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BWR BLOWDOWN/EMERGENCY CORE COOLING FIFTEENTH QUARTERLY PROGRESS REPORT JULY 1-SEPTEMBER 30, 1979

R. Muralidharan

Approved: G. W. Burnette, Manager
External Programs

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

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

Approved: J. E. Wood, Manager
Nuclear Core Technology

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CONTENTS

ABSTRACT

Blowdown/Emergency Core Cooling work completed in the third quarter of 1979 (July 1, 1979 through September 30, 1979) is summarized. During this quarter shakedown of the TLTA-5A vessel was completed and the first two matrix tests of the present series were conducted. The results from these two tests are being evaluated. Analytical effort in support of planning for the small break scoping test is near completion.

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 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, MAYUO4.[3]

4. Distribution of facility description report[4] for the BD/ECC1A phase.

5. Issuance of revised BD/ECC1A test plan.[5]

6. 64-Rod Bundle Test Topical Report completed.

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* See Appendix A for task description.

The shakedown of the Two-Loop Test Apparatus (TLTA-5A) with a new 64-rod bundle in place was completed during this quarter. Subsequently the first two matrix tests of the present series were carried out.

Evaluation of the test data from the above matrix tests has commenced. Preliminary examination of the data indicates much lower rod heatup than in the previous tests.

The analysis in support of the small break scoping test was accelerated. A tentative set of test conditions has been selected for the proposed scoping test. These efforts were directed towards mitigating the scaling compromises inherent in the present TLTA design for small break simulation.

2. PROGRAM PLANNING AND ADMINISTRATION

Following the Program Management Group (PMG) review of the TLTA configuration suggested for the BD/ECC-1B phase, the cost and schedule estimates were revised to reflect the imposed "non-LOCA" requirements,* escalation due to obtaining concurrence, and to reflect a more realistic period for test performance. It was concluded that it was no longer possible to complete the suggested BD/ECC-1B phase within the contract schedule and allocated funds. Other alternatives were developed and are being evaluated.

* The NRC required that sufficient analyses be completed to assure that modification to the TLTA would not jeopardize the potential for "non-LOCA" transient simulation. Non-LOCA transients include feedwater and recirculation flow transients, pressurizing events, etc.

3. EXPERIMENTAL WORK

3.1 BD/ECC — 1A TESTING

The first two matrix tests of the present series were conducted in TLTA-5A. The first of these was an average bundle power test without ECC (designated as test No. 6421). The second test was a reference test with ECC injection. This test can be characterized as averaged bundle power and average ECC flow and fluid temperature. The next test planned will have peak power in the bundle, low ECC flow rate and high ECC fluid temperature.

4. ANALYTICAL EFFORT

4.1 BD/ECC-1A DATA EVALUATIONS

Results from the first two matrix tests are being evaluated. The data show heater rod temperatures much lower than measured previously in similar tests. Bundle and bundle bypass fluid inventories differ from previous results and bypass flow rates are also changed as a result of the improved bypass simulation. The lower bundle temperatures are a result of both the changes made (improved typicality of core bypass flow geometry and more typical decay heat simulation).

The evaluation summary of the BD/ECC-1A data is included in Appendix C of this report.

Two additional analyses completed during this quarter were those of steam separator pressure drop and TLTA break flow. These analyses were issued as attachments to the June 1979 Forty-Fourth Monthly Report.

Analysis effort continued in support of planning for the small break scoping test. An existing system analysis method is being used to evaluate known TLTA scaling compromises and various means proposed to mitigate these compromises for small break simulation.

A pretest assessment of the response of the modified TLTA has been made. The assessment was made for the reference test (average power, nominal ECC flows and temperatures) and was distributed along with the August Forty-Sixth Monthly Report.

5. TWO-LOOP TEST APPARATUS

Work on the TLTA during this quarter mainly consisted of the checkout of all differential pressure instruments, the Metrascope (for visual display of bundle temperatures) and the new wattmeter. Shakedown testing, including an adiabatic blowdown, was completed.

6. REFERENCES

1. R. J. Muzzy, *Preliminary BWR Blowdown/Emergency Core Cooling Program Plan*, June 1976 (GEAP-21255).
2. J. P. Walker, *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Blowdown Heat Transfer Test Plan*, September 1976 (GEAP-21333).
3. W. C. Punches, *MAYU04 — A Method to Evaluate Transient Thermal Hydraulic Conditions in Rod Bundles*, 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*, 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*, February 1978 (GEAP-NUREG-21638A).

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 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 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 by 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.

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.	
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

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

Report No./Type	Title/Author(s)	Principal Contents
		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.	

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	July 1978*
BD/ECC1B Facility Description	Detailed description of TLTA configuration for BD/ECC1B	October 1978*
BD/ECC1A Final Report	Results from BD/ECC1A testing	November 1978**
Final BD/ECC Report	Summary and Conclusions from BD/ECC program	April 1981**

* As a result of program redirection by PMG, schedule subject to revision.

** Original Buff Book estimate dates — subject to revision.

A ·'ENDIX C
SUMMARY OF TLTA TEST WITH ECC INJECTION
L. S. Lee

:.1 INTRODUCTION

The Biowdown/Emergency Core Cooling (BD/ECC-1A) phase of the BD/ECC Program was intended to ·n information on the effect of ECC injection on boiling water reactor (BWR) system responses. The original test ·dentified a matrix of 20 tests. Six of these tests were selected[C-2] by the Program Management Group (PMG) pe the outcome of the test series.

Four matrix tests plus a repeat of the reference test without ECC injection were completed by September ·'78. Preliminary results were presented to the program sponsors and the Nuclear Regulatory Commission (NRC) staff in the ensuing months. Detai·ed results, interpretations, and conclusions from these tests were presented to the PMG in March 1979 and to the NRC staff in May 1979. This report summarizes the material previously presented.

The report is organized in three sections. The first section summarizes the scenario of the reference tests (average bundle power, average ECC injection). The next section summarizes the differences between tests with and without ECC. The last section summarizes highlights of other tests.

C.2 SCENARIO DESCRIPTION OF RESPONSES

System responses are discussed in this section. The configuration of the test apparatus is highlighted first. Controlled parameters that are imposed on each test are outlined. The reference test (6406/Run 1) scenario is described with the aid of a series of qualitative sketches referred to as "snap shots." Detailed quantitative measurements are presented to substantiate the descriptions.

C.2.1 TLTA Configuration

The two-loop test apparatus configuration 5 (TLTA-5) was used to conduct the BD/ECC-1A tests. Details of TLTA can be found in the Description Report.[C-3] A schematic diagram is presented in Figure C-1. Salient features of TLTA-5 are:

1. the integral system;
2. full size bundle;
3. full power;
4. prototypical pressure and temperature; and
5. the Emergency Core Cooling System.

C.2.2 Controlled Parameters

Controlled parameters refer to those quantities whose transient responses are designed and controlled to be similar to those predicted for a reactor counterpart. Included and shown in Figure C-2 are bundle power, steam line flow, ECC injection flow characteristics, and drive pump coastdown.

The bundle power, ECC pump-rated flow conditions and the temperature of the ECC water are parameters in the BD/ECC-1A test. Table C-1 shows the variation of parameters in the matrix tests.

The steam line flow (Figure C-2a) is controlled during tests by the response of the pressure control valve. This valve closes and opens in response to the vessel pressure. The set point for the valve was 1050 psi. The valve closed completely at ~12 sec for the reference test (Figure C-2a).

The ECC injections in the reference test are shown in Figure C-2b. The High Pressure Core Spray (HPCS) was activated at 27* sec; injection begins immediately. The Low Pressure Core Spray (LPCS) and Low Pressure Coolant Injection (LPCI) were activated at 37* sec; actual flow begins at 76 sec for LPCS and 88 sec for LPCI. Both the timings and the ECCS pump operating characteristics were designed[C-4] to simulate the characteristics of the BWR ECCS.

* From the instance of break initiation.

TABLE C-1
TEST PARAMETERS FOR BD/ECC 1A TESTS

ECC Flow Variation Tests

Test No.	Power	ECCS Flow	ECC Temperature
6007/26[a]	5.05 MW	No	~
6405/3	5.05 MW	Low	~120°F
6406/1[b]	5.05 MW	Average	~120°F

[a] Repeated as 6406/3

[b] Reference Test

Power Variation Tests

Test No.	Power	ECCS Flow	ECC Temperature
6401/4	1.62 MW	High	~120°F
6414/3	6.49 MW	Low	~200°F

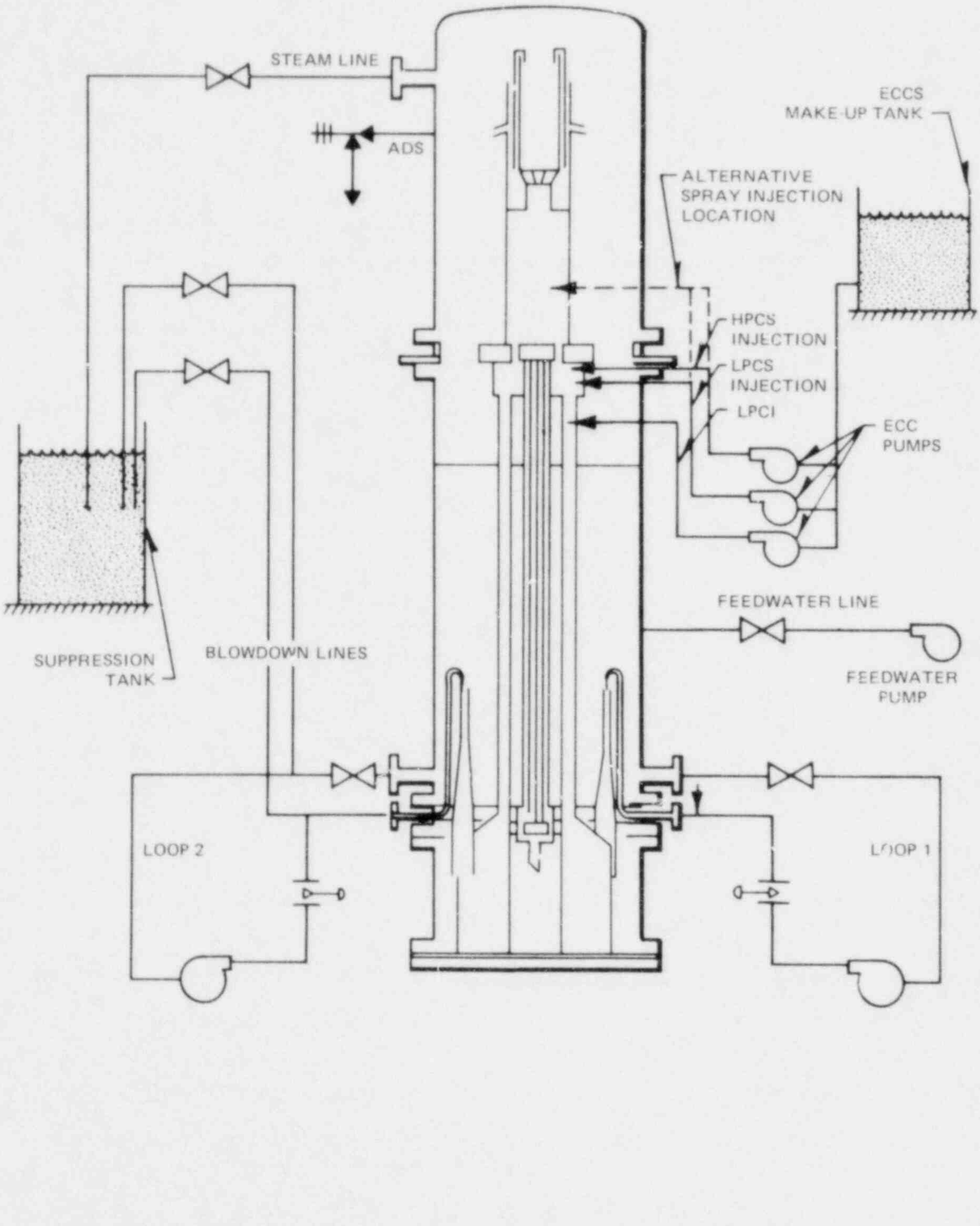


Figure C-1. TLTA5 (Two-Loop Test Appartus Configuration 5) with ECCS

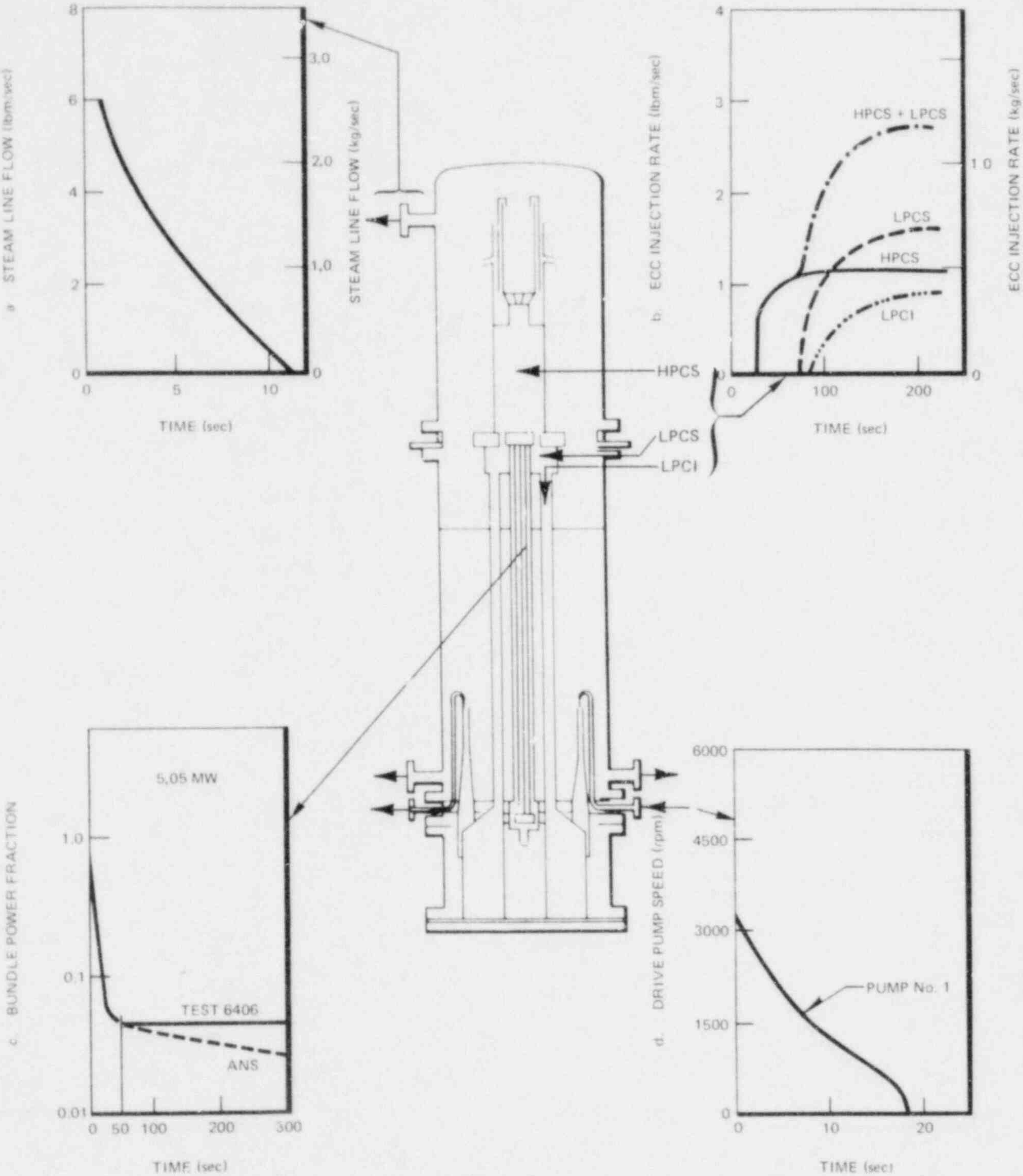


Figure C-2. Controlled Parameter Responses of Reference Test (6406 Run 1 Average Power, Average ECC)

The bundle power transient is shown in Figure C-2c. The power supplied to the bundle was programmed to simulate the stored heat and fission decay heat (based on ANS + 20%) of a BWR bundle. The capability of the mechanical controller had limited the close simulation to only 50 seconds. Beyond that time, the power supply was held constant. It becomes increasingly higher than the fission decay heat calculated from ANS + 20% reaching ~1.8 times the ANS value at the end of the test (~300 sec). A detailed discussion of the bundle power supply has been reported previously.[C-5]

Coastdown of the intact loop drive pump begins immediately in response to the loss of power (Figure C-2d). The response of pump coastdown is governed by the inertia of the rotating components. The inertia of the test pump has been designed to simulate that of the BWR counterpart.

C.2.3 Scenario of Reference Test

C.2.3.1 Early Responses

The responses from BD/ECC-1A tests, before HPCS injection at 27 sec, are similar to those of the previous, 8x8 BDHT tests (with no ECC). The early responses are governed by the liquid level in the downcomer region (Figure C-3a). This level reaches the jet pump suction plane at 7.6 sec and the recirculation line suction inlet at about 10.5 seconds (Figure C-3a).

The bundle inlet flow drops in response to the loss of jet pump flow in the broken loop; it then coasts down (Figure C-3c) following the drive pump (Figure C-2d). The flow reaches a near zero value when the jet pump suction is uncovered at ~7.6 sec. The flow surge associated with lower plenum flashing occurs at ~11.8 seconds, shortly after recirculation line suction uncovery.

The system depressurization rate increases after the recirculation line suction uncovery (Figure C-3b) due to the increased volumetric discharge that accomplishes this transition from predominantly liquid to vapor blowdown.

C.2.3.2 "Snap Shots" Presentation

A series of pictorial depictions — snap shots — of the system at selected instants of the transient is presented in Figure C-4. These snap shots convey an overview of the thermal-hydraulics responses of the TLTA sequentially. They show the qualitative characterization of the conditions in the system and are backed up with detailed, quantitative plots as appropriate.

The first snap shot (Figure C-4a) depicts the system conditions at the onset of HPCS injection which occurs at ~27 seconds from the time of the break in the recirculation line. This instant is a demarcation of difference in boundary conditions between tests with and without ECCS. Substantial mass inventory is seen in the upper plenum (see also Figure C-5 for detail). This inventory was transferred there as a result of lower plenum flashing (LPF) which redistributes fluid from the lower plenum to the core and the upper plenum. An apparent continuum of liquid (or two-phase mixture) keeps the bundle in nucleate boiling (see also Figure C-6 for thermal response details).

As the blowdown proceeds and mass inventory continues to deplete from the lower plenum, the receding two-phase level reaches the jet pump exit plane at ~34 seconds as shown in Figure C-5. The flashing lower plenum fluid discharges with increasing vapor fraction through the jet pumps. The void fraction in the jet pump increases, reducing the hydrostatic head and therefore the pressure difference across the jet pump. Accordingly, the pressure drop across the bundle path, which is in parallel with the jet pump path, also decreases. This decreased pressure difference reduces the vapor upflow and correspondingly the holdup of liquid, due to counter current flow limiting (CCFL), within the bundle. The liquid continuum within the bundle is no longer sustained, and the level drops below the bottom of heated length (BHL) at ~40 seconds (Figure C-4b and also Figure C-5 for detail).

At 40 seconds (Figure C-4b), the bundle is filled by a vapor continuum in place of the liquid continuum. Heater rods begin to dry out and bulk heatup occurs (see Figures C-6a and C-6b for detail). By contrast, the upper plenum inventory remains essentially unchanged during this period: HPCS replenishes the loss while CCFL prevents complete draining into bundle or bypass.

The vapor flow at the top of the bundle diminishes with the reduction in vapor upflow from the lower plenum through the bundle. Another contributing factor is the reduction in heat transfer that accompanies the loss of the liquid continuum.

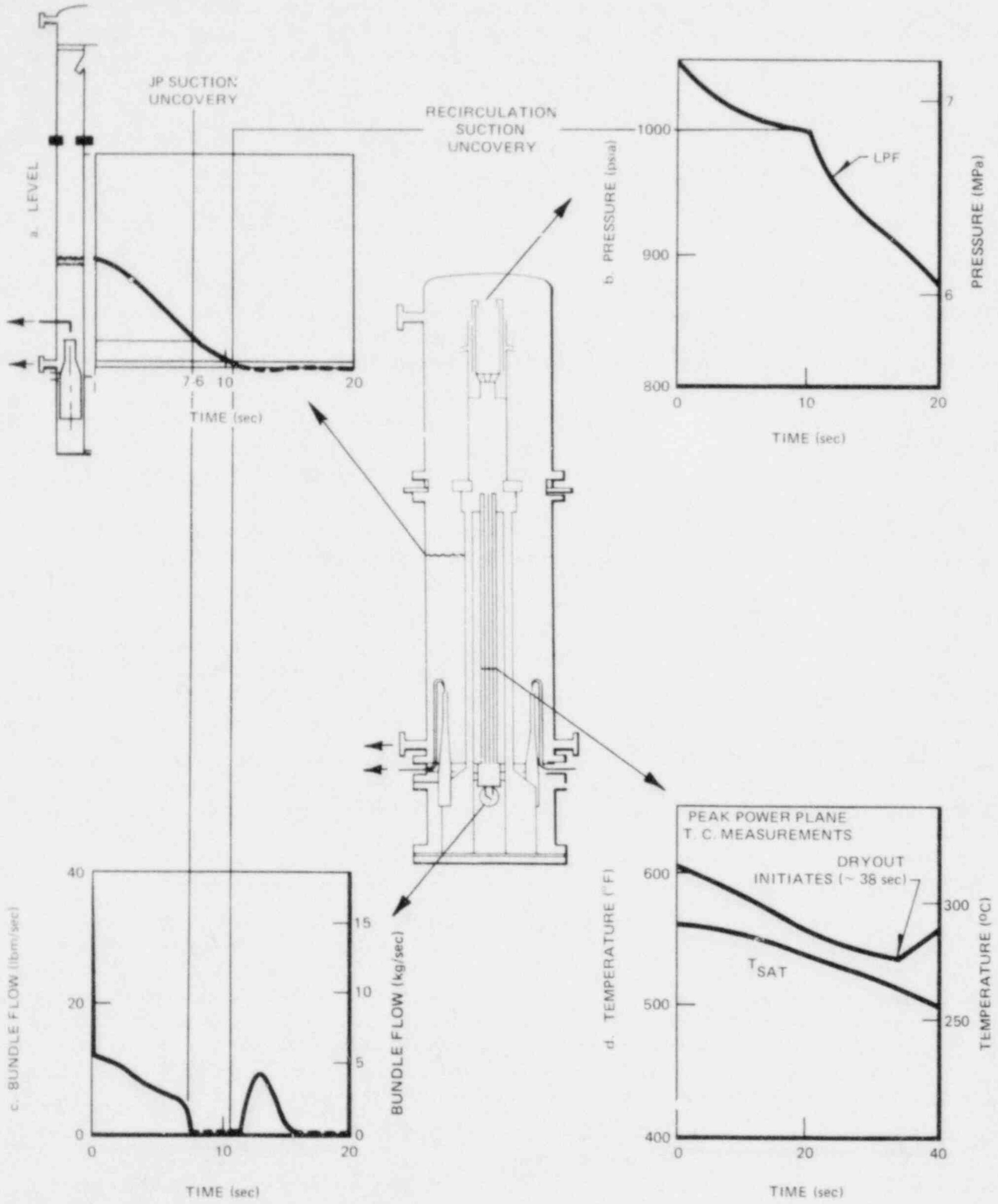
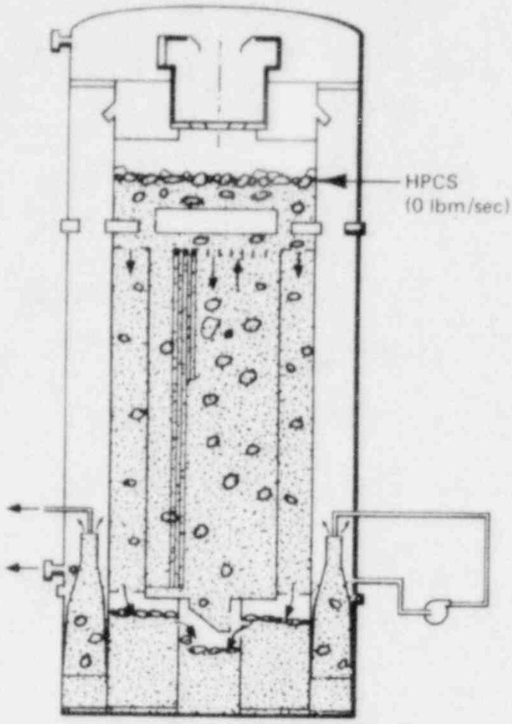
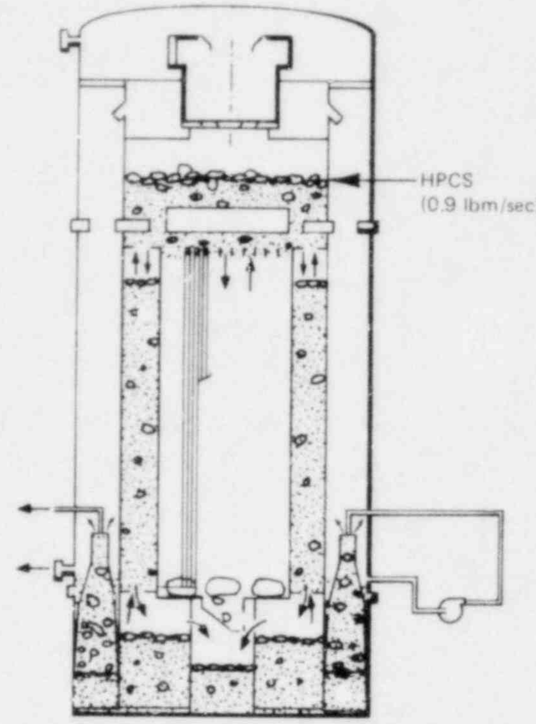


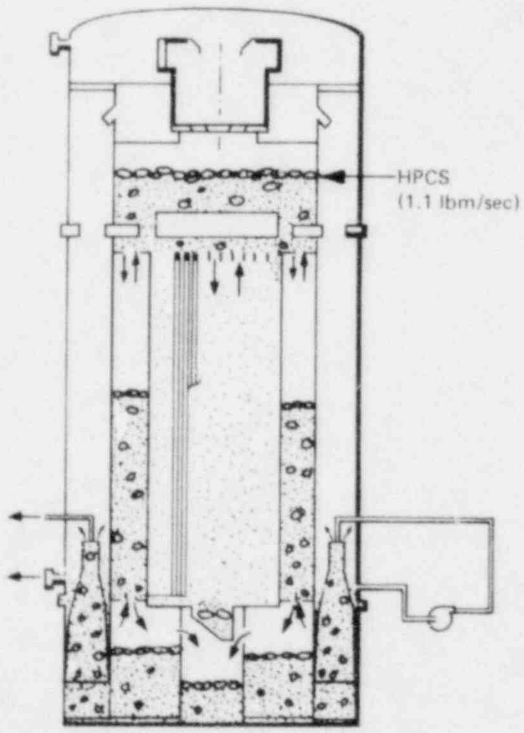
Figure C-3. System Responses in the Early Stage of the BD/ECC Transient for the Reference Test (6406 Run 1, Average Power, Average ECC)



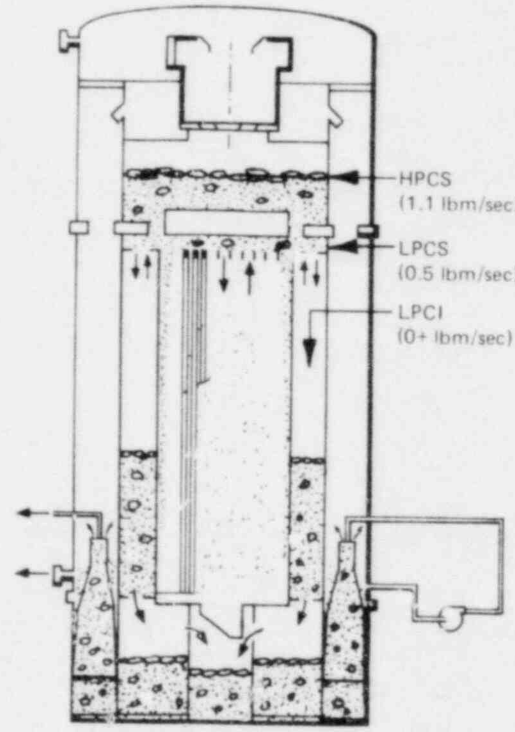
a. 6406/1 HPCS FLOW INCEPTION (27 sec)



b. 6406/1 JET PUMP EXIT EXPOSURE (~ 40 sec)

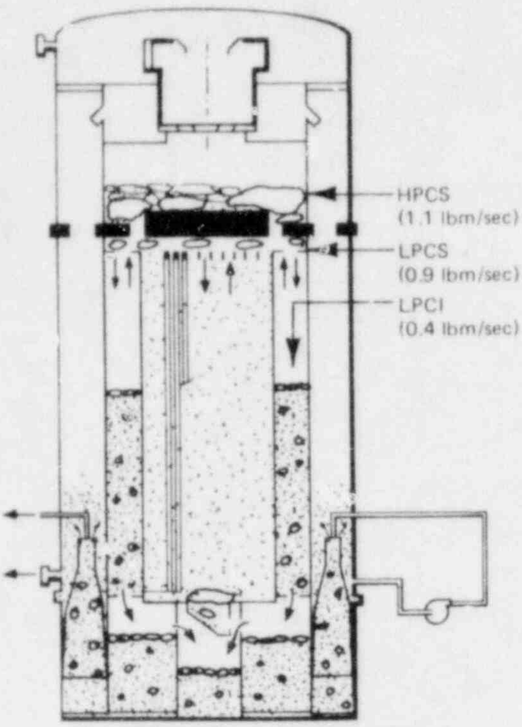


c. 6406/1 P DIFFERENCE DISCERNIBLE (~ 64 sec)

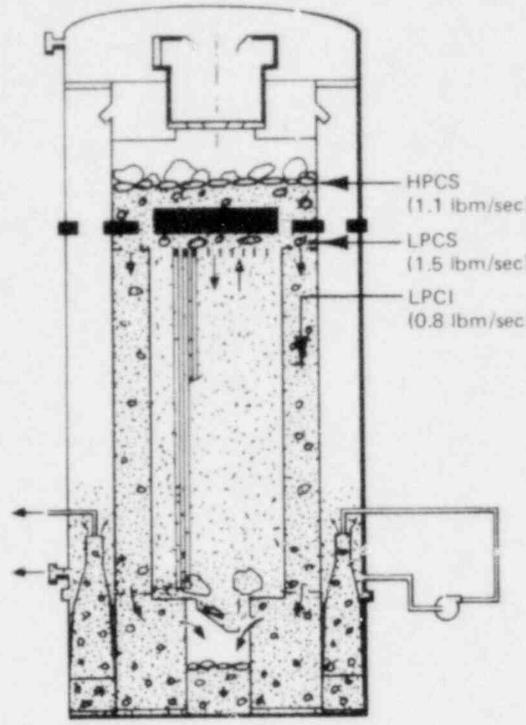


d. 6406/1 PCS AND LPCI INJECTING (~ 90 sec)

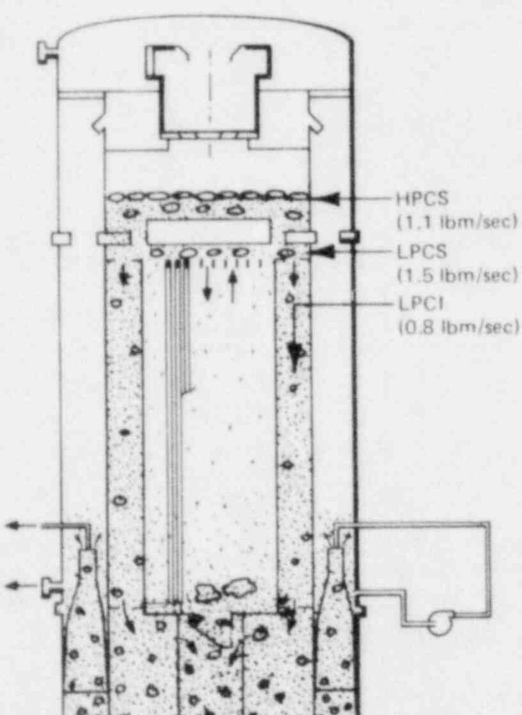
Figure C-4. Snap Shots at Selected Instances for the Reference Test (6406 Run 1, Average Power, Average ECC)



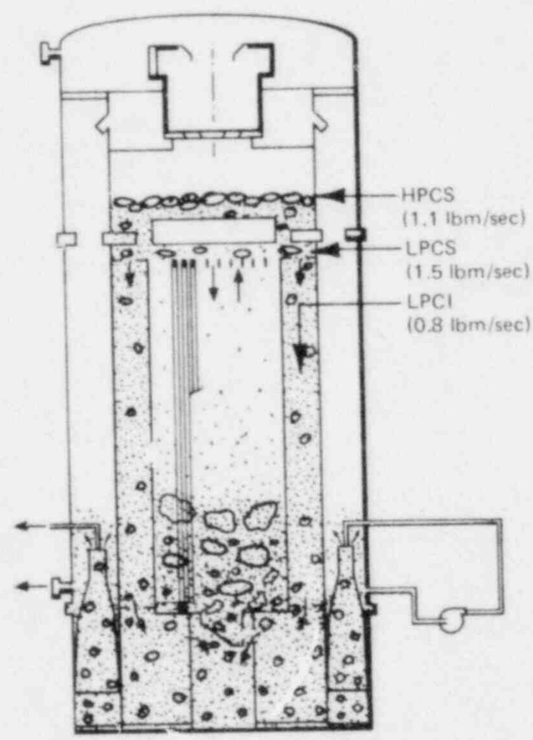
e. 6406/1 CCFL BREAKDOWN AT BYPASS (~ 105 sec)



f. 6406/1 JET PUMP REFILLED WITH LIQUID (~ 150 sec)



g. 6406/1 SYSTEM FILLING (~ 160 sec)



h. 6406/1 TLTA REFILLED (~200-300 sec)

Figure C-4. Snap Shots at Selected Instances for the Reference Test (6406 Run 1, Average Power, Average ECC) (Continued)

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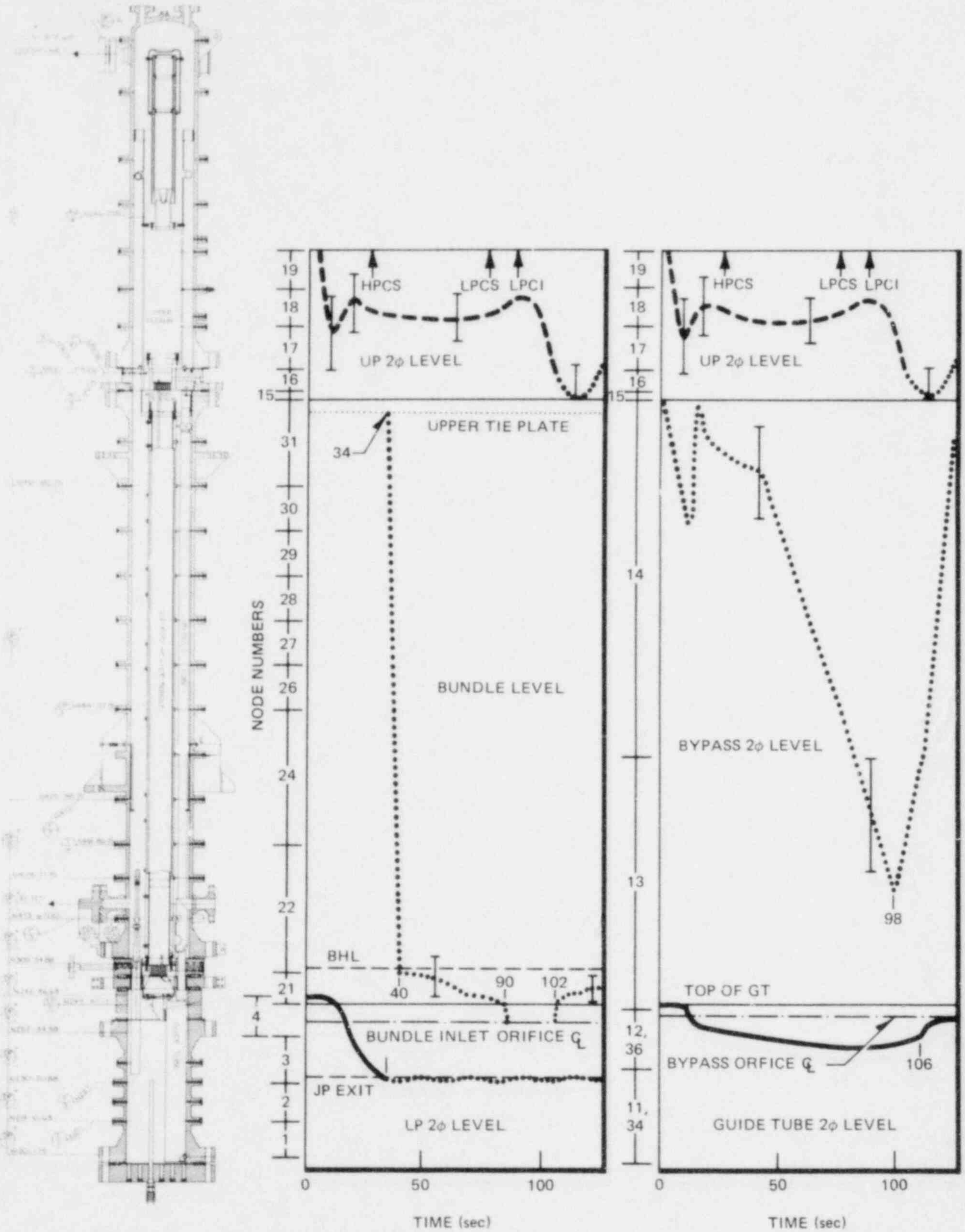

Figure C-5. Two-Phase Mixture Level Responses for the Reference Test (6406 Run 1, Average Power, Average ECC)

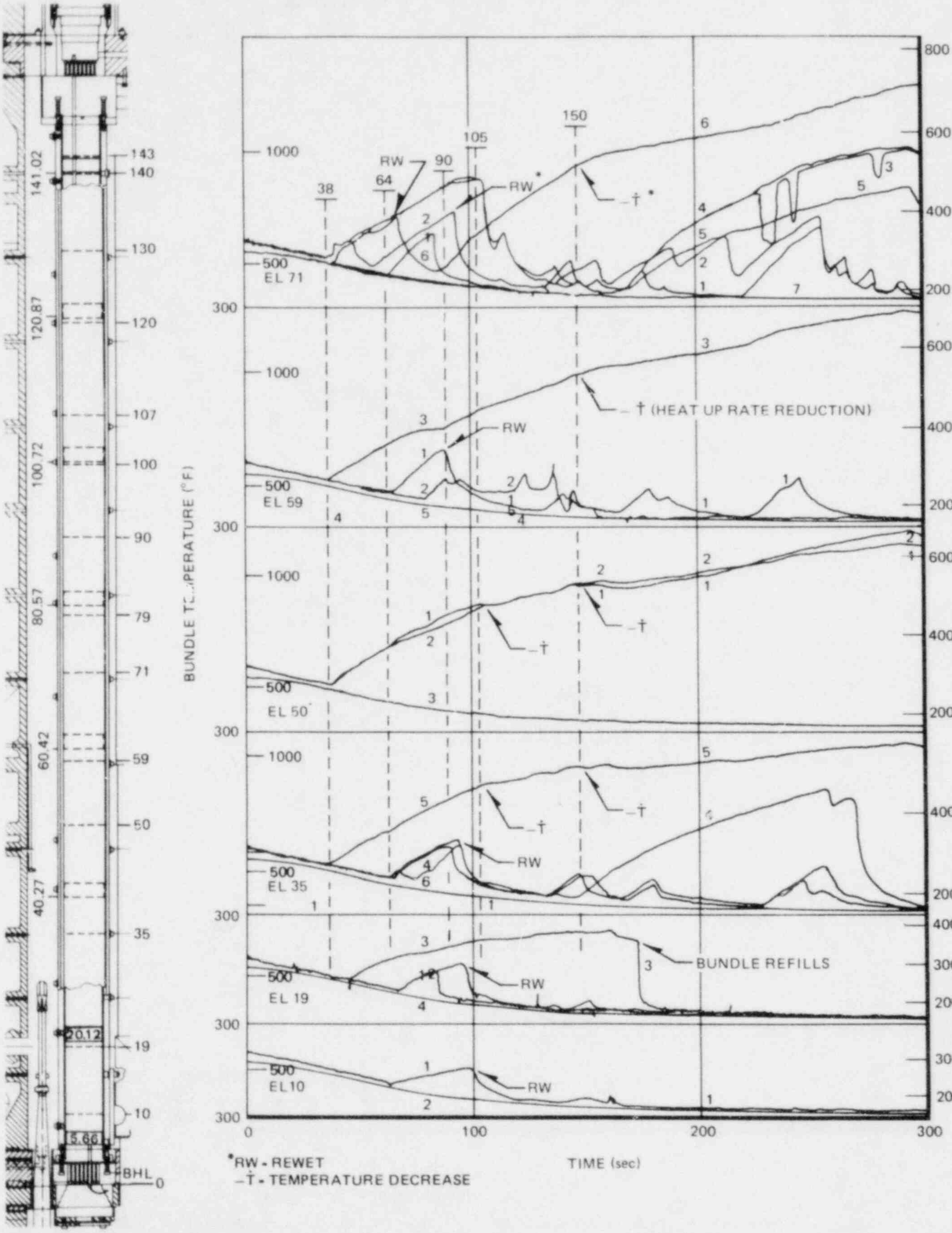

Figure C-6a. Temperature Responses of Lower Half of Bundle for the Reference Test (6406 Run 1, Average Power, Average ECC)

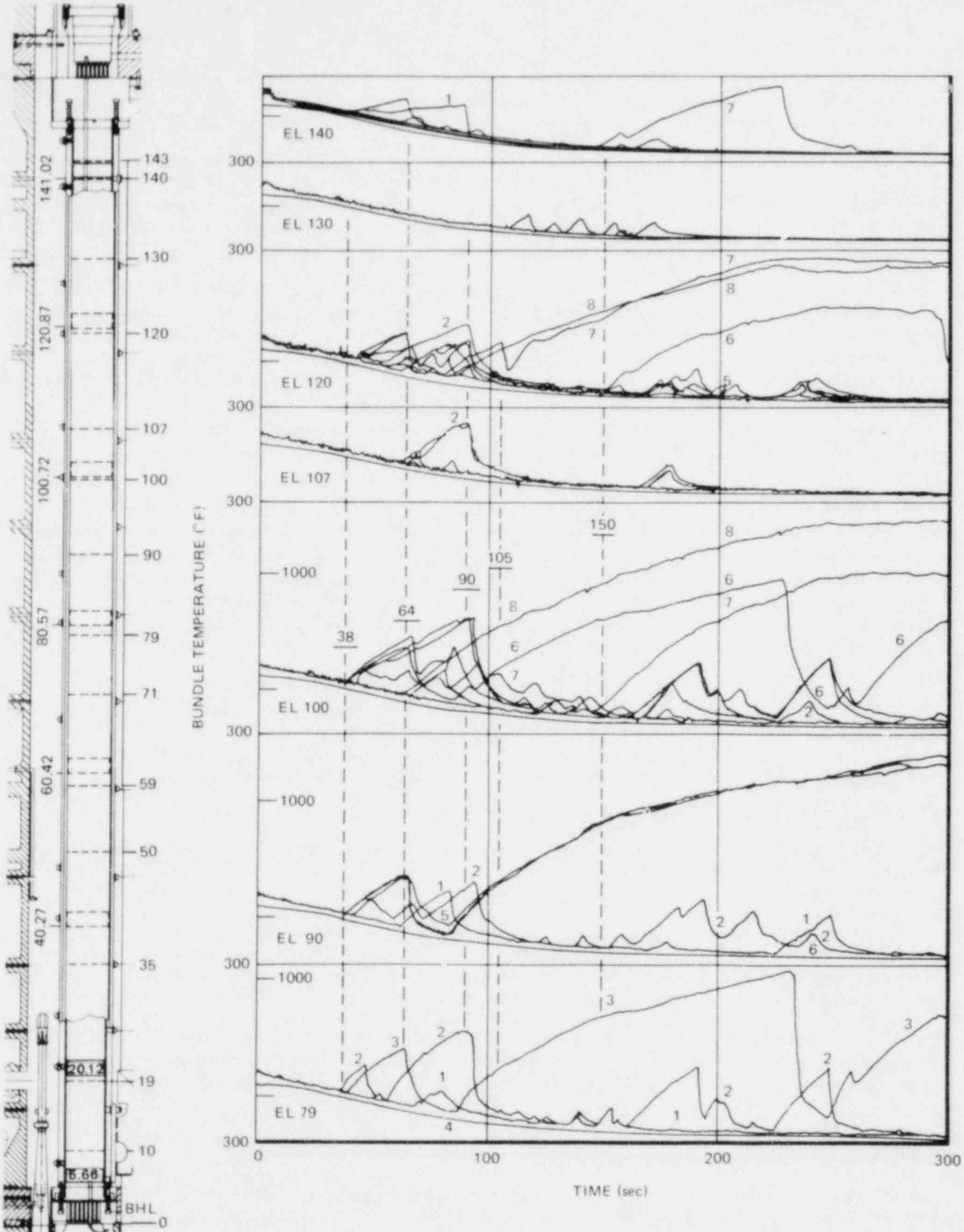

Figure C-6b. Temperature Responses of Upper Half of Bundle for the Reference Test (6406 Run 1, Average Power, Average ECC)

The CCFL conditions at the upper tieplate shift in response to reduced vapor flow from the bundle. Accordingly, an increased amount of liquid drains into the bundle (Figure C-4c), and a few of the previously dried-out rods are seen to rewet. During this period (~64 seconds), rewetting is limited to the upper portion of the bundle.

The LPCS injection begins at ~76 seconds. The injection rate increases toward the rated flow as the system pressure decreases. The upper plenum inventory is maintained by this LPCS mass influx in conjunction with that of HPCS. The vapor upflow from the lower plenum, in the meantime, diminishes as the rate of system depressurization decreases. The liquid downflow at the upper tieplate increases as the CCFL conditions shift at ~90 seconds (Figure C-4). Rewetting of previously dried-out thermocouple locations are seen at the bottom as well as the upper part of the bundle.

Also at ~90 seconds, LPCI begins to flow into the bypass region in an increasing amount (until rated flow has been reached). The net vapor outflow from this region decreases as the influx of subcooled ECC water condenses some of the steam. The CCFL condition at the bypass outlet shifts to allow the liquid in the upper plenum to drain more rapidly into the bypass region (Figures C-4e and C-7). More fluid is now in the bypass region and less in the upper plenum. The hydrostatic head is, therefore, increased in the bypass relative to the bundle. Therefore, more vapor flows through the bundle until the pressure drop across the bundle equalizes the hydrostatic head in the bypass region. The increased vapor upflow contributes to an increase in bundle heat transfer which results in a decrease in the bulk heatup rate at ~105 seconds (Figures C-6a and C-6b).

As the bypass region is being filled, some liquid drains into the guide tube and, alternatively, into the lower plenum. The mixture level in the lower plenum rises. This level rises steadily and at a faster rate after the guide tube is completely full. The jet pump exit becomes sealed by the rising mixture level at ~150 seconds (Figure C-4f). As the mixture fills the jet pump, the hydrostatic head and hence the pressure drop across the jet pump increases. The pressure drop across the bundle increases correspondingly with increased vapor flow from the lower plenum. The increased vapor flow contributes to a further increase in bulk heat transfer that results in the decrease in bundle heat-up rate noted in Figures C-6a and C-6b at 150 seconds.

The bundle begins to reflood as the lower plenum level continues to rise at a more rapid pace after the bypass region has become full (Figure C-4g). The reflooding of the bundle results in rapid quenching below the mixture level (see Figures C-6a and C-6b). The extent of the bundle reflood is limited to the height corresponding to the jet pump suction plane (see Figure C-7 for additional details). The mixture level reaches its height limit at ~220 seconds. The system is maintained at quasi-steady state for the balance of the test which ends at ~300 seconds.

C.2.4 Detailed Responses

The details of responses shown in Figures C-5 through C-7 were the bases from which the scenario for the reference test was constructed. Certain details in these figures have been cited in the preceding discussion. Additional observations are discussed here.

The two-phase mixture levels (Figure C-5) are based on differential pressure measurements as well as conductivity probes. The lower plenum level reaches the jet pump exit plane at about 34 seconds. The level is maintained at the jet pump exit until the bypass fills (Figure C-7). The jet pump exit height thus plays a major role in system responses, as will be discussed later (Section C.3).

Plots of nodal density (Figure C-8) provide information on system inventory distribution. The nodal density of the heated length is seen to be highly voided after 40 seconds. Only the node below the heated length, Node 21, and the top node which includes the upper tieplate and part of the upper plenum, Node 31, show any significant liquid inventory.

C.3 COMPARISON OF TESTS WITH/WITHOUT ECC

Comparisons of data from average-power tests with and without ECC are made in this section. Data from Test 6406/R1 (average power, average ECC) will be compared with those from Test 6406/R3 and/or Test 6007/R26 (average power, no ECC).

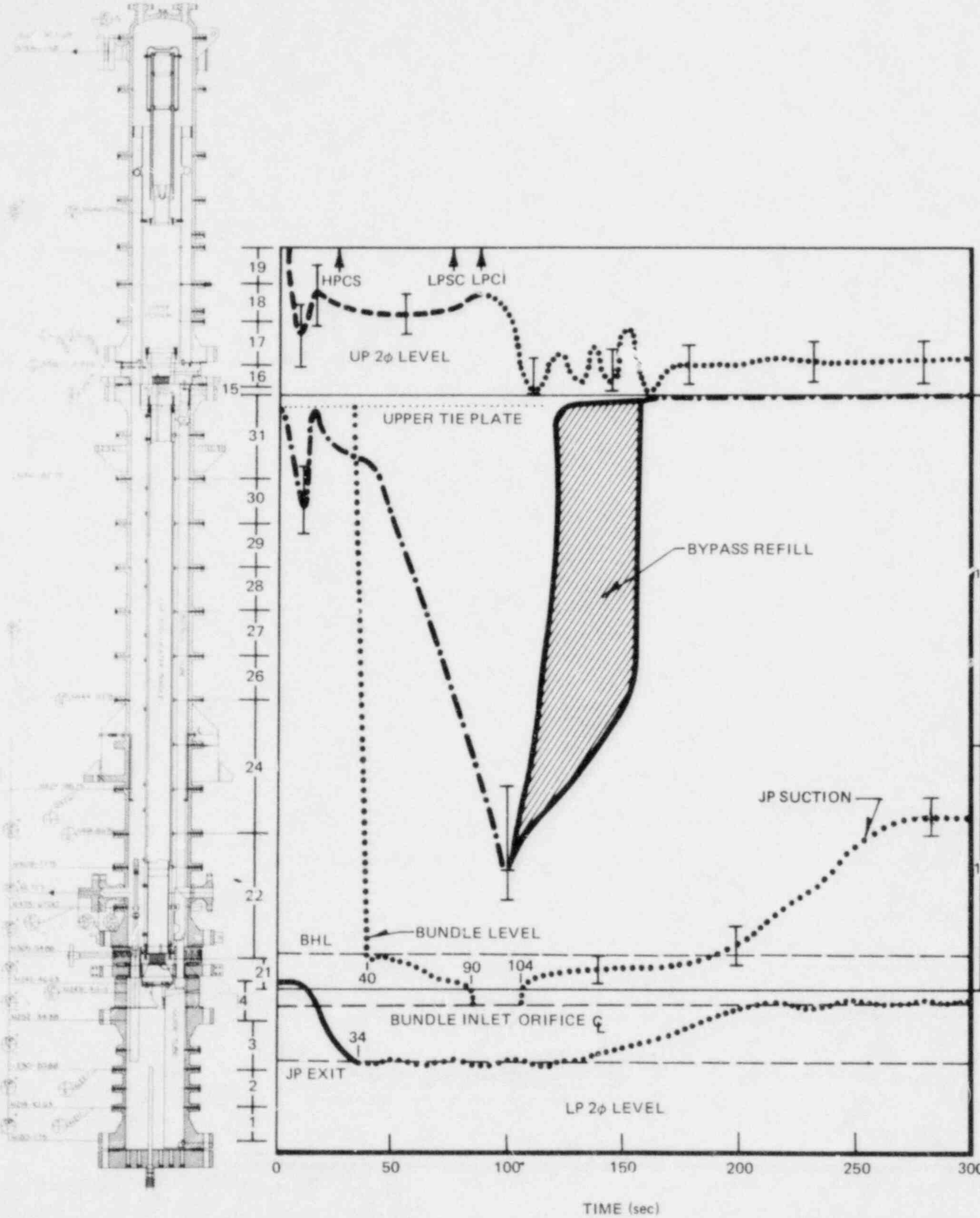

Figure C-7. Two-Phase Mixture Level Responses Illustrating Bundle Refill for the Reference Test (6401 Run 1, Average Power, Average ECC)

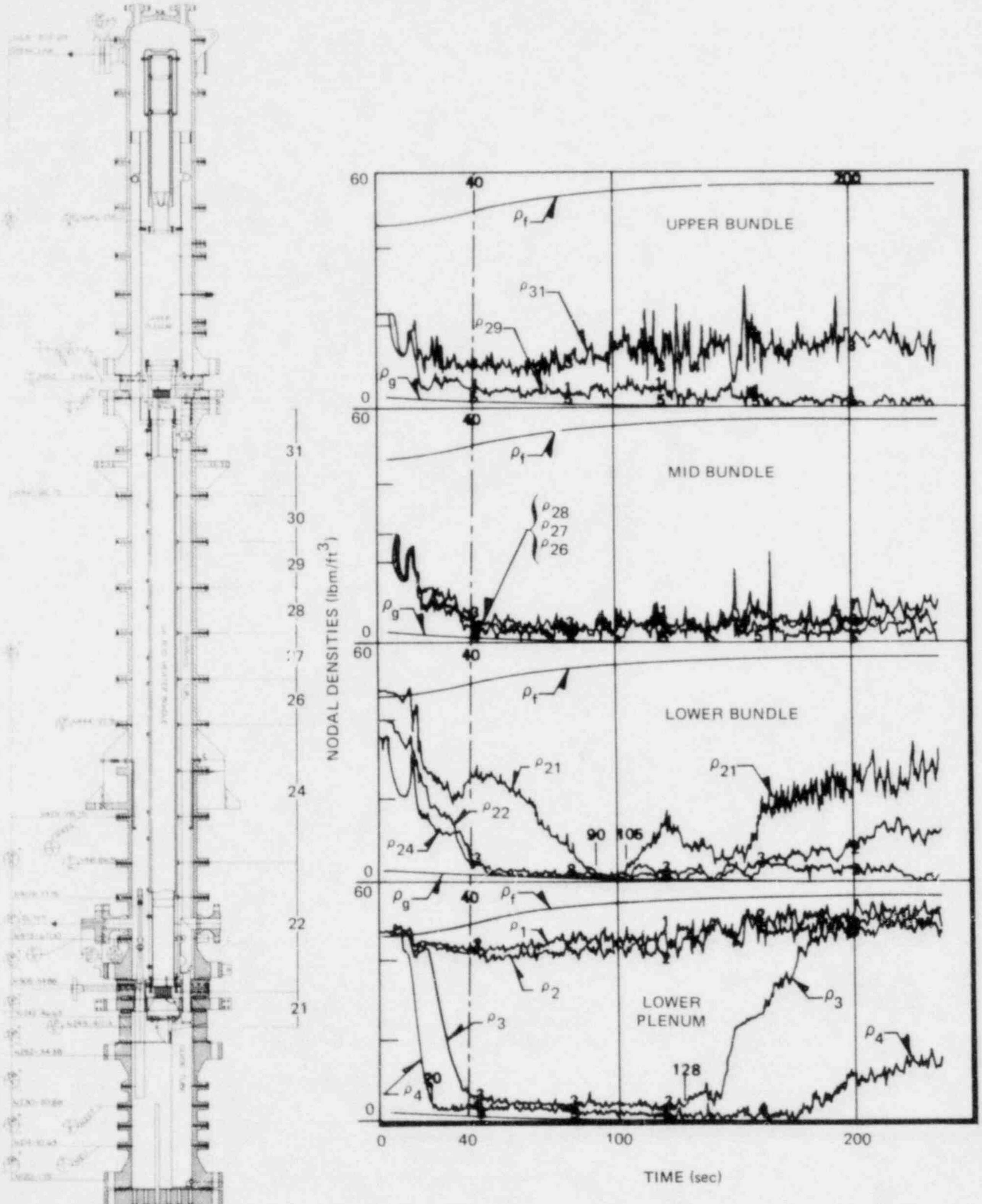

Figure C-8. Nodal Densities in Lower Plenum and Bundle of the Reference Test (6406 Run 1, Average Power, Average ECC)

The system depressurization rate is seen to be lower for the test with ECC after approximately 65 seconds (Figure C-9). The cause of this difference is discussed at length in Reference C-6. It is shown there that the flow emanating from the lower plenum for the test with ECC has a higher moisture content as well as a higher discharge rate through the jet pump. The combined effect is a sequential reduction of volumetric flow through, first, the drive/blowdown line and then the suction/blowdown line. Slower depressurization results from these lower volumetric flows through the breaks.

The system mass inventory is higher, as expected, for the test with ECC. In the upper plenum (Figure C-10a), the fluid is prevented from completely draining due to CCFL at the upper tieplate. In the test without ECC, the inventory there depletes steadily as it continues to flash throughout the transient. In the test with ECC, the core spray maintains the inventory until ~100 seconds. At that time, the LPCI has taken effect in the bypass region to reduce the vapor upflow and therefore allows the upper plenum fluid to drain into the bypass region (see also Section C.2). The ECC injection rate is given in Figure C-10d.

The bundle mass inventories for the two tests are virtually the same (Figure C-10b). In both tests, the bundle is filled with a vapor continuum after ~40 seconds. The mass inventory is derived from the bundle pressure drop measurements which show nearly identical responses for the tests with/without ECC (Figure C-11). The transition from liquid to vapor continuum is shown to occur between 34 to 40 seconds. In the test with ECC, reflooding causes liquid accumulation in the lower part of the bundle later in the transient (~200 seconds).

The lower plenum mass for the test with ECC is maintained rather constant from 35 seconds to 120 seconds (Figure C-10c). The fluid discharged through the jet pump is balanced by the ECC fluid draining from the upper plenum. For the test without ECC, in contrast, the mass inventory in the lower plenum depletes continuously as the fluid flashes off throughout the transient.

The bypass region mass inventories for the two tests are similar prior to LPCI injection (Figure C-10e). Following the LPCI injection (~90 seconds), the bypass region refills for the test with ECC. This filling becomes more rapid as the core spray fluids drain from the upper plenum.

The guide tube mass inventories (Figure C-10f) also show similar response. Discernible difference between the tests occurs when ECC fluid in the upper plenum begins (~75 seconds) to drain into and accumulate in the guide tube.

The responses in the guide tube and especially the bypass region are important in understanding the related response in the bundle. This is because the bypass region and bundle are parallel paths connecting the lower plenum to the upper plenum. The bypass region dominates the hydraulic response along the path since there is more mass inventory there.

The two-phase levels at different regions in TLTA are shown in Figure C-12. The level plots provide information on fluid distribution along each flow path and within each region. They are derived from detailed differential pressure measurements. Measurements from conductivity probes (level probes) are also used as supplementary information.

The upper plenum two-phase levels reflect the mass inventories shown in Figure C-10a. In the case with ECC, the mixture level holds up longer because of the core spray fluid.

The mixture level in the bundle drops to the bottom of the heated length at ~40 seconds. The level remains below the heated length until later when the bundle refloods in the case with ECC.

The lower plenum mixture level falls rather rapidly after lower plenum flashing, reaching the jet pump exit plane at ~34 seconds. The level in the test with ECC lingers at this elevation until it rises later in the transient (~120 seconds). In contrast, the level for the test without ECC falls and holds momentarily at the exit plane then falls below the jet pump exit at 65 seconds.

In the bypass region, the levels for the two tests are initially similar. For the test with ECC, the level rises later (~98 seconds) as the LPCI flows and the spray fluid drain into the region. Similarly, the level in the guide tube rises later for the case with ECC.

As a consequence of the difference in hydraulic responses for the two tests, the thermal responses are also different. In the test without ECC, bundle rewetting and heat-up rate reduction are not observed.

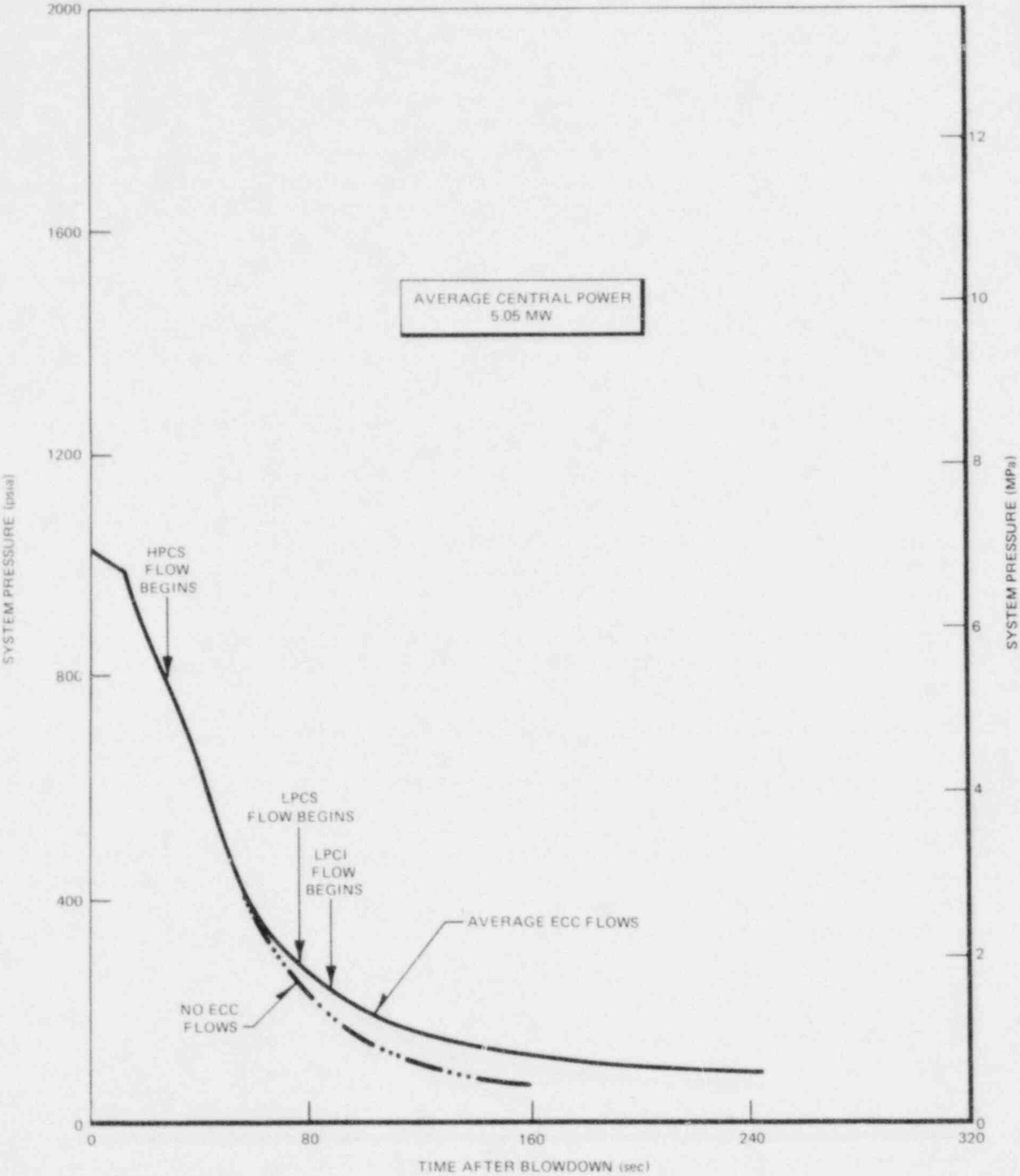

Figure C-9. Comparison of System Pressure Responses between Tests with/without ECC

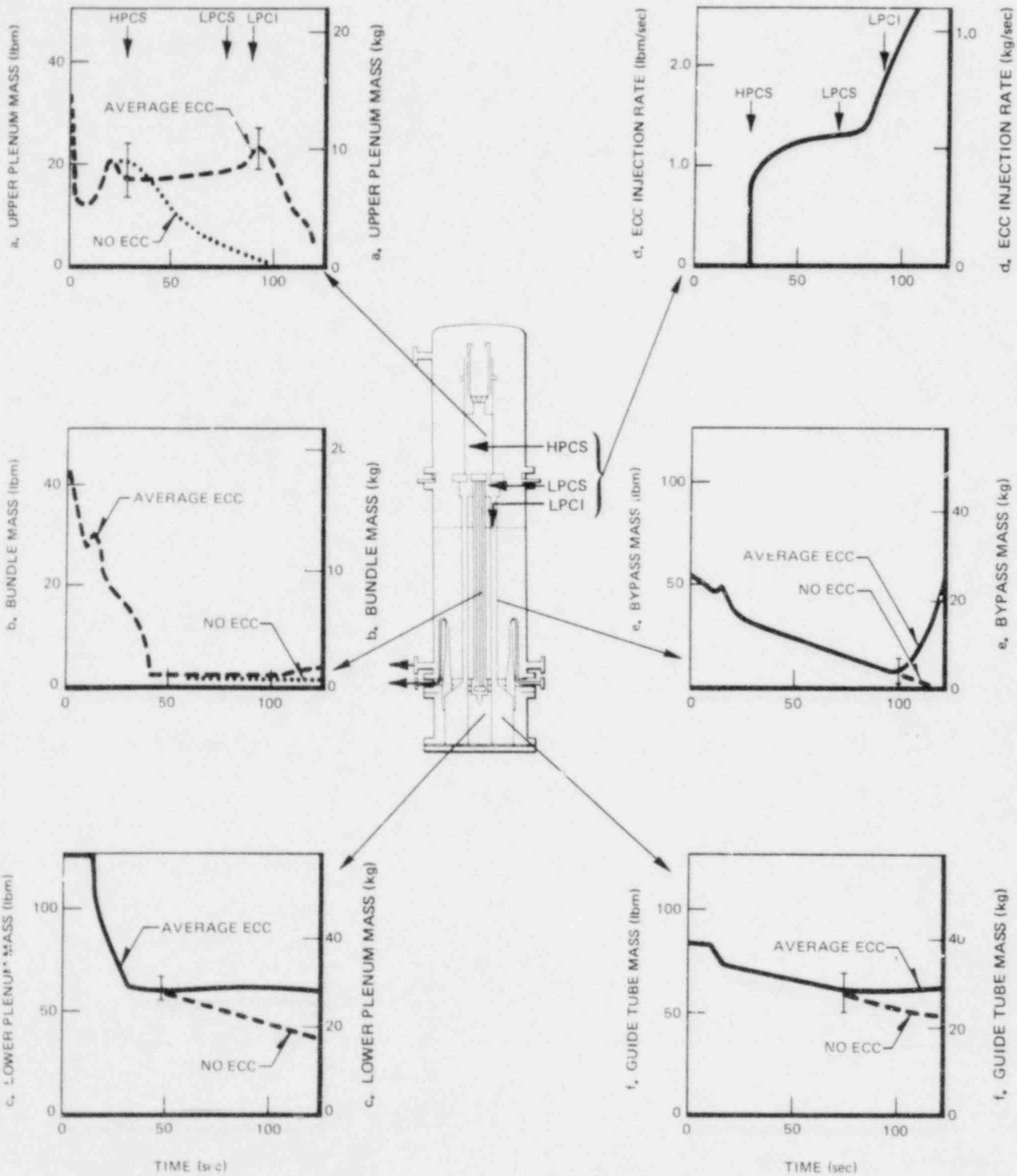

Figure C-10. Comparison of Mass Inventories between Tests with/without ECC

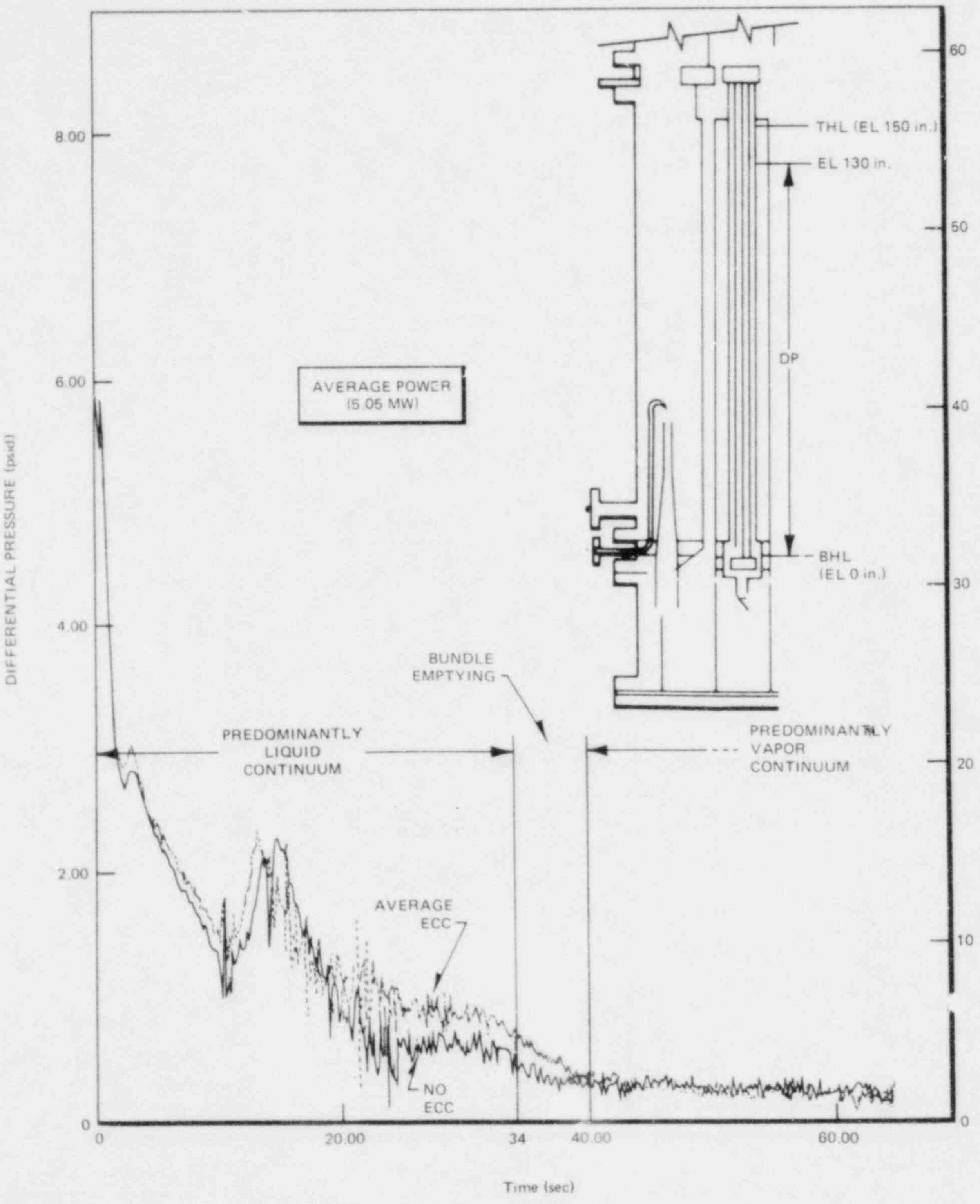

Figure C-11. Comparison of Bundle Differential Pressures between Tests with/without ECC

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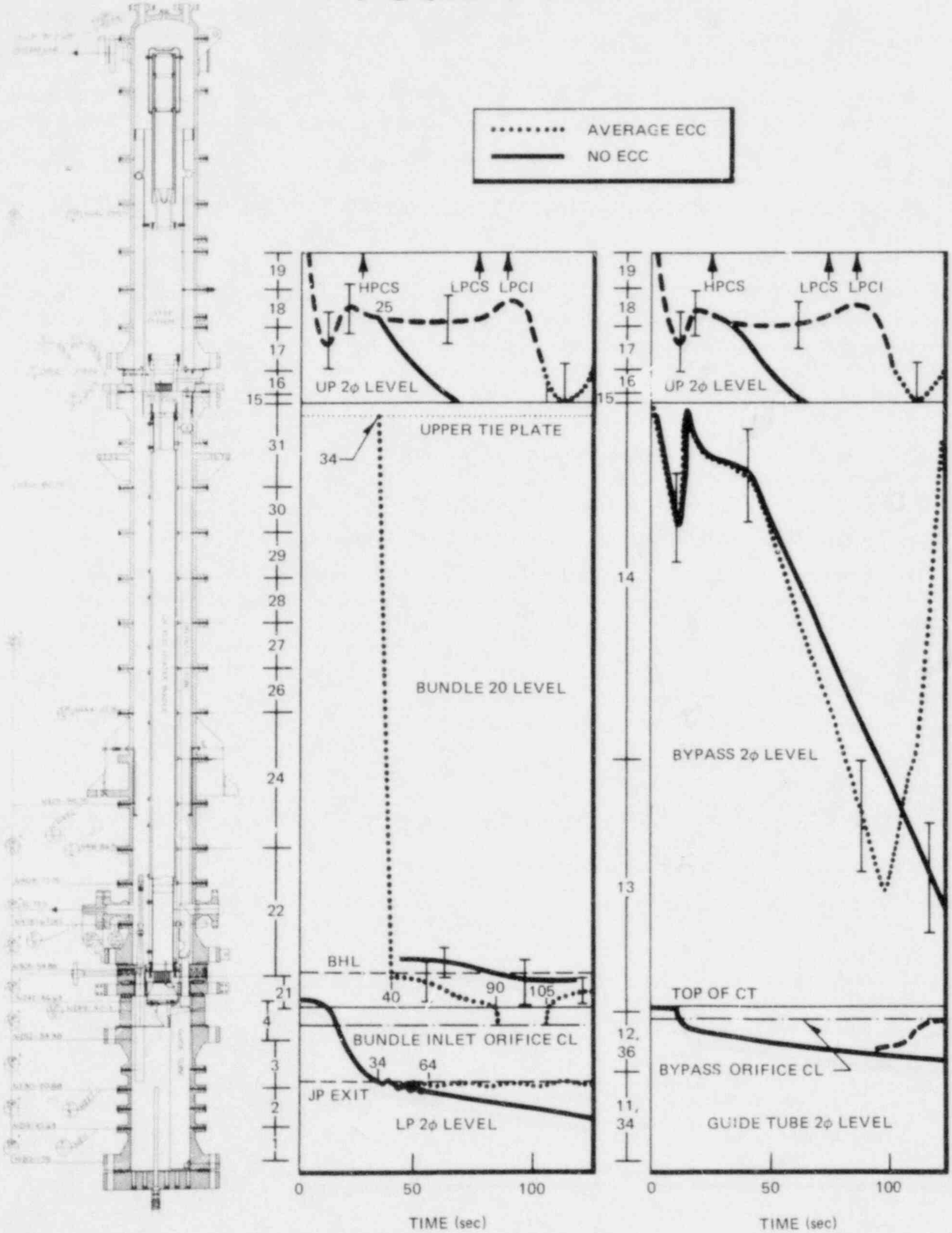

Figure C-12. Comparison of Mixture Level Responses Between Tests with/without ECC

The thermal responses for the two tests are compared in Figure C-13. The lower part of the bundle (Figure C-13a) is cooler in the test without ECC for the first ~100 seconds. This is consistent with an earlier observation (Figure C-12) that the mixture level stays longer there for that test.

Responses from the upper part of the bundle (Figure C-13b) provide evidence of improved heat transfer with ECC. A temperature difference of 375° is seen at ~150 seconds between the tests at 90-in. elevation — location of the peak cladding temperature for the test without ECC.

C.4 HIGHLIGHTS OF SIGNIFICANT DIFFERENCES OF OTHER TESTS WITH ECC INJECTION

C.4.1 Average Power, Low ECC Test (6405/Run 3)

Responses from this test are, in general, similar to those from the reference test as can be seen from Figure C-14. The system pressure of the two test with ECC starts deviating from that of the test without ECC at ~65 seconds. The difference, as has been mentioned in Section 3, is due to higher liquid content in the break flow through the drive/blowdown line. The difference at ~100 seconds between the two tests with ECC is due to the same effect, i.e., difference in liquid content in the break flow through the suction/blowdown line. The lower ECC flow results in lower liquid fraction in the downcomer region at that time.

The lower ECC injection also causes a slower system refill as expected. Nevertheless, the responses and phenomena observed are similar. The overall thermal response of the bundle shows that less ECC fluid results in higher cladding temperature at the peak power plane (Figure C-15).

C.4.2 Peak Power, Low Flow and High Temperature ECC Test (6414/Run 3)

The parameters for this test were intentionally chosen to provide an upper bound, bundle heat-up response. The ECC system was degraded to have low flow, high temperature for the test conducted with peak bundle power (6.49 MW). Nevertheless, the system response from this test is comparable to that from the average power, average ECC test. The hydraulic response of the bundle for the peak power test is similar to that of the average power as shown by the comparison of pressure drop across the bundle (Figure C-16). Because of the higher bundle power, the temperature response of the bundles is different, as can be seen from Figure C-15. It is seen that the peak power bundle has higher temperature as expected. A temperature difference of ~450°F is observed at ~170 seconds when the peak power test was terminated.

C.4.3 Low Power, High ECC Test (6401/Run 4)

The goal of this low power (1.62 MW), high spray flow test was to obtain a data base of system response with particular emphasis on draining of the upper plenum through a peripheral-power bundle. Significant differences of hydraulic responses are seen in this test as compared with the reference test. The differences are:

1. more liquid drains into the bundle due to the combined effect of higher spray flow and lower bundle power;
2. CCFL at side entry orifice holds up liquid in the bundle throughout the test;
3. the bundle is kept well cooled (below 600°F) throughout the transient (Figure C-15) due to the liquid holdup; and
4. subcooling of the upper plenum fluid leads to CCFL breakdown and rapid draining into the bundle.

*NOTE: The time delay of 27 sec for HPCS and 37 sec for LPCS is designed to simulate the startup of diesel generator and opening of valves.

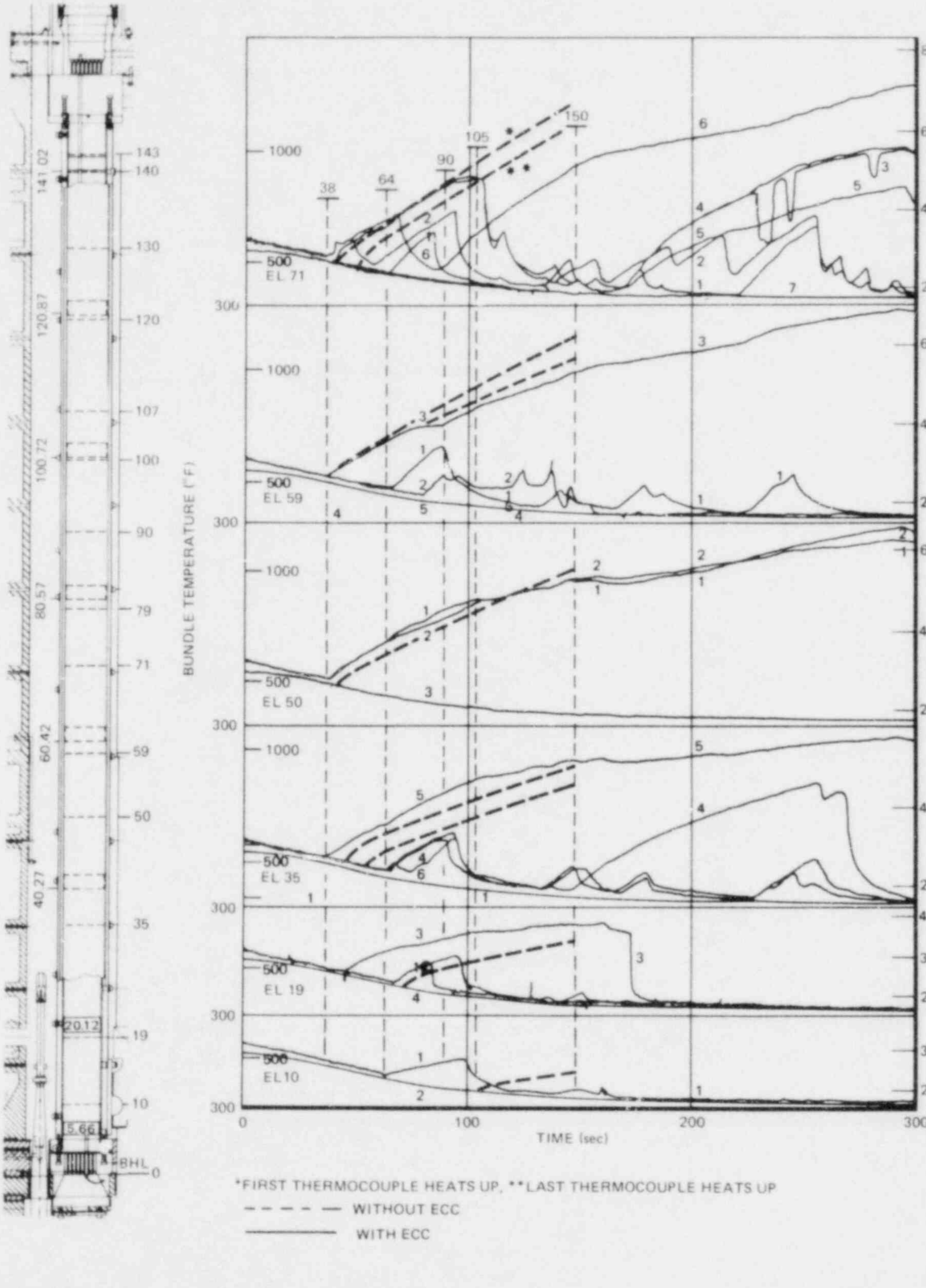

Figure C-13a. Comparison of Temperature Responses in Lower Half of Bundle Between Tests with/without ECC

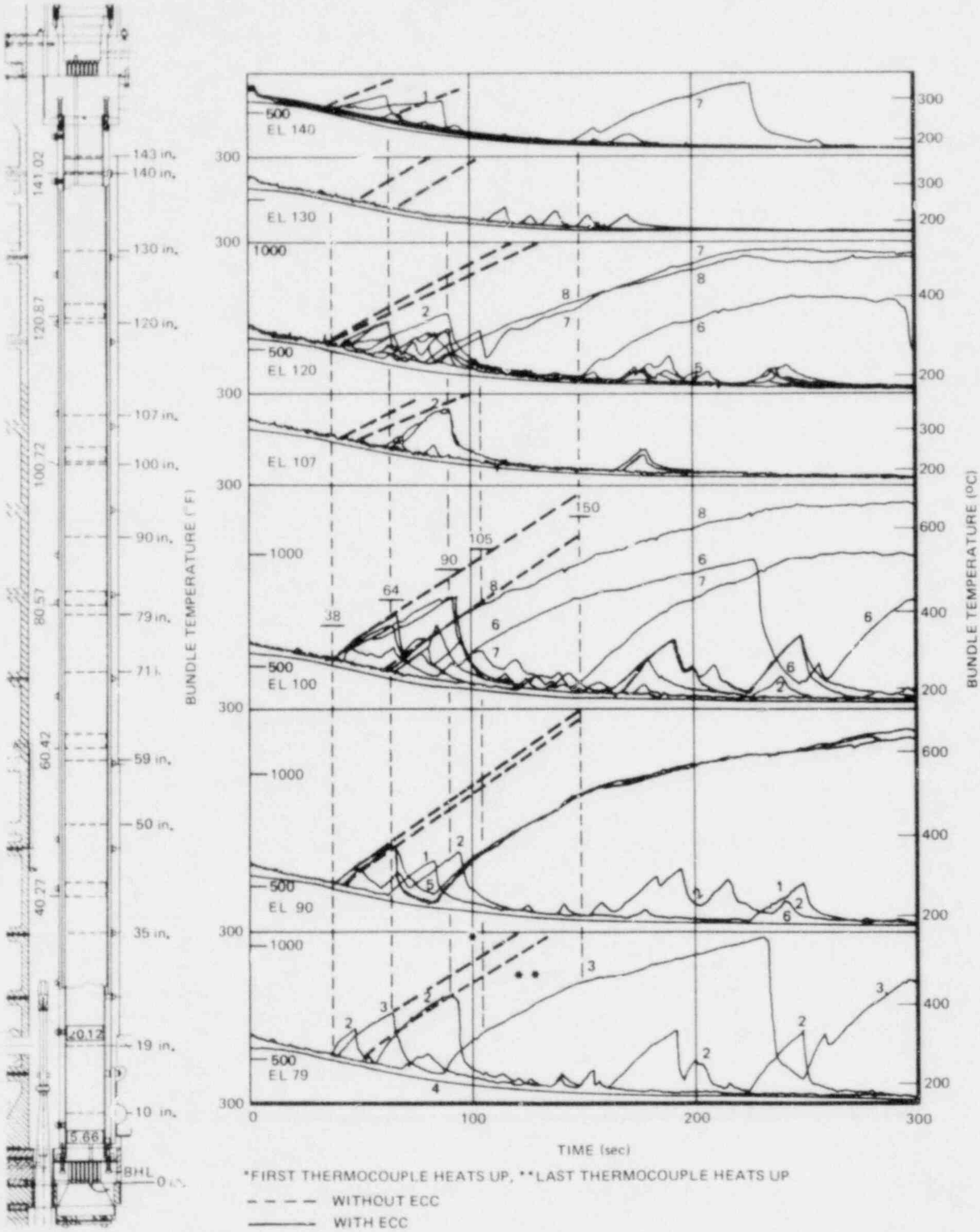

Figure C-13b. Comparison of Temperature Responses in Upper Half of Bundle Between Tests with/without ECC

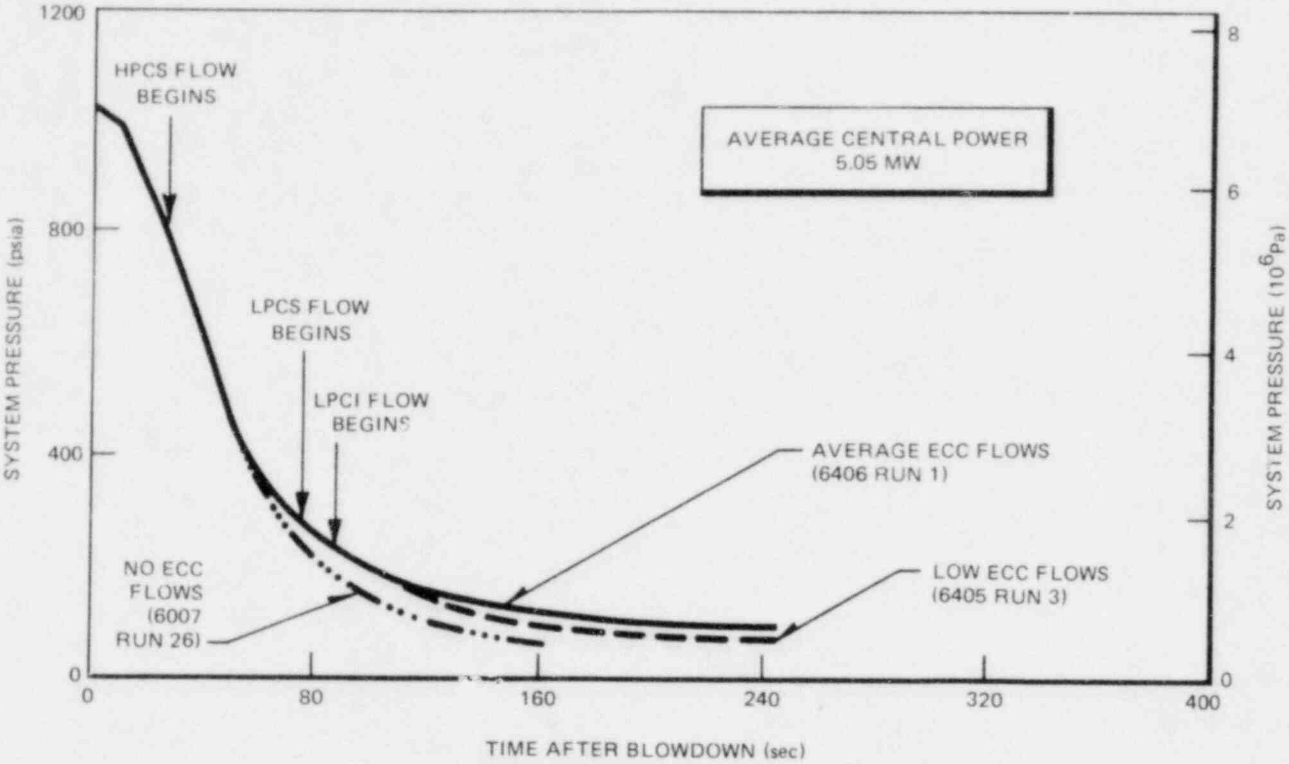

Figure C-14. Comparison of System Pressure Response o' Average Power Tests

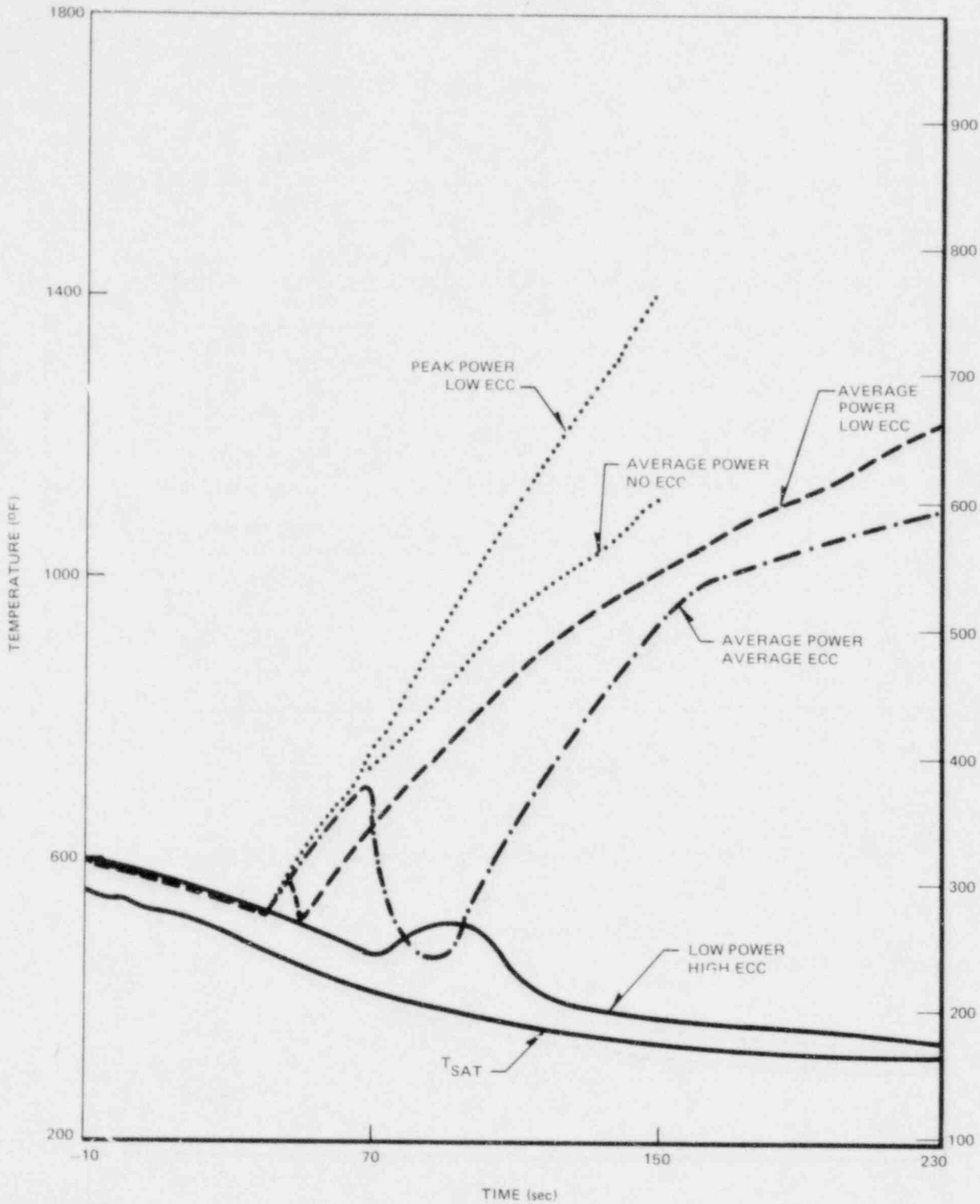

Figure C-15. Comparison of Cladding Temperatures at Peak-Power Elevation (71 in.)

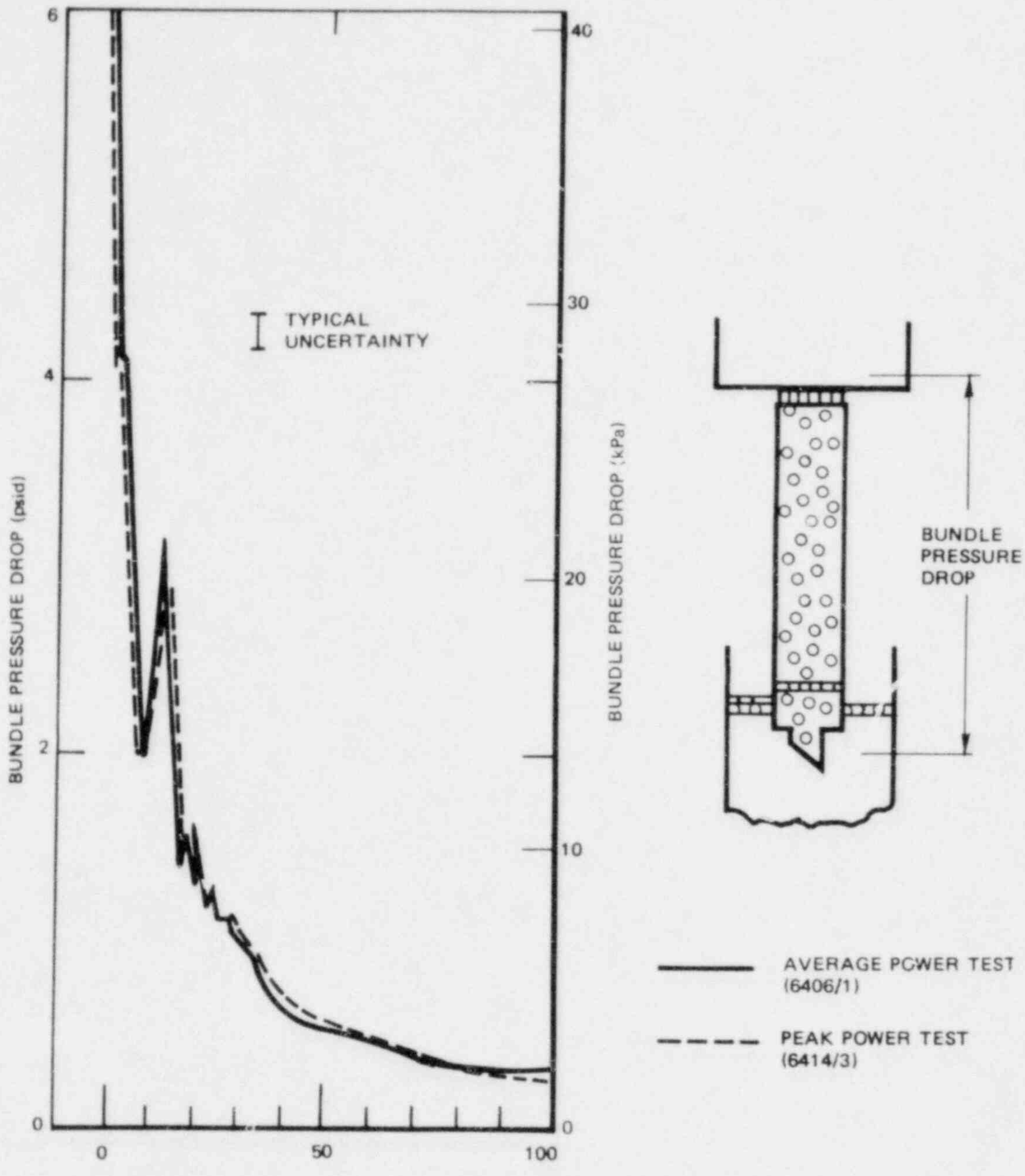

Figure C-16. Comparison of Bundle Inlet to Outlet Differential Pressures

REFERENCES

C-1. J. C. Wood, A. F. Morrison. *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Core Spray Interaction (BD/ECC-1A) Test Plan*, February 1978 (GEAP-NUREG-21638A).

C-2. Contract No. AT (39-24)-0215, "BWR BD/ECC Program Twenty-Ninth Monthly Report," March 1978, Report on Eighth PMG Meeting, March 28-29, 1978, San Jose, Ca.

C-3. W. J. Letzring, Editor, *BWR Blowdown/Emergency Core Cooling Program, Preliminary Facility Description Report for the BD/ECC-1A Test Phase*, December 1977 (GEAP-23592).

C-4 C. G. Hayes, *BWR Blowdown/Emergency Core Cooling Program ECC System Calibration and Performance Verification*, July 1978 (NEDG-21956).

C-5 Transmitted, G. W. Burnette (GE) to E. L. Halman (NRC) and M. Merilo (EPRI), Contract No. NRC-04-76-215, Informal Monthly Progress Report, January 1979.

C-6 Contract No. NRC-04-76-215, "Further Evaluation and Interpretation of BD/ECC-1A Data," July 31, 1979.

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Hitachi-Shi, Ibaraki-Ken 317, Japan

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Kraftwerk Union AG
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D-6000 Frankfurt (Main) 70
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Toshiba Mita Building
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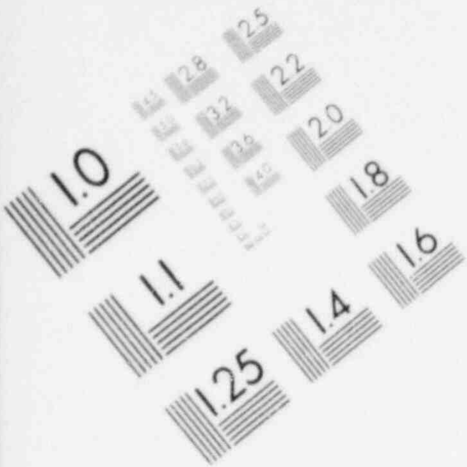

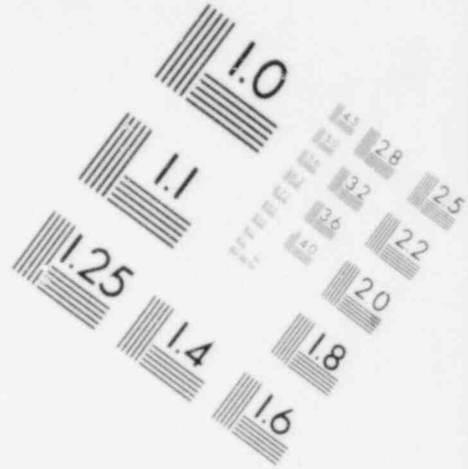

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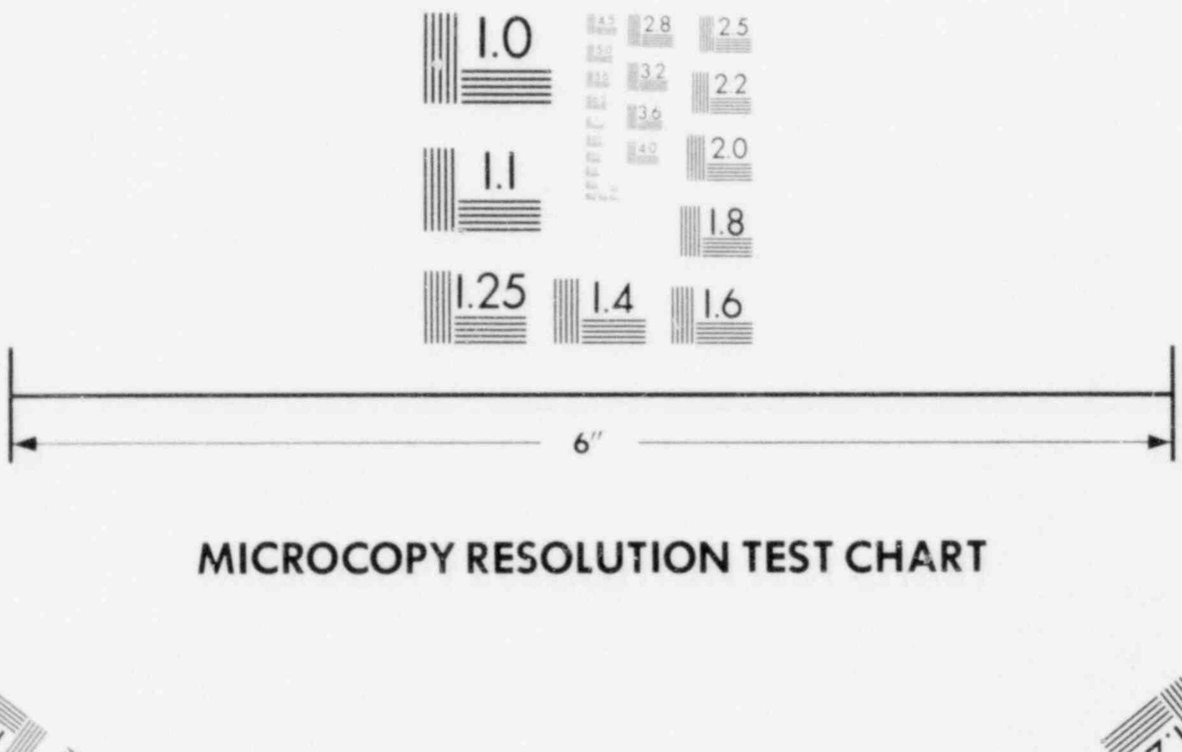

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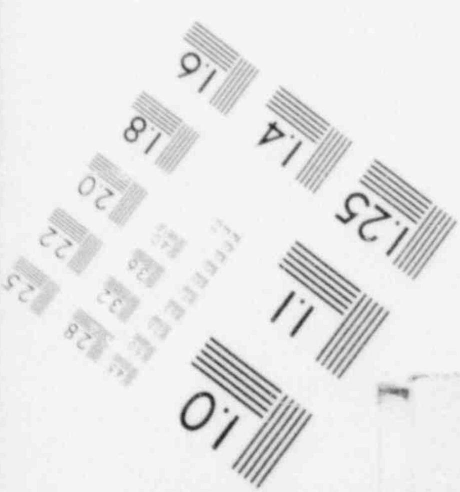

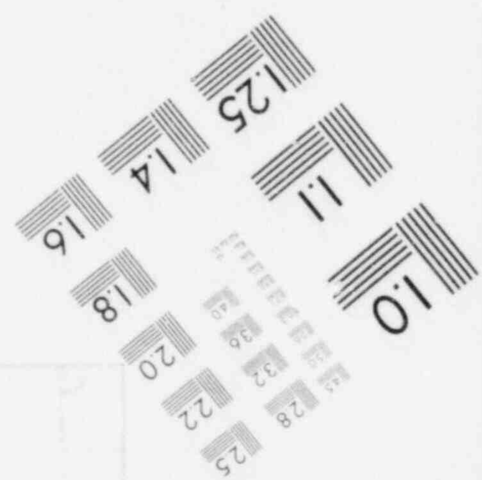

IMAGE EVALUATION
TEST TARGET (MT-3)

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16. ABSTRACT (200 words or less)

Blowdown/Emergency Core Cooling work completed in the third quarter 1979 (July 1, 1979 through September 30, 1979) is summarized. During this quarter shakedown of the TLTA-5A vessel was completed and the first two matrix tests of the present series were conducted. The results from these two tests are being evaluated. Analytical effort in support of planning for the small break scoping test is near completion.

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