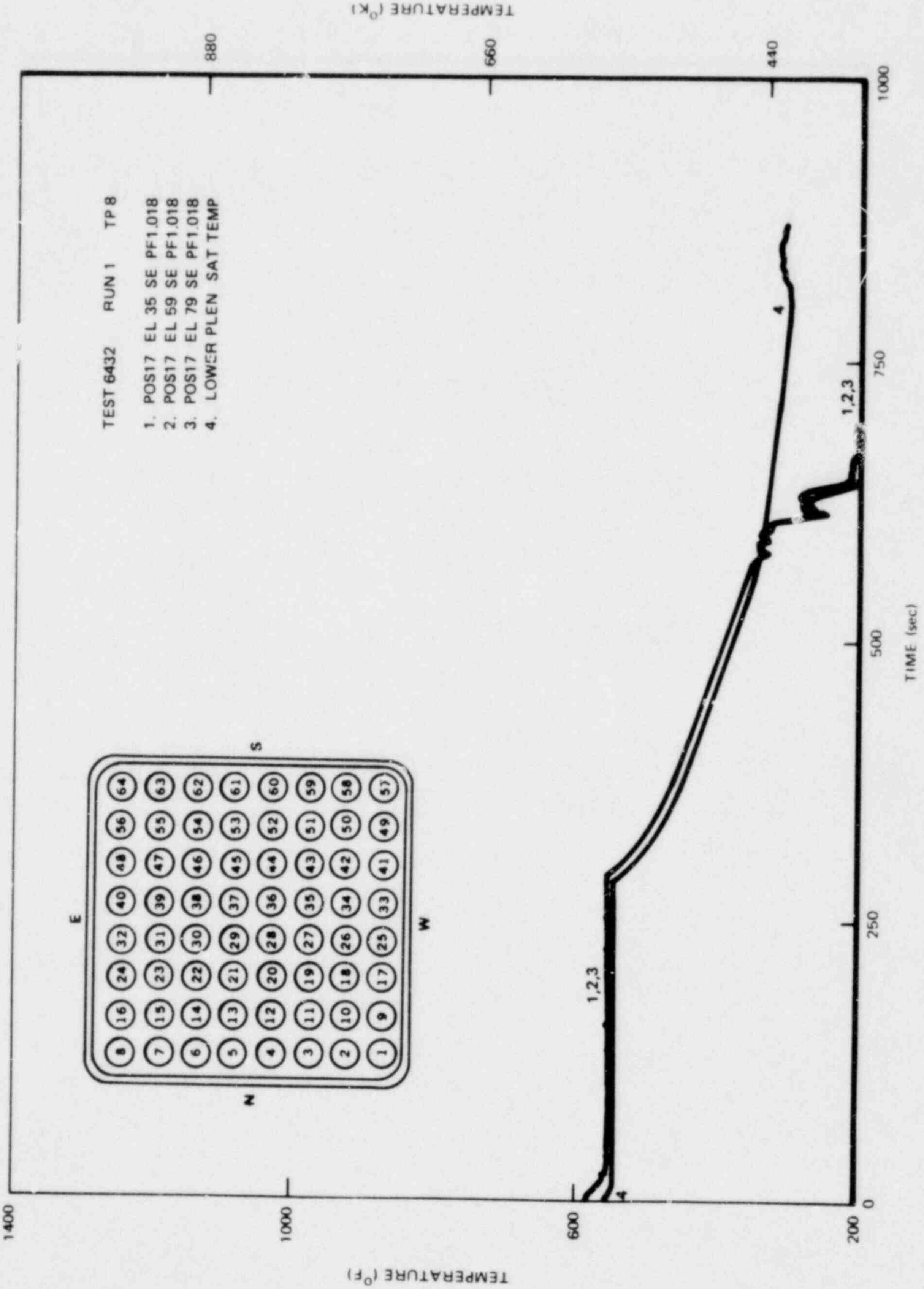


Figure C-7. Rod Cladding Temperature, Small Break Test II

APPENDIX D

BD/ECC 1A

DATA REPORT FOR TLTA-5A REFERENCE TEST

(6422 Run 3, Average Power, Average ECC Rates)

L. S. Lee, May 1980

SYNOPSIS

The reference test data, along with discussion of results, are included in this report. Also included is a recapitulation of simulation improvements made to TLTA that render configuration 5A (TLTA-5A) even more representative of a BWR system.

As a result of the realistic bundle power decay and bundle-to-bypass flow coupling, the bundle was reflooded completely at ~140 seconds and the peak cladding temperature was below 700°F.

BACKGROUND

Improvements to TLTA for additional testing were deemed desirable by the PMG in January 1979 after the PMG members had reviewed results from the scoping series[D-1] of BD/ECC1A tests. The scoping series of tests, conducted in TLTA 5, was selected from the test plan[D-2] by PMG following the March 1978 meeting. The intent of the scoping series was to obtain a data base from which to guide further testing.

The balance of BD/ECC 1A tests, conducted in the improved TLTA, was finalized with input from PMG members after the March 1979 PMG meeting. Included were five large break (DBA) tests, and a small break scoping test[D-1].

TLTA improvements, including hardware modifications and instrumentation changes, have been documented and issued[D-1]. Significant modifications included: realistic bundle power decay, improved simulation of bypass leakage path, and improved simulation of systems inventory. The resulting configuration was designated TLTA 5A (Figure D-1).

In TLTA 5A two core-leakage flow paths were included (Figure D-2). These paths simulate the leakage flow through the fuel support/lower tie plate (paths 4 to 7, Figure D-2), finger springs (path 3, Figure D-2) and holes in the lower tie plate (path 2, Figure D-2). In all previous TLTA configurations, only the leakage path from the lower plenum to the guide tube was simulated.

RESULTS

System Thermal-Hydraulic Response

The test conditions for this reference test are summarized in Table D-1. The bundle power decay for the test (Figure D-3) was based on ANS-5 for a central-average BWR/6 bundle and included the effect of decay heat and stored heat.

The system pressure response as measured at three locations is presented in Figure D-4. The pressure differences between plena are initially due to the flow and hydrostatic head differences in the system. After the recirculation pumps are tripped and blowdown begins, these pressure differences become small and the three pressures are seen to be nearly identical. Later in the transient as the system refills, the hydrostatic head difference becomes discernible (see Figure D-4).

The ECC injection rates (Figures D-5 through D-8) are governed by the system pressure as the pumps characteristics were designed[D-3] to simulated those of a BWR. Injection commences at 27 seconds for HPCS (Figure D-5), 63 seconds for LPCS (Figure D-6), and 71 seconds for LPCI (Figure D-7). The total amount of ECC injected at any time is included in Figure D-8.

An overview of the system response is presented in Figures D-9 and D-10. The initial system response is similar to the previous scoping test series[D-4]. Following the onset of lower plenum flashing the steam generation in the lower plenum holds up inventory in the bundle because of counter current flow limiting (CCFL) at the side entry orifice (SEO) below the bundle. Similarly, CCFL at the upper tie plate and the bypass outlet holds up inventory in the upper plenum. As the blowdown continues, the mixture level in the lower plenum receeds, reaching the jet pump exit plane at ~34 seconds. An alternative path becomes available for the lower plenum vapor to escape, and therefore less vapor vents through the SEO to the bundle. The liquid continuum previously maintained in the bundle by the vapor updraft is now lost and bulk heat-up within the bundle begins. During this period, the inventory in the upper plenum remains fairly constant (Figures D-9 and D-10), with drainage into the bundle being replenished by continued core spray.

The guide tube/bypass region begins to refill (Figure D-10) shortly after the onset of LPCI injection (~90 seconds). The subcooled LPCI fluid condenses steam in the bypass region and eliminates CCFL at the top of the bypass. This partially drains the upper plenum as the bypass is refilled (Figure D-10).

The bundle refloods concomitantly with bypass refill for these reasons: 1) increased hydrostatic head in the bypass region produces increased leakage flow into the bundle and 2) continuing CCFL at the SEO prevents complete drainage of the bundle inventory into the lower plenum. As the bundle refloods, its hydrostatic head increases and the leakage flow from the bypass diminishes. The subcooled LPCI that was flowing downward through the bypass region is then forced to flow upward into the upper plenum. This LPCI fluid combines with other subcooled liquid being sprayed into the upper plenum and leads to CCFL breakdown at the top of the bundle. As a result, the bundle reflood is accelerated and the upper plenum inventory completely drained. The upper plenum remains drained for the balance of the test (Figure D-9).

The filling of the bundle produces a hydrostatic head on the lower plenum fluid and increases the pressure drop across the jet pumps. The pressure drop is sufficient to carry the ECC fluid, which is now draining through the bypass and bundle, out of the lower plenum and into the downcomer region (see Figure D-11). The hydrostatic head of the bundle, therefore, prevents the lower plenum from completely refilling. The system achieves pseudo steady state for the remainder of the transient except, as discussed below for two short periods of vapor venting through the bypass region.

Plots of regional mass are included (Figures D-12 through D-17). From these plots the timing and extent of mass transfer from one region to another can be determined.

A schematic of the TLTA bundle showing pressure tap elevation is included in Figure D-18 for reference. Nodal differential pressures along the bundle are shown in Figures D-19 through D-22. Bundle reflood from the bottom and final reflooding from the top can be observed from these measurements. Nodal differential pressure along the guide tube and bypass are shown in Figures D-23 and D-24.

Bundle Heat-Up Response

The thermal response of the bundle is marked by: 1) low peak cladding temperatures below 700°F (Figure D-25), 2) well cooled bundle (~Tsat) after 150 seconds, and 3) eventual subcooling of bundle (below Tsat).

Temperature measurement locations are shown in Figure D-18. Peak cladding temperature is presented in Figure D-25, while temperature measurements at different locations are included in Figures D-26 through D-47.

Some dryouts at ~20 seconds are seen at certain locations (Figures D-32, 34, 35, 37, 38, 40) as lower plenum flashing subsides. However, these dryouts are all rewetted at approximately the time of HPCS flow inception. As the elapse times between the HPCS inception and rod rewetting are rather short, rewet of the dryout rods are attributed to fallback cooling from the inventory in the upper plenum.

Bulk dryout of the bundle occurs at approximately 34 seconds when the liquid continuum in the bundle is lost following jet pump exit uncovery in the lower plenum. The bundle heatup is, nevertheless, limited to ~700°F due to the effectiveness of the HPCS which penetrates the upper region of the bundle and rewets many of the rods. The maximum cladding temperature reached the peak value before LPCS injection begins (Figure D-25).

The upper half of the bundle becomes further cooled (Figure D-35 through D-47) following LPCS injection, which begins at 63 seconds. This causes the remaining dried out rods in the upper bundle to be rewetted and the thermocouple measurements to indicate saturation temperature.

The lower half of the bundle, by contrast, continues to show local dryout even after the heat up rate and cladding temperatures have peaked. The region becomes well cooled when the bundle refloods between 110 seconds and 140 seconds (Figure D-10, Figures 25 through D-34).

With the bundle completely reflooded and with the continuous injection of subcooled ECC, the fluid inventory within the bundle becomes subcooled. This is evident in Figures D-26 to D-47 where it is seen that after about 150 seconds the cladding temperatures in the bundle show values below the saturation temperature for the system pressure.

Further Evaluations of Bundle Heat-Up Response

Heatup rate within the bundle is being evaluated by deriving heat transfer coefficients (HTC) with HCODE from thermocouple measurements. Preliminary results indicate that during the spray cooling period, prior to bundle reflood, the HTC on the peak rod at peak power plane is ~16 Btu/°F HrFt^2. This HTC value is consistent with that required to maintain the PCT at ~700° at the decay heat level for this test. The bundle inlet flow during this period is very low and is counter current, therefore, no direct flow rate measurements are available. The vapor upflow from the lower plenum to the bundle, however, has been estimated from mass and energy balance in the lower plenum. The upper bound value of steam flow to the bundle is ~0.1 lbm/sec. The corresponding single phase HTC (from Dittus-Boelter) for this vapor flow is ~6 Btu/°F HrFt^2. The effectiveness of the spray cooling is evidently accounting for the higher heat transfer rate observed in the test.

The bundle thermal response can be summarized as follows:

- CCFL at the SEO delays bulk heatup until ~34 seconds into transient.
- Realistic bundle power simulation contributes to lower PCT beyond 50 seconds (compared to earlier TLTA 5 results).
- ECCS contributes significantly to bundle heat removal and therefore lower PCT.
- Improved simulation of leakage path in TLTA contributes to completely reflooding the bundle (even with the short jet pump) and further lowers the bundle temperatures.

Vapor Venting in Guide Tube/Bypass Region

Vapor venting in the guide tube/bypass region is primarily due to rapid filling of the bypass region with two-phase mixture coupled with inequality of fluid density in the two parallel columns (bundle and bypass).

The region refills in 30 seconds (from ~100 to ~130 seconds as shown in Figure D-9). The mass of the guide tube increases from 60 to 90 pounds, the bypass from ~0 to ~65 pounds (Figures D-15 and D-16). Of this increase of ~95 pound mass, the one LPCI system accounts for ~25 pounds, the balance comes from the two-phase fluid in the upper plenum.

When the bypass refills at ~100 seconds the bundle begins to reflood slowly. The hydrostatic head across the bypass is seen in Figure D-48 to be higher than that across the bundle. The difference in hydrostatic heads, shown in Figure D-49, causes the bypass fluid to flow into the bundle and the guide tube fluid into the lower plenum. This leakage flow from the bypass to the bundle contributes to bundle reflood; that from the guide tube contributes additional vapor to the lower plenum. The combined effects of flashing in the lower plenum and the added vapor flow from the guide tube render the counter current flow condition at the SEO to prevent liquid drainage from the bundle (Figure D-50a).

The reversed leakage flow from the bypass is accompanied by the down flow of LPCI. The subcooled LPCI fluid condenses vapor generated in the bypass and the guide tube. The reversed leakage flow as well as the downward LPCI flow diminishes as the bundle refloods and the hydrostatic heads difference decreases. On the other hand, the vapor updraft from the guide tube into the bypass increases as the leakage flow into the lower plenum decreases. The combined effect of decreased subcooled LPCI downflow and increased guide tube vapor upflow is that the vapor travels higher up into the bypass before mixing with the subcooled LPCI fluid. This decreases the bypass fluid density, hence the hydrostatic head, and further reduces the hydrostatic heads difference.

The hydrostatic head difference is also diminished by the bundle fluid density increase. This comes about when the bundle begins reflooding and cools the lower bundle. Then, as the lower bundle becomes well cooled, less vapor is generated and, hence, more liquid drains into the bundle from the upper plenum. Finally, as the bypass flow decreases, more subcooled ECC fluid becomes available to flow into the bundle (Figure D-50b).

The hydrostatic heads become equal at ~200 seconds and the bypass flow becomes zero (Figure D-49). The LPCI fluid can no longer flow downward and is forced into the upper plenum where it combines with the subcooled sprays and flows into the bundle. This renders the bundle hydrostatic head higher relative to the bypass and the leakage flow reverts to the forward direction; i.e., fluid flows from bundle to bypass and from lower plenum to guide tube.

The forward leakage flow facilitates the vapor to escape from the bypass region. As both the liquid and the vapor continue to flow upward, the liquid continuum is pushed into the upper plenum (Figure D-24, ~210 seconds). The vapor continuum is then condensed as it comes into direct contact with either the subcooled LPCI at the top of the bypass or the subcooled spray in the upper plenum. Following this, the vapor flow diminishes, and the upper part of the bypass is clear of liquid continuum (Figure D-50c). The LPCI fluid flows downward again to fill the bypass. At the same time, the hydrostatic head of the bypass region has been reduced further and allows more bundle fluid to drain into and refill the region. As the bypass refills, the hydrostatic head difference decreases and with it the forward leakage flow.

The forward leakage flow also allows the lower plenum vapor to escape through the guide tube/bypass region. Consequently, the vapor upflow at the SEO decreases, which allows more liquid downflow from the bundle to the lower plenum. As the bundle drains partially and the hydrostatic head decreases, the jet pump path pressure drop correspondently decreases. This results in a simultaneous increase of mass influx to and decrease of mass outflux from the lower plenum. Therefore mass inventory in the lower plenum increases (Figure D-51).

The forward leakage flow to the bypass reverses later (Figure D-49) when partial loss of inventory in the bundle coupled with refilling of bypass leads to reversal of the hydrostatic head difference. This allows the restoration of the pseudo-steady-state conditions that proceed the vapor venting from the guide tube; for, as the guide tube flow is reversed into the lower plenum, the combined vapor flow is forced through the SEO. The increase in the vapor flow causes CCFL at the SEO to reduce the liquid drain from bundle and allows the bundle to accumulate inventory once again. At the same time, as the hydrostatic head of the bundle increases, the pressure drop across the jet pumps increases correspondingly (Figure D-49). This results in a simultaneous decrease of mass influx to and an increase of mass outflux from the lower plenum. Therefore mass in the lower plenum decreases until the mixture level returns to that of the jet pump exit plane. With the mixture reaching that level, a pseudo steady state is momentarily restored, (see Figures D-9 and D-50d).

This process repeats itself later in the transient. However, after this later refill, a sufficient amount of subcooled liquid enters the guide tube and bypass regions. This, in conjunction with decreased flashing due to decreased depressurization rate, diminishes the vapor up-flow and further vapor venting subsides.

This venting process in the bypass region of TLTA is believed to be influenced by the one dimensional configuration of the TLTA geometry and may not be representative of a BWR. In TLTA, the bypass region volume is mocked-up by four parallel tubes which communicate from the guide tube to the upper plenum. LPCI is injected equally into each tube. In the BWR, the bypass is a more open, three-dimensional region with LPCI injection at the core shroud wall. Communication between the bypass and guide tube and the bypass and bundle are less influential as the bypass region has a large plenum effect. Therefore, the venting process observed in TLTA is not expected in a BWR.

REFERENCES

D-1. *BWR Blowdown Emergency Core Cooling Fourteenth Quarterly Progress Report (April 1-June 30, 1979)*, NUREG/CR-1154 Vol. 1, No. 2, August 1979, GEAP-21304-14.

D-2. *BWR Blowdown/Emergency Core Cooling Program-64-Rod Bundle Core Spray Interaction (BD/ECC 1A) Test Plan*, A. F. Morrison, June 1977, GEAP-NUREG-21638.

D-3. *BWR Blowdown/Emergency Core Cooling Fifteenth Quarterly Progress Report (July 1-September 31, 1979)*, NUREG/CR-1154 Vol. 1, No. 2, February 1980, GEAP-21304-15.

D-4. *BWR Blowdown/Emergency Core Cooling Program — Preliminary Facility Description Report for the BD/ECC 1A Test Phase*, W. J. Letzring, December 1977, GEAP-23592 NRC-2.

Table D-1
BD/ECC 1A, TLTA 5A, REFERENCE TEST 6422, RUN 3.

Initial Conditions	
Bundle Power	5.05 ± 0.03 MW
Steam Dome Pressure	1035 ± 5 psia
Lower Plenum Pressure	1062 ± 5 psia
Lower Plenum Enthalpy	524 ± 5 Btw/lbm
Initial Water Level	124 ± 6 in. Elevation
Feed Water Enthalpy	41 ± 2 Btw/lbm
Bundle Inlet to Outlet	17 $^{+1}_{-2}$ psi
Steam Flow	6 + 1 lbm/sec
Feed Water Flow	1.6 ± 0.3 lbm/sec
Drive Pump No. 1 Flow	8.7 ± lbm/sec
Drive Pump No. 2 Flow	8.5 ± 1.0 lbm/sec
Jet Pump No. 1 Flow	20. ± 2 lbm/sec
Jet Pump No. 2 Flow	21 ± 2 lbm/sec
Bundle Inlet Flow	35. ± 5 lbm/sec
Timings	
Blowdown Valves Opening	0.00 ± 0.02 sec
Power Decay	0.40 ± 0.05 sec
HPCS Actuated	27 sec
HPCS Flow Begins	27 sec ± 1 sec
LPCS Activated	37 sec
LPCS Flow Begins	63 ± 2 sec
LPCI Activated	37 sec
LPCI Flow Begins	71 ± 2 sec
Bundle Power Tripped	399 sec
Blowdown Valves Closed	429 sec
ECCS Temperature	120 ± 15°F

All uncertainty bands are judged from the maximum of data fluctuation and/or absolute uncertainties of the measurements.

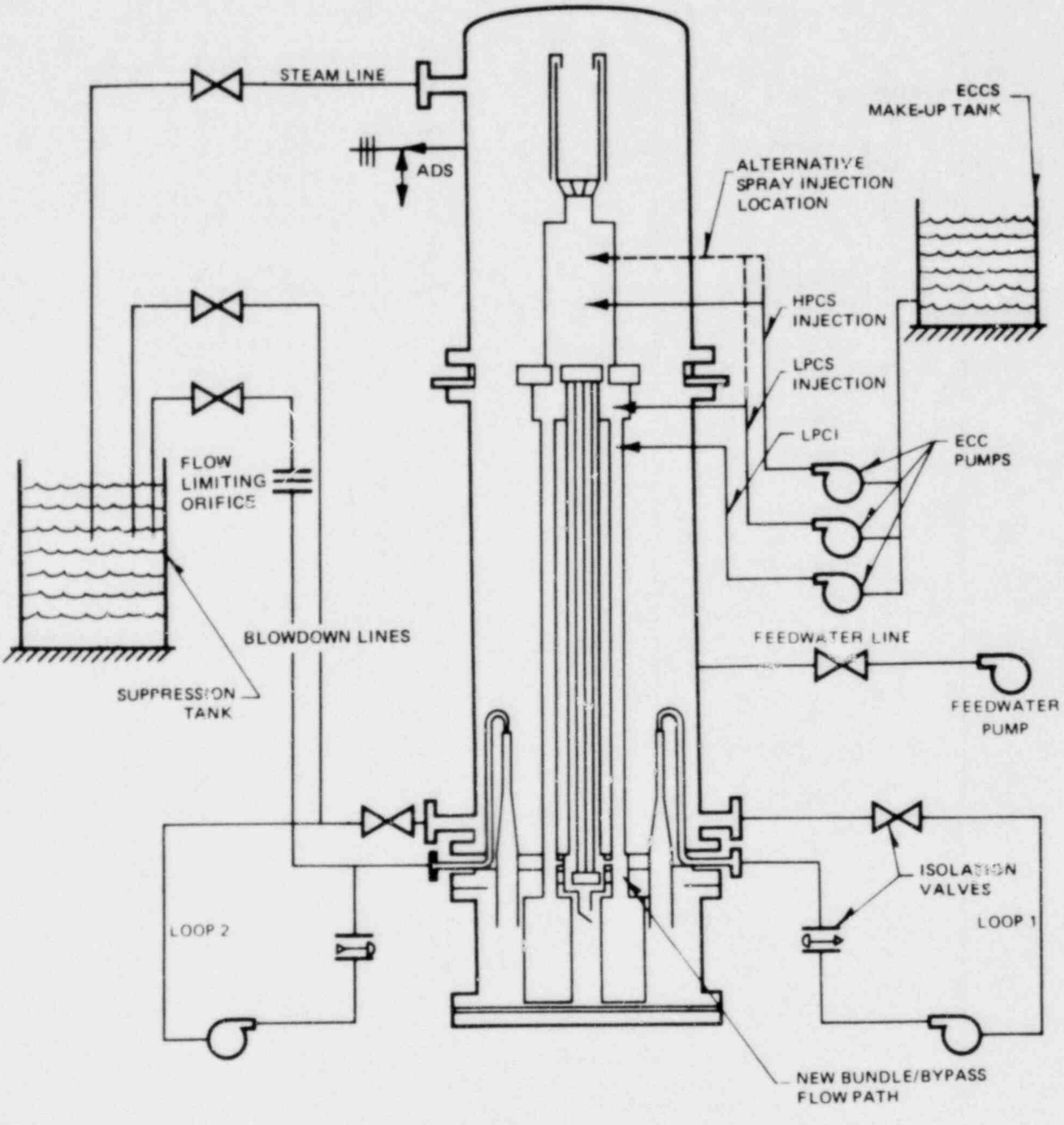
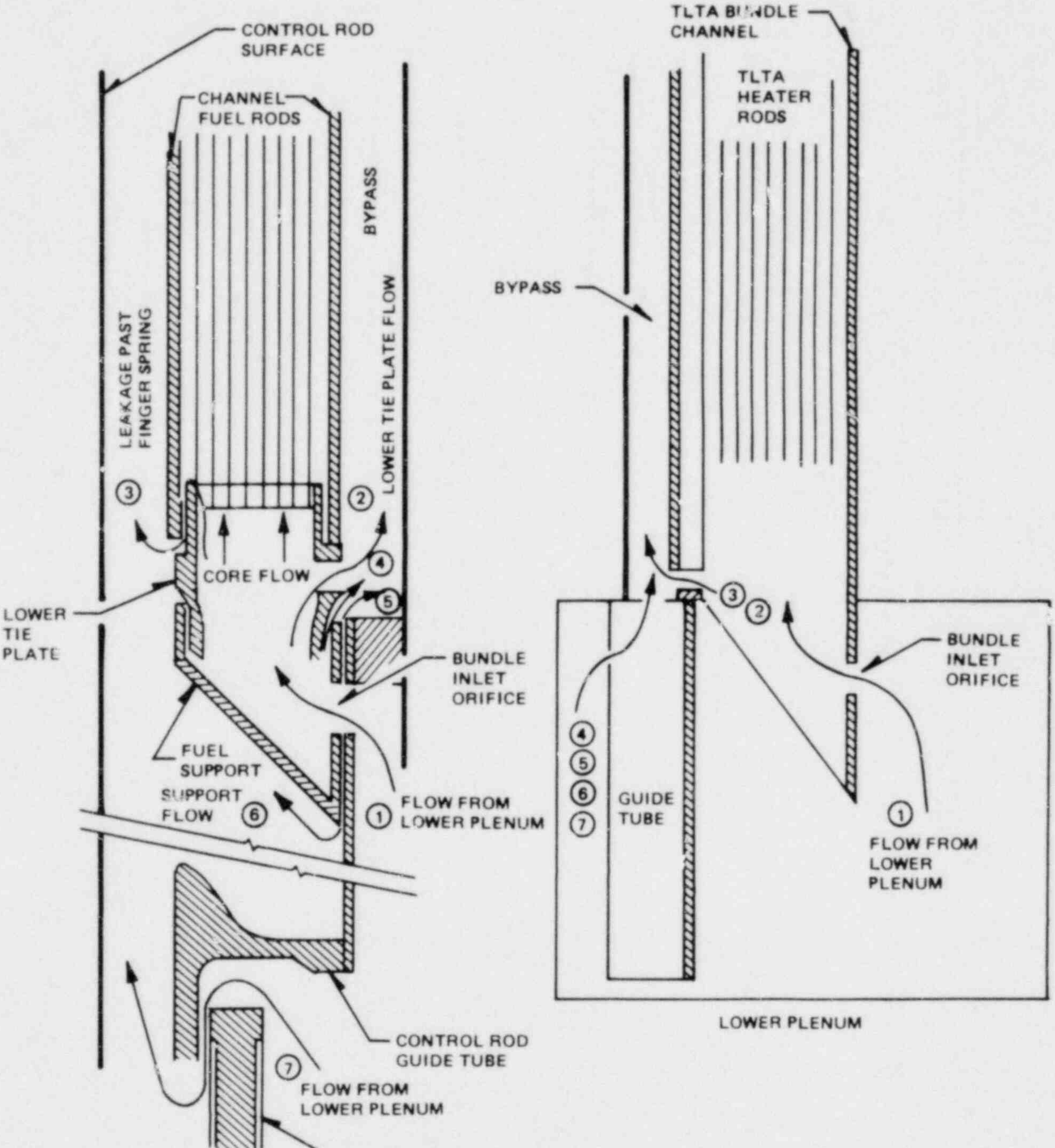


Figure D-1. Two-Loop Test Apparatus Configuration 5A (TLTA-5A) with Emergency Core Cooling Systems



(a) BWR

(b) TLTA-5A

Figure D-2. Flow Paths at Inlet Region of a BWR Fuel Bundle and the TLTA Simulation

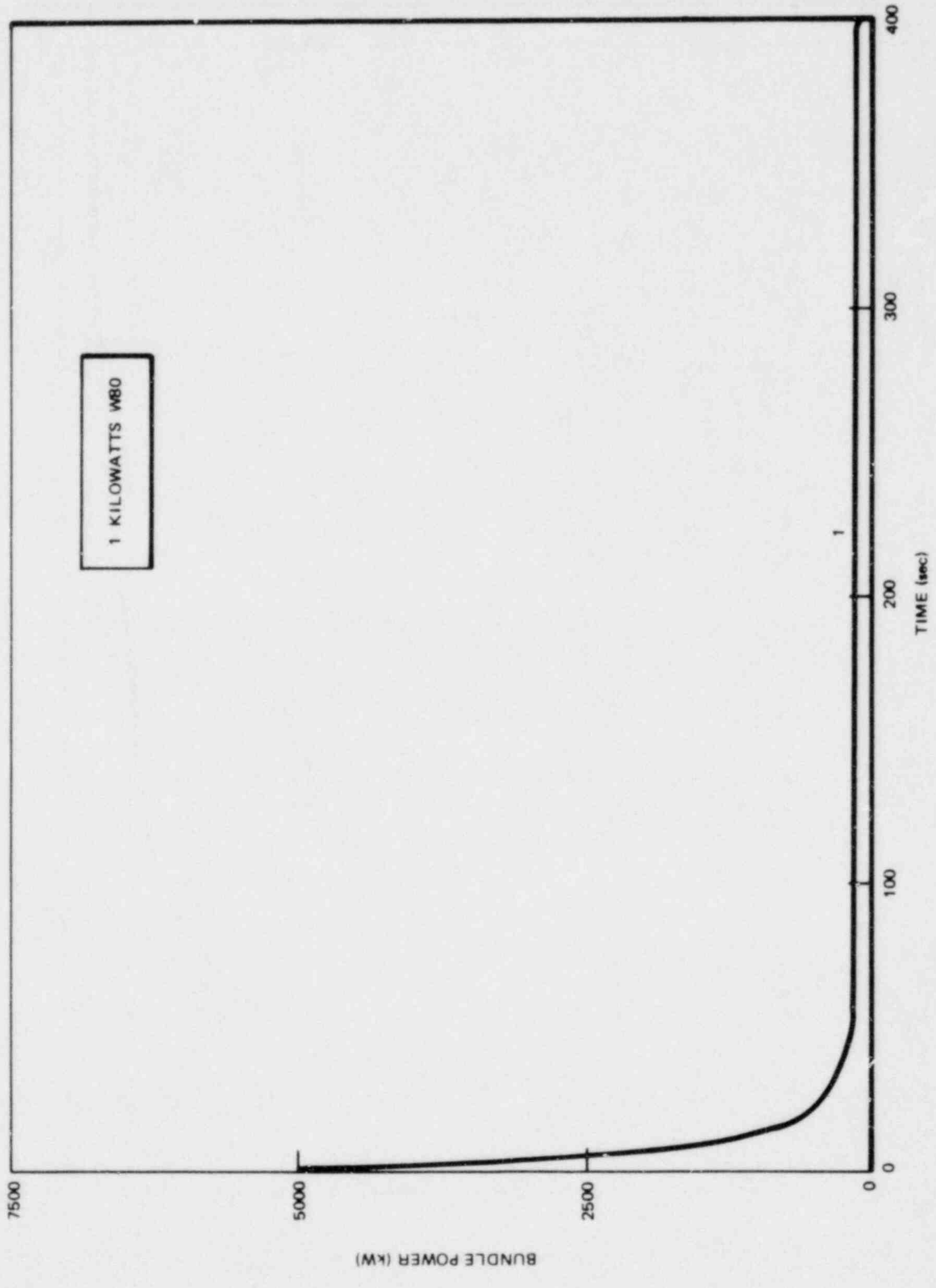


Figure D-3. Bundle Power Decay

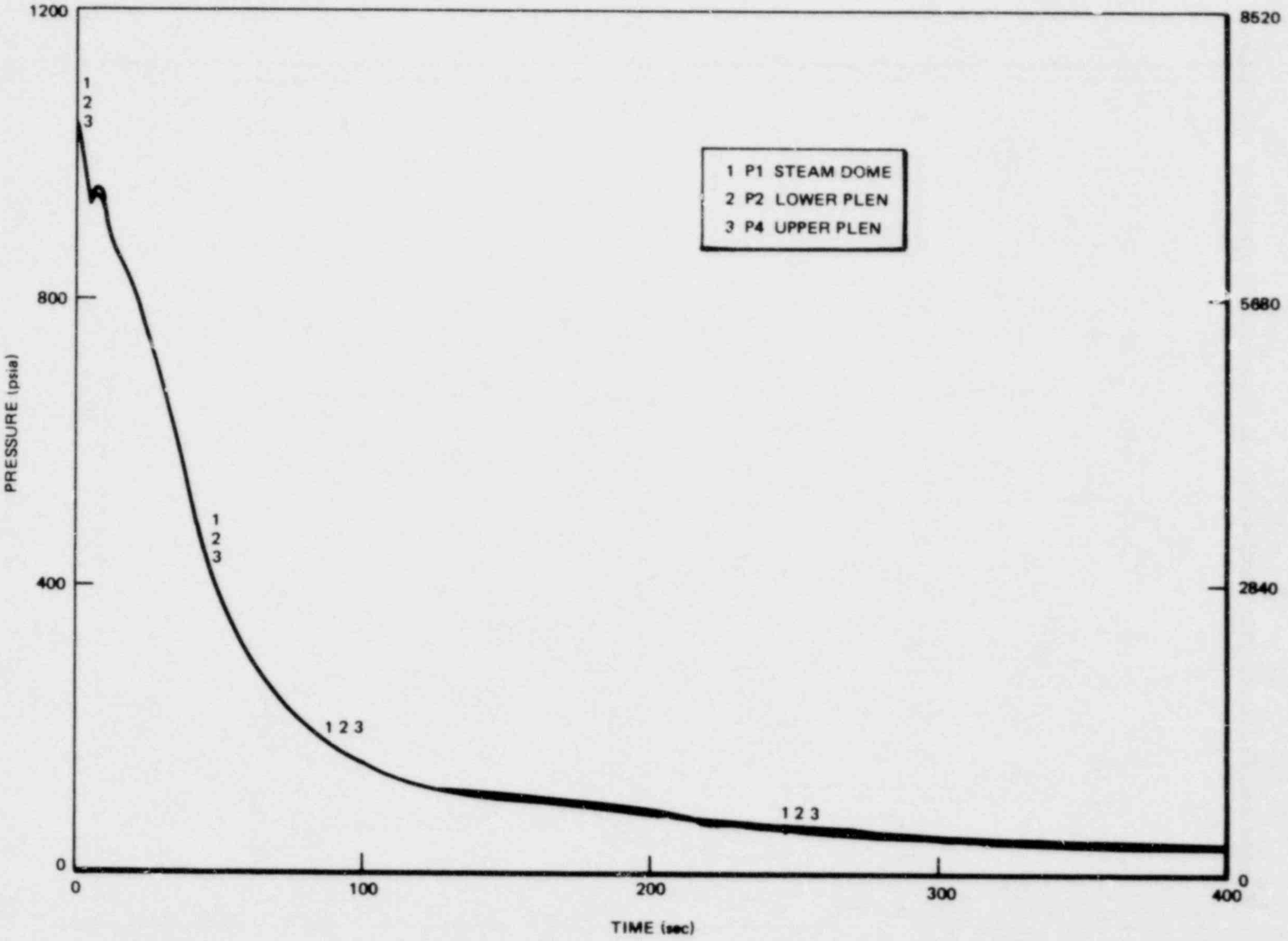


Figure D-4. System Pressures

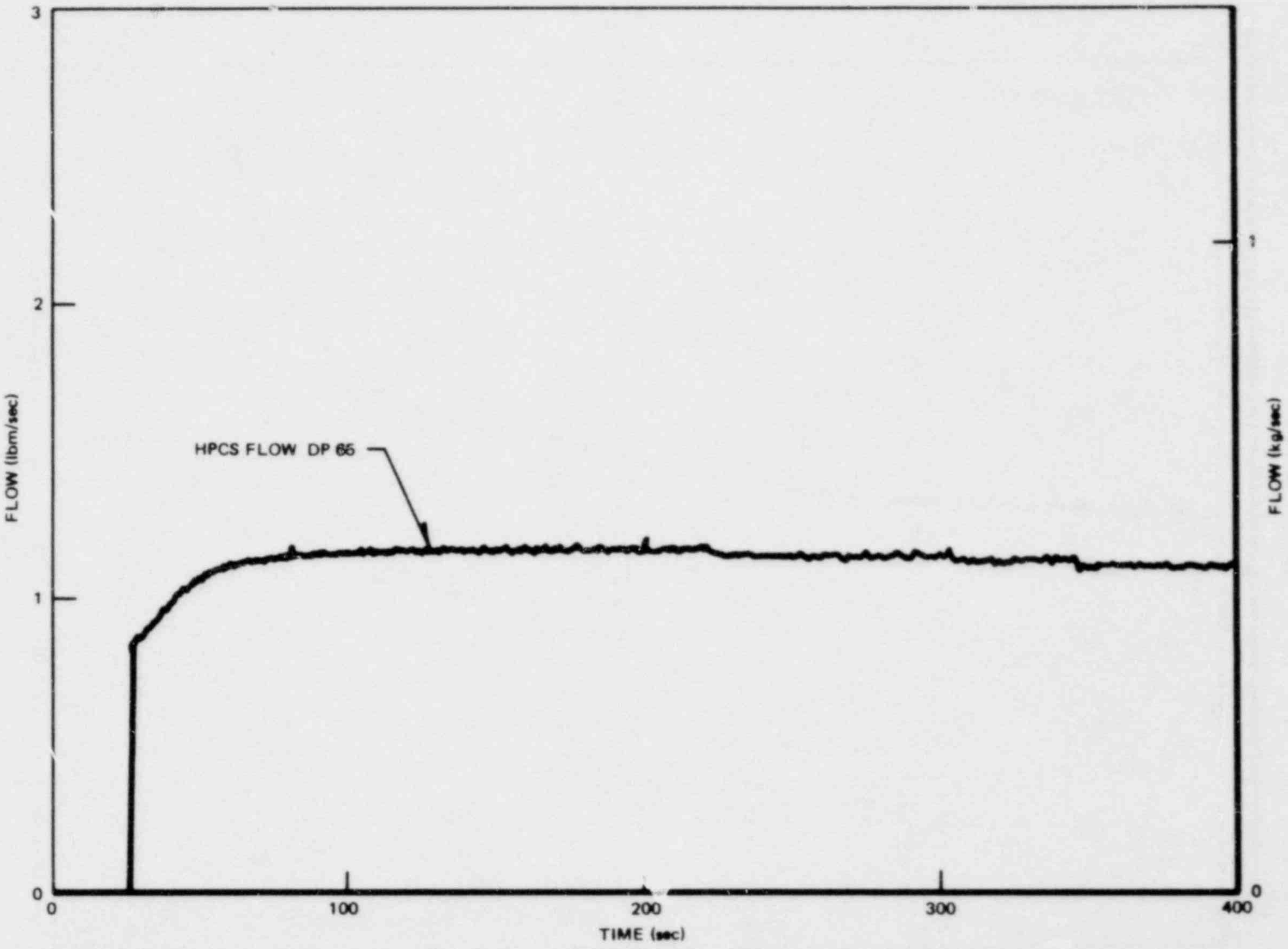


Figure D-5. HPCS Injection Rate

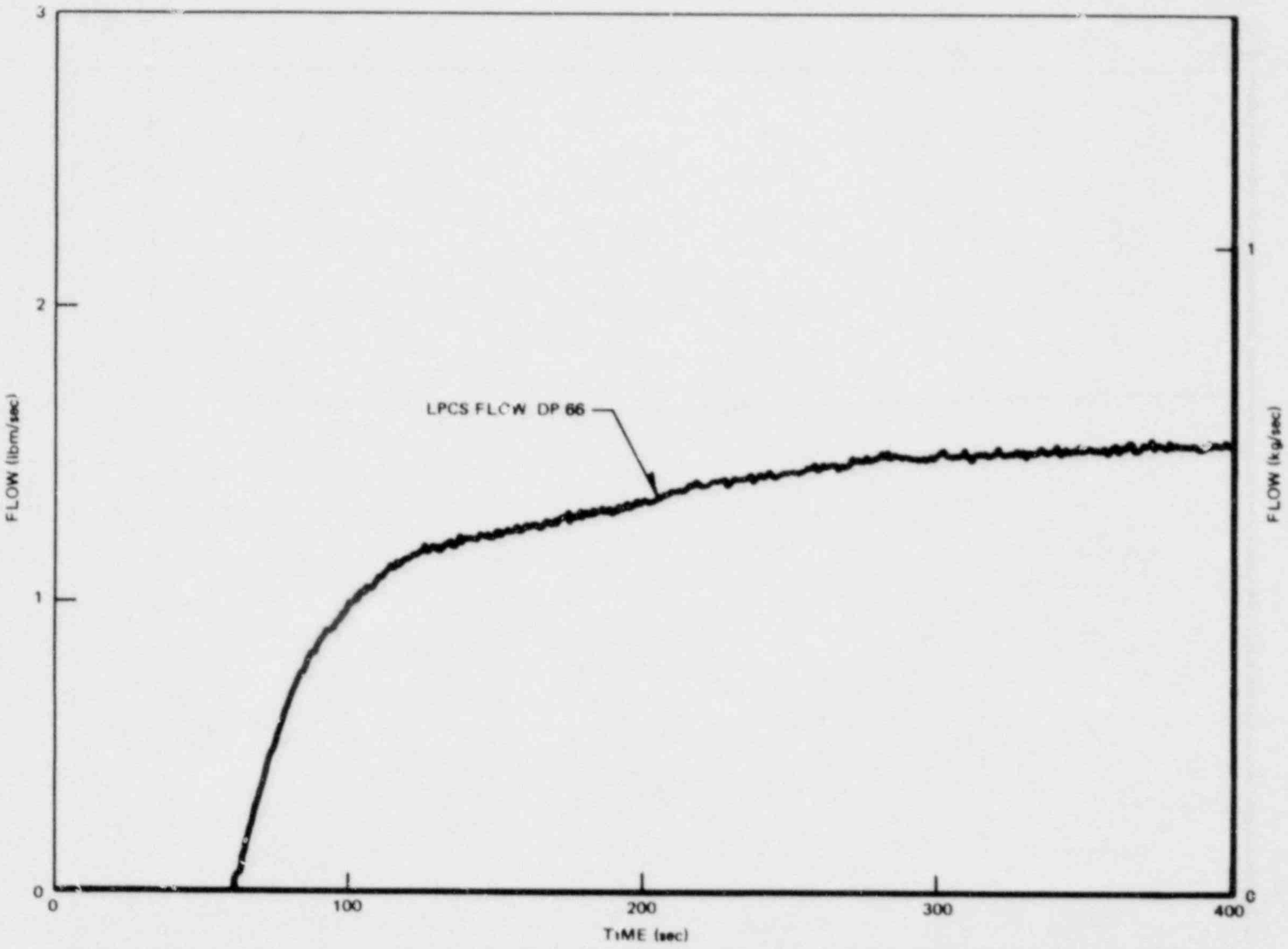


Figure D-6. LPCS Injection Rate

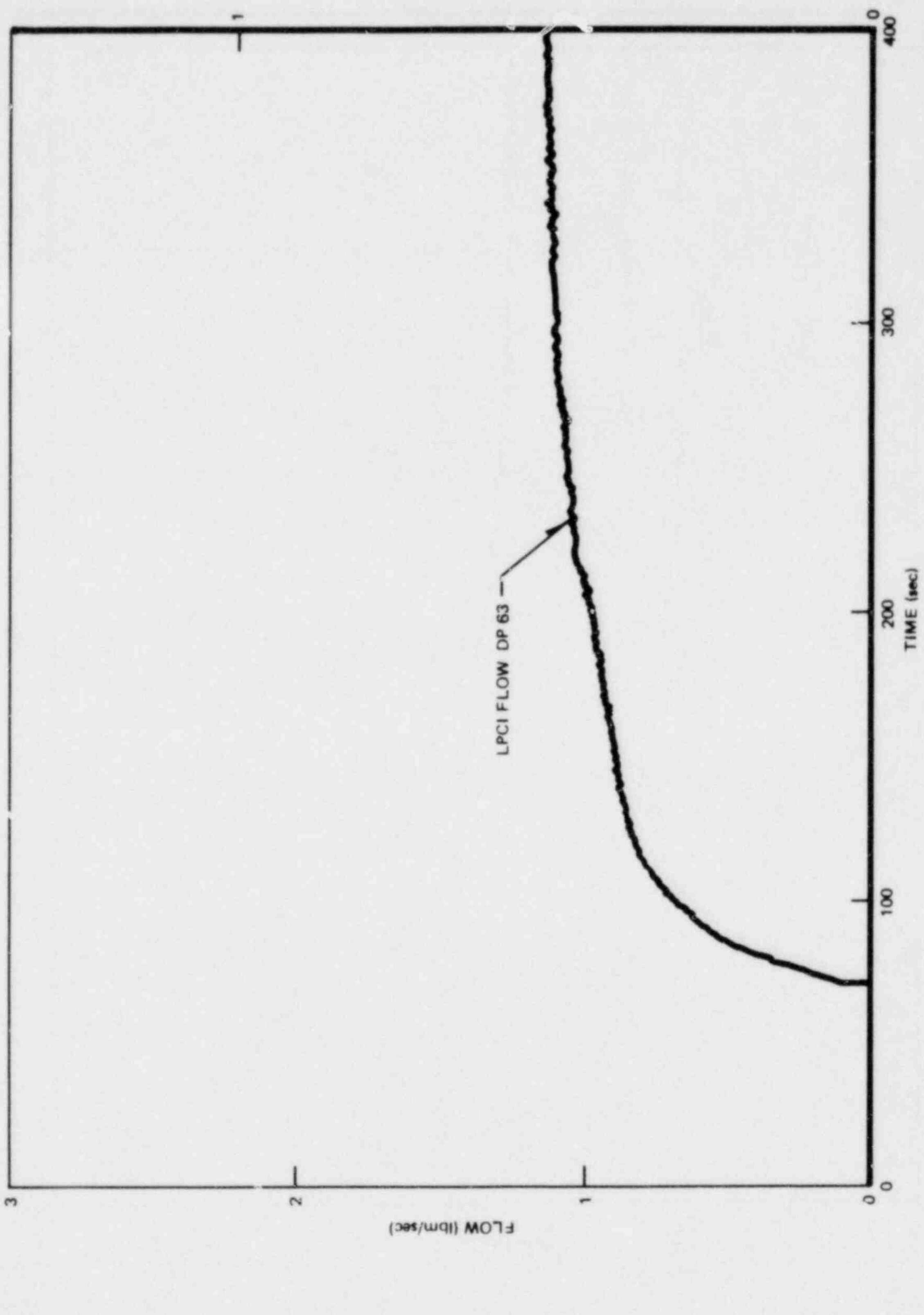


Figure D-7. LPCI Injection Rate

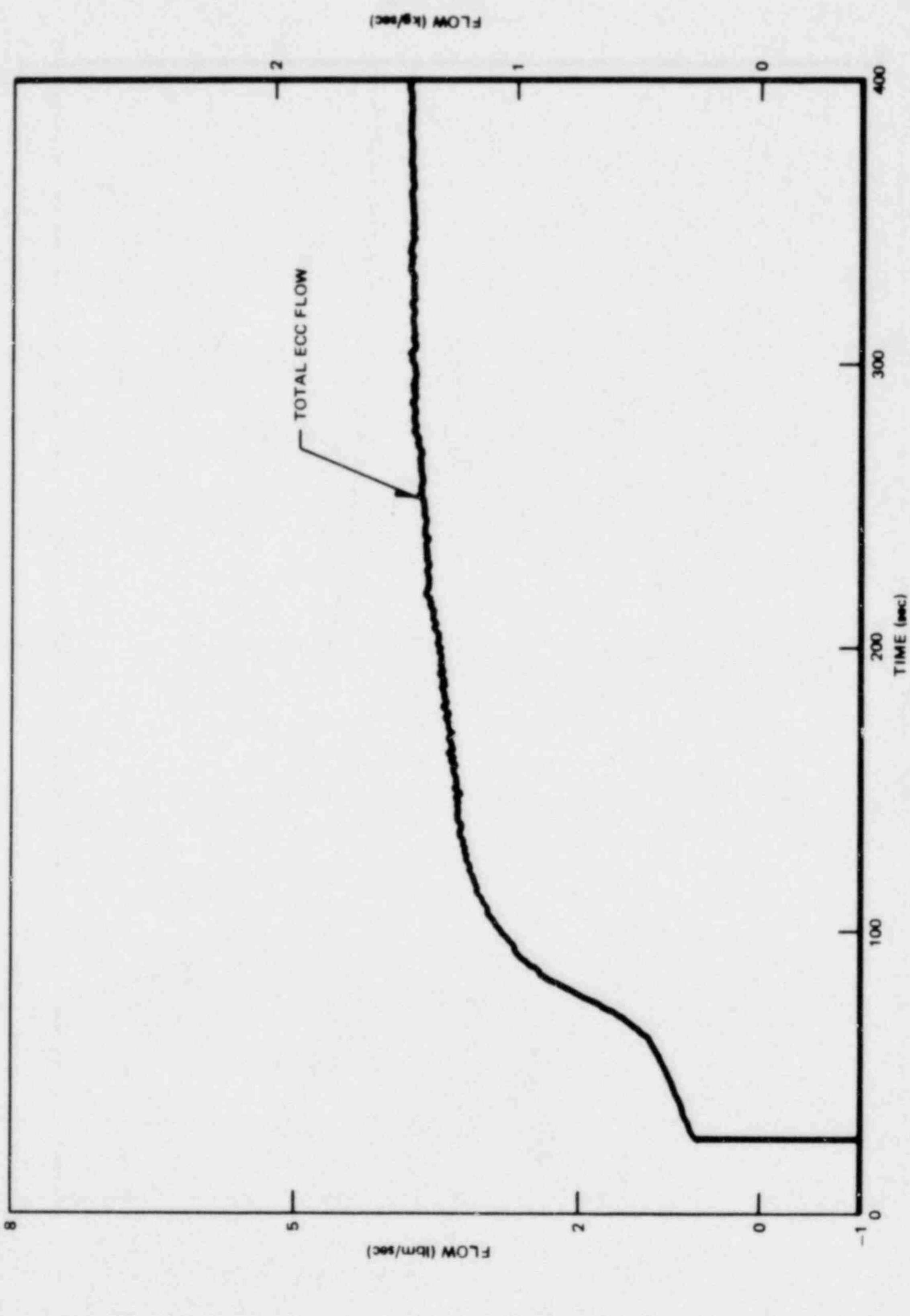


Figure D-9 Total ECC Injection Rate

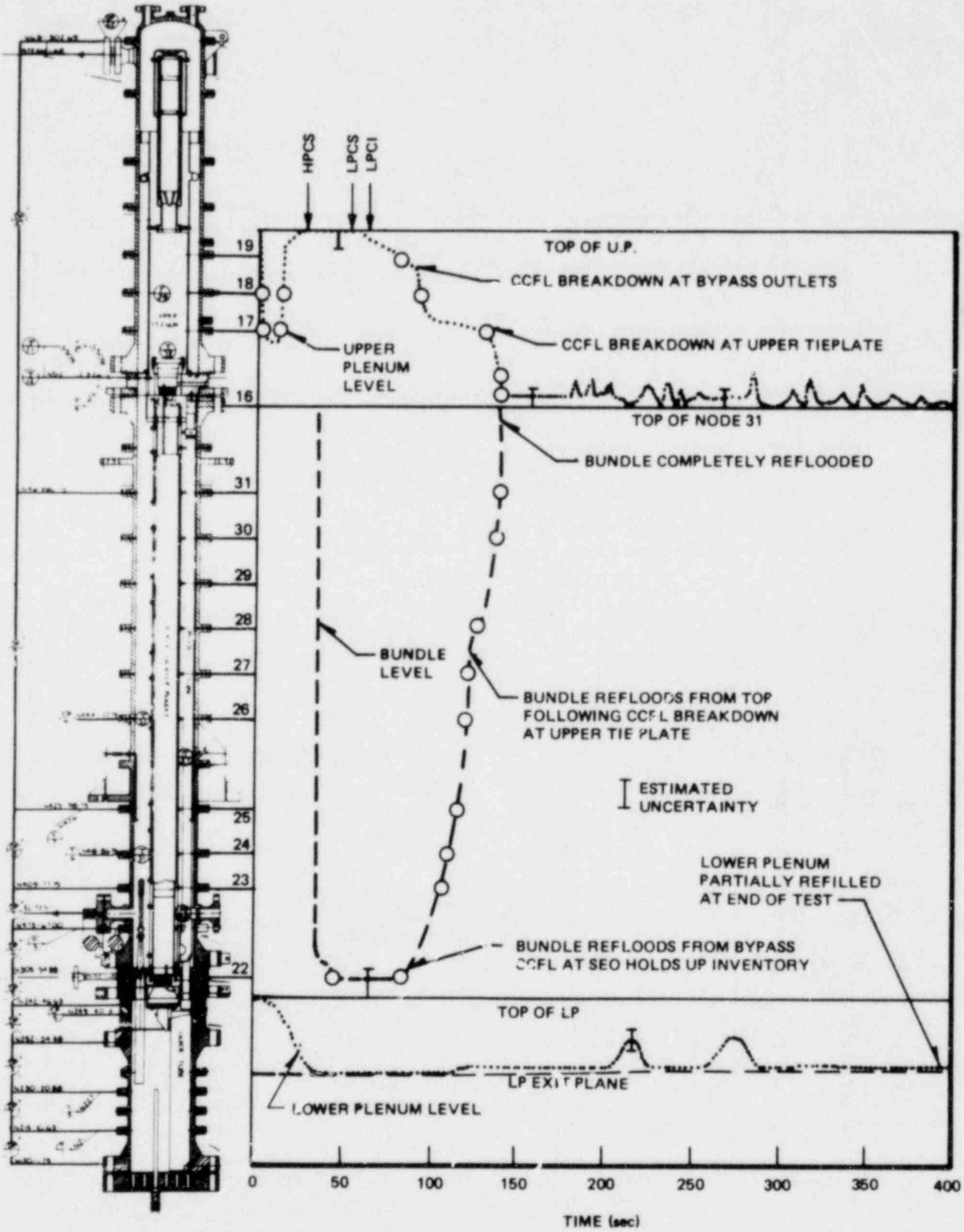


Figure D-9. Mixture Levels Along the Bundle Path; TLTA 5A Reference Test (6422 Run 3, Average Power, Average ECC Rates)

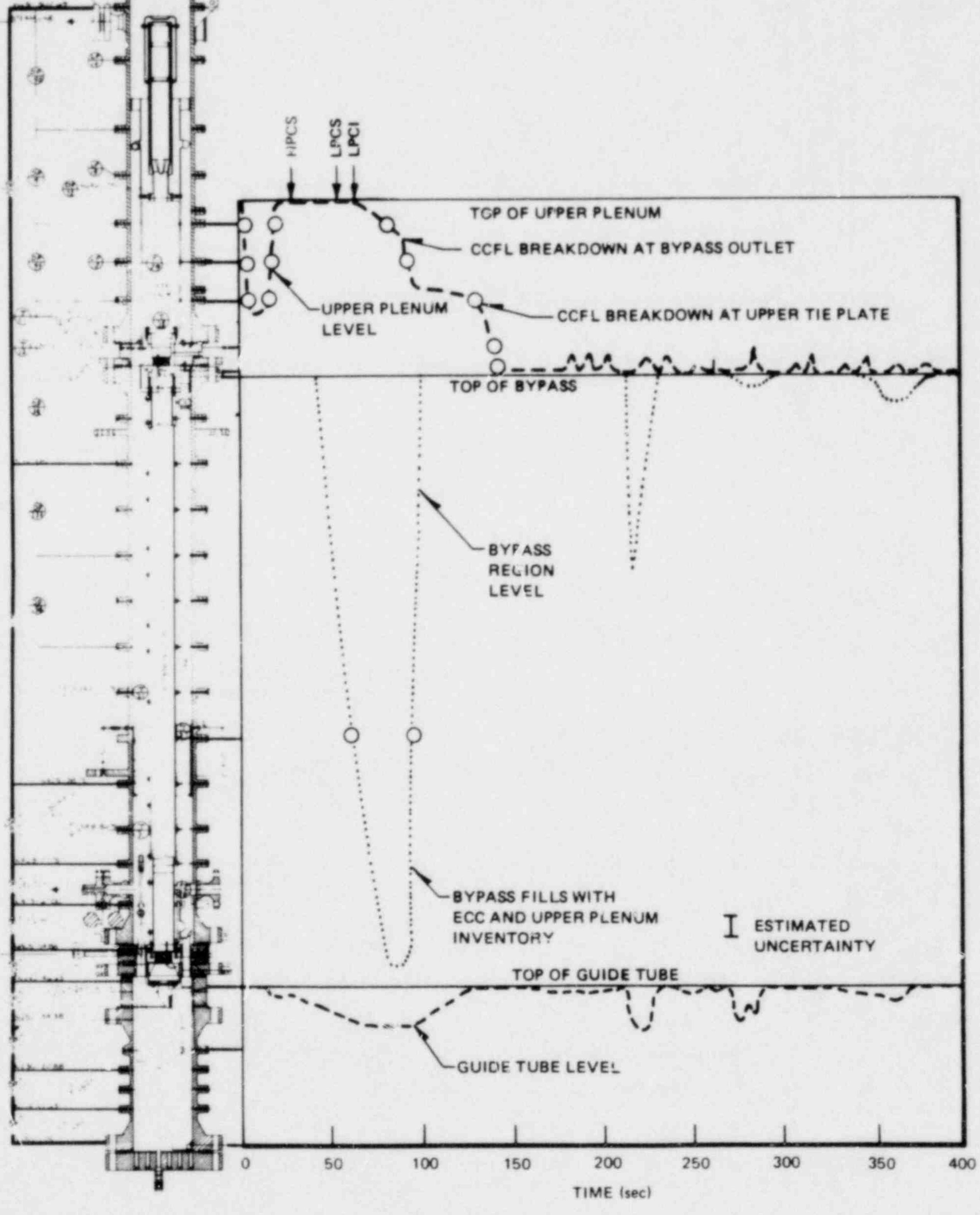


Figure D-10. Mixture Levels Along the Bypass Path; TLTA 5A Reference Test (6422 Run 3, Average Power, Average ECC Rates)

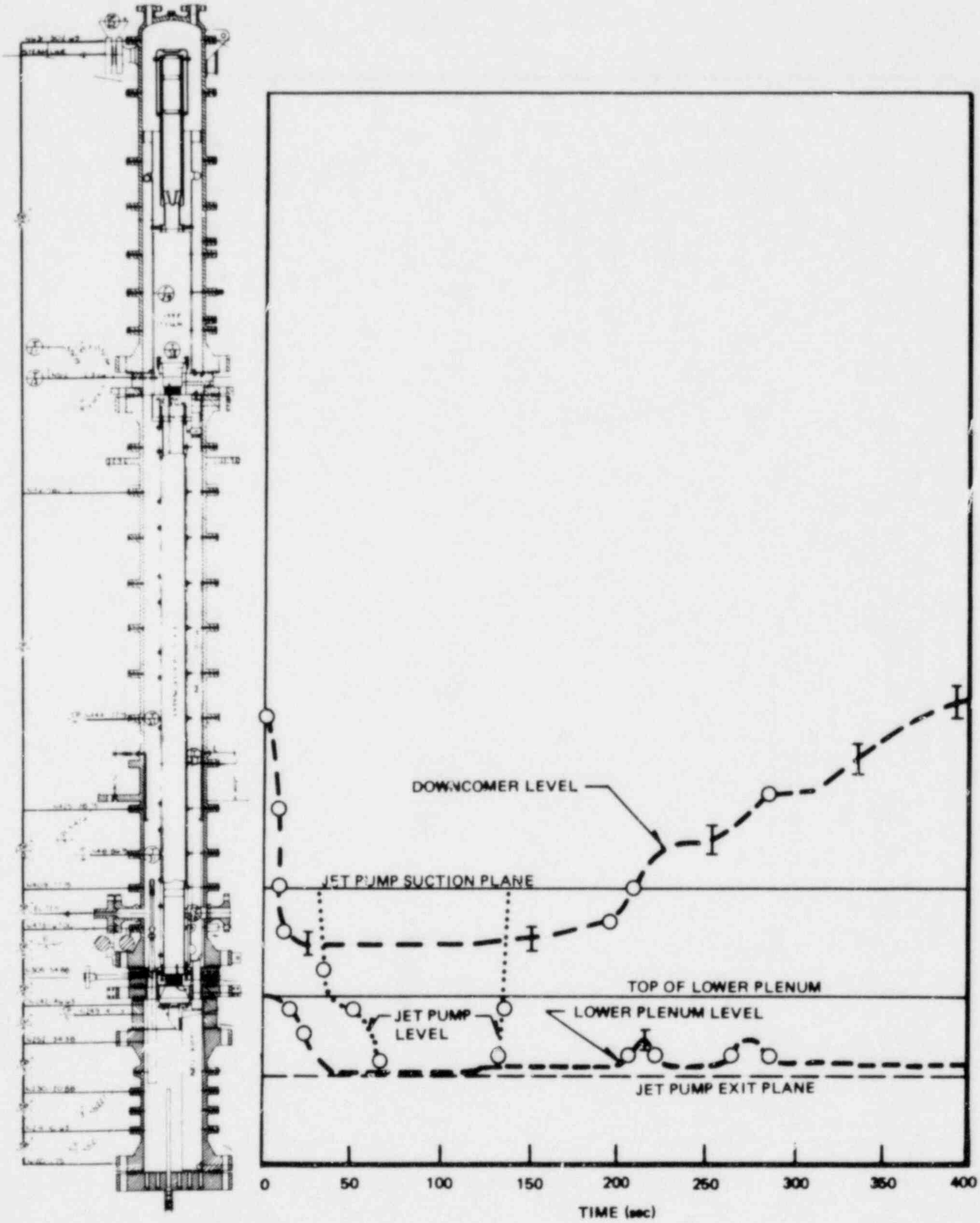


Figure D-11. Mixture Levels Along the Jet Pump Path; TLTA 5A Reference Test (6422 Run 3, Average Power, Average ECC Rates)

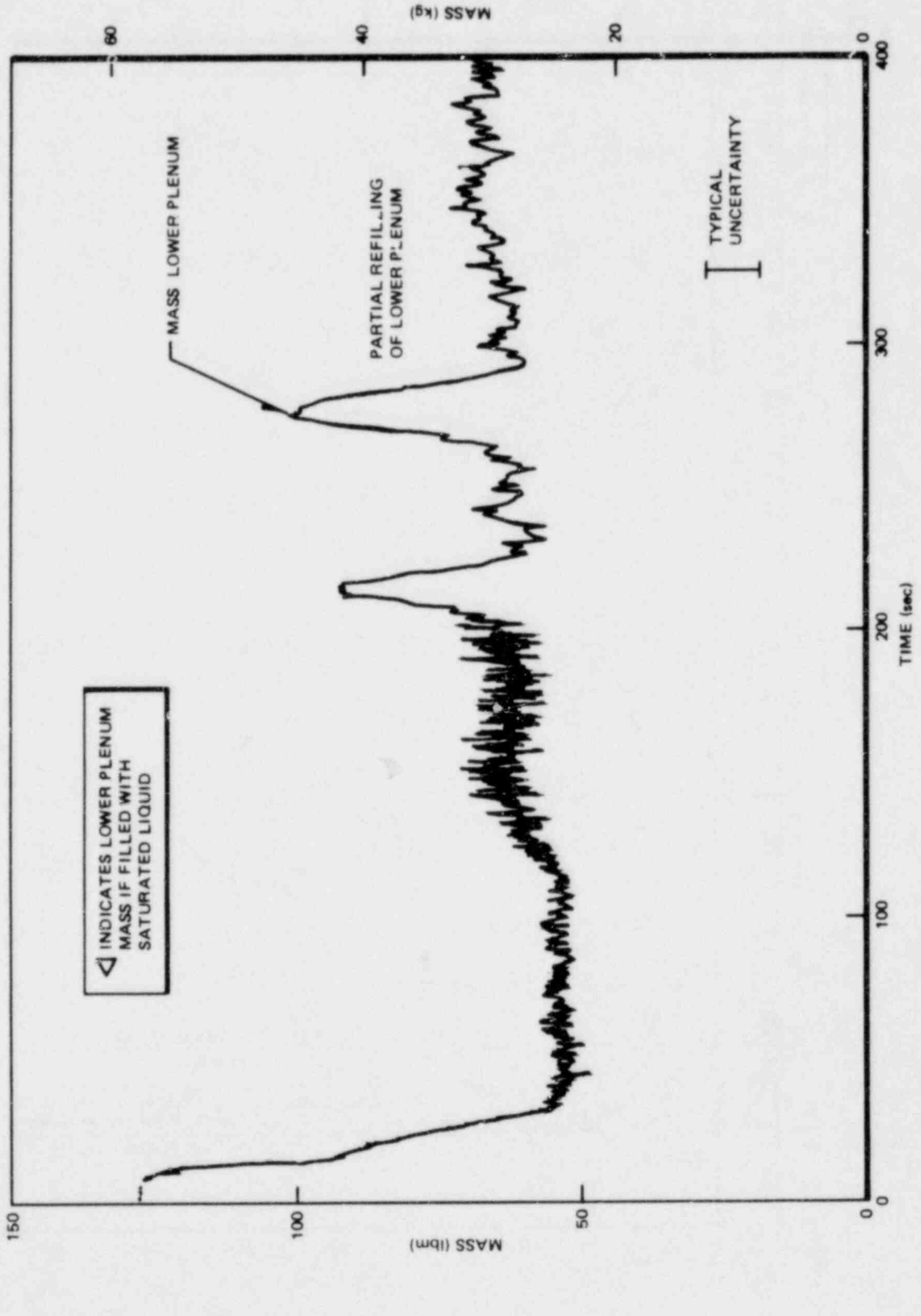


Figure D-12. Lower Plenum Mass

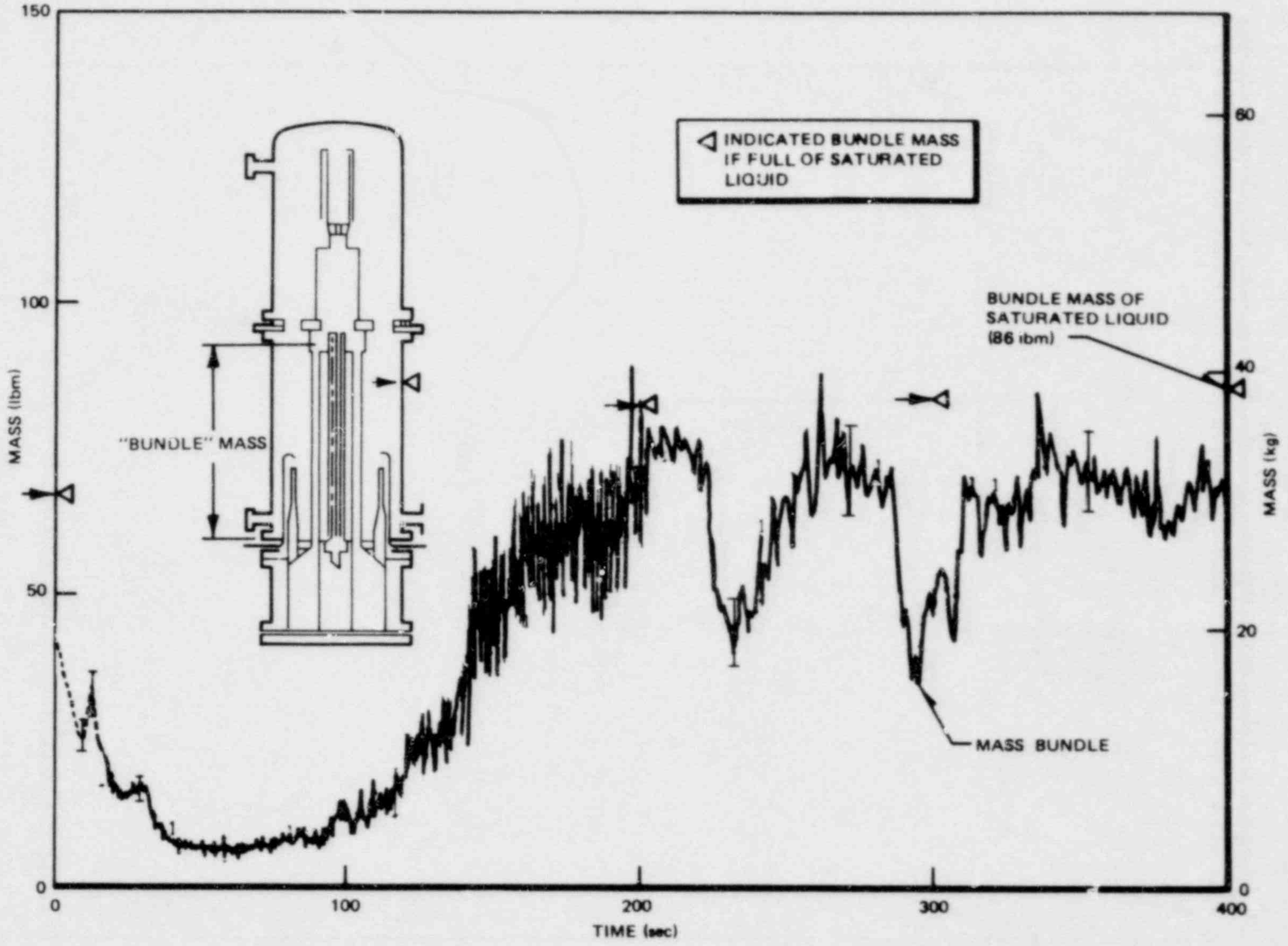


Figure D-12A. Bundle Mass

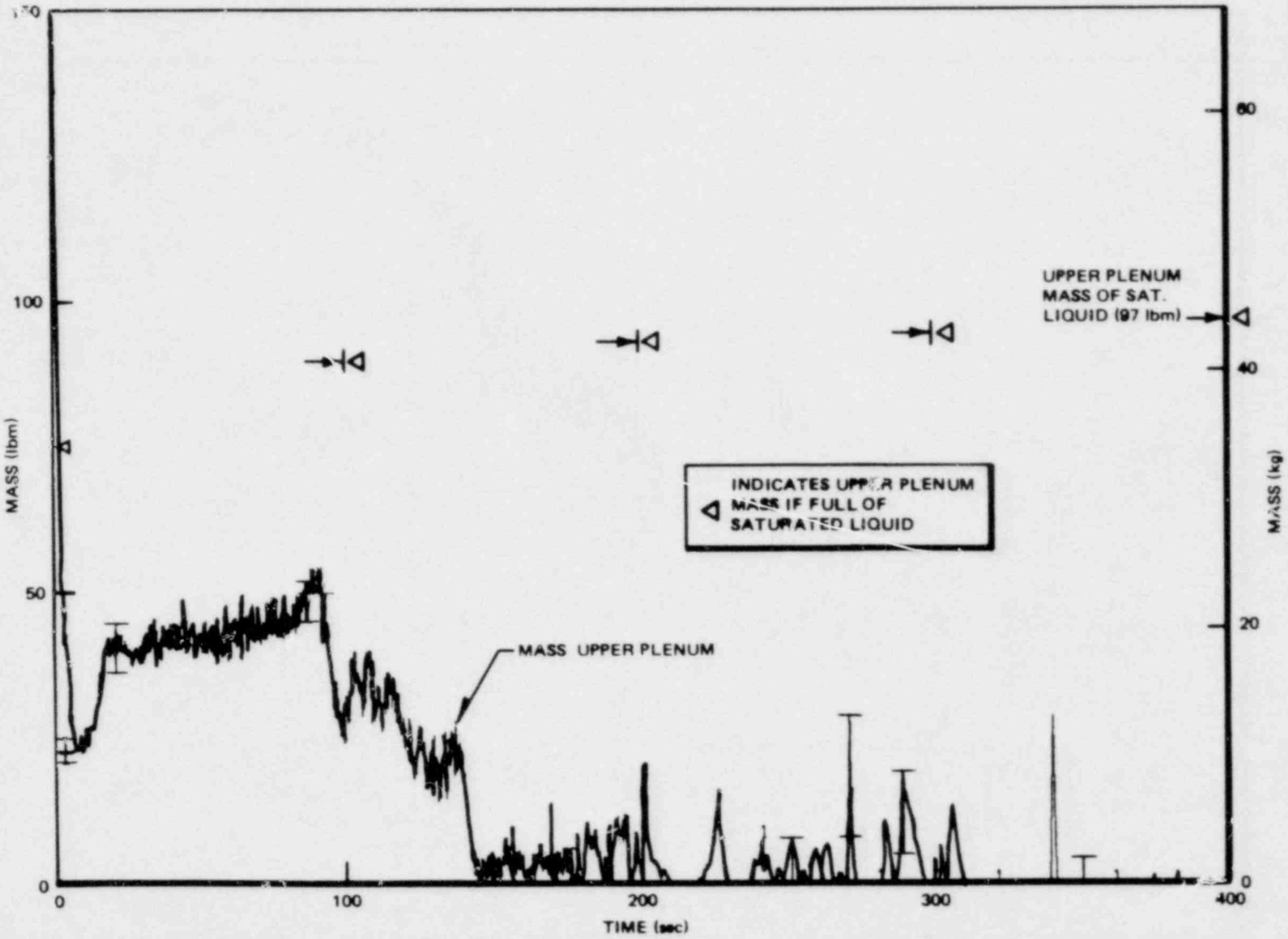


Figure D-13. Upper Plenum Mass

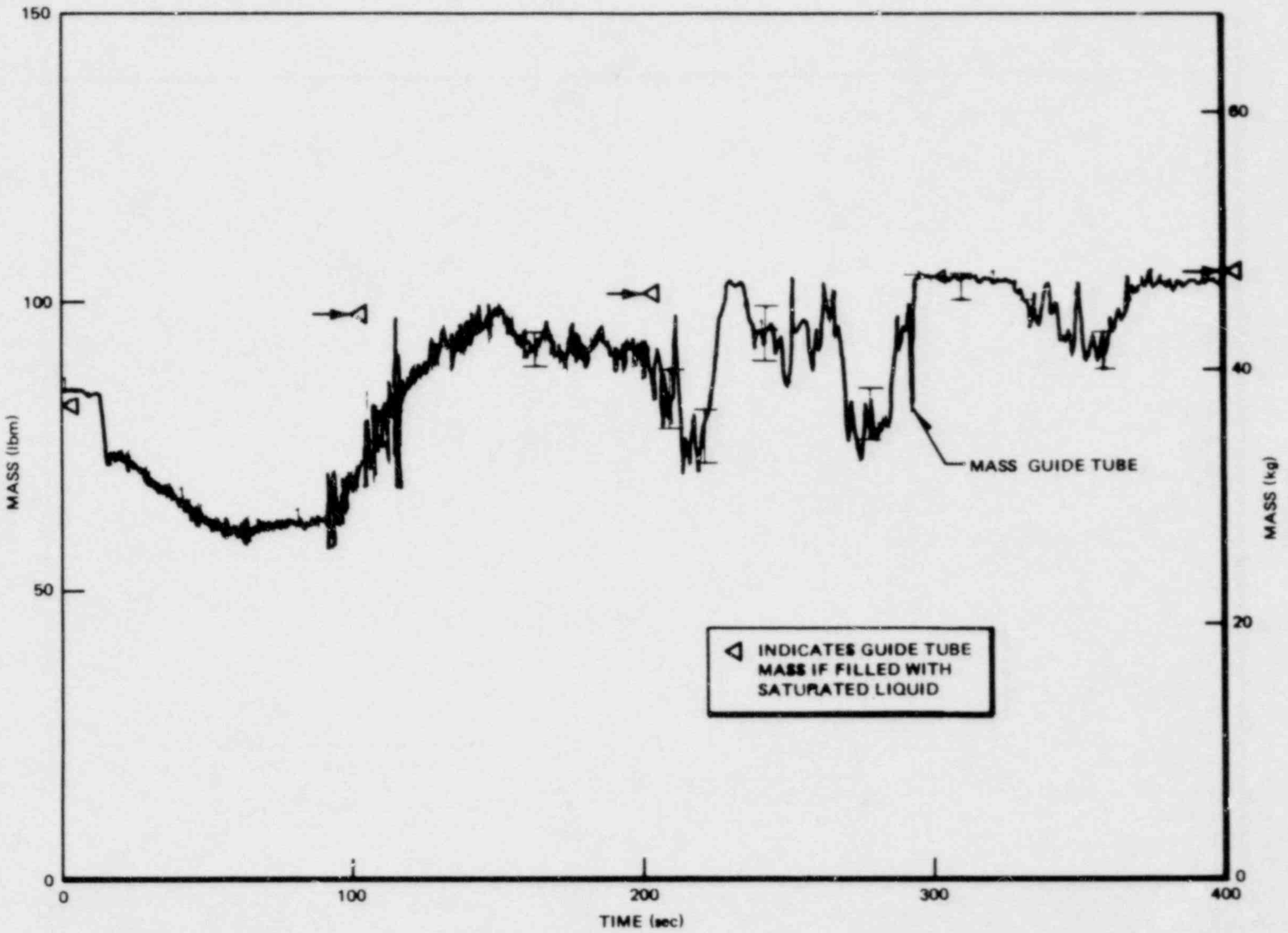


Figure D-14 Guide Tube Mass

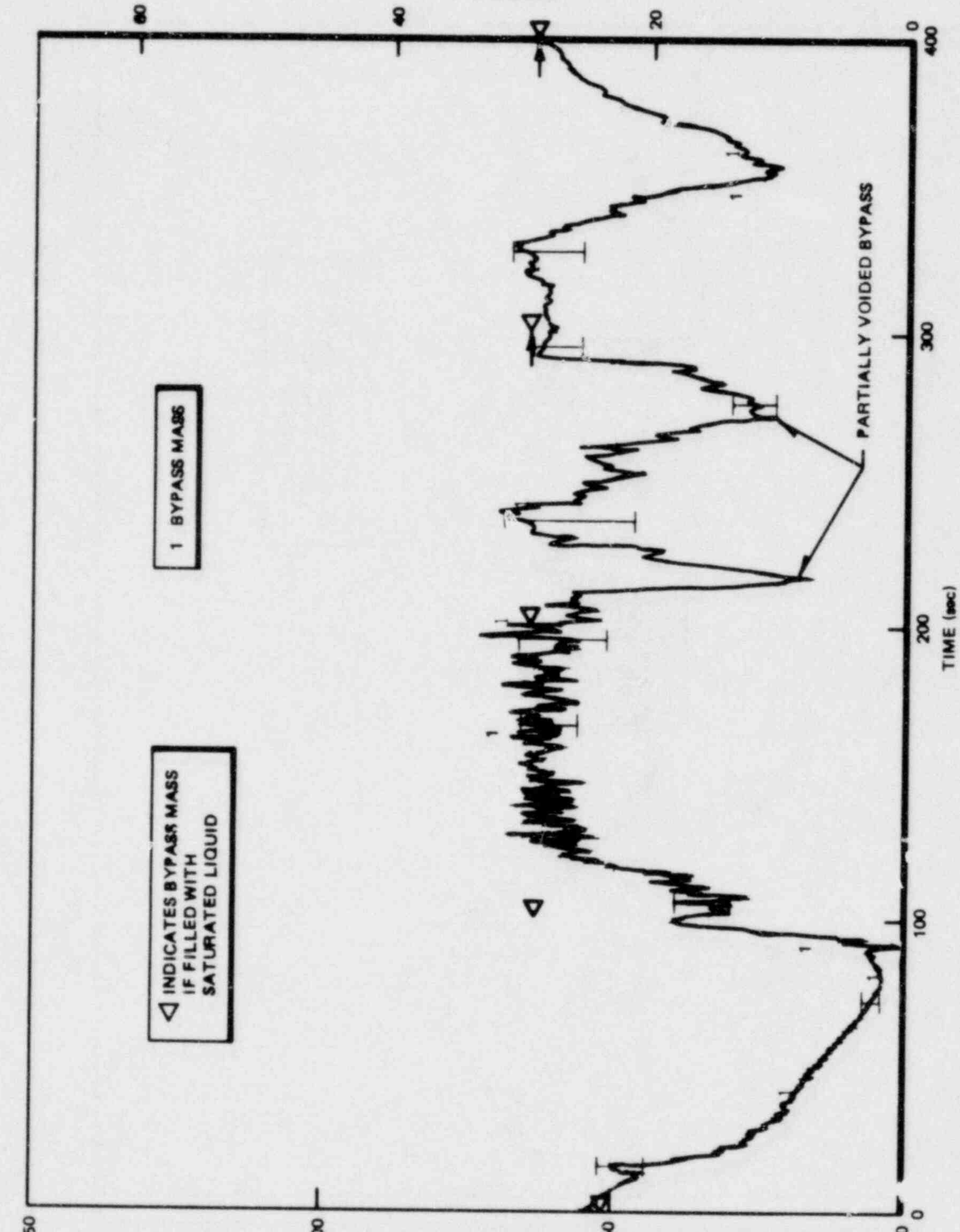


Figure D-15. Bypass Mass

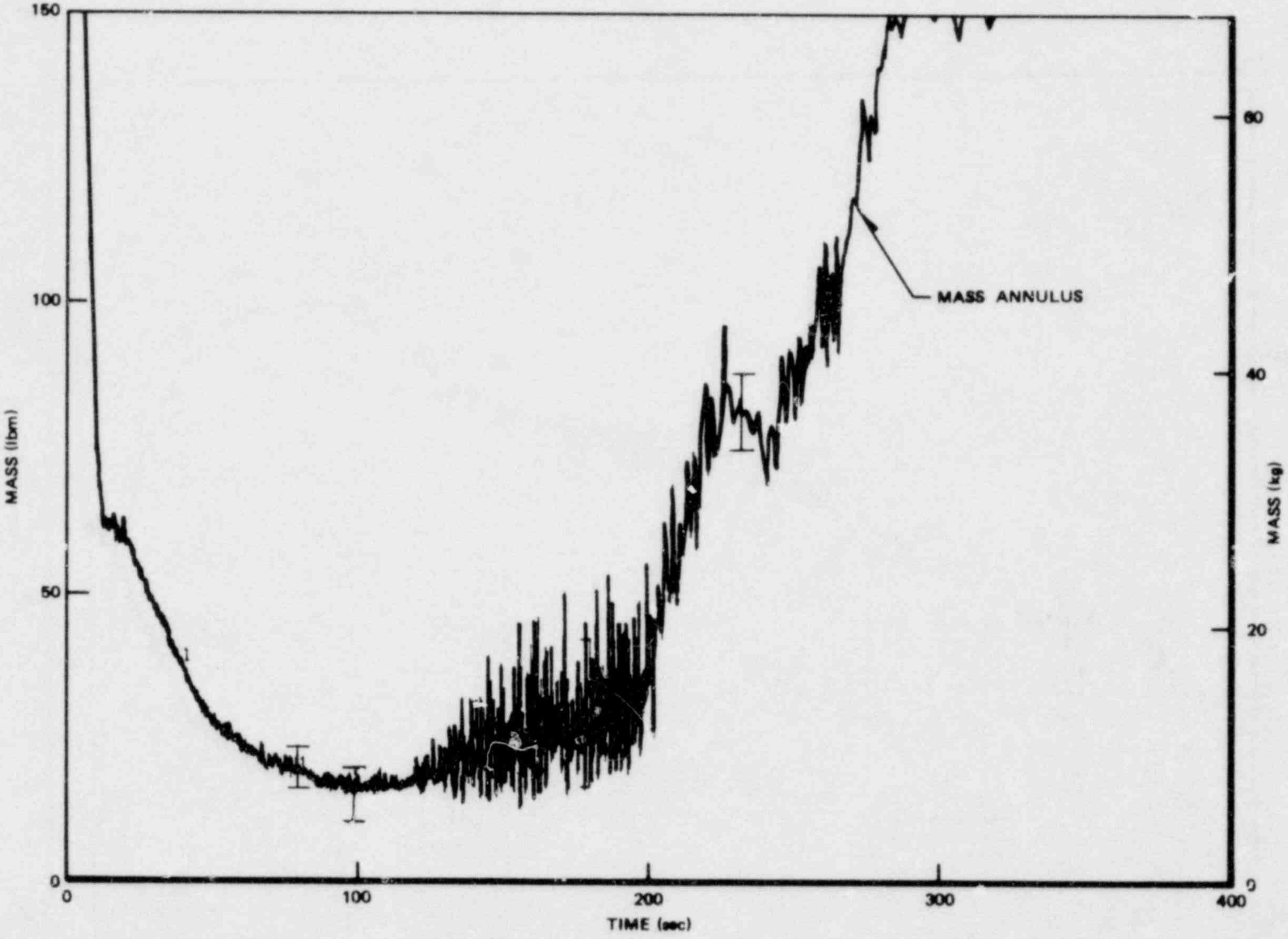


Figure D-16. Annulus Mass

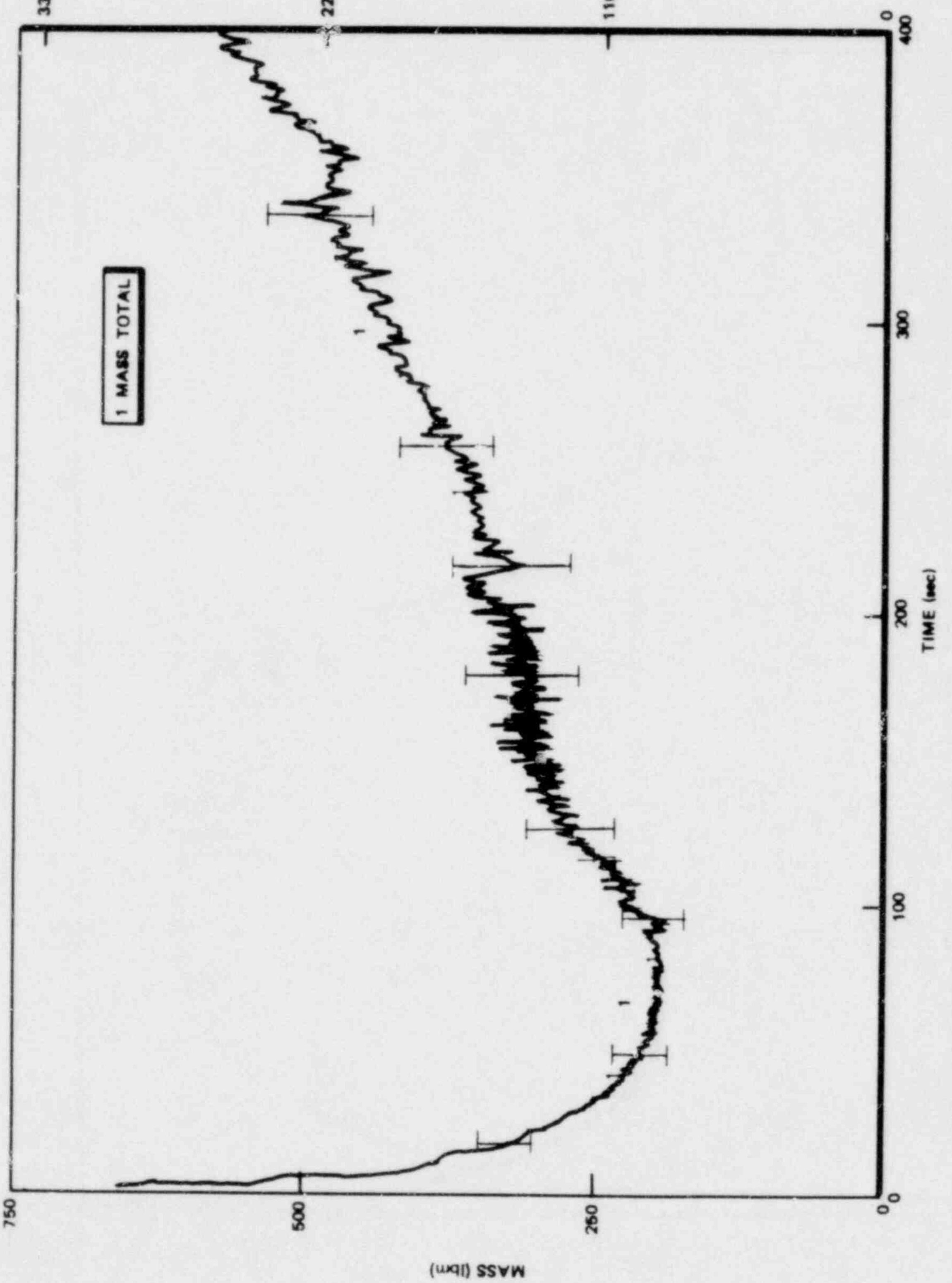
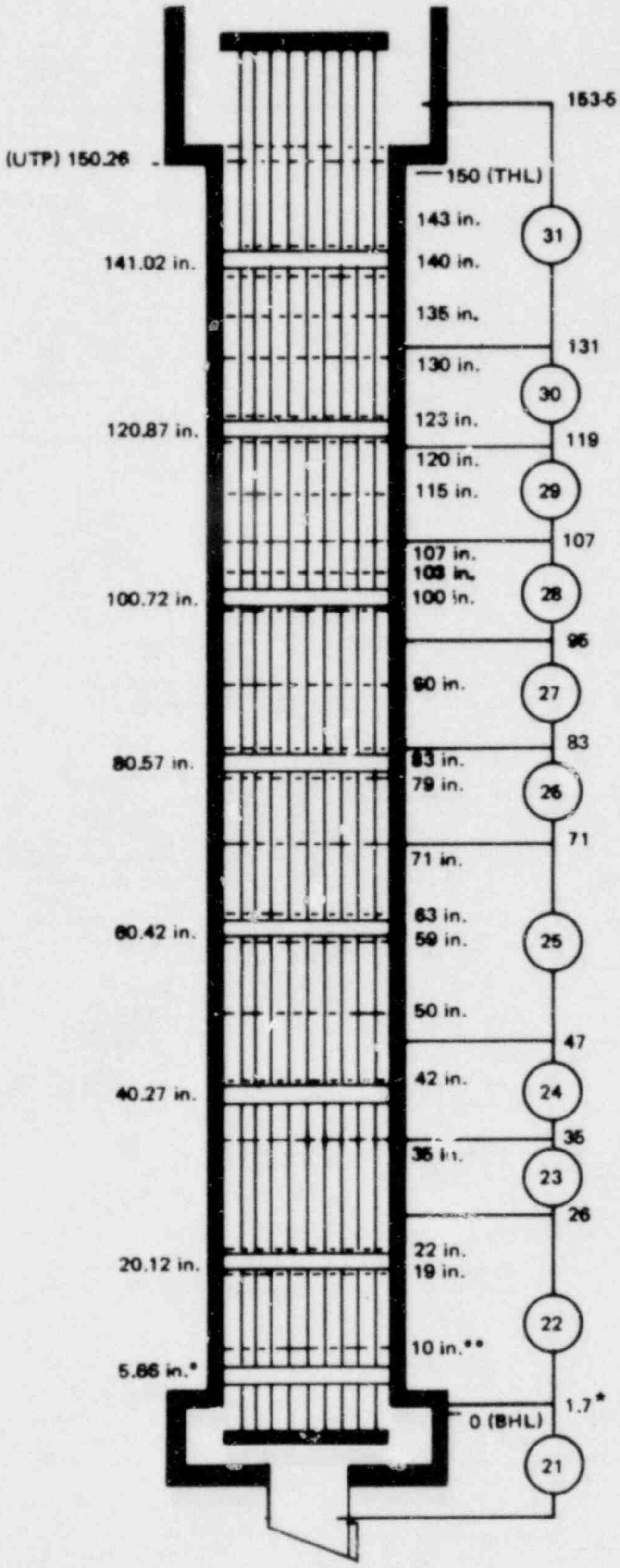


Figure D-17. Total Mass



NOTE:

*ELEVATION OF GRID SPACER BOTTOM RE BOTTOM OF HEATED LENGTH (TLTA EL 51.7 in.)

**ELEVATION OF TEMPERATURE MEASUREMENT RE BHL

* ELEVATION OF PRESSURE TRANSDUCER TAPS RE BHL

Figure D-18. Temperature and Differential Pressure Measurements in TLTA 5A

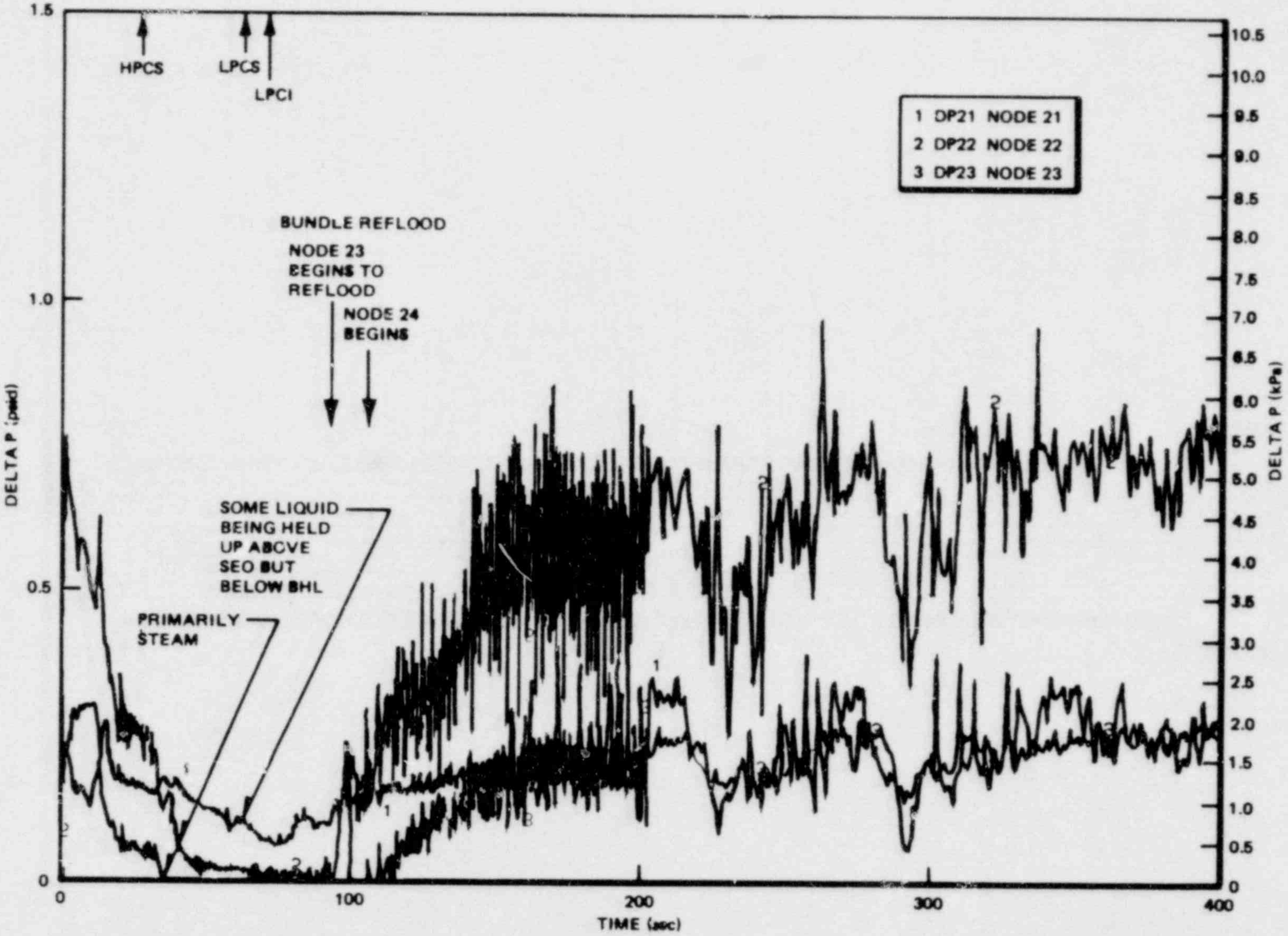


Figure D-19. Bundle DP's Bottom Nodes

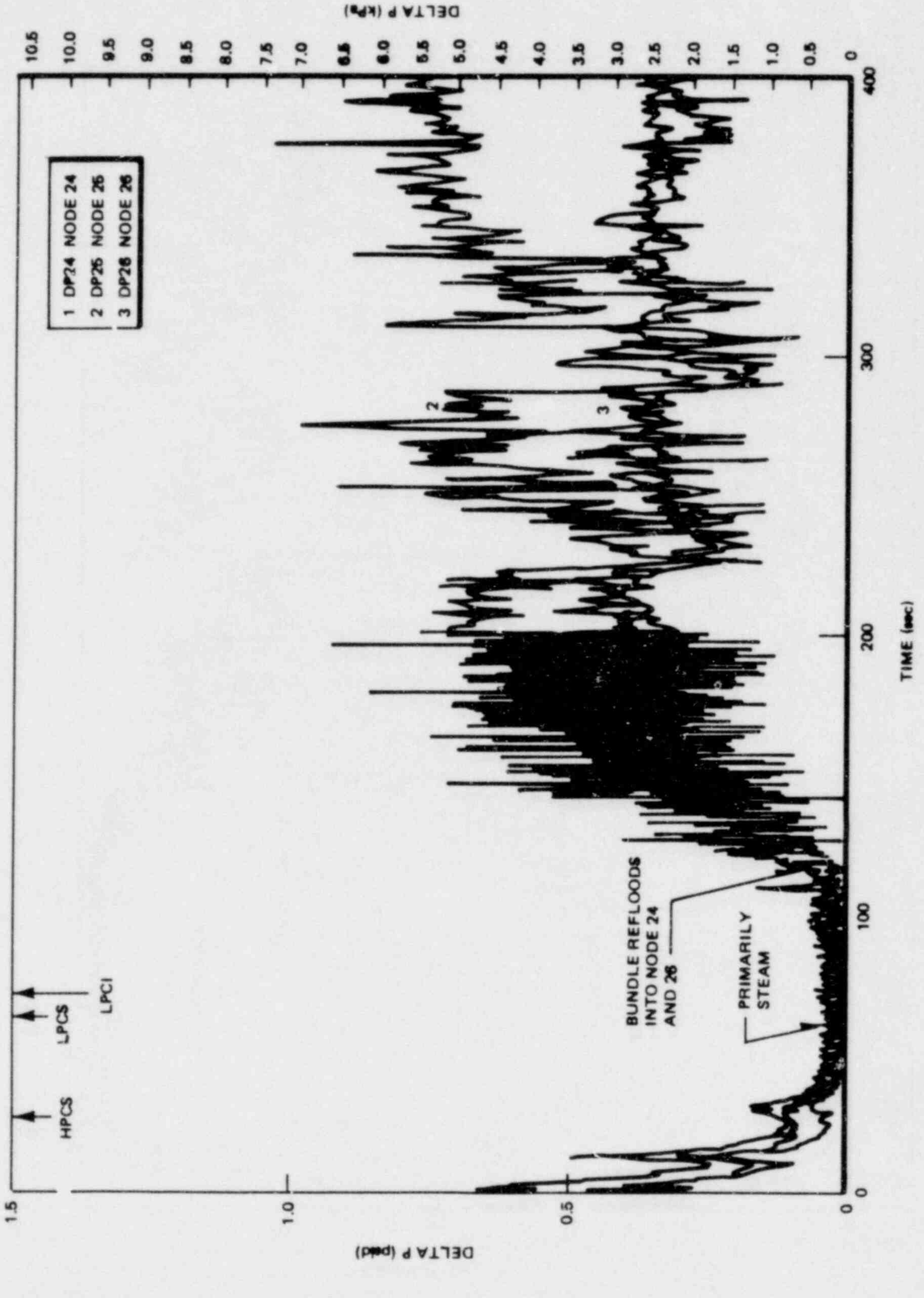


Figure D-20. Bundle DP's Lower-Middle Nodes

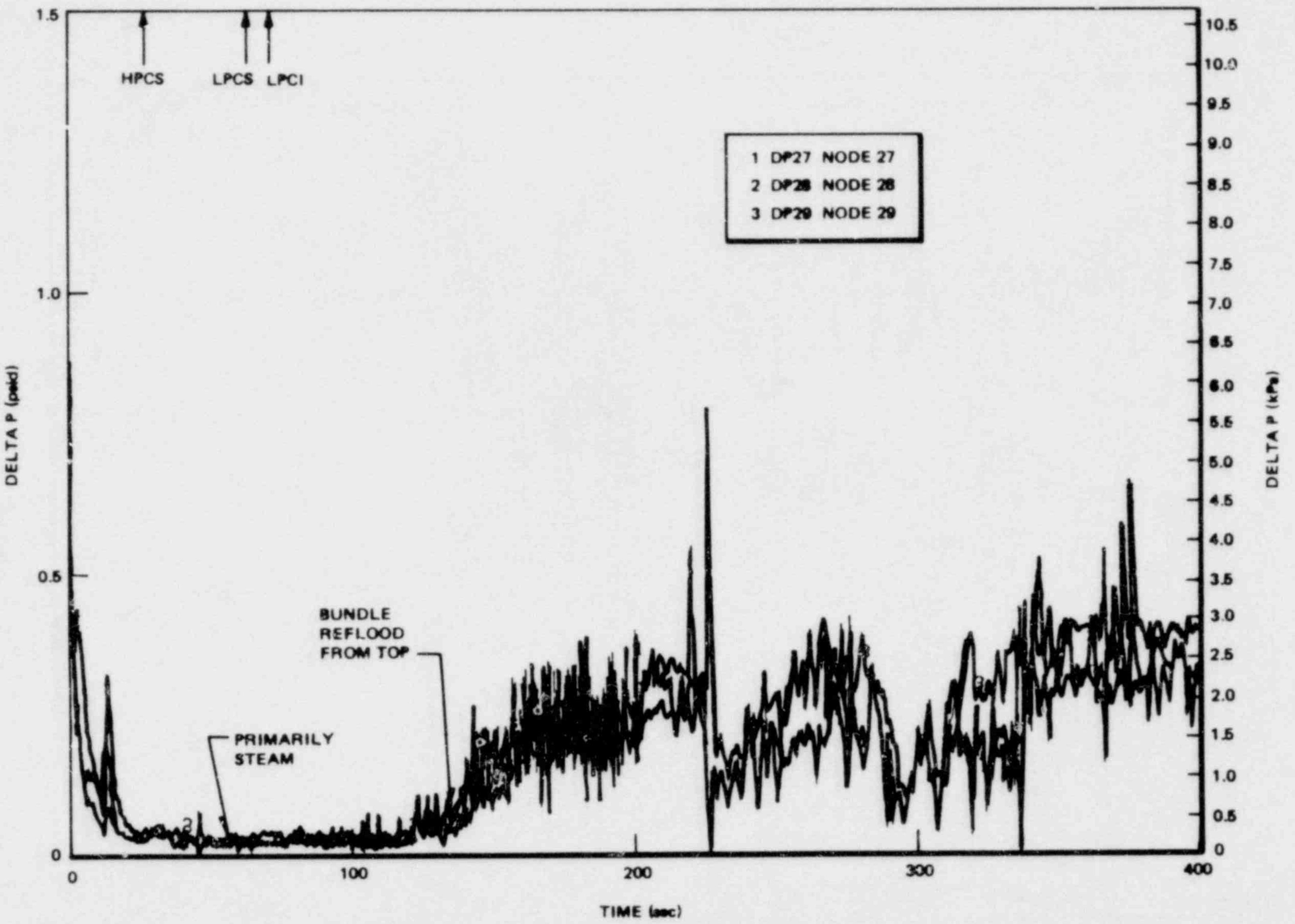


Figure D-21. Bundle DP's Upper-Middle Nodes

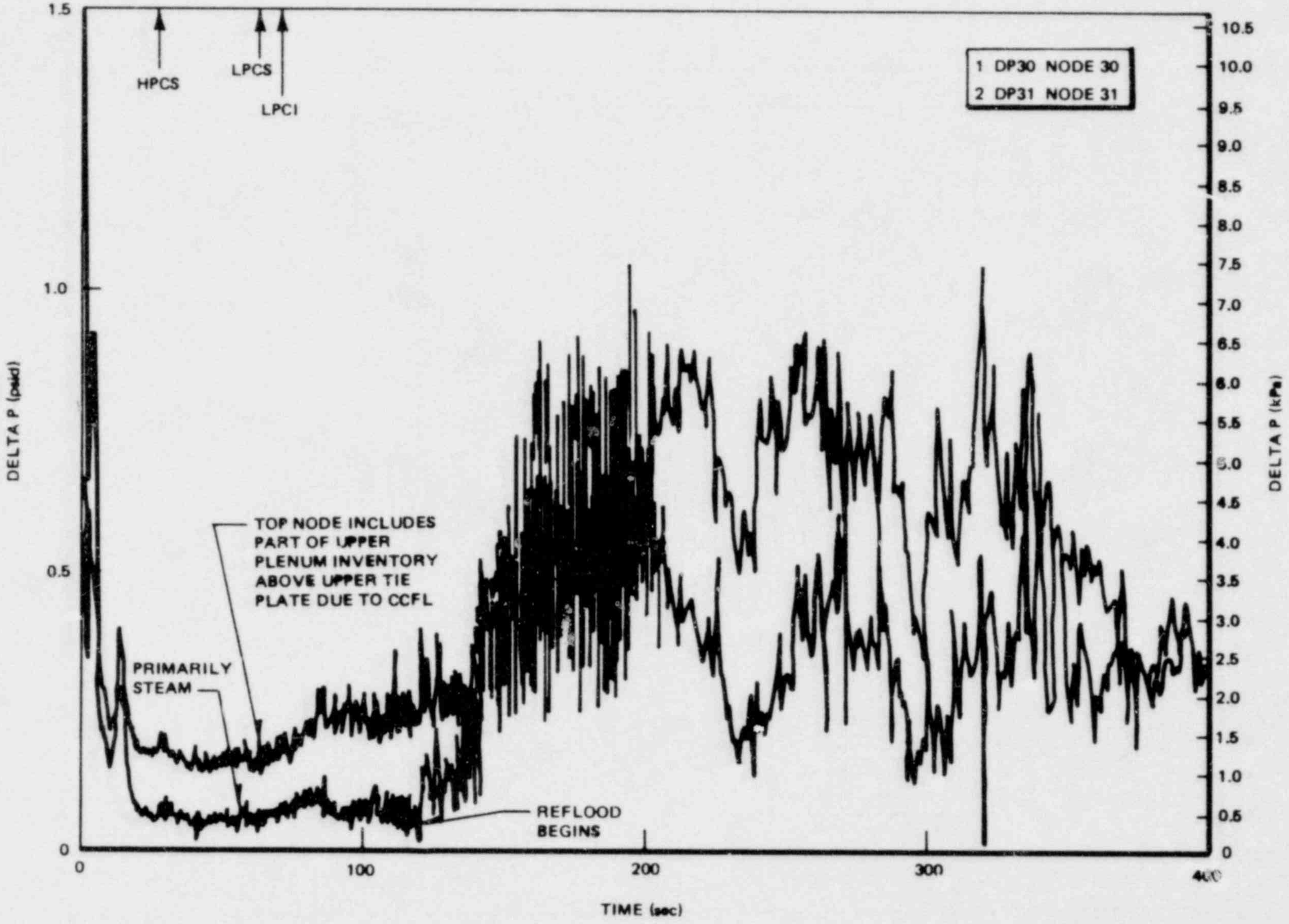


Figure D-22. Bundle DP's Top Nodes

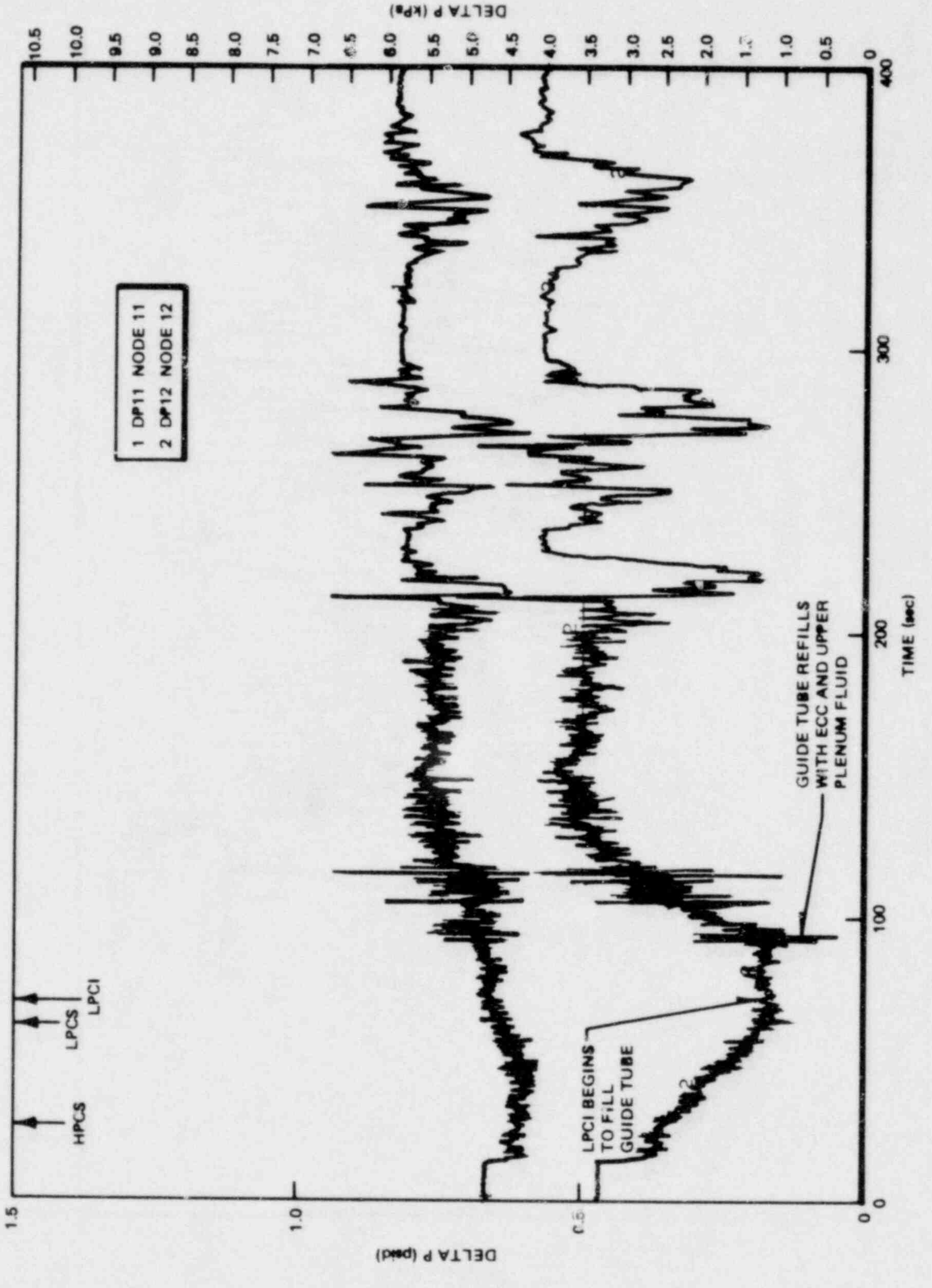


Figure D-23. Guide Tube DP's

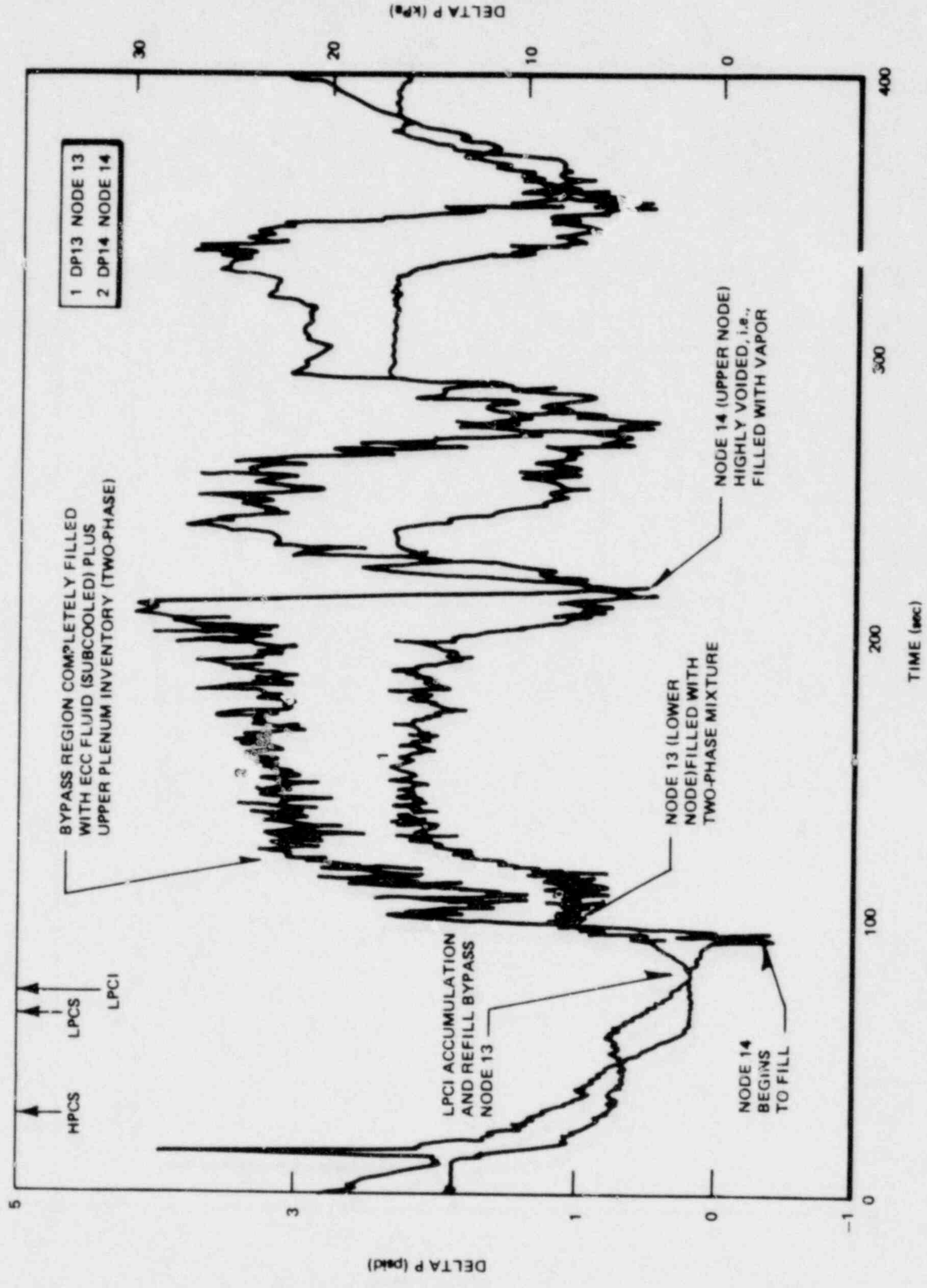


Figure D-24. Bypass Region DP's

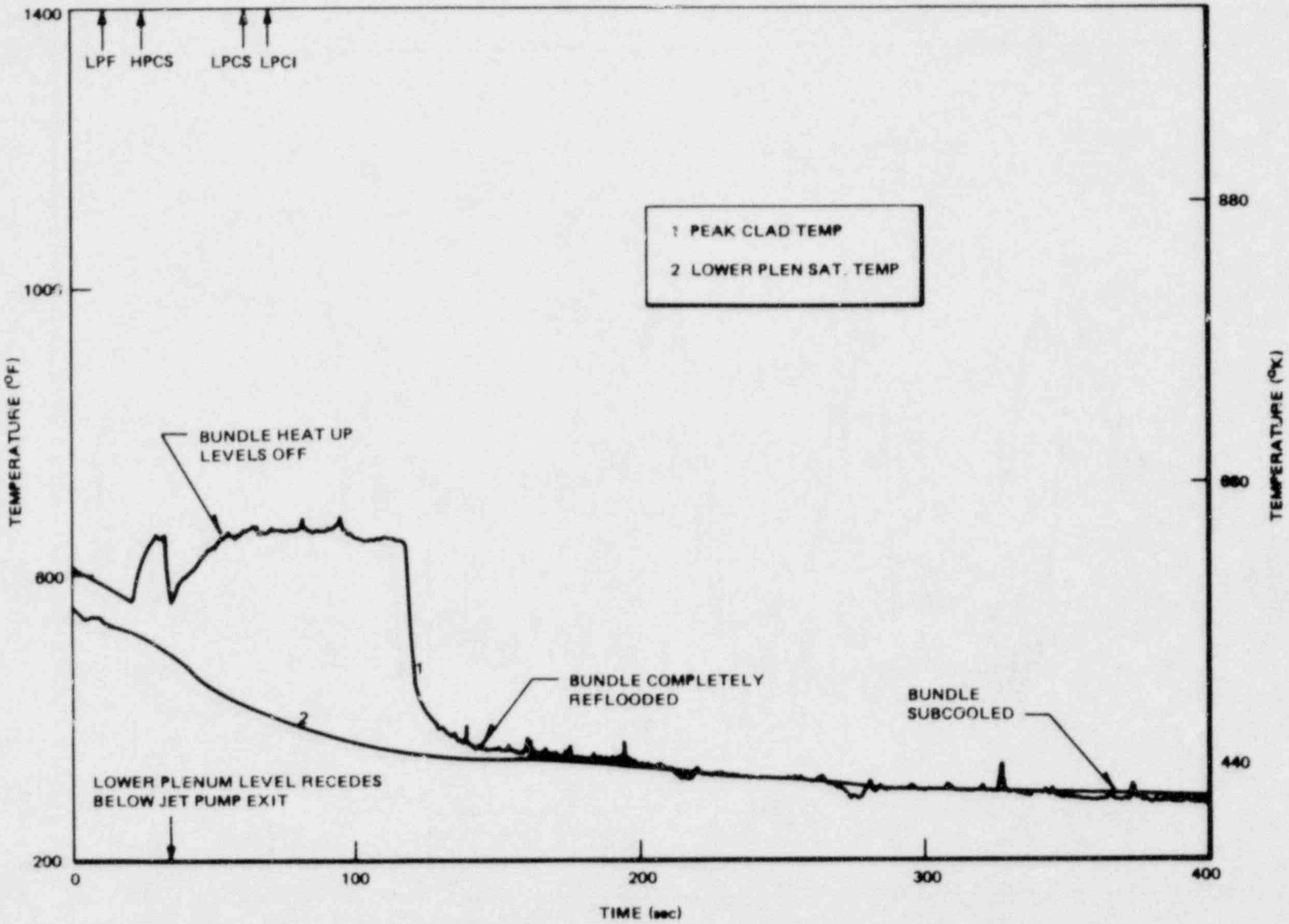


Figure D-25. Rod Cladding Temperature

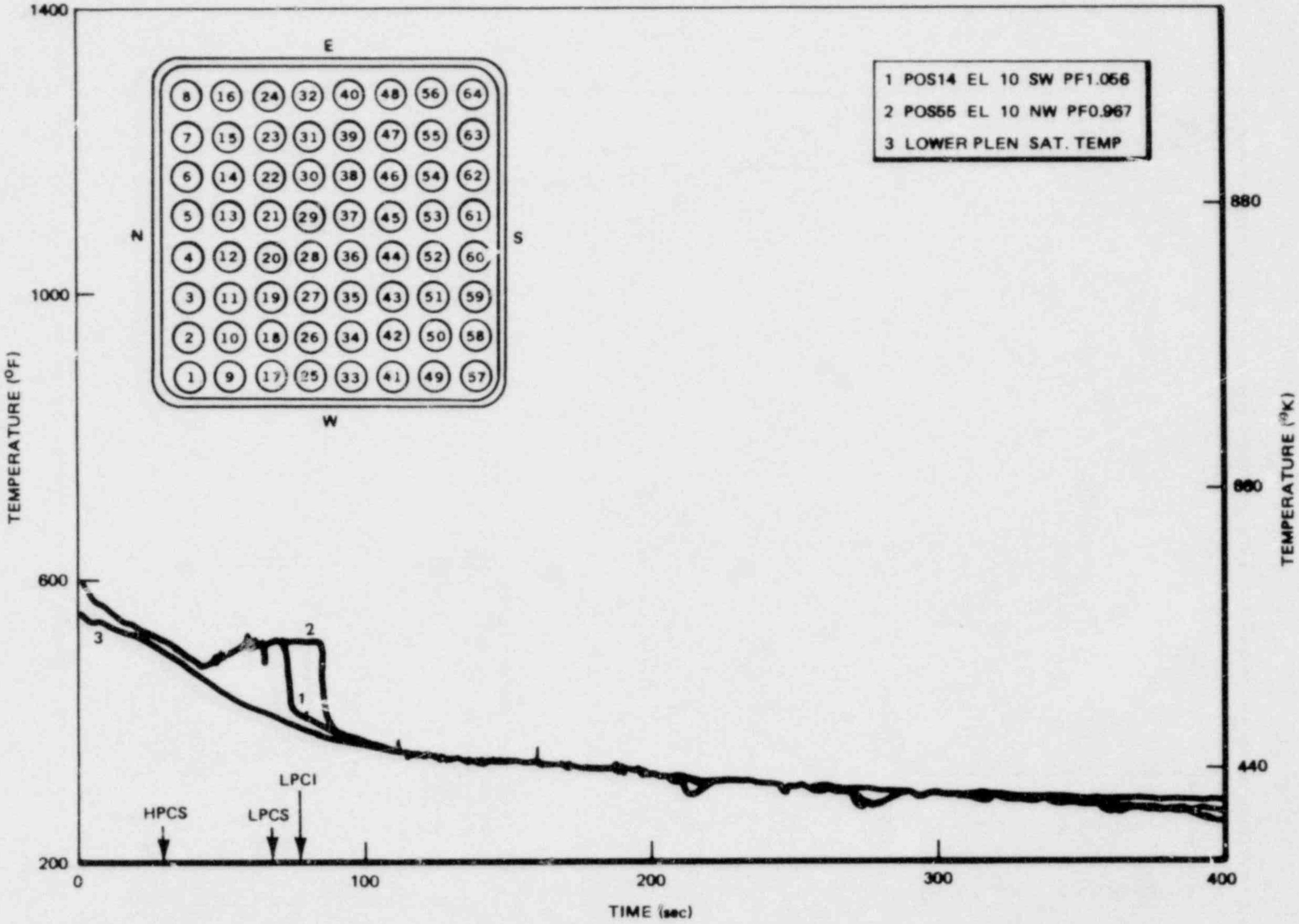


Figure D-26 Peak Cladding Temperature

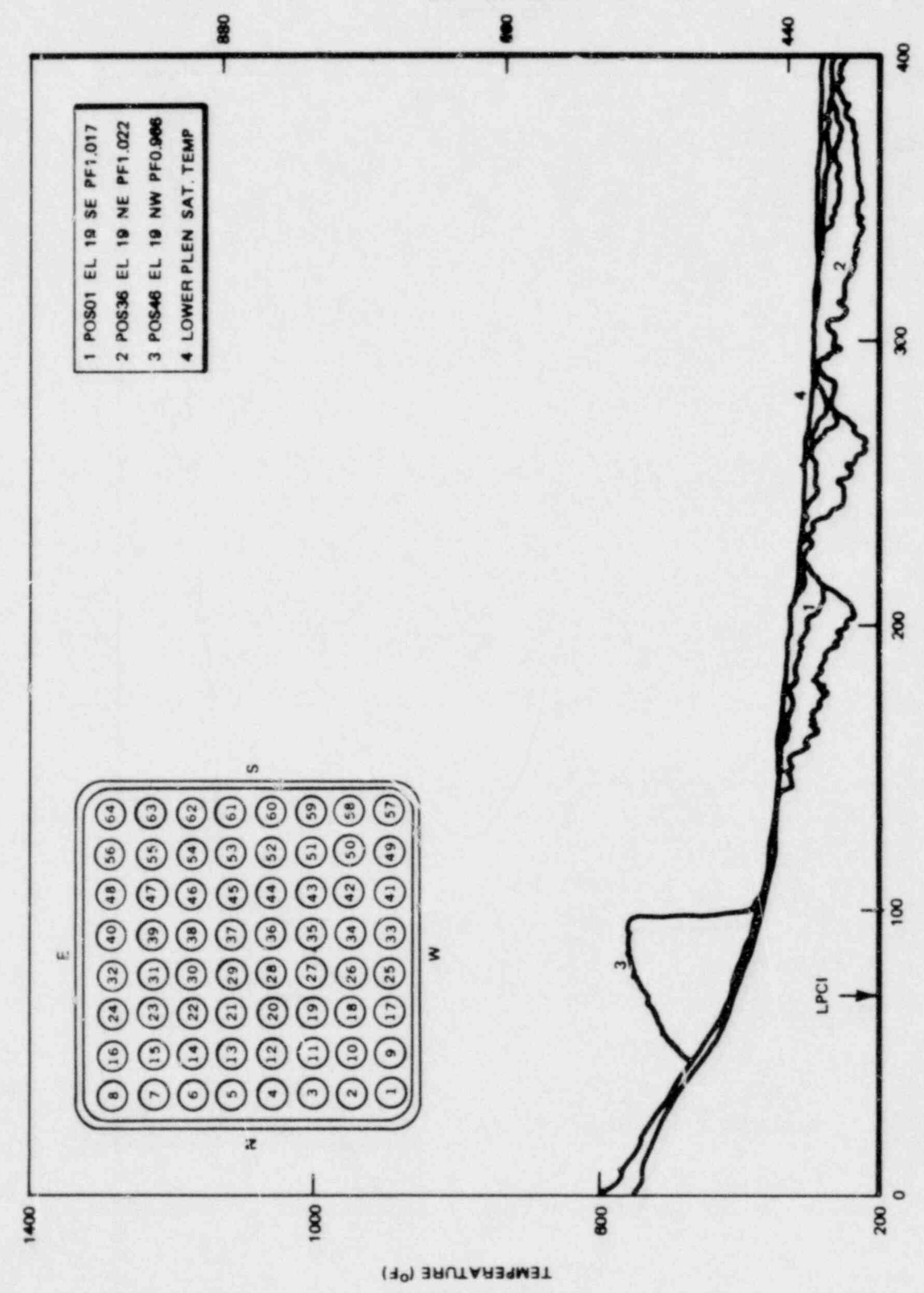


Figure D-27. Rod Cladding Temperature

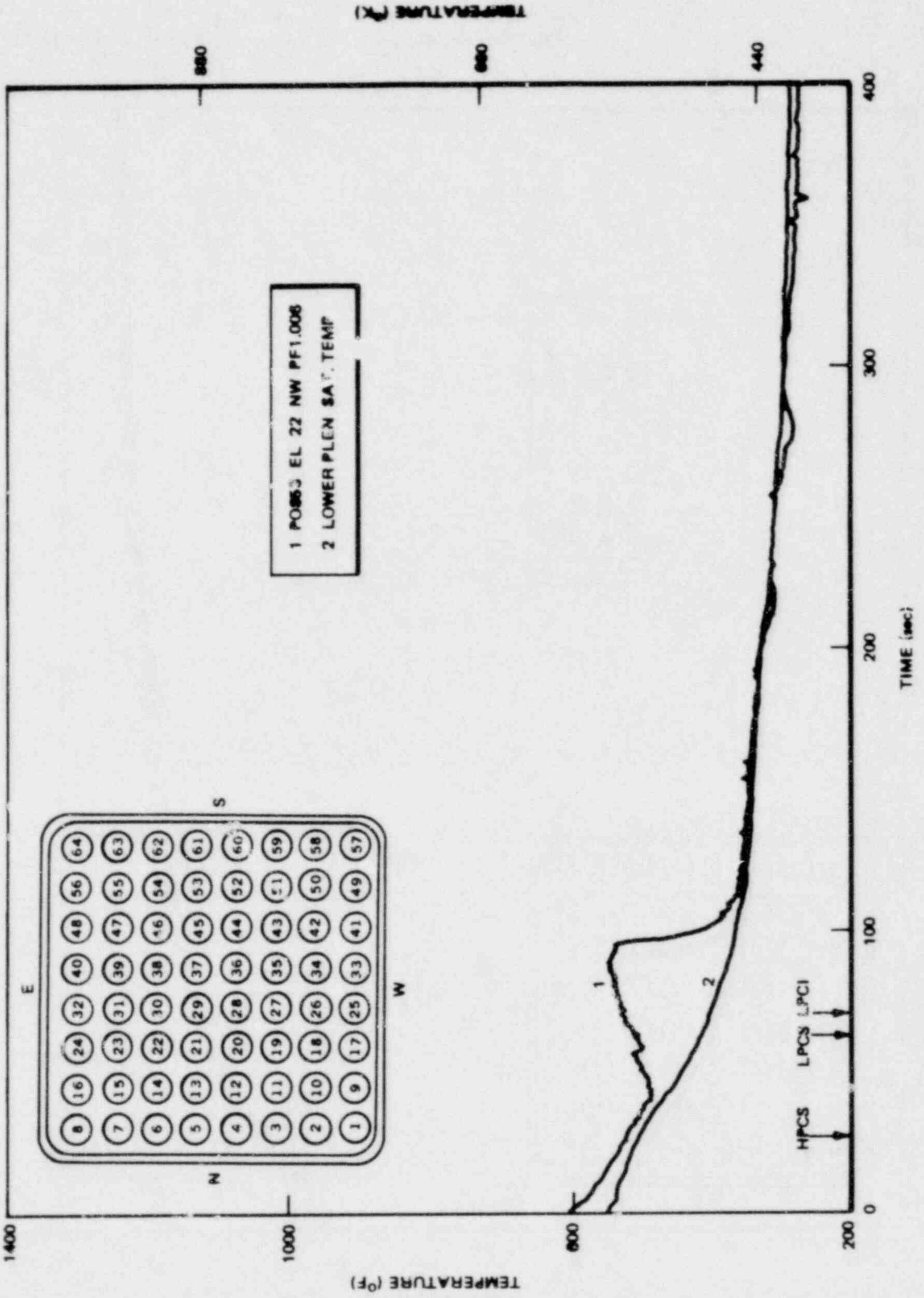


Figure D-28. Rod Cladding Temperature

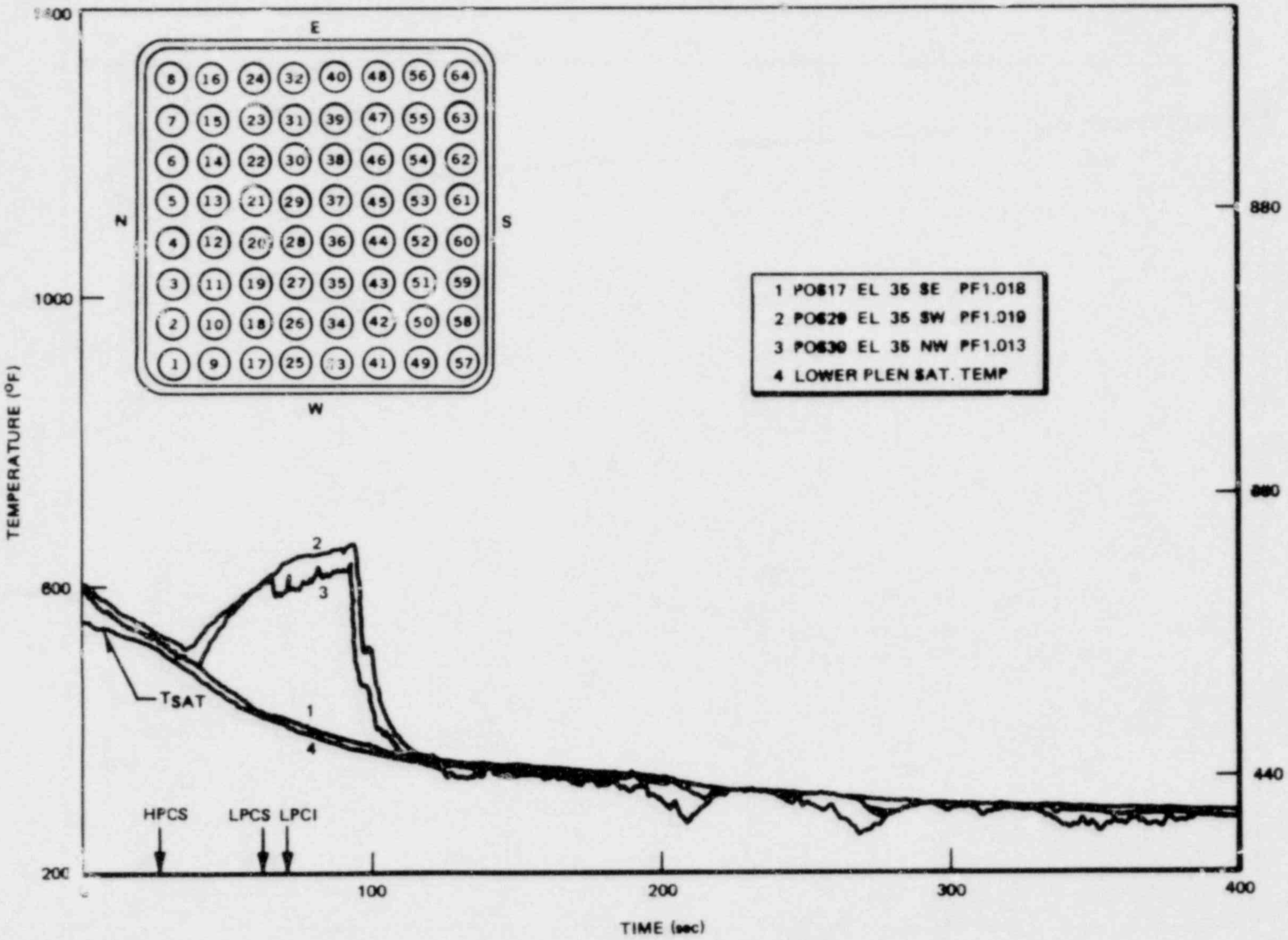


Figure D-29. Rod Cladding Temperature

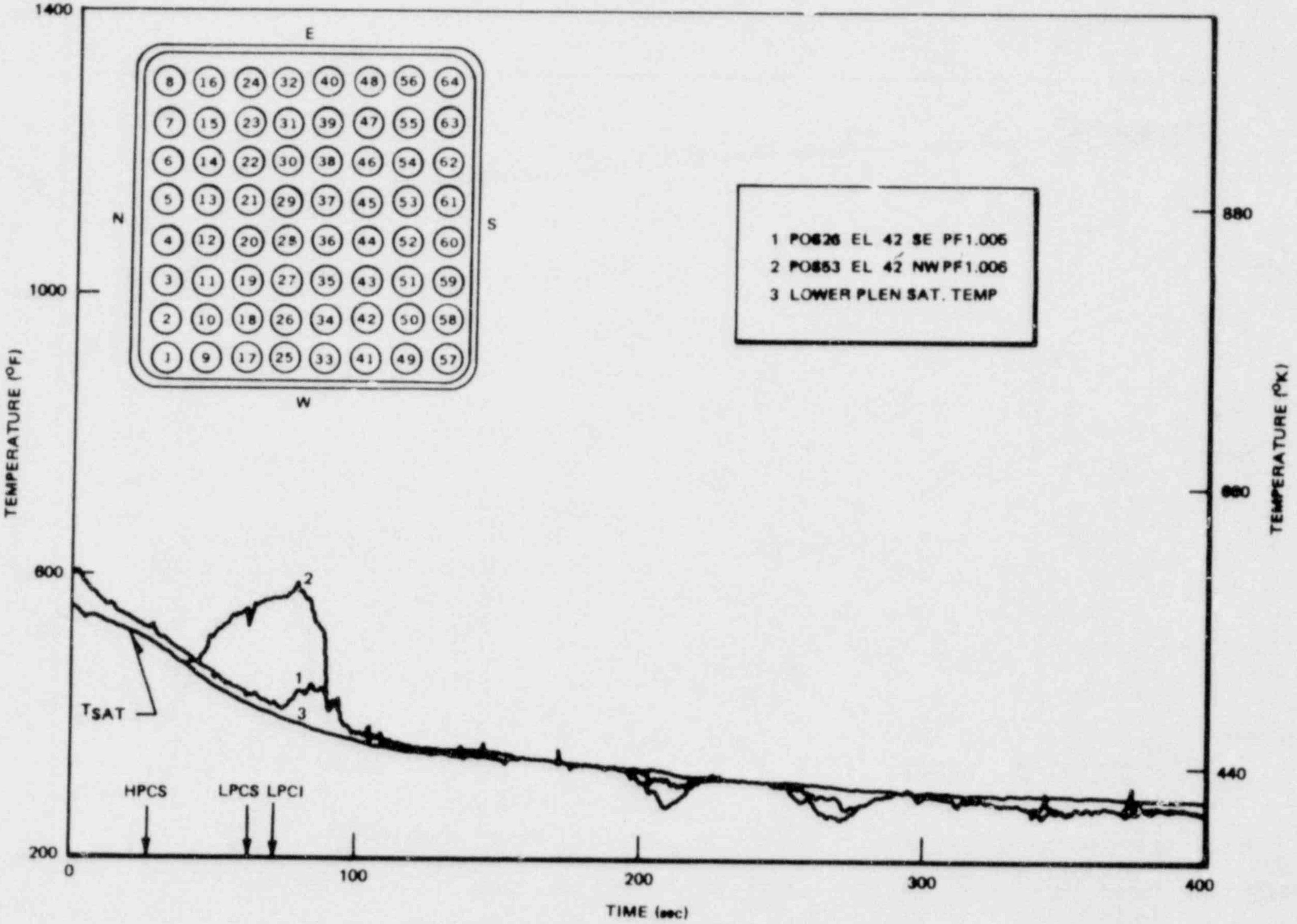


Figure D-30. Rod Cladding Temperature

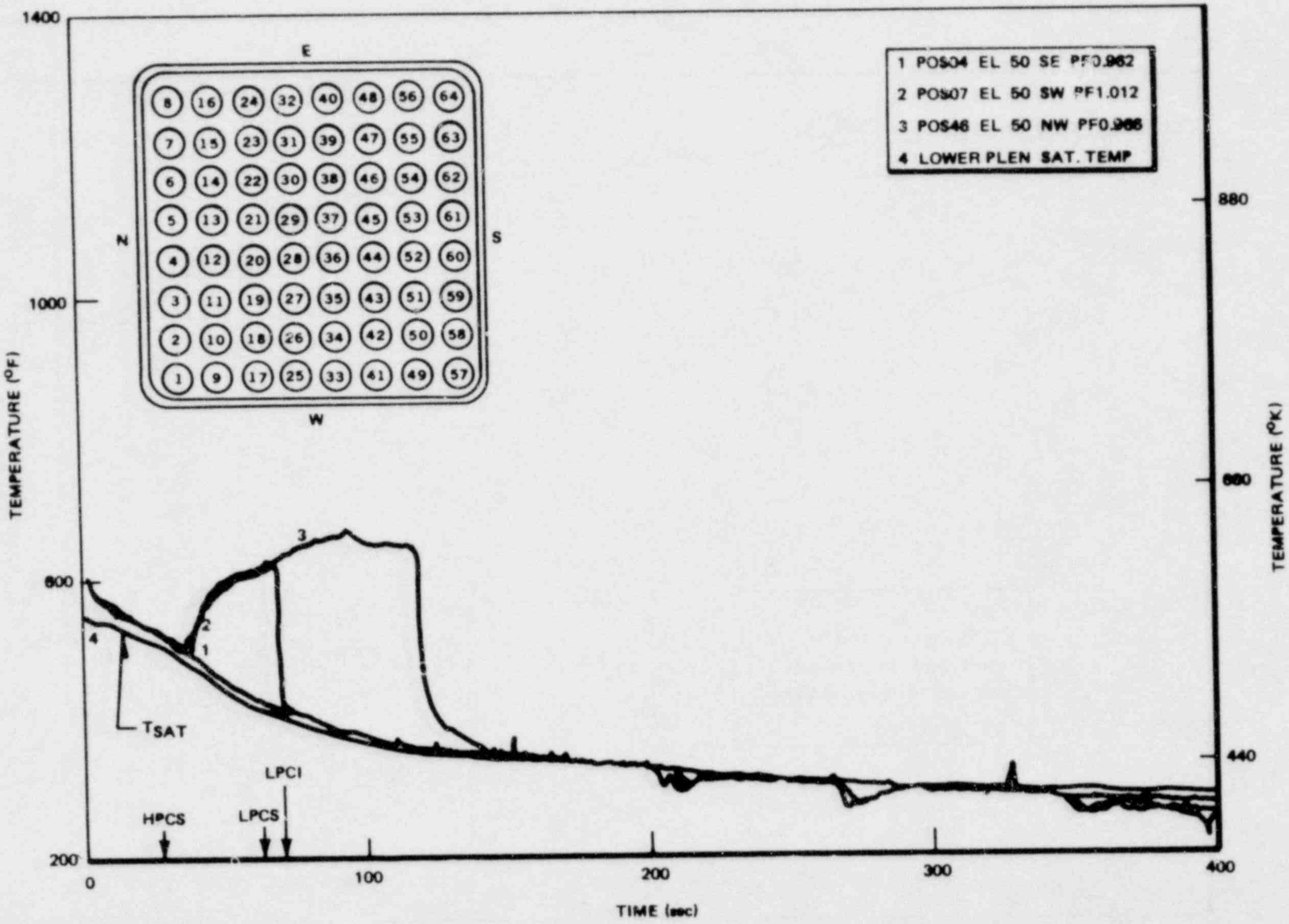


Figure D-31. *Rod Cladding Temperature*

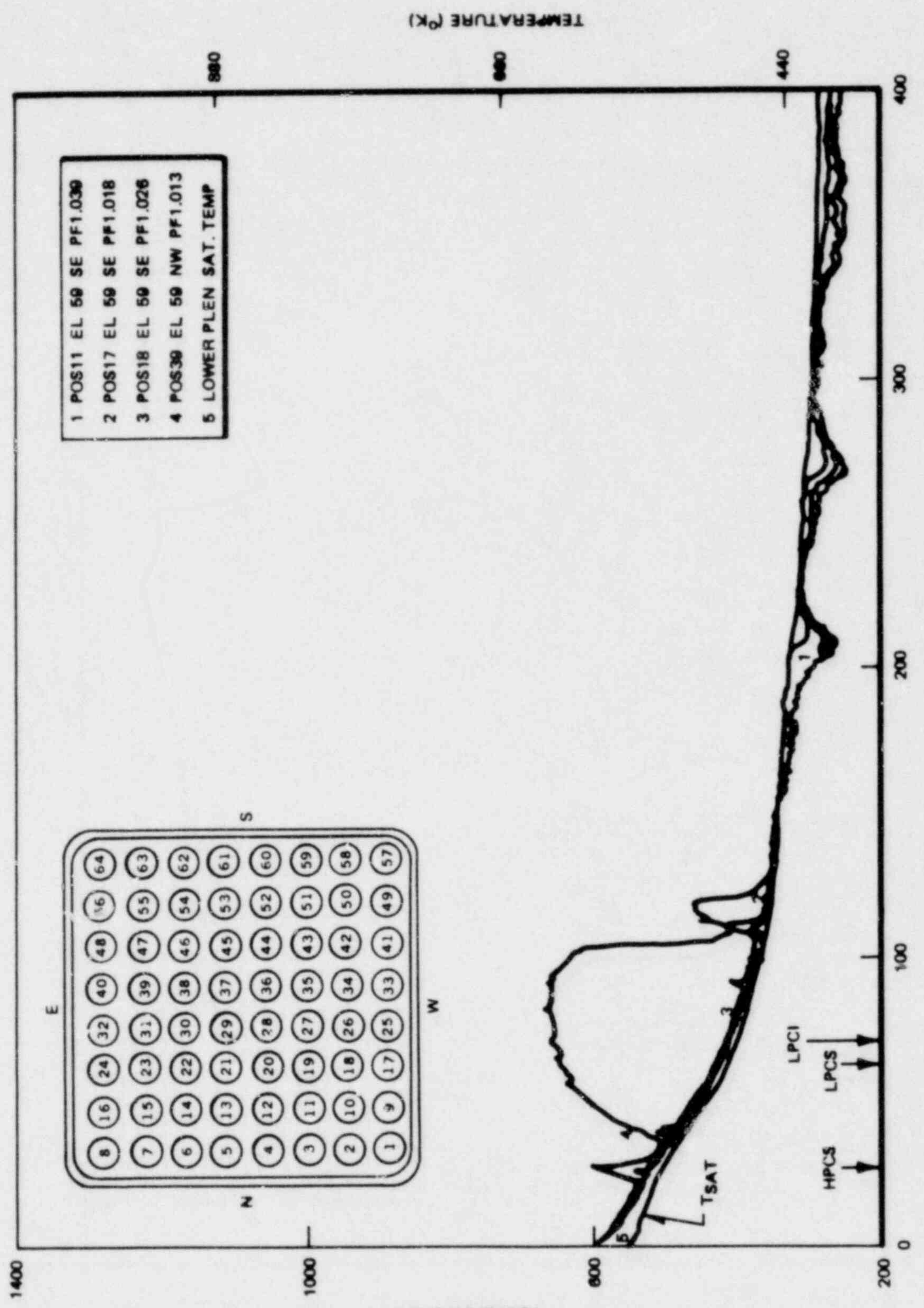


Figure D-32. Rod Cladding Temperature

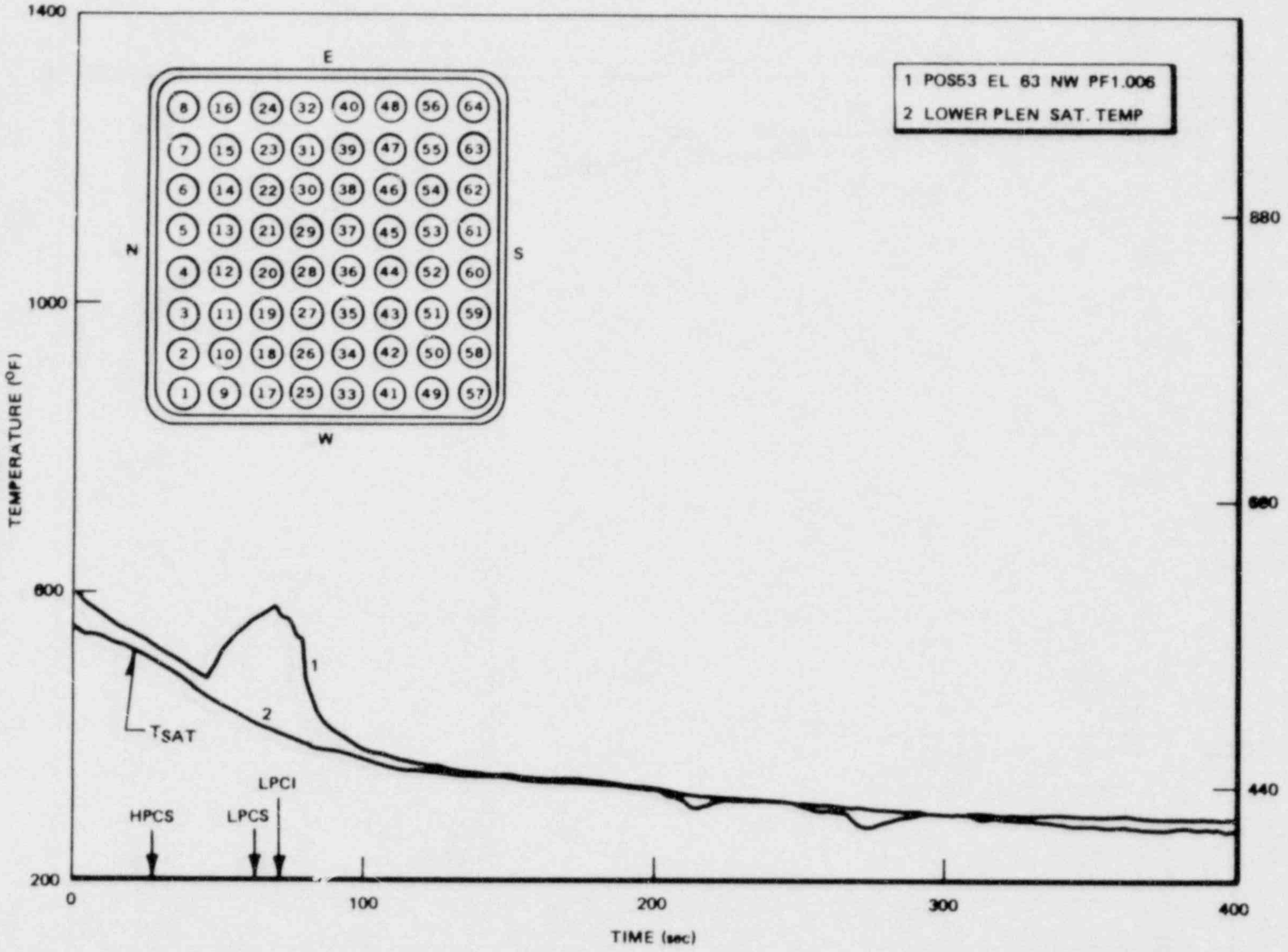


Figure D-33. Rod Cladding Temperature

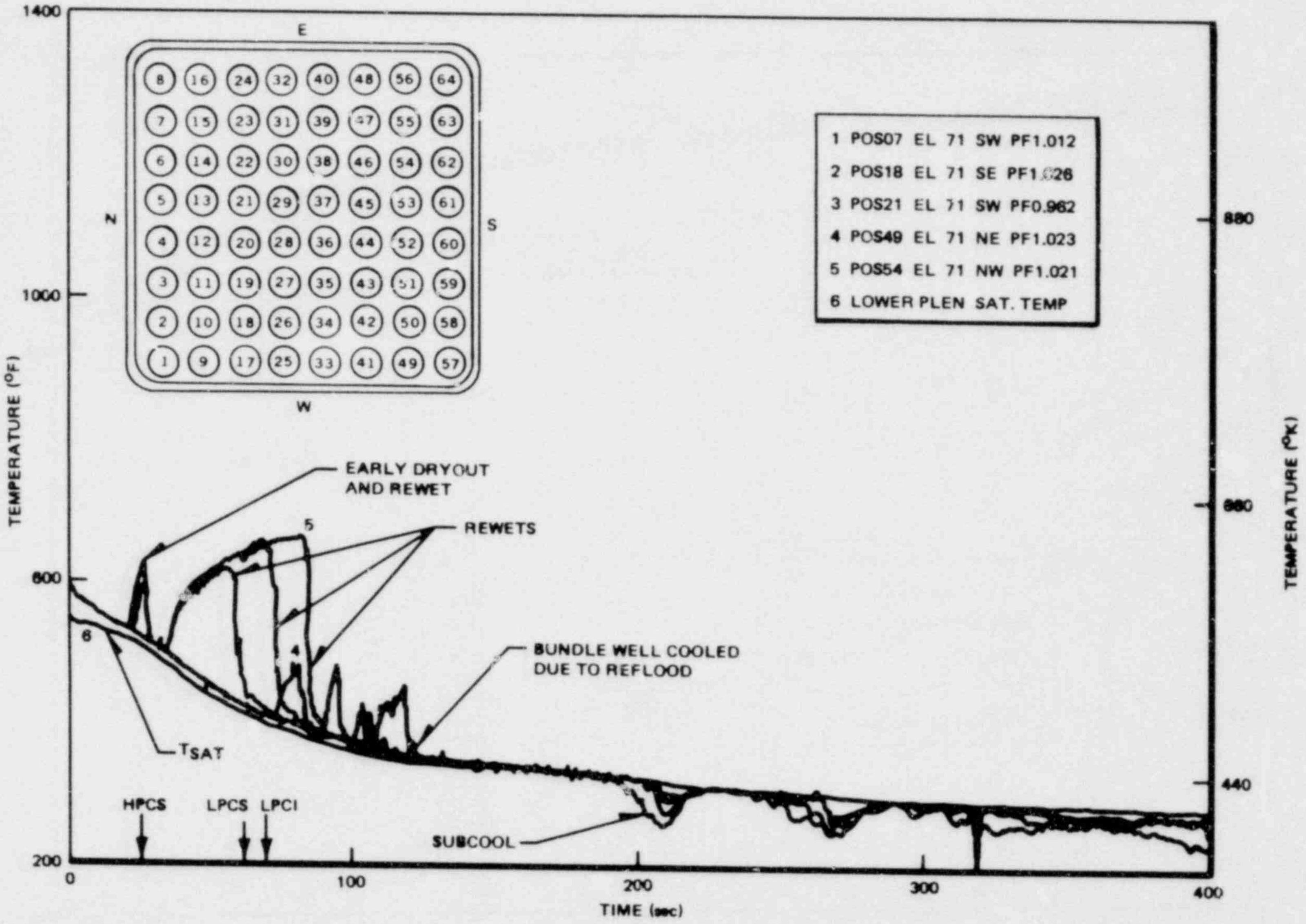


Figure D-34. Rod Cladding Temperature

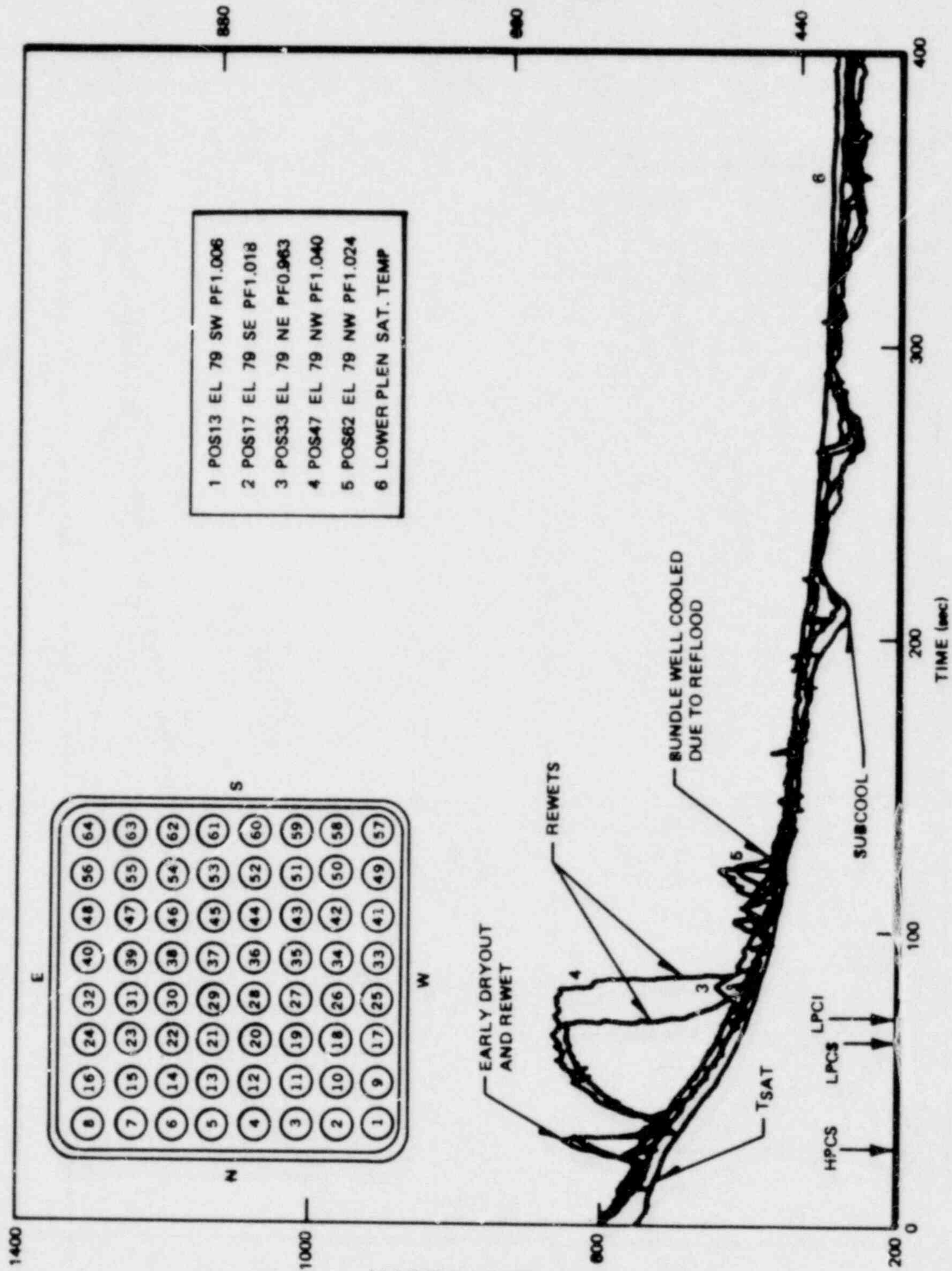


Figure D-35. *Rod Cladding Temperature*

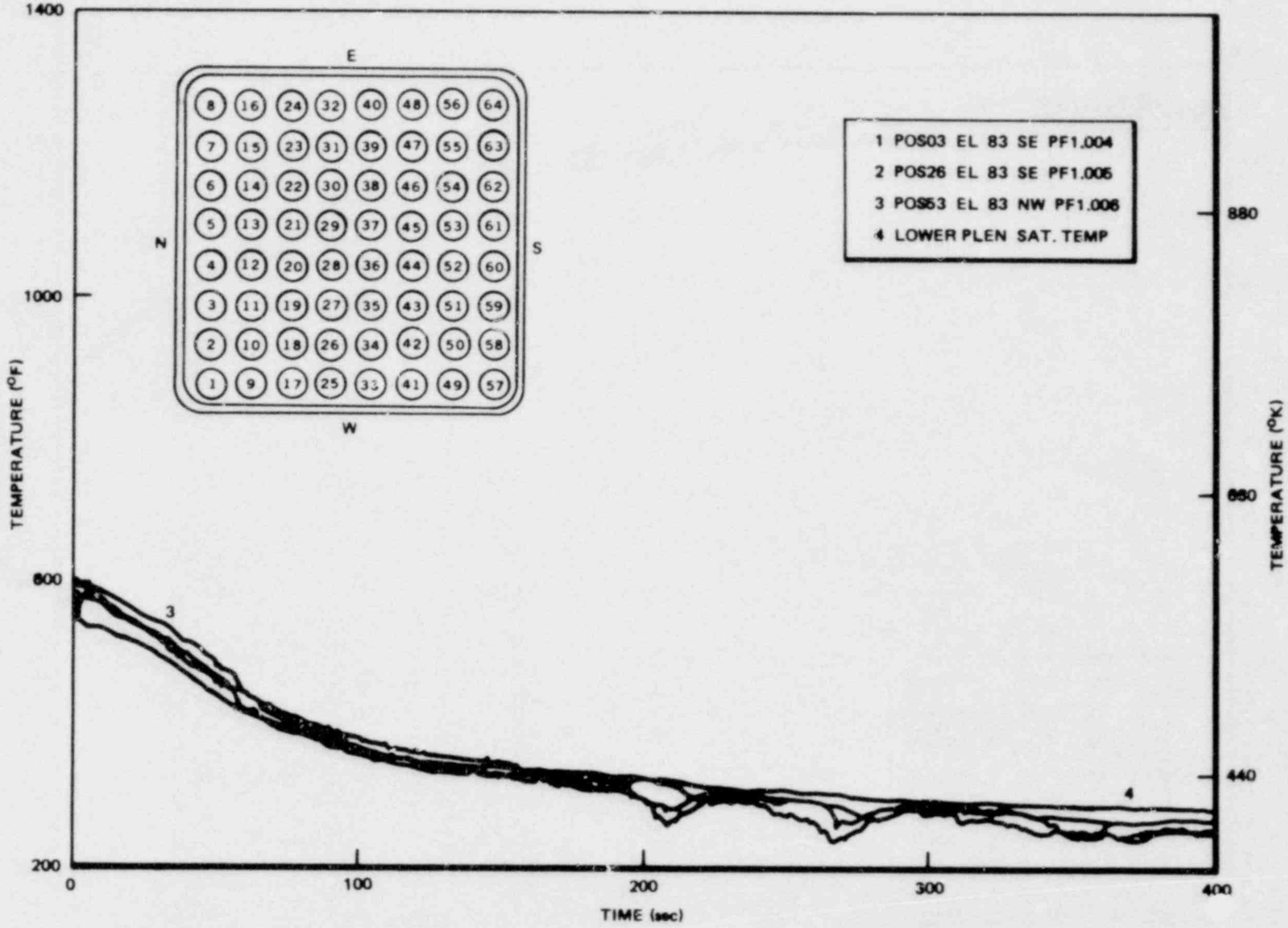


Figure D-36. Rod Cladding Temperature

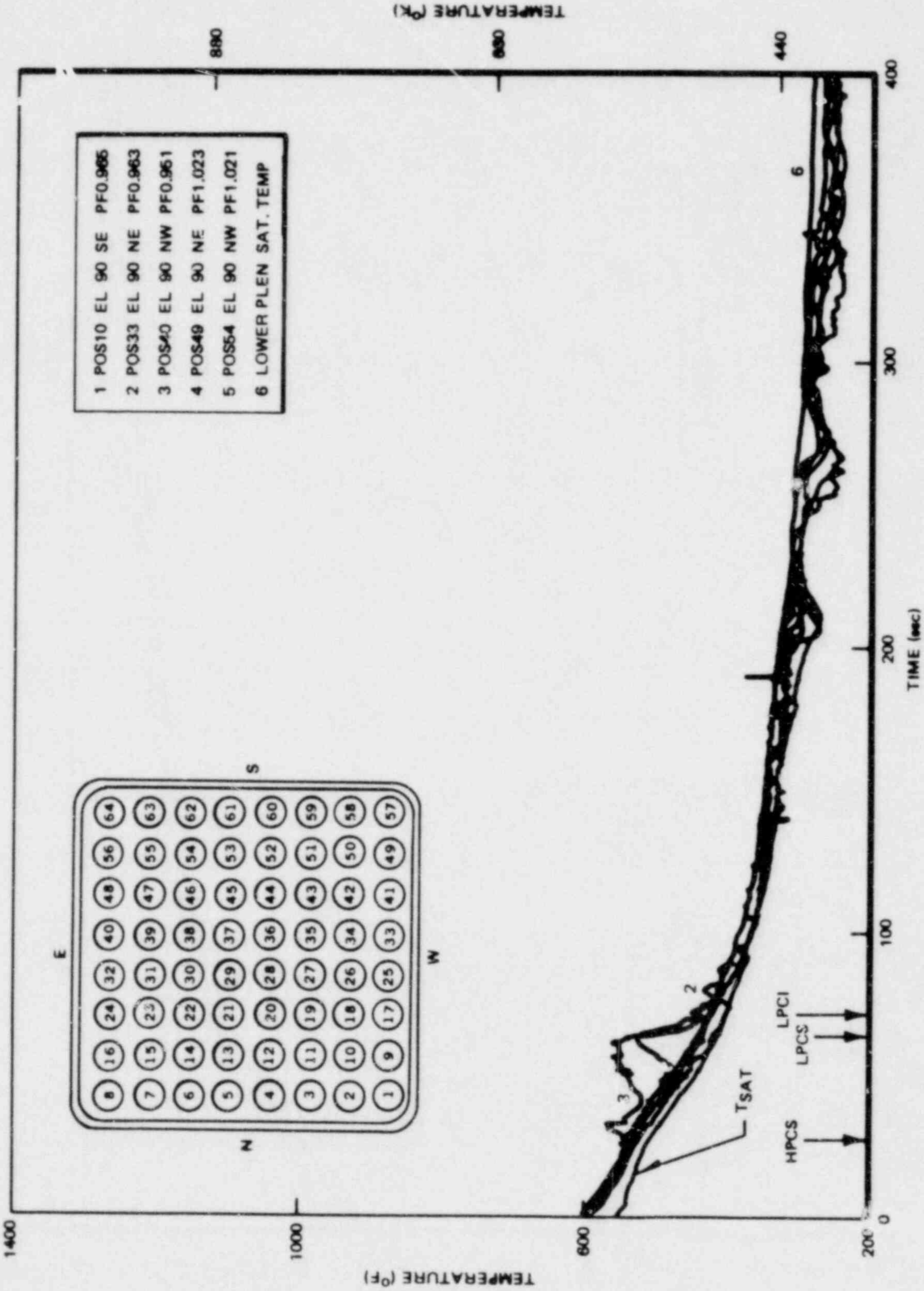


Figure D-37. Rod Cladding Temperature

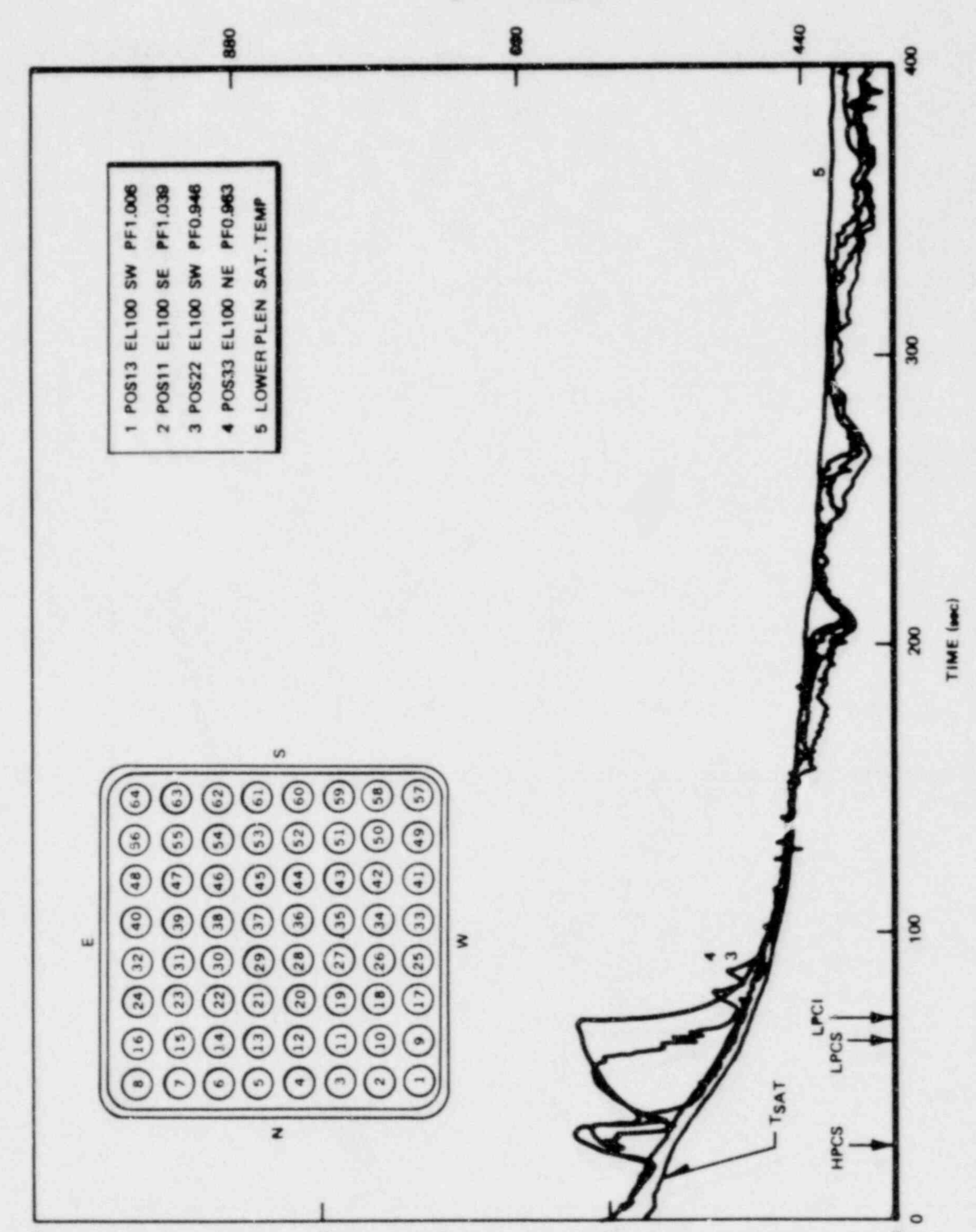


Figure D-38. *Rod Cladding Temperature*

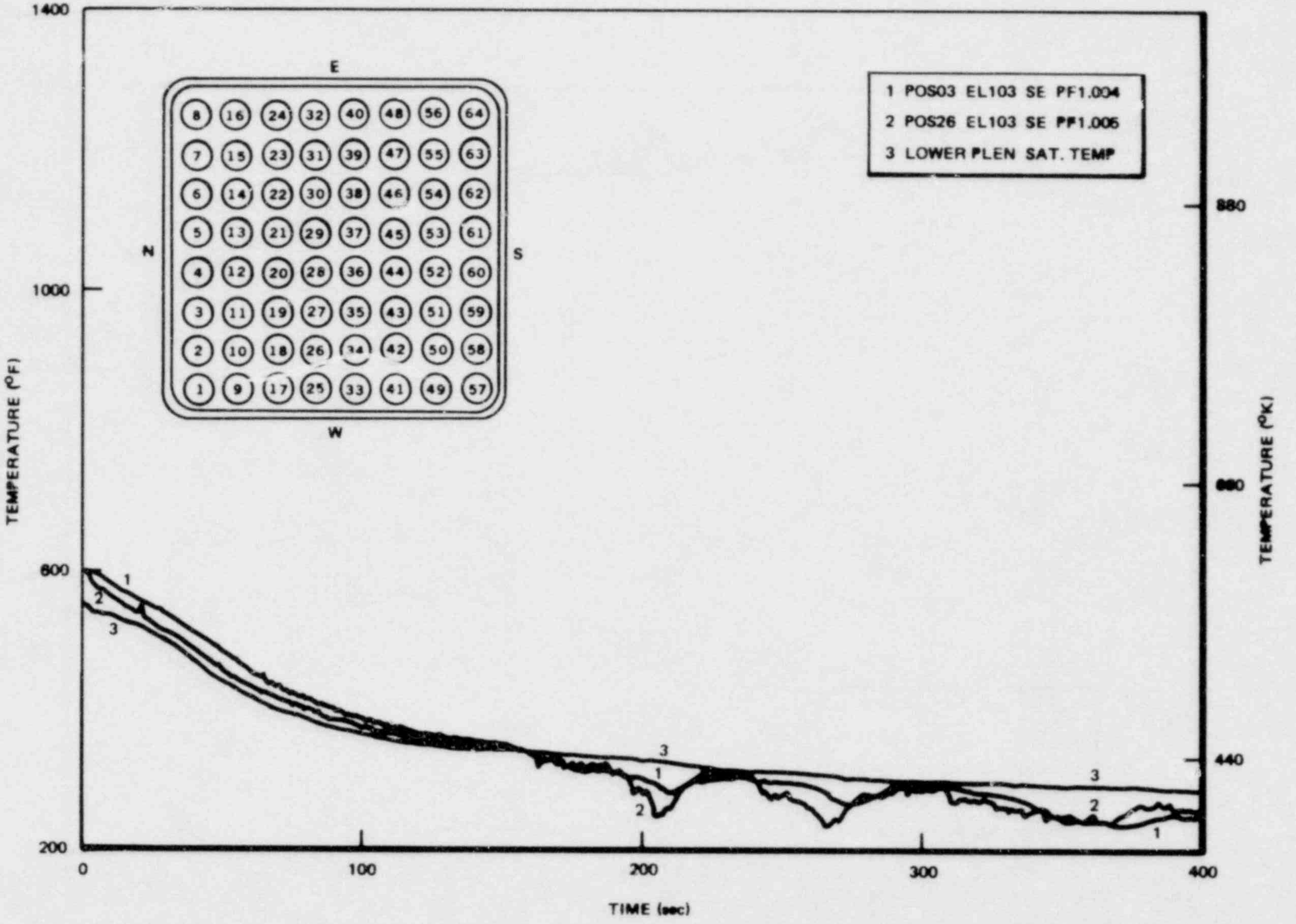


Figure D-39. Rod Cladding Temperature

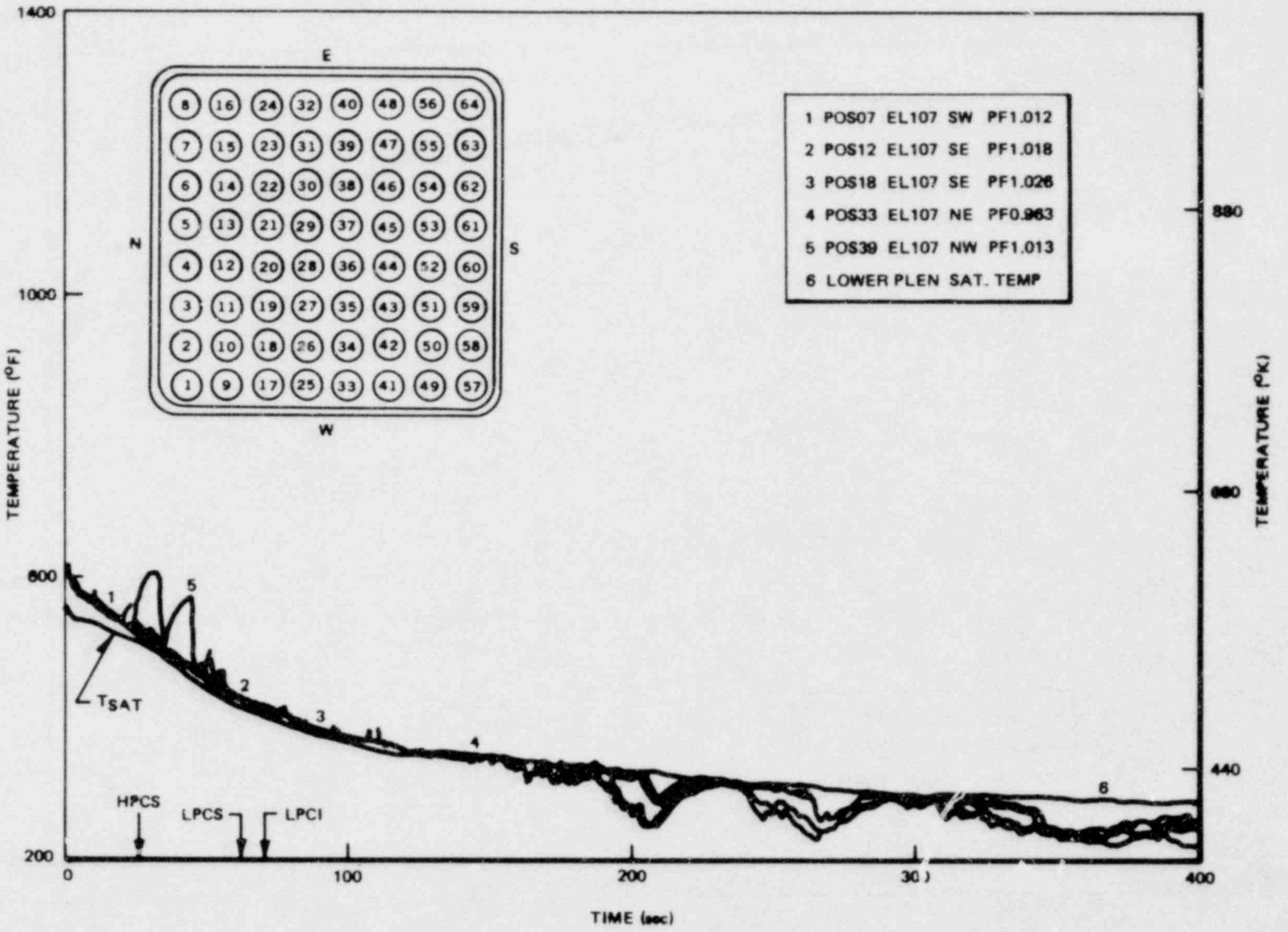


Figure D-40. Rod Cladding Temperature

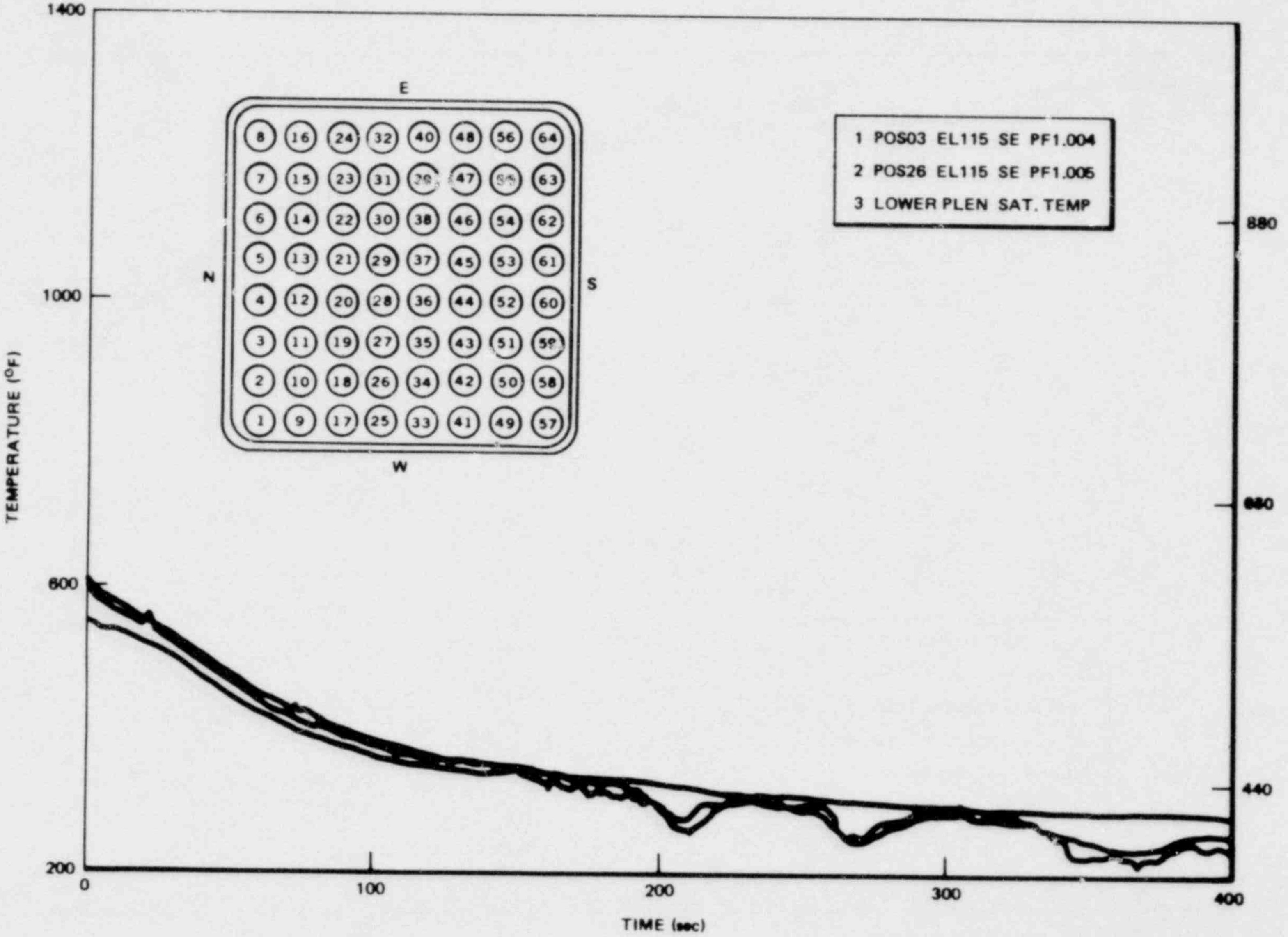


Figure D-41. Rod Cladding Temperature

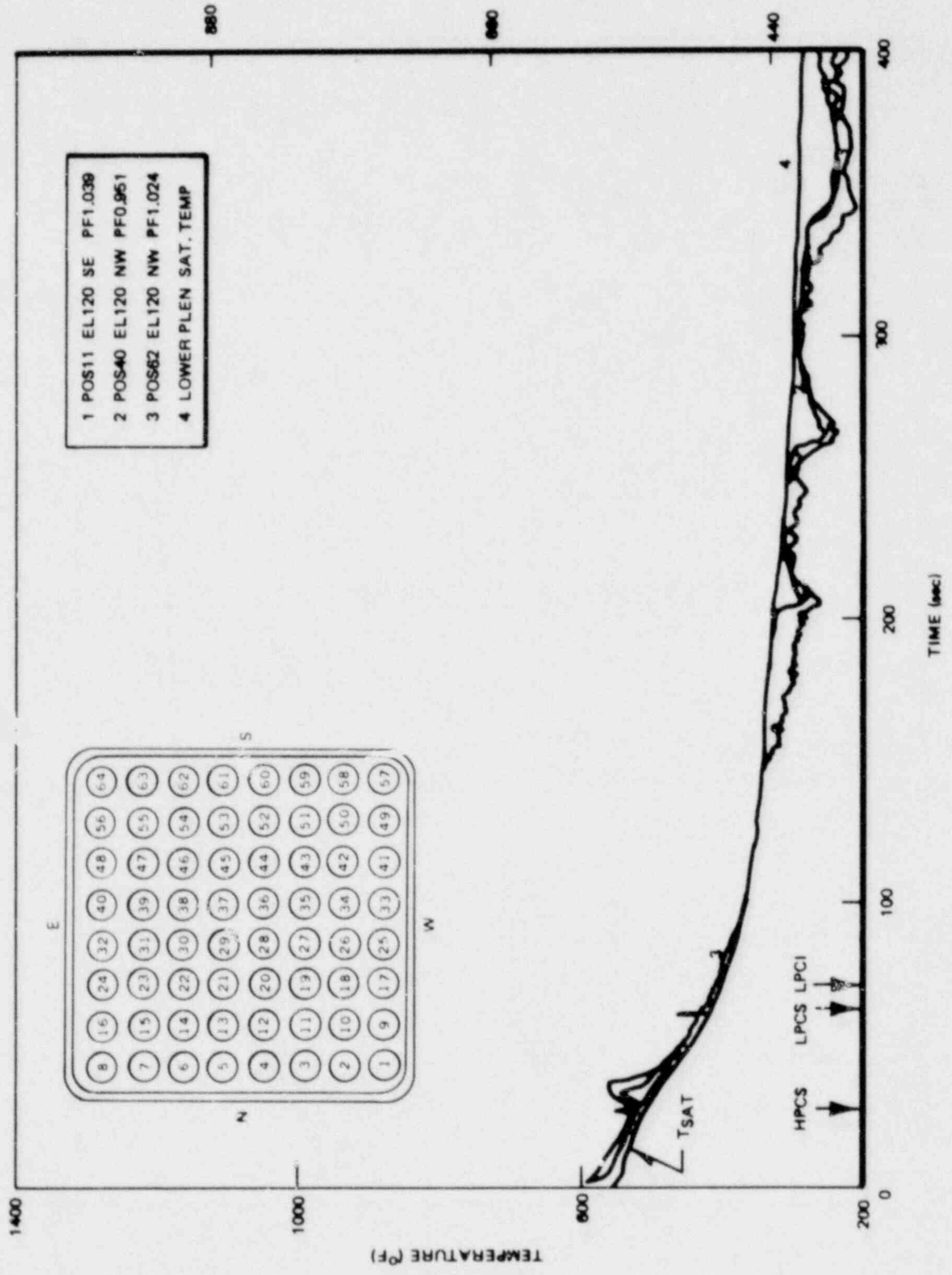


Figure D-42. Rod Cladding Temperature

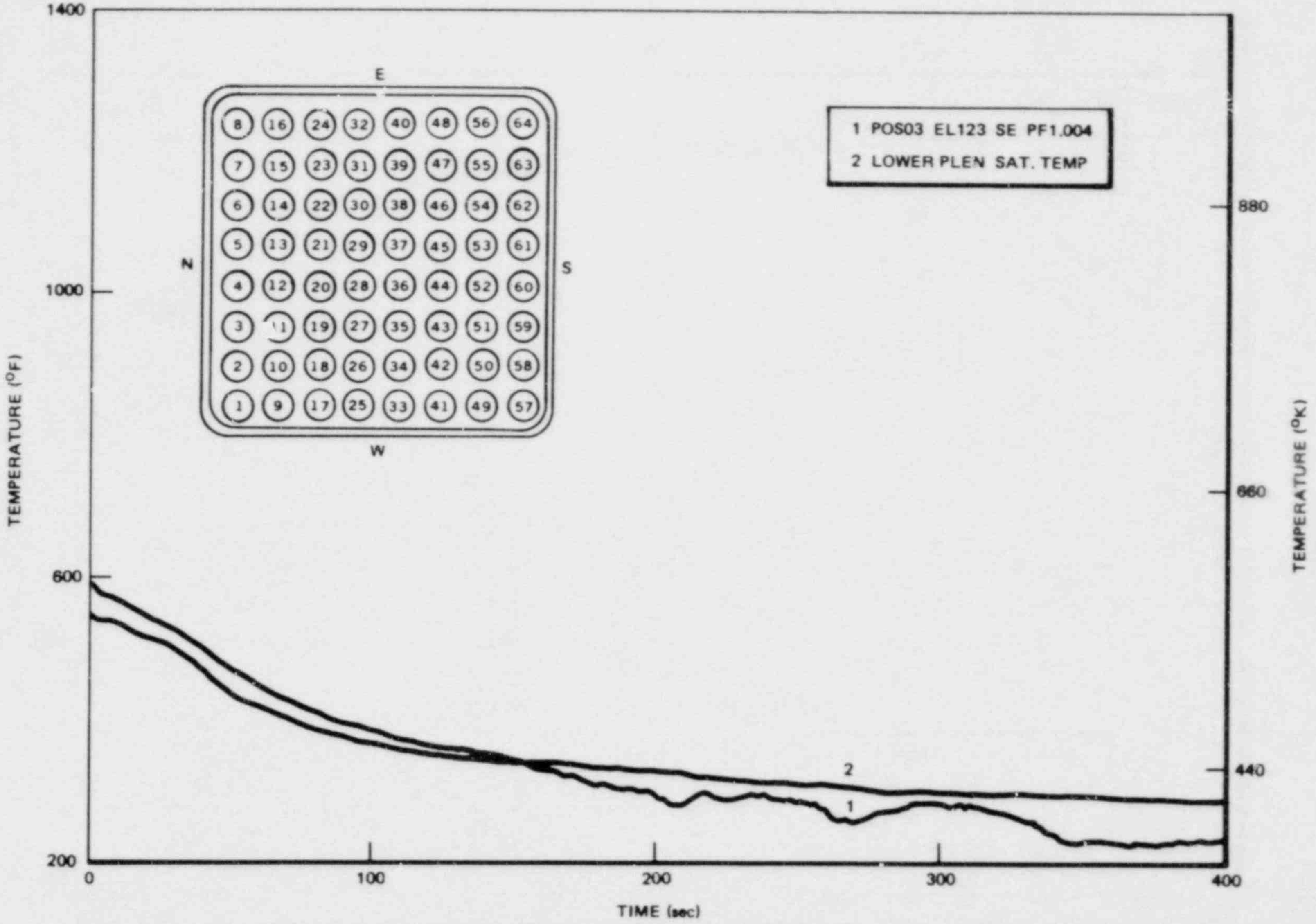


Figure D-43. Rod Cladding Temperature

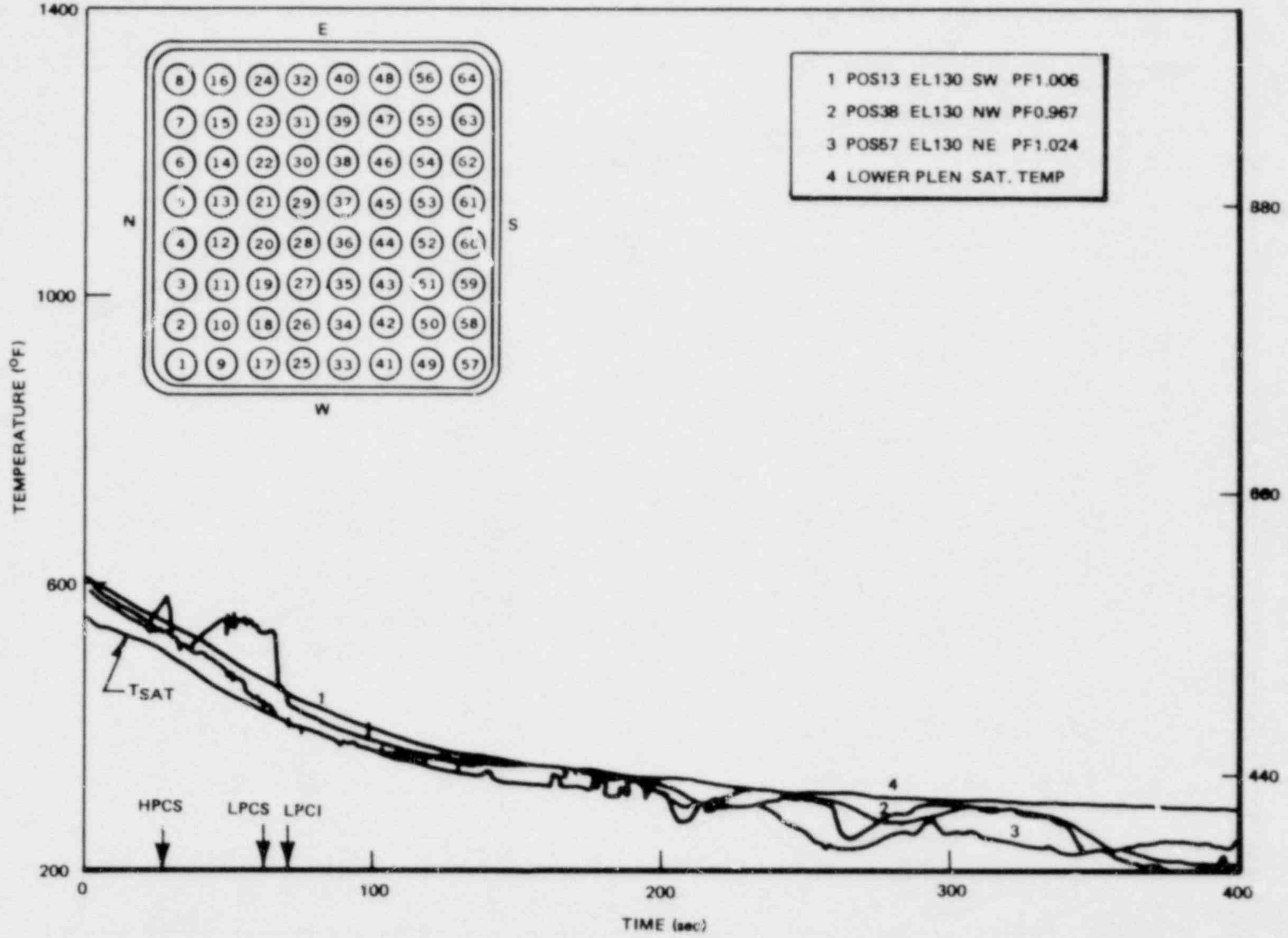


Figure D-44. Rod Cladding Temperature

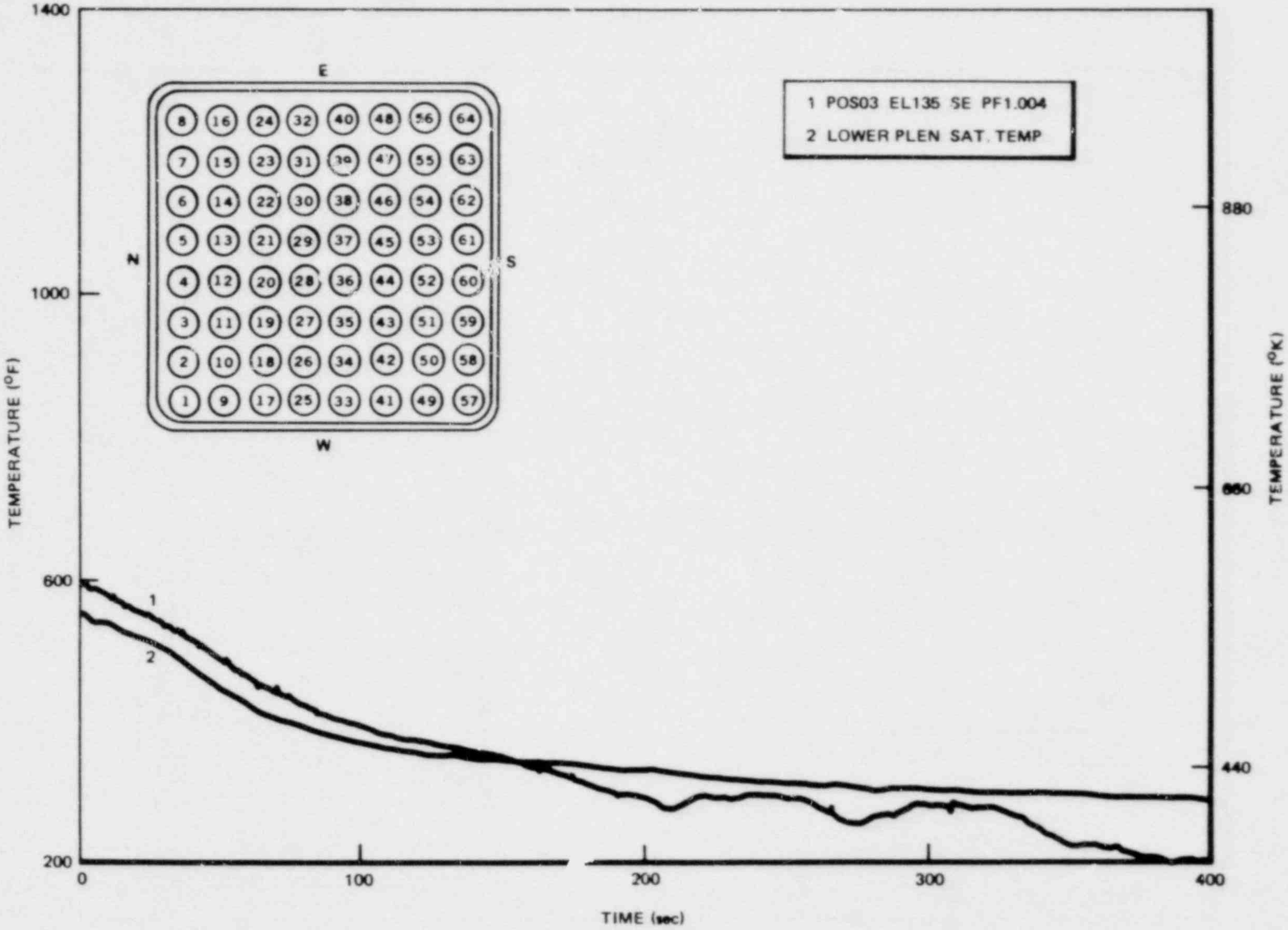


Figure D-45. Rod Cladding Temperature

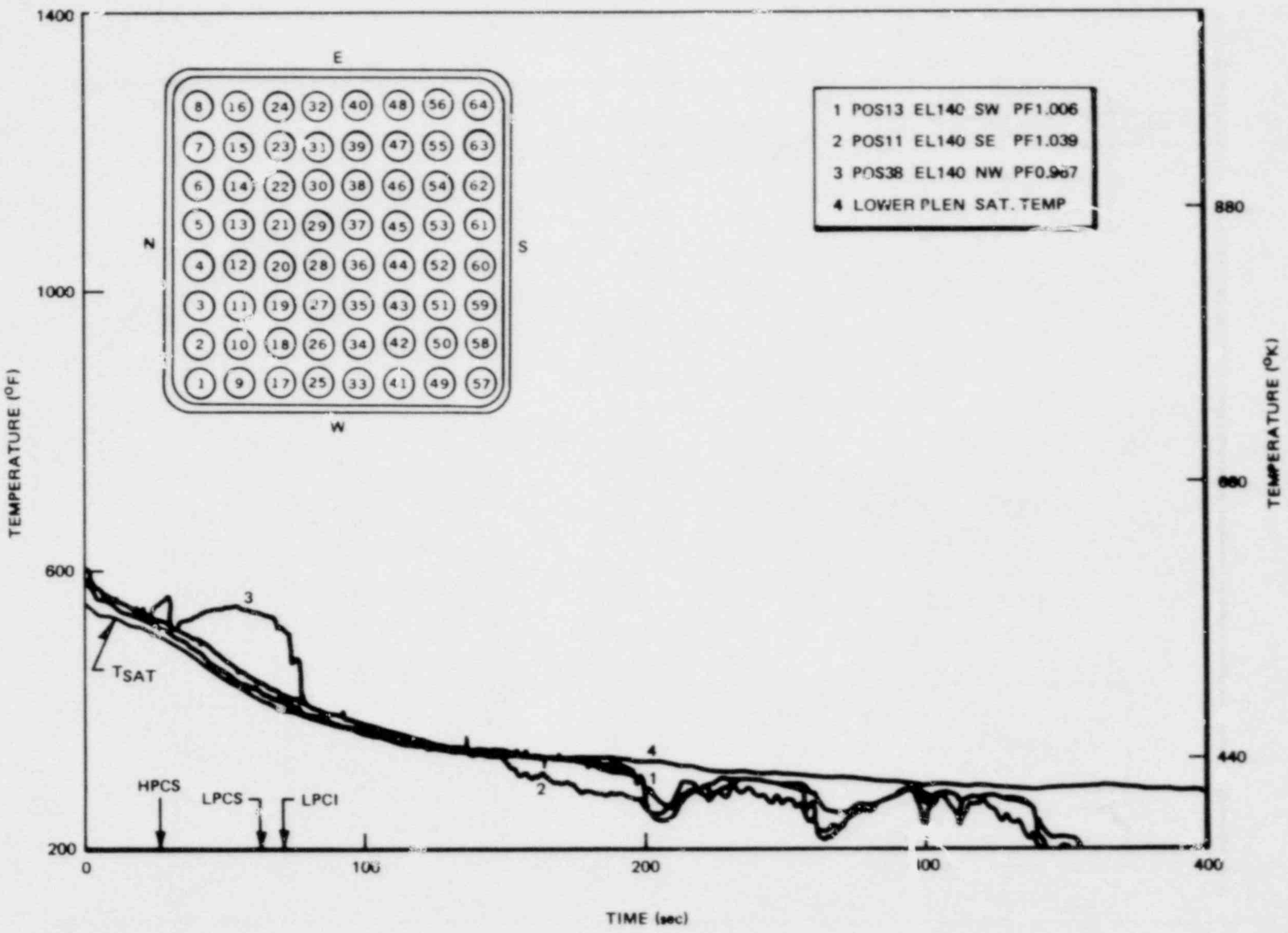


Figure D-46. Rod Cladding Temperature

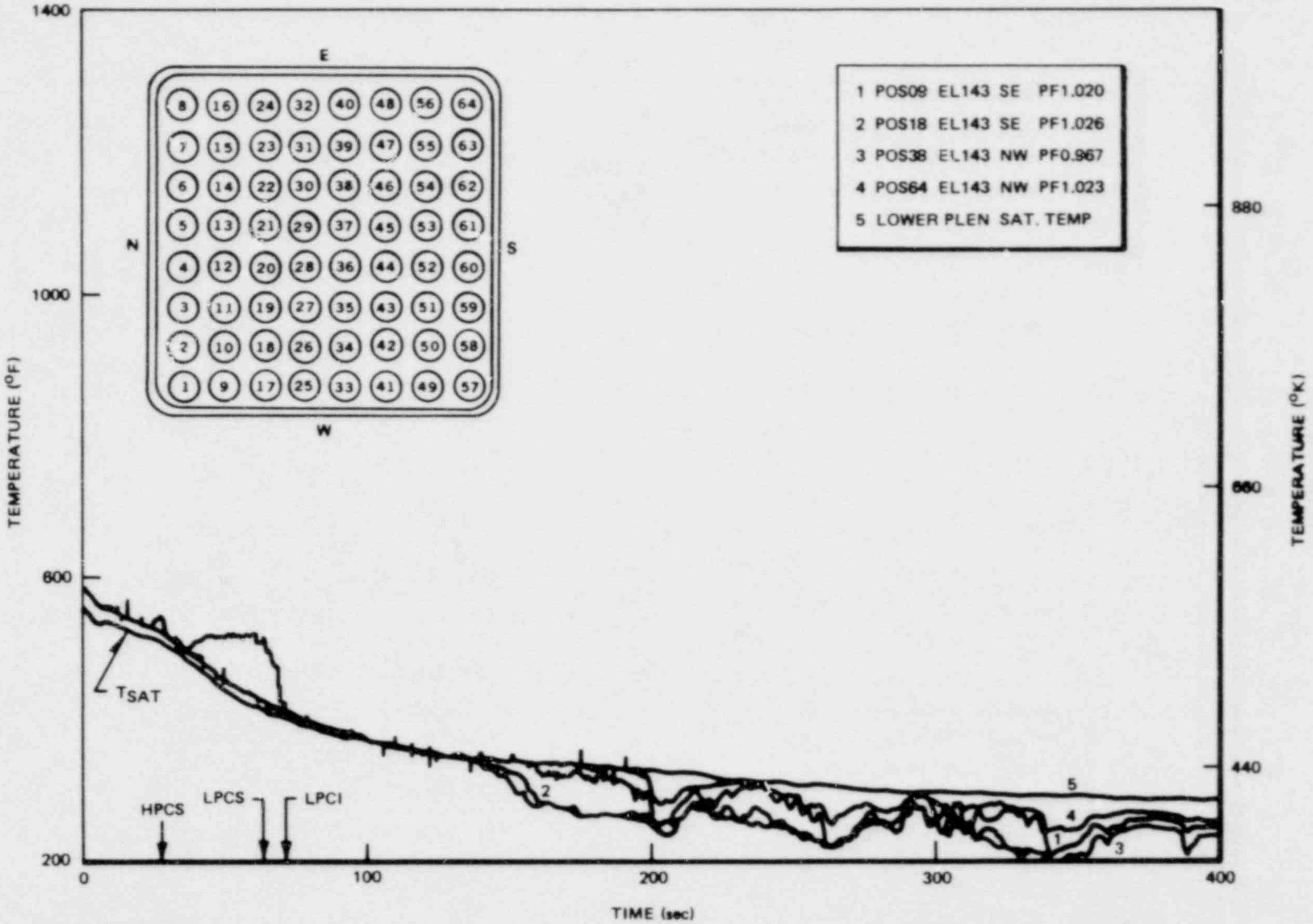


Figure D-47. Rod Cladding Temperature

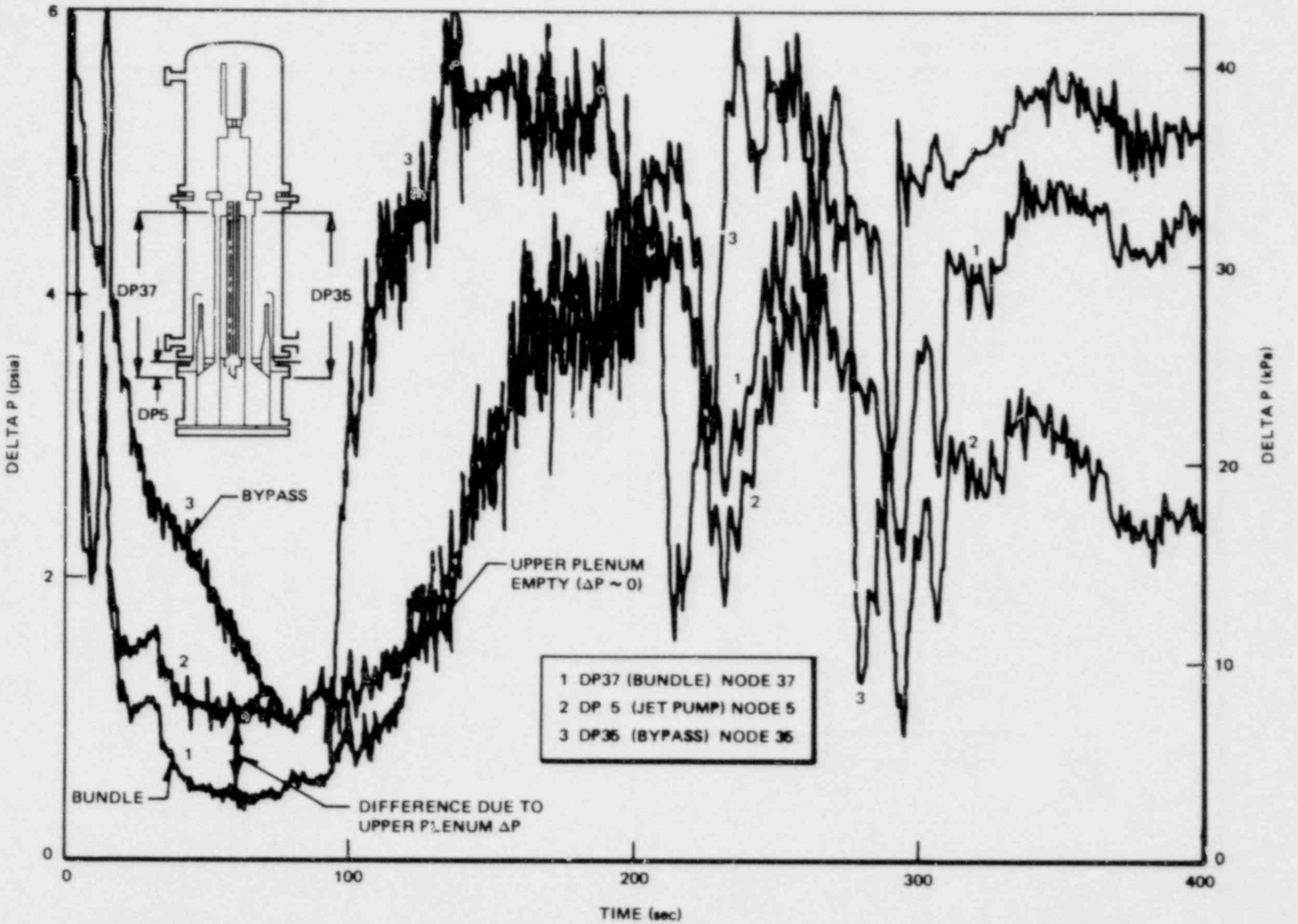


Figure D-48. Parallel Path ΔP's

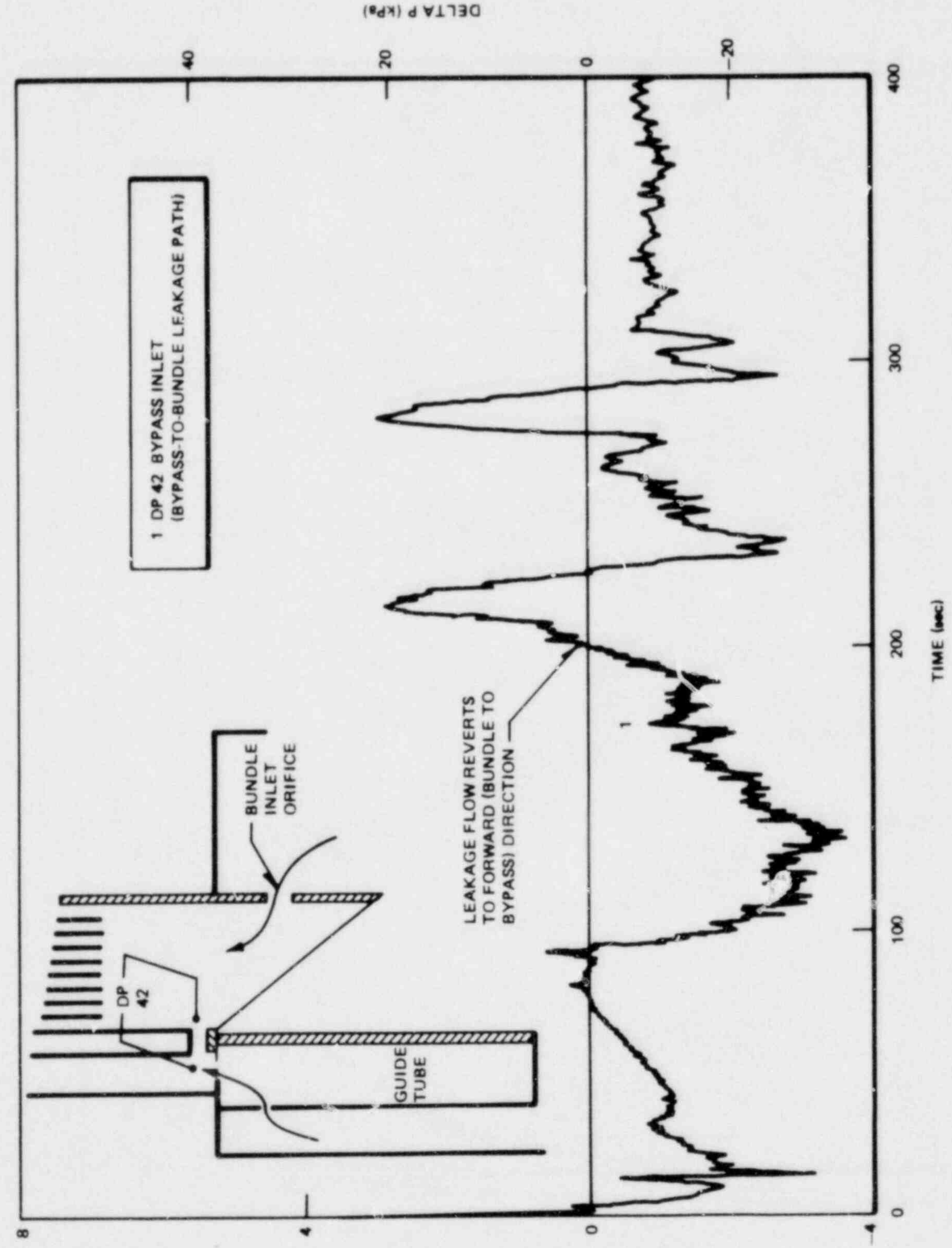
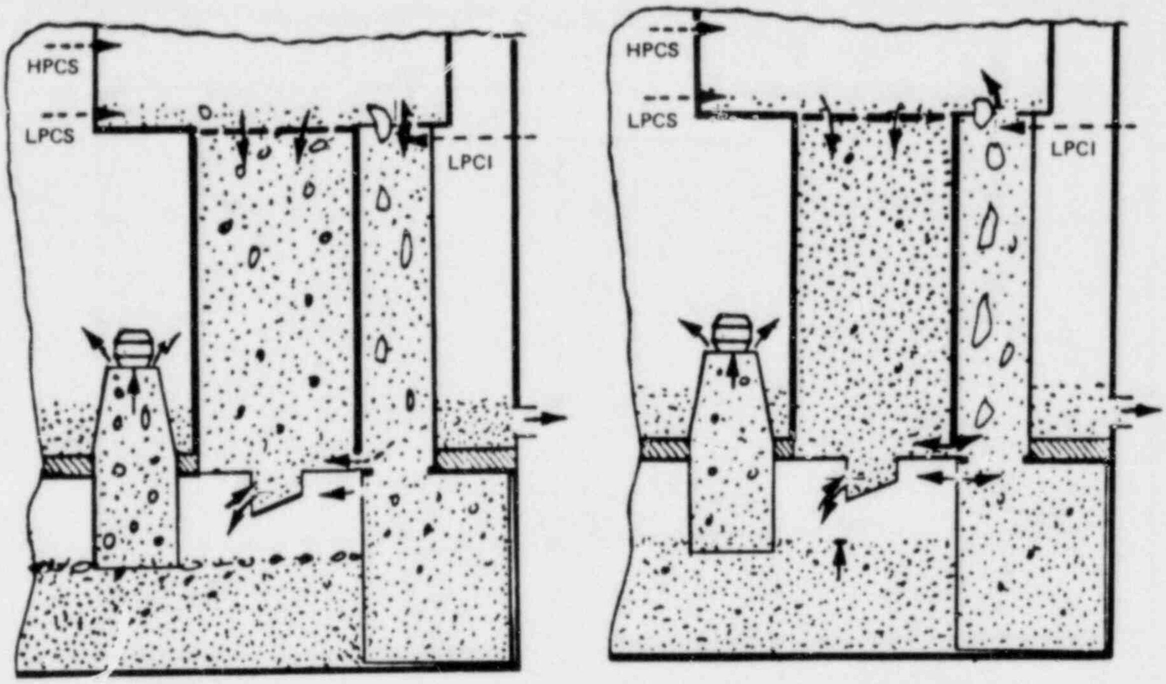
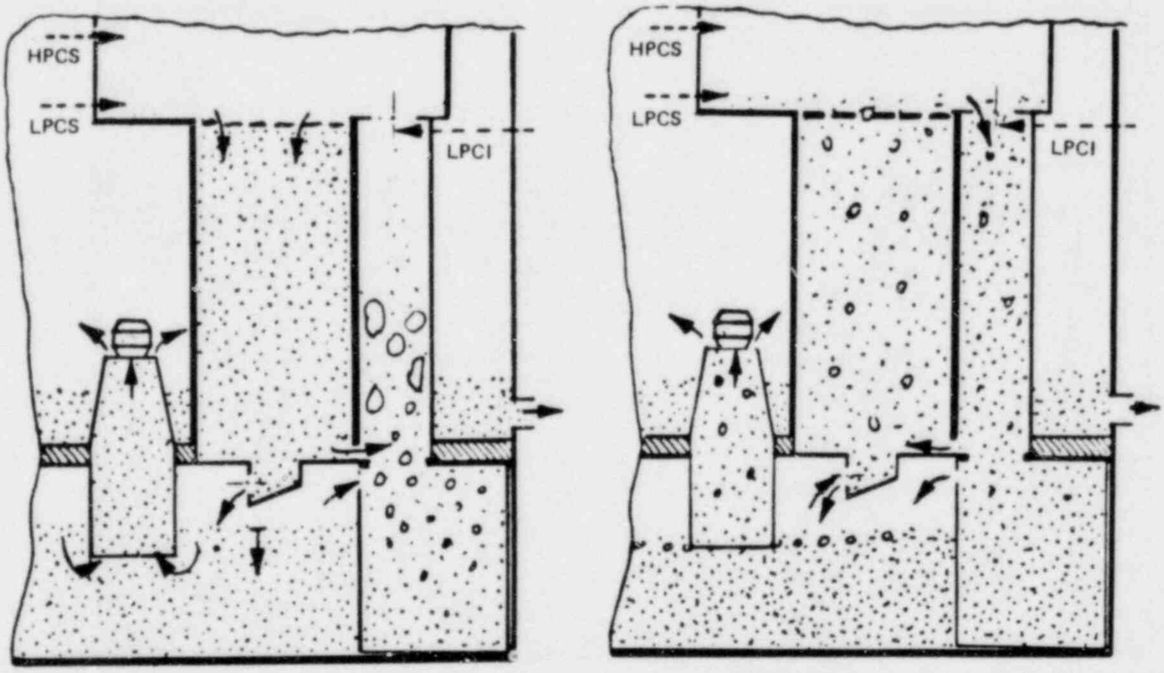


Figure D-49. Leakage Flow ΔP's



a. REFLOODED BUNDLE DIMINISHES LPCI DOWNFLOW

b. VAPOR NOT CONDENSED FLOWS UP PUSHING COLD FLUID TO BUNDLE



c. REVERTED LEAKAGE FLOW FACILITATES VAPOR VENTING

d. BYPASS REFILLS AFTER VAPOR VENTING

Figure D-50. Vapor Venting Sequence in Bypass TLTA 5A Reference Test (6422 Run 3)

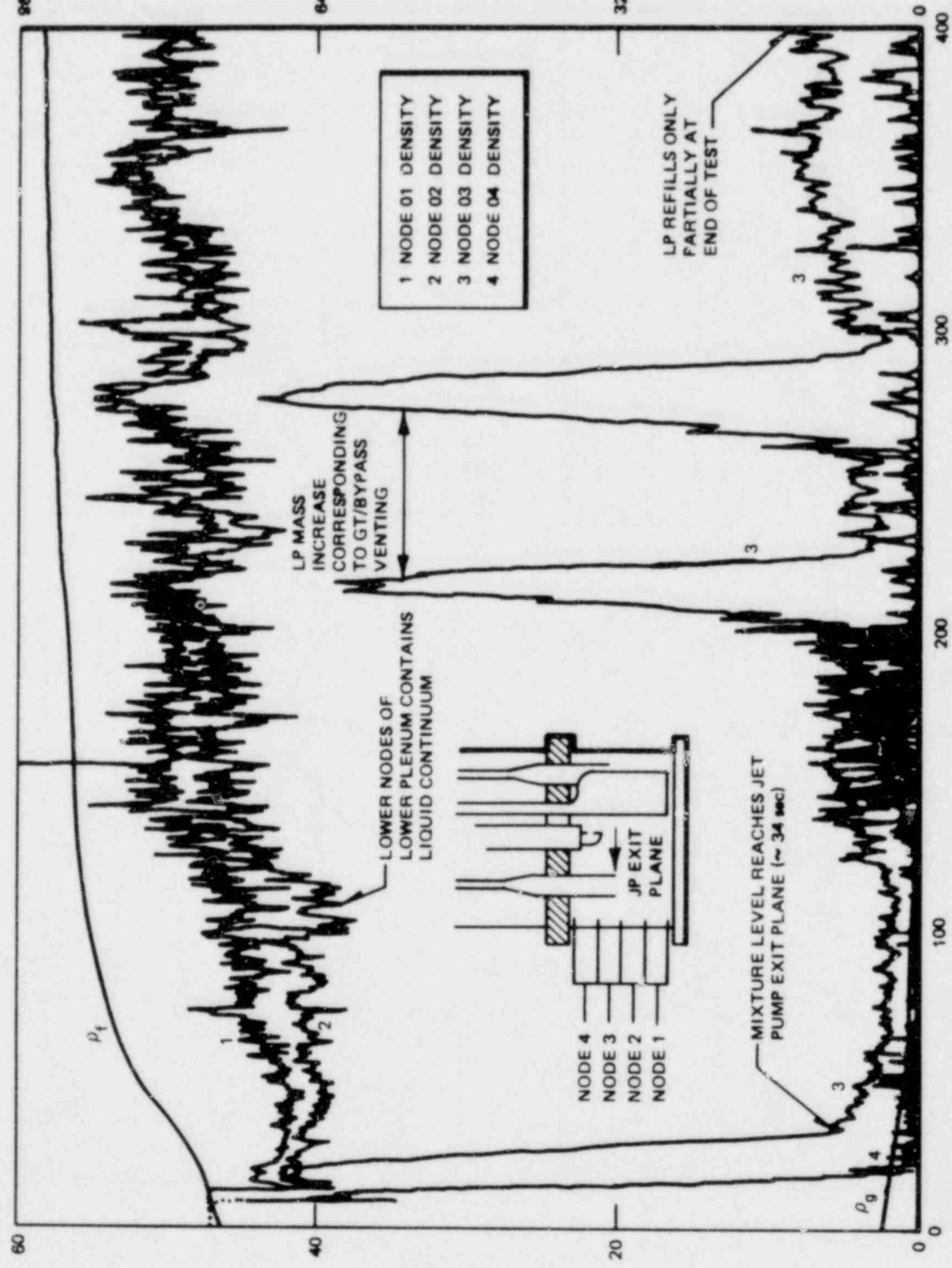


Figure D-51. Lower Plenum Nodal Densities

APPENDIX E

THE PLAN FOR EVALUATING BUNDLE HEAT TRANSFER COEFFICIENTS & LOCAL CONDITIONS

An evaluation will be completed of local rod heat transfer coefficients at several locations in the 8×8 bundle. These evaluations will be carried out using rod temperature data from both BDHT (without ECC) and BD/ECC 1A tests (Table E-1) with the 8×8 bundle. These evaluations will utilize a computational procedure solving transient heat conduction in direct (skin) heater rods with heat transfer to fluid at the outer surface.*

The corresponding local fluid conditions, including steam flow rates, will be estimated on the basis of mass and energy conservation in the heater bundle. Such an estimation requires bundle inlet conditions and, the latter will be derived from a mass energy balance in the lower plenum, accounting for counter current flow limitation at the core inlet. An upper and lower bound for these estimates will be established. It is anticipated that this work will be completed by the end of July. Table E-1 is a list of tests, rod bundle position numbers, and elevations at which these calculations will be made.

---

* Determination of Transient Heat Transfer Coefficients and the Resultant Surface Heat Flux from Internal Temperature Measurements, (GEAP-20731) January, 1975

Table E-1
ROD TEMPERATURE DATA POINTS

Test	Position	Elevation
6423	18	71 in.
6421	18	71 in.
6423	47	79 in.
6422	47	79 in.
6421	47	79 in.
6423	22	100 in.
6422	22	100 in.
6421	22	100 in.

APPENDIX F

BD/ECC 1A
DATA REPORT FOR:
TLTA SMALL BREAK TEST NO. I
(6431 Run 1)

L. S. Lee, June 1980

INTRODUCTION

This data report contains key measurements and selected results from Test 6431 Run 1 conducted on 18 December 1979. Some of these results were included previously in the Fifty-first Monthly Report (January 1980).

BACKGROUND

A small break scoping test was planned as part of the BD/ECC 1A test program (Reference F-1). The original objective of this test was to evaluate the effects of the scaling uncertainties known to be present in the TLTA Test Facility which was to be used for the small break LOCA simulation. The intent was to identify, verify, and quantify these scaling deficiencies and to propose modifications to the facility that would eliminate those compromises that were significant. A secondary objective was to develop facility operating techniques to conduct representative BWR small break simulations. This original scoping test was previously planned for the first quarter of 1980. Following the TMI-2 accident, there was considerable interest expressed by the sponsors, The Nuclear Regulatory Comission, and The Electric Power Research Institute to accelerate the test schedule. As a result, the first of the two small break tests was conducted on 18 December 1979.

BASIS FOR SMALL BREAK TEST 6431

The basis for this test is given in Reference F-2 and is summarized below:

- BWR/6-218
- 0.05 ± .02 sq. ft. recirculation line break
- Loss of feedwater and trip of recirculation pumps
- ADS not activated
- Full complement of ECCS (low pressure systems not expected to inject)
- Decay heat as per ANS-5 (1978)
- ECC water at ~70°F
- Reactor scram on high drywell pressure
- HPCS activated on high drywell pressure

TEST CONDITIONS

The initial conditions for the test are included in Table F-1. Additional information on test operation were given in Reference F-2. Other test conditions can be found among the data presented in this report.

TEST RESULTS

The first of the two small break tests was conducted in TLTA 5B (Figure F-1). The key feature of TLTA 5B is an orifice in the blowdown line simulating a small break. In addition, a heat exchanger was installed just downsteam of the break area to condense the breakflow which was measured by another orifice (Figure F-2).

Power decay plots for the tests are shown in Figures F-3 and F-3a. Mass flows to and from the vessel are included in Figures F-4 through F-6. It is seen that initially there is a net loss of inventory from the system; i.e., the break flow exceeds the HPCS injection flow. This was the basis for selecting the break size for the test. Later in the transient as the system pressure is reduced (~400 seconds), the mass inflow is seen to be higher than outflow.

Shown in Figure F-7 is the system pressure which increases initially due to the loss of feedwater flow at time zero (Figure F-4) while the bundle power was held constant. System pressure begins to decrease when the power decay is initiated at ~7 seconds as the steam outflow through the steam line exceeds the steam generation within the bundle. The system pressure increases again after ~17 seconds (Figure F-7a) when the steam valve is closed and then decreases shortly after the HPCS begins to inject at ~27 seconds.

The mixture levels measured inside and outside the core region are shown in Figure F-8. In the early transient, the outside level decreases due to the loss of inventory out the break. The inside level remains at the top of the separator because the bundle and upper plenum contain a two-phase mixture due to continuing steam generation in the bundle. The inside level starts to drop when the combined effect of bundle power decrease and subcooled HPCS condensation reduces the void fraction in the upper plenum. As the injection of subcooled HPCS continues, the upper plenum and the bundle are gradually filled entirely with subcooled water. Consequently, the level inside becomes lower than the two-phase mixture level outside. The hydrostatic head of the inside column of fluid is higher than that outside, and the subcooled HPCS fluid flows from the upper plenum, down through the bundle, out the jet pumps, and into the downcomer outside.

As a result, the bundle level stayed well above the top of the heated length and there was no heat up in the bundle. The bundle thermal responses (Figures F-9 through F-11) show that the thermocouples are measuring subcooled temperatures after ~200 seconds.

The regional masses are shown in Figures F-12 through F-17. Figure F-18 presents total system mass.

Nodal differential pressure measurements are included in Figures F-19 through F-25 for the inside column (bundle and upper plenum). Figures F-26 through F-28 show nodal differential pressures in the downcomer region. Nodes 46 and 47 in Figure F-28 are part of Node 10 in Figure F-27.

Pressure and temperature data at the vicinity of the break orifice are presented in Figures F-29 and F-30. It is seen from Figure F-30 that the heat exchanger was effective in condensing the break flow into a subcooled liquid.

Finally, some detailed responses are included in Figures F-31 and F-32. Shown in Figure F-31 is the thermocouple response indicating level fall and rise in the upper plenum. Shown in Figure F-32 are level probe responses showing phase change (level change) locations.

REFERENCES

F-1. BWR Blowdown/ECC Program, Contract No. NRC-04-76-215, Informal Monthly Progress Report for July 1979 (45th Monthly Report).

F-2. BWR Blowdown/ECC Program, Contract No. NRC-04-76-215, Informal Monthly Progres Report for December 1979 (50th Monthly Report).

Table F-1
MEASURED TEST CONDITIONS (6431 RUN 1)

Break Size	0.125 ± 0.001 in. diameter
HPCS Flow Characteristics	As shown in Figure F-6
ECC Fluid Temperature	83 ± 4°F
Initial Conditions	
Bundle Power	As shown in Table F-2
Steam Dome Pressure	1041 ± 5 psia (also see Figure F-7A)
Water Level (Outside Shroud)	283 ± 3 in. EL
Bundle (Core) Flow	43 ± 5 lbm/sec
Bypass Flow, Total	2.6 ± 0.3 lbm/sec
Steam Flow	2.5 ± 0.5 lbm/sec (t ≤ 16.6 sec)
	0 lbm/sec (t > 16.6 sec)
Bundle Inlet Subcooling	16 ± 4°F
Downcomer Temperatures	
Above J.P. Suction	552 ± 4°F
Below J.P. Suction	539 ± 4°F
Timings	
Pump No. 1 Trip	0.0 sec ± 0.1 sec
Pump No. 2 Trip[**]	4.0 sec ± 0.2 sec
Feed Water Pump Trip	0.0 sec ± 0.5 sec
Break Opening	−0.9 sec ± 0.5 sec
Loop No. 1 Isolation	19.6 sec ± 0.5 sec
Steam Valve Closing	16.6 sec ± 0.5 sec
HPCS Activation	26.8 sec ± 0.5 sec

[**] Uncertainty on bundle power is estimated to be ± 5%

Table F-2
BUNDLE POWER

Time (sec)	Bundle Power (mW)*
0	2.1
1	2.1
2	2.1
3	2.1
4	2.1
5	2.1
6	2.1
7	2.1
8	1.8
9	1.6
10	1.4
12	1.0
14	0.81
16	0.64
18	0.57
20	0.49
25	0.38
30	0.32
35	0.27
40	0.23
45	0.21
50	0.19
60	0.16
70	0.15
80	0.15
90	0.15
100	0.15
150	0.14
200	0.14
250	0.14
300	0.13
350	0.13
400	0.13
600	0.13
800	0.13
1000	0.12
1200	0.12
1400	0.11
1600	0.11
1800	0.11
2000	0.10

---

*Uncertainty on bundle power is estimated to be ±5%

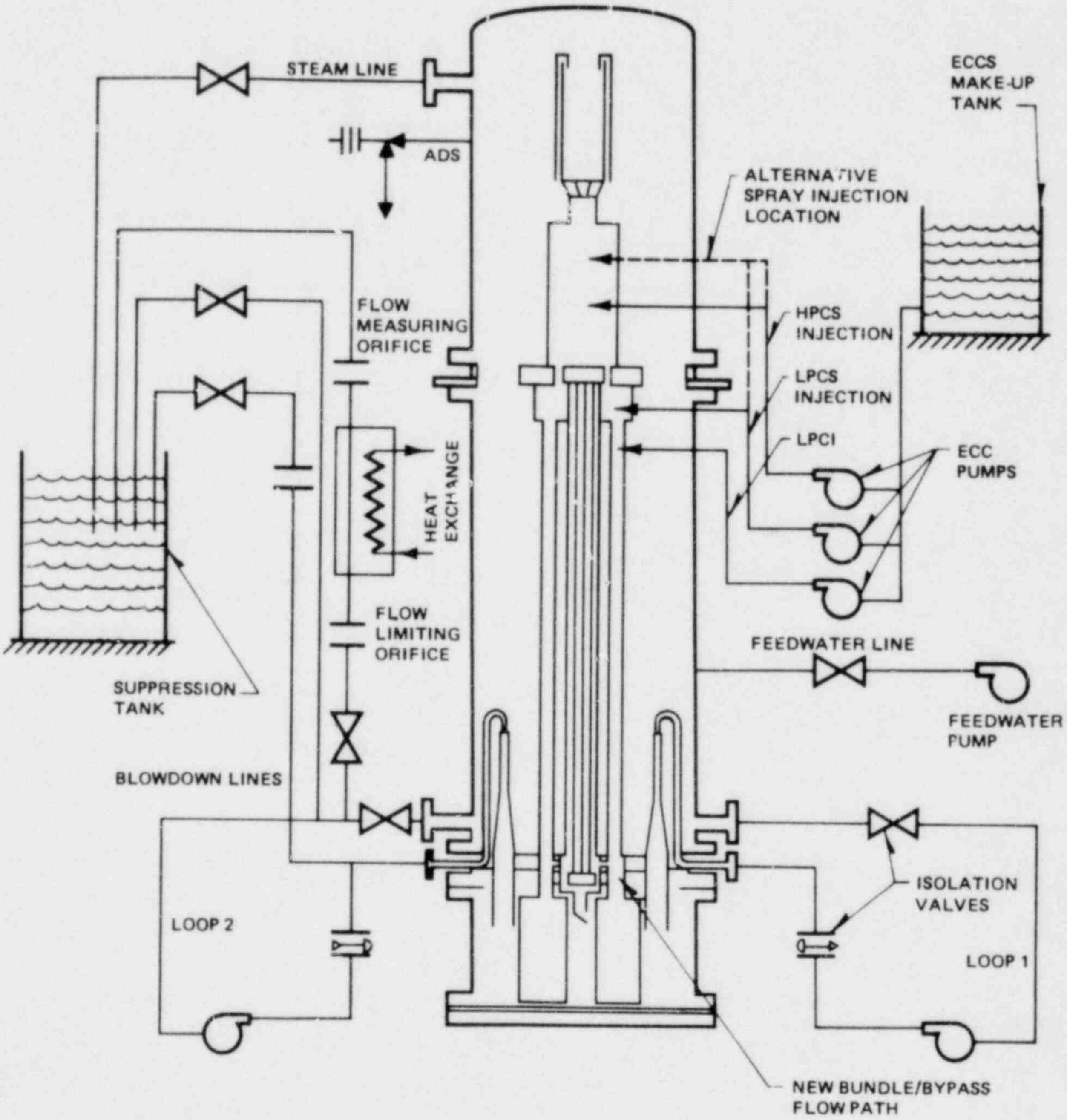


Figure F-1. Two Loop Test Apparatus Configuration 5B (TLTA-5B) with Emergency Core Cooling Systems

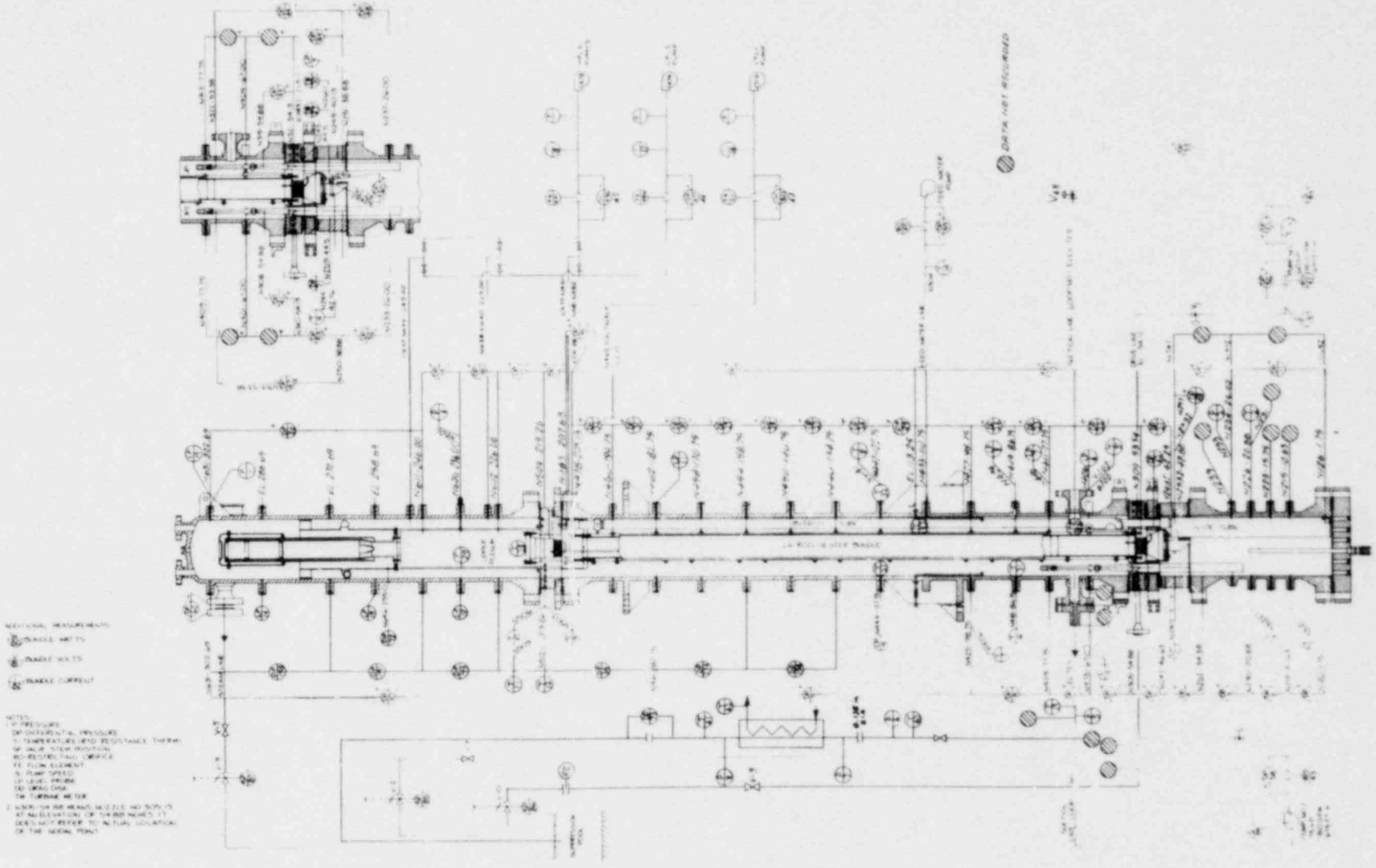


Figure F-2. Primary Measurements — Measurement Nodes for TLTA 5B

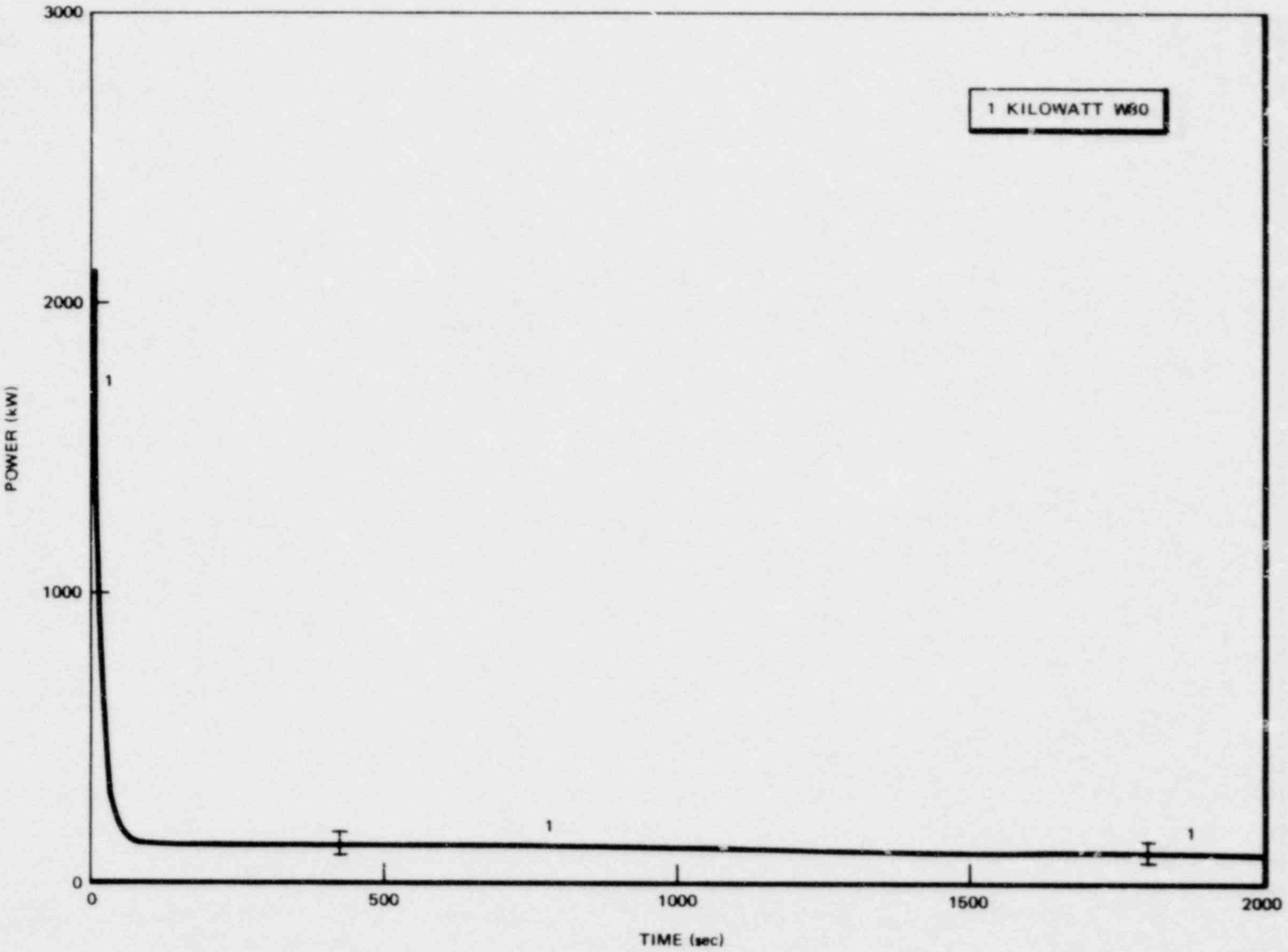


Figure F-3. Bundle Power Decay

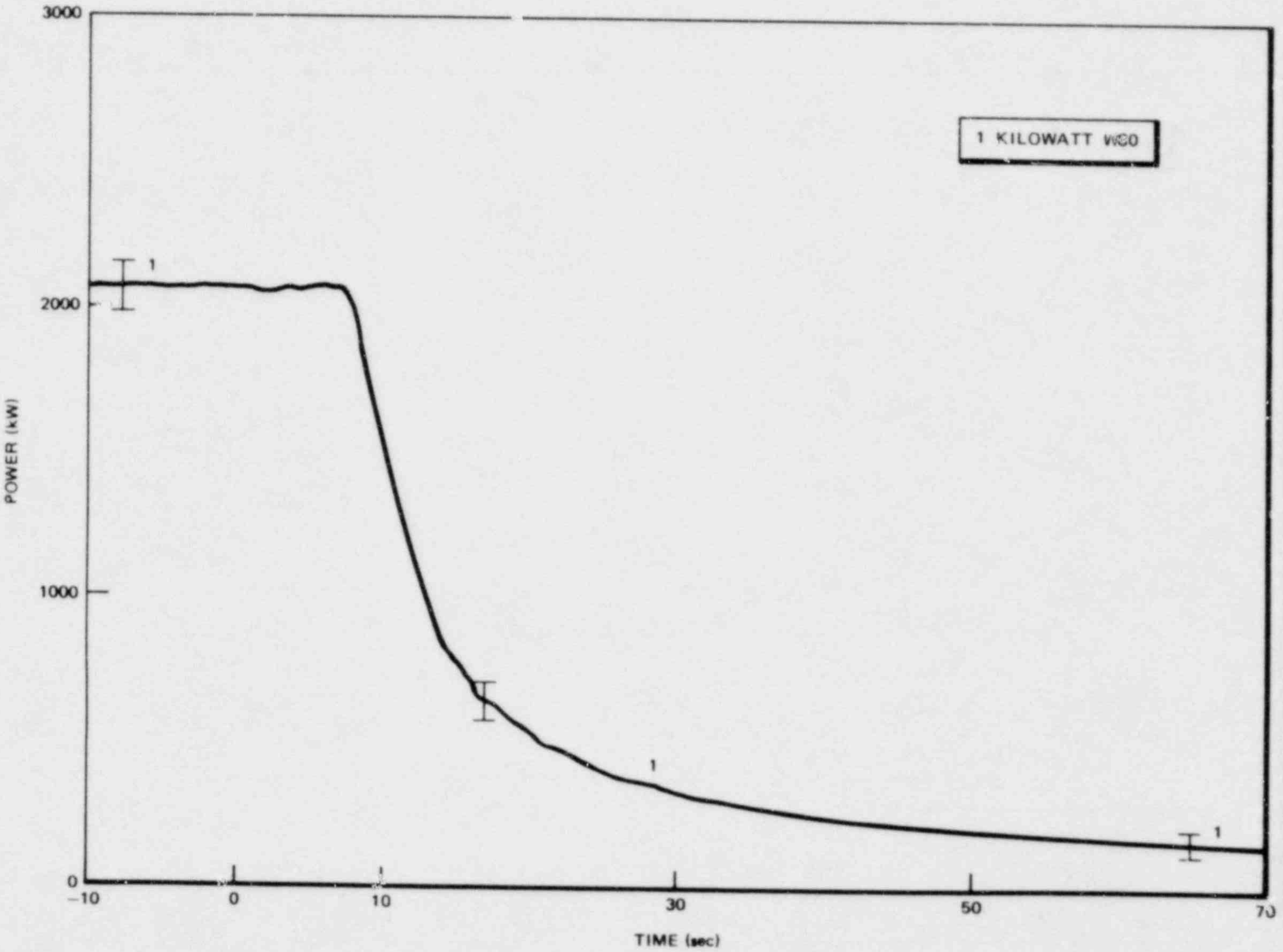


Figure F-3A. Bundle Power Decay (Expanded Scale)

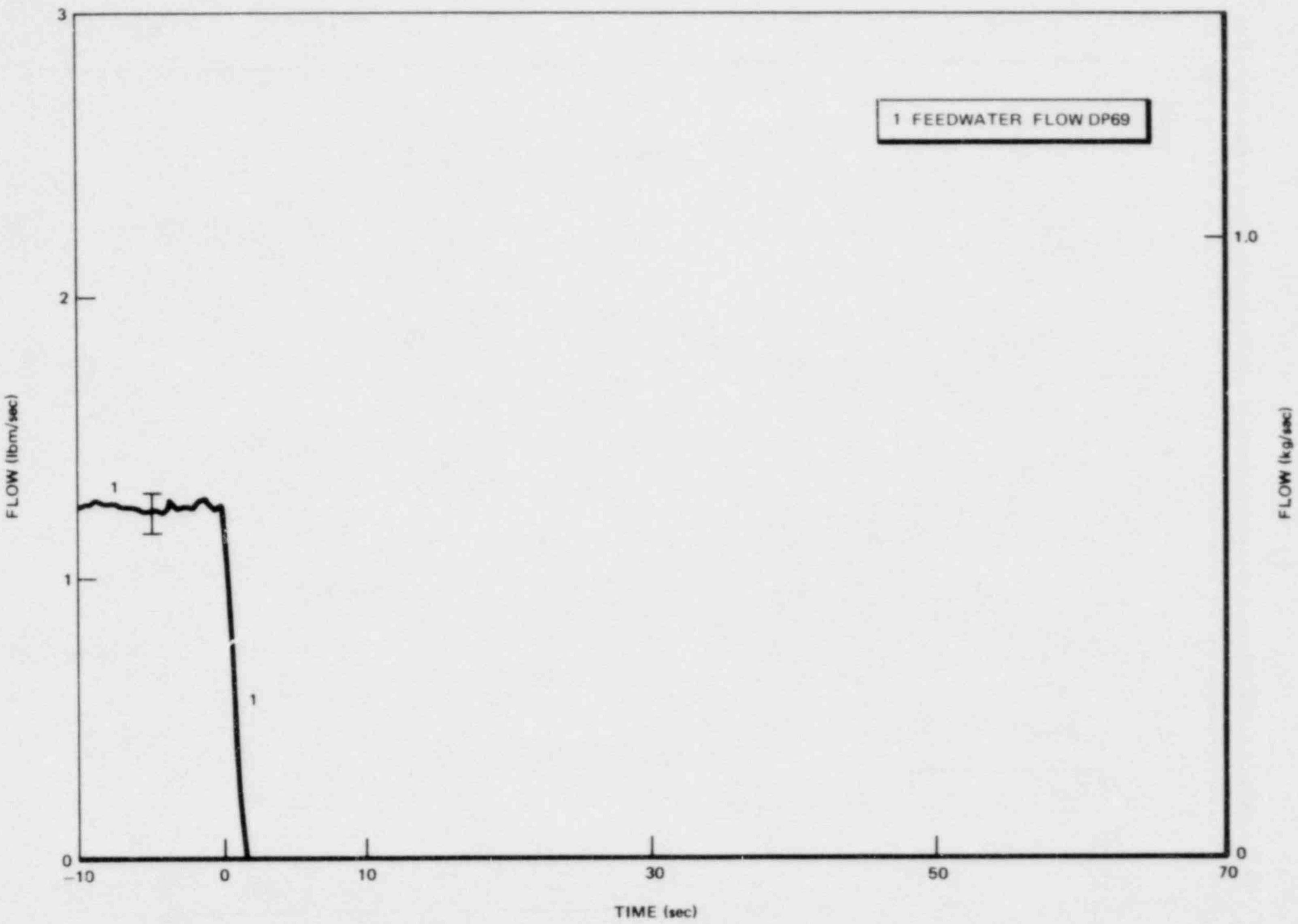


Figure F-4. Feedwater Flow

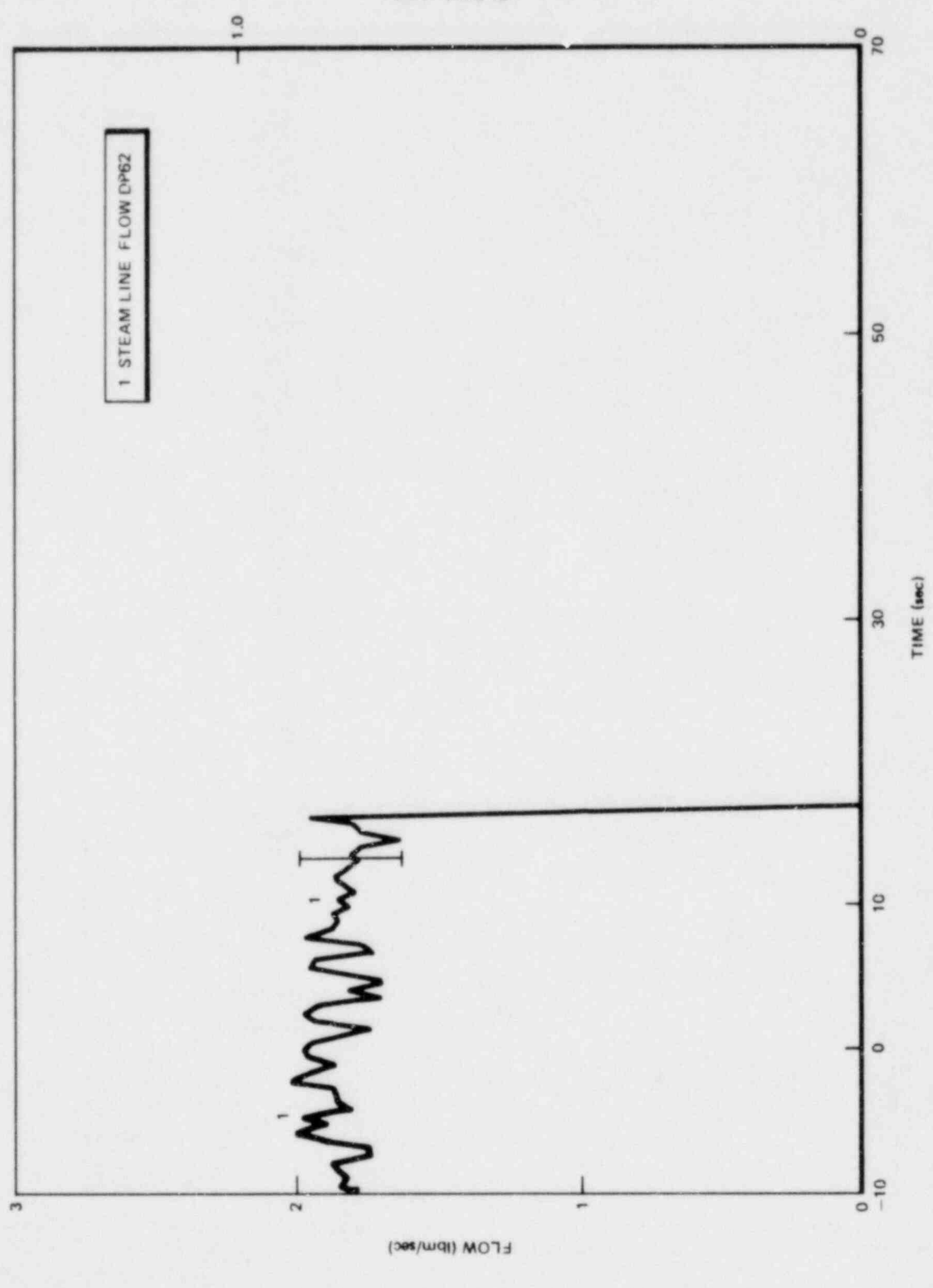


Figure F-5. Steam Line Flow

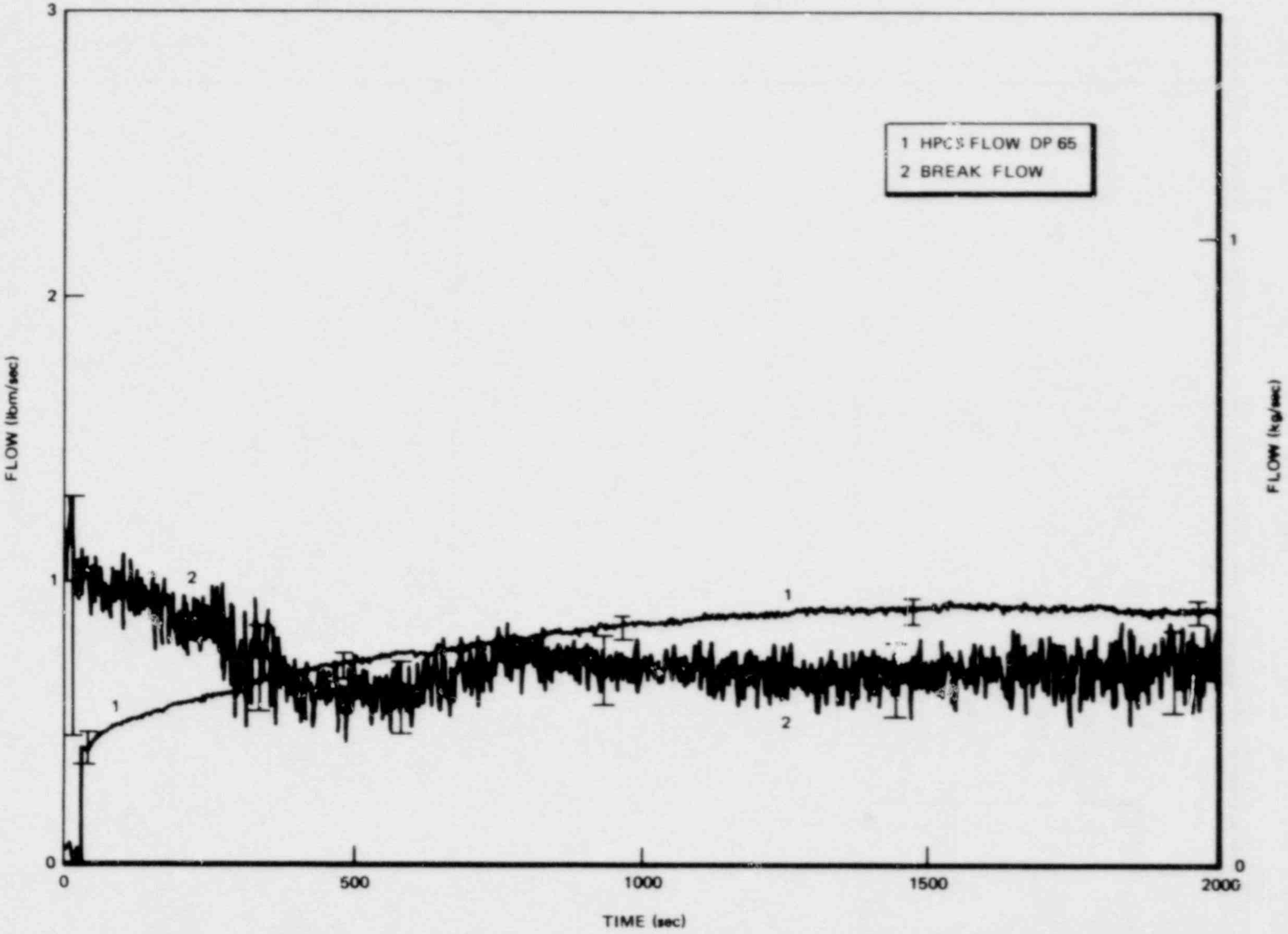


Figure F-6. HPCS Injection and Break Flow

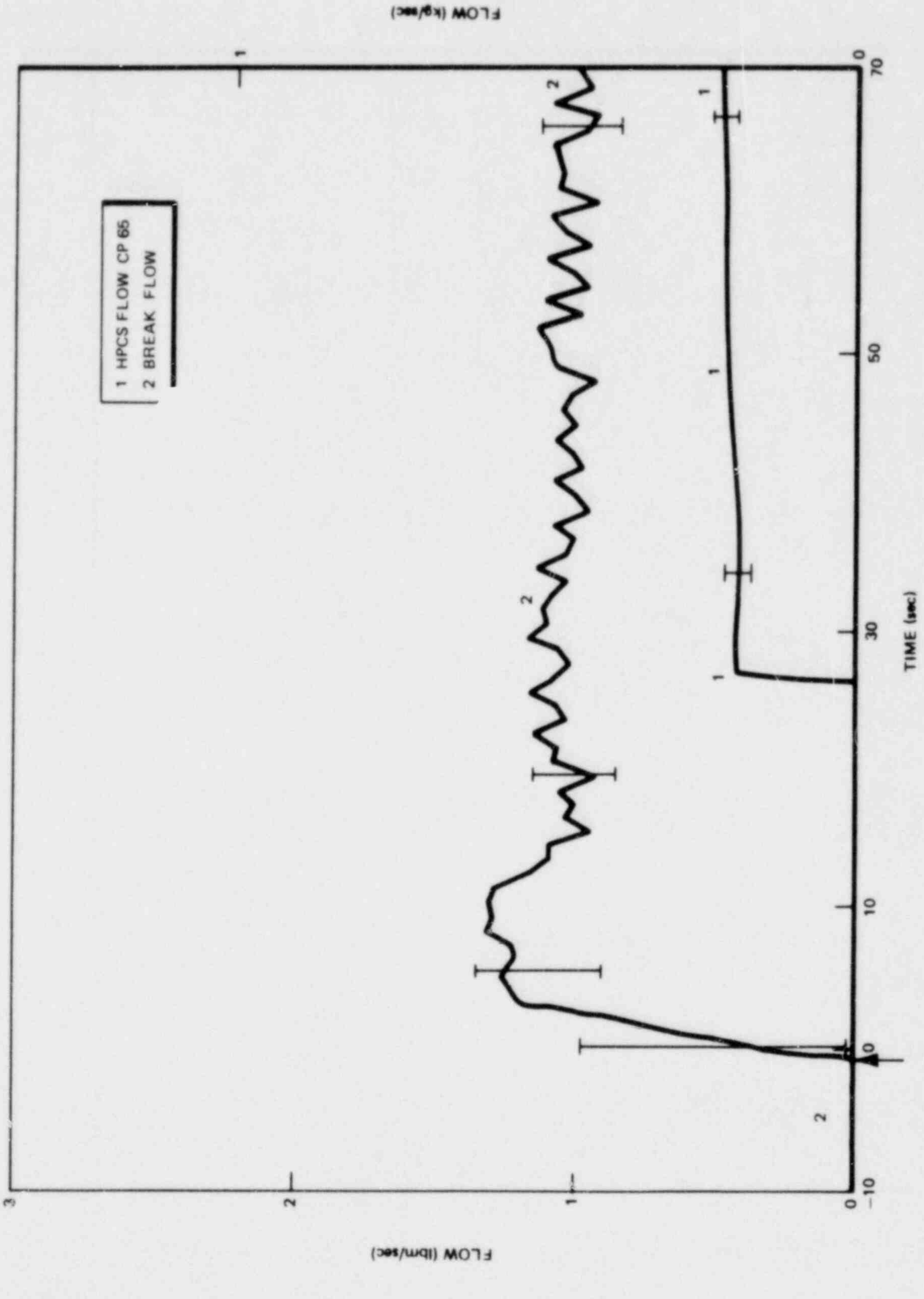


Figure F-6A. HPCS Injection and Break Flow (Expanded Scale)

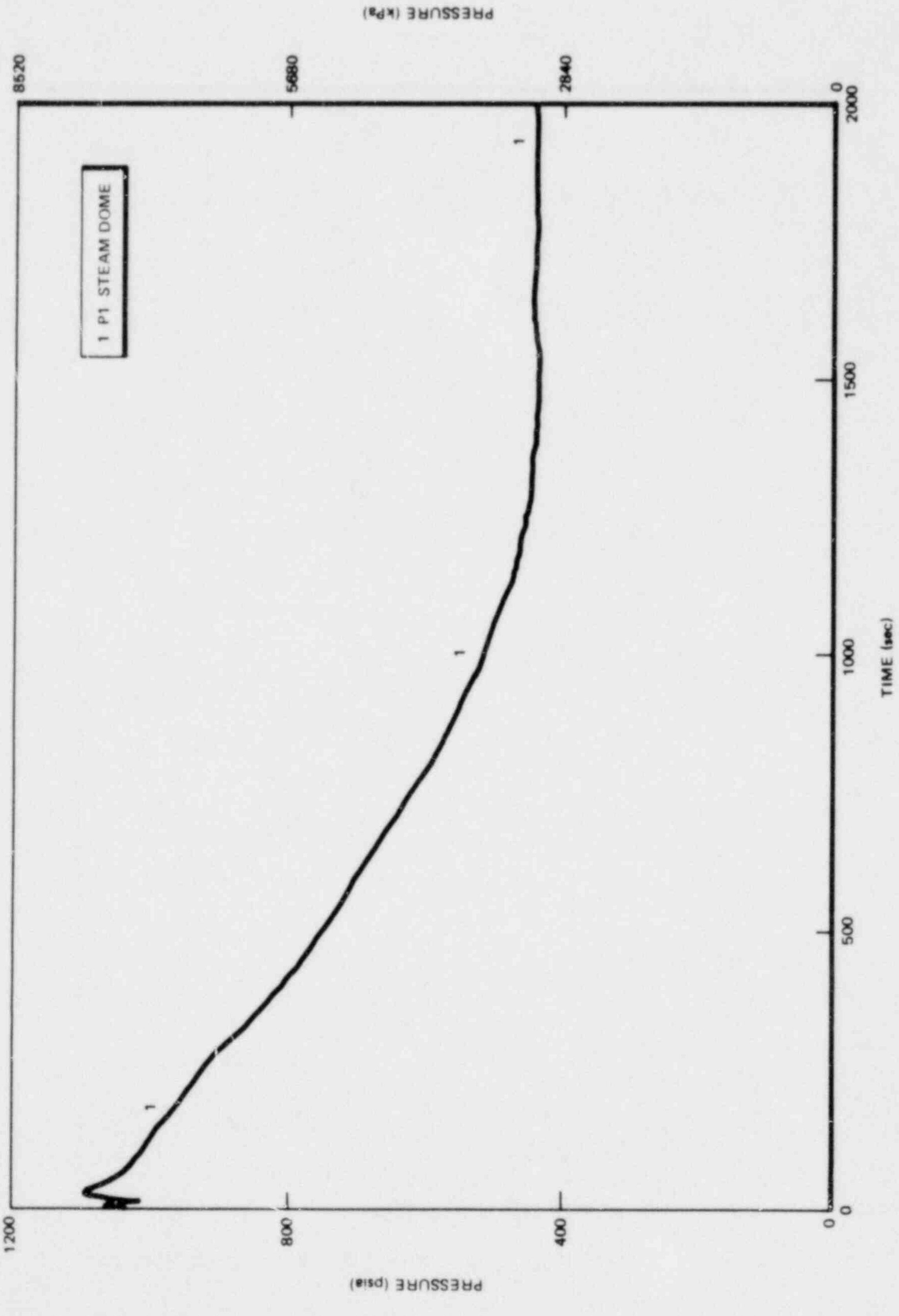


Figure F-7. System Pressure Response

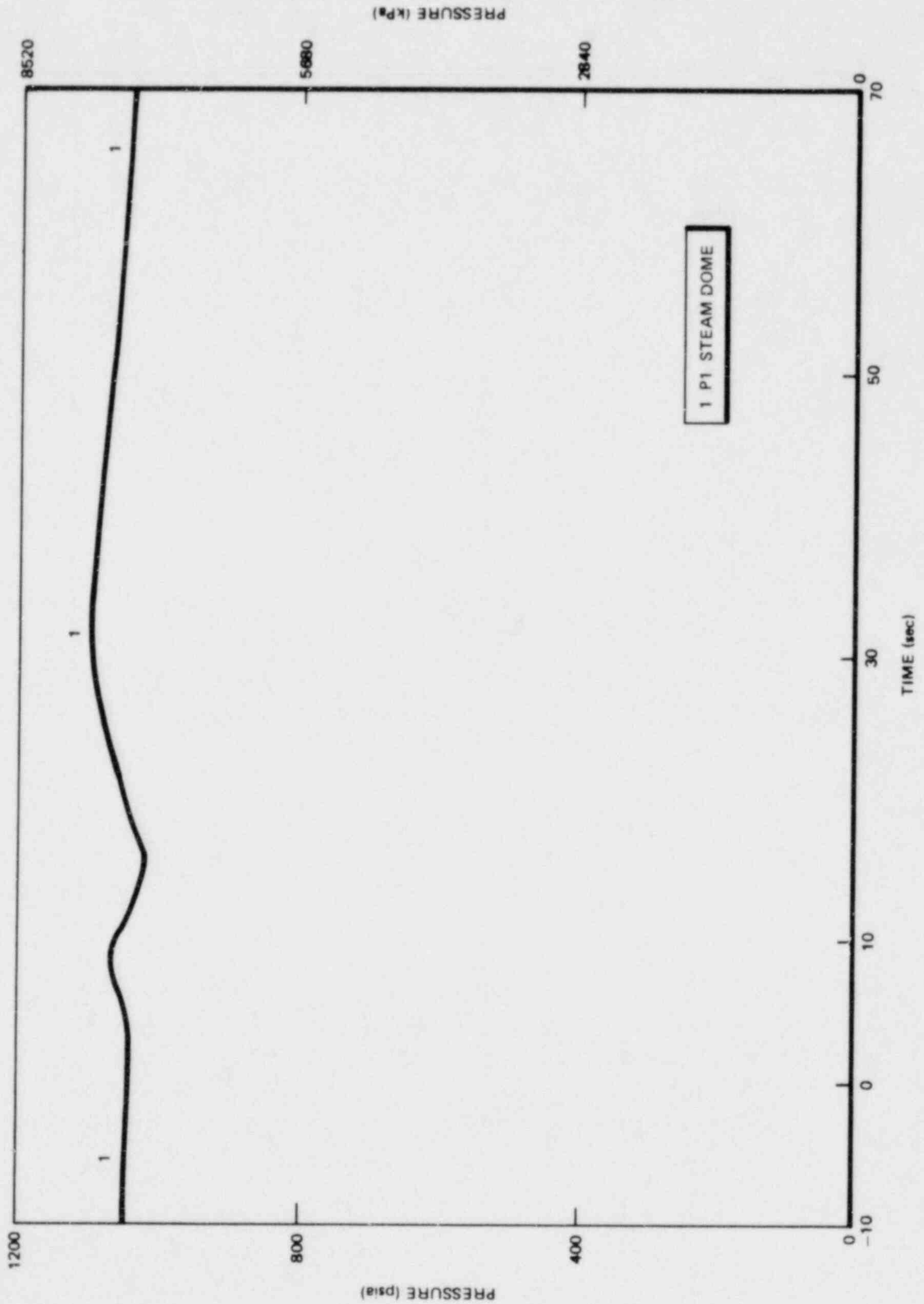


Figure F-7A. System Pressure Response (Expanded Scale)

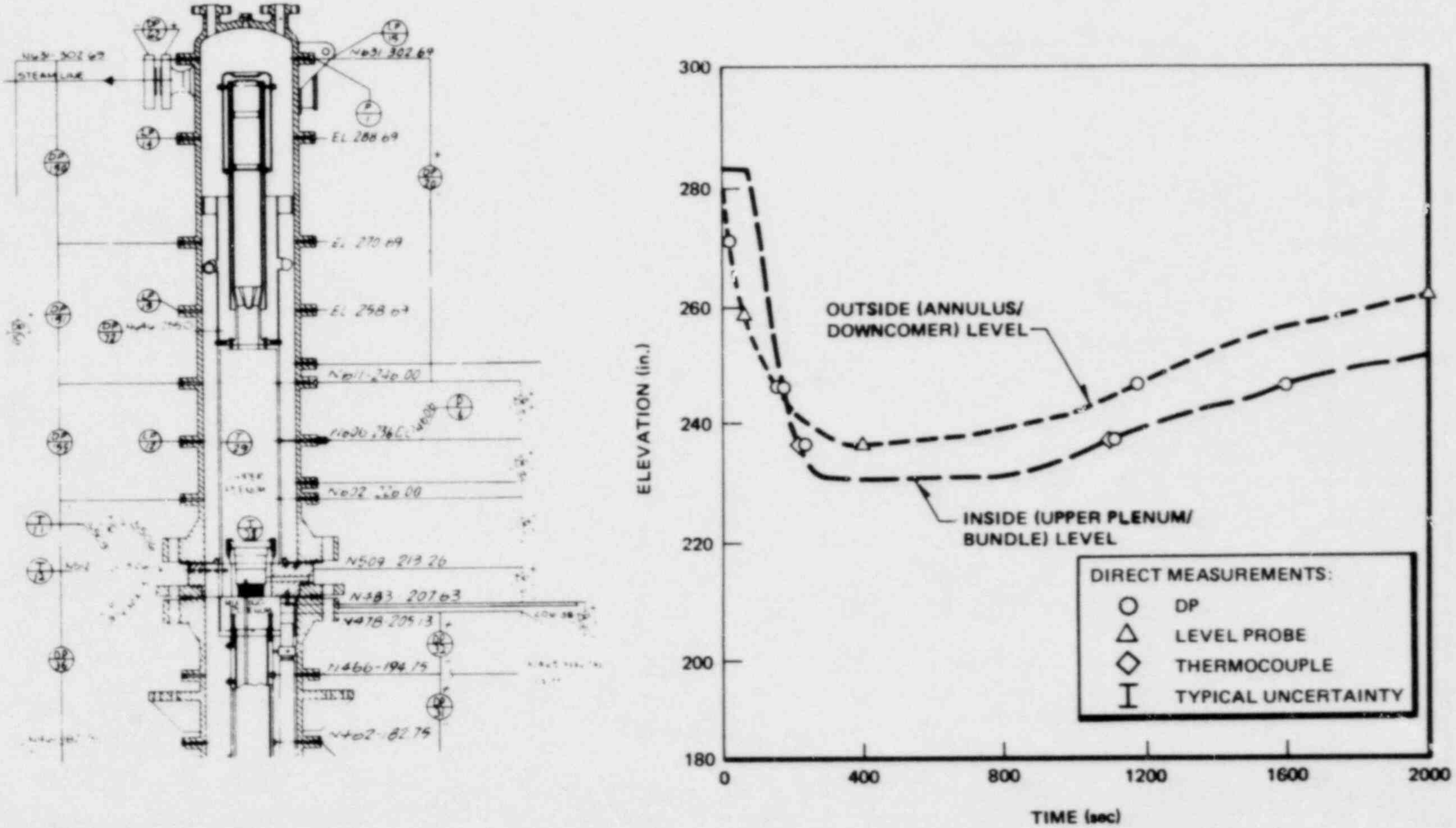


Figure F-8. Measured Levels for TLTA Small Break #1 (6431 Run 1)

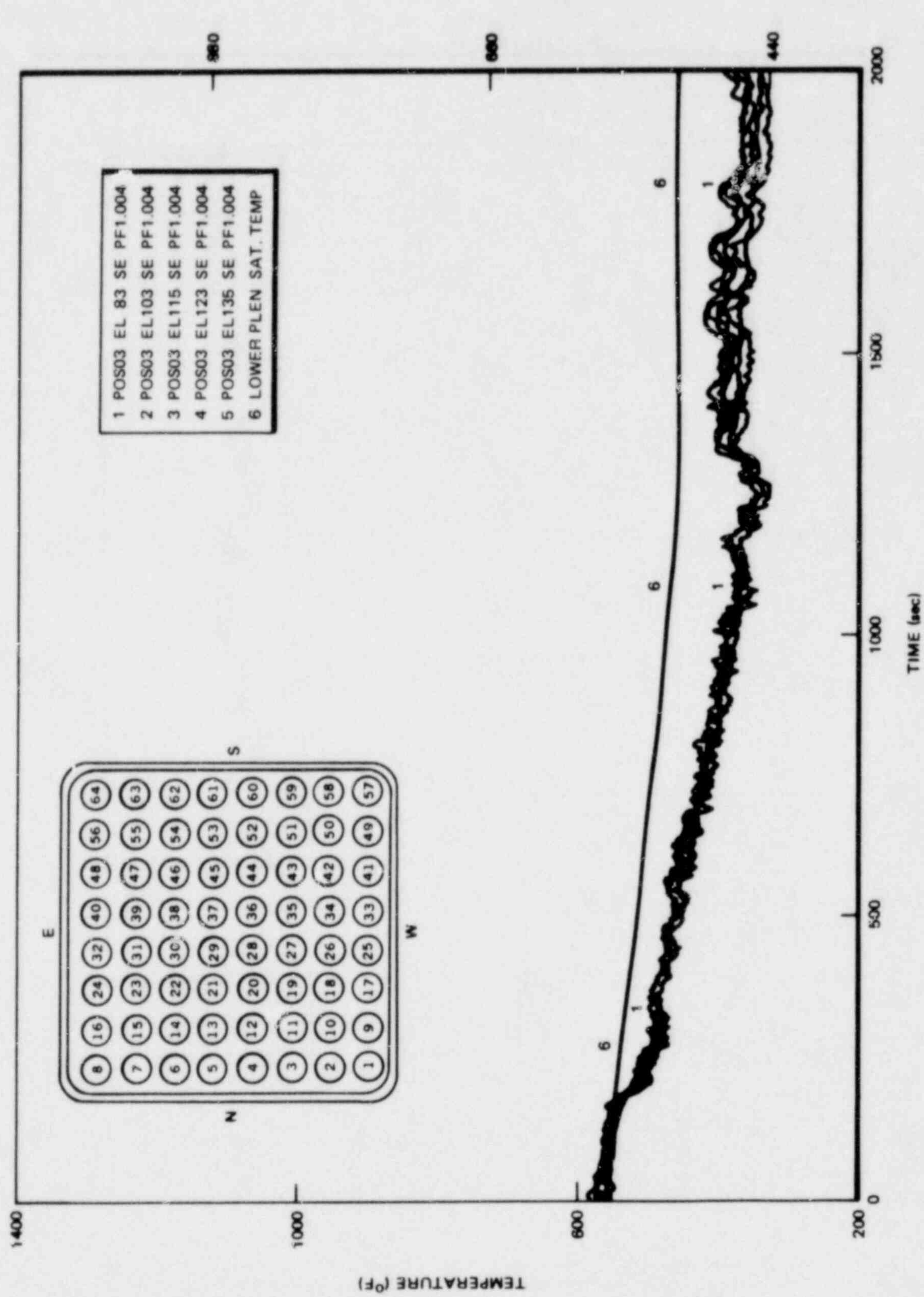


Figure F-9. Temperature Response Along Rod Position 3

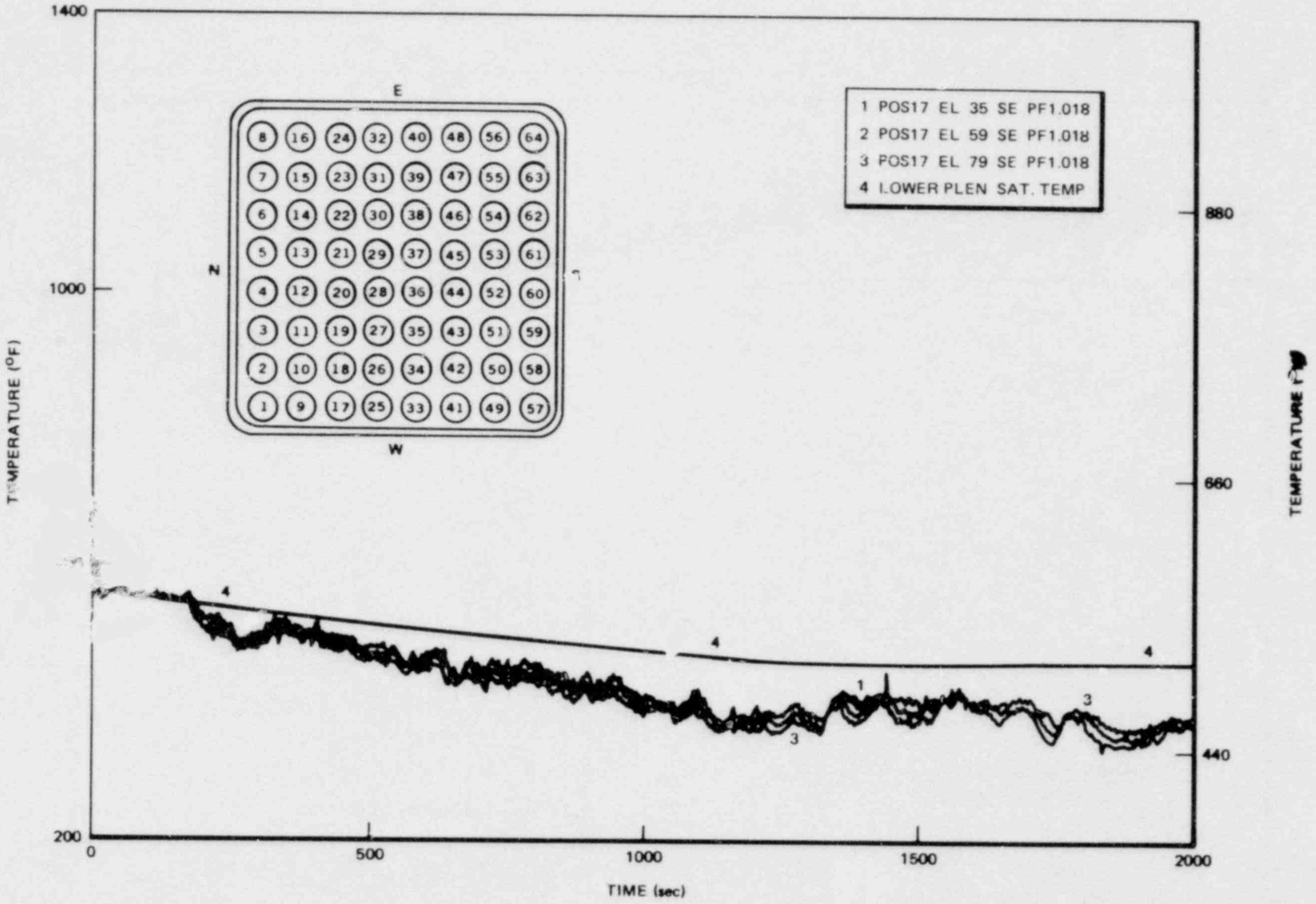


Figure F-10. Temperature Response Along Rod Position 17

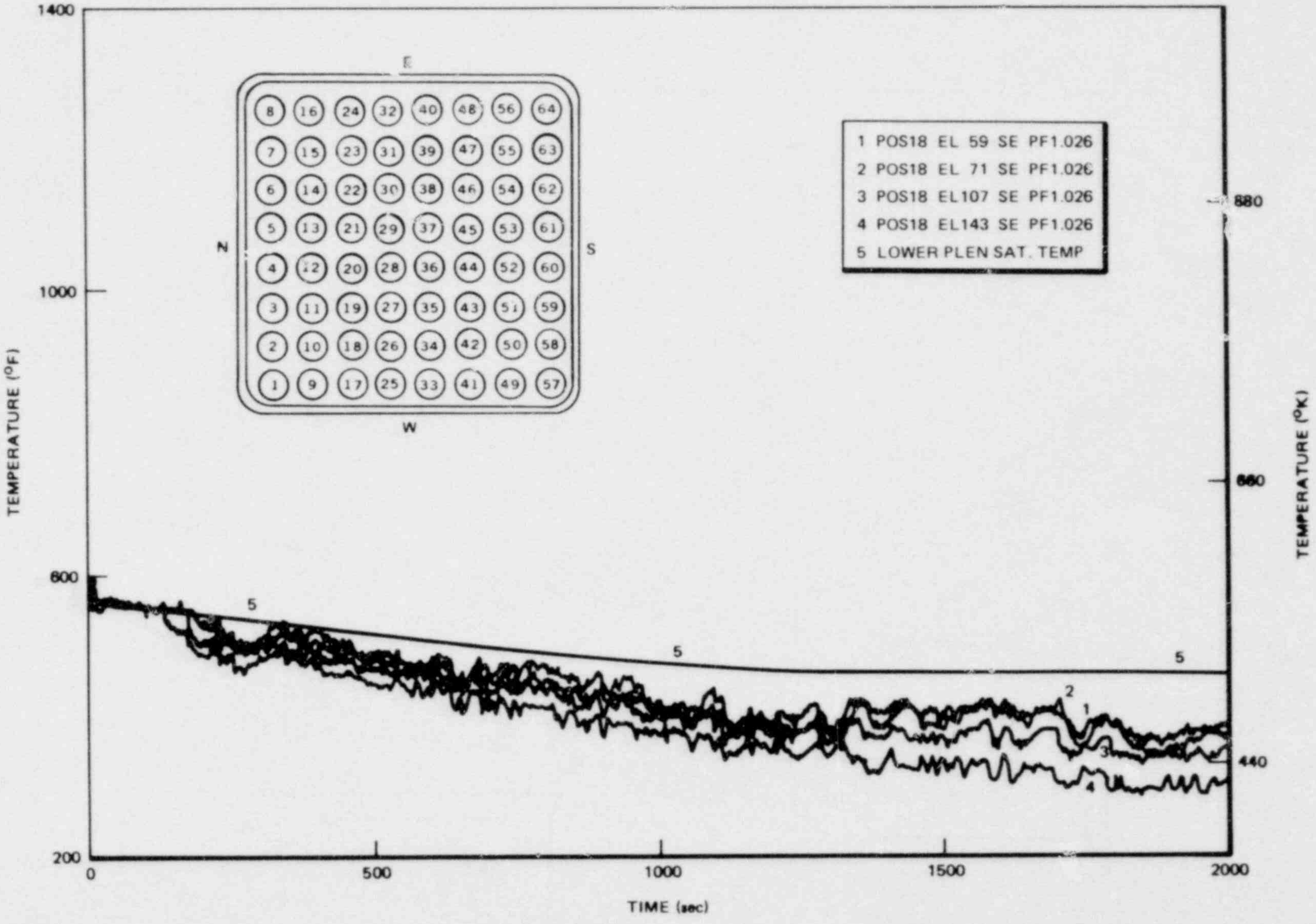


Figure F-11. Temperature Response Along Rod Position 18

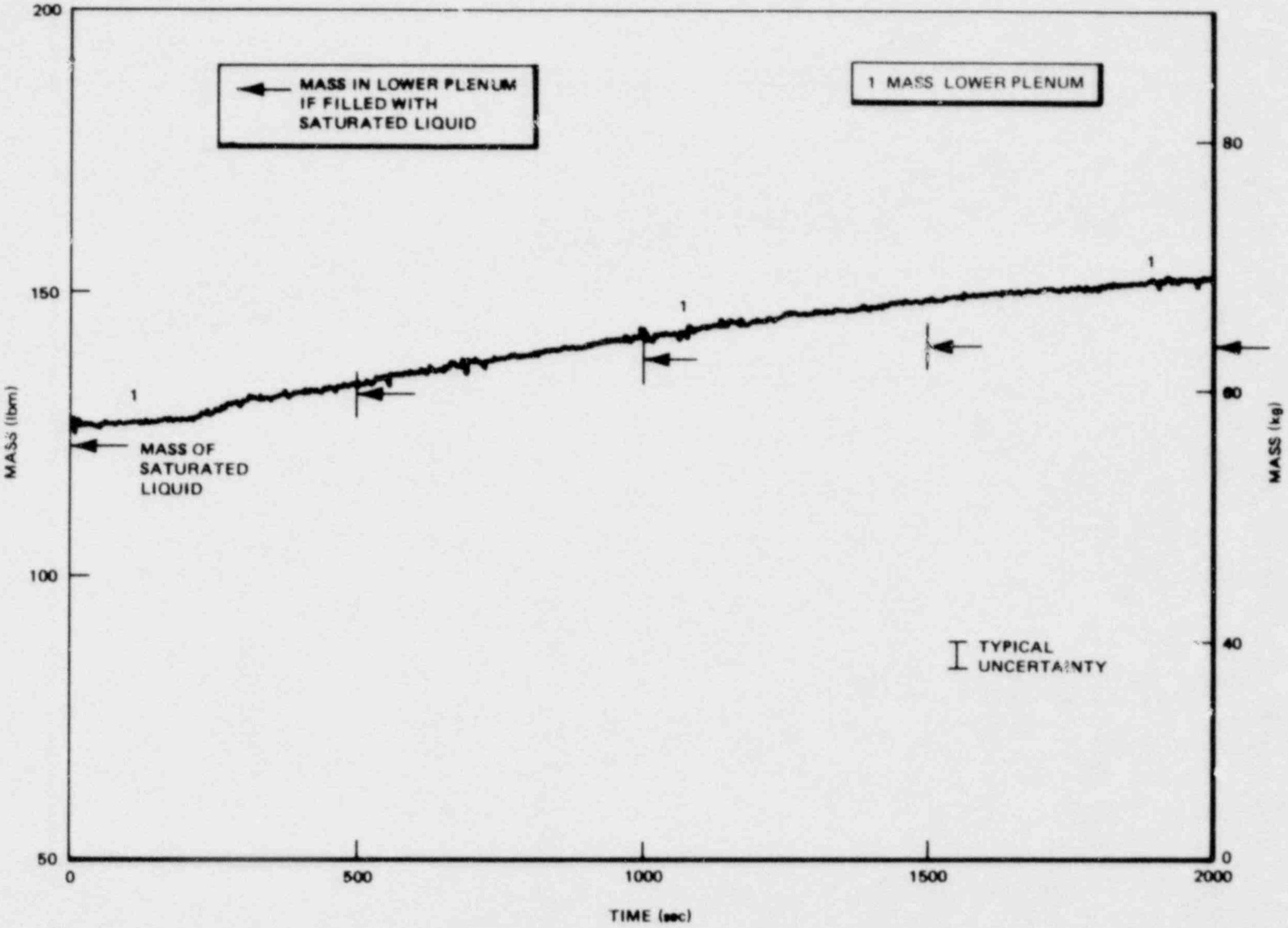


Figure F-12. Lower Plenum Mass

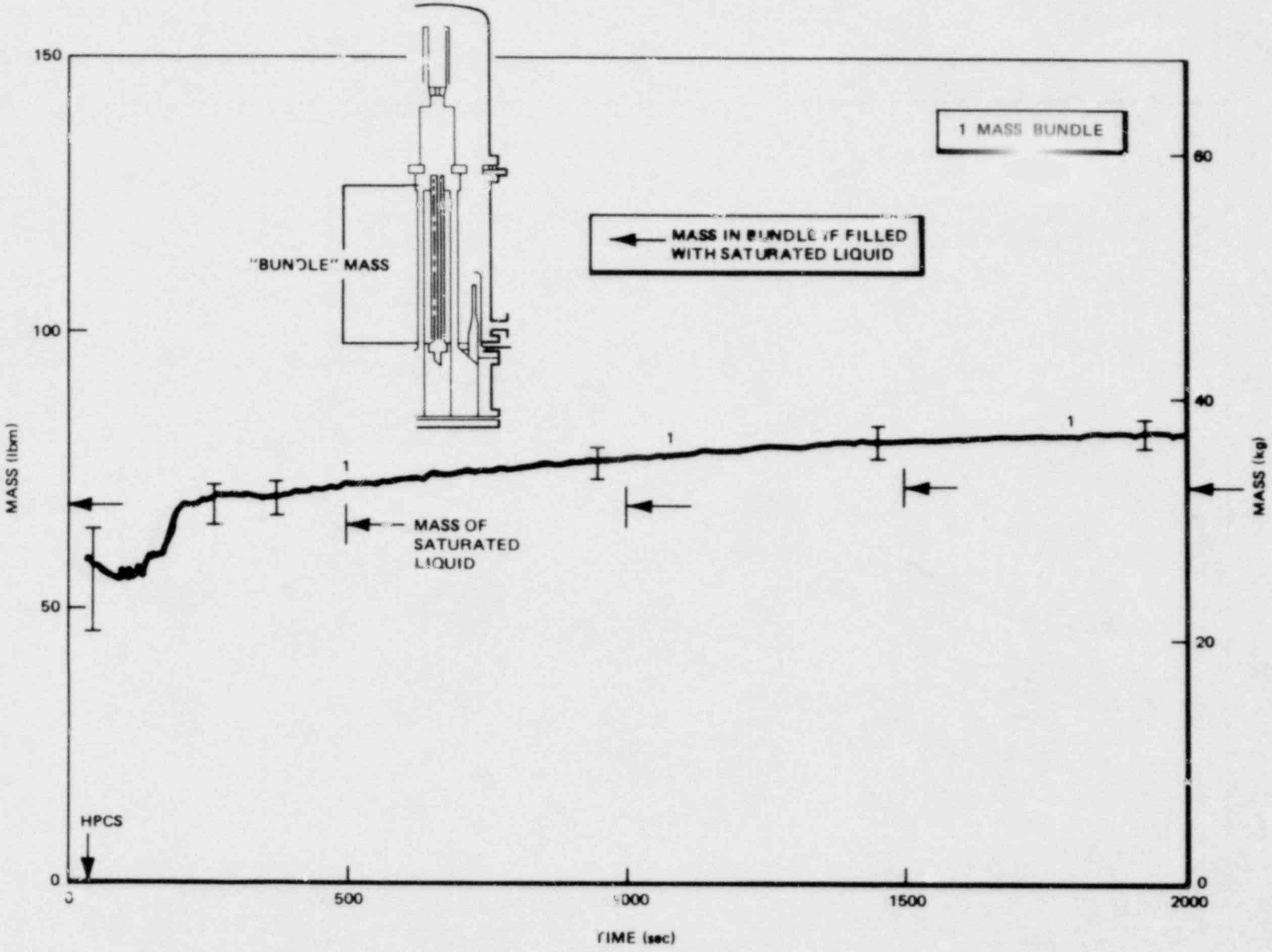


Figure F-13. Bundle Mass

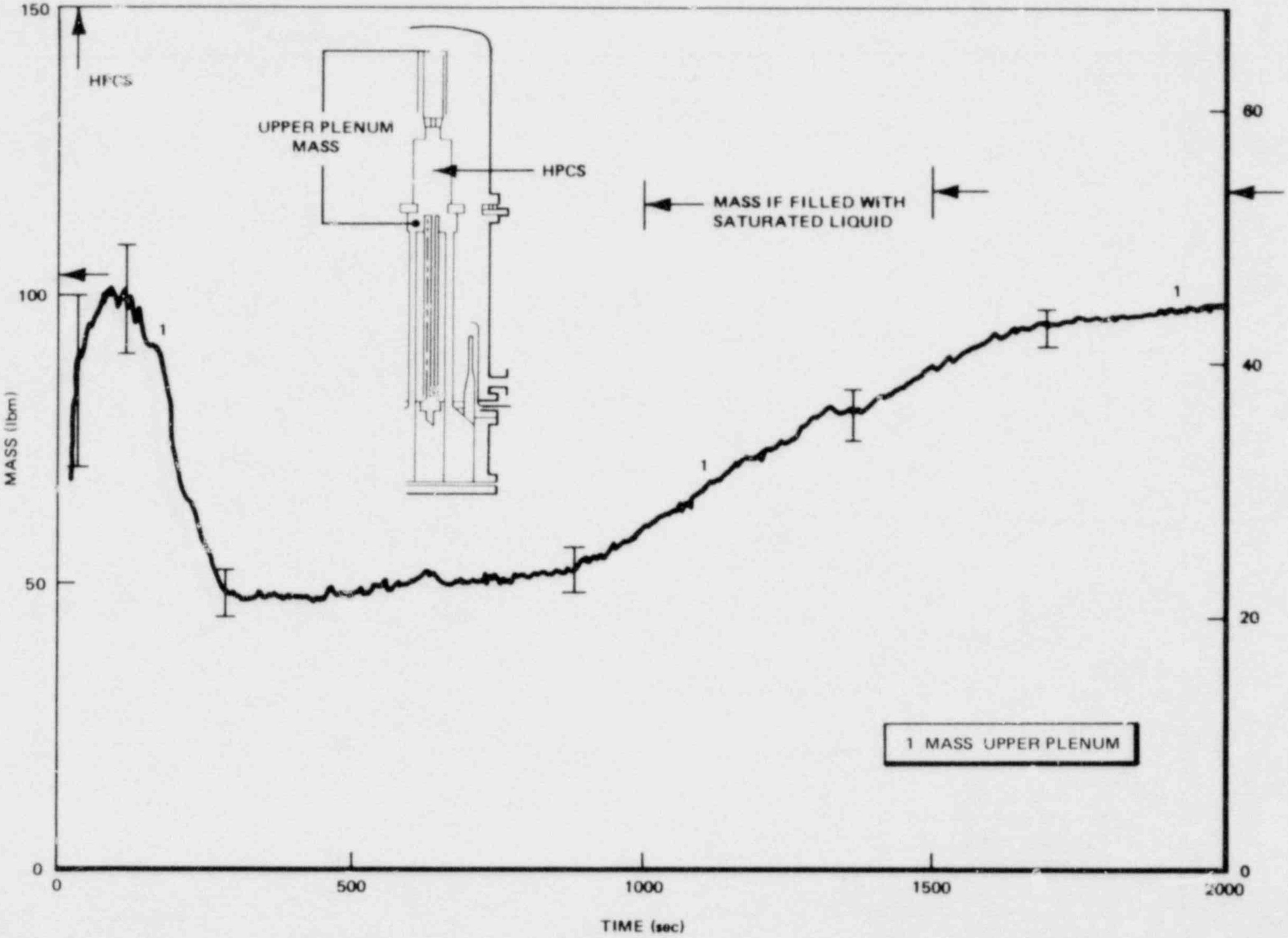


Figure F-14. Upper Plenum Mass

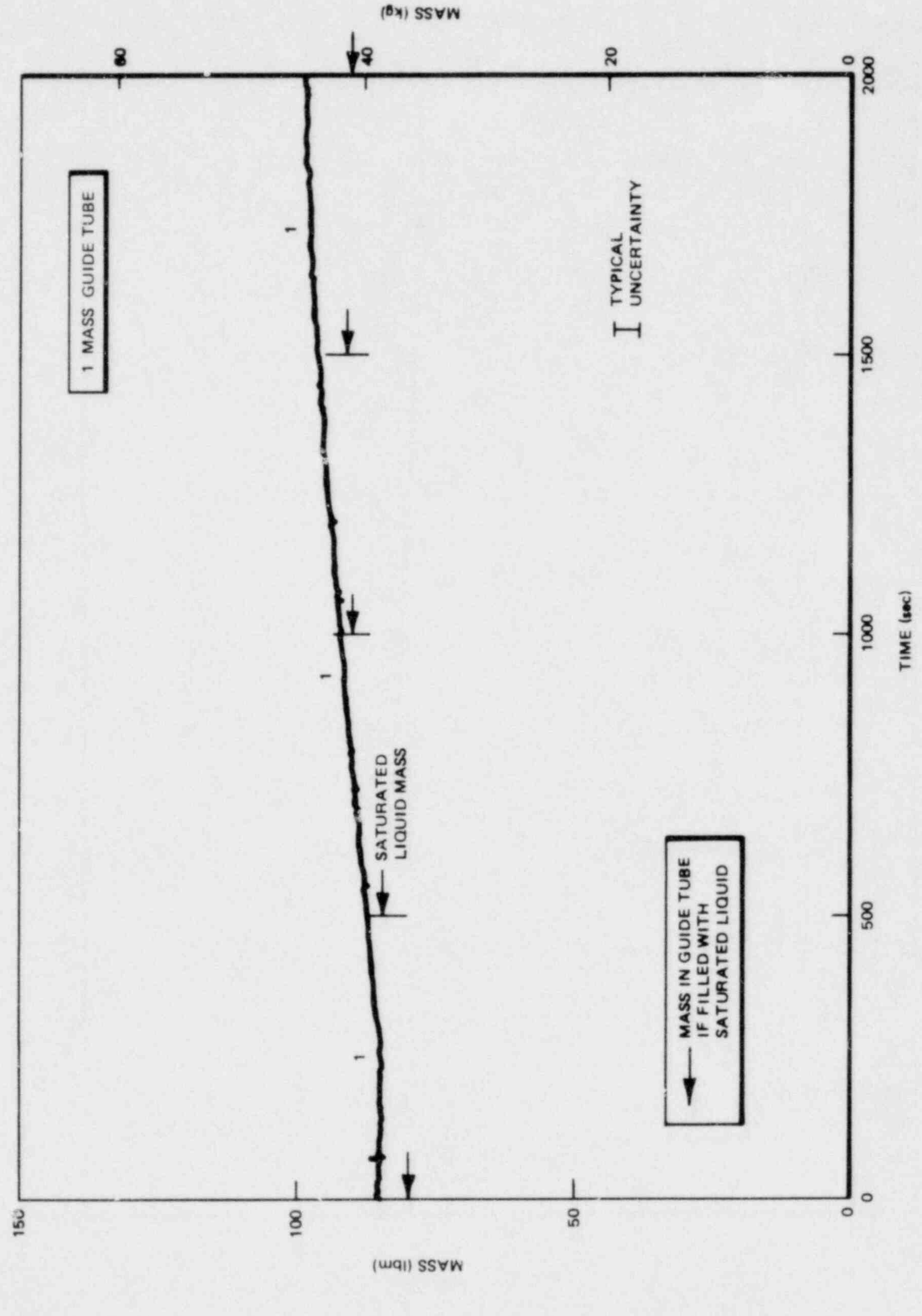


Figure F-15. *Guide Tube Mass*

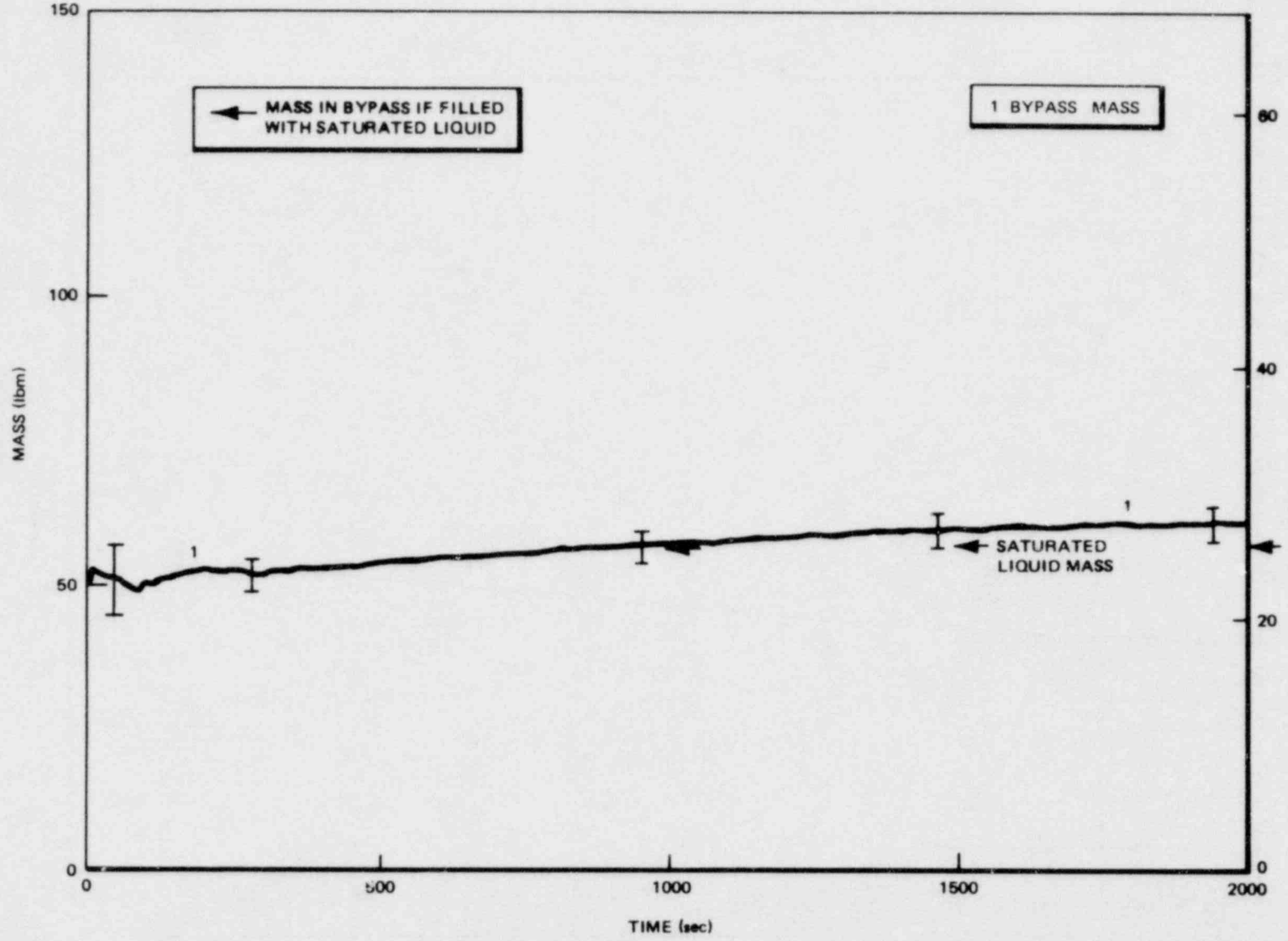


Figure F-16. Bypass Mass

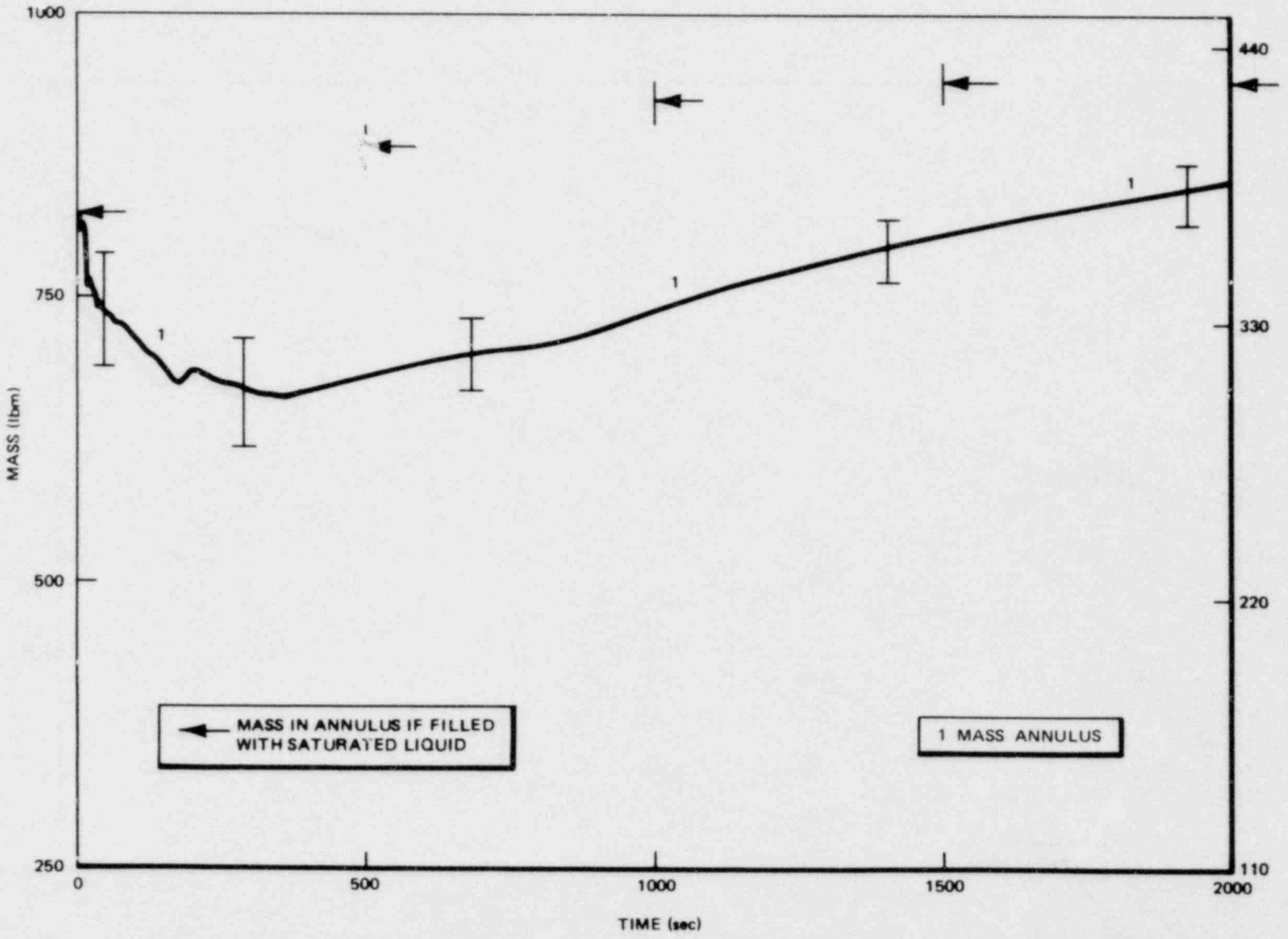


Figure F-17. Annulus (Downcomer) Mass

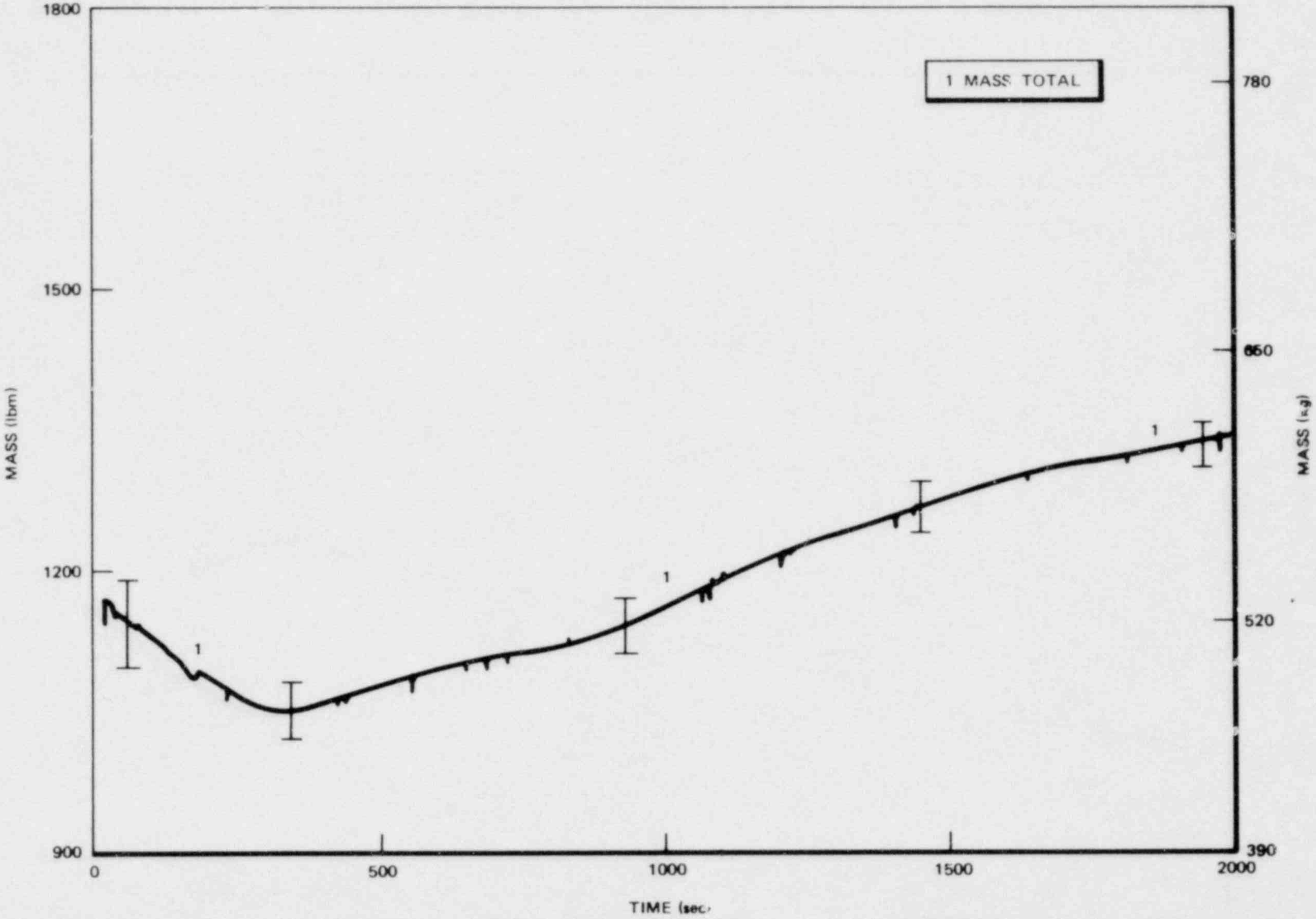


Figure F-18. Total System Mass

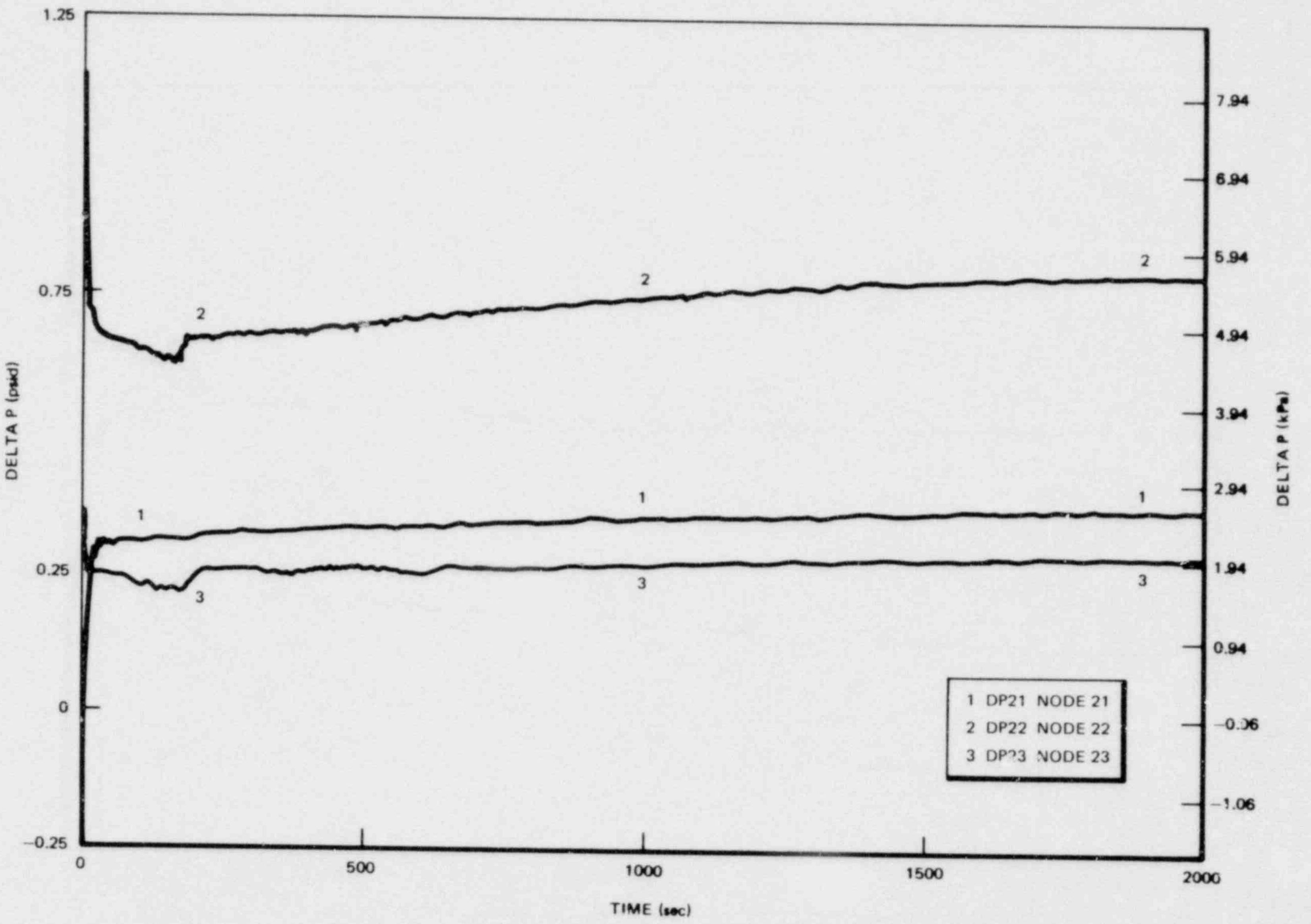


Figure F-19. Bundle DP's, Bottom Nodes

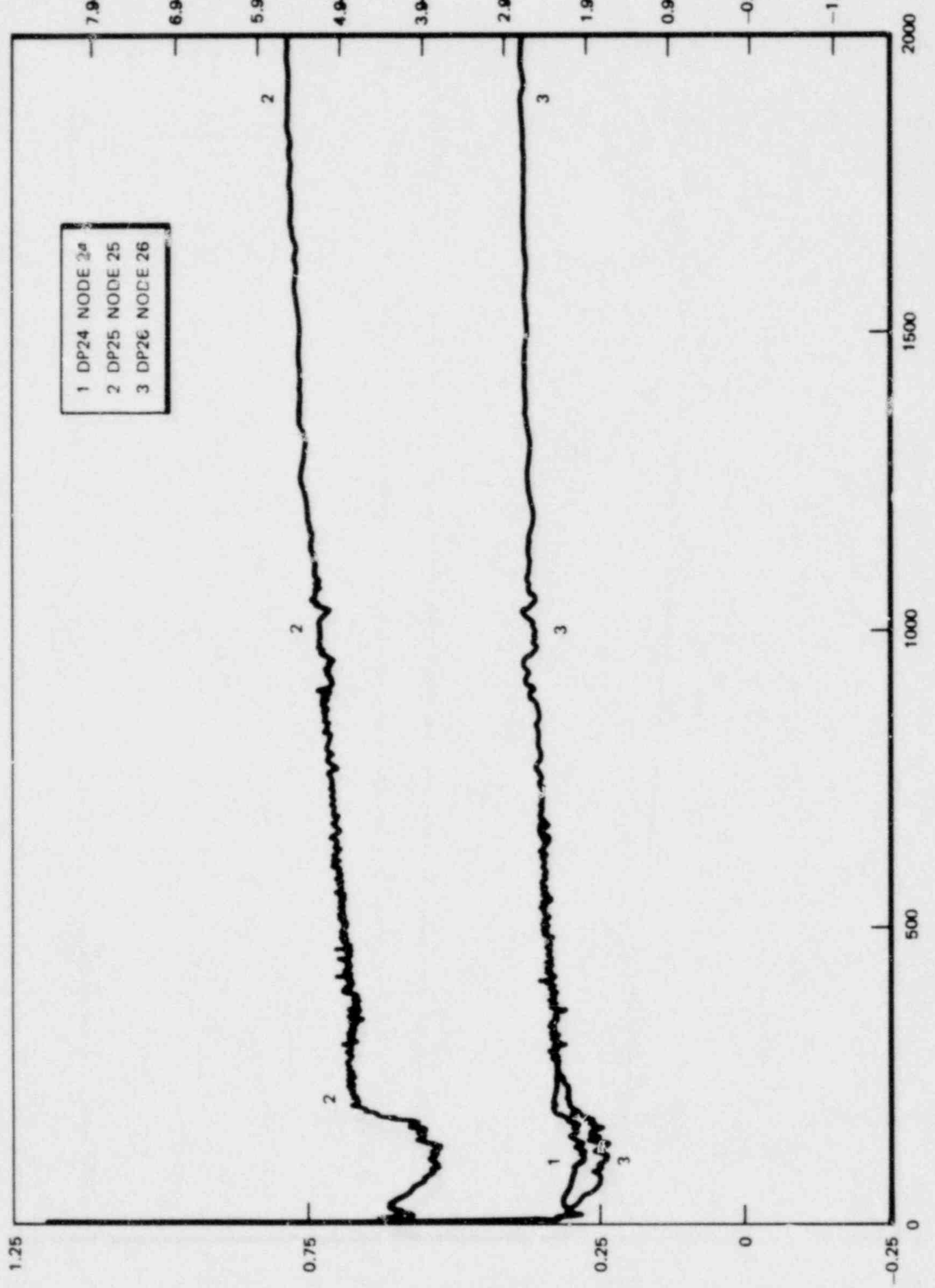


Figure F-20. Bundle DP's, Lower Middle Nodes

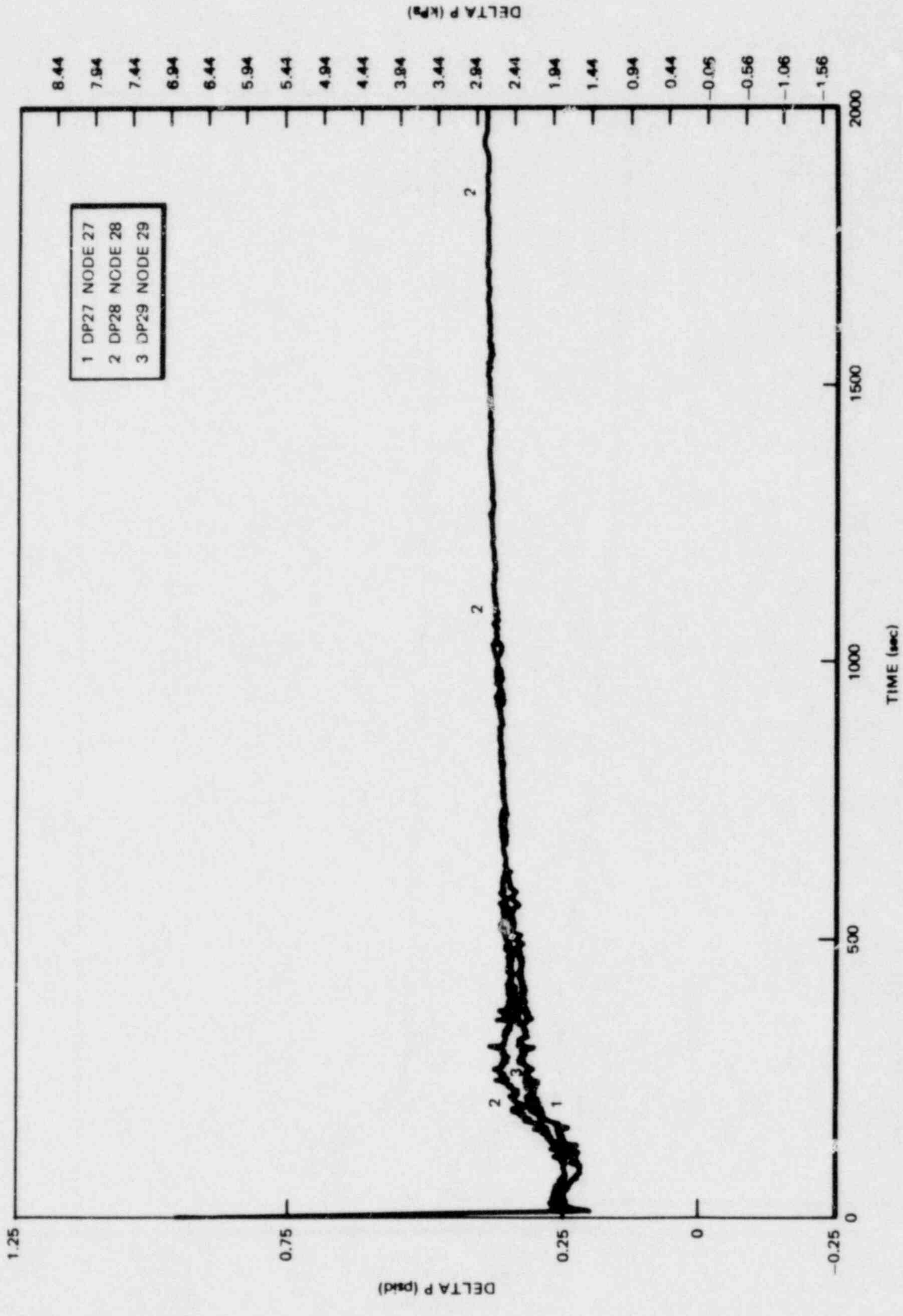


Figure F-21. *Bundle DP's, Upper Middle Nodes*

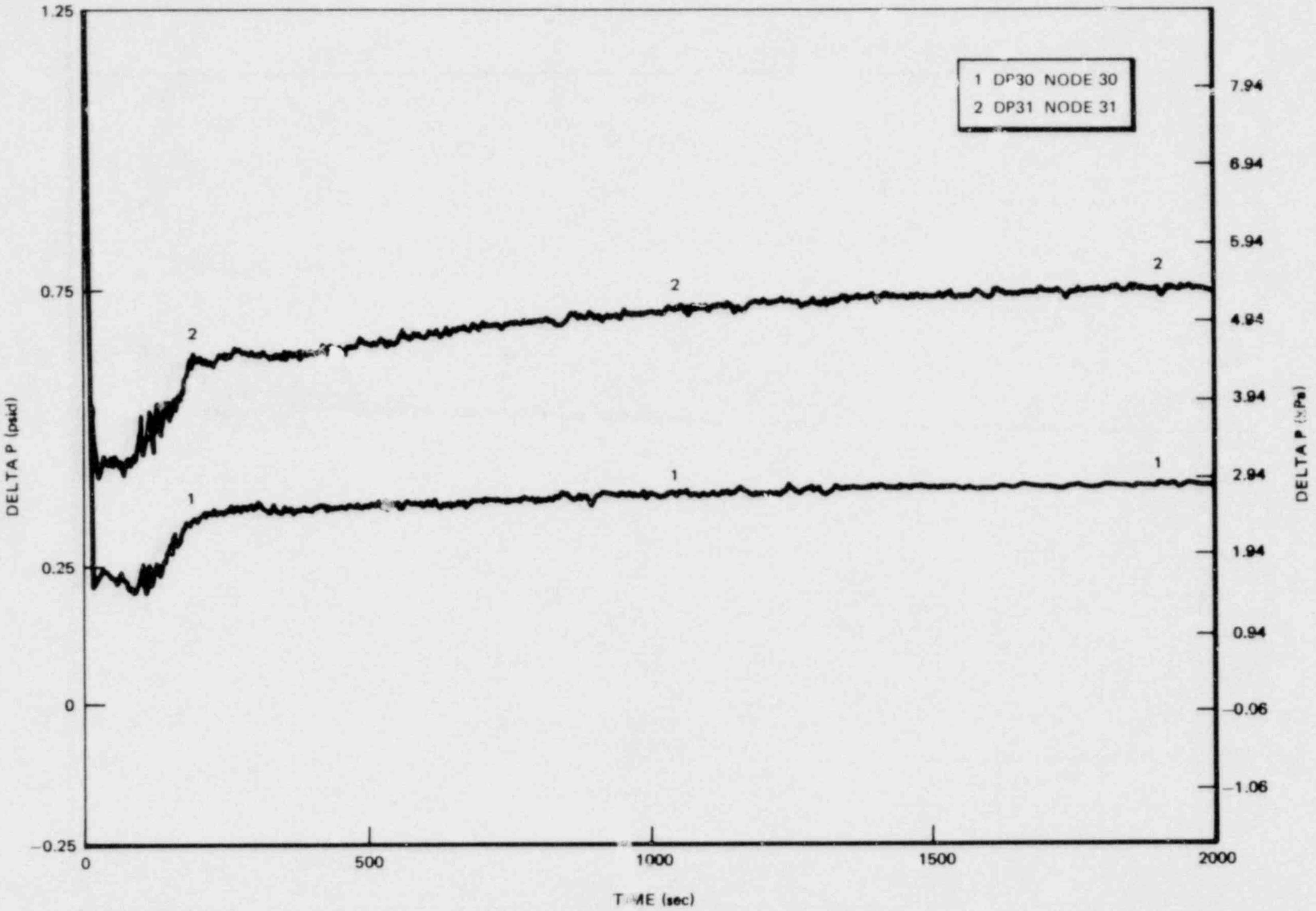


Figure F-22. Bundle DP's, Top Nodes

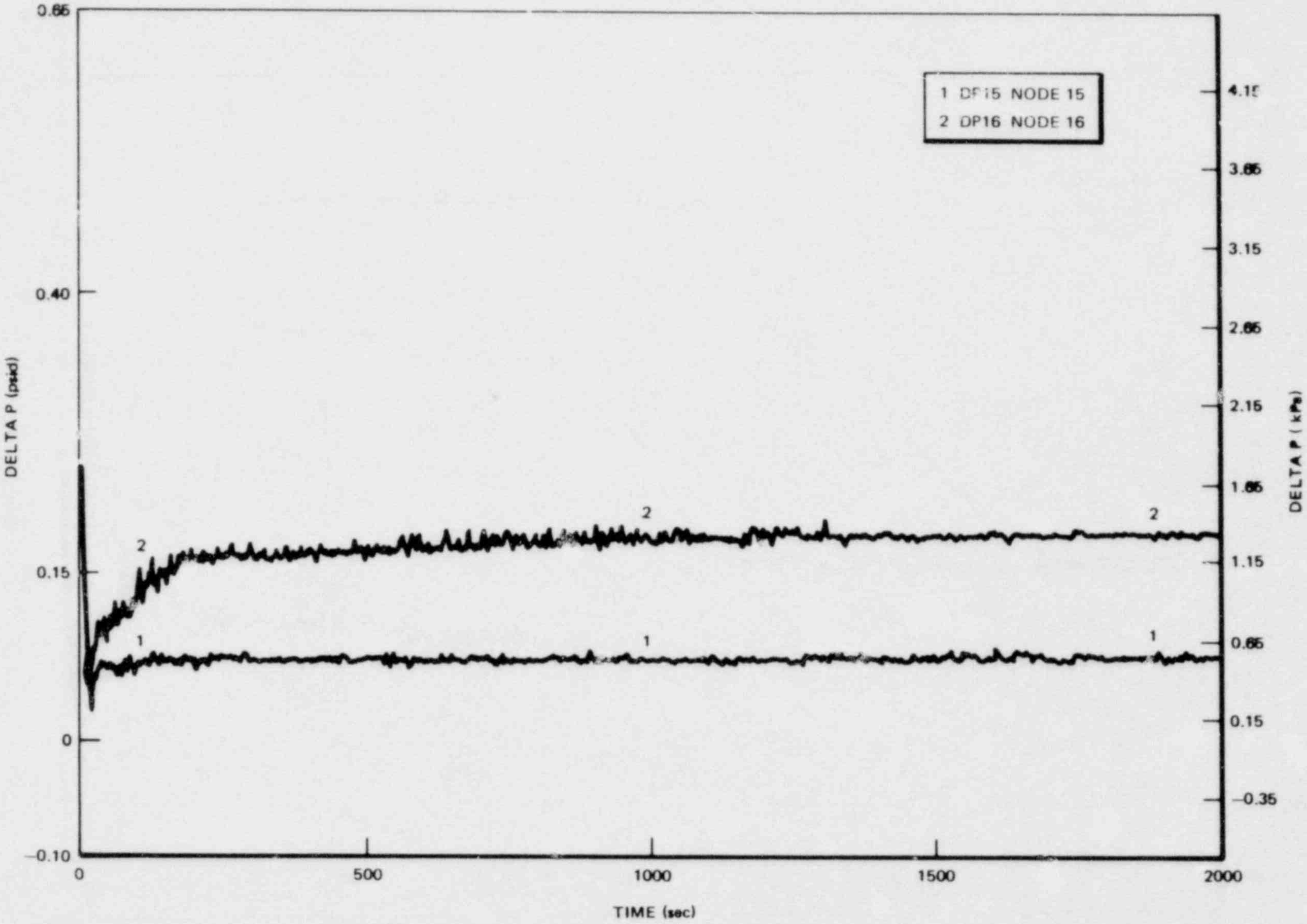


Figure F-23. Upper Plenum DP's, Lower Nodes

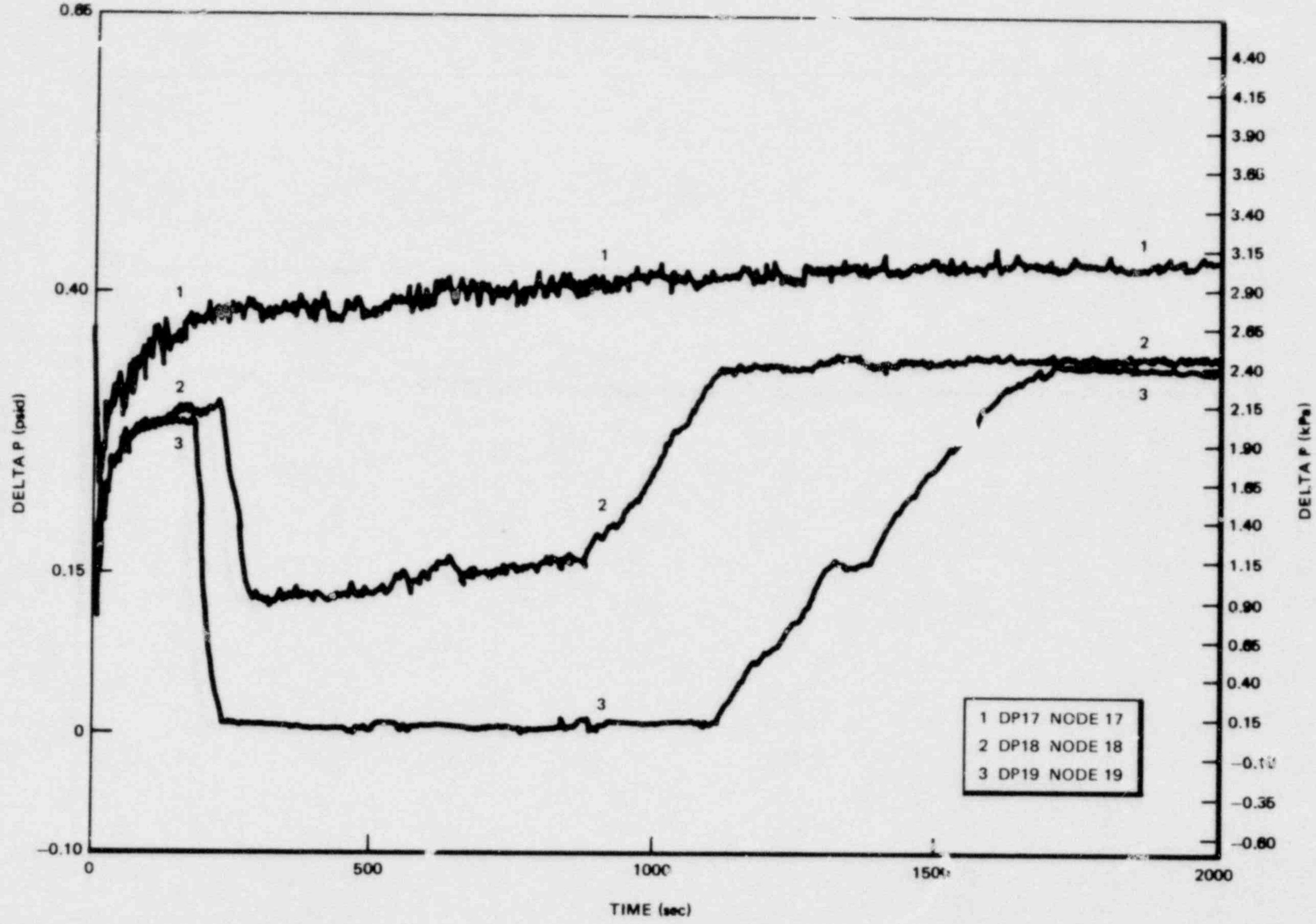


Figure F-24. Upper Plenum DP's Upper Nodes

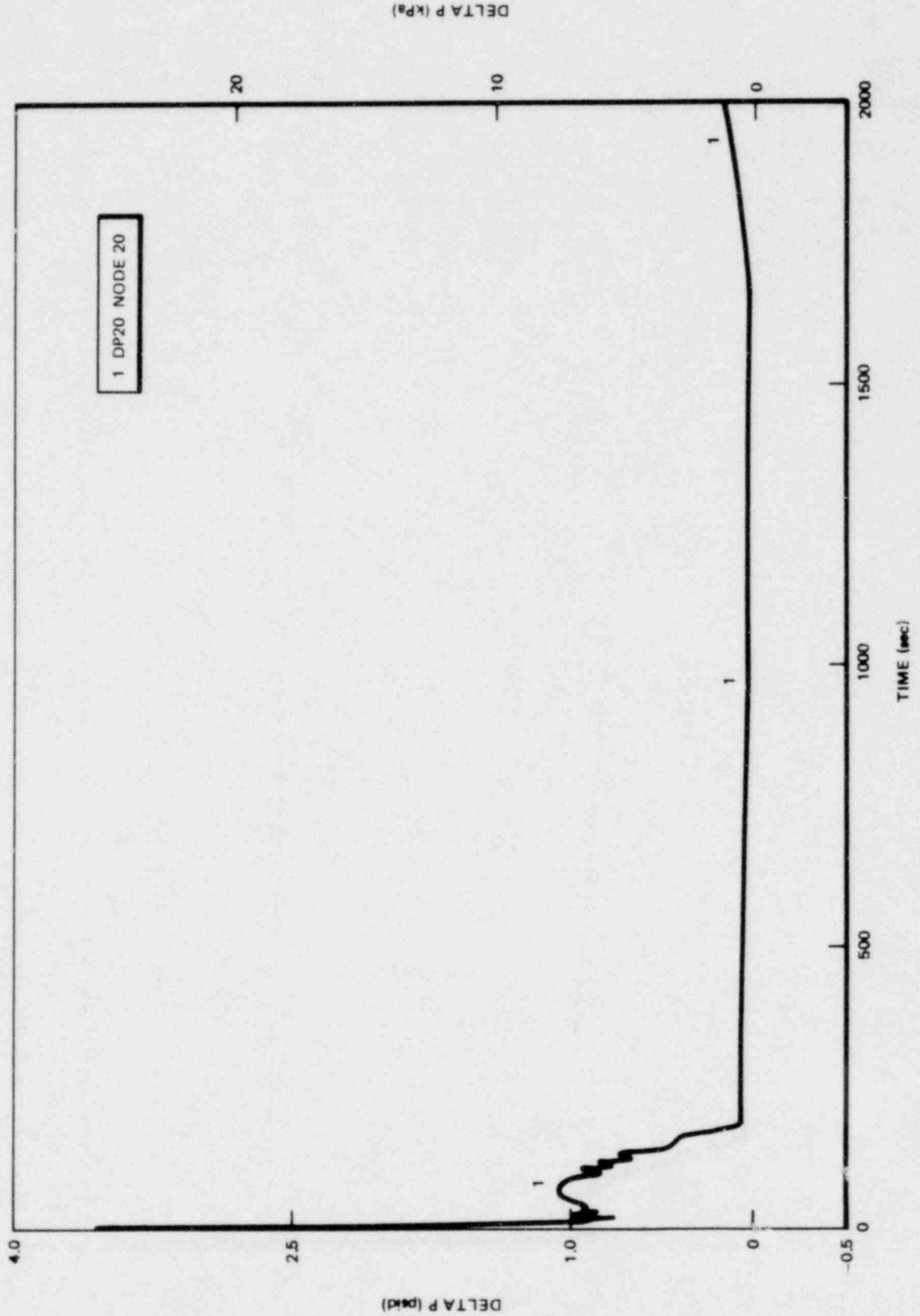


Figure F-25. Steam Separator DP

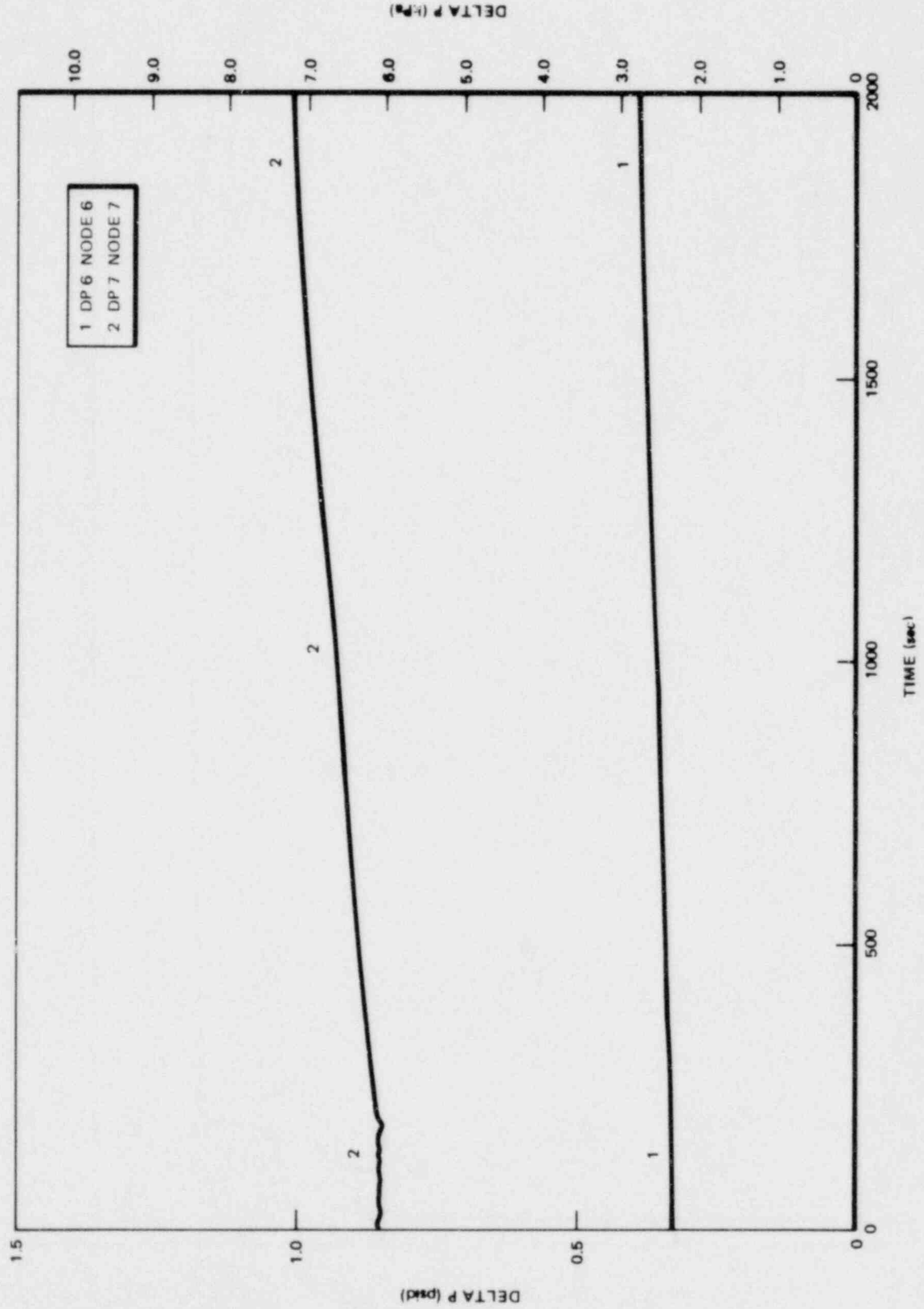


Figure F-26. Annulus DP's Bottom Nodes

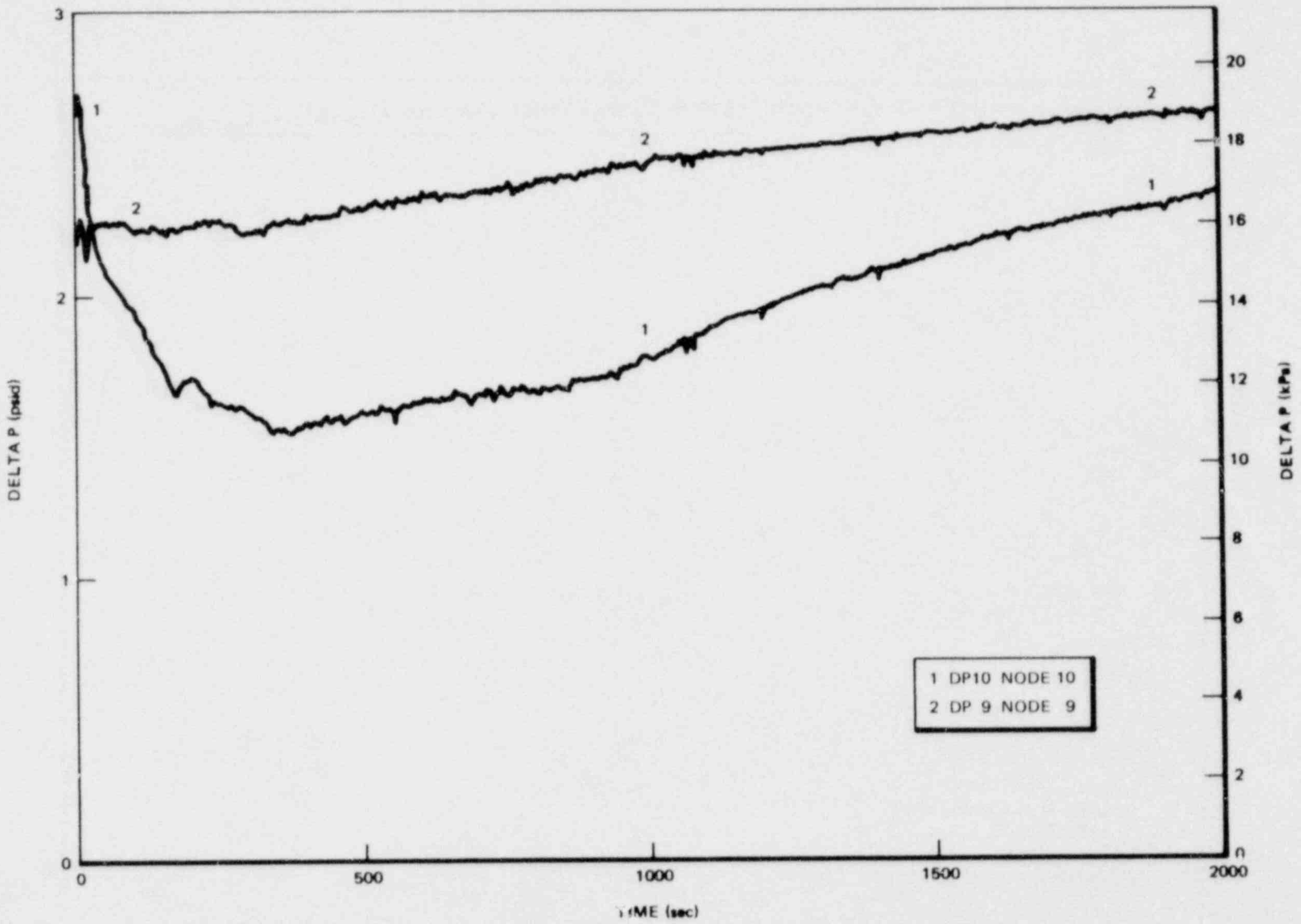


Figure F-27. Annulus DP's Upper Nodes

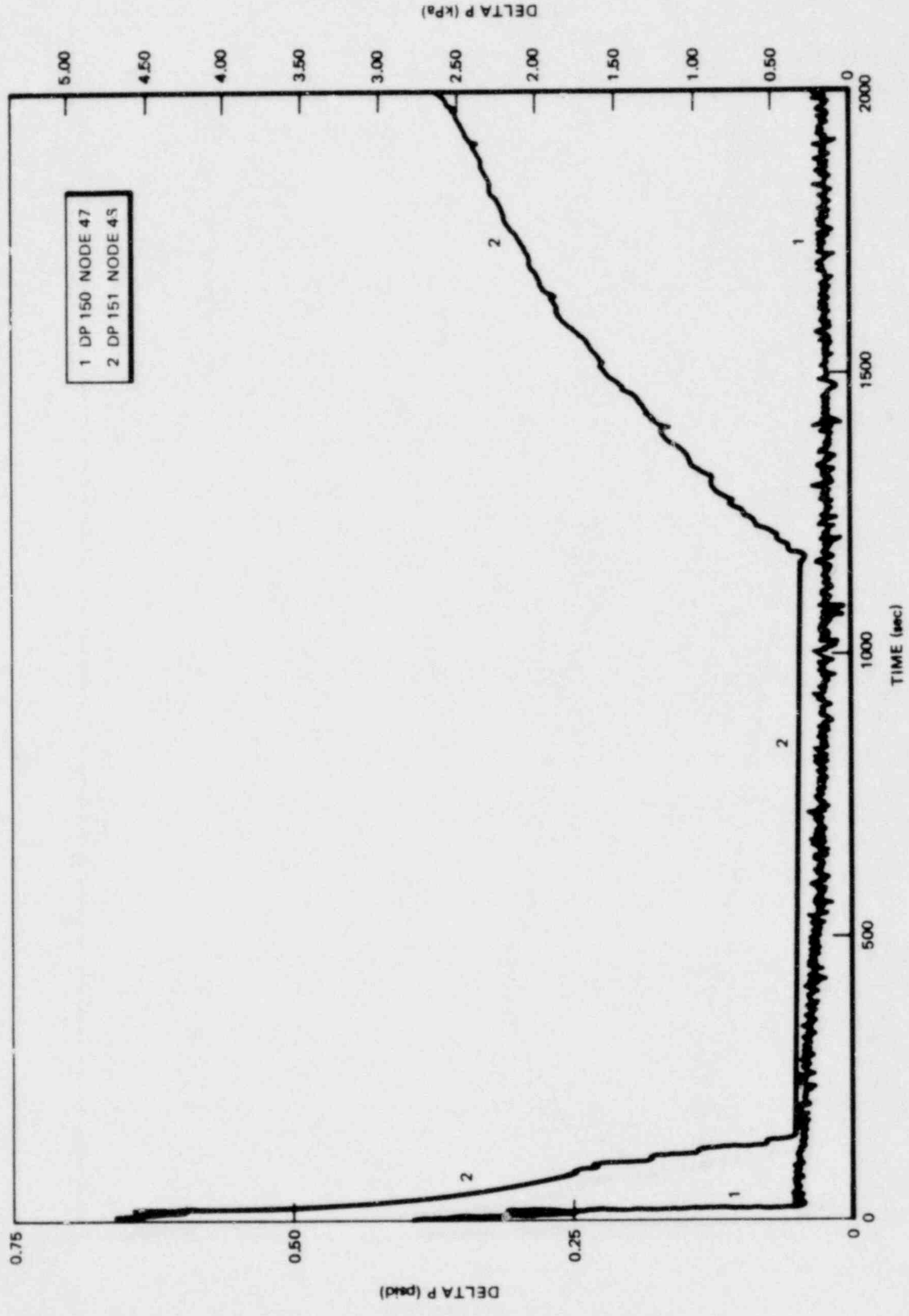


Figure F-28. *Annulus DP's Upper Nodes*

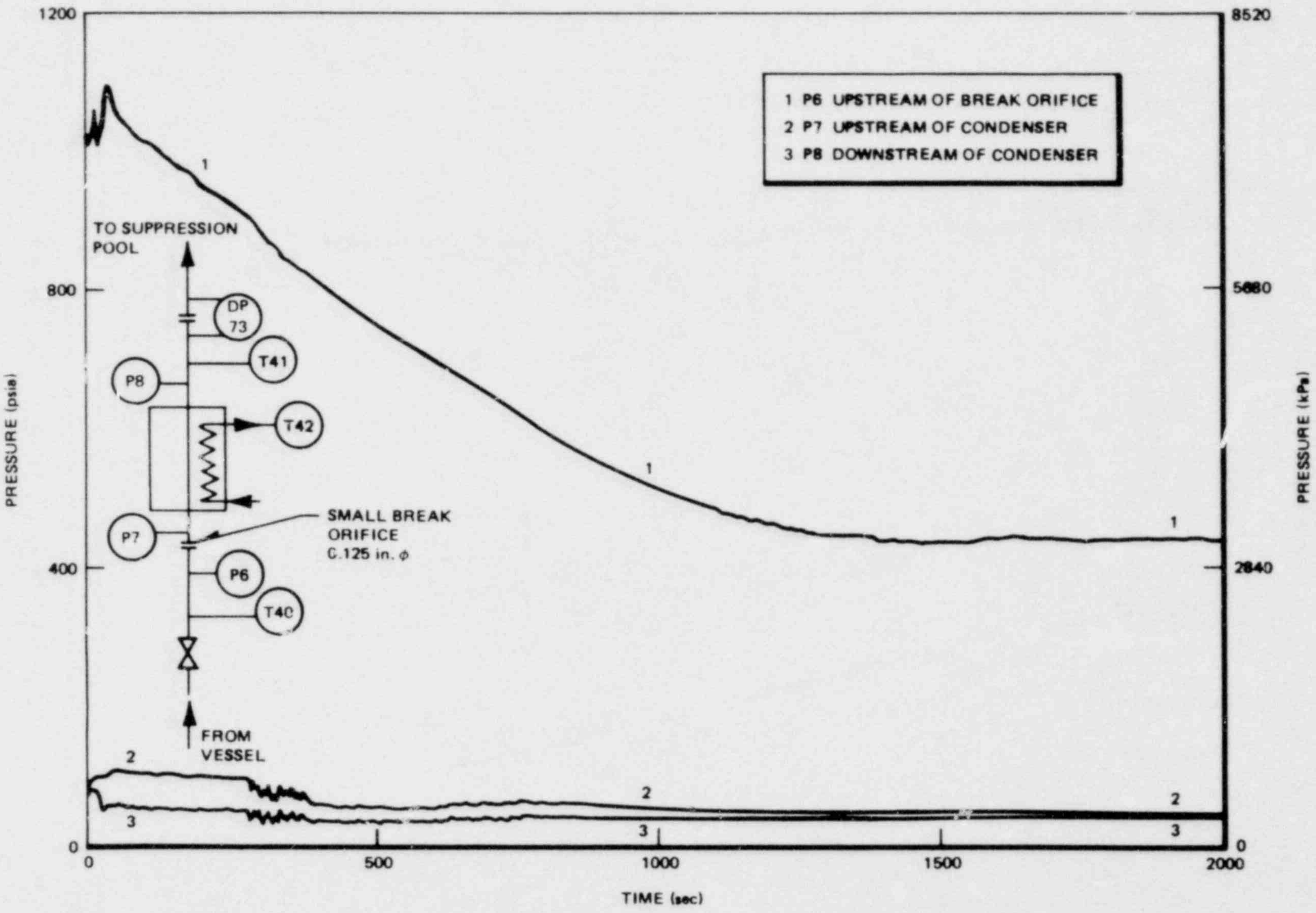


Figure F-29. Pressure Measurements at Vicinity of Small Break

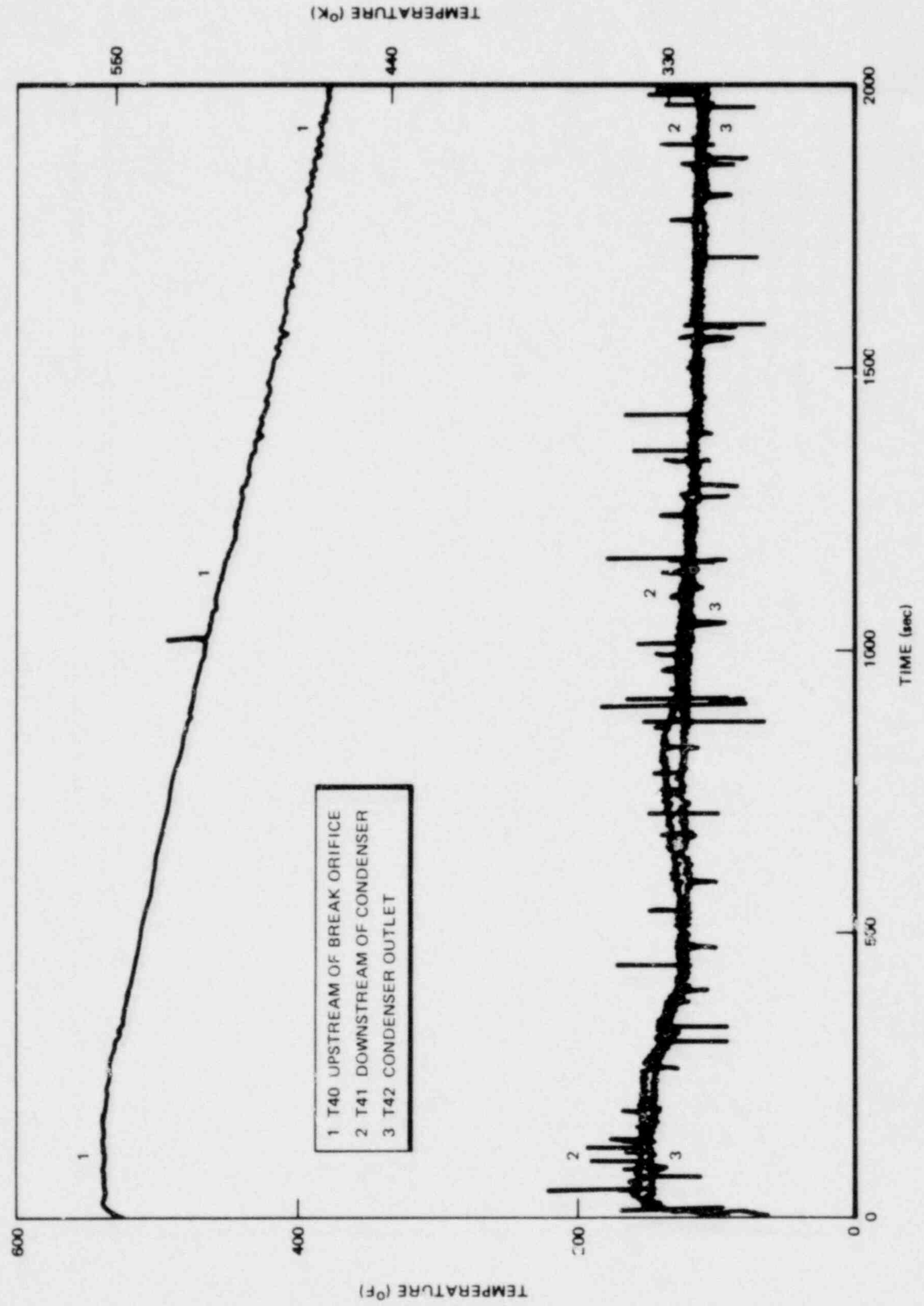


Figure F-30. Temporary Measurements at Vicinity of Small Break

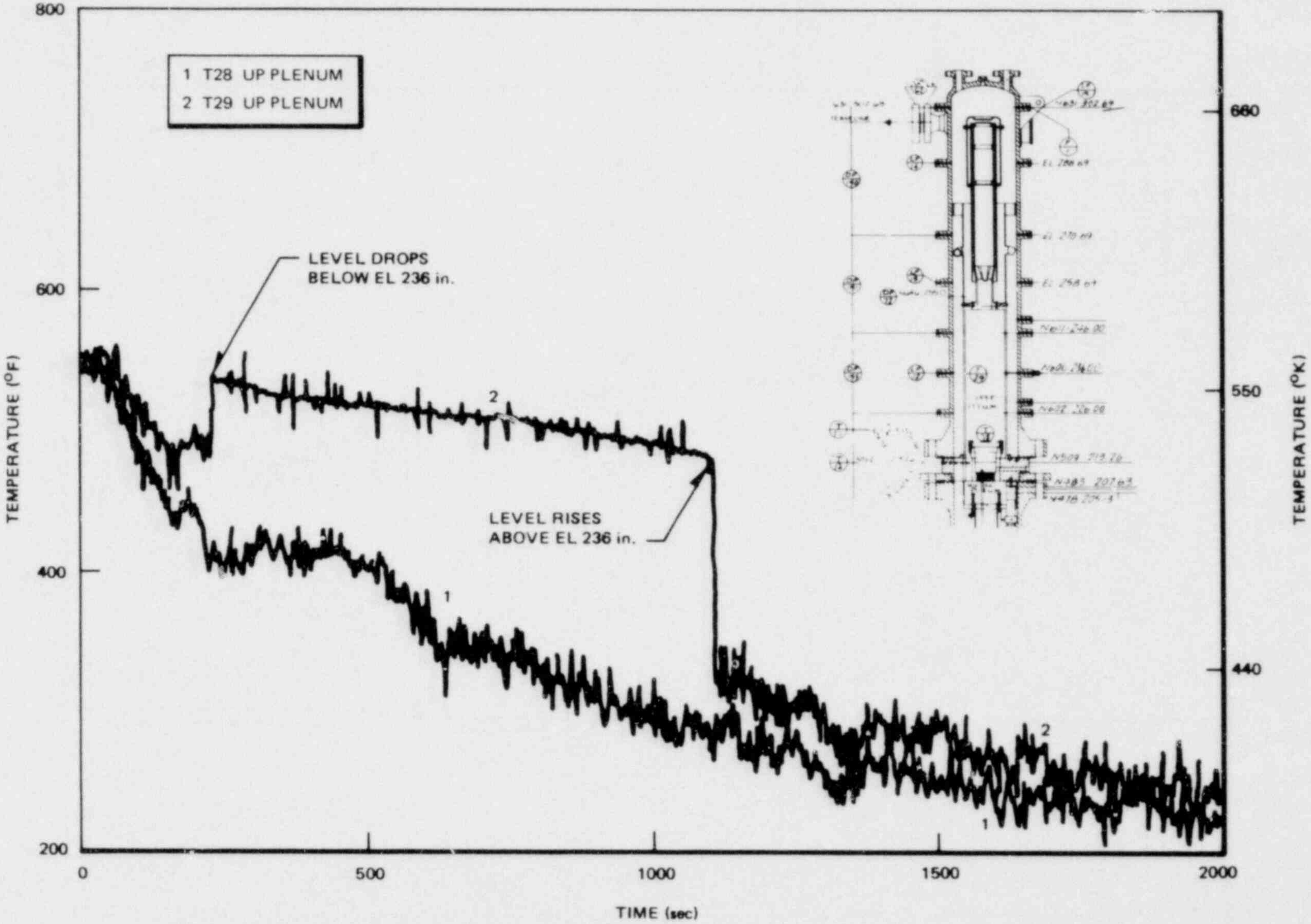


Figure F-31. Temperature Measurements at Upper Plenum

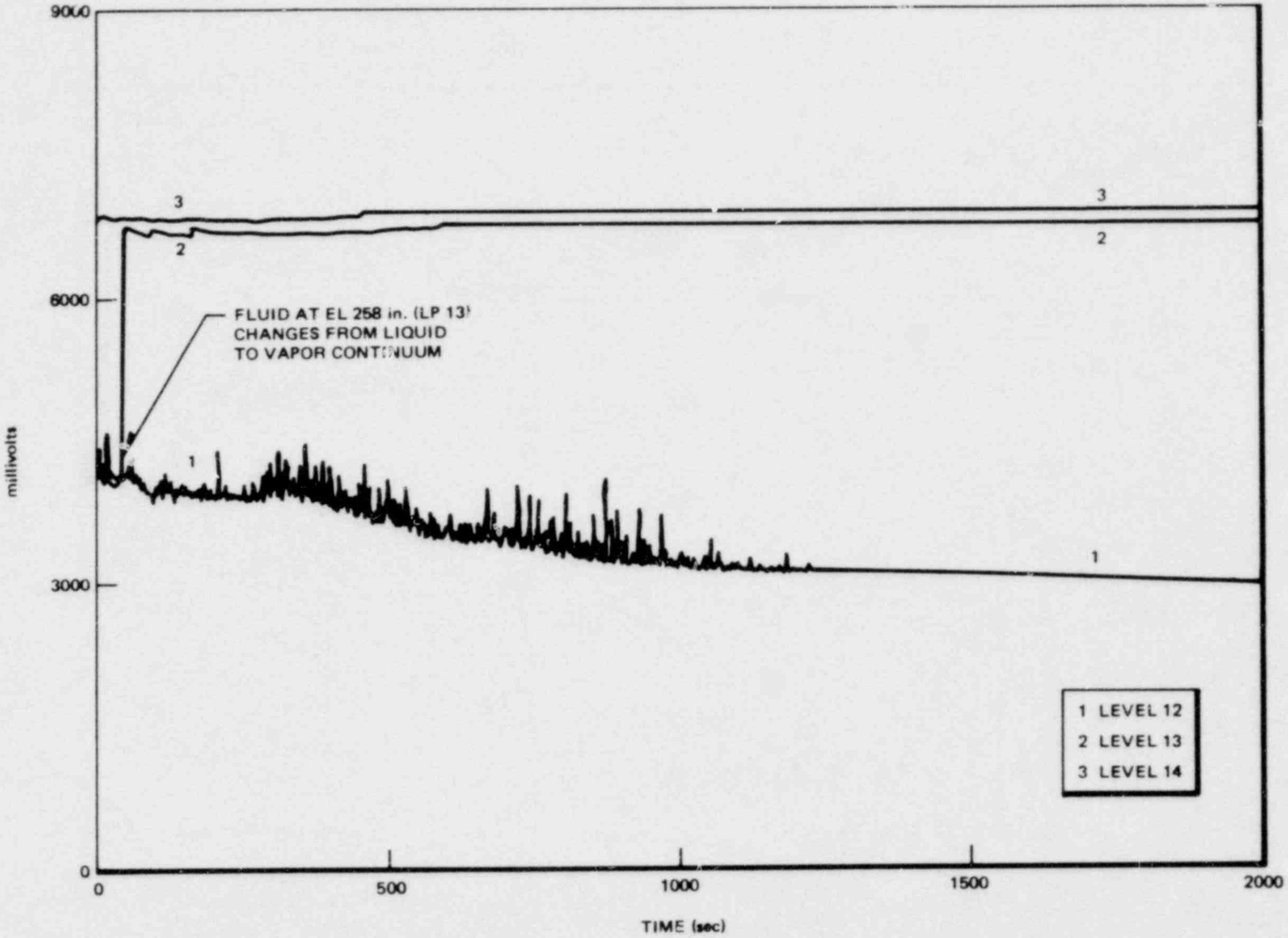


Figure F-32. Annulus Level Probe Measurements Upper Nodes

APPENDIX G

TLTA SMALL BREAK TEST NO. II

W. S. Hwang, May 1980

INTRODUCTION

The second small break test was conducted in the Two Loop Test Apparatus (TLTA). The objectives of the test were to investigate the thermal hydraulic performance of the TLTA with a small break under a degraded ECC systems condition and to provide a data base from which to judge the adequacy of the models and assumptions used in the BWR small break analysis method. Relevent background information related to the test can be found in Reference G-1. This report presents a summary of the test results.

TEST BASIS

The scaling basis for the facility and the test is the BWR/6-218. The current TLTA configuration is designated TLTA 5C (Figure G-1) and is described in detail in References G-2 and G-3.

TEST EXECUTION

The second small break test, 6432/R1, was conducted on 5 March 1980. The major initial conditions for the test were met (Table G-1). Based on the comparisons between measured and specified initial test conditions, this test was deemed acceptable.

TEST RESULTS

The system pressure response is shown in Figure G-2. In the early transient the steam line valve was used to automatically control the system pressure at about 970 psia as specified. Flow discharged through the steam line is shown in Figure G-3. The system pressure began to increase after the steamline closed completely at 166 seconds and then decreased rapidly due to the large steam discharge (Figure G-3) as ADS opened at 286 seconds. The depressurization led to LPCS and LPCI injections at about 435 seconds (Figures G-4 and G-5).

Figure G-6 shows the bundle power applied in the test. Mixture levels measured in various regions are shown in Figures G-7 and G-8. In the early transient, the upper plenum level remained near the top of the separator, while the annulus level response was governed mainly by the pressure transient and loss of mass inventory out of the break (Figure G-9). The level swell of both inside and outside levels beyond 286 seconds was due to the rapid depressurization as ADS was activated. It can be seen that shortly after ECC injection began the levels began to increase, indicating mass accumulation in the system (Figures G-10 through G-16).

A mixture level was observed in the lower plenum and bypass after ADS activated (Figure G-7), even though the bundle was full of two-phase mixture. Figure G-17 shows the fluid density in the bundle. The steam generation that accompanied the large depressurization from ADS initiation led to the occurance of counter current flow limiting (CCFL) at the side entry orifice (SEO) and the top of the bypass. Figure G-18 shows the density distribution in the lower plenum and clearly shows that the two-phase mixture level was well below the core inlet. The density in the bypass (Figure G-19) shows that node 14 was only partially filled during the period of 286 to about 465 seconds. The CCFL at the SEO prevented the bundle mass inventory (Figure G-12) from draining into the lower plenum (Figure G-13) and contributed to the cooling in the bundle. This effect is clearly seen in Figures G-20 and G-21 which show no bundle heatup with the rod cladding remaining well cooled throughout the transient.

The accumulation of subcooled ECC fluid in the bypass and eventually in the core region led to significant subcooling of the fluid in the bundle as indicated by the subcooled fluid density (Figure G-17) and the subcooled temperature (Figures G-20 and G-21) measured on the bundle cladding at ~600 seconds.

CONCLUSION

The second small break test was conducted successfully in the TLTA. The test procedure and approach developed to overcome scaling compromises and facility limitation proved to be adequate.

The test results indicate the CCFL at the side entry orifice at the bundle inlet affects the system behavior particularily after ADS is activated. This CCFL prevents the bundle mass from draining into the lower plenum and hence improves cooling in the bundle. No rod heat-up has been observed during the entire test.

REFERENCES

G-1. Letter, R. H. Buchholz (GE) to T. D. Keenan (BWR Owner's Group) and D. F. Ross (NRC), *Verification of Small Break Analysis Model*, November 30, 1979.

G-2. G. W. Burnette to W. D. Beckner (NRC) and P. Kalra(EPRI), *Basis and Conditions for TLTA Small Break Test No. 2*, February 15, 1980.

G-3. W. J. Letzring et al., *BWR BD/ECC Program Preliminary Facility Description Report*, December 1977, GEAP-23592.

G-4. *BWR BD/ECC Program, Contract No. NRC-04-76-215, Informal Monthly Progress Report for June 1979*, Transmittal, G. W. Burnette (GE) to E. L. Halman (NRC) and C. W. Sullivan (NRC), July 1979.

Table G-1
COMPARISON OF TEST CONDITIONS

(TLTA Small Break Test No. II)

	Specified	Measured
Break Size		
Line No. 1	0.125 ± 0.001 in. diameter	0.125 ± 0.001 in. diameter
Line No. 2	0.153 ± 0.001 in. diameter	0.153 ± 0.001 in. diameter
ADS Orifice Size	0.677 ± 0.001 in. diameter	0.677 ± 0.001 in. diameter
ECCS		
Inlet Fluid Temperature	80 ± 15°F	90°F
HPCS	HPCS deactivated	deactivated
LPCS	activated	activated
LPCI	activated	activated
Initial Condition		
Steam Dome Pressure	1050 ± 20 psia	1048 psia
Water Level (Outside Shroud)	283 ± 6 in. EL	283 in. EL
Bundle Flow (Core Flow)	34 ± 5 lbm/sec	34 lbm/sec
Bypass Flow, Total	1.5 ± 0.5 lbm/sec	2.1 lbm/sec
Steam Flow	1.4 ± 0.5 lbm/sec	1.6 lbm/sec
Bundle Inlet Subcooling	23 ± 5°F	21°F
Downcomer Temperature		
Above F. W. Sparger	T sat	553°F
Below F. W. Sparger	(T sat − 23°F) ± 5°F	532°F
Timings		
Pump No. 1 Trip	0.0 ± 0.2 sec	0.0 sec
Pump No. 2 Trip	4.0 ± 1.0 sec	4.0 sec
Feed Water Trip	0.0 ± 0.5 sec	0.1 sec
Break Open Line No. 1	t ⩾ 140 sec ± 1 sec	t ⩾ 138 sec
Break Open Line No. 2	140 ⩽ t ⩽ 286 sec	138 ⩽ t ⩽ 286 sec
ADS Opening	286 ± 2 sec	286 sec
MSIV (Steam Valve) Closure	166 ± 2 sec	165 sec
ECCS Activated	37 ± 1 sec	37 sec
Intact Recirculation Loop (No. 1) Isolated	20 ± 1 sec	20 sec

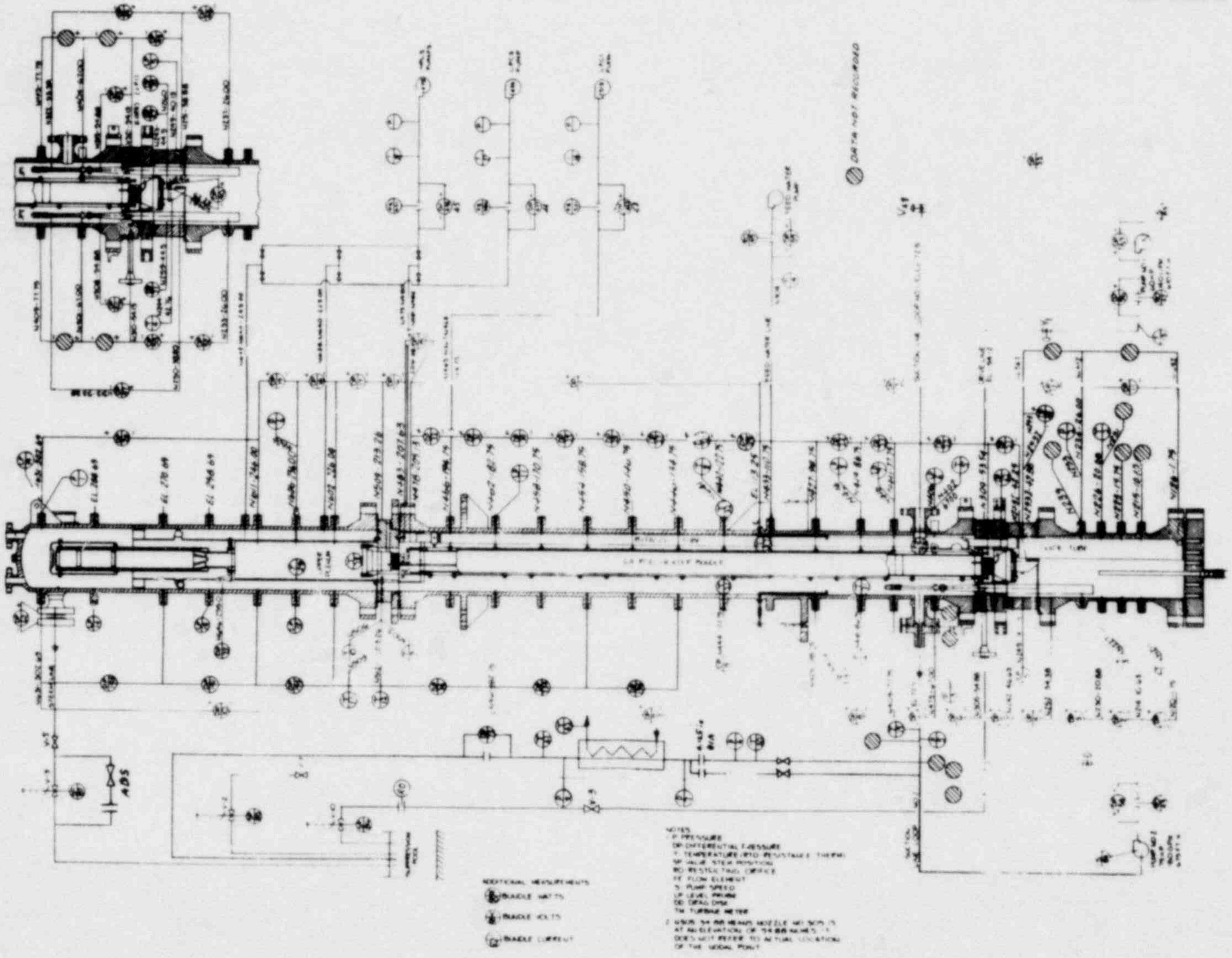


Figure G-1. Primary Measurements — Measurement Nodes for TLTA 5C

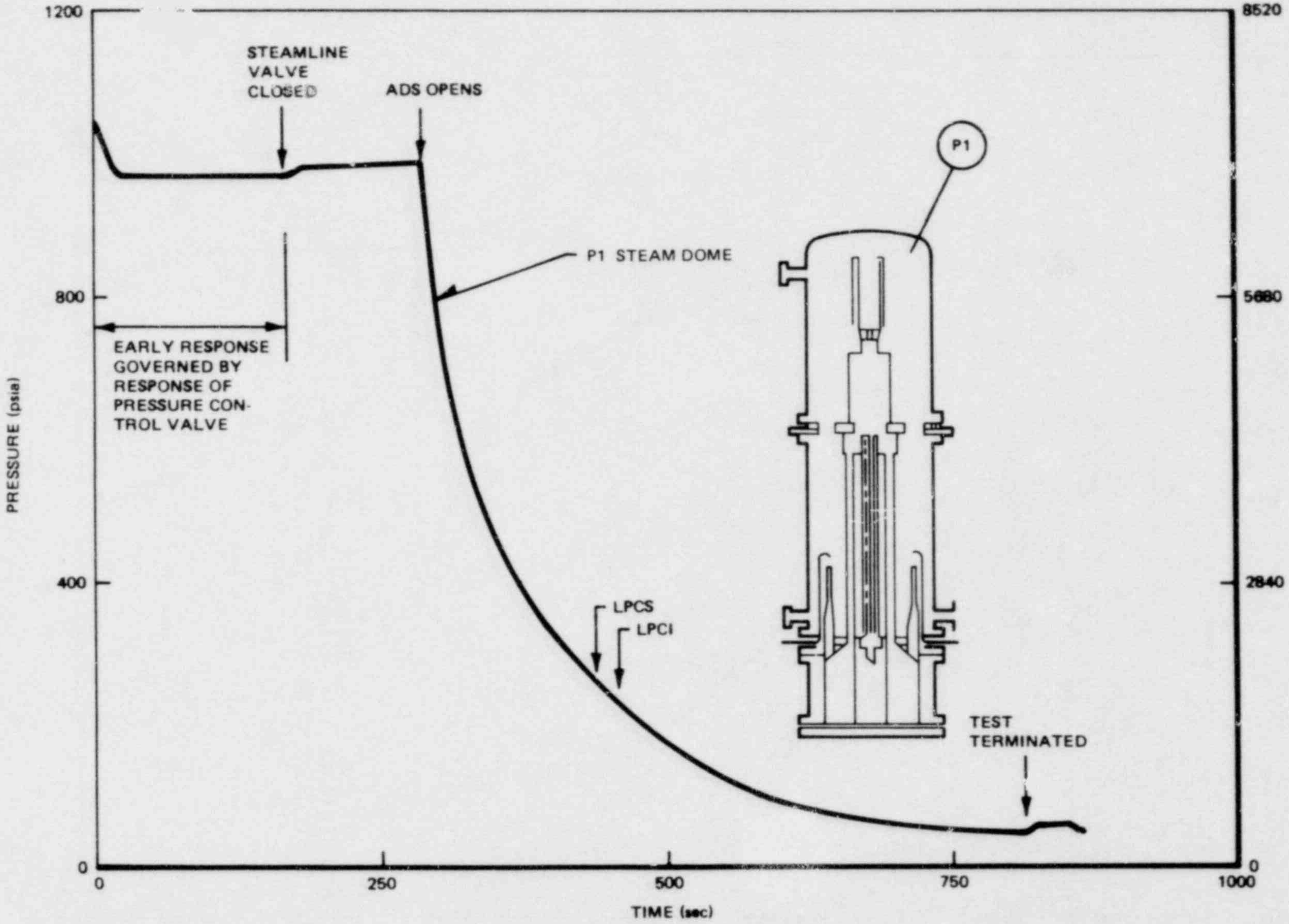


Figure G-2. System Pressure

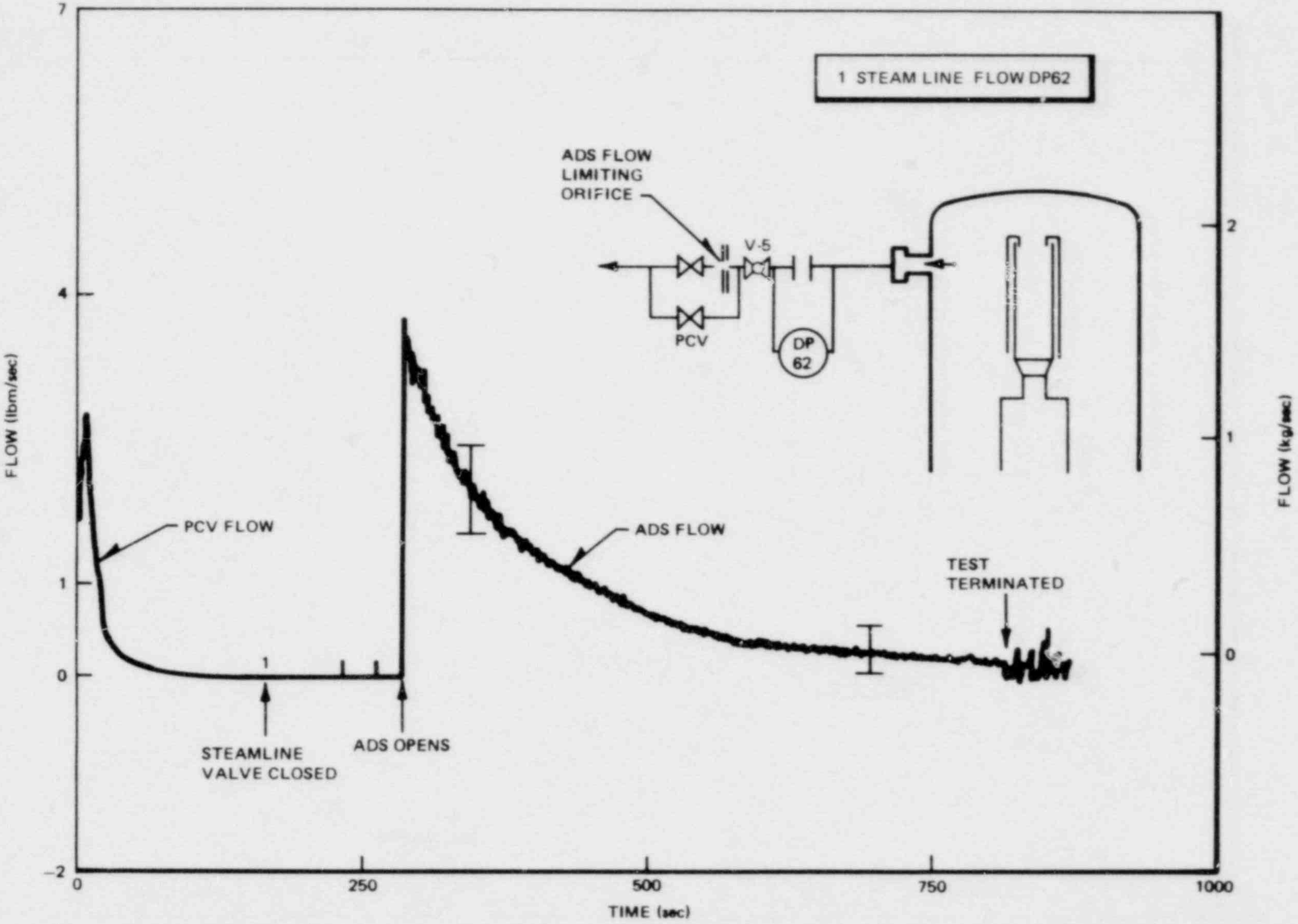


Figure G-3. Steam Line Flow

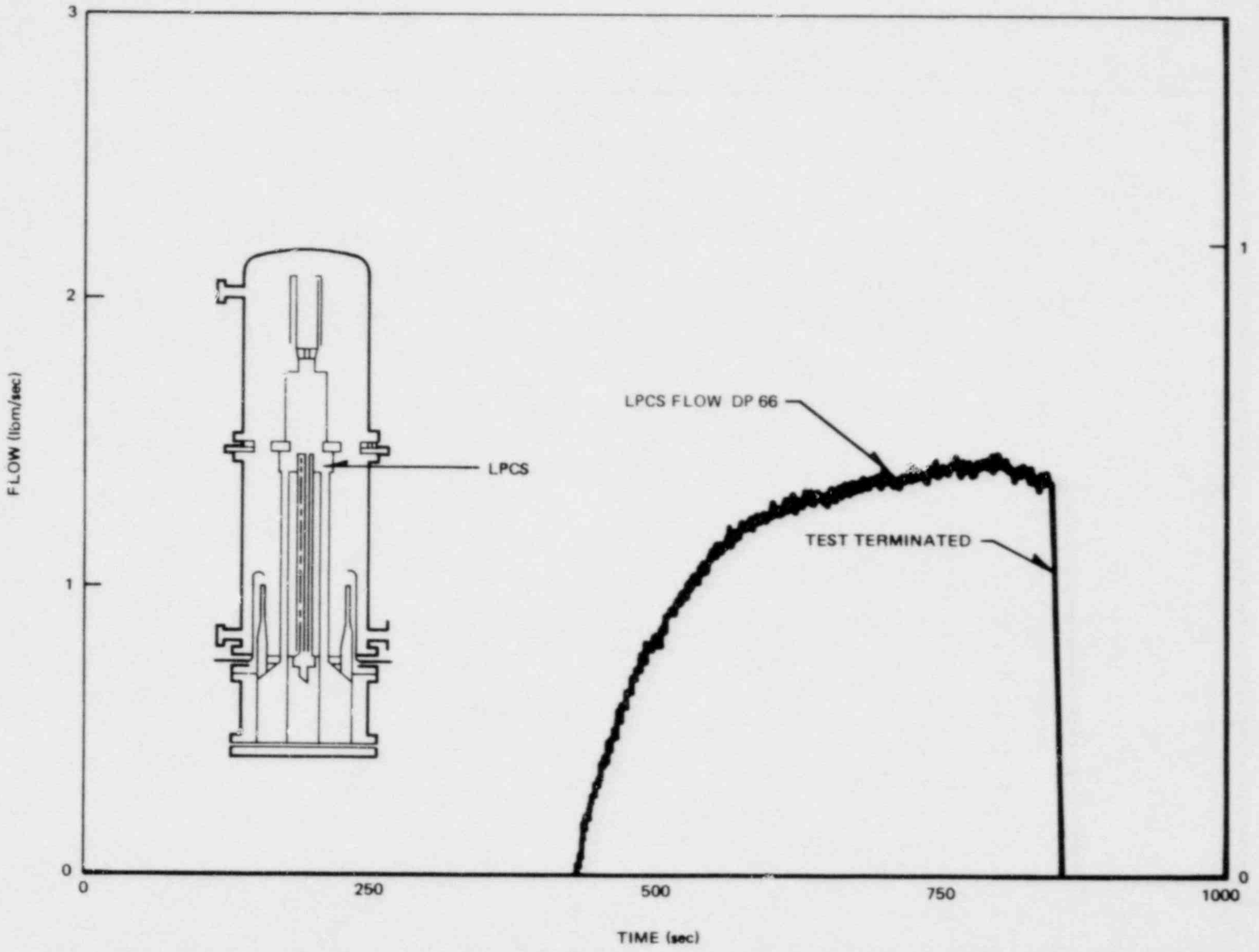


Figure G-4. LPCS Flow

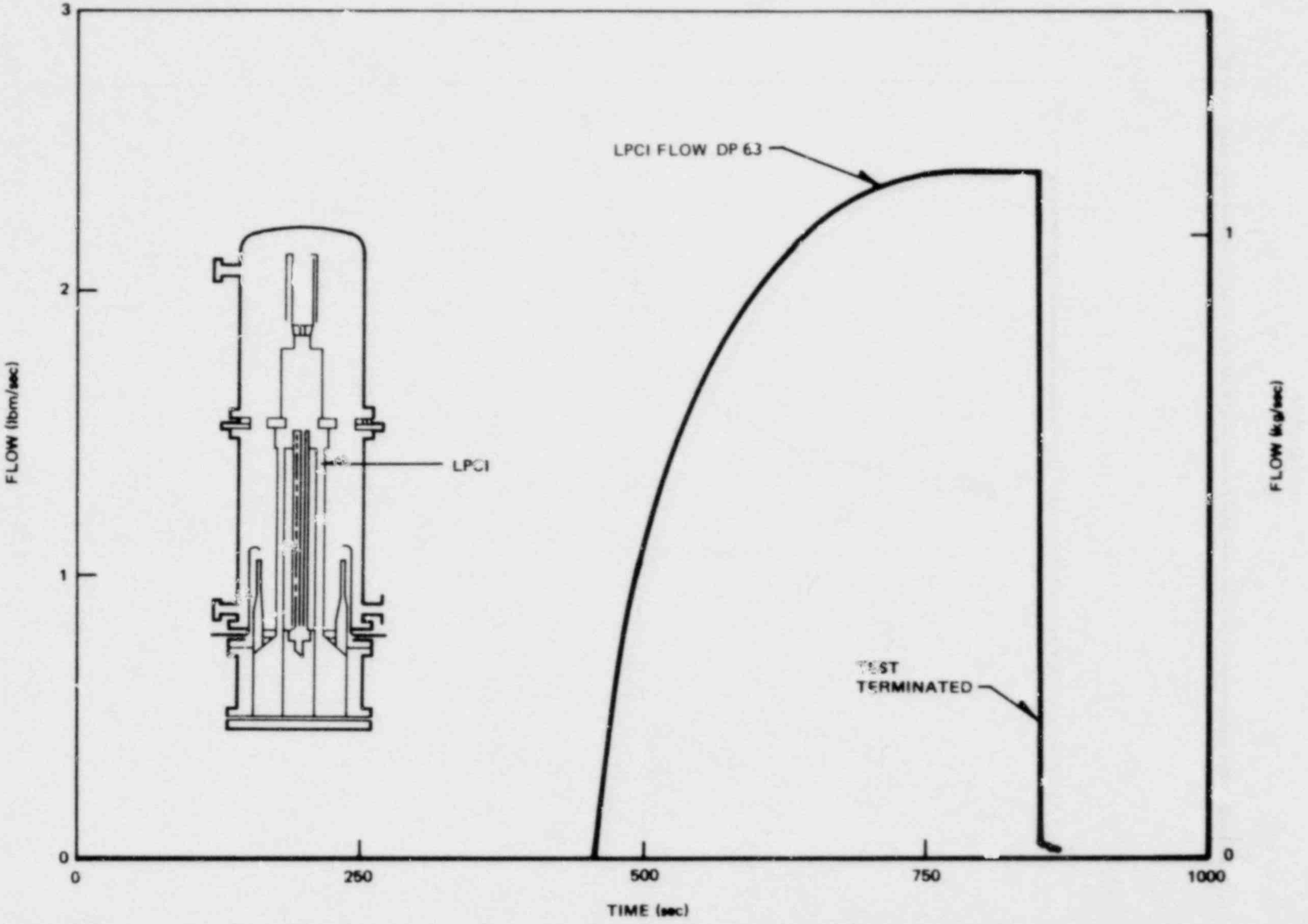


Figure G-5. LPCI Flow

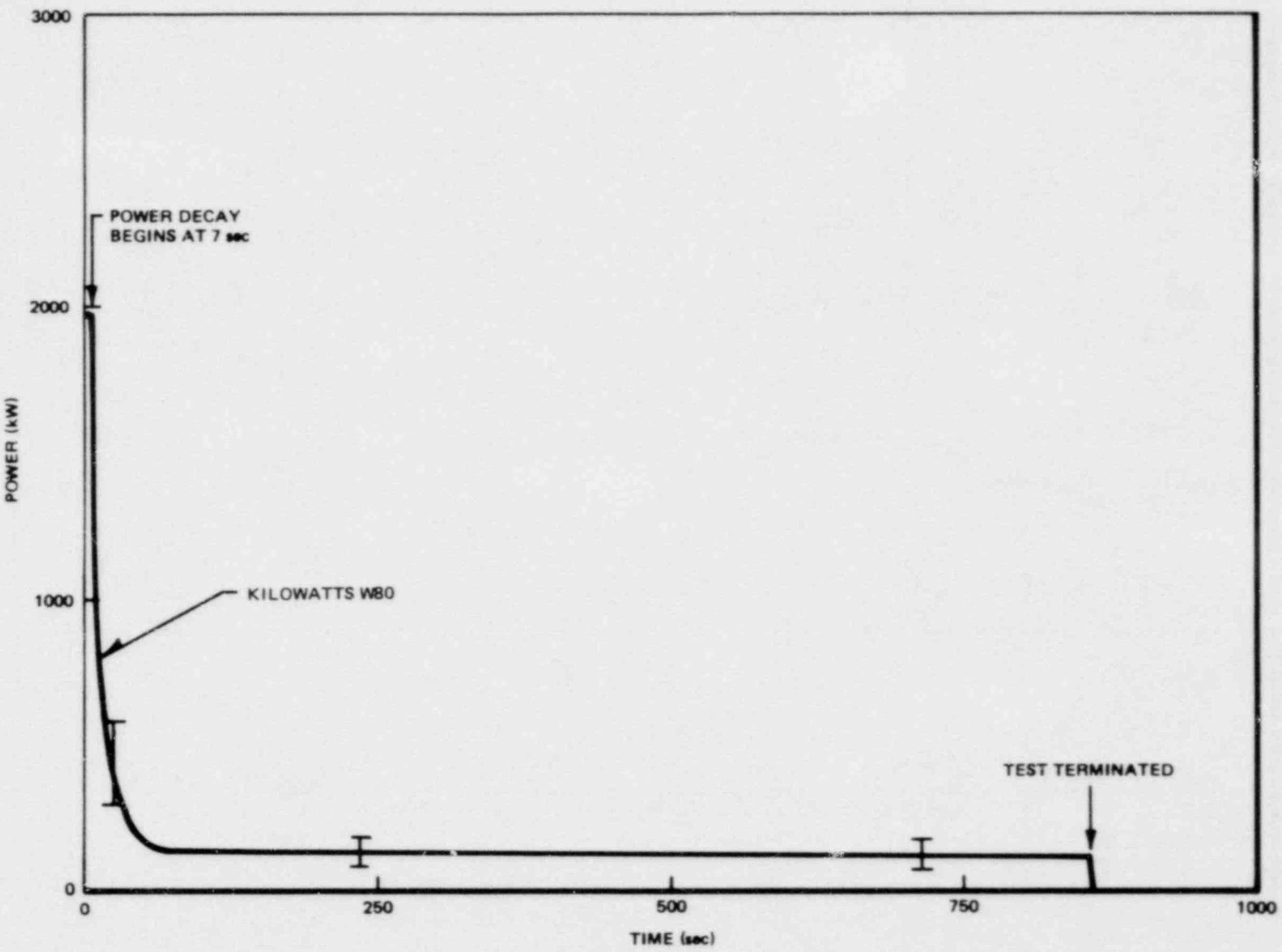


Figure G-6. Bundle Power

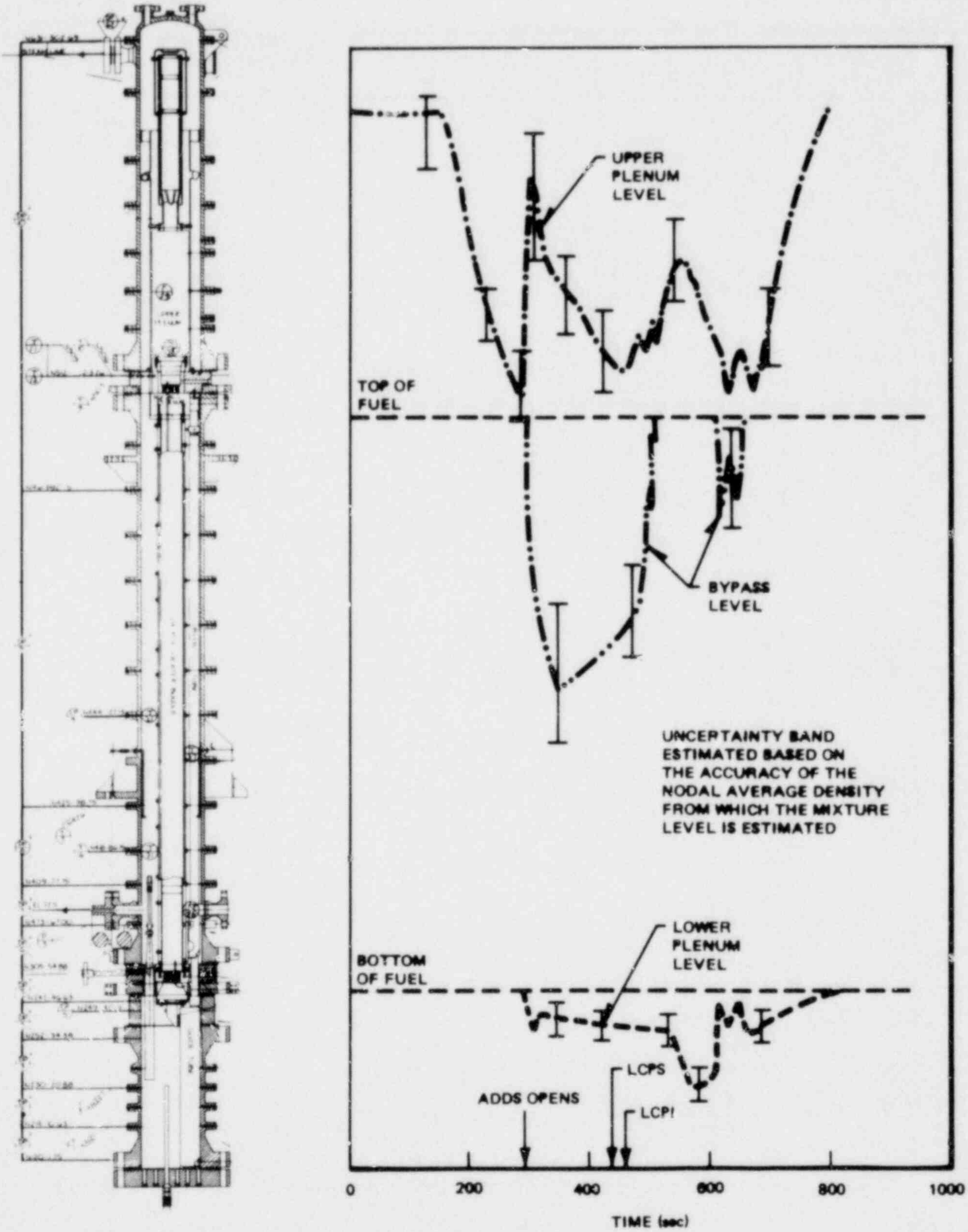
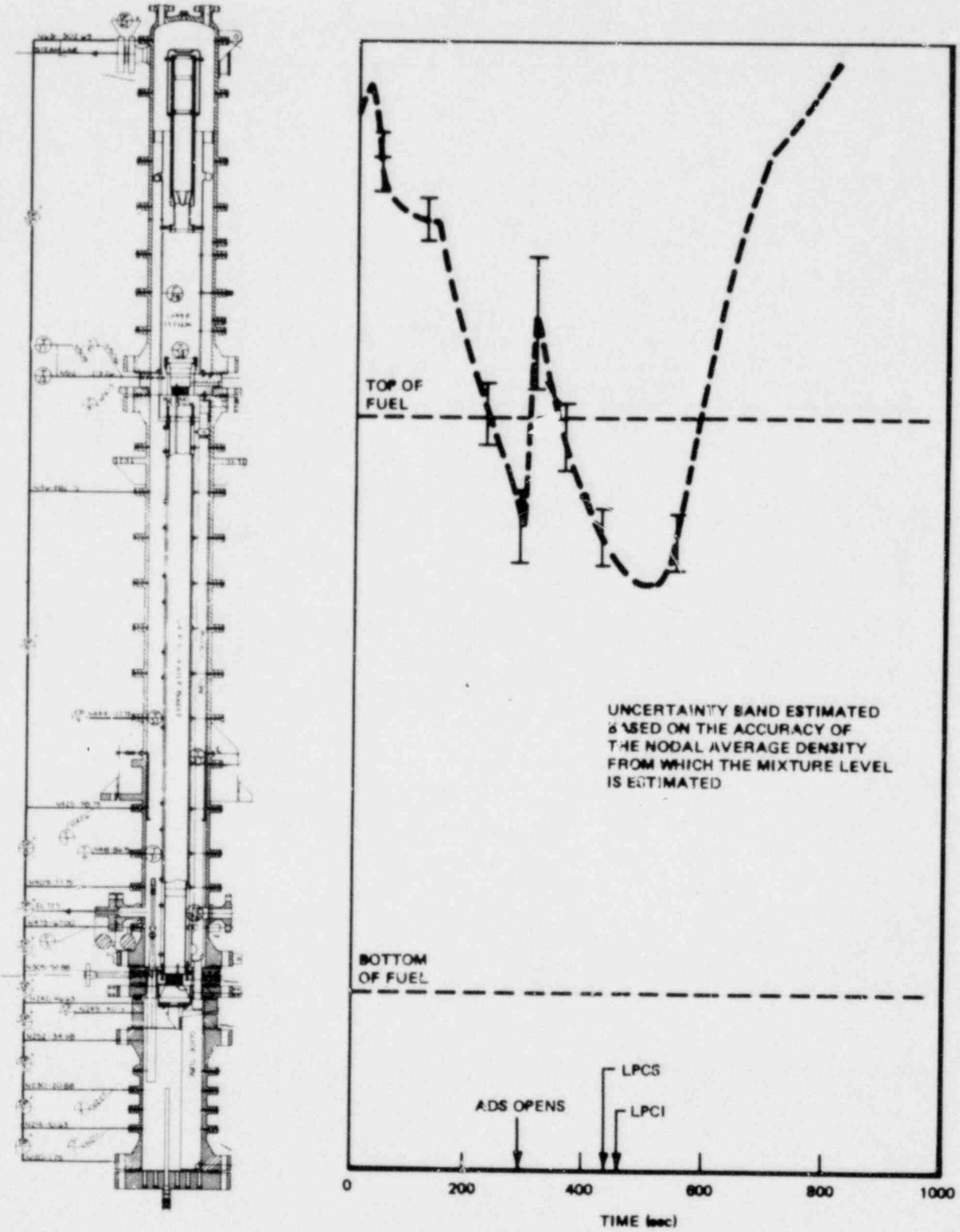


Figure G-7. Two-Phase Mixture Level — Inside the Shroud



UNCERTAINTY BAND ESTIMATED BASED ON THE ACCURACY OF THE NODAL AVERAGE DENSITY FROM WHICH THE MIXTURE LEVEL IS ESTIMATED

Figure G-8. Two-Phase Mixture Level — Outside the Shroud

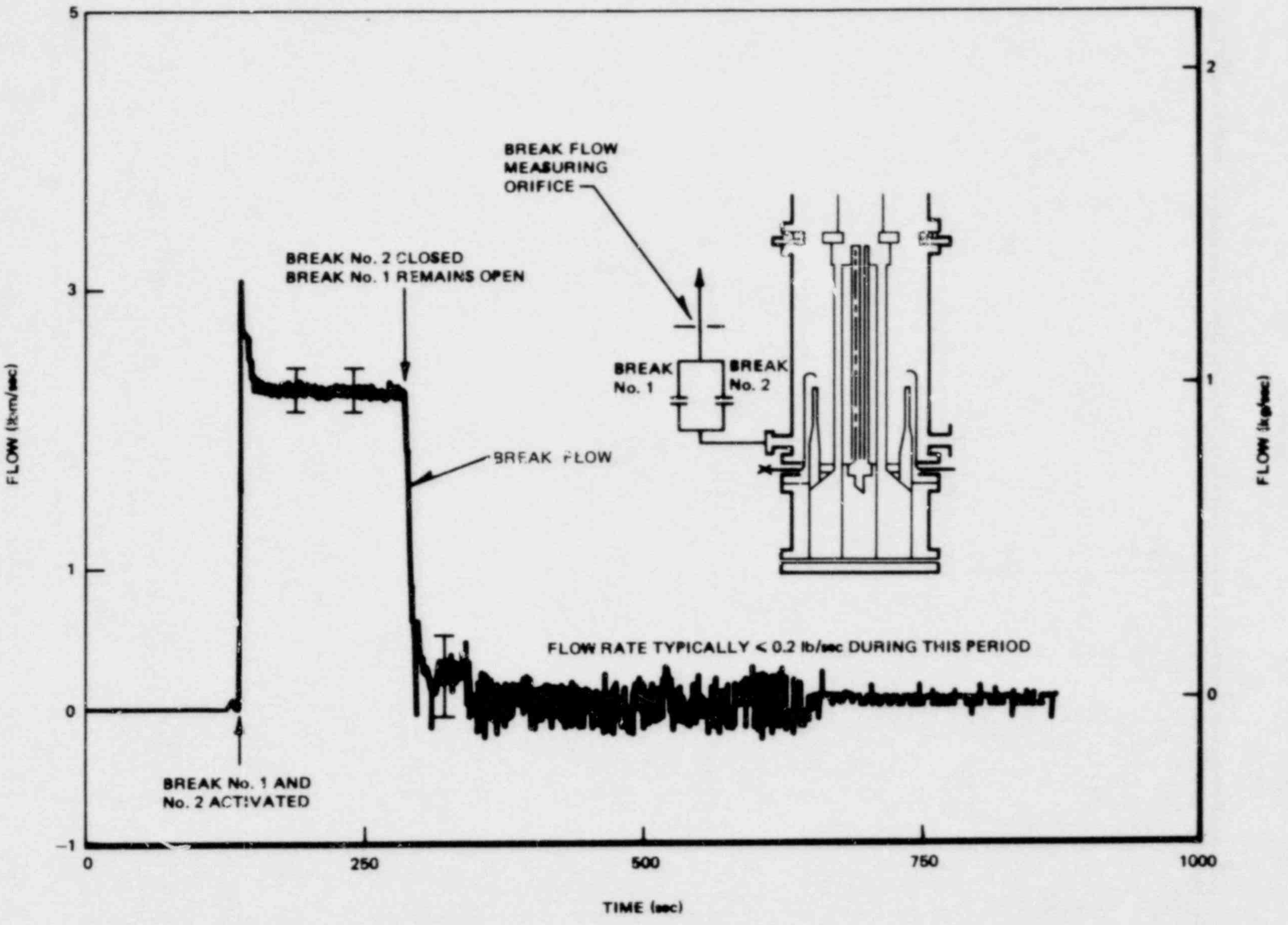


Figure G-9. Break Flow

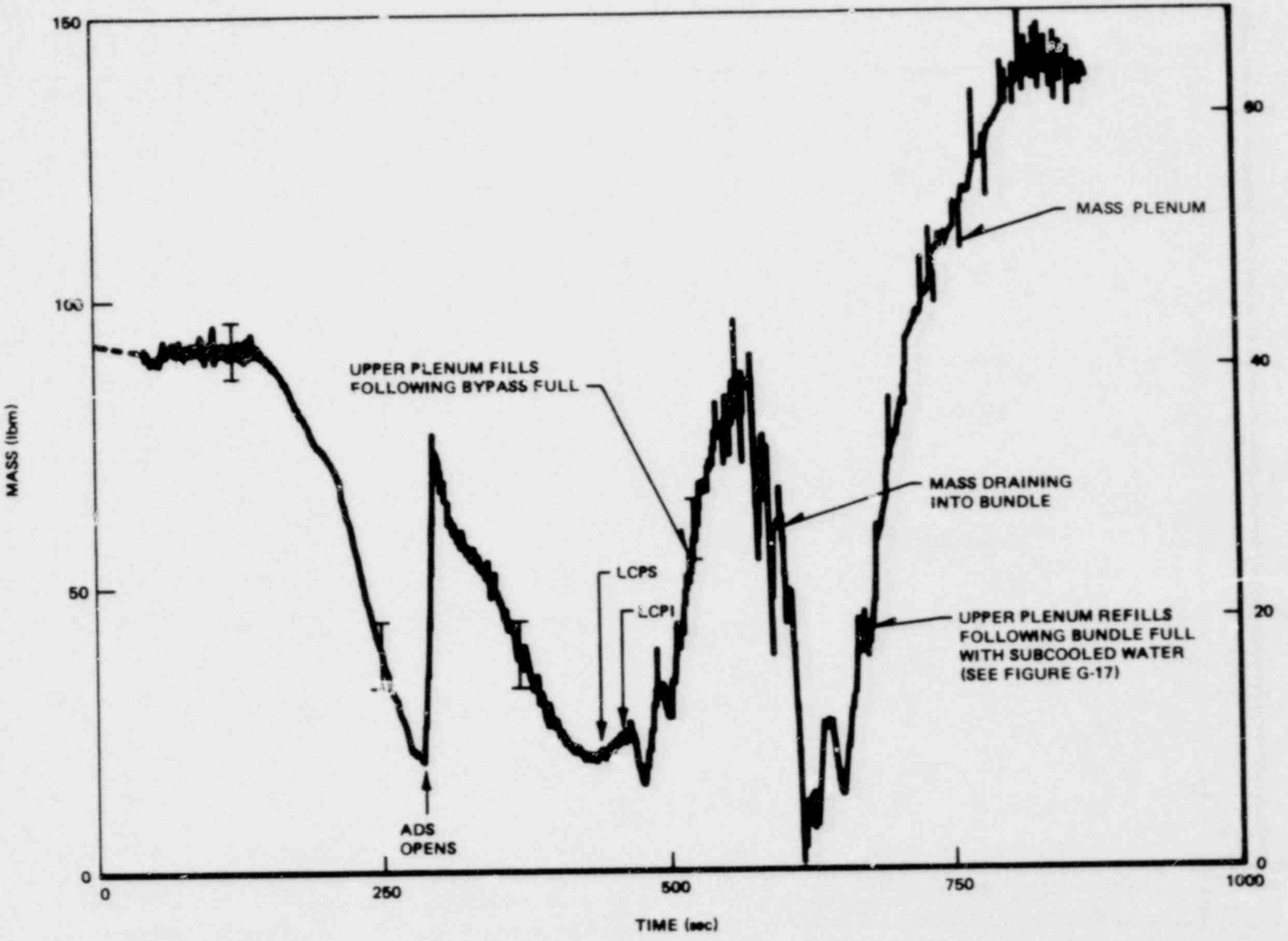


Figure G-10. Upper Plenum Mass

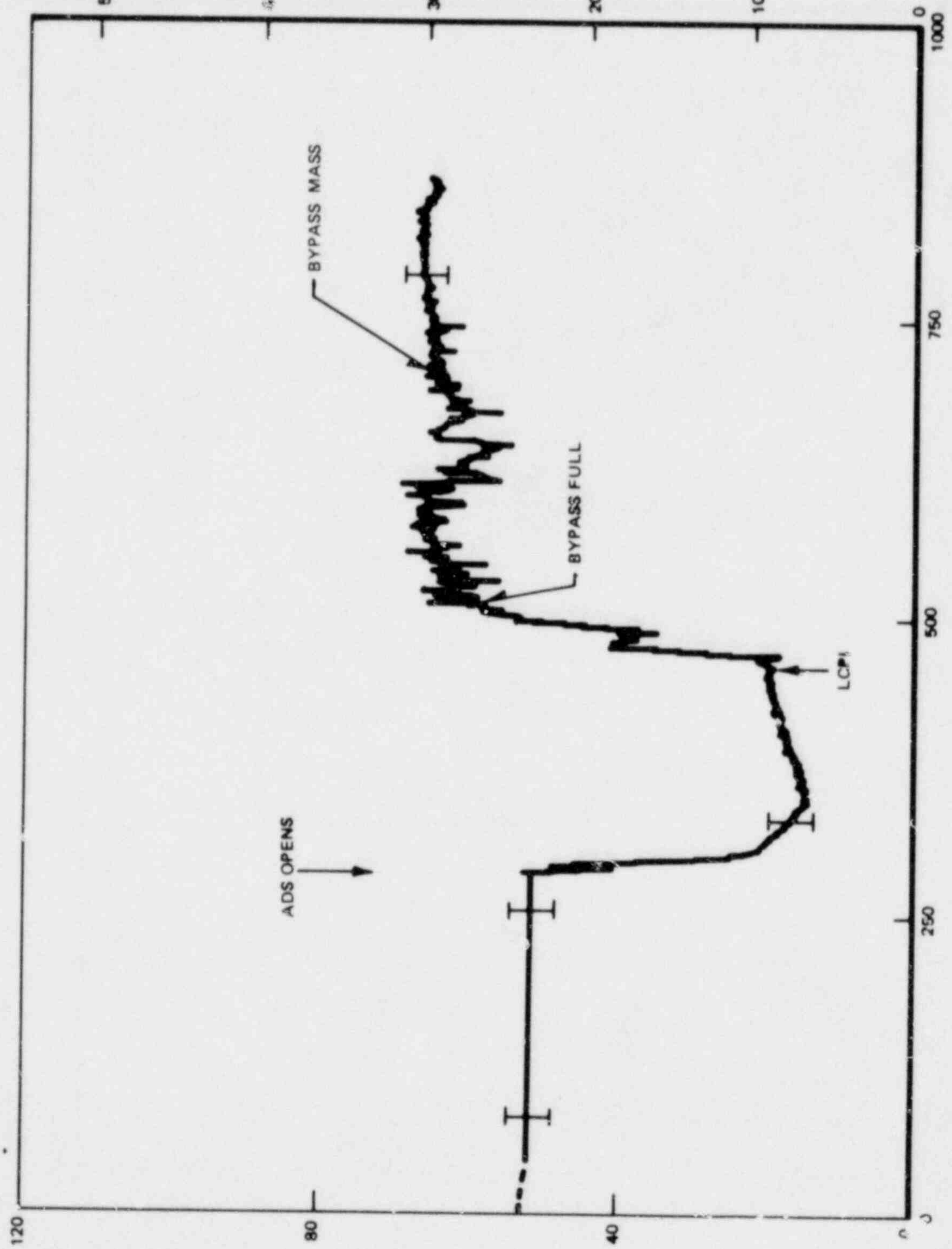


Figure G-11. Bypass Mass

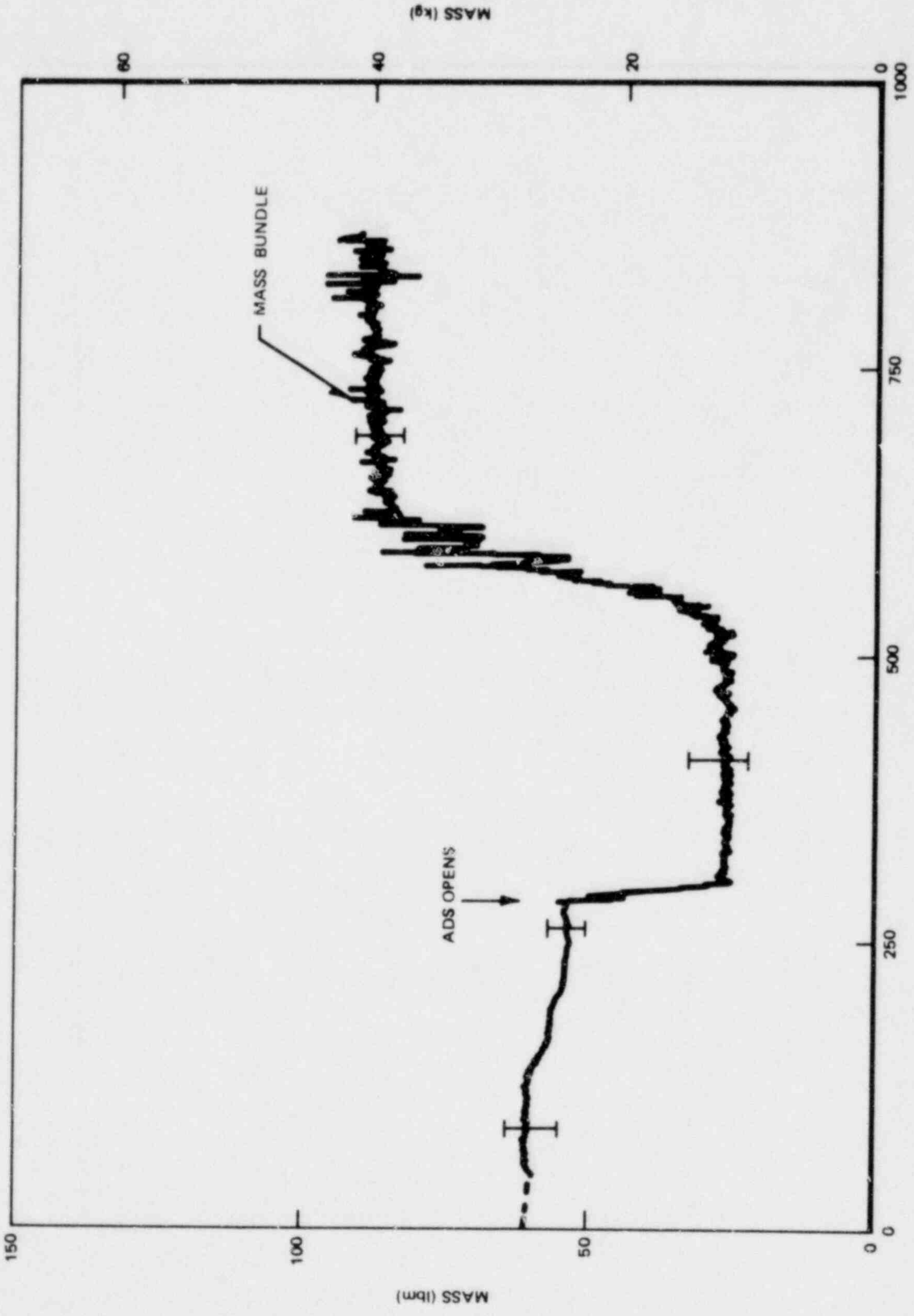


Figure G-12. Bundle Mass

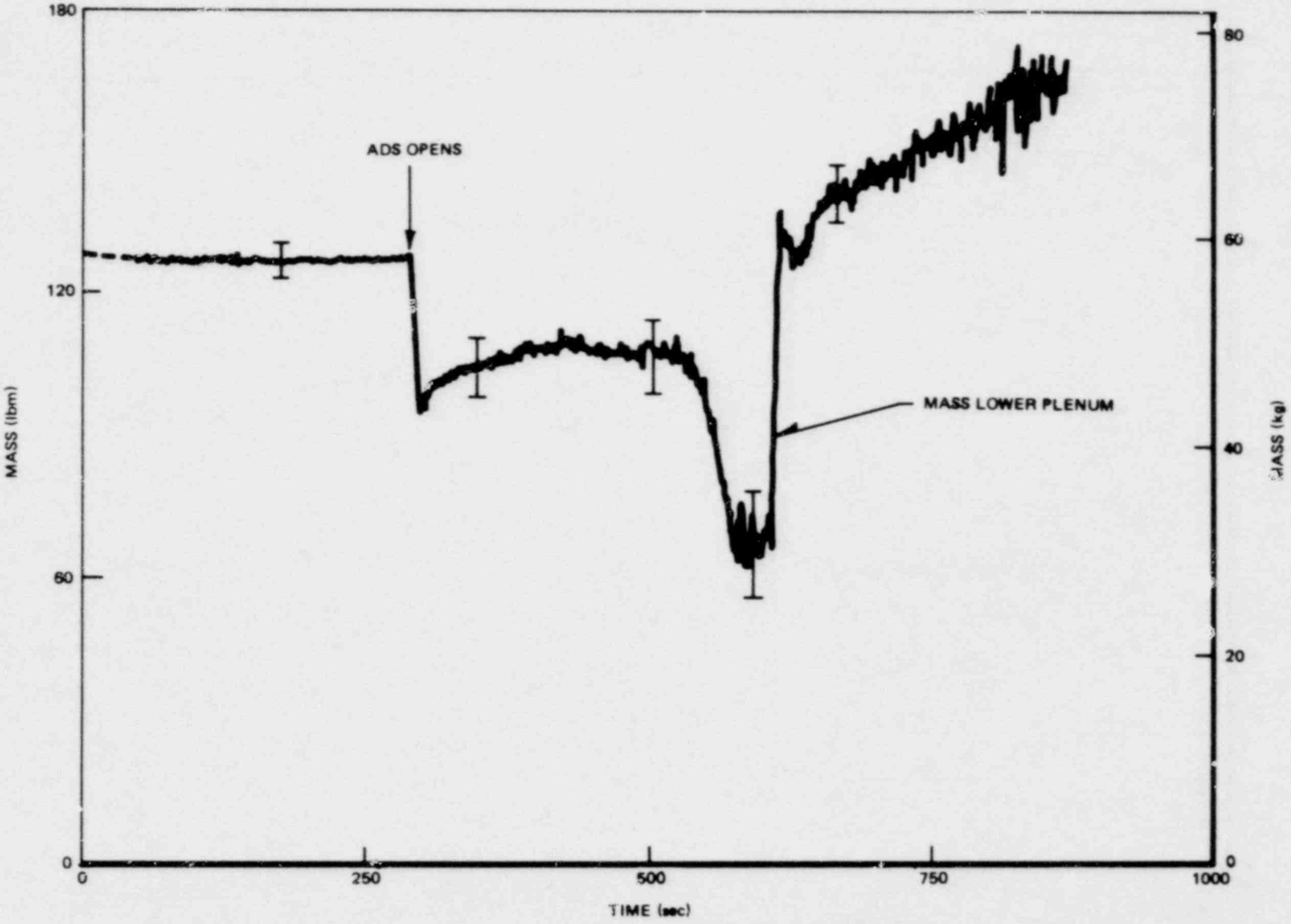


Figure G-13. Lower Plenum Mass

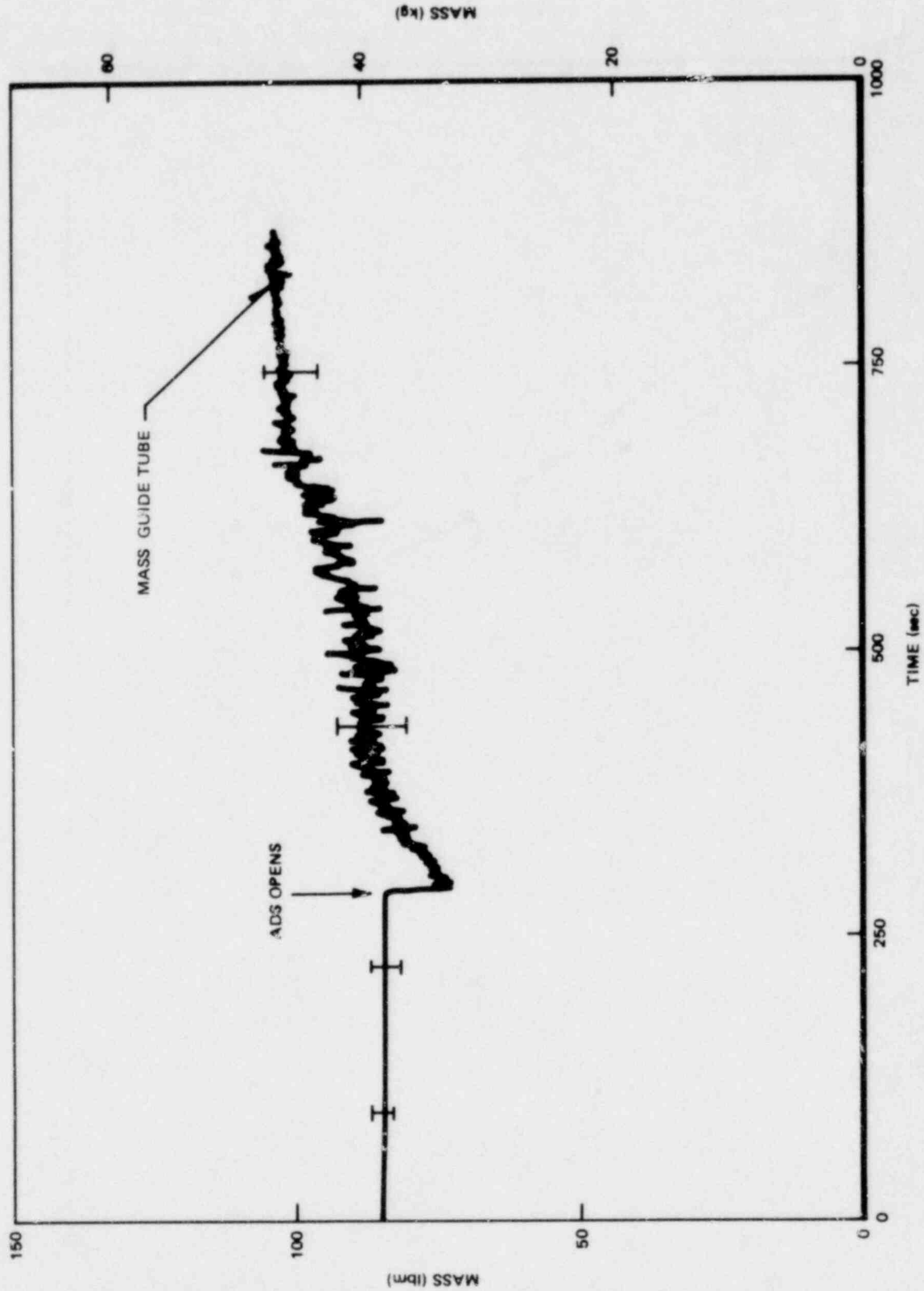


Figure G-14. Guide Tube Mass

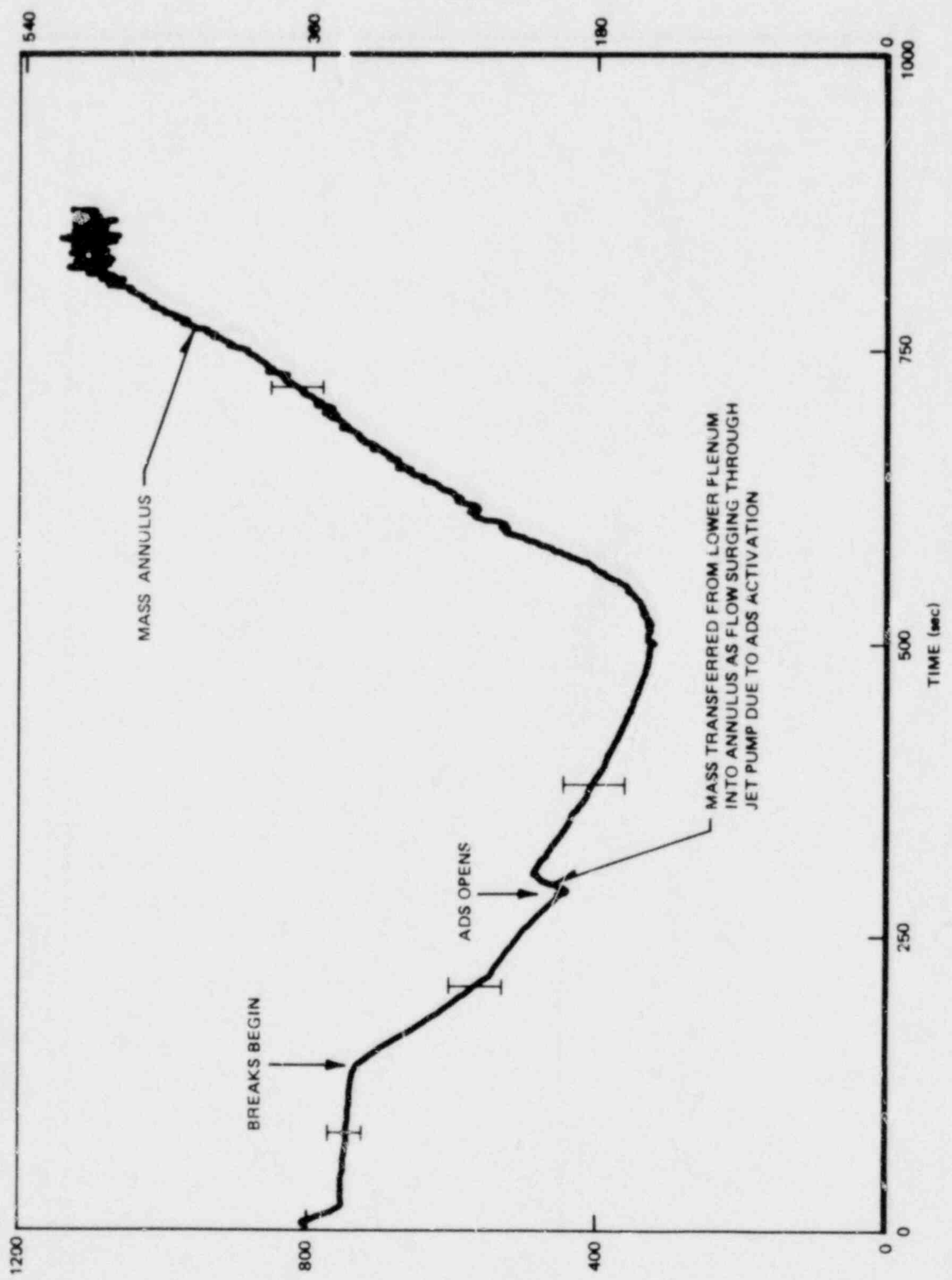


Figure G-15. Annulus Mass

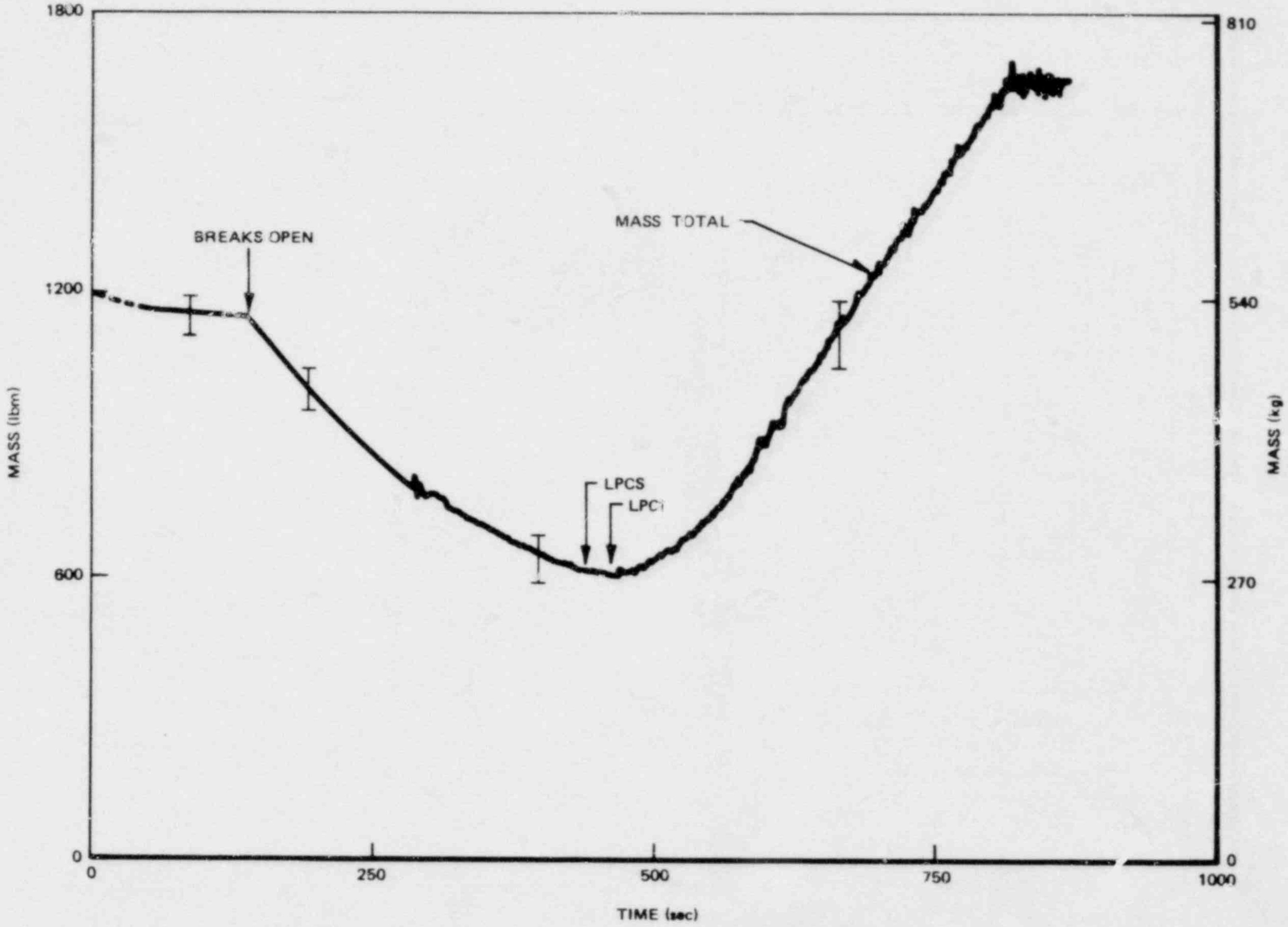


Figure G-16. System Mass

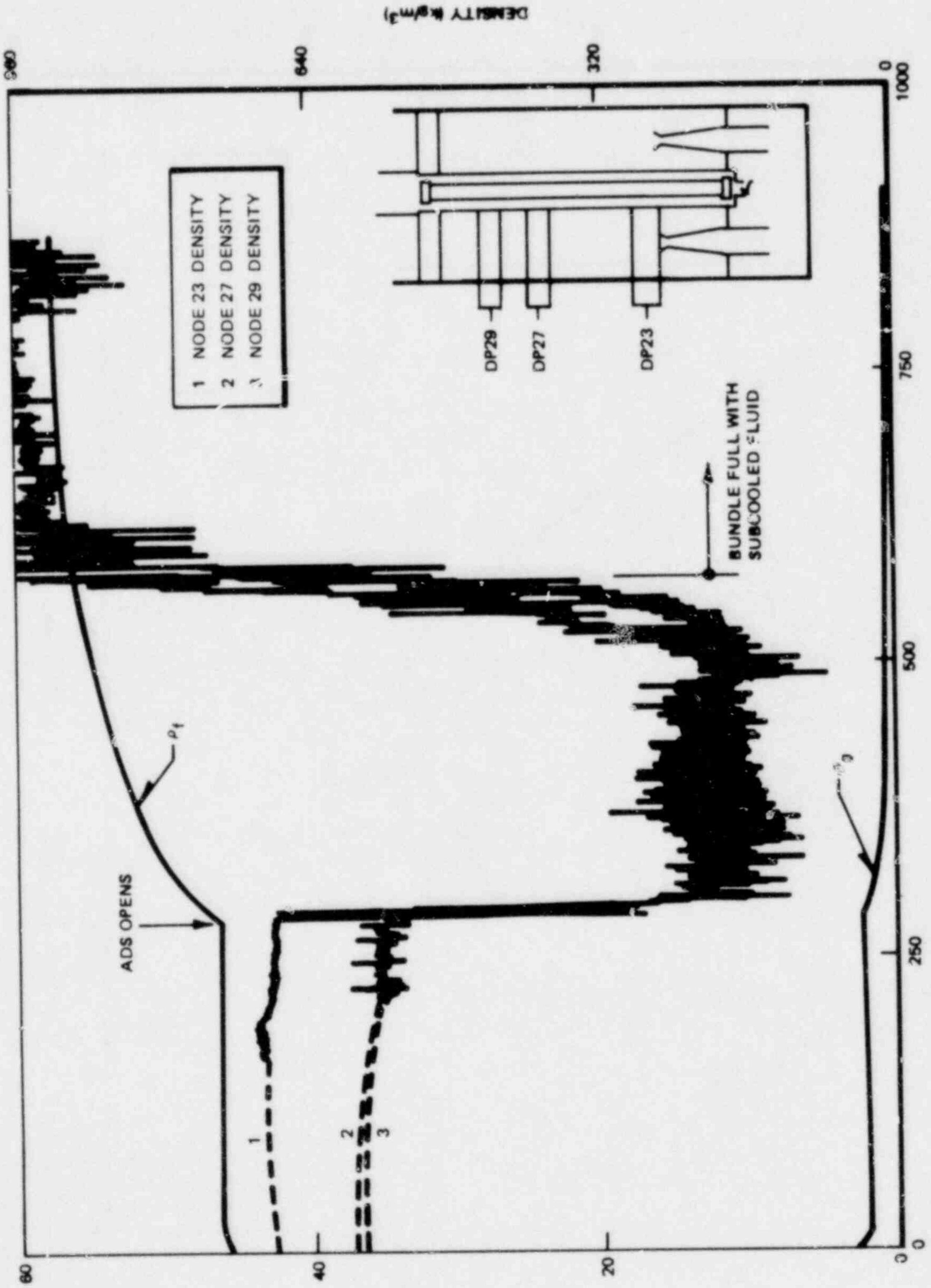


Figure G-17. Bundle Fluid Density

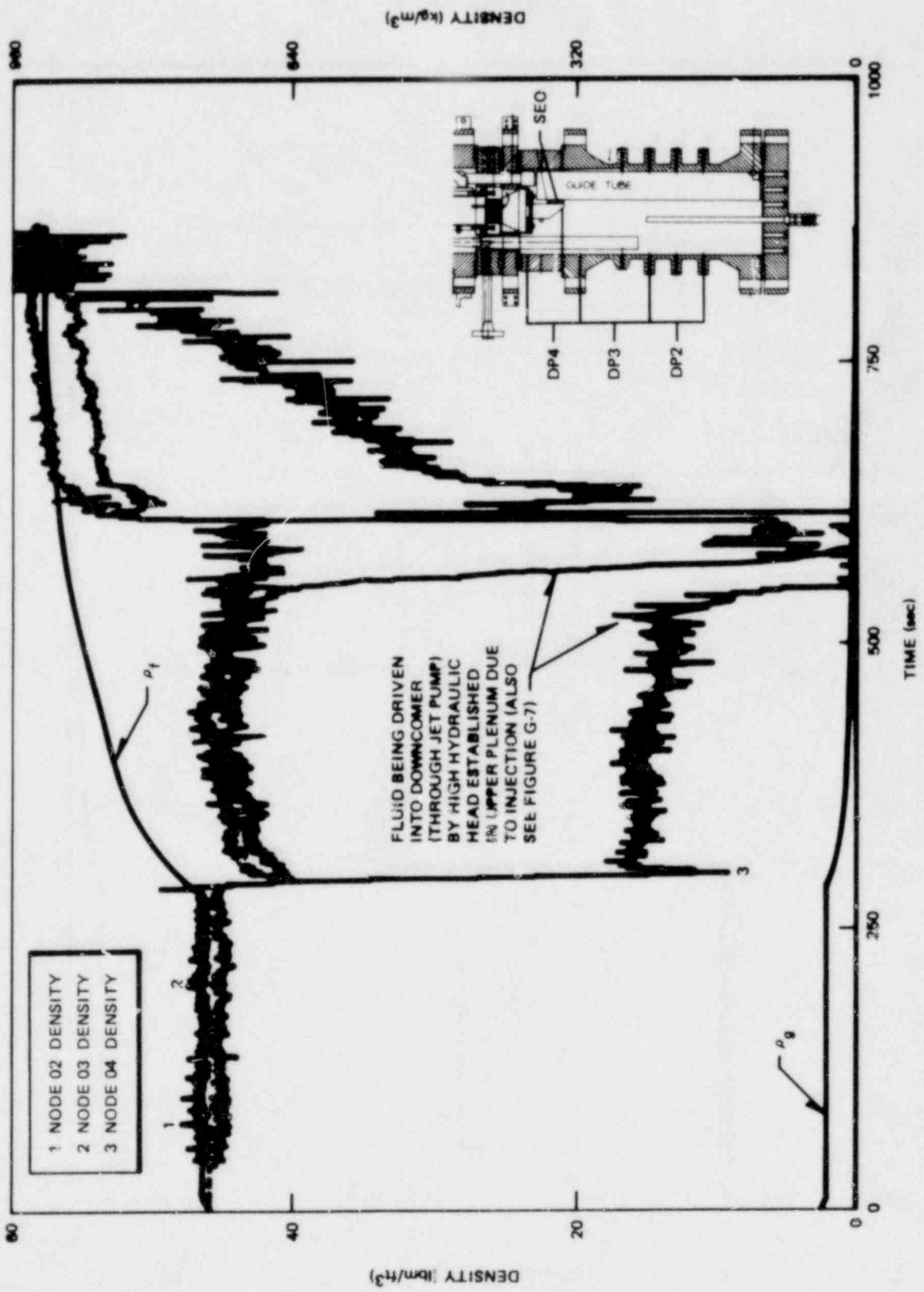


Figure G-18. Lower Plenum Density

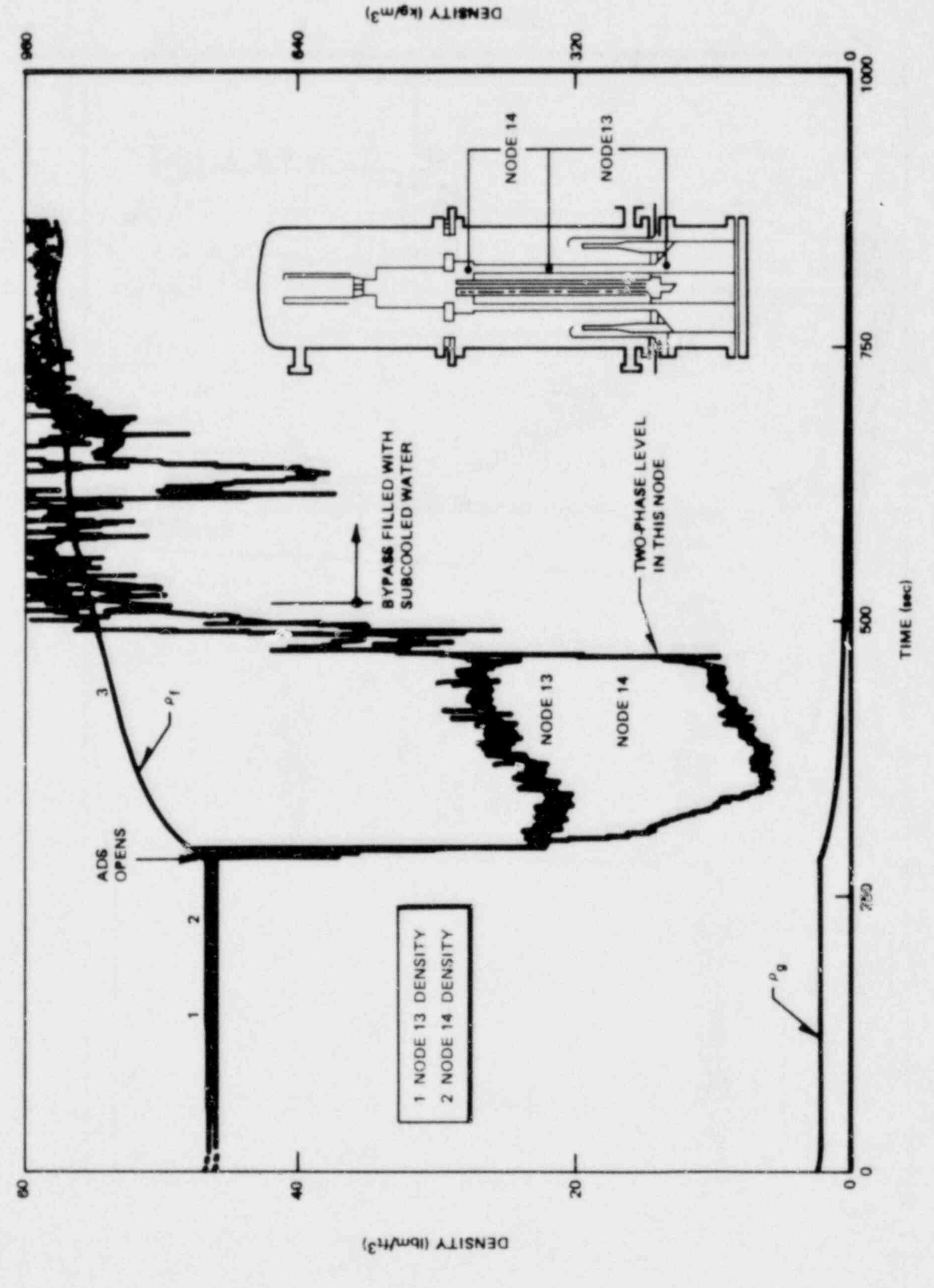


Figure G-19 Bypass Density

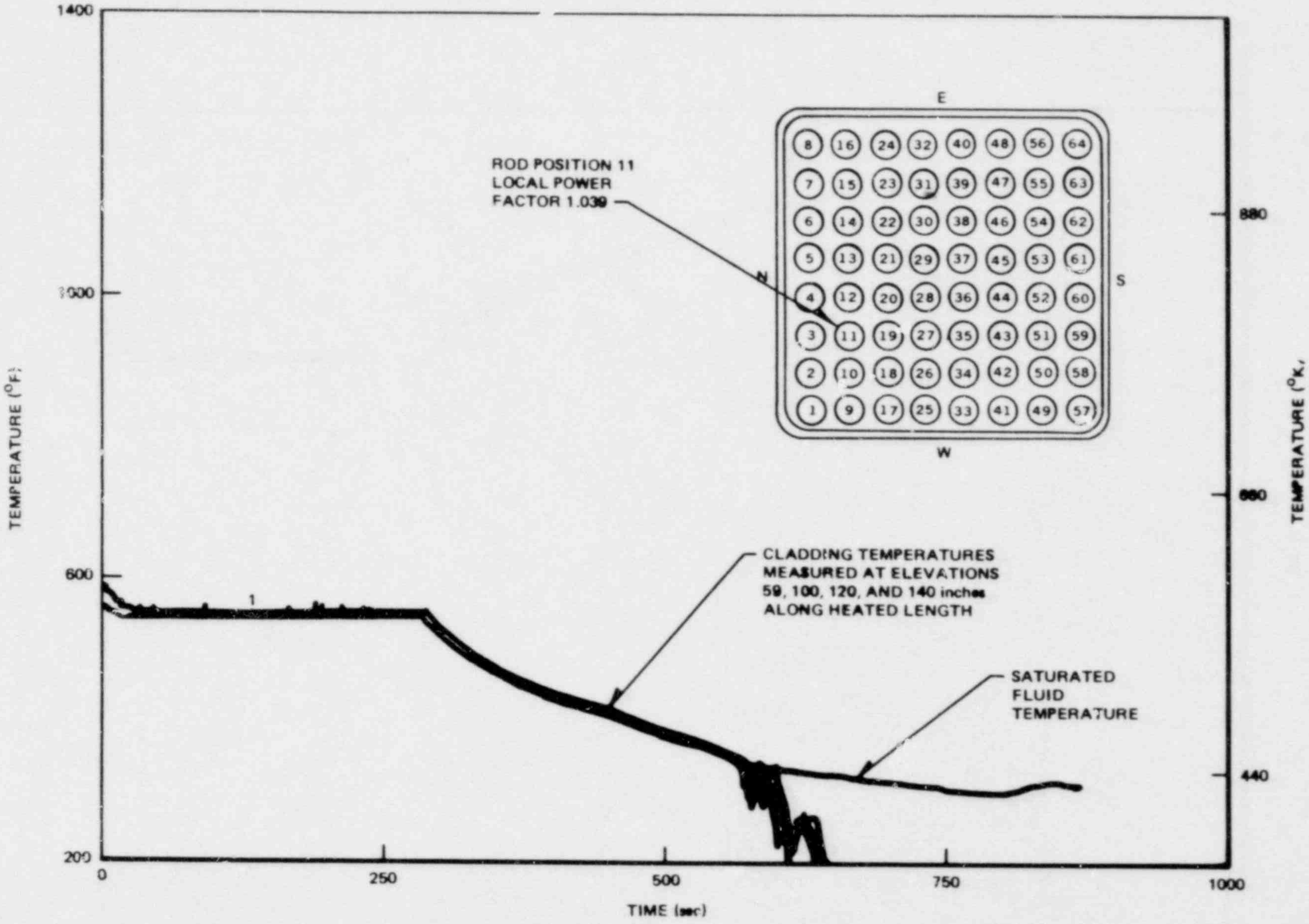


Figure G-20. Rod Cladding Temperature (TLTA Small Break Test No. 2)

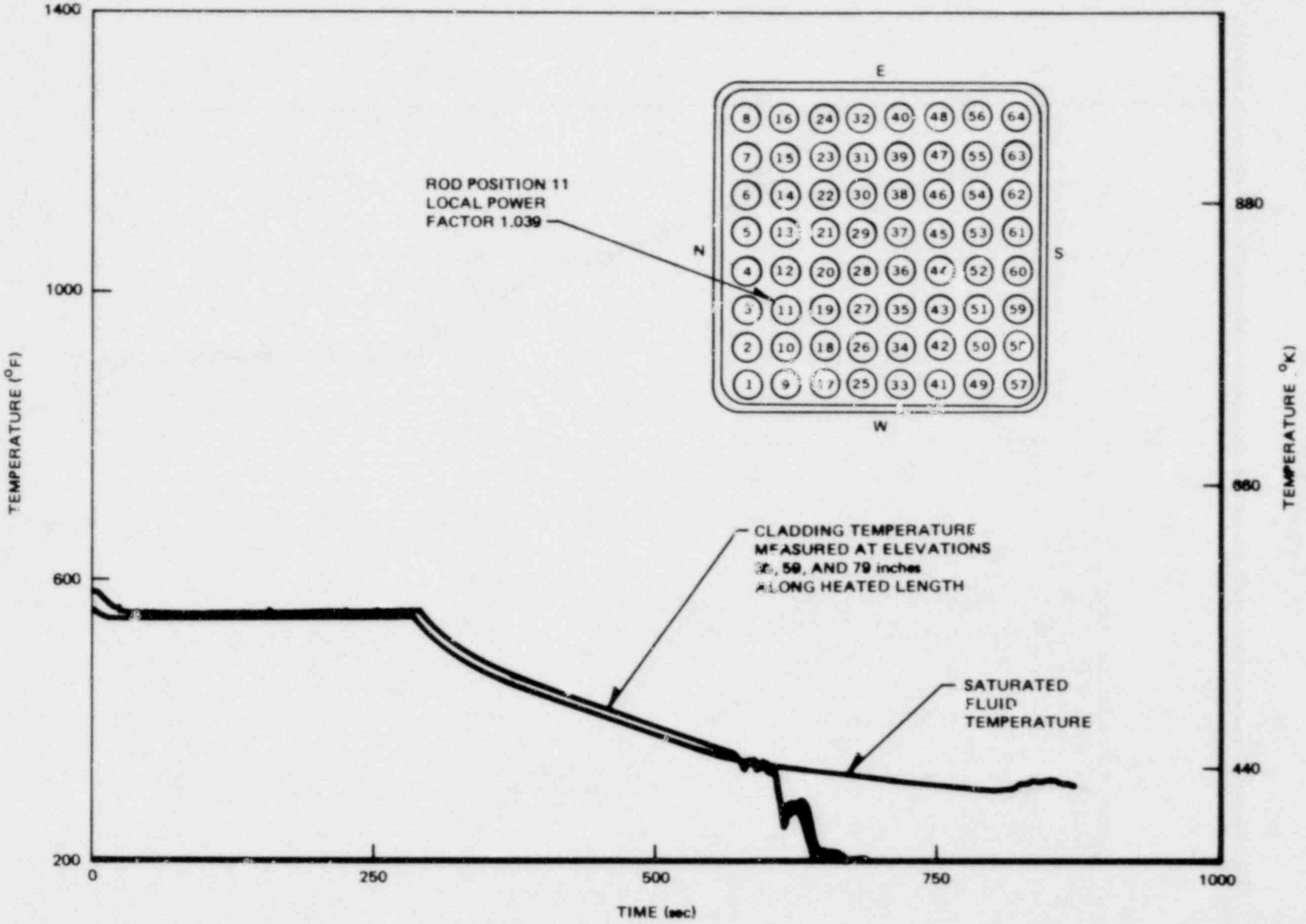


Figure G-21. Rod Cladding Temperatures (TLTA Small Break Test No. 2)

APPENDIX H

TLTA SEPARATE EFFECTS (BOIL-OFF) TEST

D. Seely and R. Muralidharan

INTRODUCTION AND OBJECTIVE

The primary objective of the boil-off tests was to obtain data for evaluating heat transfer in a partially uncovered core. Such an event occurred in the TMI-2 accident which resulted in an as yet undetermined amount of fuel damage. In a BWR, events leading to a partial core uncovery when the ECCS or other cooling systems are inoperable have not been identified. However, TMI has stimulated interest in analyzing BWR response to such a phenomena. Boil-off due to decay heat leads to inventory reduction in the core and, subsequently, to the development of a natural circulation of reactor coolant.

FACILITY CONFIGURATION

The subject test was performed in the Two-Loop Test Apparatus (TLTA) which is the primary test vehicle used in the BD/ECC Program. The scaling basis for the test and the facility is the BWR/6-218. The current TLTA configuration is designated TLTA 5A and is described in detail in Reference H-1.

TEST BASIS

The initial and operating conditions for the tests were as follows:

No.	System Pressure (psia)	Bundle Power (kW)	Initial Level (2 Phase)	Refill
1	800 ± 10	250 ± 15	Bundle Top	No
2	400 ± 10	150 ± 15	100 in. above BHL ± 10 in.	No
3	400 ± 10	250 ± 15	Bundle Top	Yes-Maximum (see below)
4	400 ± 10	400 ± 15	Bundle Top	No
5	200 ± 10	250 ± 15	Bundle Top	No

TEST PROCEDURE

The system was brought up to system test temperature and pressure approximately 10 minutes prior to test initiation. The system pressure and bundle power were held constant throughout the tests. All tests except Test 3 were terminated when the upper plenum temperature reached 800°F or the peak bundle tempertaue reached 1000°F (whichever occurred first).* In Test 3, the system was allowed to refill by injecting cold water into the downcomer through the feedwater system. The injection was achieved using maximum feedwater rate, approximately 18 gpm.

---

* These limits were set to protect the integrity of the test bundle and pressure vessel itself. It is felt that these limits did not compromise the objectives of the tests which were to provide a heat transfer data-base under partially uncovered bundle conditions.

TEST ACCEPTANCE

The boil-off tests were conducted in May 1980. Designation for the test series is 6441. The major initial conditions for the test were met. Table H-1 compares the specified conditions and actual measured conditions. Based on the comparisons between measured and specified test conditions, the tests were deemed acceptable.

TEST RESULTS AND CONCLUSIONS

The bundle two-phase level transient was determined from a series of differential pressure measurements along the bundle. The steam above the two-phase level was seen to become increasingly superheated as the bundle two-phase level dropped. Figure H-1 shows the upper plenum (superheated) steam temperature time history relative to the saturation temperature for a typical run (Run 3, Test Point 5).

The deviation of local rod temperatures from system saturation temperature, indicating dry-out at the relevant elevations, was observed to be approximately 20 to 40 seconds after the two-phase level dropped to the thermocouple elevation as illustrated in Figures H-2 through H-5. Figures H-2 and H-3 show the nodal uncovery times for nodes 30 and 29 respectively and Figures H-4 and H-5 show the temperature response at the lower end of each node (115-in. and 103-in. elevation respectively).

Figures H-6 and H-7 show the rod temperatures for two different power runs (400 and 250 kW respectively, but at the same system pressure) which indicate the rates at which the bundle two-phase level drops. As expected, the level in the higher power run (Run 3) drops at approximately twice the rate as the lower power run (Run 6). In Run 6 the system was reflooded using feedwater, and the sequential filling of the bundle nodes and the mixing plenum are presented in Figures H-8 and H-9. Figure H-10 is typical of the turn-around in the rod temperatures following the bundle level recovery subsequent to the activation of the feedwater. The bundle mixture level transients determined from the differential pressure and temperature responses are shown in Figure H-11.

ACKNOWLEDGMENTS

We acknowledge the efforts of Don Wilhelmson in the successful execution of the above boil-off tests.

REFERENCES

H-1. W. J. Letzring, *Preliminary Facility Description Report for the BD/ECC 1A Test Phase*, December 1977, GEAP 23593/NRC-2.

Table H-1
COMPARISONS OF TEST CONDITIONS

			Specified Conditions			Measured Conditions		
No.	Test Run No.	Test Point	System Pressure	Bundle Power (kW)	Initial Level (psia)	System Pressure (psia)	Bundle Power (kW)	Initial Level (2-Phase)
1	7	5	800 ±10	250 ±15	Bundle Top	790^{+2}_{-0}*	250 ±1	Bundle Top
2	3	4	400 ±10	150 ±15	100 in. above BHL ±10 in.	393 ±5	150 ±1	103 ±5
3	6	1	400 ±10	250 ±15	Bundle Top	395^{+10}_{-0}	250 ±2	Bundle Top
4	3	5	400 ±10	400 ±15	Bundle Top	394 ±3	400 ±1	Bundle Top
5	5	9	[illegible]0 ±10	250 ±15	Bundle Top	195 ±2	250 ±1	Bundle Top

---

* This test is acceptable in that the pressure is held nearly constant at 393 psia.

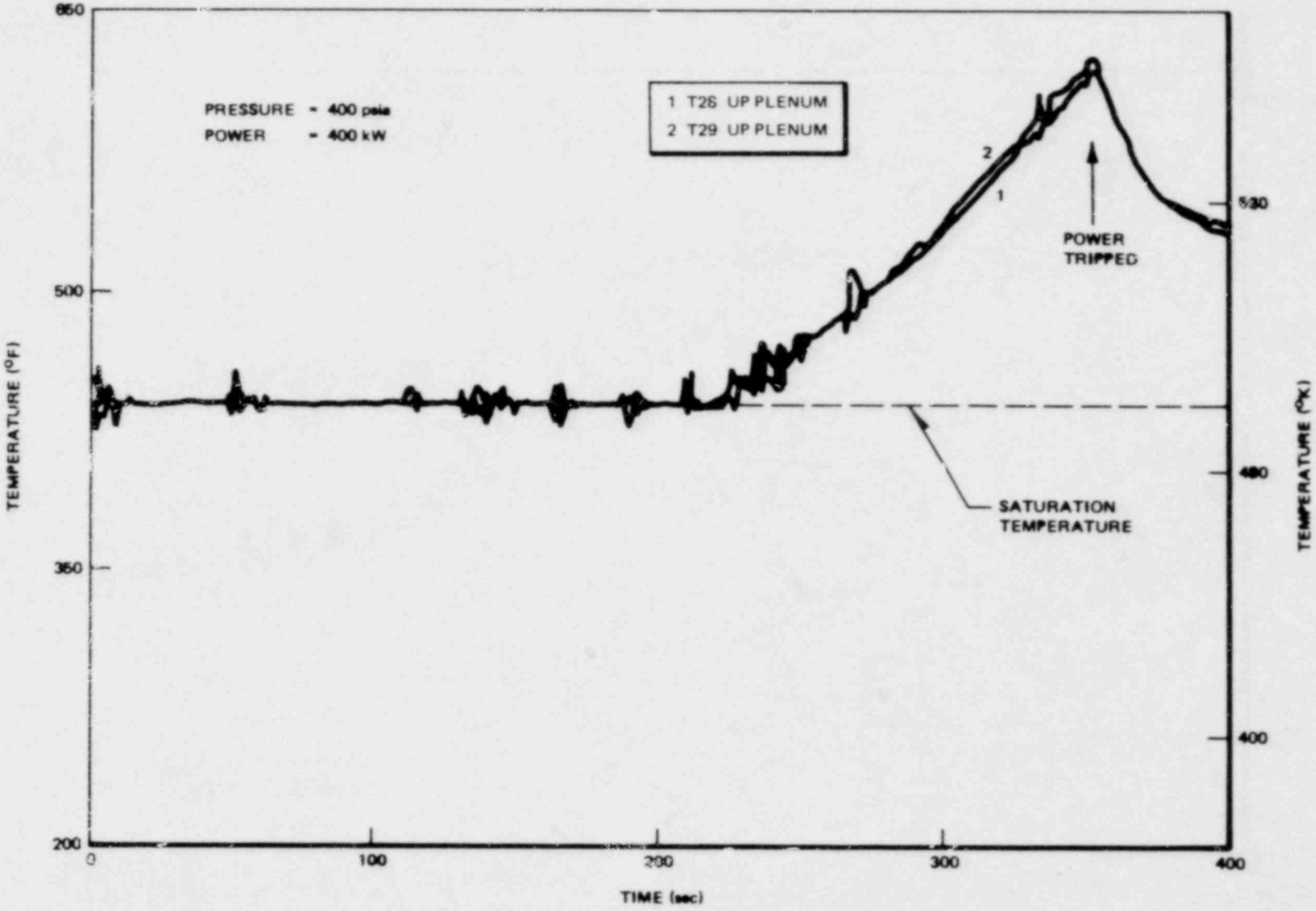


Figure H-1. Steam Temperatures in the Upper Plenum — Superheatup in the Bundle

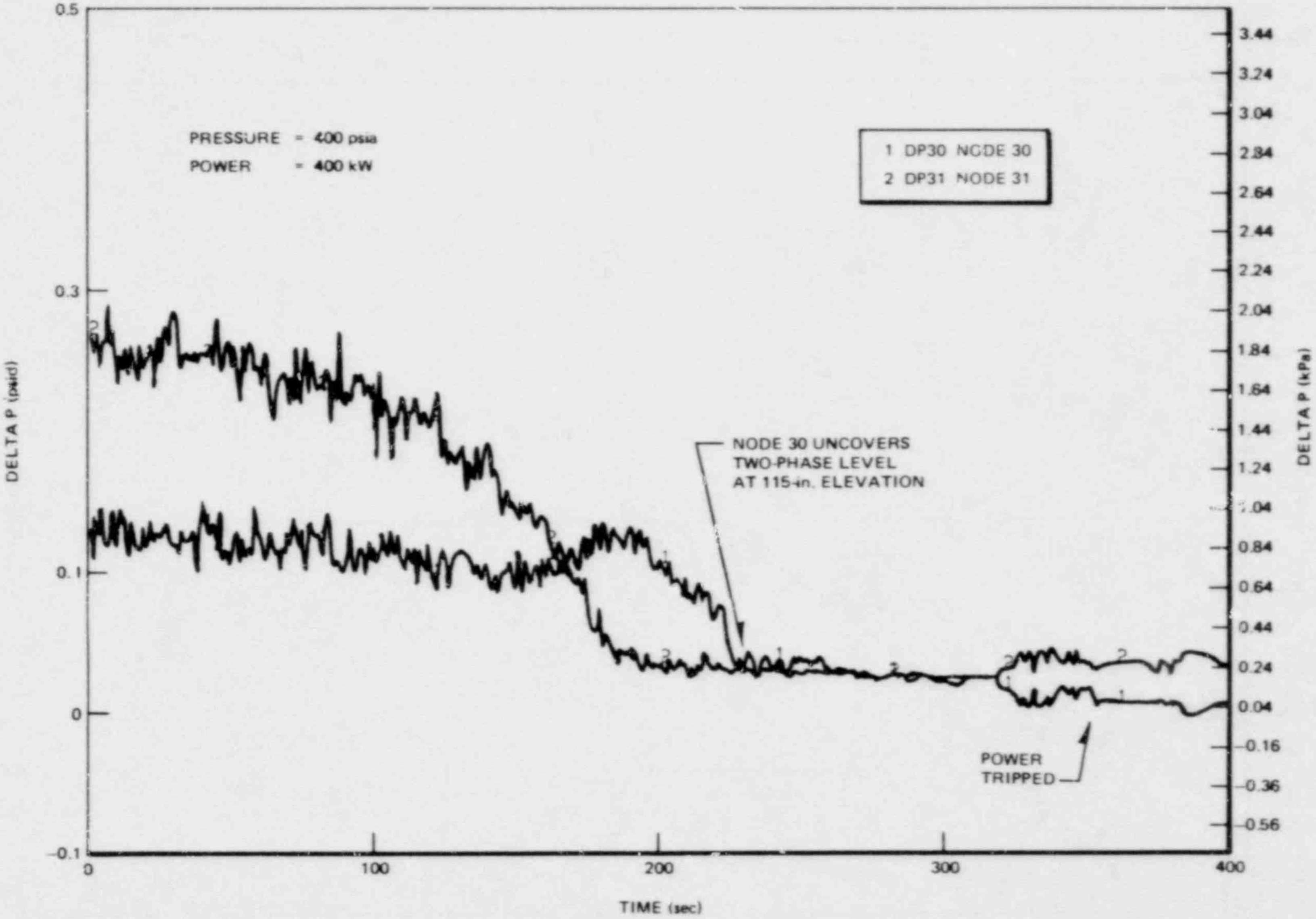


Figure H-2. Two-Phase Level Transient in Bundle

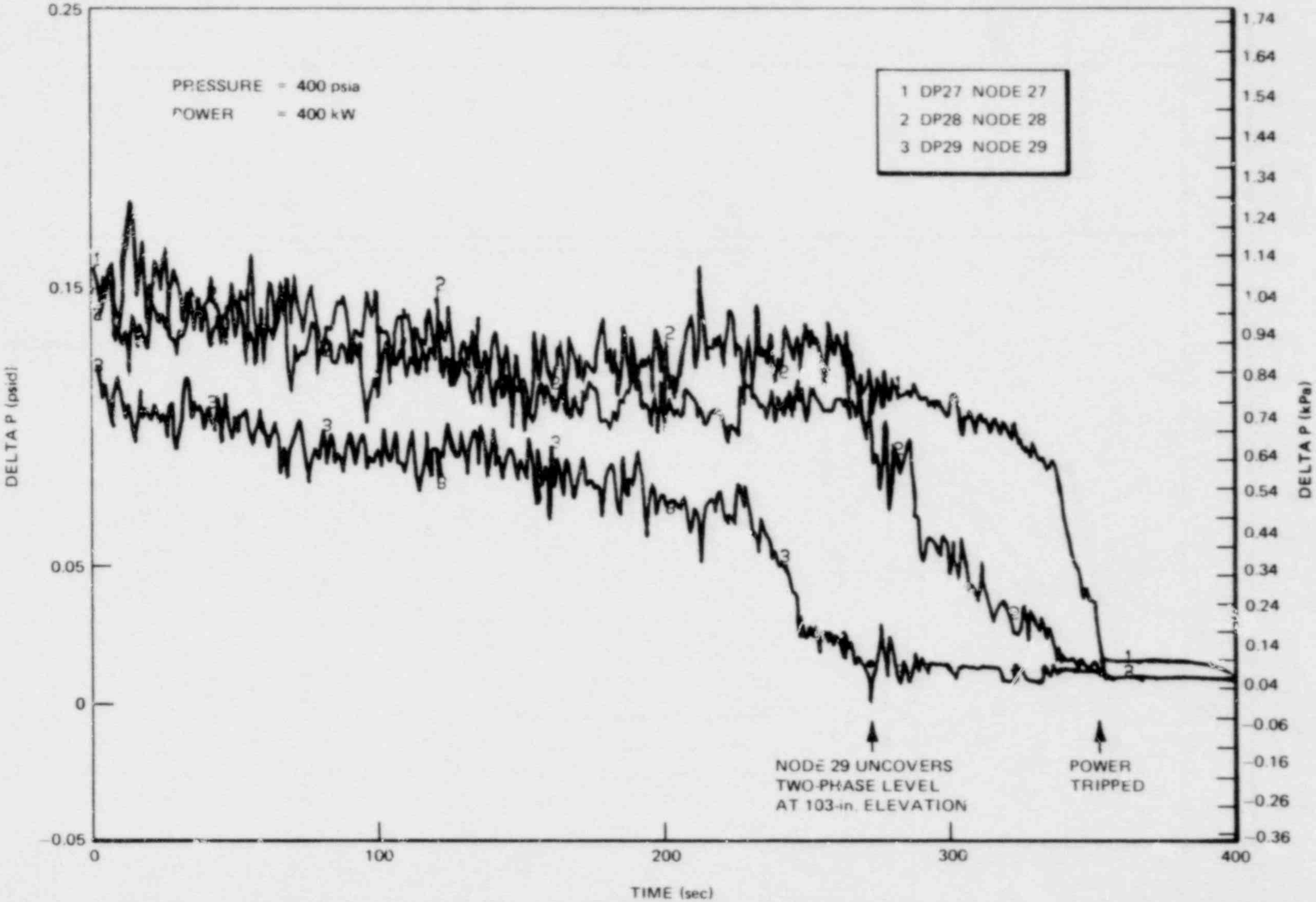


Figure H-3. Two-Phase Level Transient in the Bundle

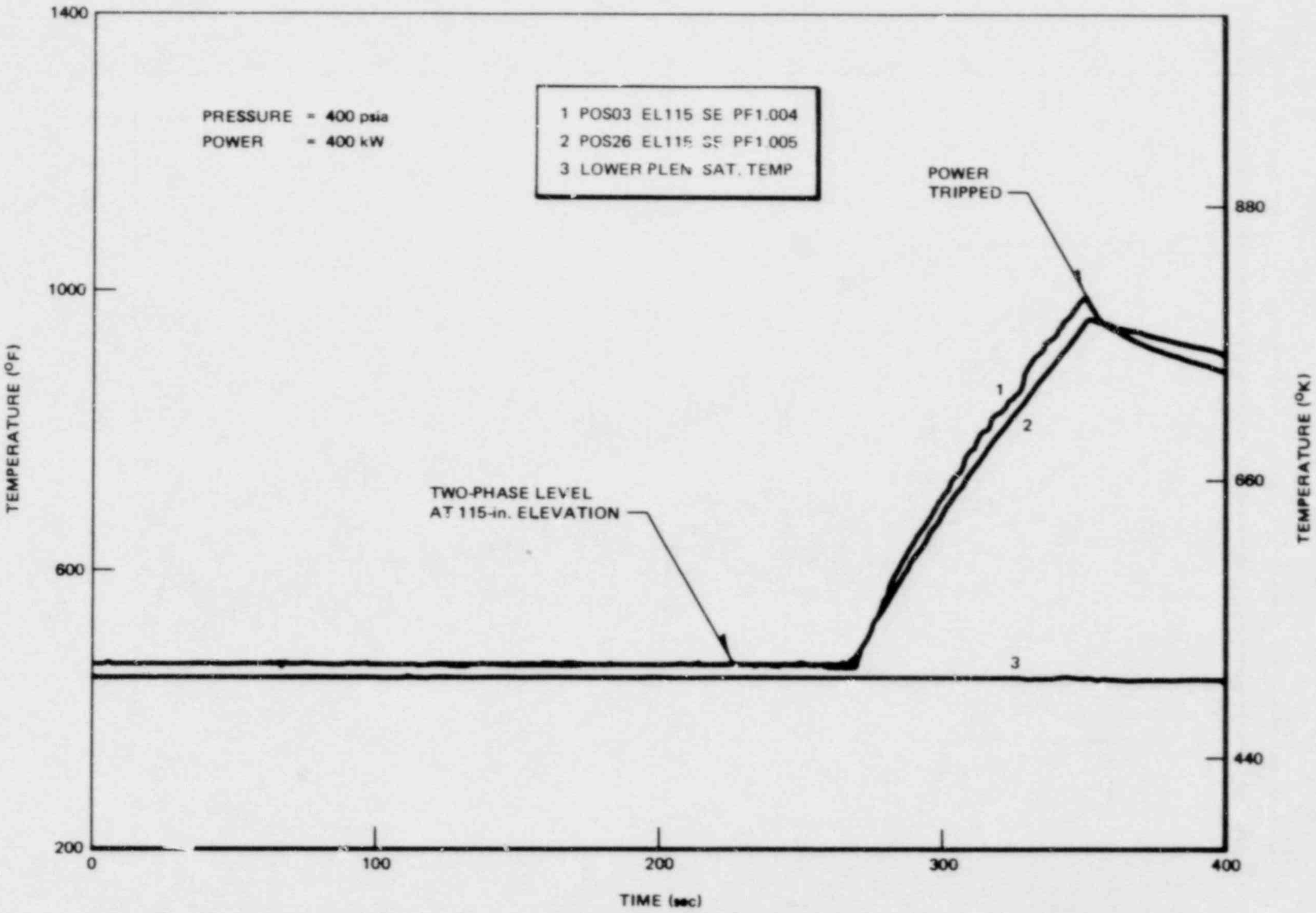


Figure H-4. Typical Bundle Heat-Up Above Two-Phase Level

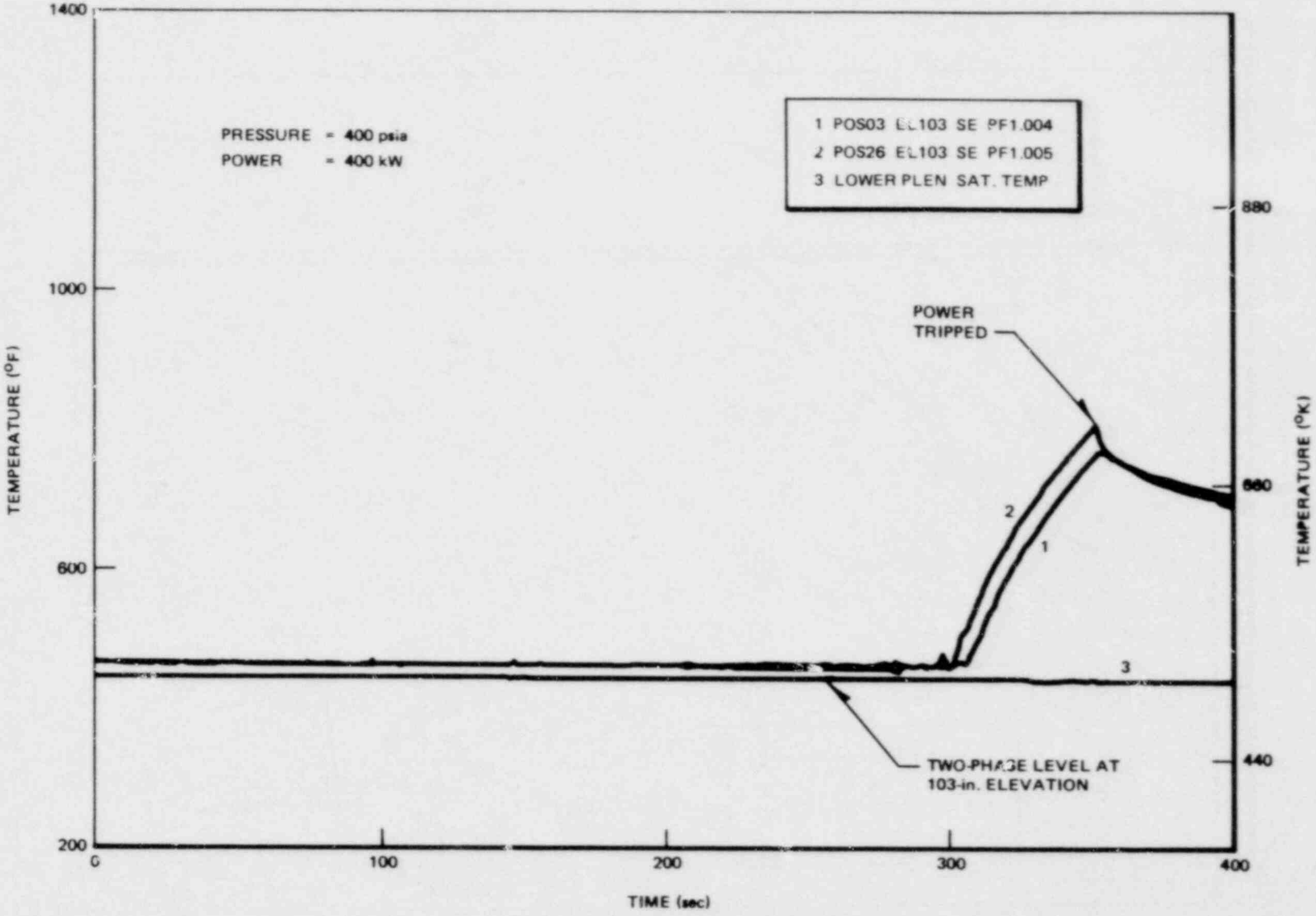


Figure H-5. Typical Bundle Heat-Up Above Two-Phase Level — Elevation 103 Inches

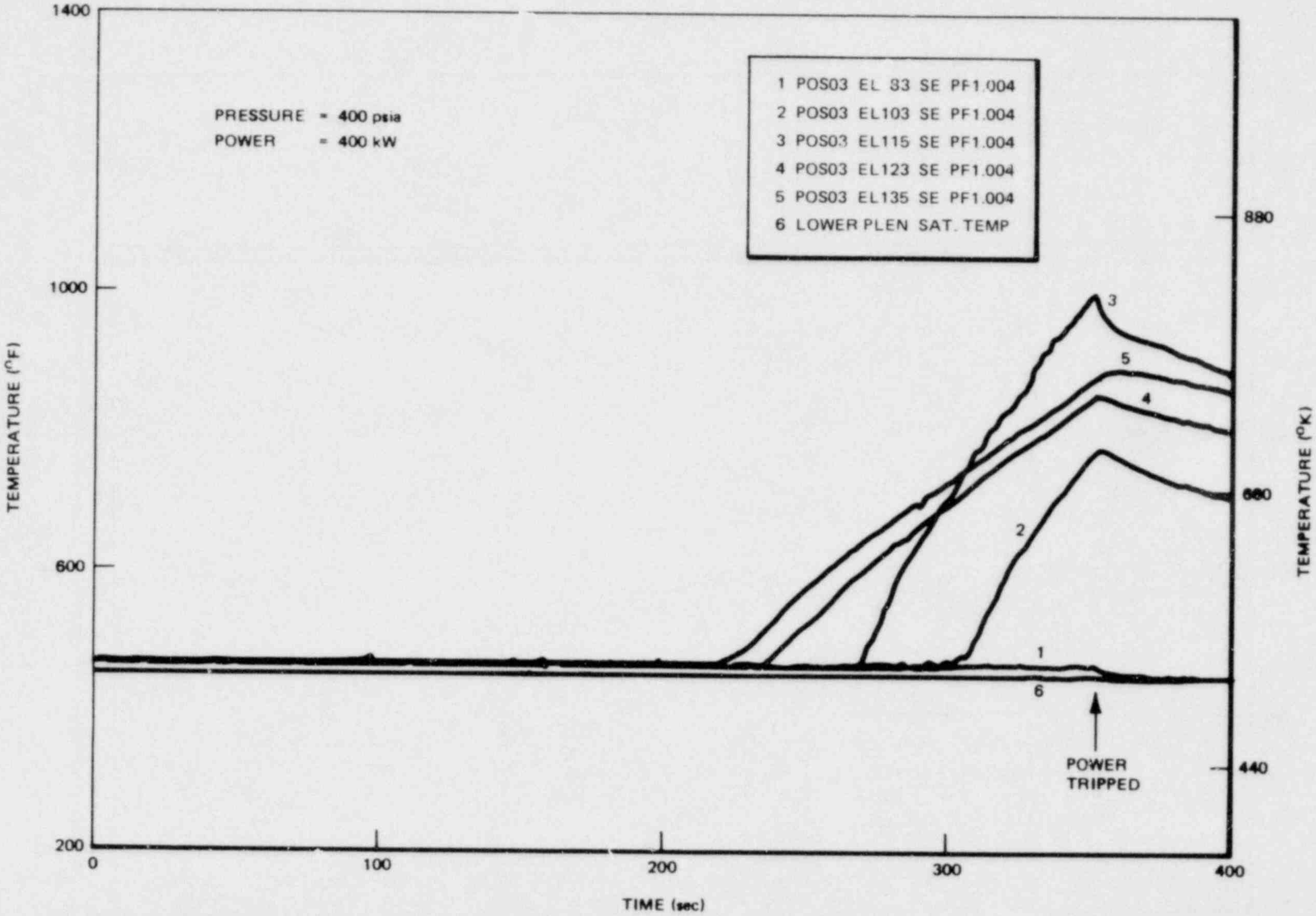


Figure H-6. Typical Heat-Up of a Rod With Two-Phase Level Drop

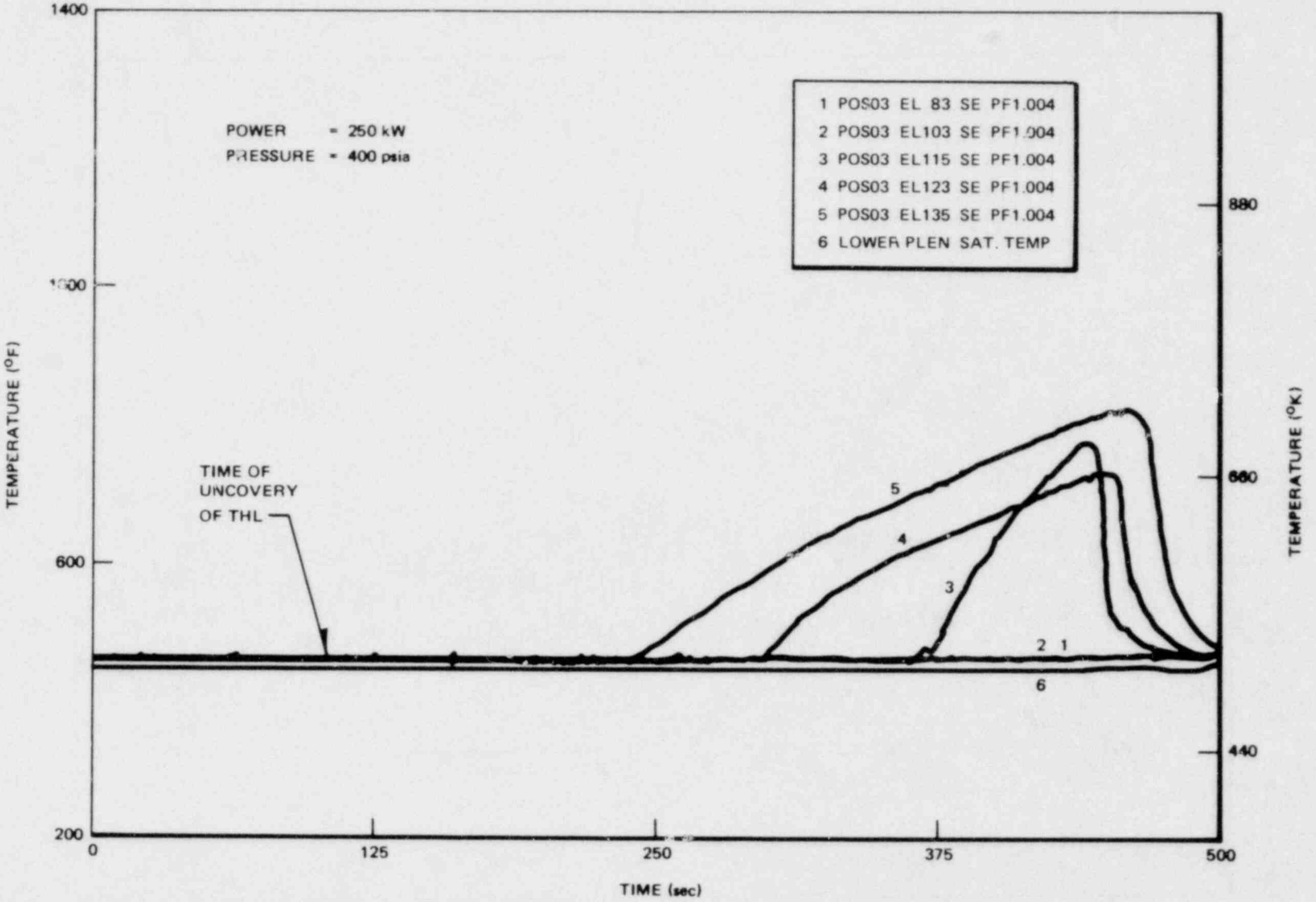


Figure H-7. Rod Heat-Up After Level Drop and Temperature Turn-Around Following Bundle Reflood

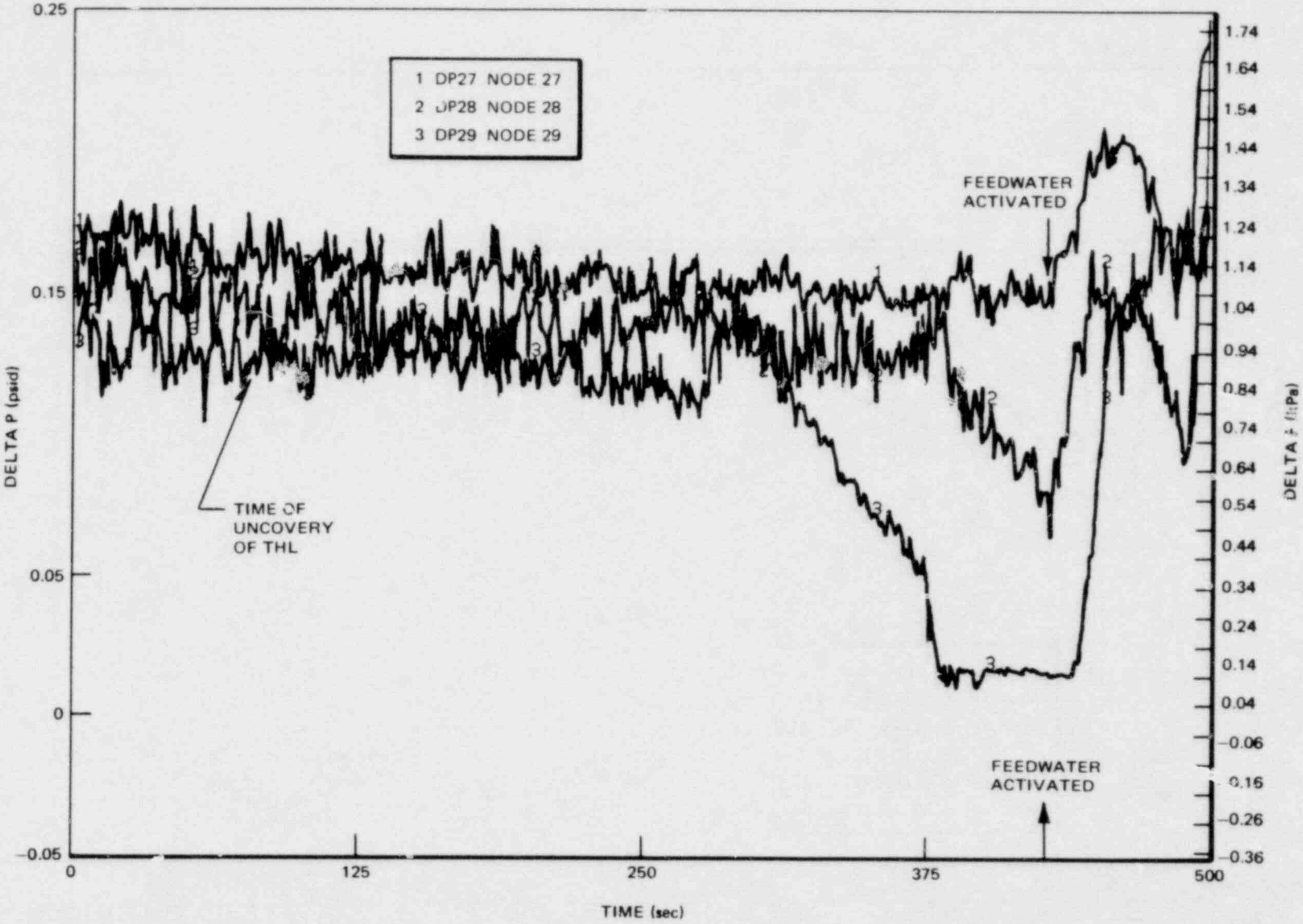


Figure H-8. Recovery of Bundle Level Following Feedwater Activation

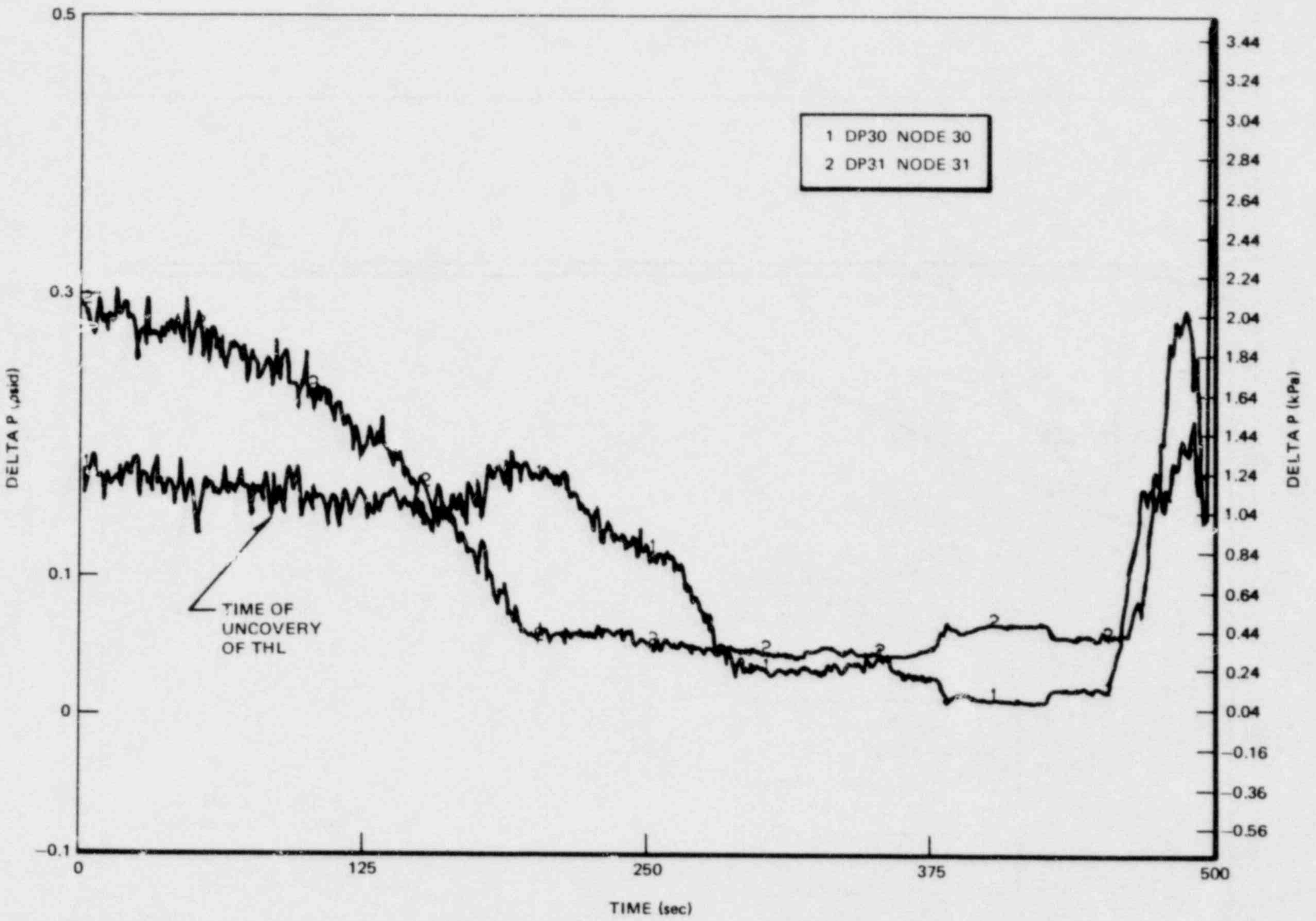


Figure H-9. Recovery of Bundle Level Following Feedwater Activation

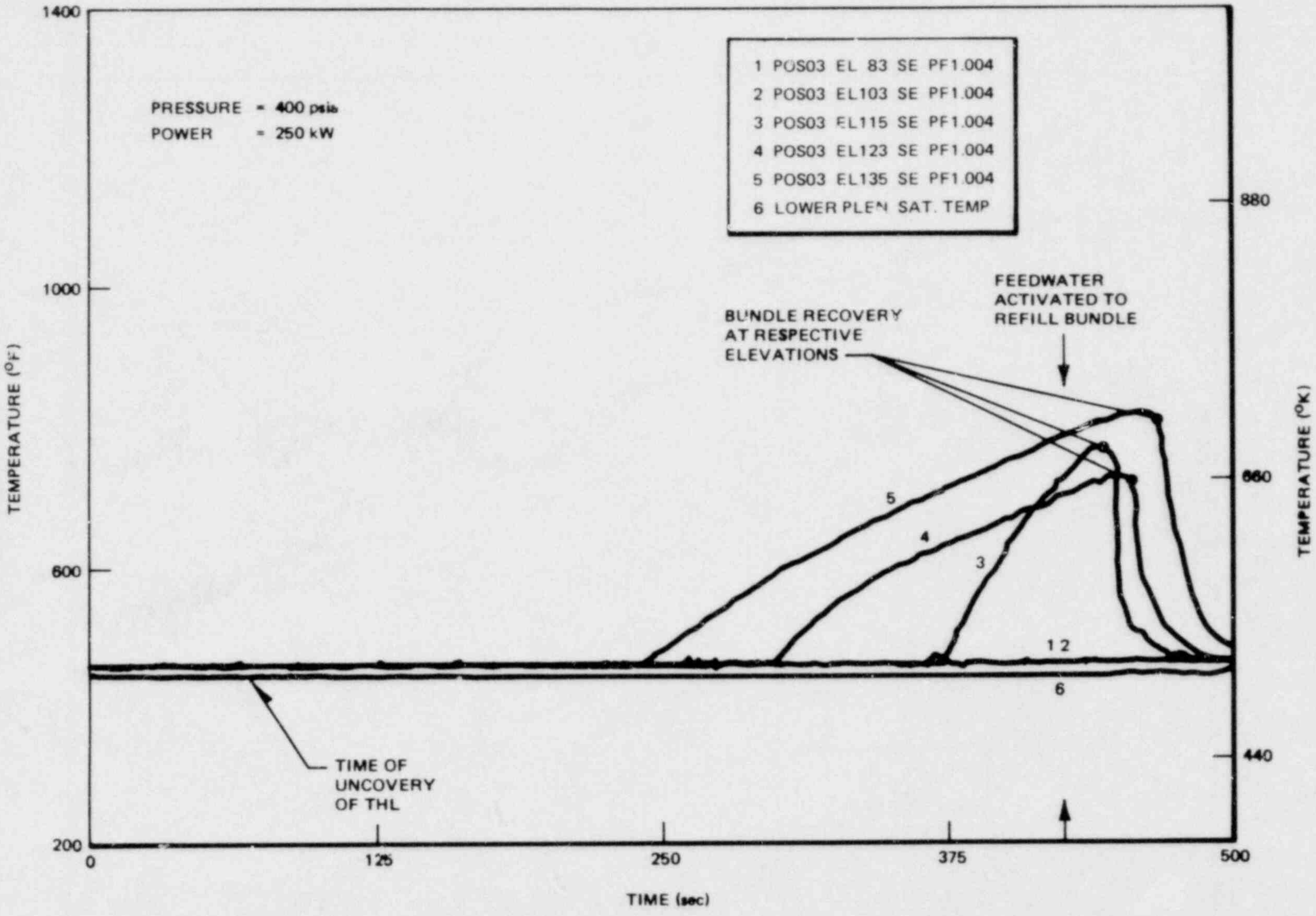


Figure H-10. Rod Heat-Up After Level Drop and Temperature Turn-Around Following Bundle Reflood

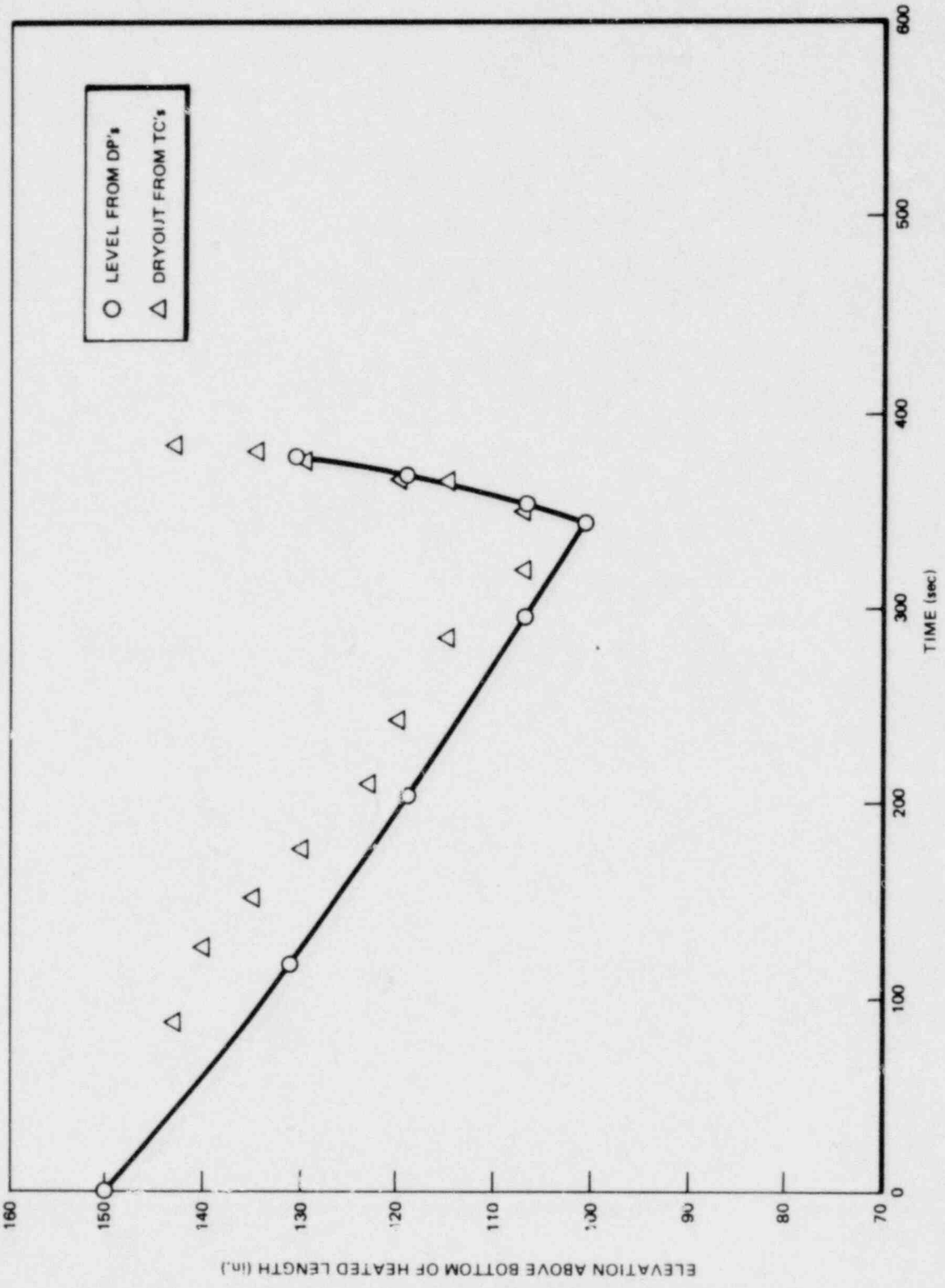


Figure H-11. Time From Uncovery of THL

CONTRACT NRC-04-76-215

DISTRIBUTION

U.S. Department of Energy Technical Information Center P.O. Box 62 Oak Ridge, TN 37830	27
Electric Power Research Institute EPRI Distribution List RP 495	205
Division of Reactor Safety Research U.S. Nuclear Regulatory Commission Washington, DC 20545 Attn: W. D. Beckner	2
Division of Reactor Licensing U.S. Nuclear Regulatory Commission Washington, DC 20545 Attn: R. K. Frahm	1
Electric Power Research Institute 4312 Hillview Avenue Palo Alto, CA 94303 Attn P. Kalra	30
Argonne National Laboratory 9700 Cass Avenue Argonne, IL 60439 Attn: P. Lottes RSR Heat Transfer Coordinator	1
EG & G 550 Second Street Idaho Falls, ID 83401 Attn: J. Dallman	1
Safety and Systems Analysis Nuclear Power Generation Division Babcock & Wilcox P.O. Box 1260 Lynchburg, VA 24505 Attn: Dr. B. E. Bingham, Manager	1
Reactor Development Center Babcock & Wilcox P.O. Box 1260 Lynchburg, VA 24505 Attn: Mr. D. Montgomery	1

Safeguards Development 1
Pressurized Water Reactor Systems Division
P.O Box 355
Pittsburgh, PA 15230
Attn: Dr. L. E. Hochreiter, Manager

C-E Power Systems 1
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, CT 06095
Attn: Mr. J. D. Crawford

Librarian, General Atomic 1
P.O. Box 81608
San Diego, CA 92138

Department of Nuclear Engineering 1
University of California at Berkeley
Berkeley, CA 94720

Department of Nuclear Engineering 1
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

Engineering Library 1
Stanford University Campus
Stanford, CA 94305

Los Alamos Scientific Laboratory 1
Los Alamos, NM 87544
Attn: C. W. Hirt, Group T-3

Environmental Protection Agency 1
P.O. Box 15027
Las Vegas, NV 89114

U.S. Nuclear Regulatory Commission 1
Reactor Analysis Section/Analysis Branch
Washington, DC 20545
Attn: W. Hodges

Mr. Kenneth Randen 1
ASEA-Atom
Box 53
S-721 04
Vaesteraas 1, Sweden

Dr. T. Kawai 1
Hitachi, Limited
Hitachi Works
3-1-1 Saiwai-Cho
Hitachi-Shi, Ibaraki-Ken 317, Japan

Mr. Dieter Ewers 1
Kraftwerk Union AG
Postfach 700649
D-6000 Frankfurt (Main) 70
Federal Republic of Germany

Dr. H. Hashimoto 1
Tokyo Shibaura Electric Company
Toshiba Mita Building
13-12, 3-Chome Mita, Minato-Ku
Tokyo 108, Japan

Mr. E. Annino 1
AMN Impianti Termici e Nucleari
Casella Postale 190
16151 Genova Sampierdarena
Italy

U.S. Nuclear Regulatory Commission 360
Division of Document Control
Attn: Steve Scott, Actg. Branch Chief
Distribution Services Branch
Washington, DC 20555

NRC FORM 335
(7-77)

U.S. NUCLEAR REGULATORY COMMISSION
BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-1154 VOL.2, #2
GEAP 21304-18

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
BWR Blowdown/Emergency Core Cooling Eighteen Quarterly
Progress Report April 1 - June 30, 1980

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
W. S. Hwang

5. DATE REPORT COMPLETED

MONTH	YEAR
September	1980

DATE REPORT ISSUED

MONTH	YEAR
April	1981

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
General Electric Corporation
175 Curtner Avenue
San Jose, CA. 95125

6. *(Leave blank)*

8. *(Leave blank)*

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
U. S. Nuclear Regulatory Commission
Div. of Reactor Safety Research
Office of Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
NRC-04-76-215

13. TYPE OF REPORT
Quarterly Technical Report

PERIOD COVERED *(Inclusive dates)*
April 1 - June 30, 1980

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*

Blowdown/Emergency Core Cooling work completed in the second quarter (April 1 - June 30) of 1980 is summarized. During this quarter efforts to improve flow measurements with the turbine flow meter and drag disc flow meter were made. Five separate-effects, boil-off tests were conducted in TLTA and data evaluation of these tests is continuing. Significant efforts to evaluate the test data of the previously completed large break integral system tests were carried out. Many test reports including large break, small break and separate effects boil-off tests were issued and some data are included herein.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

20. SECURITY CLASS *(This page)*

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (7-77)