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DETECTORS FOR MEASURING LIQUID LEVELS IN THE POWER BURST FACILITY IN-PILE TUBE

R. E. LaPointe, Jr.

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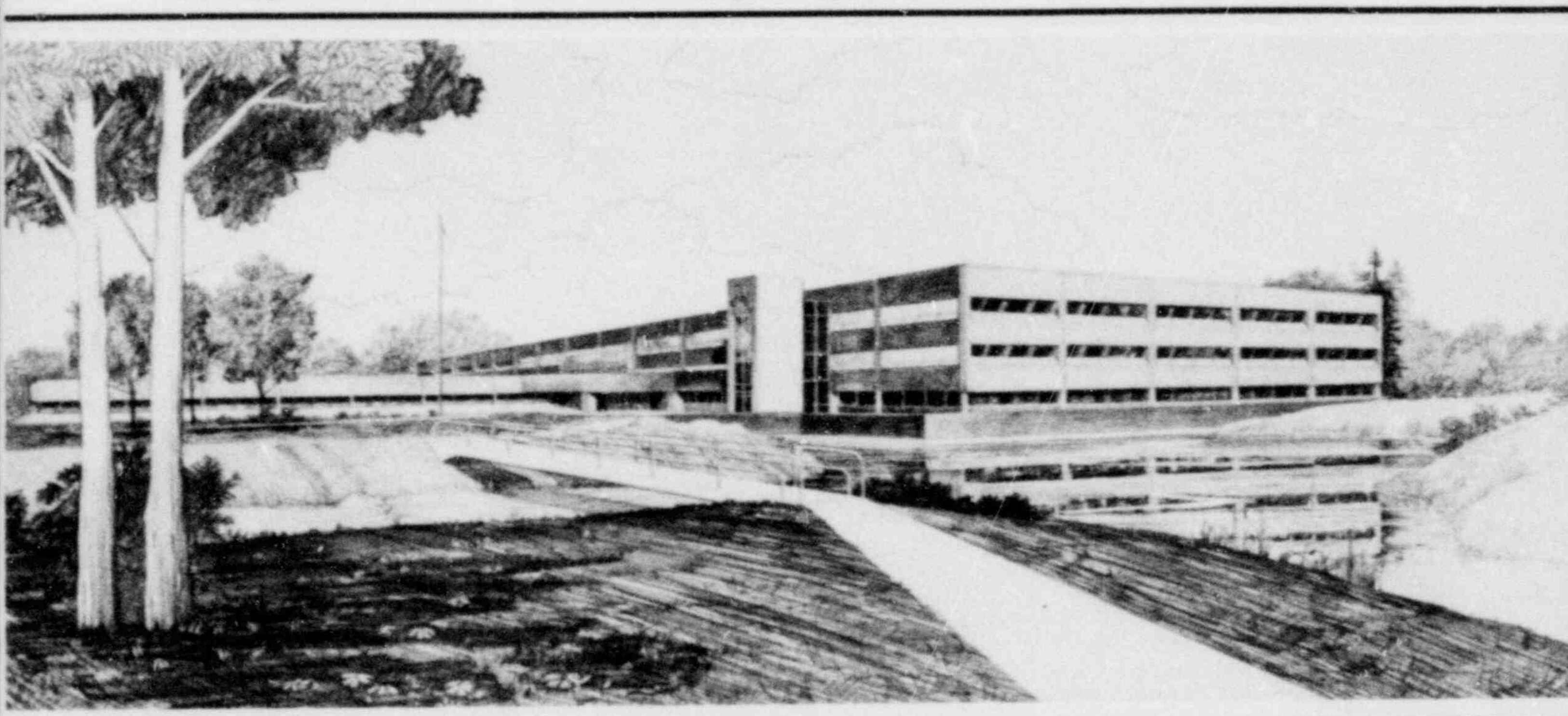

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DETECTORS FOR MEASURING

LIQUID LEVELS IN THE POWER BURST FACILITY IN-PILE TUBE

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SUMMARY

Liquid level detectors designed and built by EG&G Idaho are used to measure the coolant level in the lower plenum of the in-pile tube during loss-of-coolant tests at the Power Burst Facility. The liquid level detectors are installed on the lower portion of a nuclear fuel rod test assembly. It is necessary to know if coolant remains in the lower plenum of the in-pile tube during a loss-of-coolant test so that the proper amount of coolant will be injected during the initial phase of the reflood portion of the test.

The liquid level detectors correctly indicated dryout of the lower plenum and initiated the proper reflood rates to refill the plenum in four loss-of-coolant tests. The liquid level detectors then sensed the refilling of the plenum with coolant and returned to the wet state setting. Two detector configurations were used in the tests, one where the probes had a protective sleeve and the other where the probes were unsleeved. The unsleeved probe was sensitive to two-phase coolant conditions whereas the sleeved probes were somewhat isolated and tended to remain dry at higher qualities and therefore, more closely followed the coolant conditions in the in-pile tube lower plenum. The thermal-hydraulic conditions within the in-pile tube were substantiated by independent temperature measurements and the pretest predictions.

DETECTORS FOR MEASURING LIQUID LEVELS
IN THE PBF IN-PILE TUBE

I. INTRODUCTION

The Thermal Fuels Behavior Program (TFBP) currently uses a unique set of instruments that is capable of measuring the thermal and mechanical response of nuclear fuel rods and the thermal-hydraulic environment within the Power Burst Facility (PBF) in-pile tests. This set of instruments has been modified and expanded over the course of the PBF test program to provide reliable state-of-the-art instrumentation. This report describes the design, application and performance of the liquid level detectors used to measure the presence of liquid or void in the lower plenum of the in-pile tube during loss-of-coolant tests at the Power Burst Facility. The system conditions at the start of the tests are 15.5 MPa system pressure, 600 K coolant temperature, and 49.5 kW/m rod power.

The probe of the liquid level detector consists of two thermocouples, one heated with a resistive heater and one unheated. The liquid level detector electronics are designed to maintain a constant differential output between the two thermocouples by varying the heater power. By measuring voltage changes in the differential output, an electronic comparator determines whether the detector is in a gas or liquid environment. The response time of the liquid level detectors is 0.25 to 0.50 seconds to indicate a gas-to-liquid change and 0.5 to 1.0 seconds to indicate a liquid-to-gas change.

The liquid level detectors are used to monitor the coolant level in the in-pile tube lower plenum following the blowdown during a loss-of-coolant test. If this region is voided, the high flow reflood quench system is activated for 4.8 seconds in order to fill the lower plenum to the bottom of the active test fuel rods. If coolant remains in this region, no signal will be sent and the rapid reflood rate will be only 1 second. In the four loss-of-coolant tests of Test Series TC-1, the liquid level detectors indicated that the lower plenum was voided and were responsible for the correct reflood rates.

A description of the liquid level detectors and their application in the Power Burst Facility tests is presented in the next section. Experimental results from Test Series TC-1 utilizing the liquid level detectors are presented in Section 3, and a discussion follows in Section 4.

2. LIQUID LEVEL DETECTORS DESCRIPTION AND APPLICATION

The liquid level detector transducer used in the Power Burst Facility tests consists of two thermocouple legs connected differentially with one leg heated and the other unheated (Figure 1). The liquid level detector electronics are designed to maintain a constant differential output between the two thermocouples by varying the heater power. The thermocouples are both type K, MgO insulated, 1.6 mm diameter, 300 series stainless steel sheath with the tip reduced to 1.2 mm diameter. The elevation of the junction is the same for both legs. The heater wire placed in one leg of the transducer is 0.1 mm chromel wire. It runs down inside the sheath 90° to the thermocouples wires and crosses below the thermocouple junction (Figure 1). The transducers are sleeved or unsleeved depending upon the application needs. The sleeved version is used when liquid "frothing" is expected and the unsleeved version when the liquid level is expected to change at a smooth rate. The perforated sleeve is constructed of 321 series stainless steel.

A block diagram of a liquid level detector measurement channel is shown in Figure 2. Each channel has three physical components: a power supply, a controller, and a low current alarm and interface module. The heater power supply acts as a variable gain amplifier whose output voltage is controlled by input current supplied from the controller. The controller measures the differential thermocouple input voltage and supplies the proper current to the power supply so that it, in turn, can supply the heater with power. By varying this heater power as a function of the thermocouple output, a constant output of 5 mV is maintained when the probe is in air. The wet/dry heater detector is an electric comparator in the controller. It provides a relay closure to the low current alarm

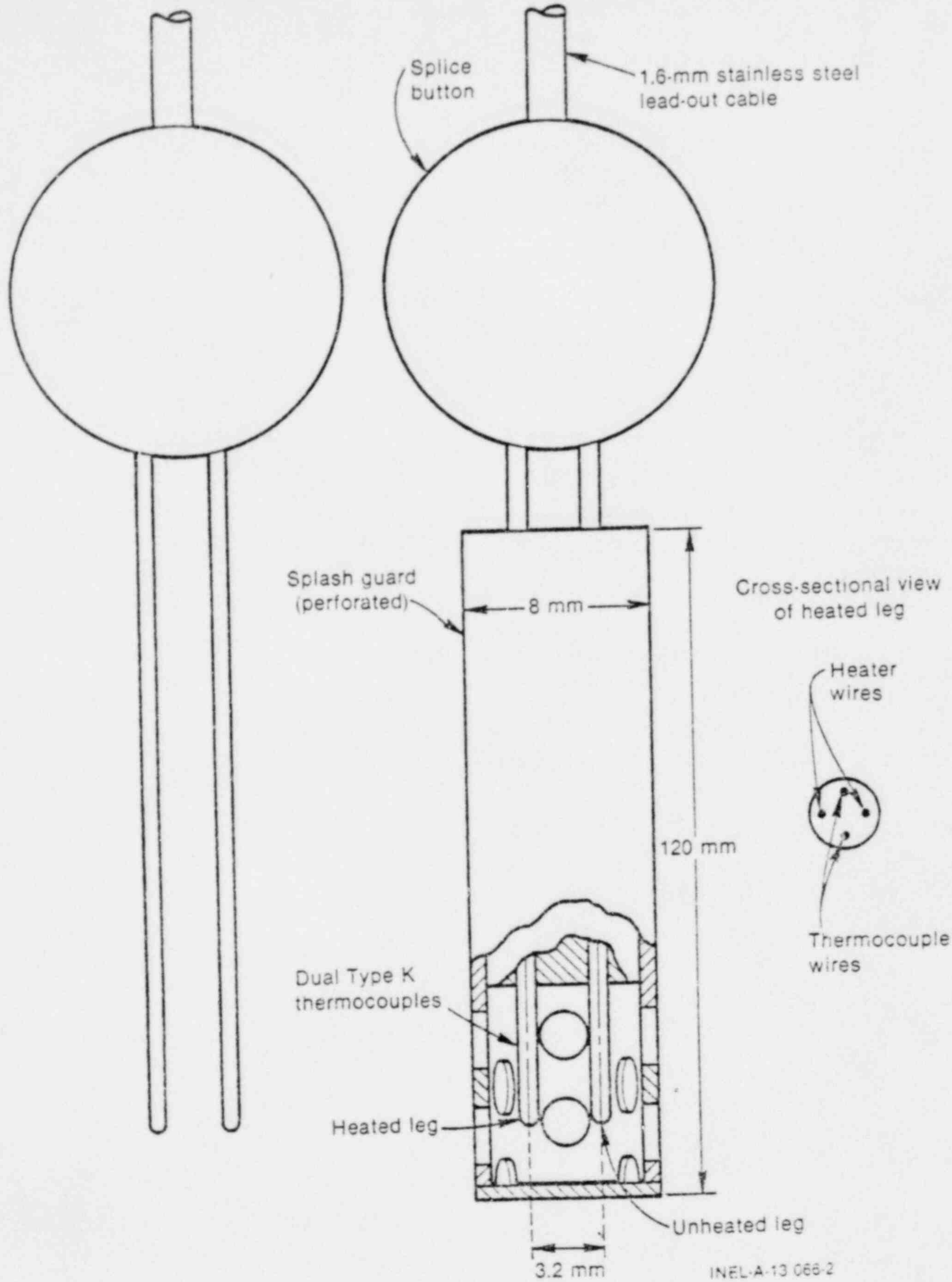

Figure 1. Liquid level detectors.

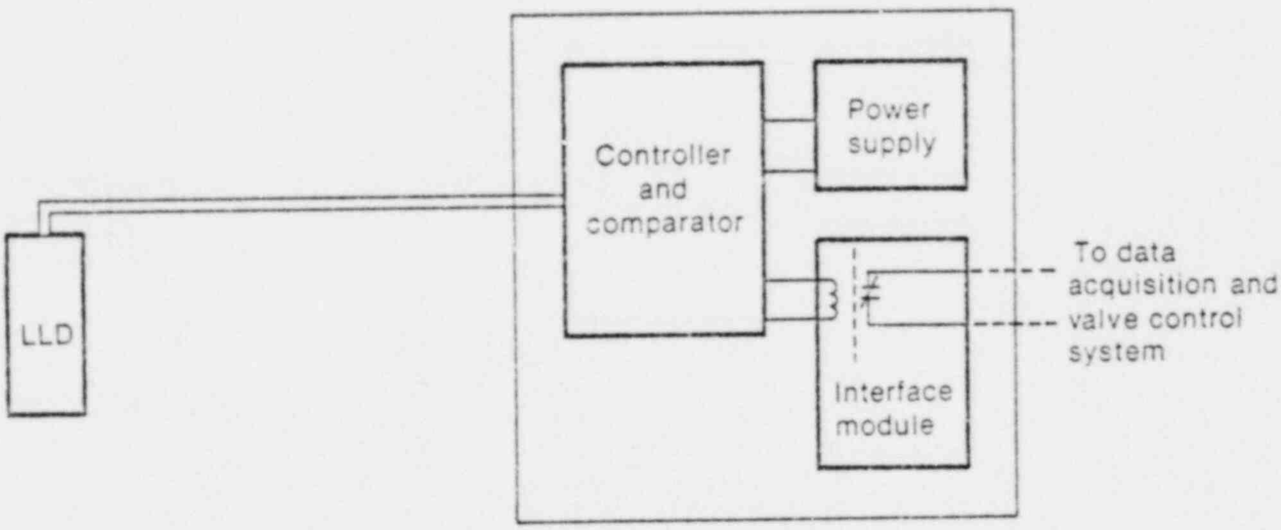

Figure 2. Liquid level detector measurement channel.

and interface module. When the probe is immersed in water, the power supply will supply up to 35 V and 1.75 Amp to the heater as it attempts to keep the thermocouple differential at 5 mV. If the environment changes from water to air, the heater leg quickly dries out and the differential voltage rises rapidly. The controller then decreases the current to the power supply so that it will decrease the power to the heater. The electronic comparator senses the low current and the low current alarm module sends the positive or dryout signal to the data acquisition system. In addition to the wet/dry detector and heater control function, the electronics will detect heater element failures. Power is shut off to the heater if the voltage exceeds 10 V and the current is less than 250 mA.

The liquid level detectors are located in two places on a test train (Figure 3). The unsleeved version is placed at the bottom of one of the flow shrouds (zircaloy tubes) that surrounds each test fuel rod. The two sleeved liquid level detectors are placed below the test fuel rods and shrouds on the lower test train support plate. These two liquid level detectors are used during loss-of-coolant tests to determine the proper valve sequence timing for the reflood system.

The reflood system is part of the quench system that provides water at a controlled flow rate to the in-pile tube heat at a predetermined time after blowdown. The loss-of-coolant accident test train is designed to route the reflood water directly to the lower plenum without cooling the massive in-pile tube. System operation involves filling the lower plenum to the bottom of the active fuel within 5 seconds and maintaining this level prior to quenching of the test fuel rods.

The reflood logic is as follows: After initiation of the blowdown (time = 0), reflood will occur at a predetermined time (100 s). If the lower plenum region below the fuel rods and shrouds has dried out, the liquid level detectors detect the dryout which latches the relay and subsequently sends a signal to the data acquisition system and the valve sequencing system (REDCOR). The REDCOR receives this signal and the high flow reflood (1.58 l/s) valve remains open for 4.8 seconds after the

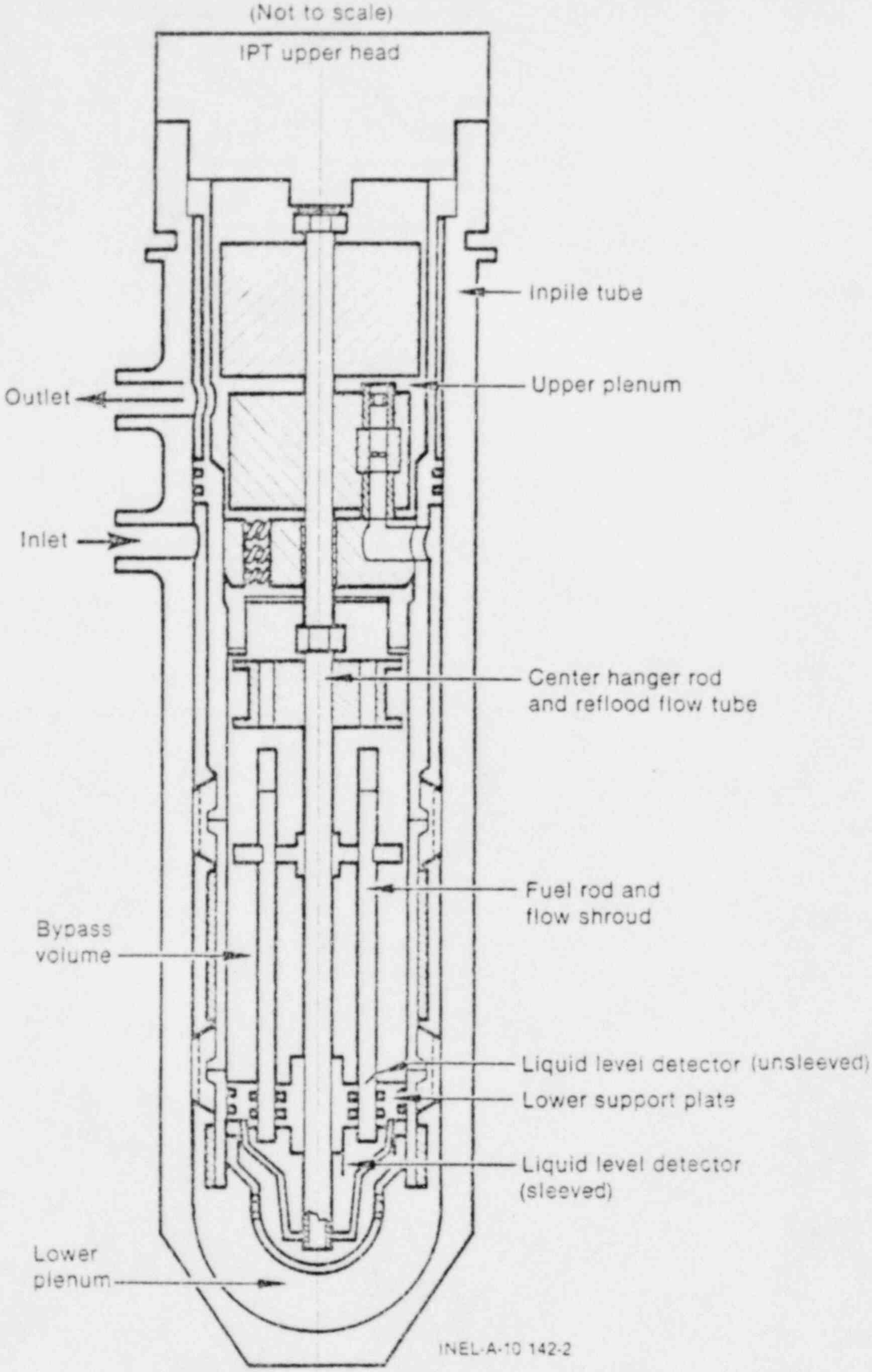

Figure 3. PBF LOCA test train illustration.

onset of reflood at which time only the low flow reflood remains open (0.95 l/s). If the liquid level detectors do not dry out (liquid remains in this region), no signal is received from the liquid level detectors and the high flow reflood valve will remain open for only one second before it is closed leaving only the low flow line open. These reflood rates were calculated to insure filling of the lower plenum in the in-pile tube up to the bottom of the active fuel rod within the designated time limit.

3. EXPERIMENTAL RESULTS

This section discusses the use of three liquid level detectors during four loss-of-coolant accident tests, designated TC-1A, B, C, and D, conducted at the Power Burst Facility. An unsleeved liquid level detector was mounted on a flow shroud and was positioned below the active fuel 0.38 m above the two sleeved liquid level detectors that were located on the lower support of the test train. The shroud liquid level detector was not used for the reflood logic, but its output was recorded to help gain information on the environment in the test train during a loss-of-coolant test.

Upon initiation of blowdown, the cold leg blowdown valves were opened and the system was depressurized from PWR conditions (15.51 MPa, 600 K) to atmospheric conditions within about 30 seconds. The coolant, subcooled prior to blowdown, was rapidly expelled from the test rod flow shrouds, the lower plenum, and the downcomer through the cold leg. The rapid decompression was followed by coolant flashing and two-phase flow.

Plots of the two lower liquid level detector output signals as a function of time are shown in Figures 4 and 5 for the four TC-1 tests A, B, C, and D. The detector electronics signal is 0 for the wet state and positive for the dry state. The magnitude of the signal as recorded is dependent on the data acquisition system signal conditioning electronics. As shown in all tests, liquid level detector 2 (Figure 4) indicates a dryout condition at approximately 2 seconds after the start

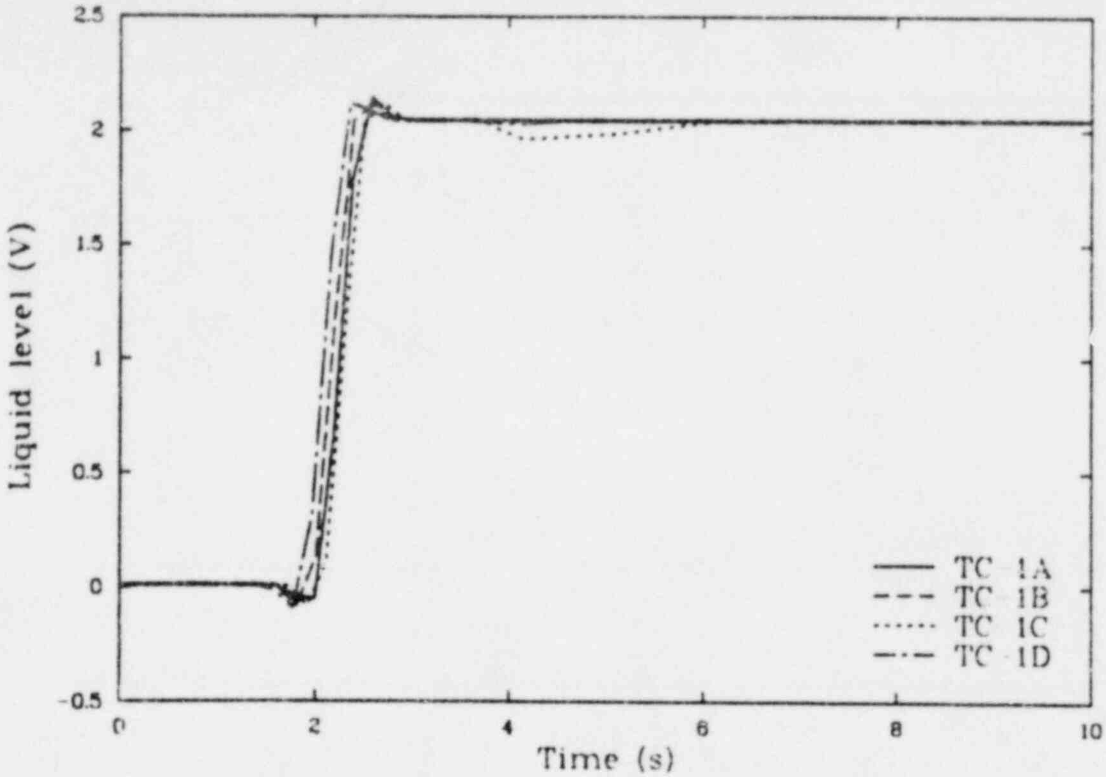

Figure 4. Lower detector #2 indicating dryout after blowdown (T = 0 sec).

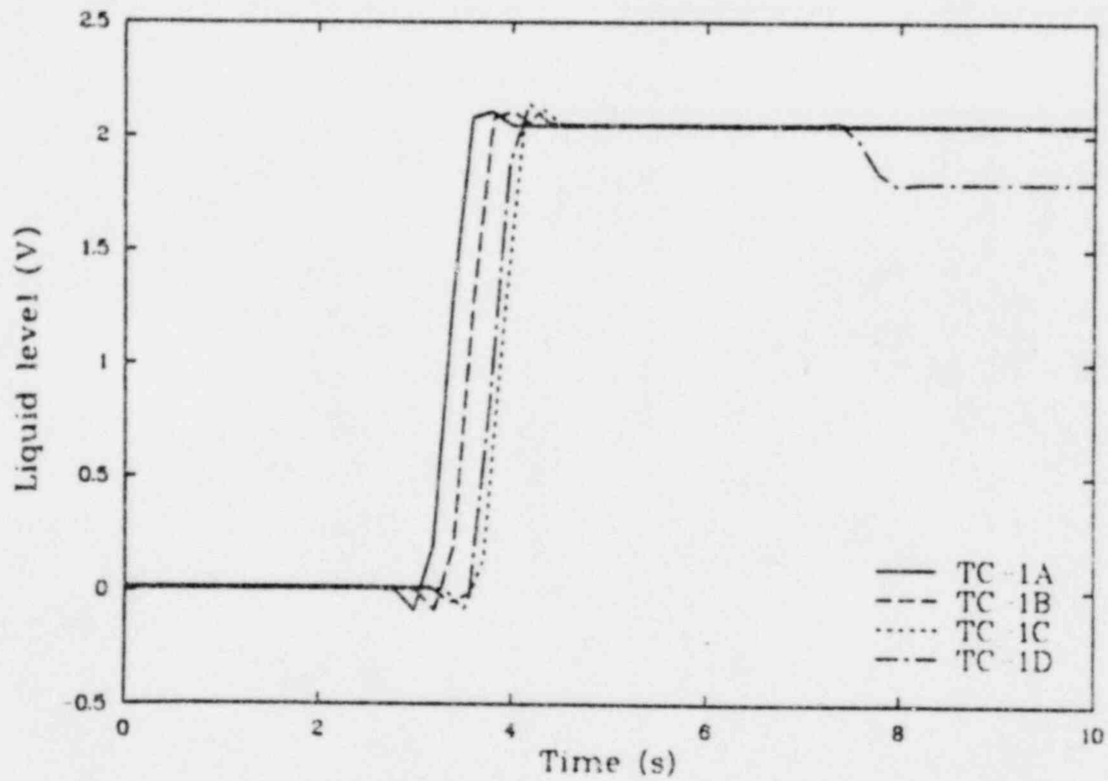

Figure 5. Lower detector #1 indicating dryout after blowdown (T = 0 sec).

of blowdown while liquid level detector 1 indicates dryout occurred 3 to 3.5 seconds after blowdown (Figure 5) initiation. This time difference suggests an uneven distribution of the coolant phases in the lower plenum, or a variation in the heat differential (across the liquid level detector heated versus unheated legs) required to close the relay switch sending the signal to the data acquisition system.

The shroud level liquid level detector indicated dryout 8 to 11 seconds after initiation of the blowdowns (Figure 6). This liquid level detector did not have the protective splash guard and was vulnerable to wetting by the two-phase coolant. The legs of the unsleeved probe remained wet during the early depressurization, and this prevented the differential temperature across the legs from increasing enough to indicate a dry condition.

A two-phase slug of liquid was forced from the lower plenum up through the flow shrouds past the fuel rods 5 to 11 seconds after blowdown during all four tests. This two-phase mixture was not sensed by the lower sleeved liquid level detectors, but in Test TC-1C, the shroud liquid level detector detected this two-phase slug as shown by its momentary return to the wet state setting (Figure 6). Once the legs of the probe are dried out, it would take a larger amount of liquid to rewet the probe than it takes to keep the probe wetted during the initial loss-of-coolant. The heated leg of the probe would be hot enough to vaporize any coolant drops coming in contact with it. In Test TC-1C, there was apparently enough liquid in the two-phase slug to cool the heated leg causing the electronics to revert back to the wet state setting momentarily.

The sleeved detectors indicated a continual dry state from 2 to 3.5 seconds until shortly after the reflood phase of the tests began. At 100 seconds after blowdown, the high flow reflood line was opened and 311 K coolant flowed down the center hanger rod into the lower plenum of the in-pile tube. The plenum pressure was approximately 0.45 MPa at this time. Between 102 and 104 seconds (in all four tests), the sleeved liquid level detectors showed a rewetting and about 1 second later in all the tests, the shroud detector indicated the rewetting (Figures 7, 8, and 9).

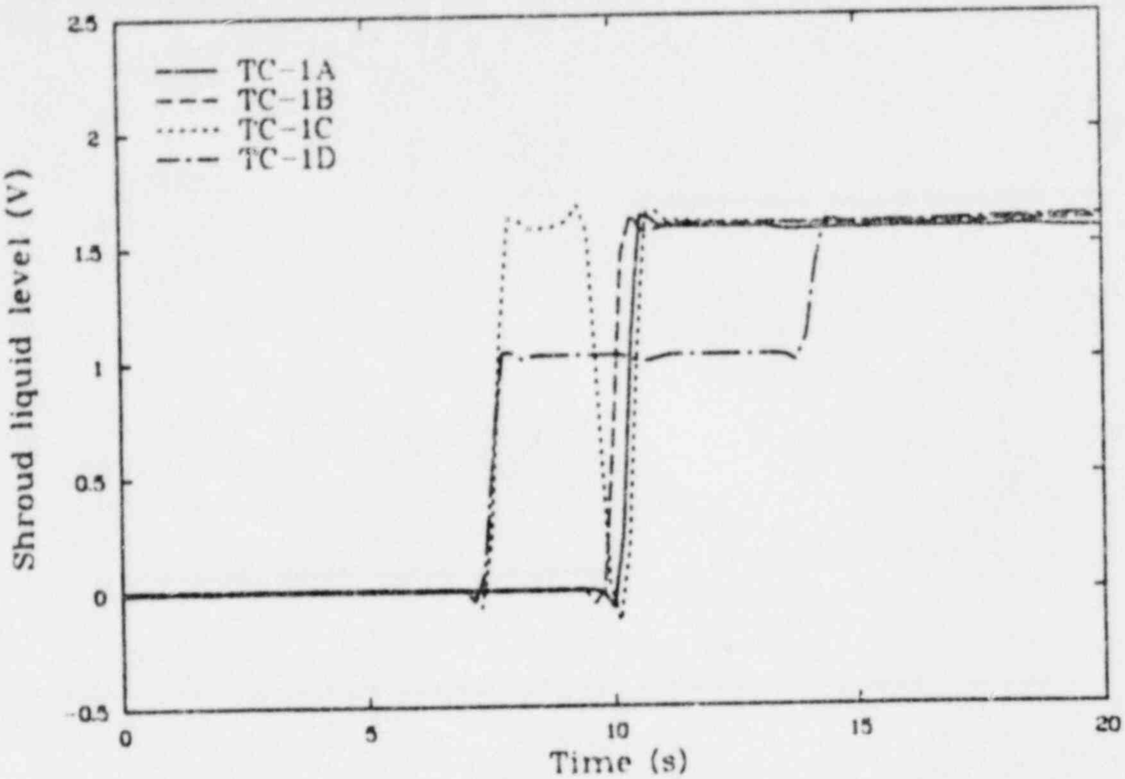

Figure 6. Shroud level detector indicating dryout.

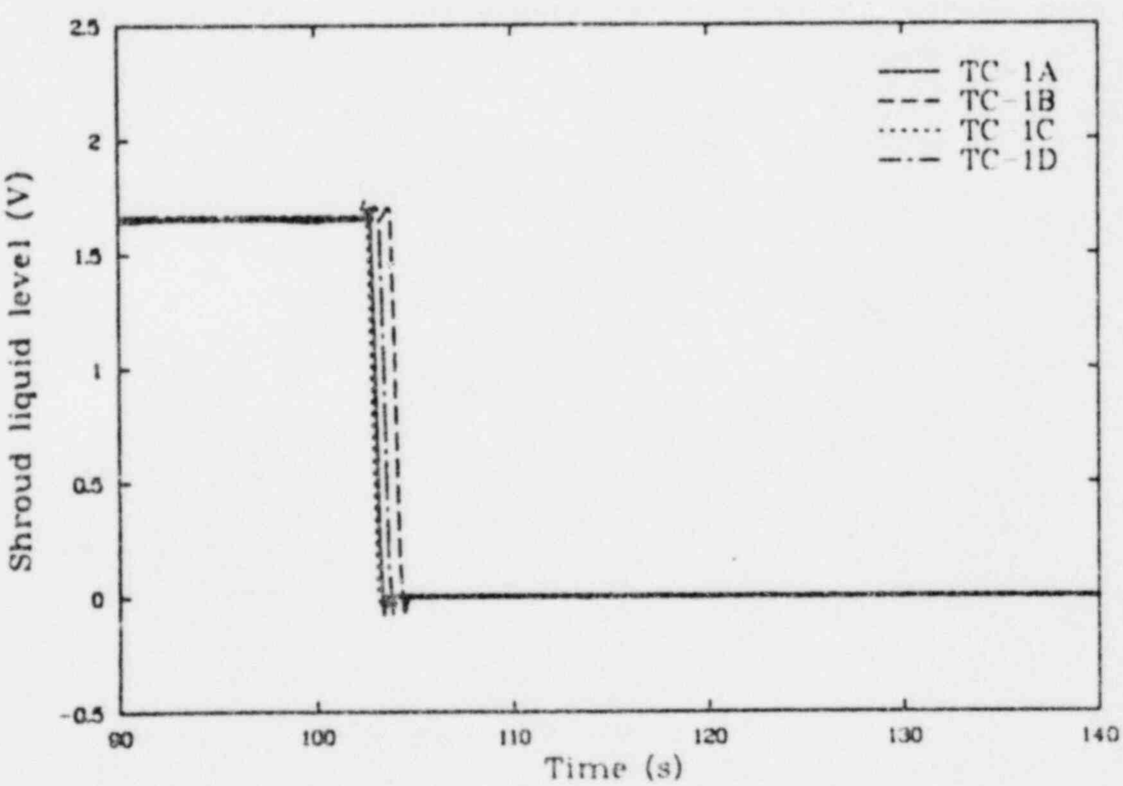

Figure 7. Shroud level detector indicating rewet.

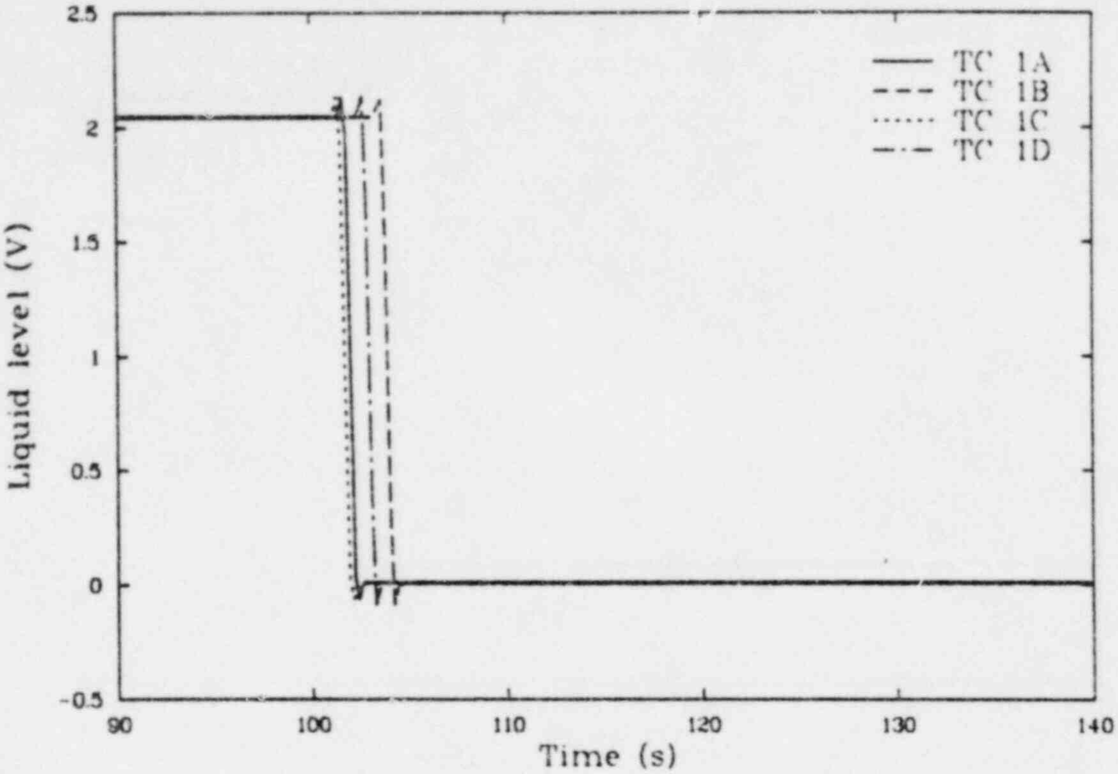

Figure 8. Lower detector #2 indicating rewet after onset of reflood.

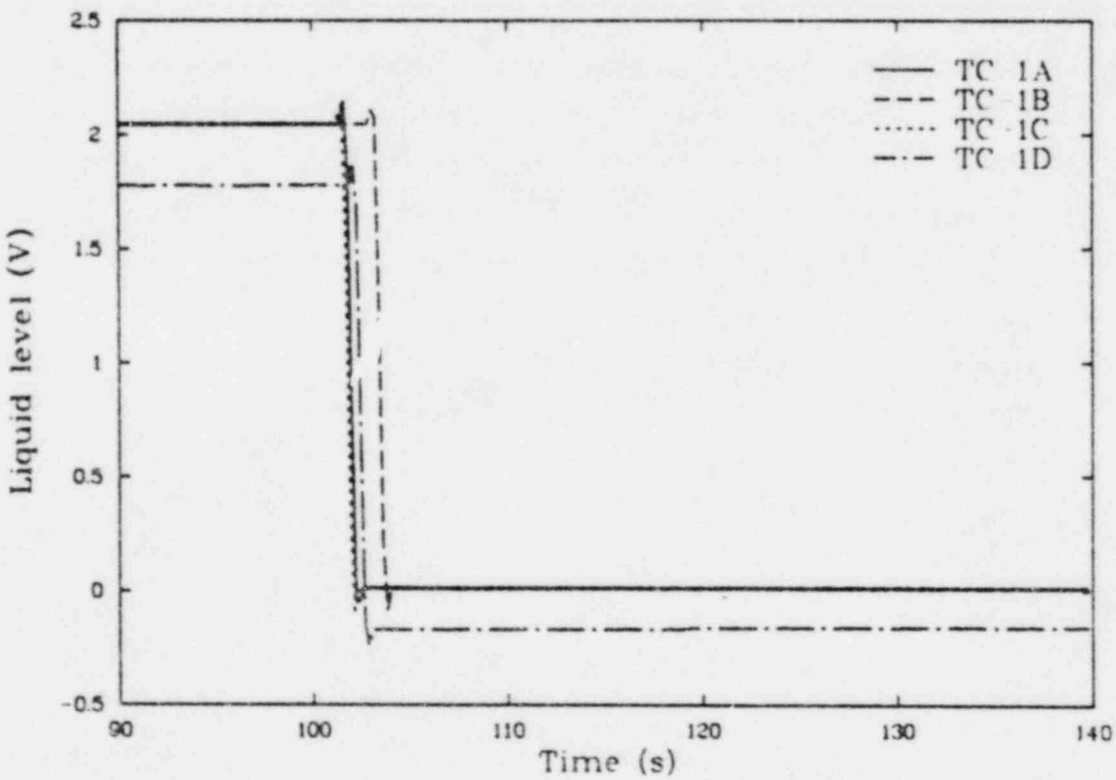

Figure 9. Lower detector #1 indicating rewet after onset of reflood.

The high flow reflood remained on for approximately 5 seconds, an indication that the dryout signal was sent to the valve sequence system.

A type K thermocouple located at nearly the same elevation as the sleeved liquid level detectors showed a slight drop in temperature (in all four tests) at about 102 seconds followed by a rise in temperature before it rewet at about 106 to 107 seconds (Figure 10 shows one test, TC-1B). The slight decrease was caused by splashing of the coolant as it came in contact with the hot surfaces in the lower plenum followed by the temperature rise before rewetting caused by the super heated steam environment. This suggests that the detectors were sensitive to the steam environment as they indicated the rewetting, in all the tests, before they were totally immersed in liquid. It is not known what the void fraction was during this portion of the tests.

The computer program RELAP4/MOD6/UPDATE4 (Configuration Control Number H00411B) has been used to predict system thermal-hydraulic blowdown response. The results provide the coolant and heat transfer boundary conditions for fuel behavior analyses. During a blowdown, the coolant temperatures follow the system depressurization saturation curve until the coolant quality of 1.0 is attained approximately 5 seconds into the blowdown. At 1.5 seconds after blowdown, a coolant quality of 0.1 is predicted in the lower plenum region where the sleeved detectors are located. Assuming a slip ratio of 1, the void fraction at the predicted temperature and pressure would be 55% to 60%. Three seconds after blowdown begins, the void fraction will be 80% or greater. The sleeved detectors indicated dryout 2 to 3.5 seconds after blowdown in all four tests. Adding the 0.5 second response time of the detector to the predicted times, this suggests that the sleeved detectors indicated the dryout when the void fraction was 55% or greater. The predicted quality in the shroud is higher than that in the lower plenum for the corresponding times. The shroud detector should have also indicated a dryout if it were not vulnerable to the two-phase and turbulent conditions. The coolant conditions during the blowdown are very turbulent, however, in the in-pile tube, and they may not be precisely as predicted. The

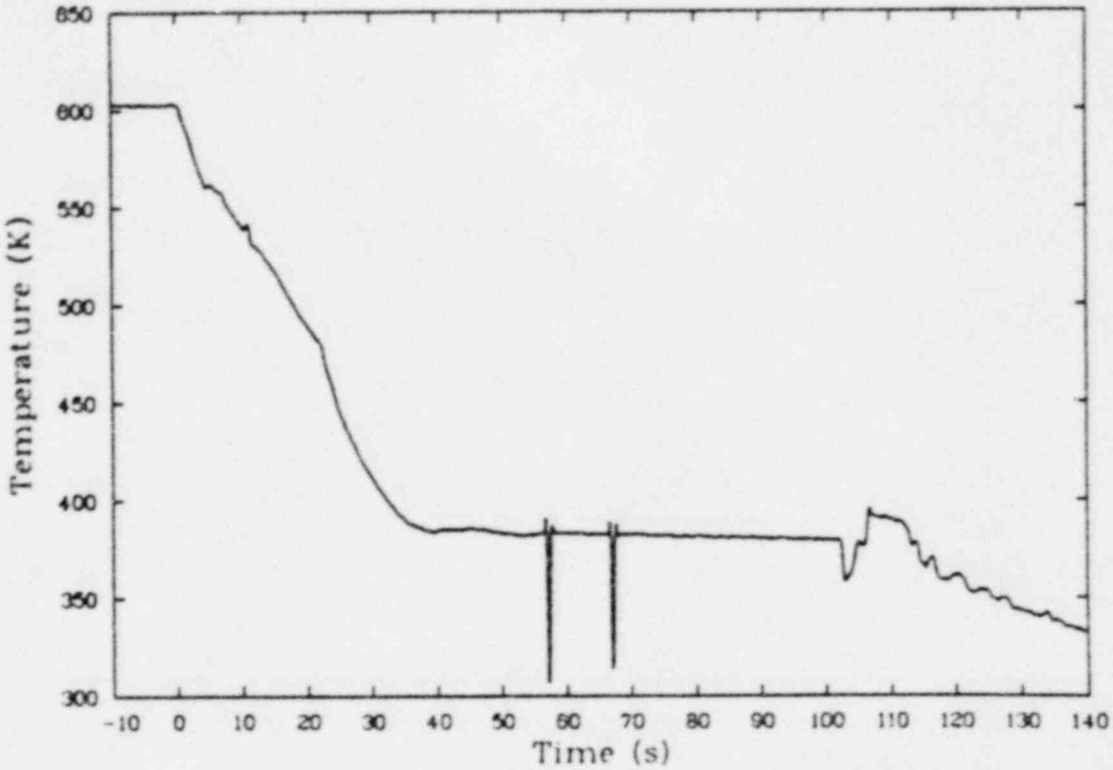

Figure 10. Lower test train thermocouple.

test conditions were nearly identical in all tests, as shown by the repeatability of the other measurements (pressure, temperature, flow rate, etc.) which were used as input parameters to the RELAP program suggesting that the predicted values were accurate. The quality of the coolant during reflood was not predicted by RELAP4, but there was sufficient entrained liquid in the steam to rewet all the detectors before the coolant had immersed them completely.

IV. CONCLUSIONS

The heated differential temperature liquid level detectors have been successfully used at PBF in loss-of-coolant tests to indicate a dryout condition in the lower plenum region of the in-pile tube. In four loss-of-coolant tests, the liquid level detectors indicated the dryout state 1 to 4 seconds after initiation of the blowdown and the subsequent rewetting 2 to 4 seconds after the reflood sequence began.

These test results are in close agreement with the computer programs used to predict the coolant conditions, in the lower plenum region where the liquid level detectors are located, for loss-of-coolant and the subsequent reflooding or refilling of this region with coolant. Thermocouples placed in the proximity of the liquid level detectors verify the times of coolant loss and refilling.

The splash guards protected the liquid level detectors from premature rewet when coolant splashing or turbulent conditions existed and enabled them to indicate the presence or absence of coolant more accurately. The unsleeved liquid level detectors are vulnerable to rewet when two-phase coolant conditions exist.

This type of liquid level detector shows potential for use in commercial light water reactors to monitor the coolant conditions at all times. Their use at the Power Burst Facility has shown that they can function properly in the harsh nuclear environment of a pressurized water reactor. Their durability is demonstrated by the fact that the detectors underwent four tests where the conditions varied from 15.5 MPa pressure and 600 K coolant temperature to atmospheric conditions without failure or loss of accuracy.