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# **BWR Refill-Reflood Program: Task 4.3 — Single Heated Bundle. Final Report**

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## ABSTRACT

Separate effects and system response tests conducted in the Single Heated Bundle (SHB) facility have produced data for evaluating: (a) low flow core spray heat transfer; (b) bundle bottom reflood heat transfer; (c) channel to bypass heat transfer; and (d) BWR refill-reflood controlling phenomena. These data support model development and qualification.

Transient Loss of Coolant Accident (LOCA) experiments conducted in the SHB test facility have demonstrated that an adiabatic bundle system, using steam injection to simulate vaporization, simulates the thermal-hydraulic system response of a heated bundle system. These tests which were conducted by subjecting the adiabatic bundle and then an electrically heated bundle to the same LOCA transients, confirm the application of the adiabatic steam injection technique to a large-scale test facility.

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## ACRONYMS

BHL	Bottom of Heated Length
BP	Bypass
BWR	Boiling Water Reactor
CCFL	Counter-Current Flow Limiting
CE	Conductivity Element
DP	Pressure Difference
ECCS	Emergency Core Cooling System
GPM	Gallons Per Minute
GT	Guide Tube
HPCS	High Pressure Core Spray
LAB	Lynn Adiabatic Bundle
LOCA	Loss of Coolant Accident
LP	Lower Plenum
LPCI	Low Pressure Coolant Injection
LPCS	Low Pressure Core Spray
LTP	Lower Tie Plate
PSIA	Pounds Per Square Inch Absolute
SEB	Separate Effects Bundle
SEO	Side Entry Orifice
SET	Separate Effects Tests
SHB	Single Heated Bundle
SP	Standpipe
SSTF	Steam Sector Test Facility
TBP	Top of Bypass
TC	Thermocouple
THL	Top of Heated Length
TLTA	Two Loop Test Apparatus
TRAC	Transient Reactor Analysis Code
UP	Upper Plenum
UTP	Upper Tie Plate



## 1.0 Introduction

### 1.1 Objectives

The objectives of the Single Heated Bundle (SHB) Task are:

- a) To obtain test data to identify and evaluate system interaction phenomena that control heated bundle thermal-hydraulic performance during the refill-reflood phase of a postulated loss-of-coolant accident (LOCA).
- b) To provide single heated bundle separate effects and system interaction data in support of model development and qualification.
- c) To provide reference single bundle system response data as a basis for evaluating the application of the adiabatic steam injection technique in the Steam Sector Test Facility (SSTF).
- d) To develop an adiabatic steam injection bundle design for use in the SSTF that simulates steam generation resulting from heated bundles; and develop a method for determining representative steam injection rates.

The relationship of the SHB task to the overall program is outlined in Reference 3.

### 1.2 Single Heated Bundle Test Facility

The Single Heated Bundle (SHB) Test Facility, shown schematically in Figure 1-1, is a 1/624 volume scale mock-up of a BWR/6-218 reactor. The facility is designed to simulate the refill-reflood system response to a postulated loss of coolant accident (LOCA); and to obtain separate effects test data under quasi-steady conditions. See References 1 and 2 for further facility description.

The facility accommodates either a full scale electrically heated rod bundle, or an adiabatic bundle designed for the Steam Sector Test Facility (SSTF). The adiabatic bundle uses steam injection to simulate vaporization due to rod heat transfer. This approach makes it possible to compare system response data using the adiabatic bundle with similar data using the heated bundle.

The SHB facility is designed to operate at constant; near atmospheric, pressure. Higher pressure conditions are simulated by injecting steam in the lower plenum and guide tube regions to simulate flashing from depressurization, and scaling the counter-current flow limiting (CCFL) steam flows at the channel inlet side entry orifice (SEO) and the upper tie plate (UTP). Scaling of this phenomenon simulates the same drainage into and out of the channel as would occur at higher pressures. This pressure scaling has been demonstrated by comparing SHB system response scaled to Two Loop Test Apparatus (TLTA) conditions, with the

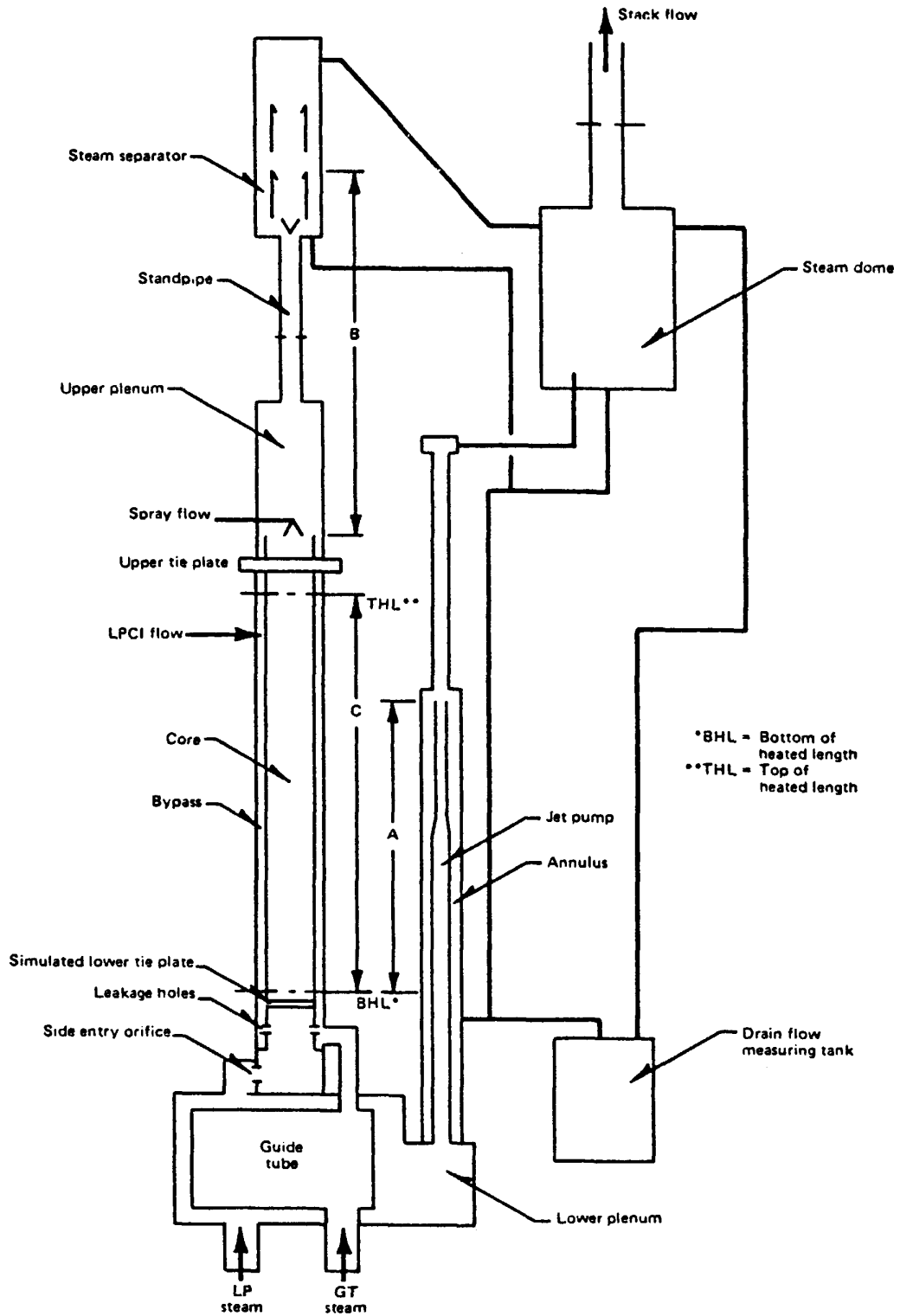


Figure 1-1. Single Heated Bundle Test Facility

actual TLTA refill-reflood performance. These demonstration tests are summarized in Appendix A.

The major features of the facility are shown in Figure 1-1. These features include a full-scale simulated fuel channel volume, and scaled lower plenum, guide tube, core, bypass, upper plenum, separator, steam dome, annulus, and jet pump (non-active). The height of the core is full scale (length C). The height of the top of the jet pump above the bottom of the heated length of simulated fuel pins (length A), and the height of the first spillover point in the steam separator above the top of the fuel channel (length B), are also full scale. The ECC systems are simulated with (a) liquid spray injection 26 inches above the upper tie plate for high pressure core spray (HPCS) and low pressure core spray (LPCS) flows, and (b) liquid injection into the bypass region on all four sides of the fuel channel at 18.7 inches below the upper tie plate for low pressure coolant injection (LPCI) flows. The spray and the LPCI share a common water supply, and thus are injected at the same temperature. The spray and LPCI flows may be individually controlled from 0.5 to 30 gpm and 1 to 10 gpm, respectively, at temperatures from ambient to near saturation. The test facility and its operation are described in detail in Reference 1 and 2.

Tests were run to verify the facility operation and to calibrate important facility characteristics. Tests which address bundle characteristics were run for each of the three bundle designs used, i.e., (a) Stage 1 electrically heated simulated fuel rods utilized to evaluate system performance; (b) Stage 2 Lynn Adiabatic Bundle (LAB) which simulates the bundles installed in the 30 degree SSTF; and (c) Stage 3 electrically heated simulated fuel rods used to provide separate effects test data.

The calibration tests, which are reported in Appendix B, include: (a) bypass to channel leakage, (b) side entry orifice (SEO) pressure drop factors for peripheral orifices (1.247" diameter) and central orifices (2.43" diameter), (c) jet pump and core single phase steam flow split from the lower plenum, (d) jet pump loss factor, and (e) upper tieplate CCFL for the Lynn Adiabatic Bundle (LAB).

### 1.3 Demonstration of Adiabatic Injection

Adiabatic bundles, which use steam injection to simulate vaporization due to rod heat release, are used in the Steam Sector Test Facility (SSTF). Verification that this steam injection technique adequately simulates the response of a system with heated bundles is empirically demonstrated in the SHB facility. This is accomplished by running several sets of system response tests with the Lynn Adiabatic Bundle (LAB) and the Single Heated Bundle (SHB), and comparing the refill-reflood responses of the bundles. Similar system responses confirm the adequacy of the adiabatic injection technique.

The methodology used to determine the adiabatic steam injection rates for the SSTF is based upon estimation of the total steam generation rate by the fuel rods in the BWR transient being simulated. The steam generation rate is the steam produced by the decay power and the release of stored energy in the fuel rods and other core components. The technique is used in the SHB Task for determining the injection rates in the adiabatic bundle reference tests.

#### 1.4 Model Development and Qualification Data

The SHB/ECCS Test Loop is a system mock-up of the important volume regions of a BWR. This provides an opportunity to perform tests which produce the same phenomena, and the same interactions between region, that would occur during a BWR LOCA. Tests are run with specific parameters and conditions to investigate a hypothesized system response, and to identify other parameters or phenomena which are important. These results can be used for model development work.

A number of phenomena models and correlations are identified in the various composite LOCA and low flow heat transfer models. The SHB Task provides separate effects tests over a range of conditions for further development and improvement of these models. Core spray heat transfer performance is investigated over a range of low spray flow rates and over a range of steam flow rates from the lower plenum. Core to bypass heat transfer is an investigation of the effectiveness of the fluid in the bypass in removing heat through the channel wall. Reflood heat transfer, entrainment, core liquid carryover, condensation effects of lower tieplate (LTP) leakage, spacer differential pressure, bundle temperature history, and quench front propagation are addressed in a group of Reflood Heat Transfer (RHT) Tests. CCFL is evaluated at the Upper Tie Plate (UTP). Data from a number of SHB tests provide transient refill thermal-hydraulic data for preliminary model assessment.

## 2.0 Summary of Test Results

### 2.1 Adiabatic Bundle Demonstration Tests

These tests empirically demonstrate that steam injection into an adiabatic bundle is an acceptable technique for simulation of steam generation in a heated bundle during refill-reflood tests. Verification of this steam injection technique confirms that the technique is adequate for use in the Counter-Current Flow Limiting (CCFL)/ Refill System Effects Test (SET) in the Steam Sector Test Facility (SSTF) under Task 4.4. Figure 2-1 identifies the test runs used for direct comparison of results to demonstrate the adequacy of the pressure scaling basis and the adiabatic bundle simulation. The experimental base for evaluating the adiabatic bundle simulation consists of six pairs of tests. For each of the test pairs, the same sequence of events occurred and the same phenomena controlled the refill of the adiabatic and heated bundle regions. The heated bundle-coolant heat transfer feedback was accommodated with a simplified core steam injection transient in the adiabatic bundle. In each test case the adiabatic core reflood time matched the heated bundle reflood time within the expected limits. These test cases covered the range of expected BWR refill-reflood LOCA conditions as well as a TLTA simulation and an extreme, non-typical "hot-dry" bundle simulation. This demonstrates that the adiabatic core steam injection is appropriate for use in the SSTF.

### 2.2 Separate Effects Tests

The separate effects heat transfer data are presented in Section 3.2. These data include: (a) low flow core spray heat transfer from the bundle, (b) bottom flooding bundle heat transfer, and (c) channel wall heat transfer to the bypass.

The core spray heat transfer tests all exhibit monotonically increasing bundle temperatures. The heat up rates are inversely proportional to the spray flow for the tests with no bundle inlet steam flow. The bundle midplane temperature increases 550 F in 150 seconds for 0.5 gpm spray flow, and 300 F for 3.0 gpm. The initial bundle power for each test is 250 kw, which is decayed to 218 kw at 150 seconds. The initial rod temperatures, which are relatively uniform across the bundle, vary from 1100 F at top and bottom to 1420 F at the maximum heat flux density midplane, as shown in Figure 2-2.

The heat up rate of 480 F per 150 seconds for 1.0 gpm spray flow and zero inlet steam flow increases slightly with a steam flow of 200 lb/hr and then decreases to 220 F per 150 seconds as the steam flow is increased to 600 lb/hr. Channel inlet steam flow also tends to smooth out any temperature asymmetries.

In a typical controlled bottom reflood heat transfer test (#2314) the initial dry bundle midplane temperature is approximately 1100 F. The power is set at 250 kw and decays to 218 kw in 150

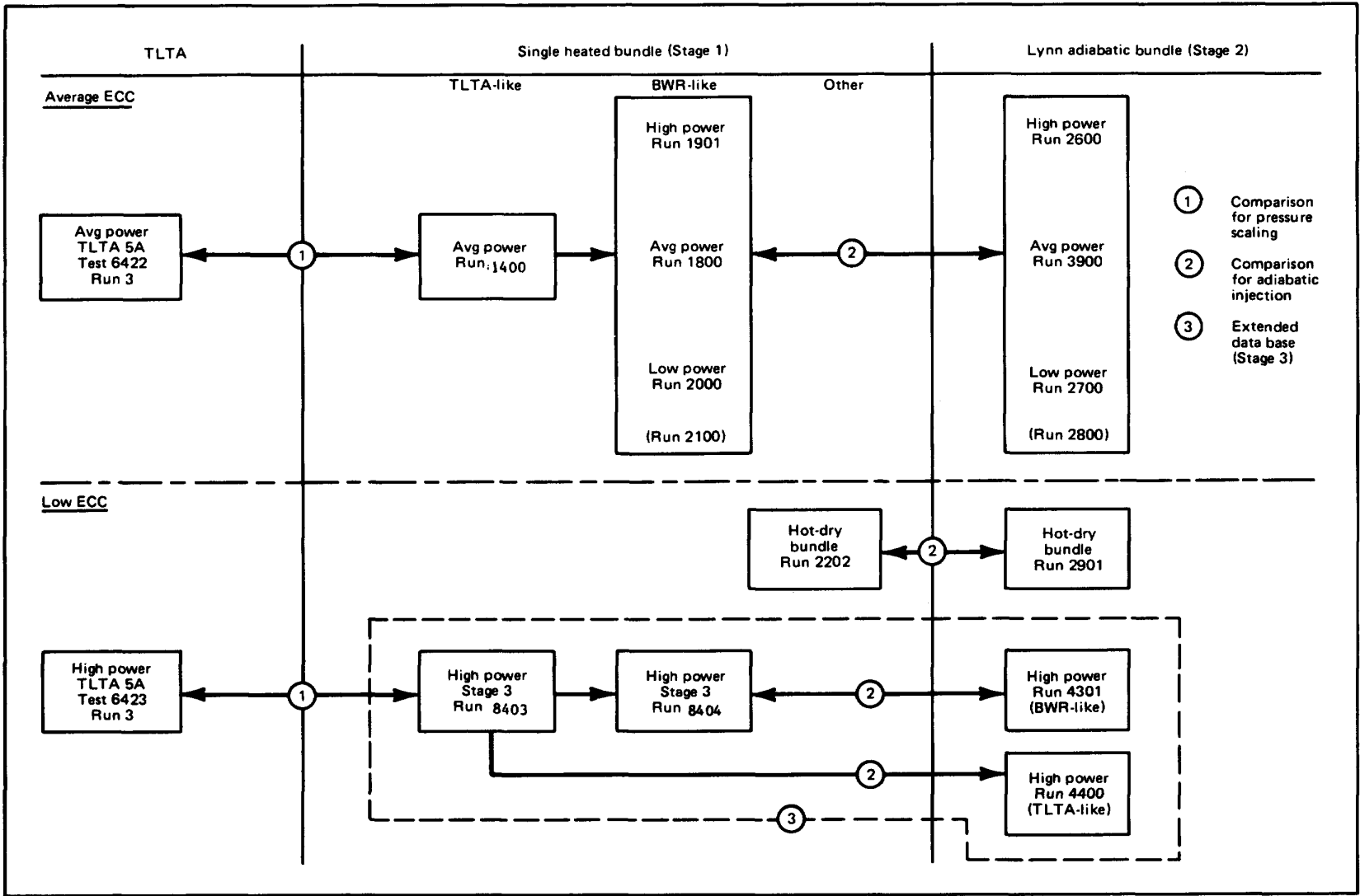


Figure 2-1. Adiabatic Bundle Demonstration Tests

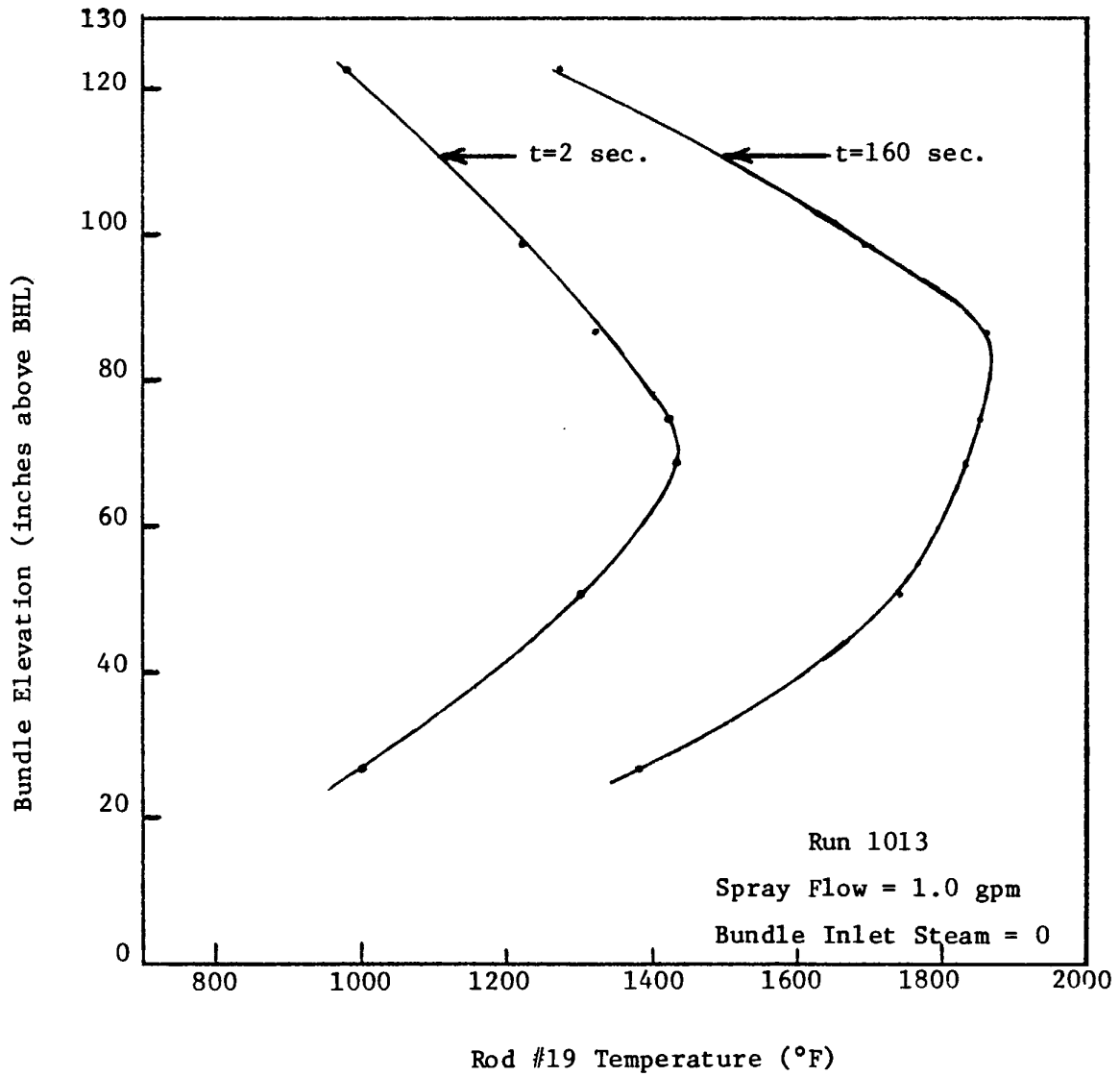


Figure 2-2. Core Spray Heat Transfer Rod #19 Temperature Profile

seconds, the channel inlet steam flow is held constant at 155 lb/hr. and the inlet flooding rate is constant at 8 gpm. The reflooding starts cooling the bundle immediately, as the temperatures near the bottom reach their peak and start decreasing. At approximately 50 seconds the remaining upper two-thirds of the bundle temperatures peak and also start decreasing. As the two-phase level continues to rise, the bottom of the rods start quenching. The 25 inch elevation quenches at 75 seconds and the 70 inch elevation quenches at 310 seconds. The quench front moves at a near constant rate of 0.15 in/sec. up the bundle. A similar response is observed in the other reflooding tests.

The steady state channel to bypass heat transfer tests give an overall heat transfer rate of 100 - 200 Btu/(hr-sq ft-deg F). These rates correspond to a full bypass with steady state liquid flow rate, and a channel at saturation temperature.

### 3.0 Test Program

#### 3.1 Adiabatic Bundle Demonstration Tests

The objective of these tests is to demonstrate that steam injection into a channel of the SSTF design can be used to simulate steam generation in a BWR heated bundle during the refill phase of a LOCA transient. To verify the adiabatic steam injection technique an electrically heated bundle of the BWR design and an adiabatic bundle of the SSTF design were tested in the same single channel mock-up of the BWR system.

The procedure involved (a) defining reference initial conditions and independent test parameter values representative of typical BWR LOCA transients, (b) identifying dependent test parameters which characterize the system refill-reflood response during ECCS injection, (c) heated bundle tests simulating these reference transients, (d) adiabatic bundle tests with steam injection rates corresponding to the steam generation in the heated bundle tests, and (e) comparison of the system characterizing parameters for these reference tests to determine if the responses are similar. The comparisons take into consideration experimental uncertainty, as well as some small mechanical differences between the two bundles. Acceptance is based on the similar refill response for the two systems, and ensuring that important governing phenomena are simulated.

The experimental base for evaluating the adiabatic bundle simulation consists of six pairs of tests. These tests cover a wide range of LOCA conditions. There are four sets that are representative of the BWR LOCA, one set which simulates a TLTA (Two Loop Test Apparatus) high power low ECCS flow test, and one which simulates a non-typical extreme ("hot-dry") bundle condition.

The measurements for comparison of heated and adiabatic tests are the fill transients in five principal regions, i.e., lower plenum, core, upper plenum, guide tube, and bypass regions. The static head instrumentation that measures these transients is shown in Figures 3-1(a) and (b).

The test procedure for the high, average and low power bundles with average ECC is the same as for the pressure scaling tests (Appendix A), with the addition of core steam injection in the adiabatic tests at a rate equal to the measured steam generation in the heated test. The procedure was modified for the "hot dry bundle" and high power with low ECC tests so that the bundle reflooded from the top down; (i.e., no water was allowed to fill the bundle from the bypass/guide tube leakage), so as to achieve a sudden upper tie plate CCFL breakdown into a hot bundle.

The heated and adiabatic tests have two system differences: 1) the adiabatic test bundle volume is 28% greater than the heated test bundle, and 2) the adiabatic test bypass to bundle leakage

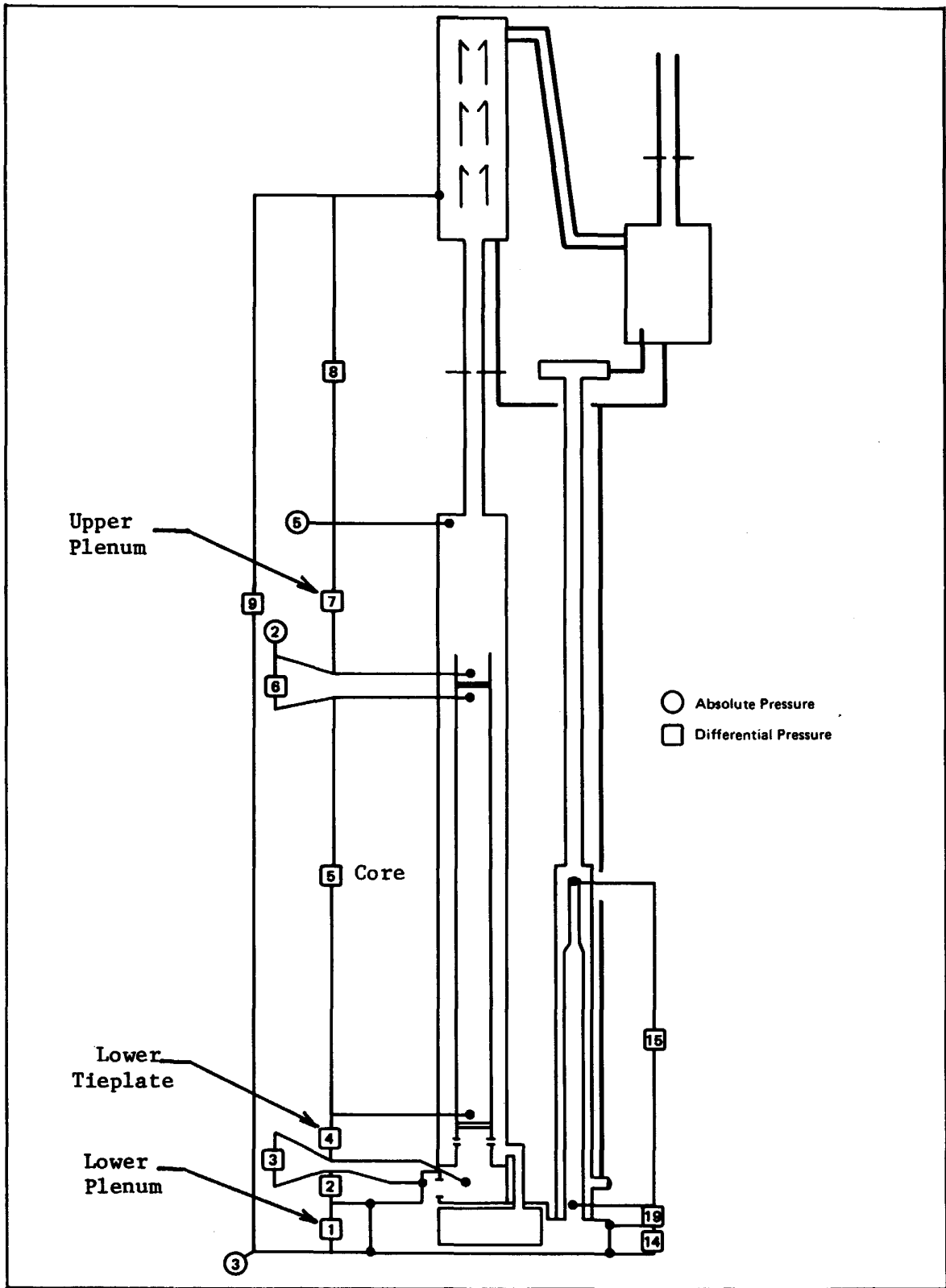


Figure 3-1 (a). Differential Pressure Instrumentation - Lower Plenum, Core, Upper Plenum

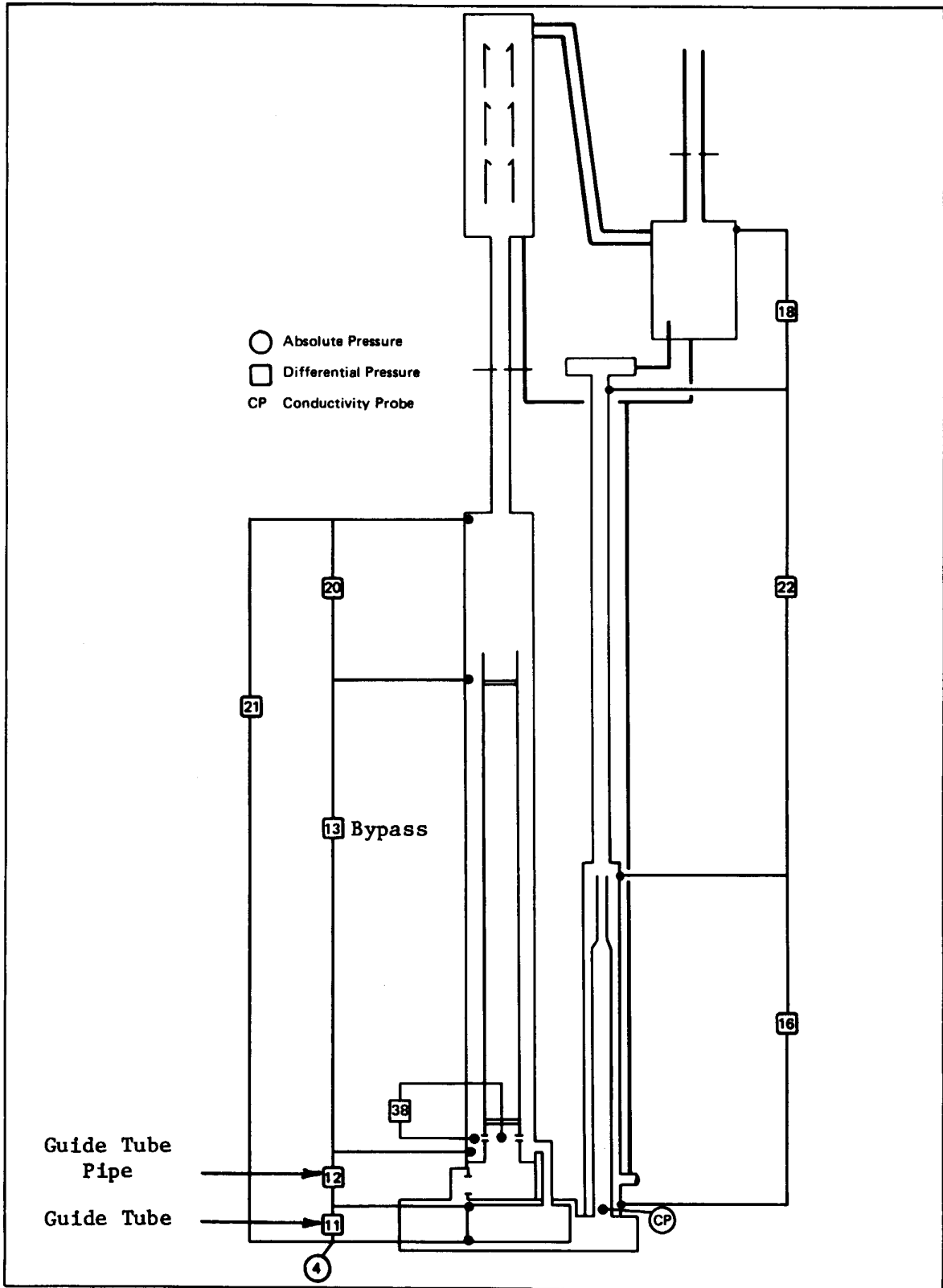


Figure 3-1 (b). Differential Pressure Instrumentation - Guide Tube, Bypass

rate is 11.5 gpm with a 136" driving head in the bypass while the heated test bypass to bundle leakage rate is 18.1 gpm for the same driving head in the bypass. The bypass leakage area in the heated test was adjusted to match a specified value that included all leakage paths, and the adiabatic test bypass leakage is the "as-built" flow through just the lower tieplate holes and the finger springs of the Lynn bundle.

The results of the average power and average ECC test comparisons (SHB 1800 vs. LAB 3900) are shown in Figure 3-2(a). These tests show excellent adiabatic vs. heated agreement in the refill/reflood scenario. The key points in the scenario, that occur in both tests, are that the lower plenum begins to fill immediately, and that the bundle also begins to fill immediately due to CCFL at the side entry orifice. After the lower plenum has filled, the bundle fills rapidly (DP5). Throughout this period there is no holdup of core spray in the upper plenum (DP7).

The two low power bundle tests with different size side-entry orifices are shown in Figures 3-2(b) and (c), and the high power bundle test in Figure 3-2(d). All tests show a similar excellent level (i.e., mass vs. time) agreement in the lower plenum and bundle. Slight differences between the adiabatic and heated tests in the bundle region are attributable to a larger volume in the adiabatic bundle, and the fact that the cross sectional flow area is not constant as a function of elevation. The adiabatic bundle bypass fills faster than the heated bundle due to the different bypass leakage rates discussed above. The high power heated bundle bypass fills more rapidly than the average and low power bundles, and as fast as the adiabatic bundles, due to the leakage rate being slowed by the higher back pressure associated with the higher steam generation rate.

#### Forced CCFL Breakdown

For these tests there is no liquid in the guide tube, and high steam flow is injected into the guide tube and the lower plenum to insure CCFL at both the upper tieplate and the top of the bypass. Core power, or the corresponding core steam injection, is started and saturated liquid sprayed into the upper plenum to establish an initial two-phase level. Once the conditions are well established (including 1000 F core temperature for the heated bundle), the test is initiated by increasing the spray flow to 25 gpm, decreasing the lower plenum steam injection to the nominal 155 lbm/hr, and starting the core power transient in the heated test or the core steam injection transient in the adiabatic test. The steam injection transients are determined by the steam generation measured in the heated test. The refill/reflood performance of the hot dry heated bundle test, (Run 2202), with the initial rod temperature of 1000 F, is shown in Figure 3-2(e). The upper plenum and the standpipe fill with a two-phase mixture during the first part of the transient. CCFL breakdown is achieved at approximately 150 seconds when the core exhibits a sudden refill (sudden drop in DP7 and corresponding

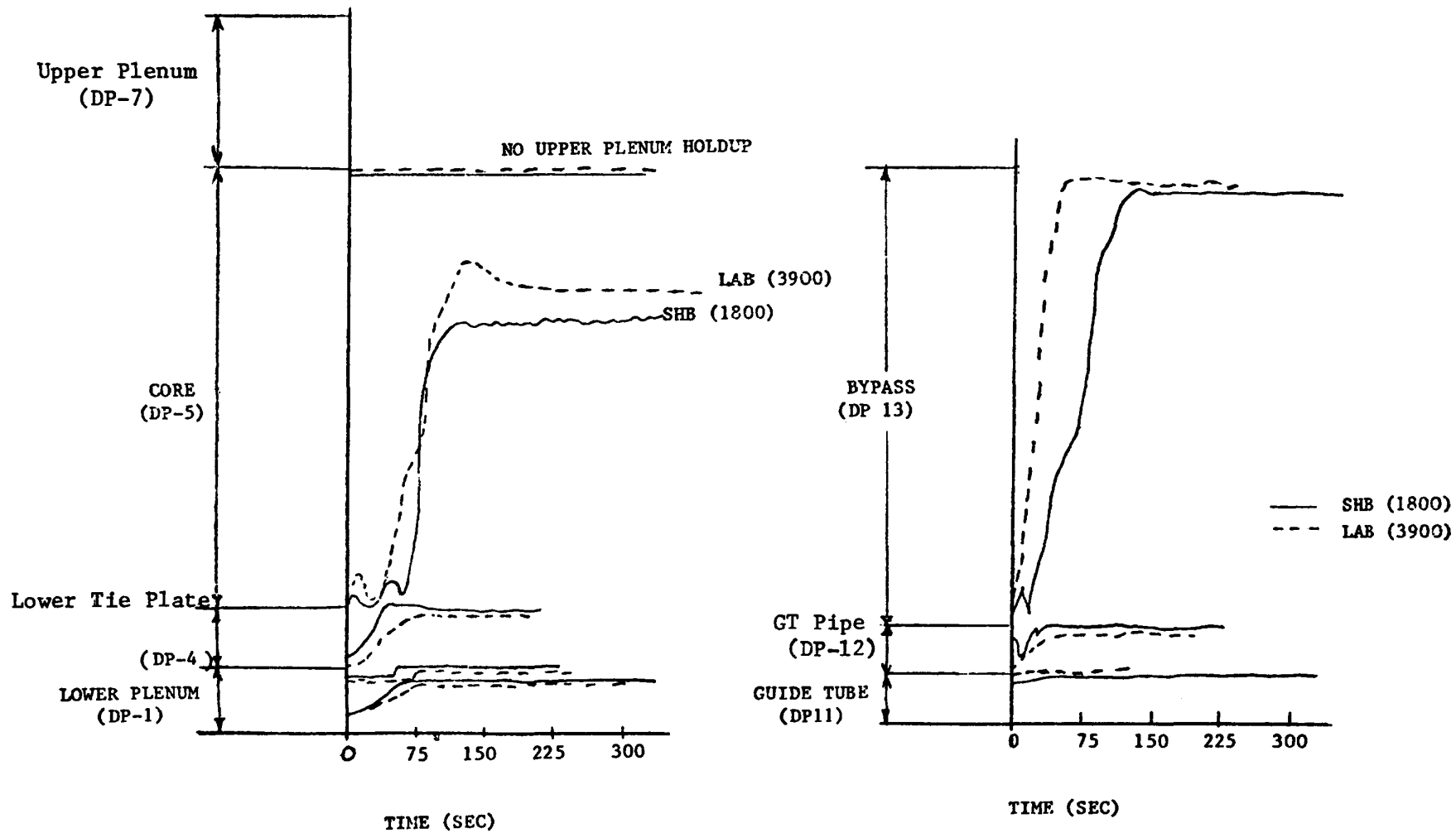


Figure 3-2 (a). Adiabatic vs. Heated Bundle Refill-Reflood Collapsed Level Comparisons  
Average Power/Average ECCS

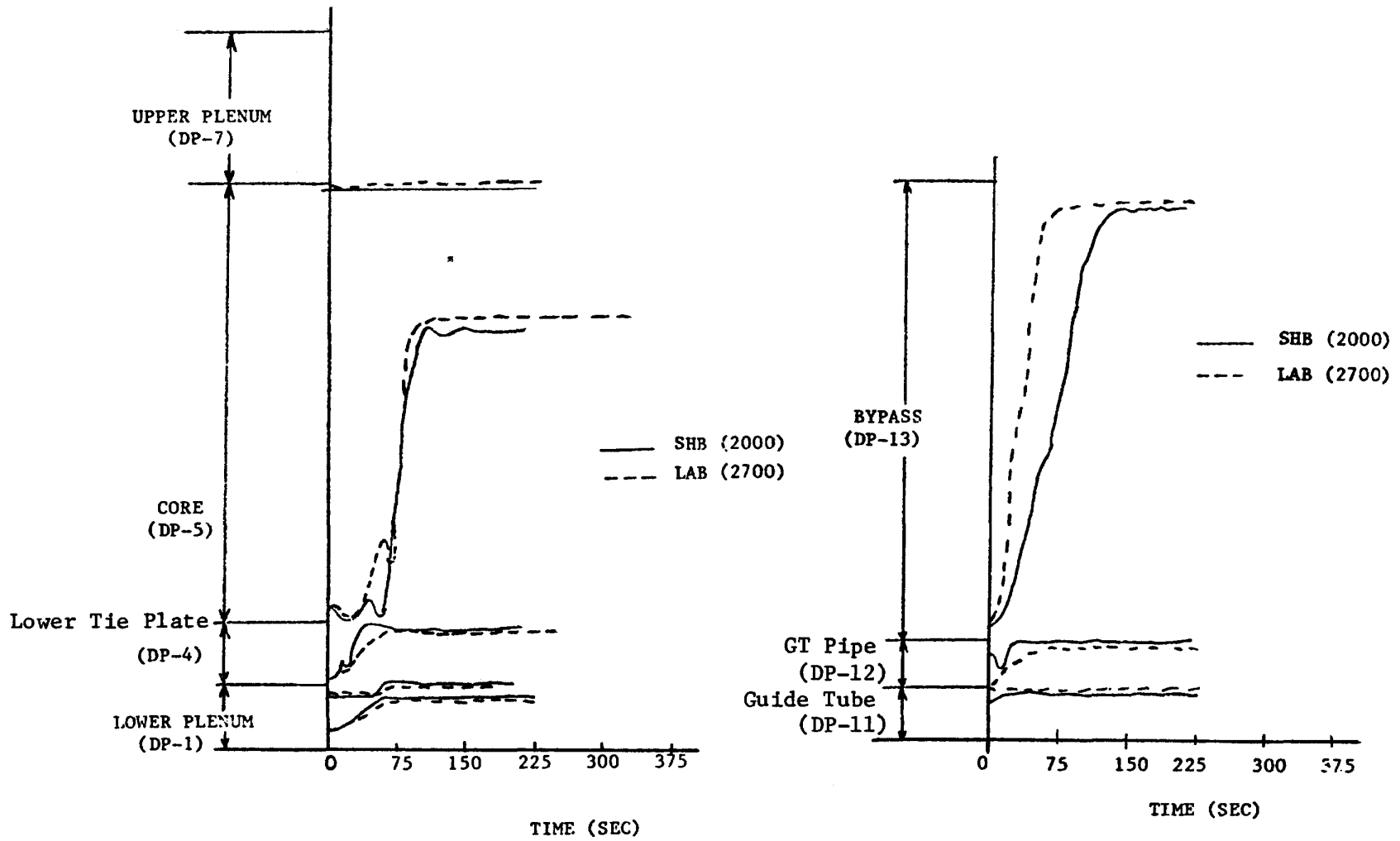


Figure 3-2 (b). Adiabatic vs. Heated Bundle Refill-Reflood Collapsed Level Comparisons  
 Low Power/Average ECCS/2.43" Dia. SEO

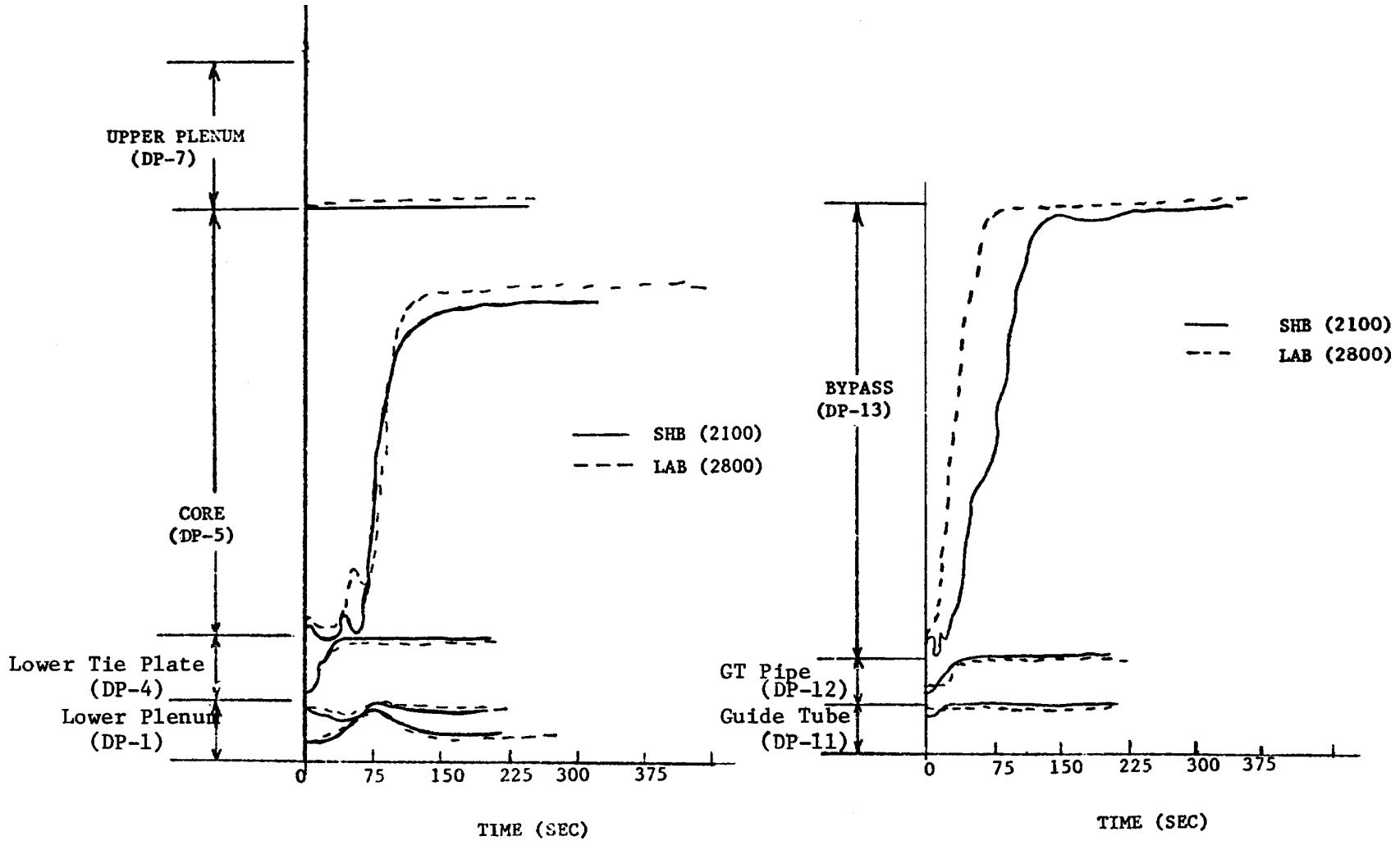


Figure 3-2 (c). Adiabatic vs. Heated Bundle Refill-Reflood Collapsed Level Comparisons  
 Low Power/Average ECCS/1.257" Dia. SEO

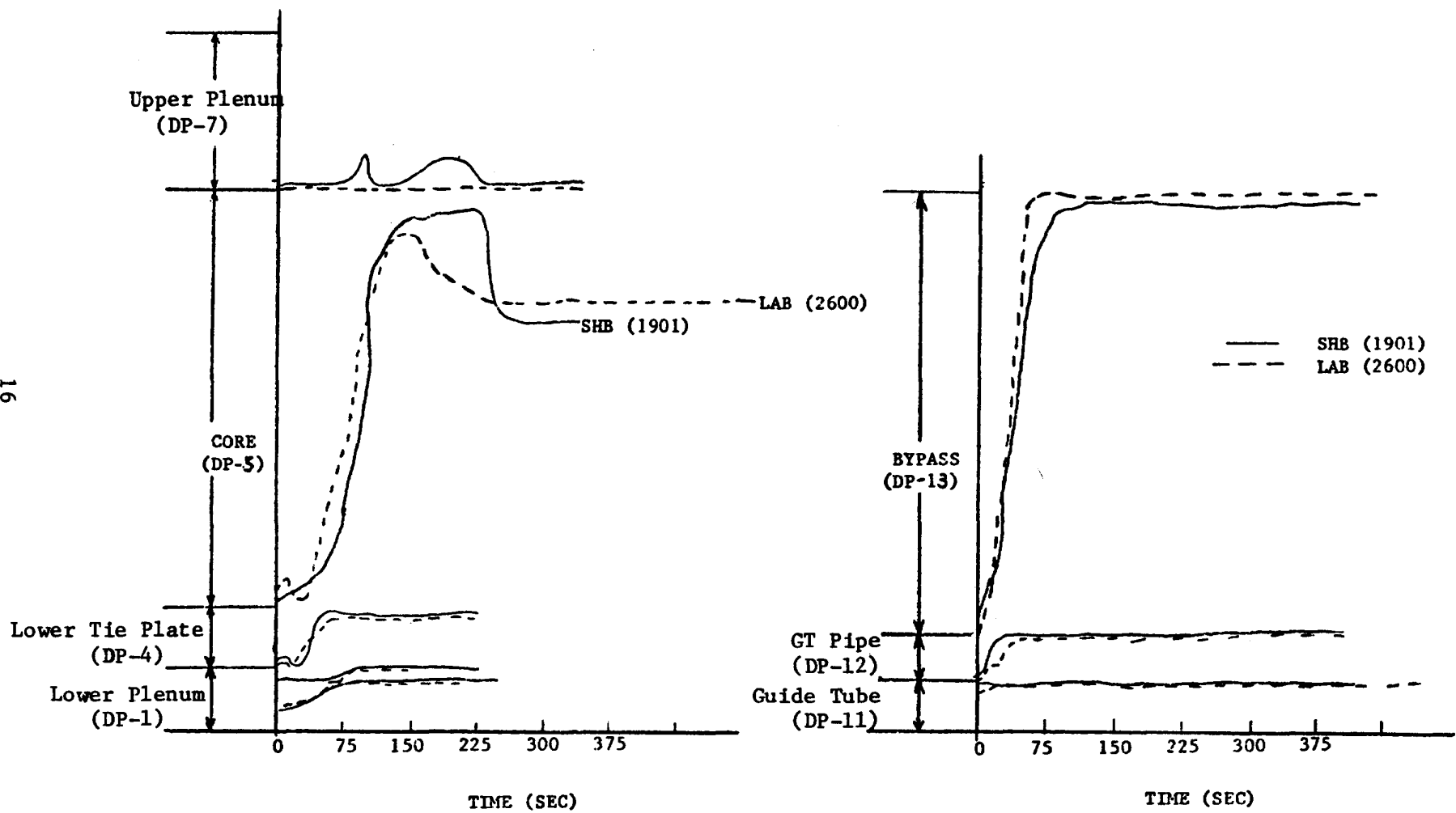


Figure 3-2 (d). Adiabatic vs. Heated Bundle Refill-Reflood Collapsed Level Comparisons  
High Power/Average ECCS

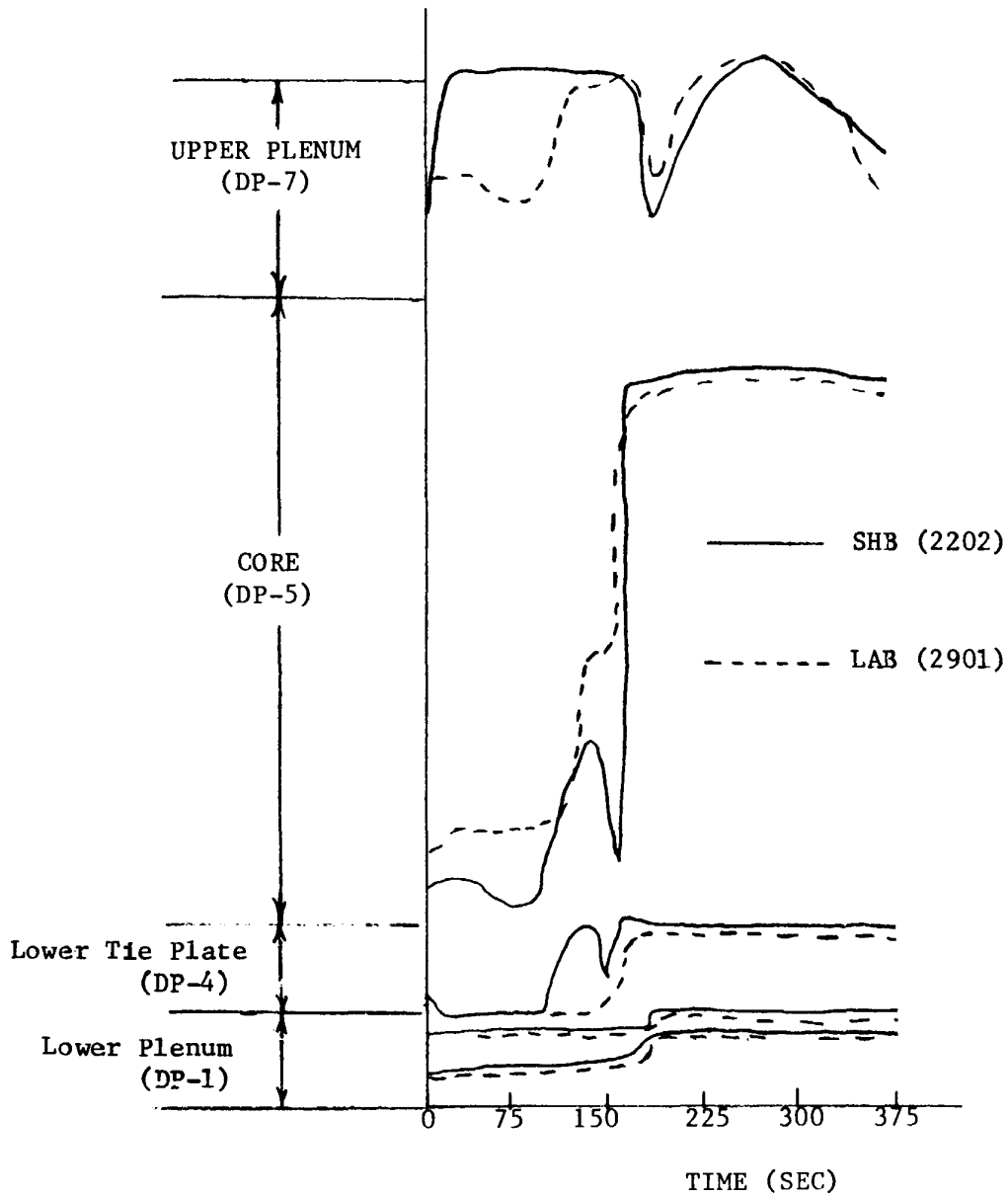


Figure 3-2 (e). Adiabatic Vs. Heated Bundle Refill-Reflood  
 Collapsed Level Comparisons  
 "Hot-Dry Bundle"

sudden increase in DP5). The guide tube remains empty for the entire test, and the bypass does not fill until the core refloods.

Run 2901 was conducted with steam injection corresponding to the steam flow measured in Run 2202. Although the core steam injection was manually controlled for this test, excellent agreement between the actual and target transients was achieved. The refill/reflood performance of the adiabatic simulations of the heated bundle test is also shown in Figure 3-2(e). Comparison with run 2202 shows that run 2901 is an excellent simulation of the heated test. The major features of the refill/reflood performance, i.e., the lower plenum and core, agree very well. Both tests exhibit a sudden refill of the core and corresponding upper plenum drainage, at approximately 150 seconds and lower plenum refill at approximately 190 seconds. Although there are some minor differences, i.e., in the upper plenum for the first 120 seconds and the core level just prior to breakdown, it is clear that steam injection into the core satisfactorily simulated the refill/reflood performance of a hot, dry bundle in which there was upper tieplate CCFL breakdown.

## 3.2 Separate Effects Tests

### 3.2.1 Core Spray Heat Transfer

The objective of this test series is to determine bundle core spray heat transfer characteristics at low spray flows for two types of outside channel wall wetting. In the first type the bypass region is flooded throughout the test. In the second type the bypass region is initially filled with steam and liquid is injected at a rate that is 20% of the spray flow.

The test configuration isolates the bypass region from the bundle by blocking the bypass leakage holes and the top of bypass. The bypass and lower plenum are drained independently, and the jet pump is blocked so that all steam leaves through the top of the bundle.

The spray heat transfer is characterized by the temperature response of the heated rods, the core steam generation rate, and the void distribution in the bundle. The test series covers various spray rates and various steam injection rates. The maximum bundle temperature is limited to 1800 F to prevent mechanical damage and preserve the test bundle for other separate effects tests. The core spray heat transfer test matrix target values are listed in Table 3-1. The spray and lower plenum steam were both maintained at saturation temperature.

The tests are run by establishing either a dry bypass (i.e. filled with saturated steam) or a flooded bypass (i.e. filled with saturated water), setting the lower plenum injection steam (if required), and setting the power to 250 kw. The rods heat up to the desired initial temperature. At this time,  $t = 0$ , the

TABLE 3-1

CORE SPRAY HEAT TRANSFER TEST MATRIX

Run	Nominal Spray Rate (gpm)	Lower Plenum Steam (lb/hr)	Initial Power (Kw)	Initial Core Temp. ( F)	Bypass LPCI Injection (% of Spray)
1004	1.0	400	250	1100	20%
1006	0.0	400	250	1100	20%
1007	1.5	0	250	1100	20%
1008	2.0	0	250	1100	20%
1011	1.0	800	250	1100	Dry Bypass
1012	1.5	0	250	1100	Flooded Bypass
1013	1.0	0	250	1100	20%
1014	1.0	600	250	1100	20%
1018	1.0	200	250	1100	20%
1024	0.5	0	250	1100	20%
1027	1.0	400	250	1100	20%
1028	2.0	0	250	1100	Flooded Bypass
1029	0.5	0	250	1100	Flooded Bypass
1030	1.0	0	250	1100	Flooded Bypass
5101	3.0	0	250	1400	20%
5130	1.0	0	250	1100	Flooded Bypass

spray flow and the power decay transient are initiated. For the unflooded bypass cases, LPCI flow equal to 20% of the spray flow is also initiated to simulate spray falling into the voided bypass. The transient continues until the peak temperature reaches 1800 F, at which time power is terminated.

### Temperature Distribution in the Bundle

Surface temperatures are measured on each of the 62 heated rods and two water rods at nine elevations, and on the four channel walls at five elevations. The bundle layout is shown in Figure 3-3 and a typical temperature distribution in the bundle is shown for Run 1013 in Figures 3-4(a) through (d). Figure 3-4(a) is a "cross section" along the third row of rods (e.g. rods 17 to 24) for elevations 27 inches to 75 inches, and Figure 3-4(b) is for elevations 75 inches to 123 inches. The distribution is seen to be symmetrical across the bundle, dropping off equally on the rods adjacent to the channel wall (e.g. 17 and 24). The interior rod temperatures range from about 1250 F to 1450 F from 51 inches to 99 inches, and drop off to somewhat lower temperatures at the bottom and top regions of the bundle. A "cross section" along the sixth row (e.g. rods 41 to 48), Figures 3-4(c) and (d), shows a similar pattern. From these four figures, the initial temperature distribution is seen to be well balanced across and along the bundle.

The inner channel wall temperatures, shown in Figure 3-5, are about 500 F at the 27 inch elevation and in the range of 700 F to 850 F from elevations 69 inches to 99 inches, and symmetrical around the bundle. At 160 seconds into the transient the temperatures on three walls have climbed to 1100 F to 1300 F at the mid elevations (Figure 3-6). The north inner channel wall is seen to have rewet at elevations of 81 inches and above, and near the bottom. One explanation for the other three walls not rewetting by this time is that the very low LPCI flows injected in the bypass may simply run down the outer channel wall since there is little turbulence to distribute the liquid in the bypass. The outer wall temperatures are at saturation throughout the transient.

The "cross sections" along the third row of rods are shown in Figures 3-7(a) and (b) at 160 seconds into the transient. The sixth row exhibits a similar profile. The distribution is still symmetrical and well balanced across and along the core, indicating that no one region is preferentially cooled at the expense of another region.

### Effect of Spray Flow Rate

Transient heat up of the hottest rod, rod 19, is shown in Figure 3-8(a) for various spray flows and zero lower plenum steam injection. Run 5101, 3 gpm, shows the lowest heat up rate, and Run 1024, 0.5 gpm shows the highest heat up rate. Runs 1007 and 1013, at 1.5 and 1 gpm, show heat up rates clustered in between.

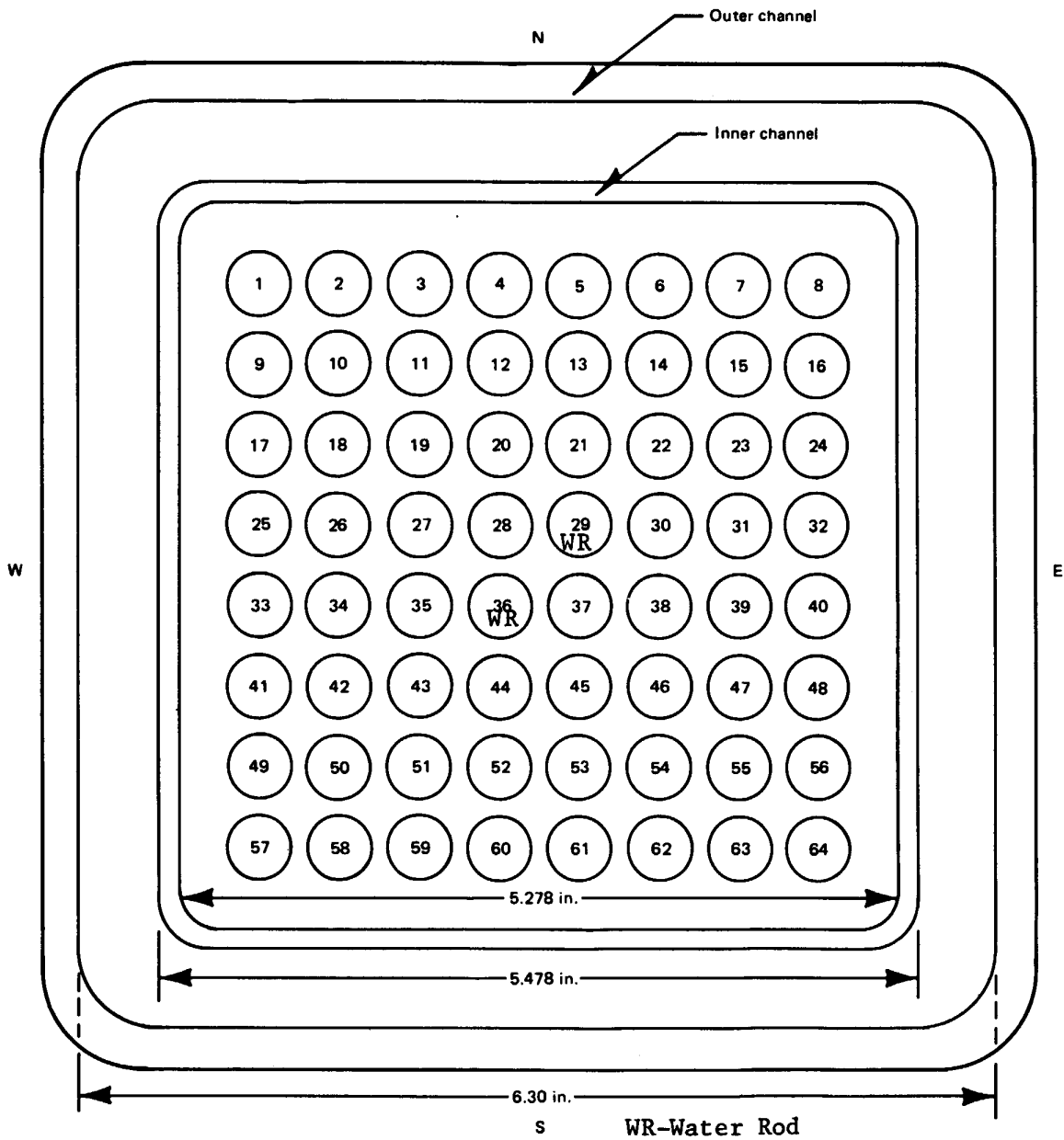
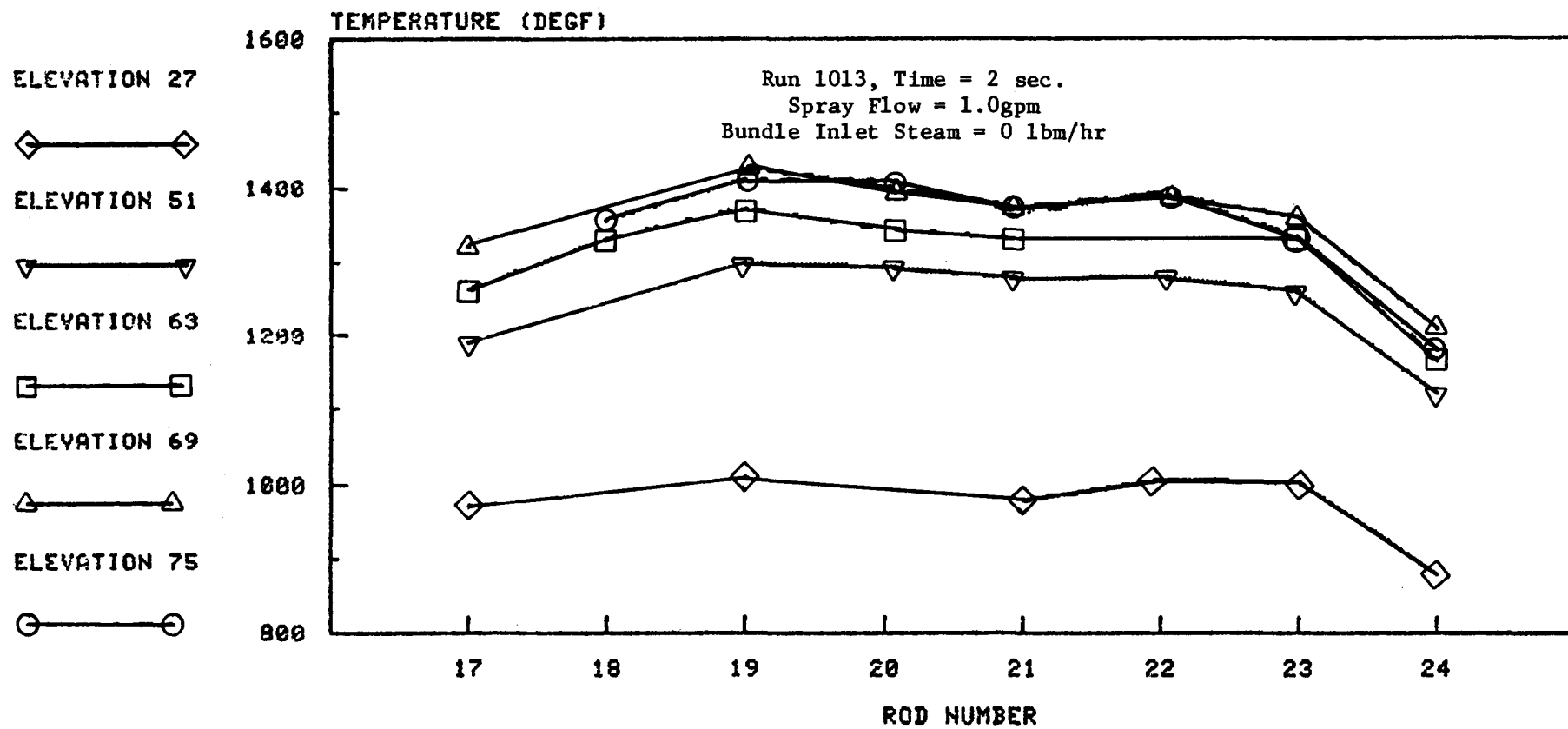


Figure 3-3. Bundle Cross Section Showing Rod Locations



Note: Symbols indicate valid temperature measurements.

Figure 3-4 (a). Core Spray Heat Transfer Bundle Temperatures (T = 2 sec.)  
Rods 17 to 24, Elevations 27" to 75"

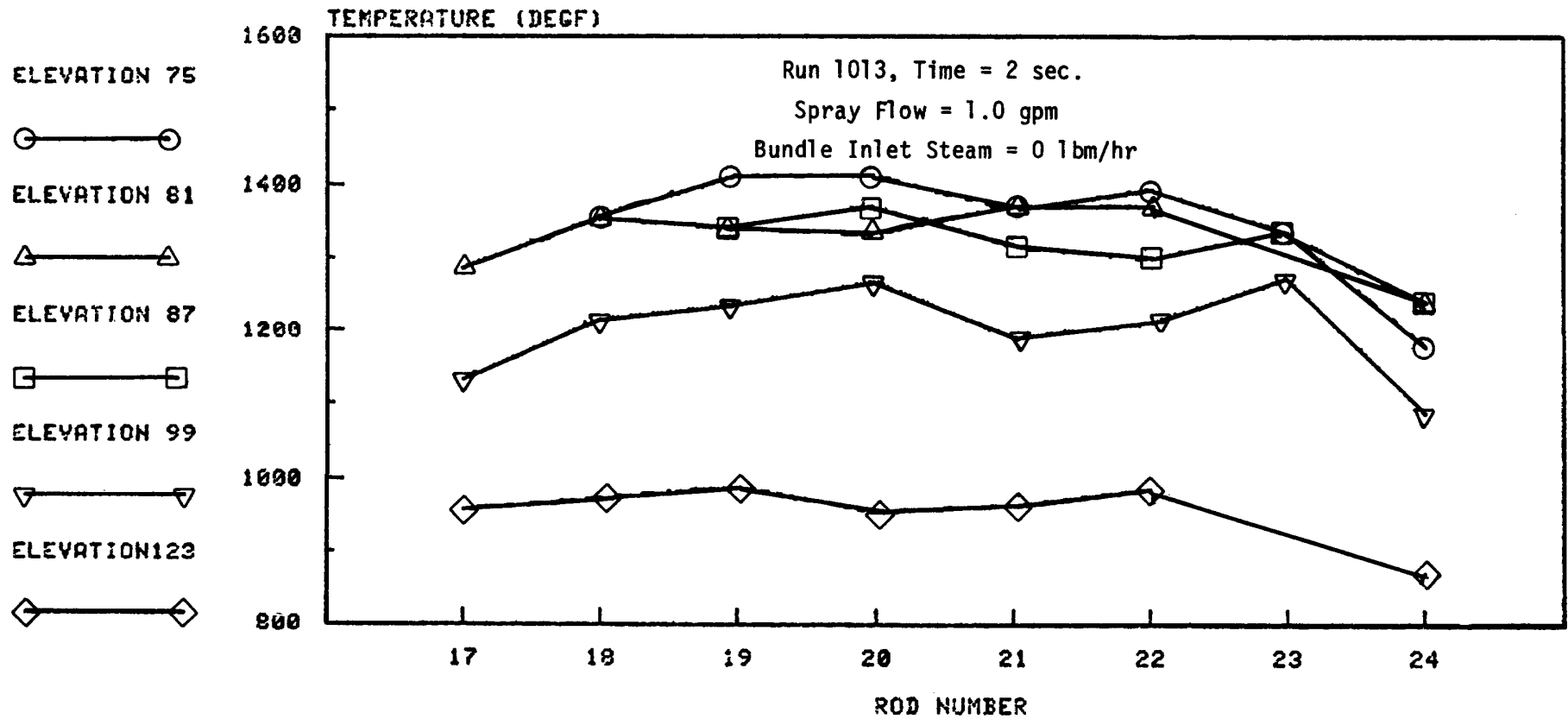


Figure 3-4 (b). Core Spray Heat Transfer Bundle Temperatures (T = 2 sec.)  
Rods 17 to 24, Elevations 75" to 123"

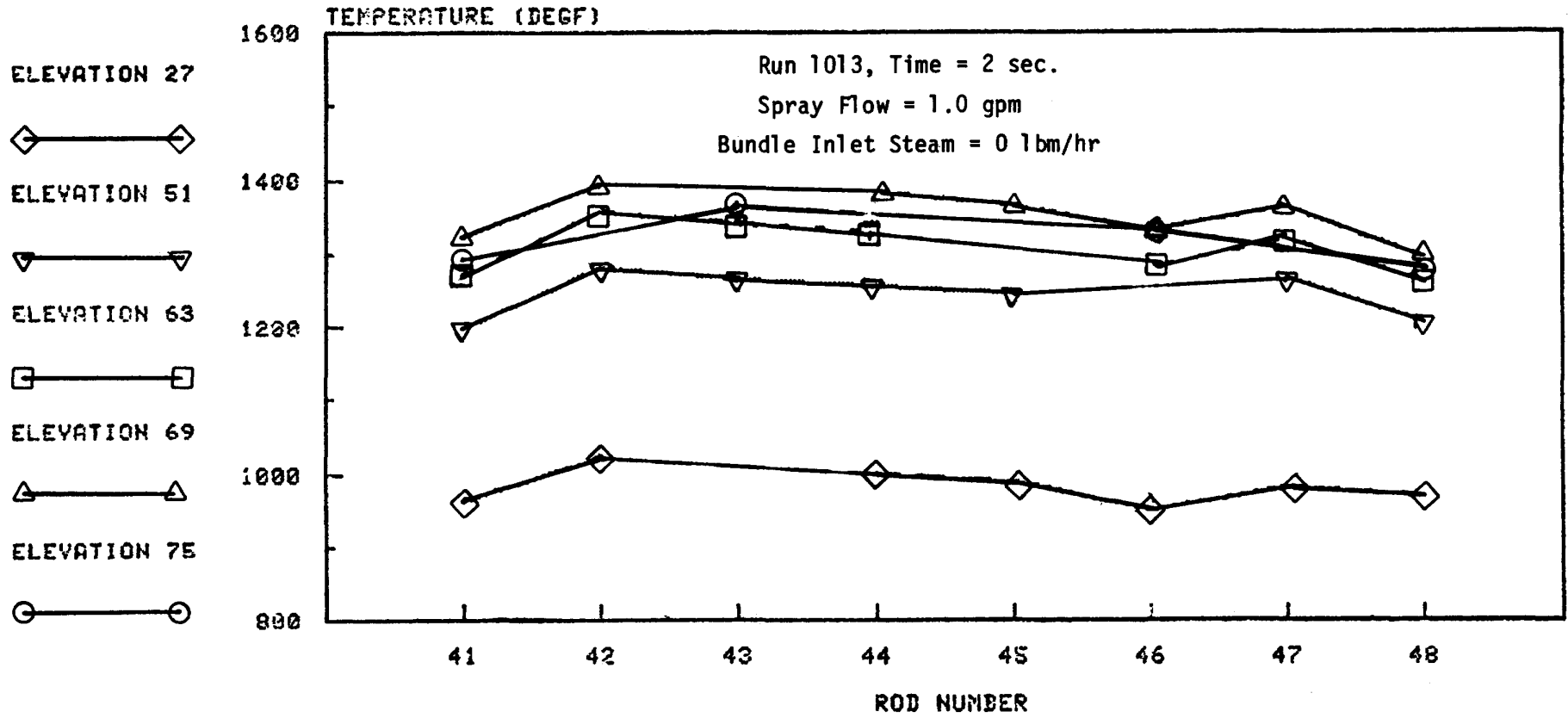


Figure 3-4 (c). Core Spray Heat Transfer Bundle Temperatures (T = 2 sec.)  
Rods 41 to 48, Elevations 27" to 75"

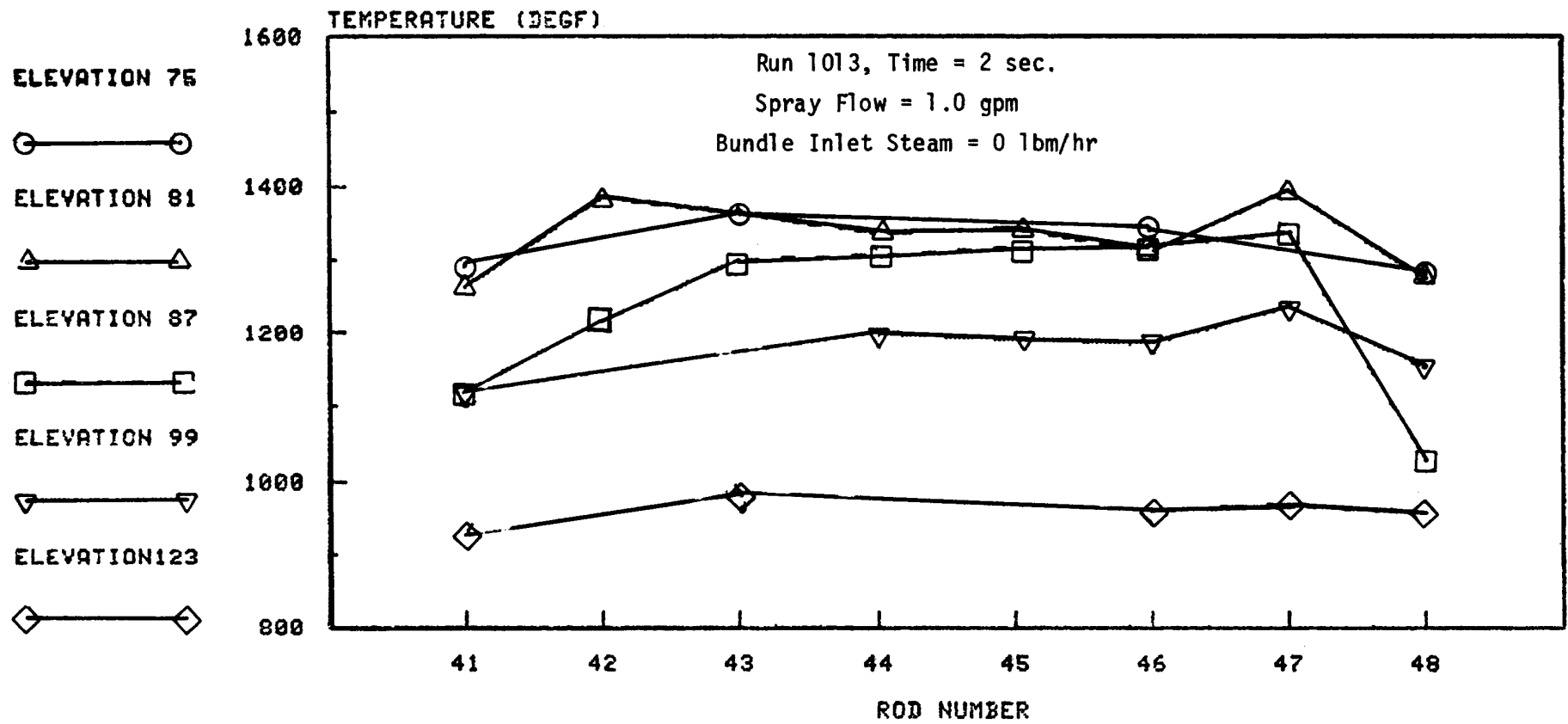


Figure 3-4 (d). Core Spray Heat Transfer Bundle Temperatures (T = 2 sec.)  
Rods 41 to 48, Elevations 75" to 123"

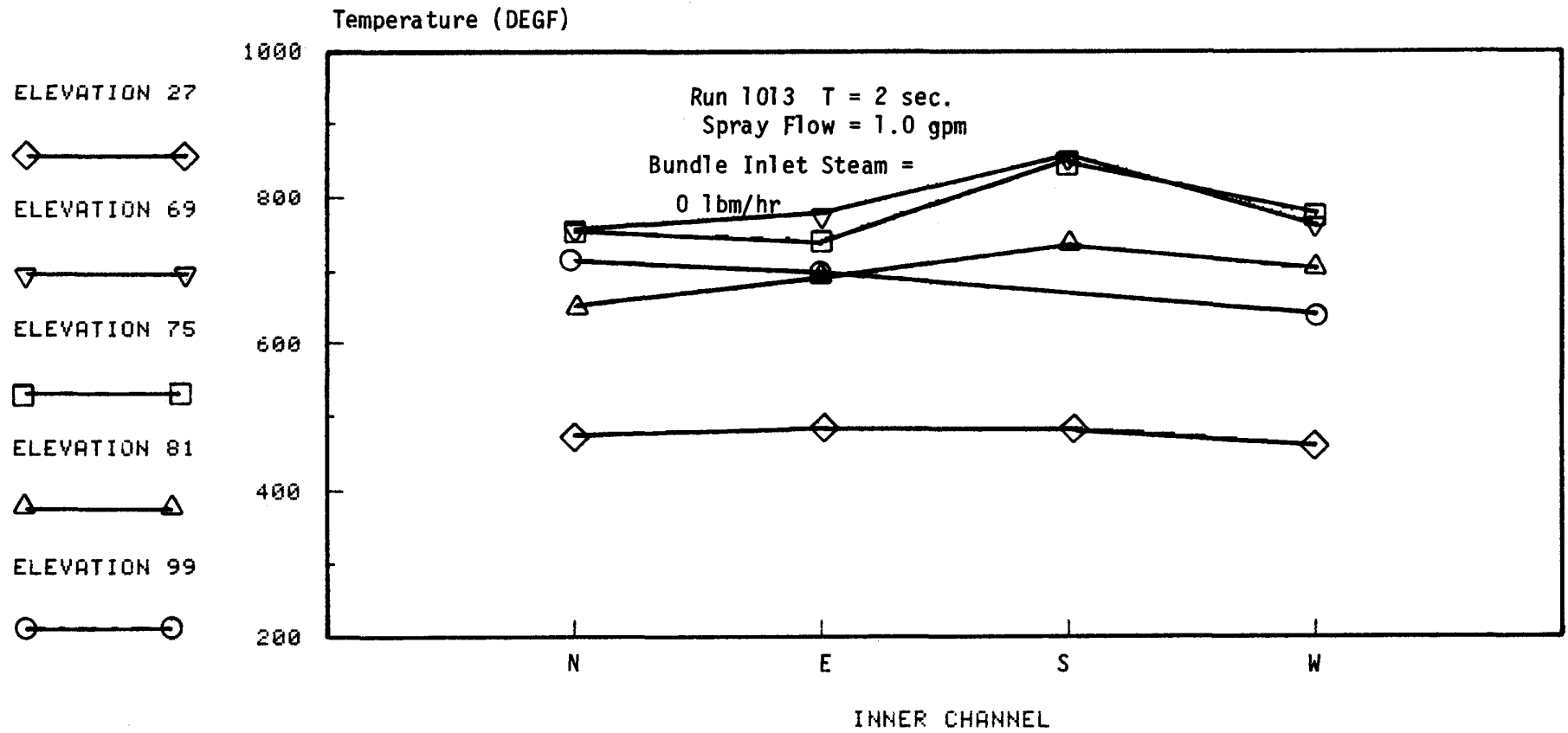


Figure 3-5. Core Spray Heat Transfer Wall Temperatures (T = 2 sec.)

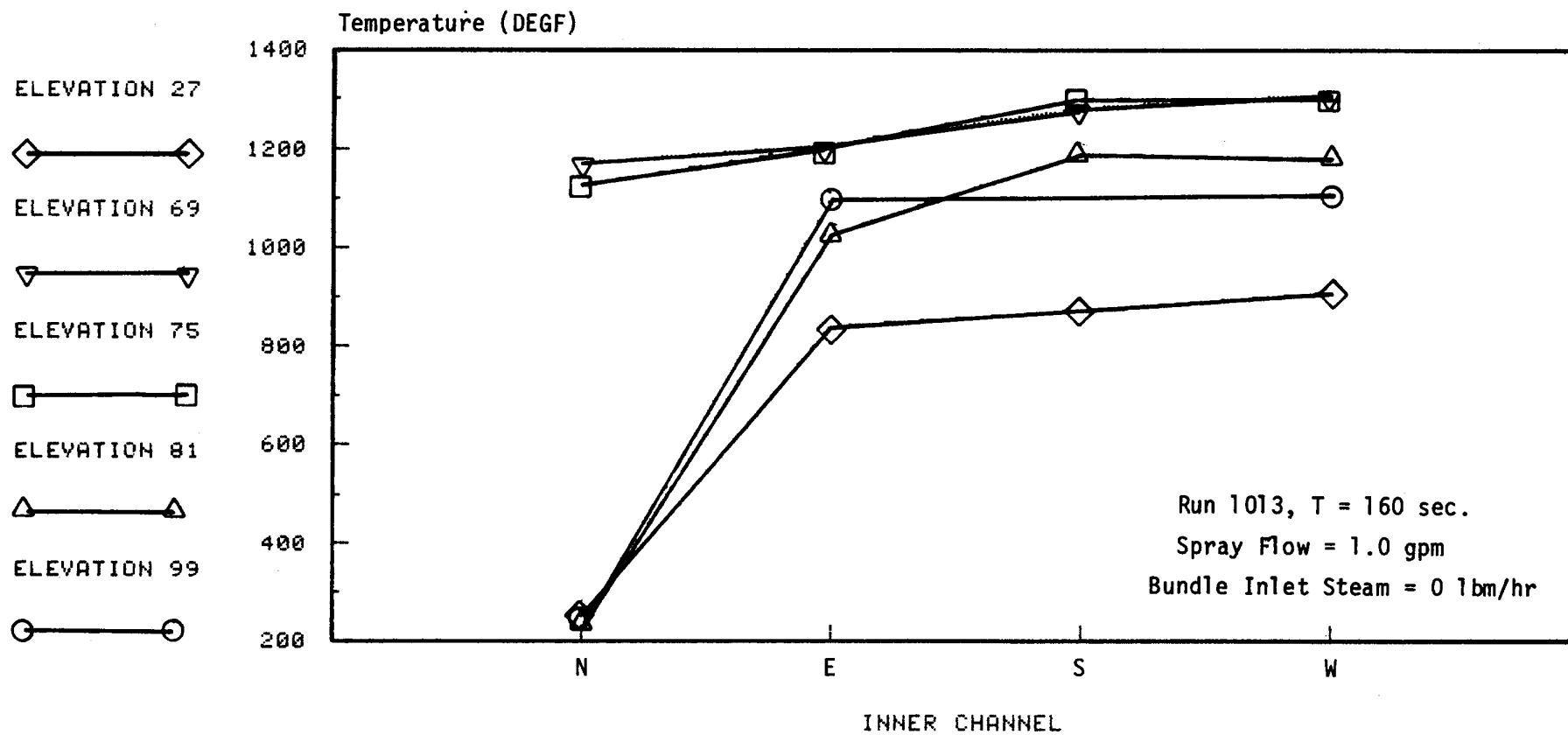


Figure 3-6. Core Spray Heat Transfer Wall Temperatures (T = 160 sec.)

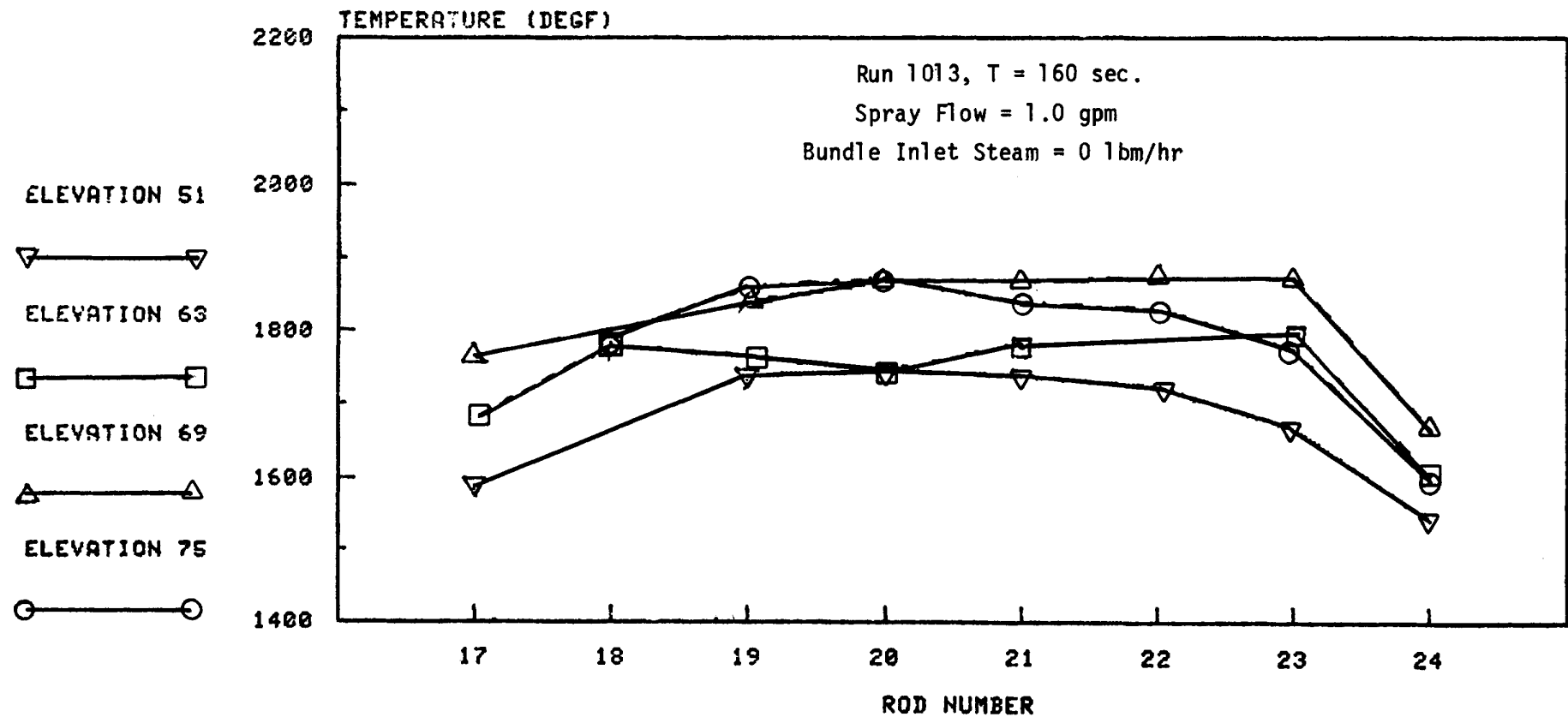


Figure 3-7 (a). Core Spray Heat Transfer Bundle Temperatures (T = 160 sec.)  
Rods 17 to 24, Elevations 51" to 75"

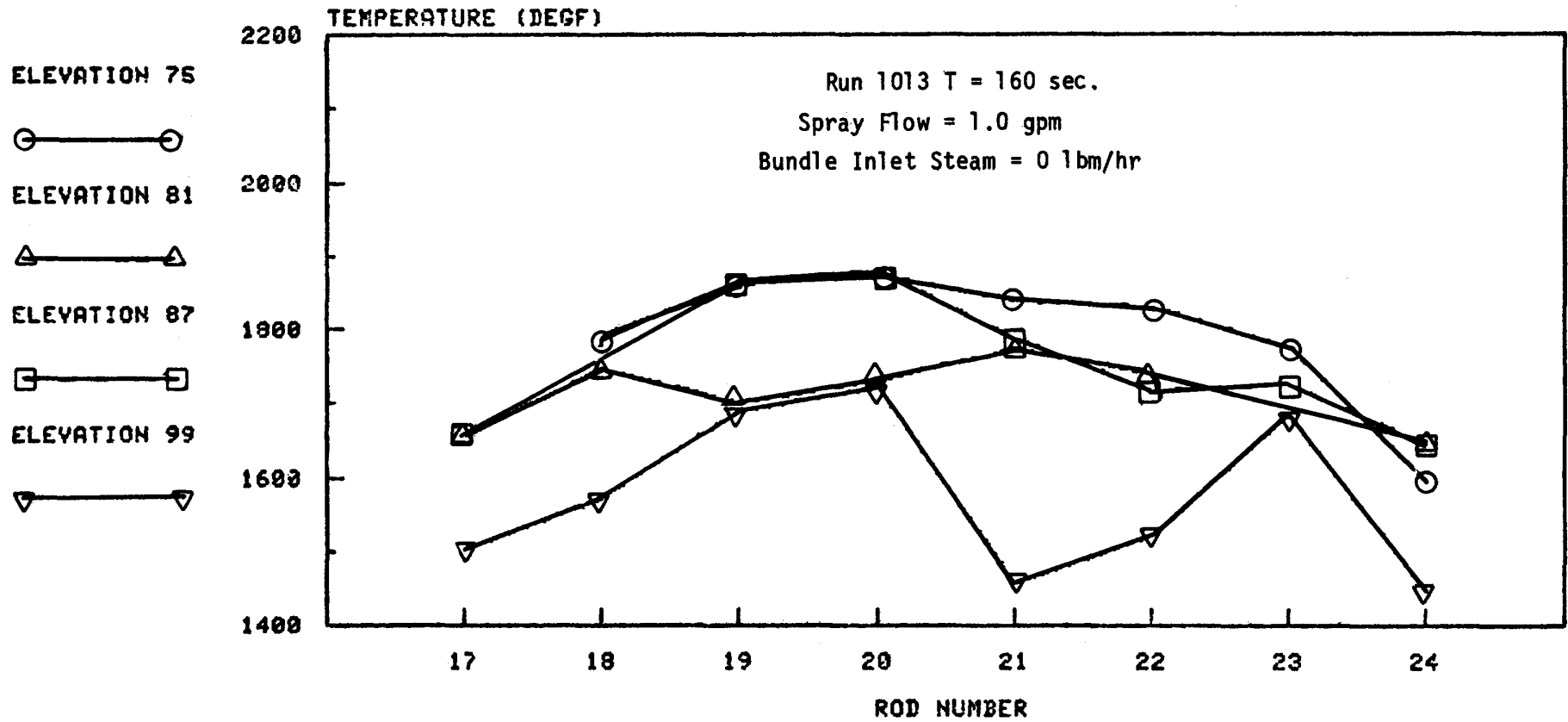


Figure 3-7 (b). Core Spray Heat Transfer Bundle Temperatures (T = 160 sec.)  
Rods 17 to 24, Elevations 75" to 99"

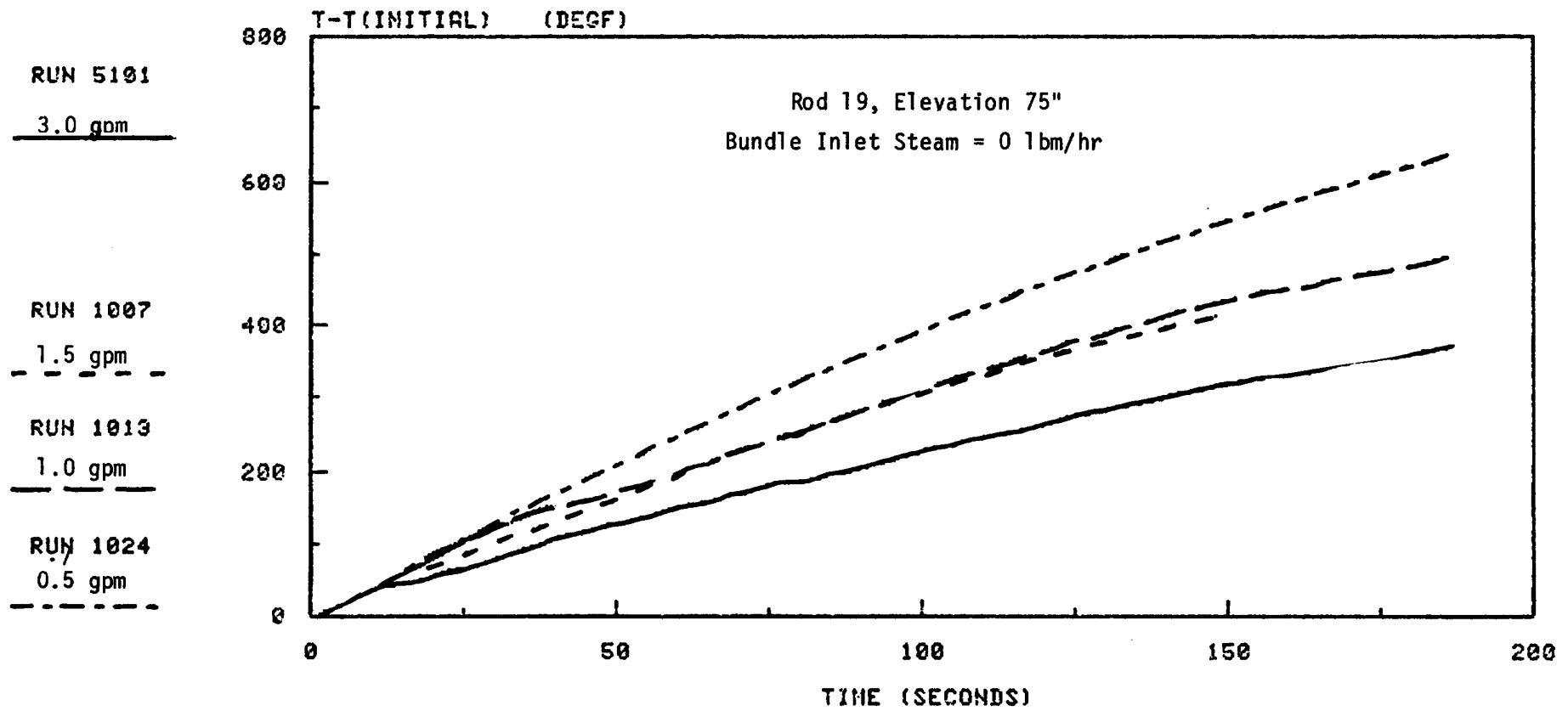


Figure 3-8 (a). Bundle Temperature Transient vs. Core Spray Rate, Rod 19, Elevation 75"

Figure 3-8(b) shows the "symmetrical twin", Rod #46, for each of these runs. The heat up rates are identical in Runs 5101 and 1024. However, in Runs 1007 and 1013 the temperature on Rod 46 is initially lower and its heat up rate leads Rod 19 as the temperature distribution in the bundle tends to flatten. As a result, comparing Rod 46 in Figure 3-8(b) shows that Runs 1007 and 1013 cluster toward the upper bound of Run 1024. Thus, lower spray rate leads to the expected higher overall heat up rate, and what are seemingly small and random asymmetries lead to variation in local heat up rates. The mean value temperature increase at 150 seconds for Rods 19 and 46 is shown in Figure 3-9. Run 1008, 2.0 gpm had a significant asymmetry in the initial temperature distribution, and although the mean value temperature increase is consistent with the trend shown in Figure 3-9, rods 19 and 46 do not represent the mean value for the bundle.

An indication of steam generated in the heated bundle is shown by the standpipe flow (calculated from orifice pressure differential and assuming saturated steam density) in Figure 3-10 for the various spray flows. The transient response is characterized by a delay in the start of steam generation inversely proportional to spray flow rate. Steam generation then quickly builds up to an "initial" value, point A on Figure 3-10, directly proportional to spray rate, followed by a gradual increase in generation rate.

#### Effect of Steam Injection Rate

Transient heat up of Rod 46 is shown in Figure 3-11 for various lower plenum steam injection rates and spray flow of 1.0 gpm. Zero steam injection shows the highest heat up rate. No reduction in heat up rate is seen for 200 lb/hr, but above this rate, 400 lb/hr and 600 lb/hr, there is an improvement from the steam cooling. The heat up rate of the "symmetrical twin", Rod 19, was found to be identical for all steam injection cases. Only for zero injection did the heat up rate differ. This indicates that the small random asymmetries observed with zero injection are evened out by steam injection cooling. The mean value temperature increase at 150 seconds for Rods 19 and 46 is shown in Figure 3-12.

The standpipe flow is shown in Figure 3-13 for various lower plenum steam injection rates, and with 1 gpm spray rate. The delay in the start of standpipe steam flow observed in the case of zero injection is not present in the tests where steam flow is established by lower plenum injection at the onset. The true standpipe flow is somewhat higher, and contains an appreciable liquid fraction carry over from the spray injection. However, the true flow was not determined since the quality was not measured.

#### 3.2.2 Reflood Heat Transfer

The objective of this test series is to determine core bottom flooding heat transfer characteristics for two types of system characteristics. In the first type, controlled bottom flooding,

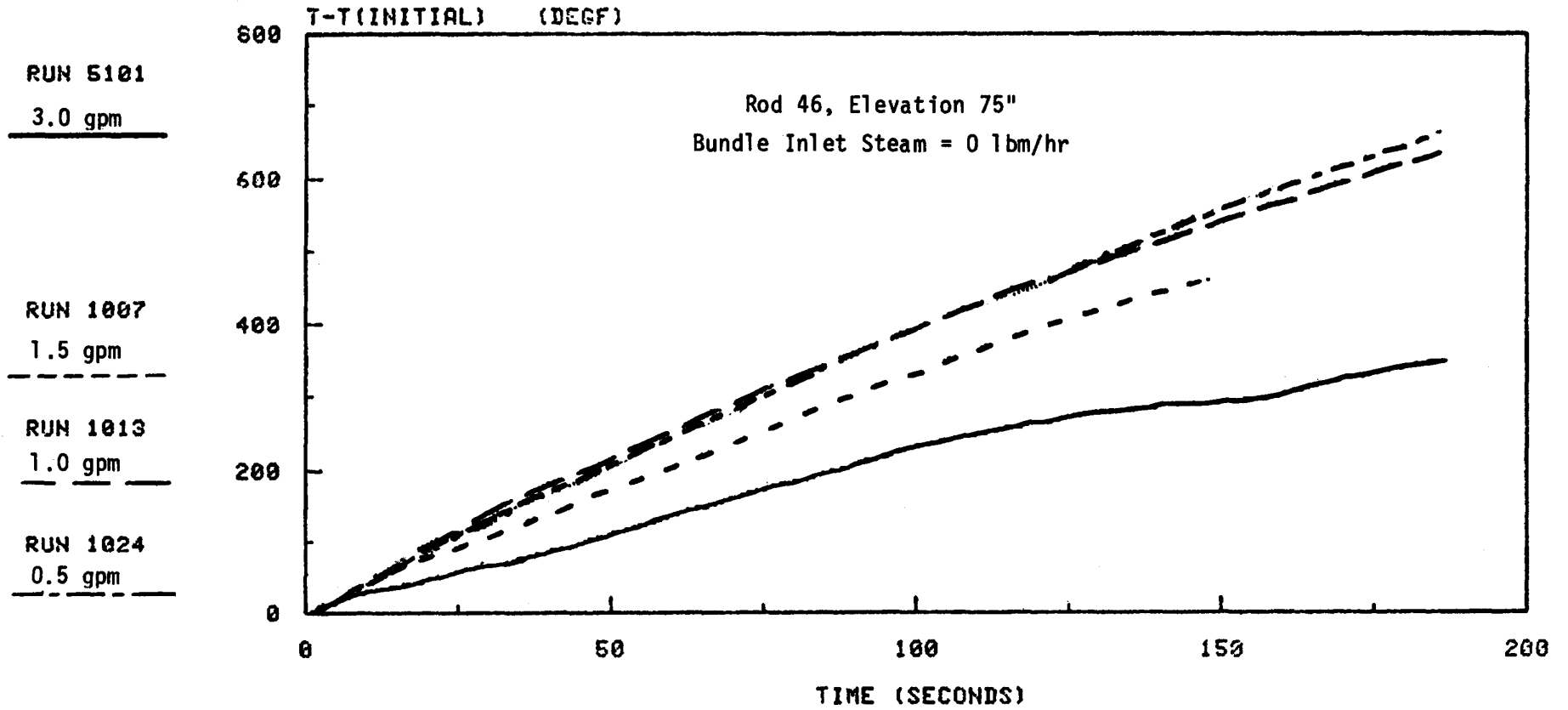


Figure 3-8 (b). Bundle Temperature Transient Vs. Core Spray Rate; Rod 46, Elevation 75"

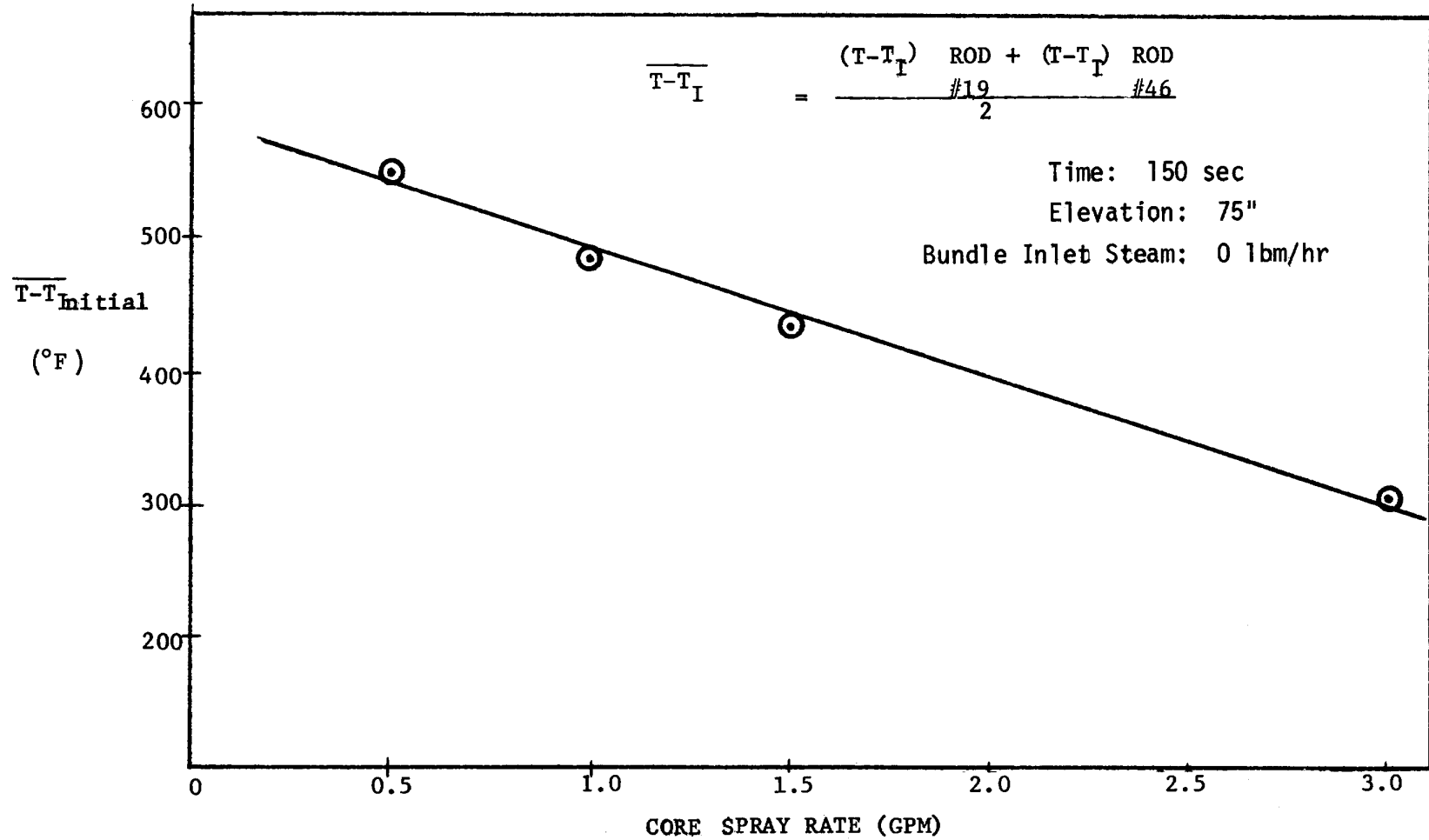


Figure 3-9. Mean Hot Rod Heat Up vs. Core Spray Rate

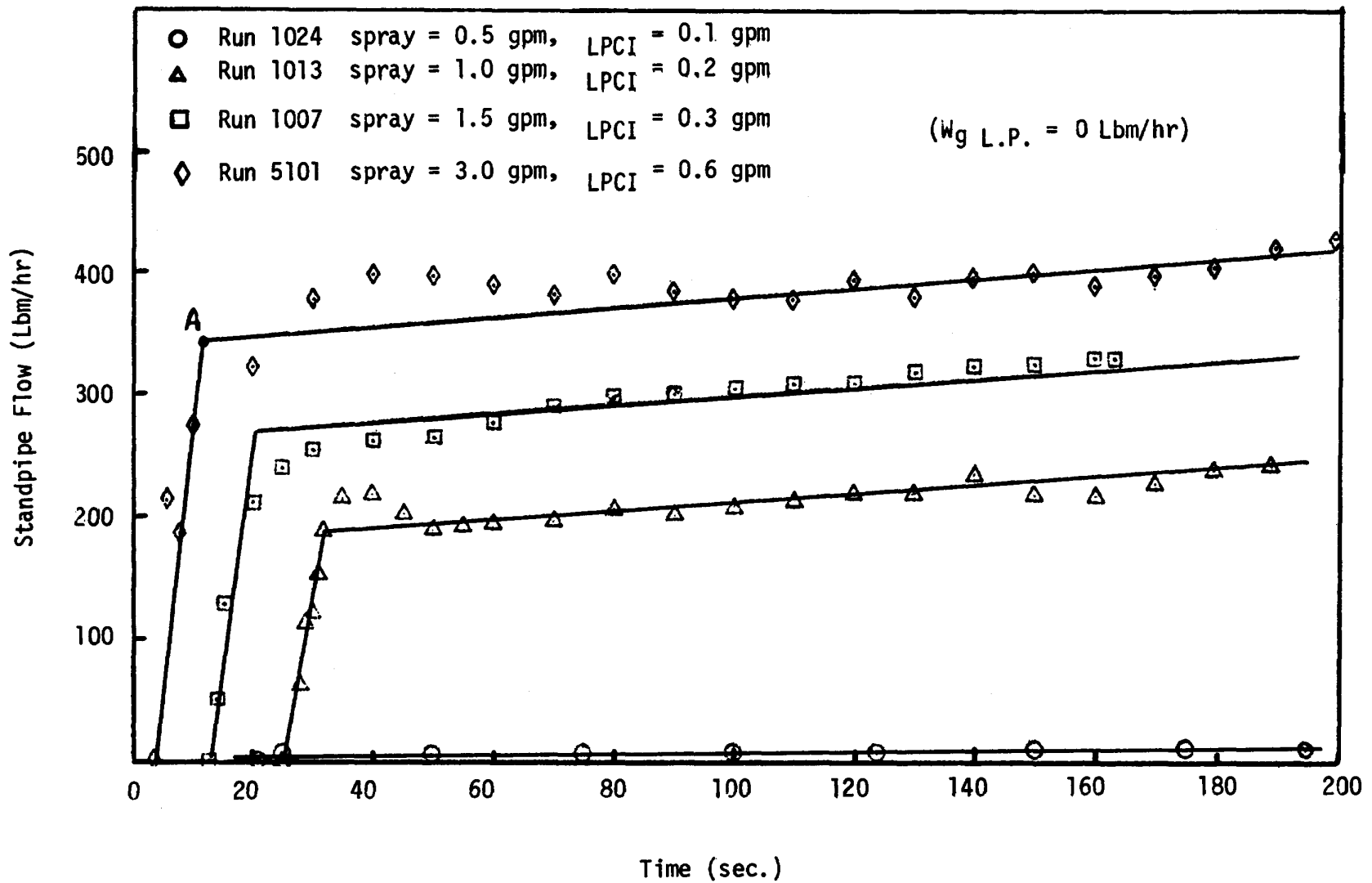


Figure 3-10. Core Vaporization Rate vs. Core Spray Rate

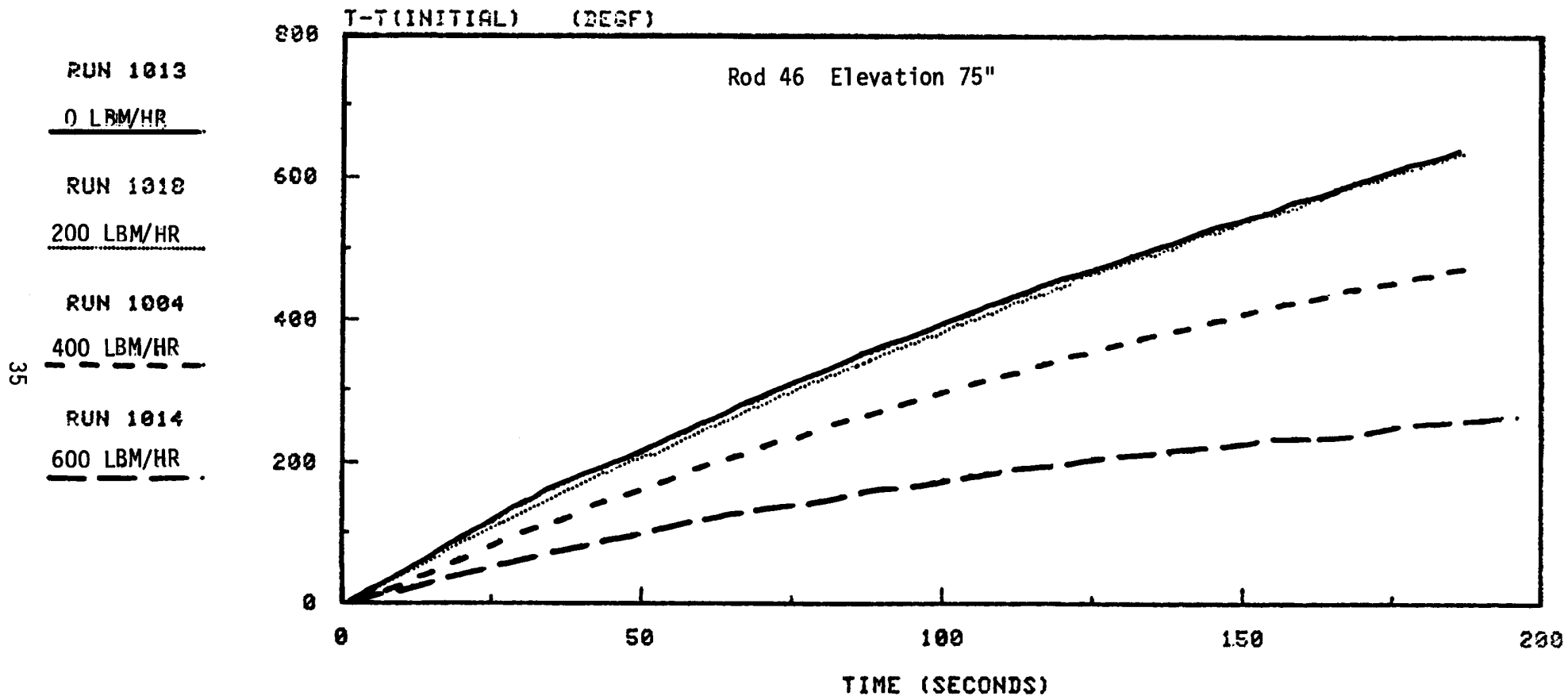


Figure 3-11. Bundle Temperature Transient vs. Channel Inlet Steam Flows -  
1.0 GPM Core Spray Rate

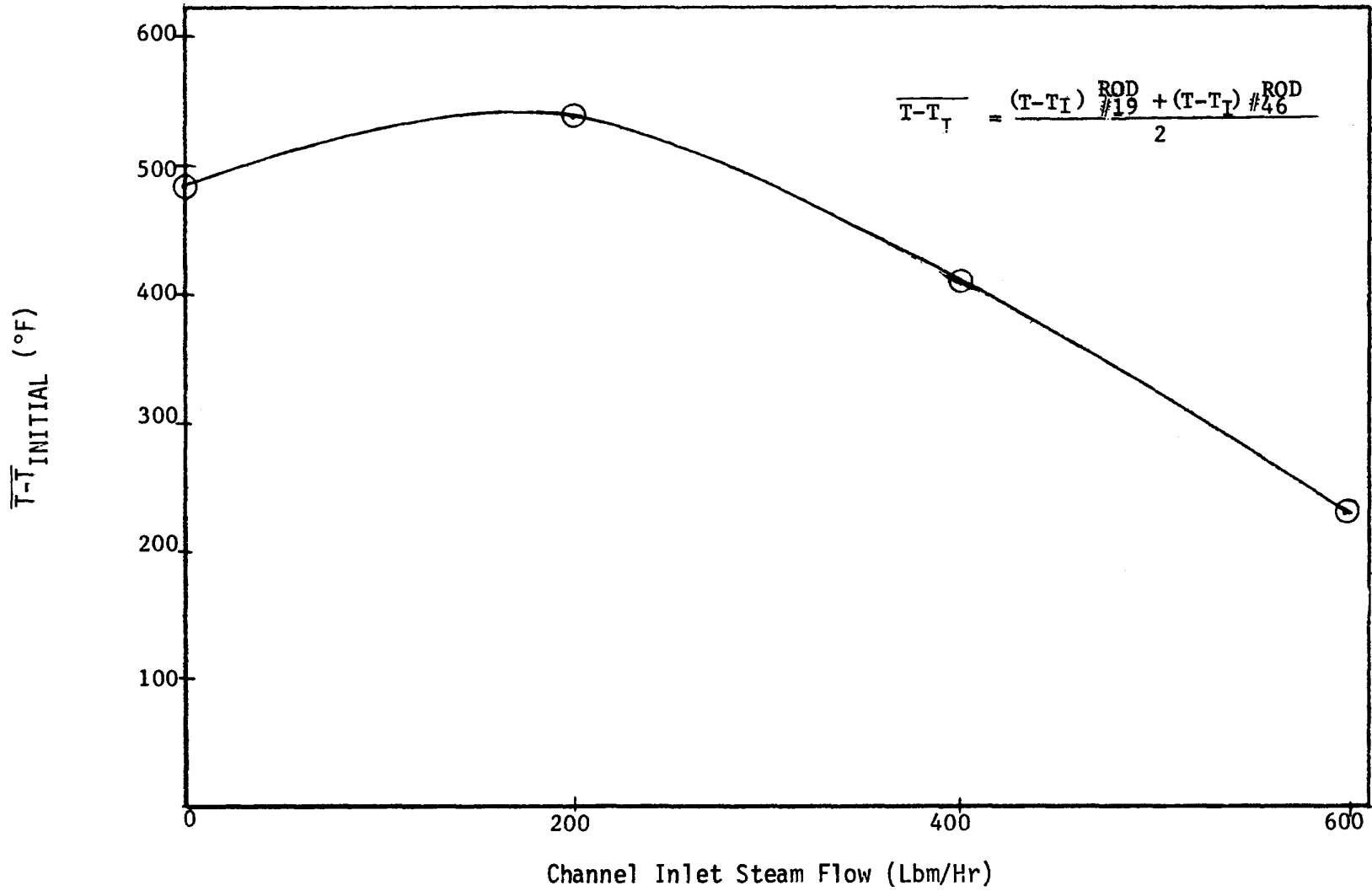


Figure 3-12. Mean Hot Rod Heat Up vs. Channel Inlet Steam Flow -  
1.0 GPM Core Spray Rate (t=150 sec)

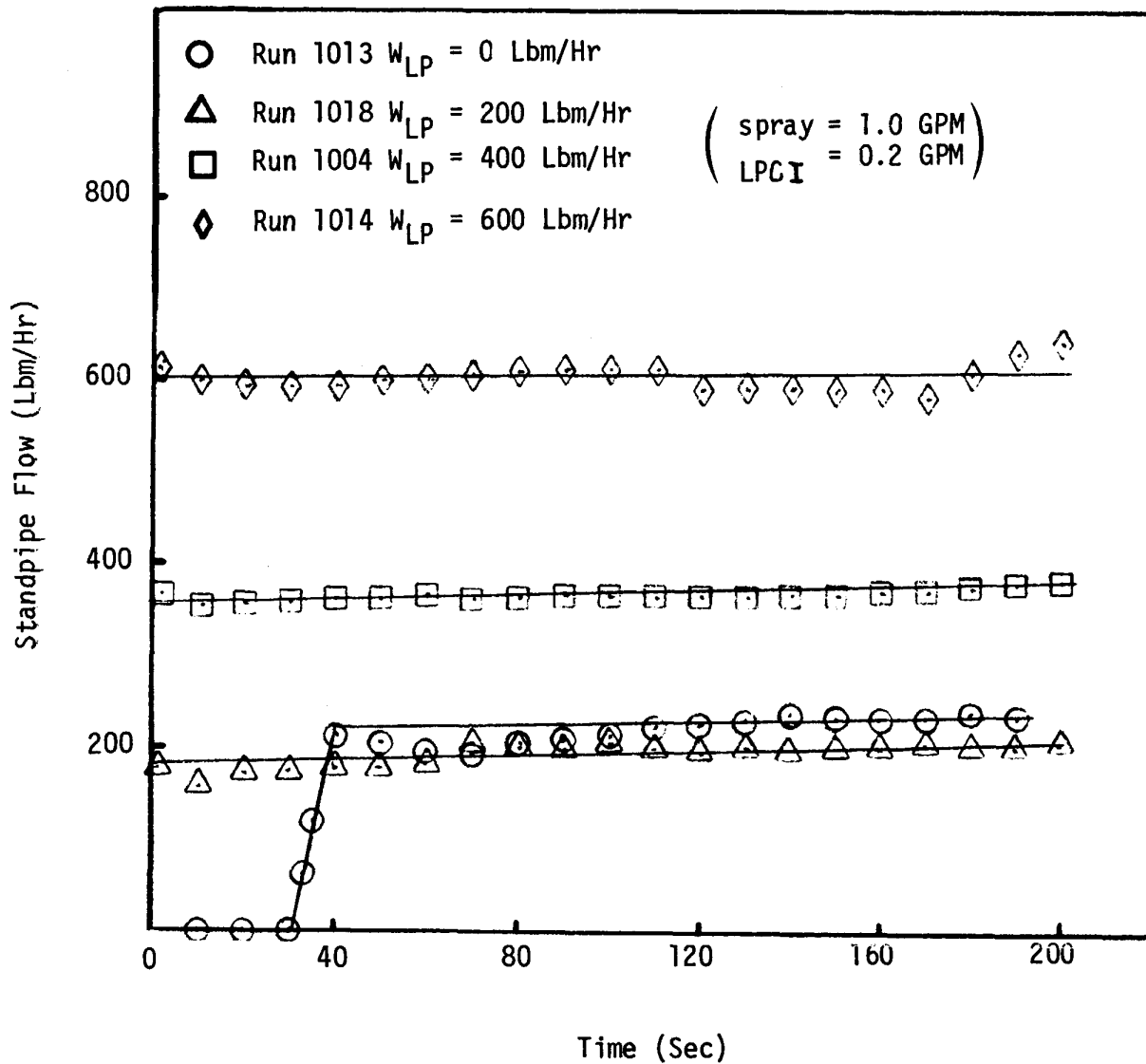


Figure 3-13. Stand Pipe Steam Flow vs. Channel Inlet Steam Flow - 1.0 GPM Core Spray Rate

the reflood flow is forced to enter the bundle at a constant rate. In the second type, system interaction, the reflood flow is free to enter the bypass and jet pump regions as well.

The test configuration for the first type isolates the bypass region and jet pump. For the second type, the bypass leakage holes are unblocked to allow core-bypass interaction, and the jet pump is unblocked to allow core-bypass-jet pump interaction.

The reflood heat transfer is characterized by the temperature response of the heated rods and the liquid accumulation, and corresponding void distribution, in the bundle. The test series covers various flooding rates, lower plenum steam injection rates (simulating lower plenum flashing), and bundle power. The reflood heat transfer test matrix nominal values are listed in Table 3-2. The tests are run by setting the lower plenum steam rate and the core power. The rods heat to an initial temperature of about 1100 F at the mid plane. At this time,  $t=0$ , the flood rate and power decay transient are initiated. The transient continues until the rods quench.

#### Temperature Distribution In the Bundle

Initially the bundle is partially cooled by single-phase steam flow from the lower plenum entering at saturation temperature and exiting highly superheated. With the addition of flooding water to the inlet flow there is a transition period in which liquid accumulates within the bundle and steam generation, from vaporization of some of this liquid, rapidly builds up. The rod temperature rise rate is attenuated during this transition, and the temperature turnover marks the end of this period. As shown in Figure 3-14, the peak clad temperature is reached simultaneously at all elevations along the top 3/4 of the bundle, and coincides closely with a step change in the outlet steam temperature from highly superheated to saturation. Following this, the quench front moves up in the bundle with a net accumulation of liquid in the bundle.

Evaluation of bundle temperature turnover, quench front motion, and liquid accumulation has been completed with Run 2314 to develop the data evaluation technique. Similar response is observed in the remaining tests in this series, with event timing shifted due to the parameter variations.

#### 3.2.3 Bypass Heat Transfer

The objective of this test series is to determine core to bypass heat transfer characteristics at different LPCI and core heat capacity rates. The test is conducted by isolating the bypass from the bundle and measuring the steady state heat transfer across the channel wall. This test configuration is achieved by blocking the jet pump, isolating the guide tube, blocking the bypass leakage holes, and blocking the top of bypass, as shown in Figure 3-15. Bypass heat transfer rates are determined from the

TABLE 3-2  
REFLOOD HEAT TRANSFER TEST MATRIX

Run	Lower Plenum Flow Rate (gpm)	Lower Plenum Steam Rate (lb/hr)	Bundle Power (Kw)	Comments
2314	8	155	250	Controlled Bottom Flood
2319	8	155	100	Controlled Bottom Flood
2329	8	0	250	Controlled Bottom Flood
2330	8	0	100	Controlled Bottom Flood
2331	4	155	250	Controlled Bottom Flood
2101	8	155	250	Core-Bypass Interaction
2201	8	155	250	Core-Bypass-Jet Pump Interaction

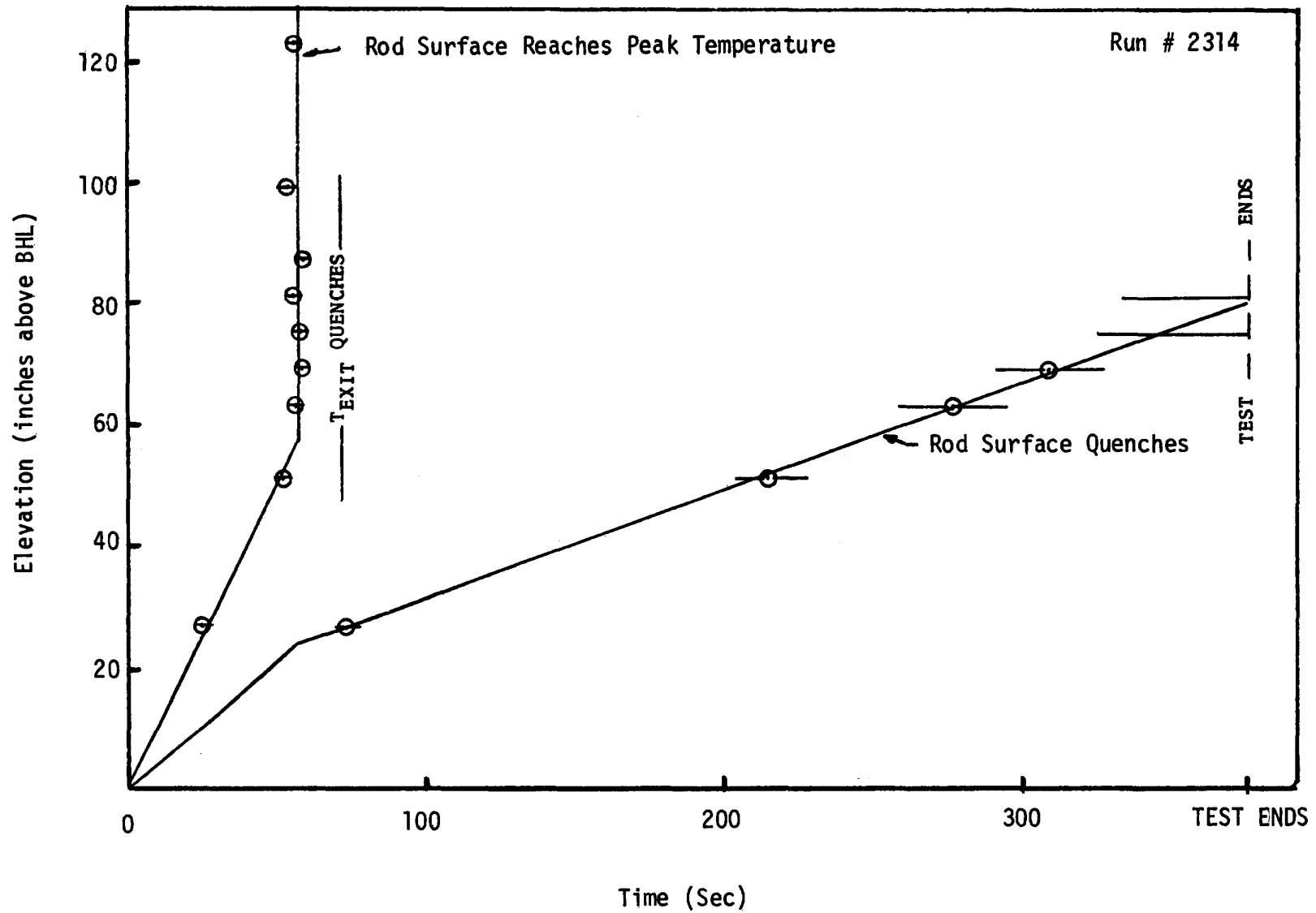


Figure 3-14(a). Bottom Reflood Heat Transfer Characteristics  
Quench Front vs. Time

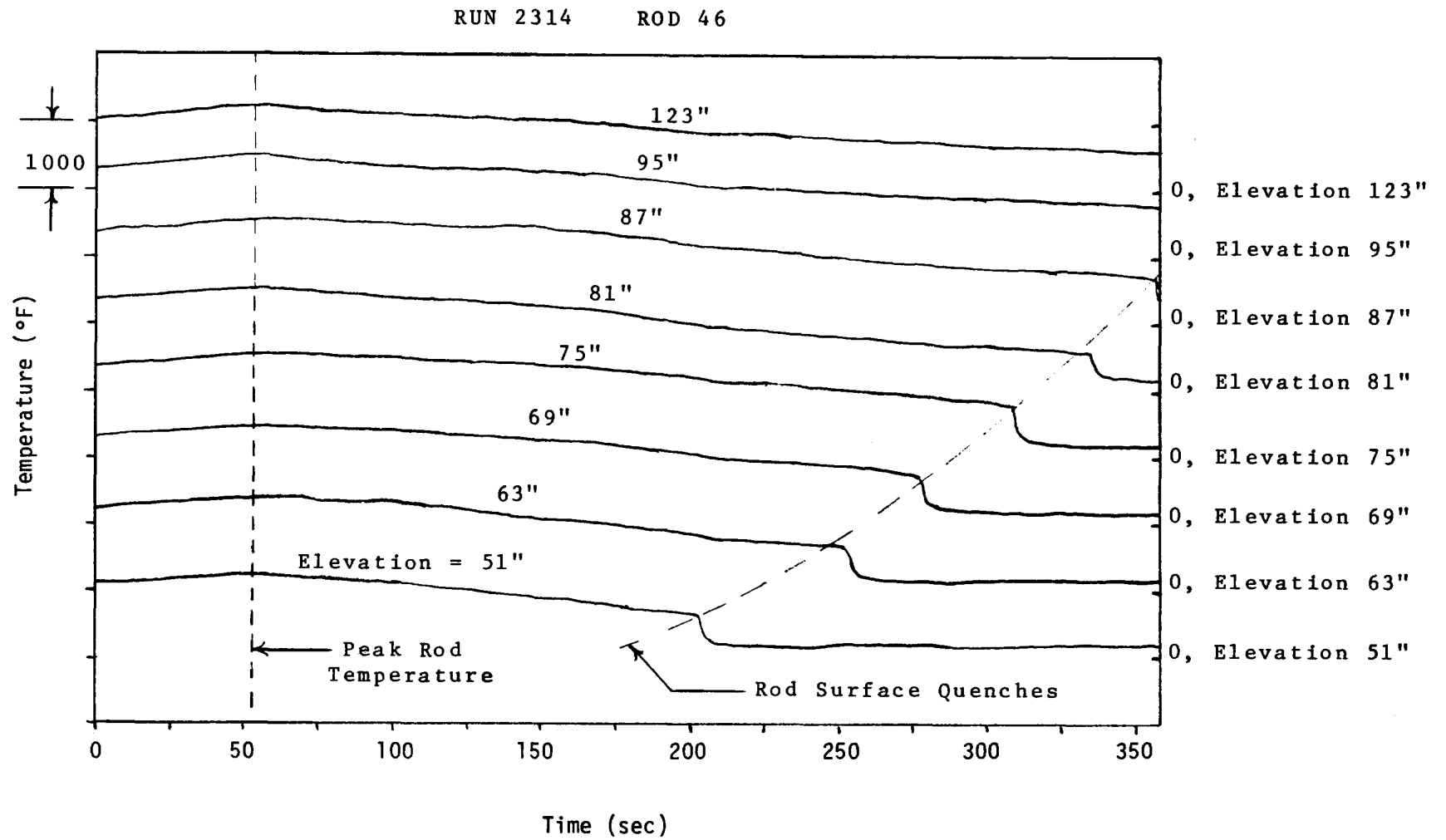


Figure 3-14(b). Bottom Reflood Heat Transfer Characteristics  
Typical Rod Temperatures

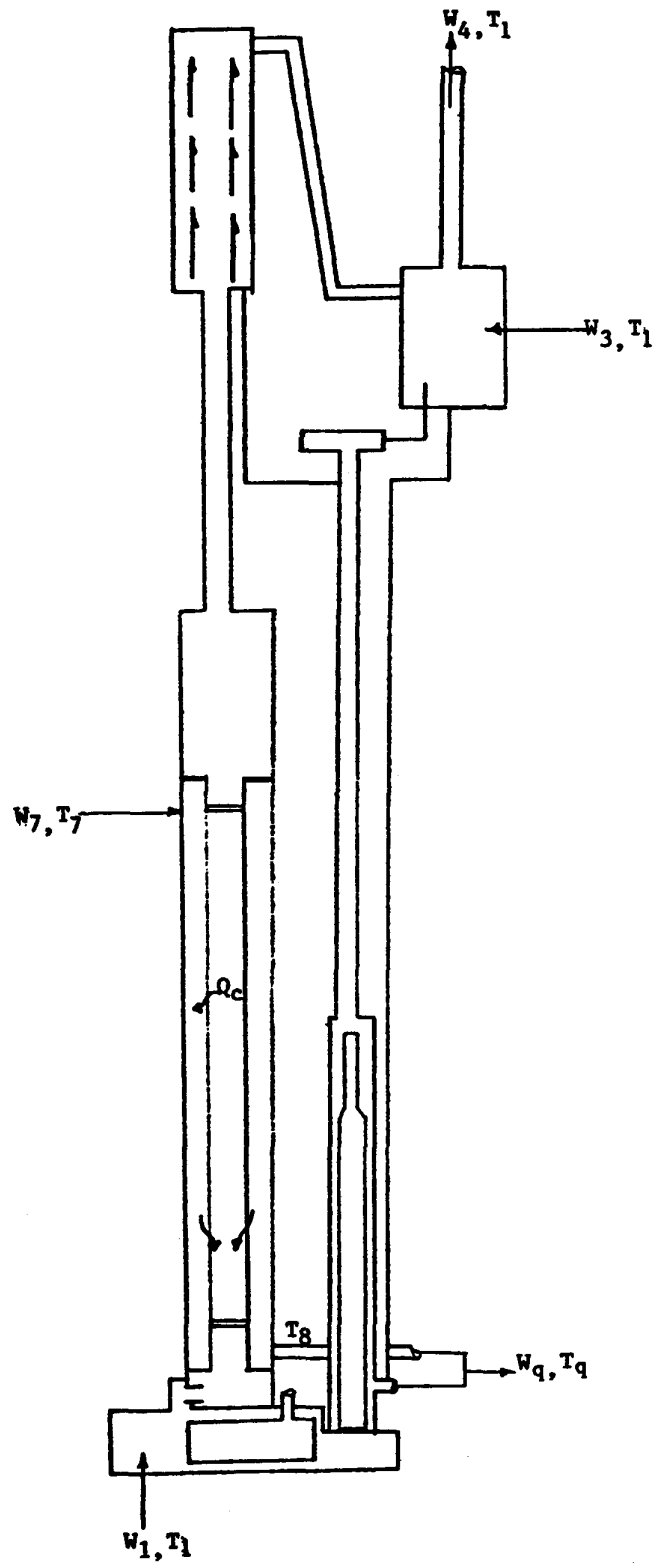


Figure 3-15. Bypass Heat Transfer Test Configuration

bypass flow temperature rise. The test matrix, shown in Table 3-3 includes tests with various LPCI flows and temperatures, and various steam injection rates.

These tests are run in steady state. Lower plenum steam injection rate is first set. Next, bypass flow is set and the bypass drain valve adjusted so that a full bypass is maintained. Core power is initiated (if required), and the system allowed to reach steady state as evidenced by a constant bypass drain temperature. The test measurements, averaged over the test period, are given in Table 3-3. Despite the fact that bypass leakage holes were blocked, a small amount of bypass-to-core leakage occurred at the lower channel connecting flange. This leakage resulted in a two-phase mixture in the bundle. The void fraction of the mixture varied with the power and steam injection, but in all cases it was sufficient to sustain a saturated two phase mixture in the core. Therefore, the temperature throughout the core is saturated. Due to an instrument malfunction, the LPCI flow rate,  $W_7$ , was not directly measured in these tests. Instead, a mass balance is performed to determine the LPCI flow.

The heat transferred to the bypass flow, the bypass flow Reynolds number, and the overall heat transfer coefficient ( $U$ ) of the bypass region are given in Table 3-3. Figure 3-16 shows the correlation of overall heat transfer coefficient  $U$  with Reynolds number.

TABLE 3-3: BYPASS HEAT TRANSFER TEST MATRIX AND RESULTS

RUN =	3020	3021	3022	8008
T1 = Steam Inlet Temp. (F)	225	206	219	227
T7 = LPCI Temp. (F)	129	122	121	122
T8 = Bypass Drain Temp. (F)	190	149	149	158
W1 = LP Steam Flow (lb/hr)	400	398	399	807
W3 = Steam Dome Flow (lb/hr)	86	99	98	102
W4 = Stack Flow (lb/hr)	218	39	33	298
W7 = LPCI Flow (lb/hr)	3,506	12,588	14,539	12,632
W9 = LPHT Flow (lb/hr)	3,774	13,047	15,004	13,243
Q = Heat Trans. ( $10^3$ BTU/hr)	215	340	402	452
U = Heat Trans. Coef. (BTU/hr sq ft F)	129	176	175	190
Re = Reynolds Number	2,895	9,526	11,000	9,558

$$W7 = W4 + W9 - W1 - W3$$

$$Q = W7 C_p (T8 - T7)$$

$$U = Q / (A \cdot \Delta T_{1m})$$

$$Re = VDe/\nu$$

$$V = W7 / (\rho A_f)$$

$$A_f = 0.0672 \text{ sq ft}$$

$$\rho = \text{Density of LPCI} \\ (62 \text{ lb/cu ft})$$

$$De = \text{Bypass Hydraulic} \\ \text{Diameter (0.069 ft)}$$

$$C_p = \text{Specific Heat of LPCI} \\ (1 \text{ BTU/lb F})$$

$$A = \text{Bypass Heat Transfer} \\ \text{Area (27.69 sq ft)}$$

$$\Delta T_{1m} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

$$\Delta T_1 = T_1 - T_7$$

$$\Delta T_2 = T_1 - T_8$$

$$\nu = \text{LPCI Kinematic Viscosity} \\ (0.02 \text{ sq ft/hr})$$

OVERALL HEAT TRANSFER COEFFICIENT

$$U = \frac{Q}{A \Delta T} \left( \frac{\text{BTU}}{\text{hr Ft}^2 \text{ F}} \right)$$

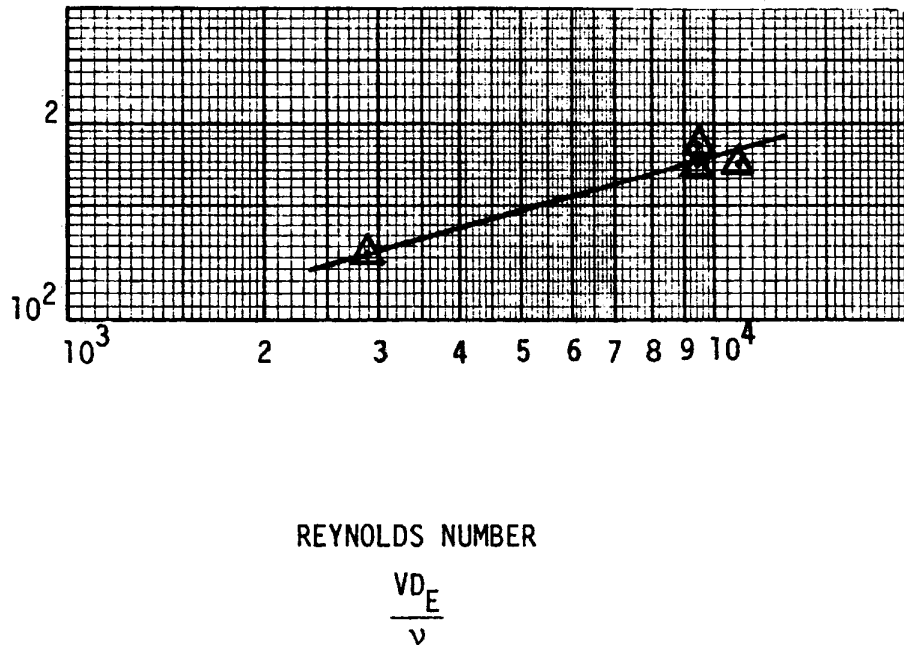


Figure 3-16. Bypass Heat Transfer Coefficient



#### 4.0 Conclusions

Comparisons between TLTA system response data and SHB simulation of the same test demonstrate that the Single Heated Bundle Facility can reasonably simulate LOCA depressurization transients. Steam injection is used to replace depressurization flashing, and the steam and vaporization rates are pressure scaled based on CCFL areas.

The appropriateness of using adiabatic steam injection to simulate bundle heat transfer vaporization in the Steam Sector Test Facility (SSTF) has been empirically demonstrated.

Core spray heat transfer cooling capability increases linearly with spray flow over the range tested (0.5 to 3.0 gpm). The addition of bundle inlet steam flow increases heat transfer at higher rates (400 to 600 lb/hr).

Bottom reflooding of a heated bundle first limits the temperature rise of the rods and then quenches them starting at the bottom and progressing to the top with a well defined quench front. The steady state heat transfer from the channel wall to a flooded bypass is characterized by an overall heat transfer coefficient of 100 to 200 Btu/hr sq ft F.



## 5. References

1. BWR Refill-Reflood Program Task 4.3 - Single Heated Bundle Experimental Task Plan, D.D. Jones, L.L. Myers, J.A. Findlay, General Electric Company GEAP-24865, Nuclear Regulatory Commission NUREG/CR-1708, Electric Power Research Institute EPRI NP-1524, March 1981.
2. BWR Refill-Reflood Program Task 4.3 - Single Heated Bundle Experimental Task Plan Addendum 1 Stage 3 - Separate Effects Bundle, D.D. Jones, General Electric Company GEAP-24865-Add. 1, Nuclear Regulatory Commission NUREG/CR-1708-Add. 1, Electric Power Research Institute EPRI NP-1524-Add.1, March 1981.
3. BWR Refill-Reflood Program Task 4.1 - Program Plan, G. W. Burnette, General Electric Company GEAP-24924, Nuclear Regulatory Commission NUREG/CR-1972, Electric Power Research Institute EPRI NP-1522, August 1981.



## 6. Nomenclature

A	Area (ft <sup>2</sup> )
C <sub>p</sub>	Specific Heat (Btu/lb F)
D	Characteristic Diameter (ft)
D <sub>e</sub>	Hydraulic Diameter (ft)
h	Head (In H <sub>2</sub> O)
j <sub>f</sub>	Volumetric Liquid Flux = W <sub>f</sub> /Aρ <sub>f</sub> (ft/sec)
j <sub>g</sub>	Volumetric Steam Flux = W <sub>g</sub> /Aρ <sub>g</sub> (ft/sec)
j <sub>f</sub> *	Dimensionless Liquid Velocity = j <sub>f</sub> [ ρ <sub>f</sub> /gD(ρ <sub>f</sub> - ρ <sub>g</sub> ) ] <sup>1/2</sup>
j <sub>g</sub> *	Dimensionless Vapor Velocity = j <sub>g</sub> [ ρ <sub>g</sub> /gD(ρ <sub>f</sub> - ρ <sub>g</sub> ) ] <sup>1/2</sup>
K	Flow Correlation Constant (gpm/(In H <sub>2</sub> O) <sup>1/2</sup> ) or (lb/hr)/(In H <sub>2</sub> O lb/ft <sup>3</sup> ) <sup>1/2</sup>
ΔP	Pressure Difference (In H <sub>2</sub> O)
Q	Heat Transfer (Btu/hr)
Re	Reynolds Number = V D <sub>e</sub> /ν (Dimensionless)
T	Temperature ( F)
ΔT	Temperature Difference ( F)
t	Time (sec)
U	Overall Heat Transfer Coefficient (Btu/hr ft <sup>2</sup> F)
V	Velocity (ft/hr)
W	Mass Flow Rate (lb/hr)
Greek Symbols	
ρ	Density (lb/ft <sup>3</sup> )
ν	Kinematic Viscosity (ft <sup>2</sup> /hr)
Subscripts	
f	Saturated Liquid
g	Saturated Vapor
LP	Lower Plenum
SP	Stand Pipe



**APPENDIX A**

**DEMONSTRATION OF SHB PRESSURE SCALING**



The objective of this test series is to evaluate if TLTA performance during a blowdown can be simulated in SHB, operating at constant pressure, by utilizing steam injection to represent flashing.

The pressure scaling is based on CCFL controlled liquid flow rates, and mass and energy balances, for each region of the test facility. Data from the Two-Loop Test Apparatus (TLTA) is used as a reference to establish conditions for SHB tests. The steps followed are: (a) scaling analysis of a TLTA-5A transient test to define base case initial conditions and independent test parameter values, (b) base case test, and tests over a range of test parameter values, in the SHB/ECCS Test Loop with a heated bundle to simulate TLTA transient, and (c) comparison of the SHB response to the TLTA response to evaluate if responses are similar.

The determining factor in this scaling qualification is similarity of TLTA and SHB mass fill transients in the five principal regions. The test is based on a maximum break size LOCA with 1 LPCI and 2 core spray systems operational. The steam injection rates, core stored heat, and bundle power are scaled from TLTA 5A and varied to determine the sensitivity of refill/reflood performance to the scaling. The selected scaling values are shown in Table A-1.

The initial mass is set in the lower plenum, guide tube, and annulus and steady state steam flow injected into the lower plenum and guide tube. With core power on, the rod temperature rises to the specified initial value. The ECC flow and core power transient are then started.

For scaling confirmation the results of SHB and TLTA 5A are compared over the first 120 seconds of the transient. This corresponds to the core refill period over which the scaling technique is applicable.

The TLTA lower plenum remains approximately half full for the entire period, which corresponds to a "collapsed" level below the jet pump. As shown in Figure A-1, the SHB mass varies between 70 and 90 lbm, which also is below the jet pump (93 lbm is the mass required to reach the bottom of the jet pump in the SHB), satisfactorily simulating the TLTA 5A lower plenum refill transient.

The TLTA 5A bundle refloods with two-phase mixture at 120 sec. As shown in Figure A-1, SHB agrees well with TLTA 5A up to 70 seconds, and then increases to a mass of approximately 90 lbm. TLTA 5A levels off at a mass of about 60 lbm. The difference in the final mass value is due to differences in the final void fractions of the tests. However, the general trends agree well.

The TLTA 5A bypass fills rapidly and is full at 30 seconds, as shown in Figure A-1. The SHB bypass filling is not as rapid, but

TABLE A-1  
 TLTA 5A SCALING FOR SHB (RUN 1400)

Core Power	100 Kw
Core Initial Temperature	250 F
Lower Plenum Steam Injection	378 lb/hr
Guide Tube Steam Injection	86 lb/hr
Steam Dome Steam Purge	100 lb/hr
ECCS at 130 F	
Spray	17.1 gpm
LPCI	6.3 gpm
Initial Mass	
Lower Plenum	56 lb
Guide Tube	110 lb
Annulus	12 lb

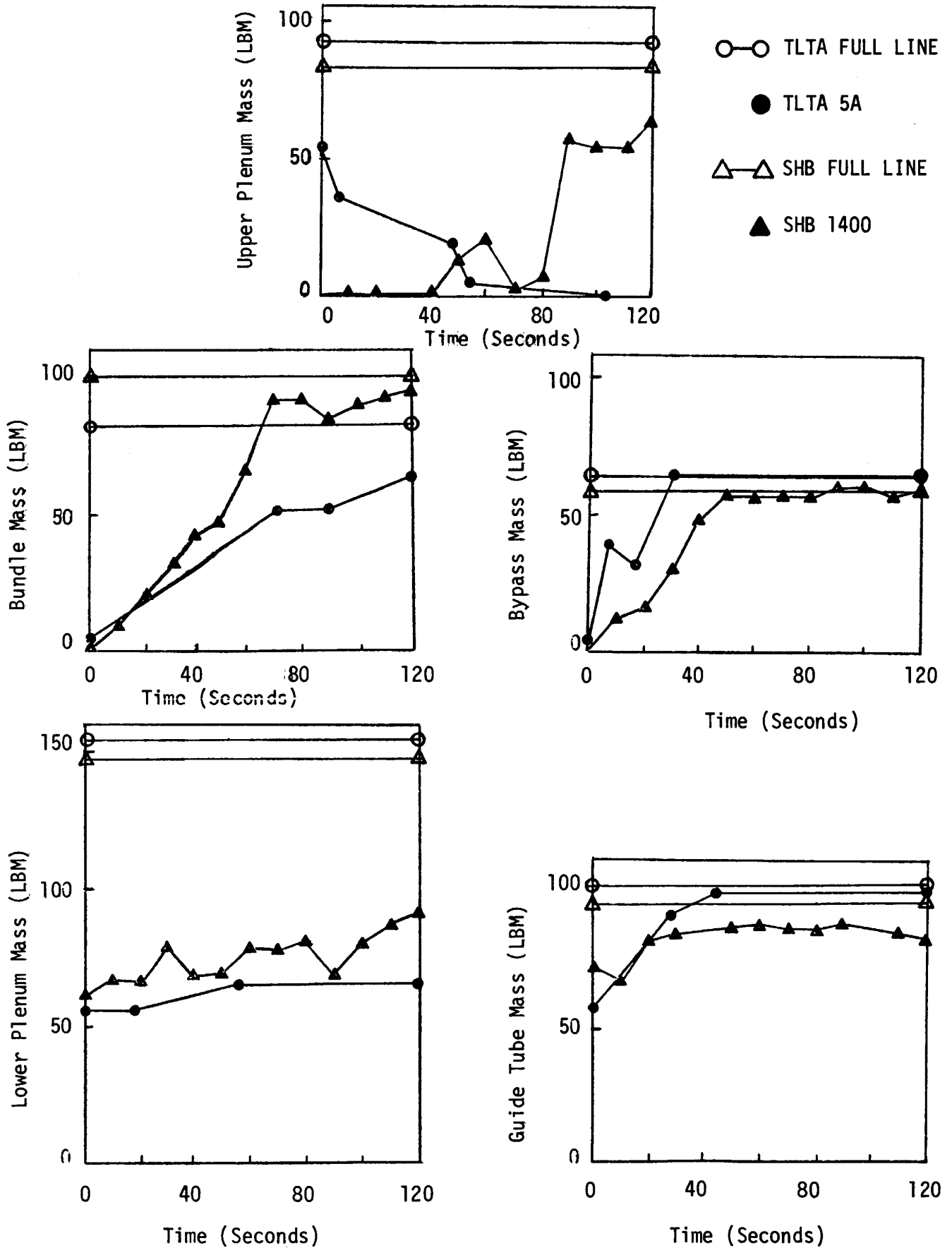


Figure A-1. TLTA vs. SHB Refill-Reflood Comparisons

it does completely fill within 50 seconds. In the TLTA, part of the mass in the upper plenum drains into the bypass, thus contributing to the bypass filling. This is not the case in SHB since there is no mass in the upper plenum during the initial period.

For both tests, TLTA and SHB, the guide tube is initially 60-80% full and is essentially completely full within 45-50 seconds. This is shown in Figure A-1. Thus, the SHB provides a good simulation of the guide tube refill transient.

The TLTA upper plenum starts with an initial mass of 54 lbm that drains within 55 seconds, as shown in Figure A-1. Since the SHB test is not initiated with a mass accumulation in the upper plenum, the SHB upper plenum remains empty until the core level is high enough to support an inventory above the tie plate. This begins at about 70 sec. Although these two responses appear quite different, the mass accumulation in this region is found to be a secondary consideration, being the result of a filled bypass and core, rather than a controlling phenomena.

Based on these outcomes it is concluded that the steady pressure SHB, conducted with scaled TLTA 5A parameters, reasonably simulates the refill/reflood performance of TLTA 5A.

**APPENDIX B**  
**FACILITY CALIBRATION AND SHAKEDOWN TESTS**

## B.0 Test Results

### B.1 Facility Calibration and Shakedown

This section discusses tests run to verify facility operation and calibrate important facility characteristics. Some tests were run only at the onset of the test program, such as tests on the ECCS loop. Others tests, which address bundle characteristics, were run for each of the three bundle mock-ups.

#### B.1.1 Bypass Leakage Tests

The SHB leakage test objectives are to 1) measure the flange leakage from the bypass into the core region, and 2) adjust the lower tieplate bypass leakage flow area until the total leakage from bypass to core is 18.1 gpm with 4.7 psi (136 in. water) head in the bypass. The LAB leakage test objective is to determine the leakage flow rate versus head. The Separate Effect Bundle (SEB) leakage test objective is to adjust the leakage area to achieve 18.1 gpm at 4.7 psi, as in the SHB.

The Single Heated Bundle (SHB) channel and bypass region is shown in Figure B-1. There are four holes (0.295 in. DIA.) located 4.7 inch below the top of the simulated lower tieplate to simulate the reactor lower tieplate leakage path. One or more of these four holes may be plugged to adjust the leakage flow to a specified amount. The channel extension flange is a non-gasketed flange and results in a small additional leakage from the bypass to the core at the elevation shown in Figure B-1. The Lynn Adiabatic Bundle (LAB) has no channel extension flange (Figure B-2) and the lower tieplate holes are of a fixed area. The Separate Effects Bundle (SEB), also shown in Figure B-1, also has no channel extension flange, but does have an adjustable area for the lower tieplate leakage path.

Leakage flow tests are conducted by injecting LPCI water, at steady state flow rates ranging from 2 to 22 gpm, into the bypass region with the lower plenum continuously drained to provide a free leakage path. The results from the three bundles are shown in Figures B-3 through B-5. The specified leakage is found to occur with 2 holes open in the SHB and 3 in the SEB. The results show, as expected, that bypass volumetric leakage rate is independent of water temperature and is linear with the square root of the driving head. Finally, water overflows the bypass into the core for flowrates greater than 20 gpm in the SHB and SEB and 13 gpm in the LAB.

#### B.1.2 Side Entry Orifice (SEO) Flow Tests

The objective of this test is to obtain flow coefficients for side entry orifices 1.257 and 2.43 inches in diameter. The jet pump entry is blocked so that all steam entering the lower plenum

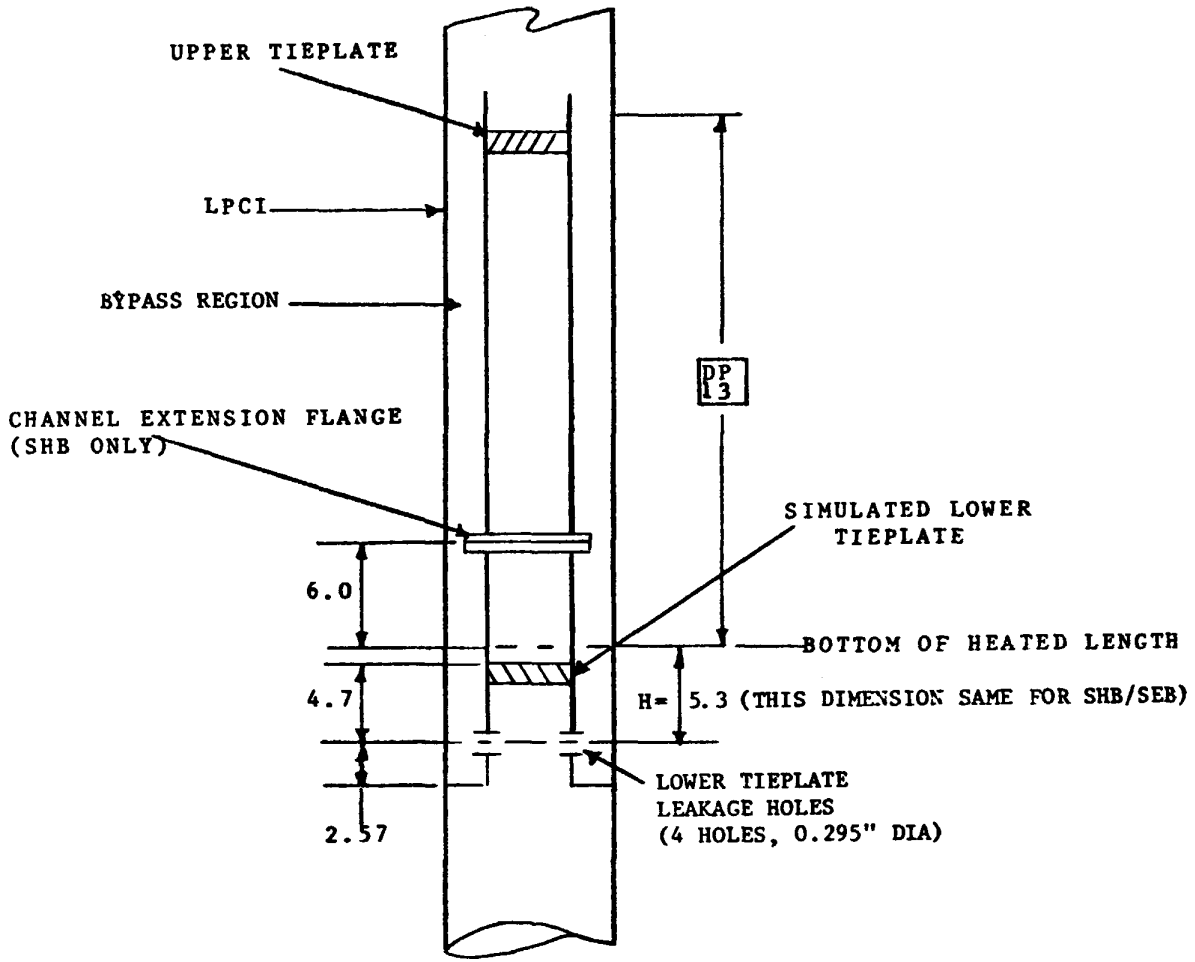


Figure B-1. SHB Bypass Leakage Geometry

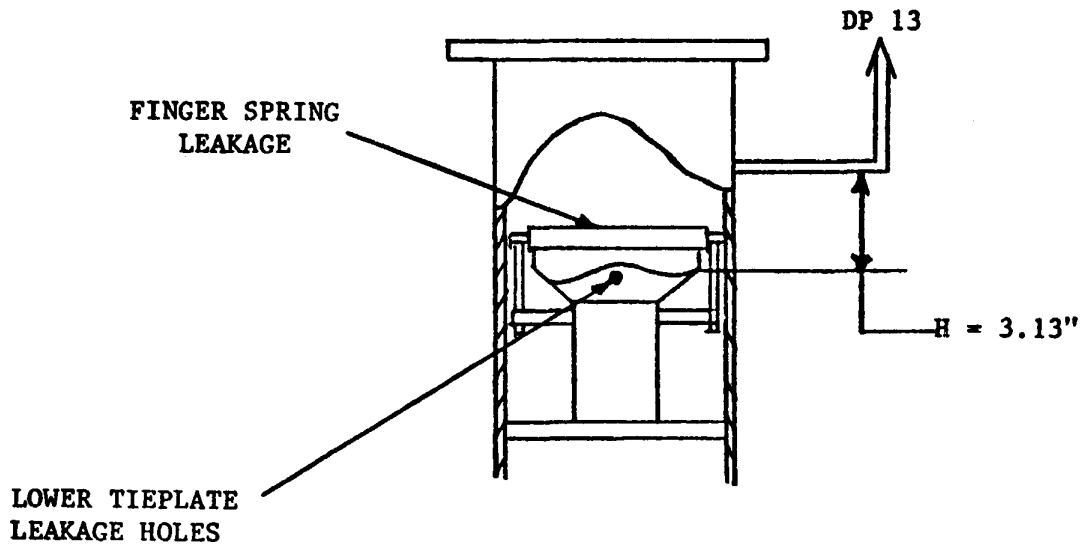


Figure B-2. Relationship of DP-13 to LAB Bypass Leakage Paths

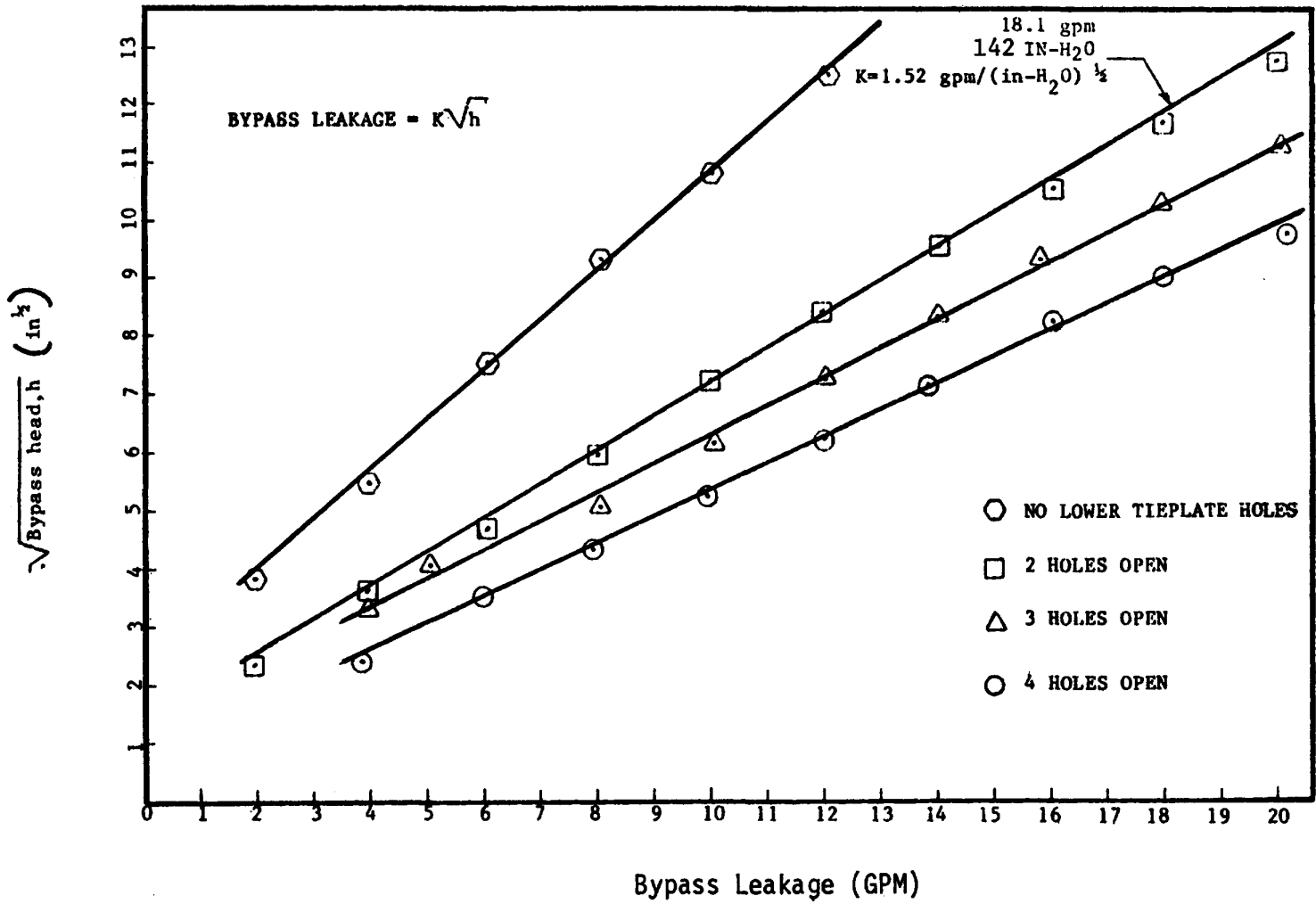


Figure B-3. Bypass Leakage for Single Heated Bundle

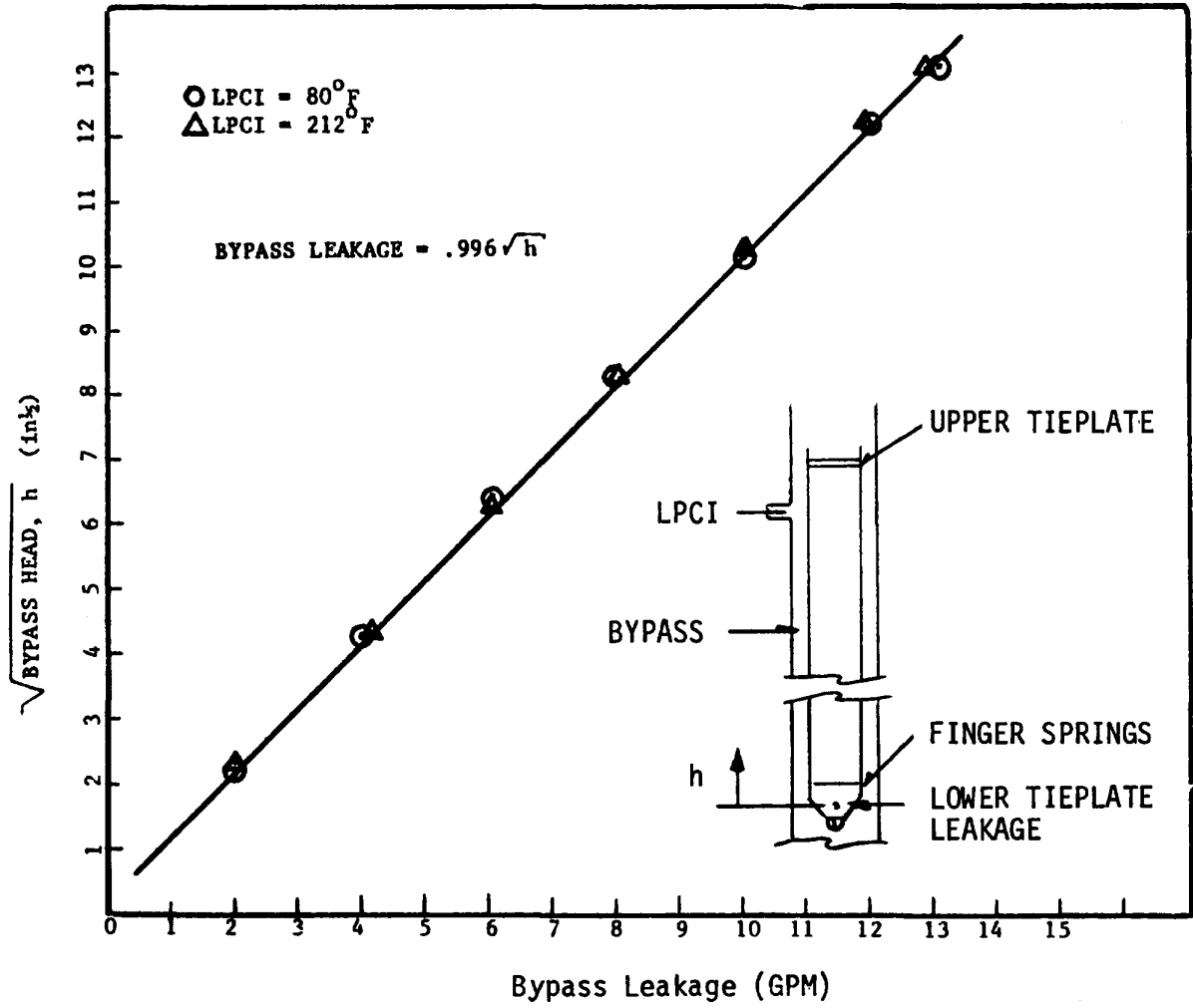


Figure B-4. Bypass Leakage for Lynn Adiabatic Bundle

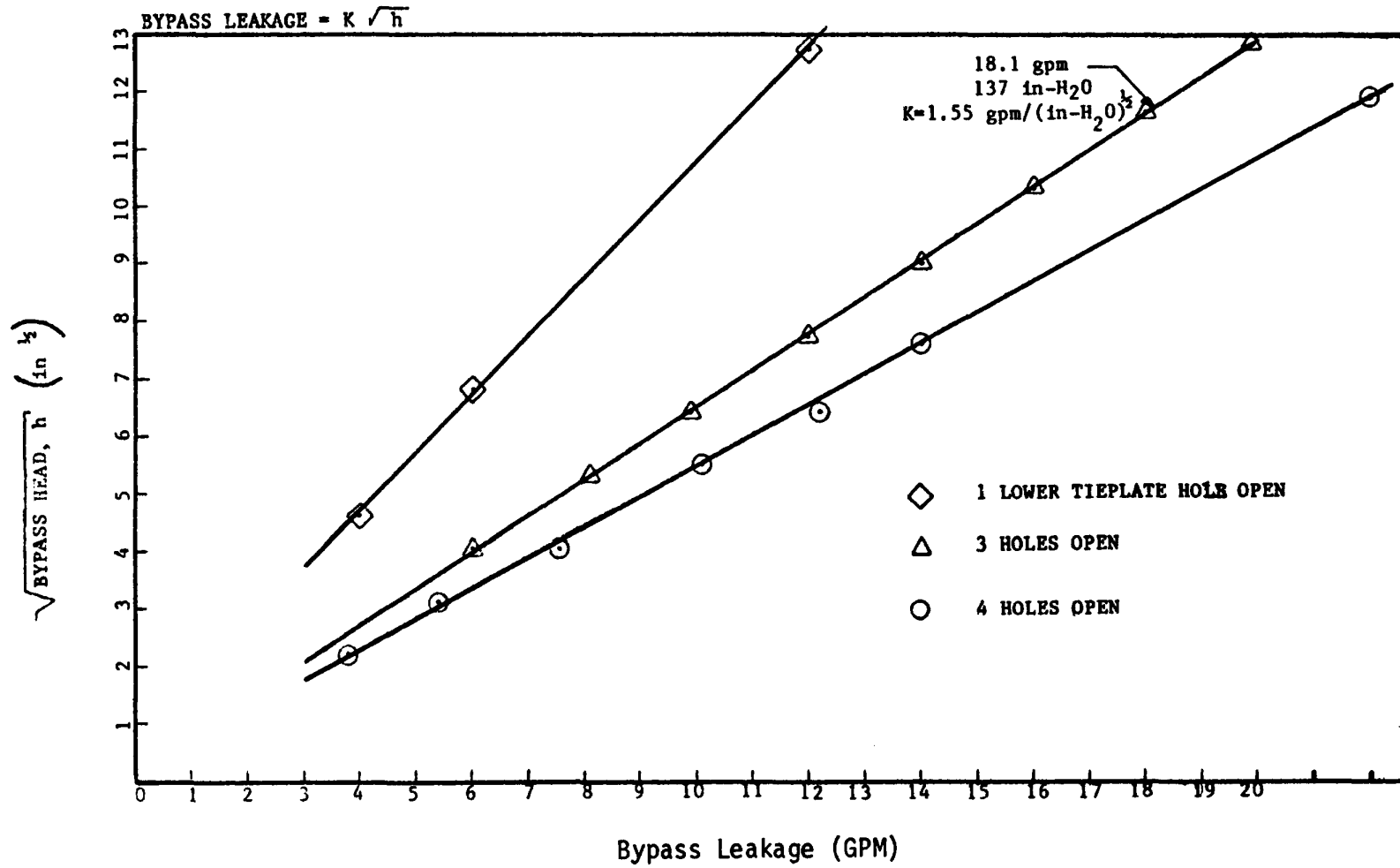


Figure B-5. Bypass Leakage for Separate Effects Bundle

passes through the side entry orifice. Steam is injected at rates from 100 to 800 lbm/hr, with the flow measured by the pressure drop across the orifice.

Results of the SEO flow tests for the 2.43" and 1.257" diameter orifices are shown in Figure B-6. These orifice diameters are the nominal values for the central and peripheral fuel bundle regions in the SSTF.

#### B.1.3 Core/Jet Pump Steam Flow Split

The objectives of this test are to determine the core/jet pump single phase steam flow split with and without the bottom of the jet pump submerged, and to determine the flow coefficients for the jet pump flow length and the jet pump entrance.

This series consists of two types of tests. In the first type steam is injected into an empty lower plenum and measurements made at flow rates ranging from 100 to 500 lbm/hr. In the second type steam flow is injected and saturated LPCI injected to fill the test section. The flow split is measured when the core fills with water.

Table B-1 includes the steam injected in the lower plenum, steam flow up the standpipe, and the resulting flow split for steady state flow tests. The average flow split is 51% (i.e., the fraction of steam from the lower plenum that passes through the core when the plenum is empty). The flow split with the jet pump submerged can only be determined for the two lowest lower plenum steam injection flows, and is found to average 85% through the core. At higher steam flows the core pressure drop is sufficient to force the lower plenum liquid level down to the point where the jet pump entrance is no longer submerged, and the flow split is once again evenly split. Referring to Table B-1, it is seen that the core/jet pump flow split varies from 0.80 to 0.92 with the jet pump entry submerged, and drops to approximately 0.50 when the jet pump entry is uncovered. The jet pump single phase flow data are shown in Figure B-7.

#### B.1.4 Upper Tieplate CCFL (Lynn Adiabatic Bundle)

The objective is to determine the CCFL characteristic of the LAB upper tie plate. In the standard system configuration the upper plenum drains through both the top of the bypass path and the upper tie plate path. To measure the flow through the upper tie plate path, techniques are used to independently control the flow through the top of the bypass path. The CCFL tests are run in three different ways to ensure that the bypass leakage, and phenomena associated with re-establishing CCFL for each steam injection rate, are adequately accounted for.

Procedure 1 uses the LPCI to fill the test section, as shown in Figure B-8(a). The LPCI flow is adjusted such that no water spills into the core from the top of the bypass region, but flows

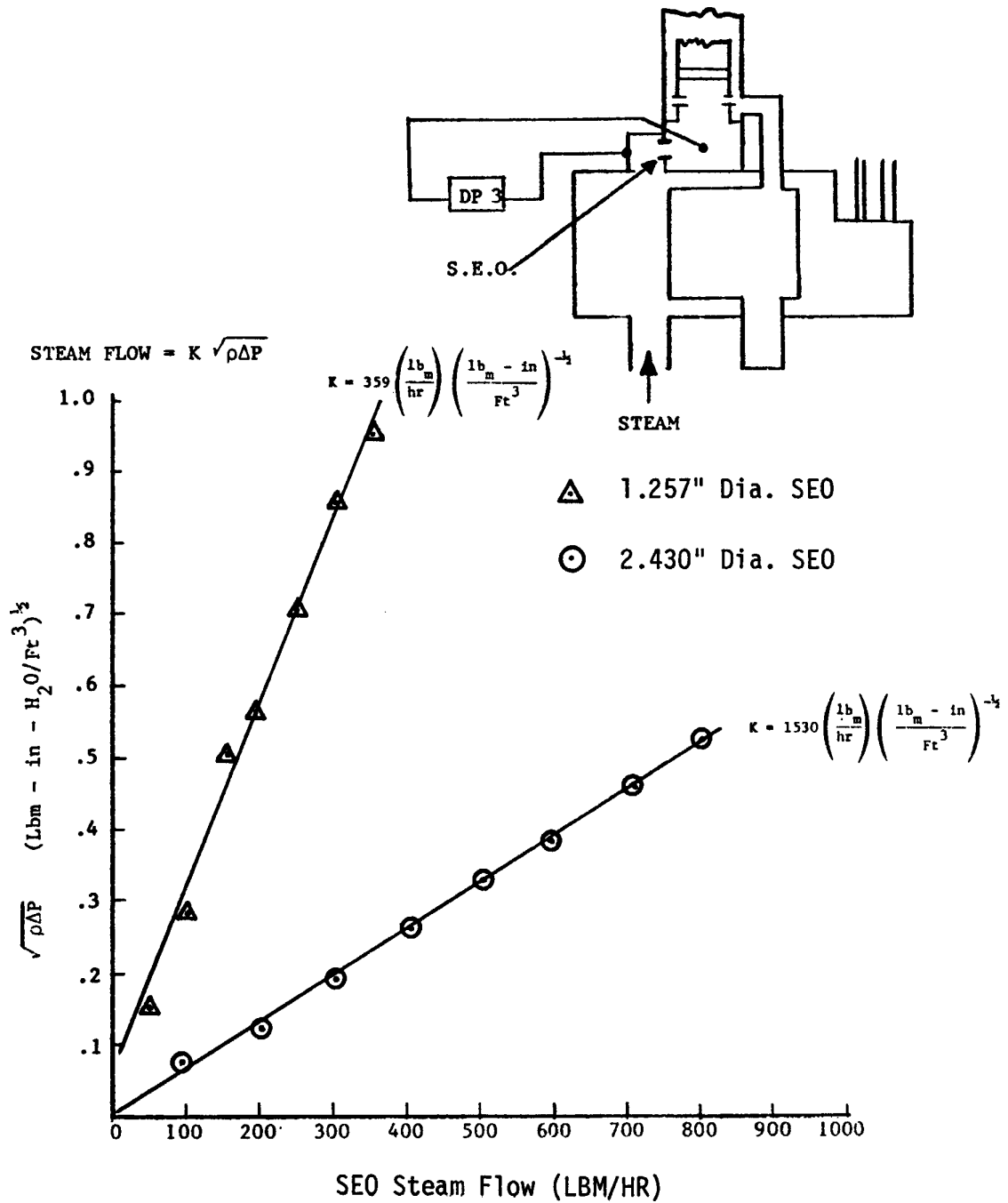


Figure B-6. SEO Pressure Drop Characteristics

TABLE B-1

## CORE/JET PUMP FLOW SPLIT

	Lower Plenum Steam				Standpipe Steam				*Flow Split
	<u>P<sub>11</sub></u> (psia)	<u>T<sub>31</sub></u> (F)	<u>T<sub>SAT</sub></u> (F)	<u>W<sub>LP</sub></u> (lb/hr)	<u>P<sub>13</sub></u> (psia)	<u>T<sub>28</sub></u> (F)	<u>T<sub>SAT</sub></u> (F)	<u>W<sub>SP</sub></u> (lb/hr)	
	23	267	234	123	15	214	212	50	.41
Empty	32	257	255	206	15	214	212	106	.51
Lower	46	279	276	301	15	214	213	173	.57
Plenum	62	298	295	405	15	214	214	218	.54
	79	314	311	507	16	215	215	275	.54
Jet	34	259	257	210	15	214	213	169	.80
Pump	46	278	275	294	15	214	214	270	.92
Covered									
Jet	61	297	294	400	15	214	214	203	.51
Pump	79	314	311	510	15	215	214	249	.49
Uncovered	95	327	324	610	16	215	215	294	.48

\*Flow Split ( $W_{SP}/W_{LP}$ ) = Fraction of Lower Plenum Steam through the Core.

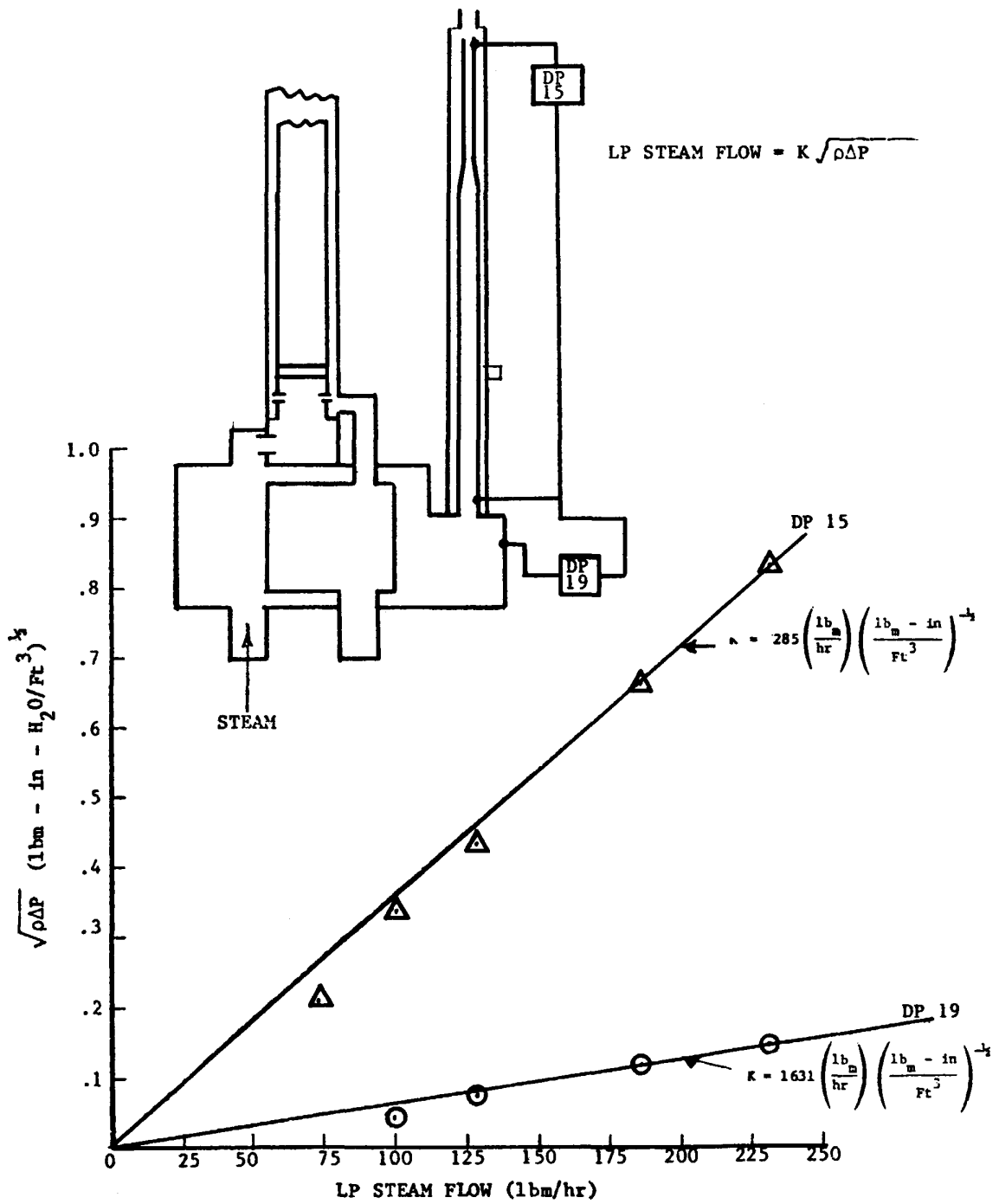


Figure B-7. SHB Jet Pump Pressure Drop Characteristics

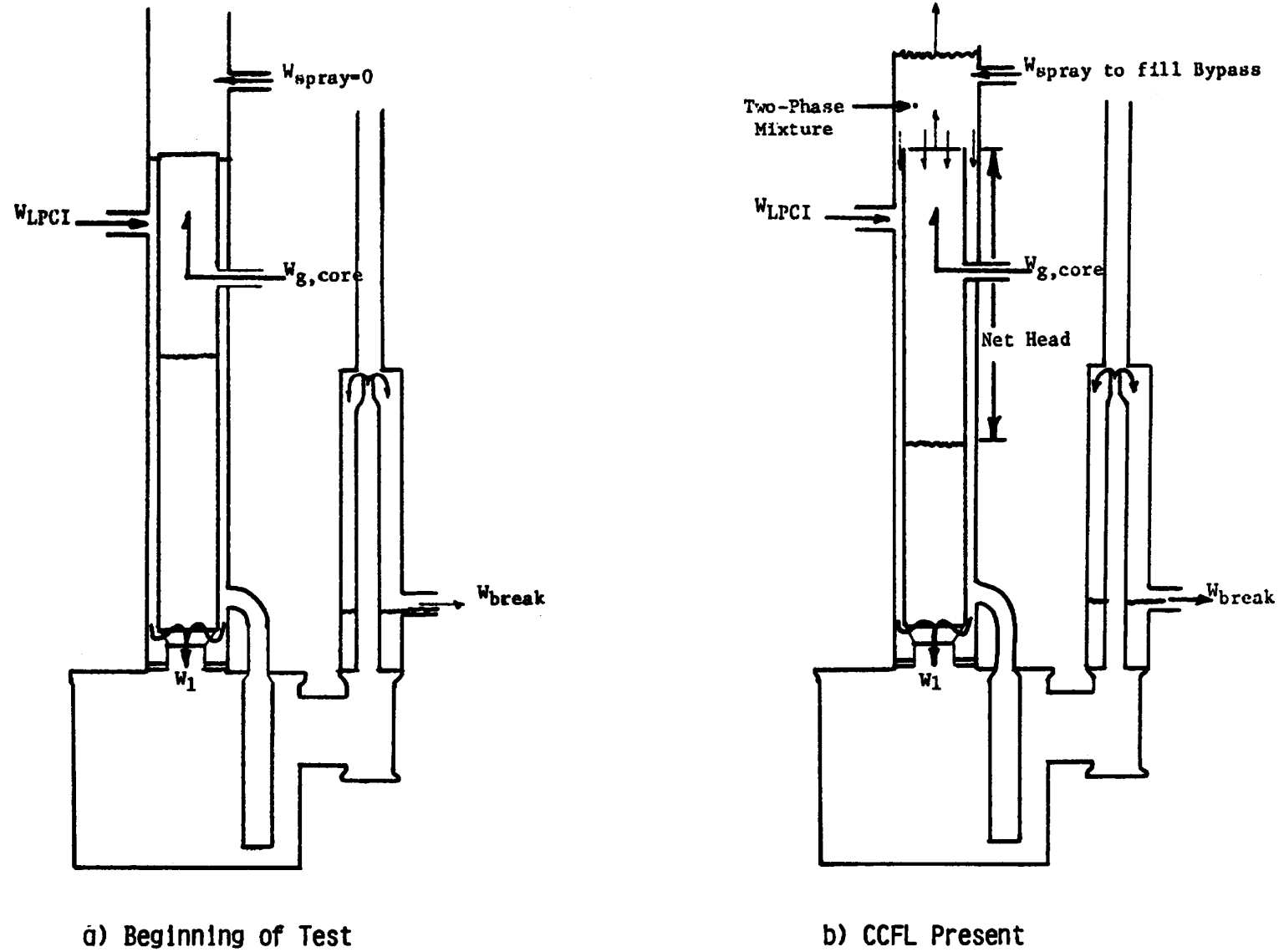


Figure B-8. Test Section Water Levels for UTP CCFL Test

through the leakage holes into the core and then up to the jet pump. The core steam and spray flows are then initiated to achieve CCFL at the upper tie plate, and adjusted to maintain a constant level in the upper plenum, as shown in Figure B-8(b). The pressure head due to the upper plenum level drives the water level in the core down slightly. This increases the net driving head on the bypass leakage paths and, correspondingly, increases the bypass leakage rate. The net liquid downflow through the upper tie plate is the total spray flow less the amount of spray going into the bypass region. The spray flow going into the bypass region is the total tie plate leakage determined from the net driving head (c.f. Figure B-4) less the LPCI flow.

Procedure 2 differs from the first in that the LPCI flow is adjusted such that no water spills into the core from the top of the bypass region after the core steam injection rate is set, but before the spray is initiated. Core steam injection flow causes the system pressure to be slightly above atmospheric pressure, and this procedure allows initial conditions to be set at operating pressure.

Procedure 3 differs from the first two procedures in that the liquid downflow is drained directly from the lower plenum instead of flowing up through the jet pump. The water level in the lower plenum is kept below the jet pump entrance throughout the test, as shown in Figure B-9. Since some of the core steam now diverts up the jet pump, the steam flow through the upper tie plate is determined from the standpipe flow rate plus the amount of steam condensed by the subcooling of the spray flow. The LPCI flow is adjusted to maintain the bypass level just full which, since there is no back pressure from a level in the core, remains constant throughout the test series and prevents spray flow from entering the bypass path. The liquid downflow through the upper tie plate is determined from the spray flow rate plus the amount of steam condensed by the subcooling of the spray flow.

All the data taken with these three procedures correlate very well, as shown in Figure B-10.

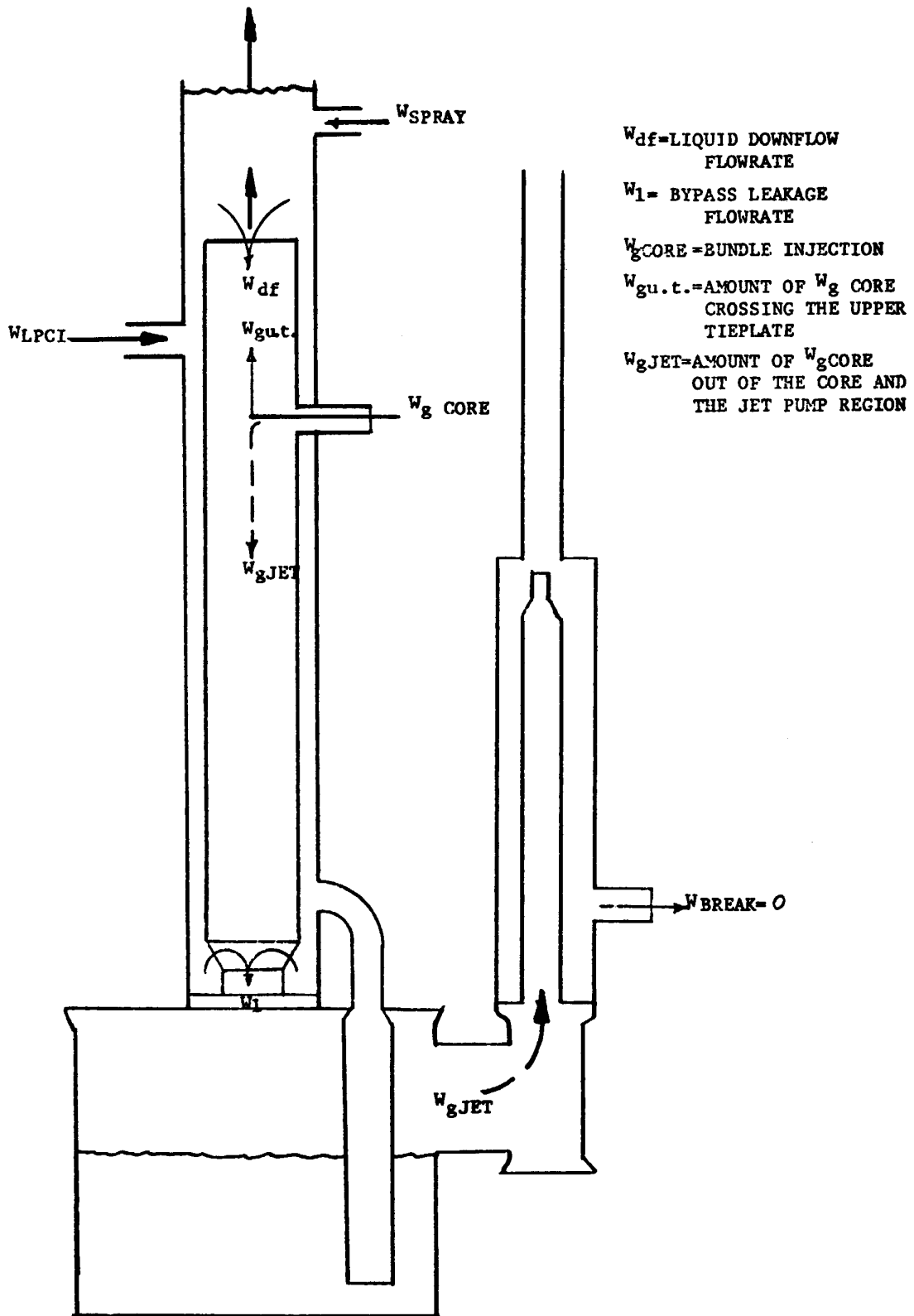


Figure B-9. Test Section Water Levels for UTP CCFL Test LAB 5049/5050

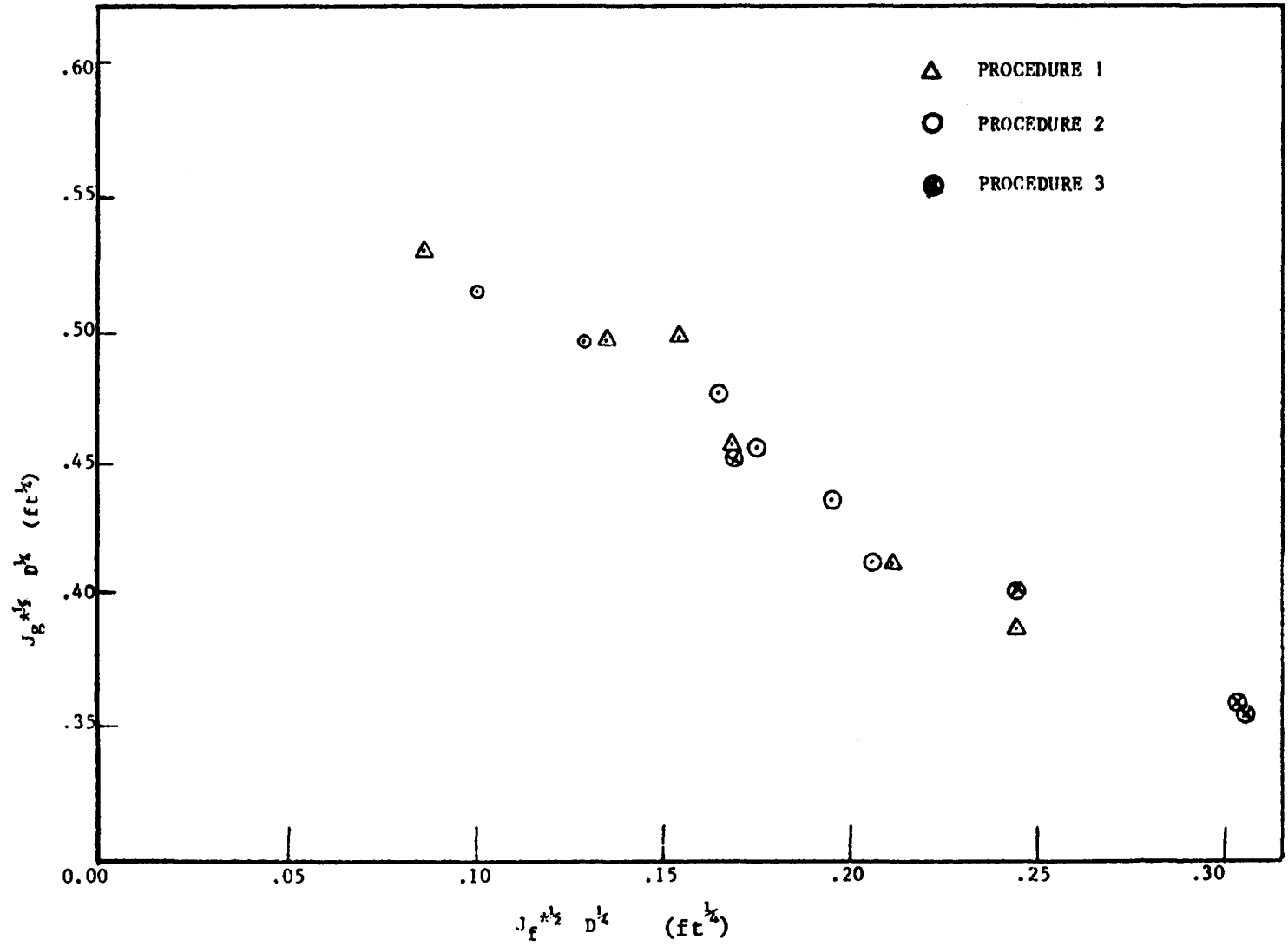


Figure B-10. Lynn Adiabatic Bundle Upper Tie Plate CCFL Data