UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

September 16, 1981

MEMORANDUM FOR: S. Varga, Chief
Operating Reactors Branch #1, DL

R. Clark, Chief
Operating Reactors Branch #3, DL

B. Youngblood, Chief
Licensing Branch #1, DL

A. Schwencer, Chief
Licensing Branch #2, DL

FROM: D. Crutchfield, Chief
Operating Reactors Branch #5, DL

SUBJECT: TMI TOPIC II.F.2.3

Re: Westinghouse Reactor Vessel Level Instrumentation System
for Monitoring Inadequate Core Cooling

Please instruct your cognizant PM's to send out the attached Sample Letter to licensees for the plants listed below:

Indian Point 2/3
North Anna 1/2
Salem 1/2
Surry 1/2
Trojan
Zion 1/2
Sequoyah
McGuire

If there is need for clarification or additional information, contact Jim Shea, Lead Project Manager, on extension 27231. Rosetta Johnson has Vydec tape for your secretaries use (extension 27403).

Dennis M. Crutchfield, Chief
Operating Reactors Branch #5
Division of Licensing

cc:
G. Lainas
R. Tedesco
J. Olshinski
K. Parrish
D. Neighbors
W. Ross
E. Reeves
J. Shea
P. Kreutzer
C. Trammell
L. Engle
M. Rushbrook
R. Birkel
M. Service
C. Stahle
H. Smith

8109280684

XA

A/5

SAMPLE LETTER

Docket No. 50-

Licensee's Address

Dear Mr.

SUBJECT: TMI TOPIC II.F.2.3 - (PLANT NAME)

We understand that you plan to install the Westinghouse ΔP reactor vessel level instrument. Westinghouse has made a generic submittal to the NRC entitled "Summary Report, Westinghouse Reactor Vessel Level Instrumentation System for Monitoring Inadequate Core Cooling (7300 System), (UHI Plant), and (Microprocessor System)", dated December 1980.

Since the Westinhouse generic submittal has an option for three different levels of data processing, you should provide a plant specific submittal showing the option selected. Also, please respond to the enclosed request for additional information within 30 days.

Sincerely,

Branch Chief

Enclosure:
Request for Additional
Information

cc w/enclosure:
See next page

Δ

*Please note that a symbol ("triangle") should appear before P in first sentence.

Also, in addition to regular distribution, copies should be sent to Tai Huang, Jim Shea & John Olshinski

ON SUMMARY REPORT
"WESTINGHOUSE REACTOR VESSEL LEVEL INSTRUMENTATION SYSTEM FOR MONITORING INADEQUATE CORE COOLING"

1. Justify that the single upper head penetration meets the single failure requirement of NUREG-0737 and show that it does not negate the redundancy of the two instrument trains.

2. Descrive the location of the level system displays in the control room with respect to other plant instrument displays related to ICC monitoring, in particular, the saturation meter display and the core exit thermocouple display.

3. Describe the provisions and procedures for on-line verification, calibration and maintenance.

4. Describe the diagnostic techniques and criteria to be used to identify malfunctioning components.

5. Estimate the in-service life under conditions of normal plant operations and describe the methods used to make the estimate, and the data and sources used.

6. Explain how the value of the system accuracy (given as +/- 6% was derived. How were the uncertainties from the individual components of the system combined? What were the random and systematic errors assumed for each component? What were the sources of these estimates?

7. Assume a range of sizes for "small break" LOCA's. What are the relative times available for each size break for the operator to initiate action to recover the plant from the accident and prevent damage to the core? What is the dividing line between a "small break" and a "large break"?

8. Describe how the system response time was estimated. Explain how the response times of the various components (differential pressure transducers, connecting lines and isolators) affect the response time.

9. There are indications that the TMI-2 core may be up to 95% blocked. Estimate the effect of partial blockage in the core on the differential pressure measurements for a range of values from 0 to 95% blockage.

10. Describe the effects of reverse flows within the reactor vessel on the indicated level.

11. What is the experience, if any, of maintaining Dp cells at 300% overrange for long periods of time?

12. Five conditions were identified which could cause the Dp level system to give ambiguous indications. Discuss the nature of the ambiguities for 1) accumultor injection into a highly voided downcomer, 2) when the upper head behaves as a pressurizer, 3) upper plenum injection, and 4) periods of void redistribution.

13. No recommendations are made as to the uncertainties of the pressure or temperature transducers to be used, but the choice appears to be left to the owner of AE. What is the upper limit of uncertainties that should be allowed? Describe the effect of these uncertainties on the measurement of level. What would be the effect on the level measurement should these uncertainties be exceeded?

14. Only single RTD sensors on each vertical run are indicated to determine the temperatures of the impulse lines. Where are they to be located? What are the expected temperature gradients along each line under normal operating conditions and under a design basis accident? What is the worst case error that could result from only determining the temperature at a single point on each line?

15. What is the source of the tables or relationships used to calculate density corrections for the level system?

16. The microprocessor system is stated to display the status of the sensor input. Describe how is this indicated and what this actually means with respect to the status of the sensor itself and the reliability of the indication.

17. Describe the provisions for preventing the draining of either the upper head of hot leg impulse lines during an accident. What would be the resultant errors in the level indications should such draining occur?

18. Discuss the effect of the level measurement of the release of dissolved, noncondensible gases in the impulse lines in the event of a depressurization.

19. In some tests at Semi-scale, voiding was observed in the core while the upper head was still filled with water. Discuss the possibility of cooling the core-exit thermocouples by water draining down out of the upper head during or after core voiding with a solid upper head.

20. Describe behavior of the level measurement system when the upper head is full, but the lower vessel is not.

21. One discussion of the microprocessor system states that water in the upper head is not reflected in the plot. Does this mean that there is no water in the upper head or that the system is indifferent to water in the upper head under these conditions?

22. Describe the details of the pump flow/Dp calculation. Discuss the possible errors.

23. Have tests been run with voids in the vessel? Describe the results of these tests.

24. Estimate the expected accuracy of the system after an ICC event.

25. Describe how the conversion of RTD resistance to temperature made in the analog level system.

SEP 30 1981

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[redacted] Dave

Docket No. 50-286

Mr. George T. Berry, President
and Chief Operating Officer
Power Authority of the State of New York
10 Columbus Circle
New York, New York 10019

Dear Mr. Berry:

SUBJECT: REACTOR VESSEL LEVEL INSTRUMENTATION SYSTEM (RVLIS)

On September 16, 1981 we received a letter indicating you plan to install the 7300 Analog version of the Westinghouse dP reactor vessel level instrument. In December 1980, Westinghouse made a generic submittal entitled "Summary Report, Westinghouse Reactor Vessel Level Instrumentation System for Monitoring Inadequate Core Cooling (7300 System), (UHI Plant), and Microprocessor System)".

Our review of the Westinghouse report has generated a series of questions. Some of the questions are generic in nature while others are plant specific. It is requested that you respond to the enclosed request for additional information within 45 days of receipt of this request.

Sincerely,

Original signed by:

Steven A. Varga, Chief
Operating Reactors Branch #1
Division of Licensing

Enclosure:
Request for Additional
Information

cc w/enclosure:
See next page

8110150196
PDR/LPDR

A/6

OFFICE	ORB#1:DL	ORB#1:DL	ORB#5:DL				
SURNAME	JThoma:ds	SVarga	JShea				
DATE	9/25/81	9/[illegible]/81	9/25/81				

NRC FORM 318 (10-80) NRCM 0240

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USGPO: 1981—335-960

Mr. George T. Berry
Power Authority of the State of New York

cc: White Plains Public Library
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Assistant Attorney General
Environmental Protection Bureau
New York State Department of Law
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ON SUMMARY REPORT
"WESTINGHOUSE REACTOR VESSEL LEVEL INSTRUMENTATION SYSTEM FOR MONITORING INADEQUATE CORE COOLING"

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25. Describe how the conversion of RTD resistance to temperature made in the analog level system.

Dave

CEN - 185
Supplement 1

HEATED JUNCTION THERMOCOUPLE

PHASE I Test Report

Prepared for the C-E OWNERS GROUP

November, 1981

8112160066
PDR

POWER
SYSTEMS
COMBUSTION ENGINEERING, INC

A/7

LEGAL NOTICE .

ABSTRACT

This document summarizes results of testing performed to demonstrate the principle of opertion for a Reactor Vessel Level Monitoring System Sensor using a Heated Junction Thermocouple. During the series of tests a sensor comprised of a Heated Junction Thermocouple (HJTC) with a splash shield was tested. The test results demonstrated its capability to distinguish between low and high quality coolant under a variety of conditions. Also included is a series of tests on an HJTC probe consisting of a sensor enclosed in a separator tube. These test results demonstrated the ability of the probe to create and to measure an effective water level in a two-phase mixture. The test results provide fundamental information on HJTC sensor behavior and are not intended to provide a demonstration of behavior characteristics in an RVLMS application.

TABLE OF CONTENTS

1.0 INTRODUCTION

Combustion Engineering is developing a Reactor Vessel Level Monitoring System (RVLMS) for measuring the water inventory above the fuel alignment plate in a reactor vessel. The sensing elements of this system are pairs of heated and unheated junction thermocouples (HJTC). This report describes and provides the results of tests conducted to demonstrate the principle of operation of these sensing elements. The tests were conducted over a wide range of hydraulic conditions most of which are more severe than conditions to which the sensing elements will be exposed in a reactor application. Therefore, the test results provide fundamental information on HJTC sensor behavior and are not intended to provide a demonstration of behavior characteristics in an RVLMS application.

1.1 HJTC PRINCIPLE

The Heated Junction Thermocouple consists of two electrically opposed thermocouple junctions, one of which is surrounded by a heating element. The output of the HJTC is a measure of the difference in temperature between the heated and unheated junctions. When immmersed in liquid the surface heat transfer coefficient is high and the heated junction is cooled to near the temperature of the surrounding liquid. The unheated junction measures the temperature of the liquid, and thus the HJTC temperature output (ΔT) is low. When in steam the heat transfer coefficient is much lower. The heater then functions to increase the heated junction temperature. Again, the unheated junction measures the temperature of the surrounding medium and the HJTC ΔT output increases to a relatively high level. Therefore, the ΔT output from the HJTC can be used to determine whether the heated junction is surrounded by liquid or steam.

1.2 PHASE I TEST OBJECTIVES

The testing reported herein is the Phase I portion of a three phase test program. The Phase I or proof-of-principle testing has been completed.

The objectives of the Phase I Test Program were to experimentally determine the basic performance characteristics of an HJTC for use as a sensor in an RVLMS, and to establish the performance characteristics of HJTC probe asssembly components. Specific objectives of the Phase I experiments were to determine:

1. Response of an unshielded HJTC to steam and water at various pressures and temperatures.

2. Response of an unshielded HJTC to two-phase conditions.

3. Response of a shielded HJTC to single and two-phase conditions.

4. Response of a shielded HJTC in a separator tube to single and two-phase conditions.

2.0 SUMMARY AND CONCLUSIONS

2.1 SUMMARY OF PROOF-OF-PRINCIPLE TESTING

Phase I testing consisted of a series of five tests performed at CE and ORNL test facilities. These tests demonstrated the feasibility of using the HJTC as a level sensing device and provided information necessary to the development of a preliminary RVLMS probe assembly. The first four experiments consisted of component tests and concentrated on evaluating the performance characteristics of the shielded and unshielded HJTC devices for a range of two-phase flow, pressure and temperature environments. The final test in this series (Test 5) was an atmospheric air-water test on a preliminary Reactor Vessel Level Monitoring probe assembly (HJTC, splash shield and separator tube, see Figures 2-1 and 2-2).

2.2 CONCLUSIONS

Conclusions obtained from Phase I testing were:

1. A shielded HJTC can be used effectively as a level sensing device.
2. When the probe assembly is immersed in a two-phase mixture, the collapsed liquid level is created within the separator tube. This liquid level may be measured by the HJTC sensor.
3. An RVLMS probe configured from a shielded HJTC (HJTC sensor) housed within a separator tube has the potential of being used for monitoring system liquid inventory (through measurement of separator tube collapsed liquid level).

Figure 2-1
RVLMS SENSOR

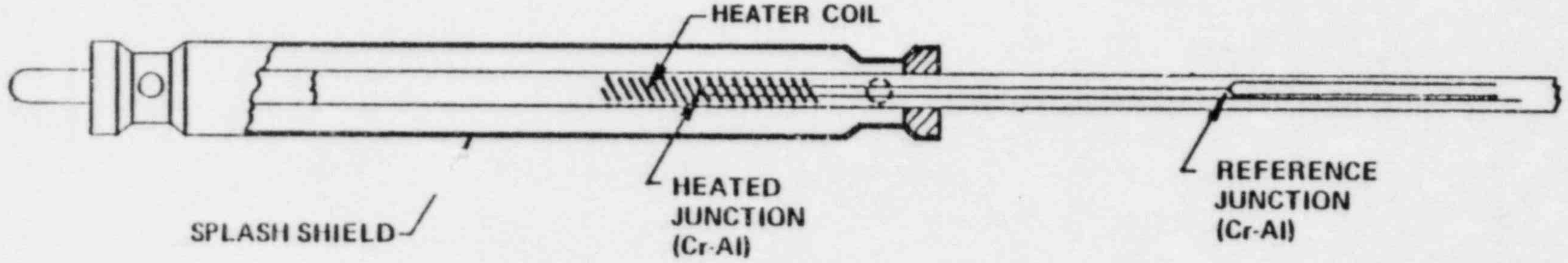
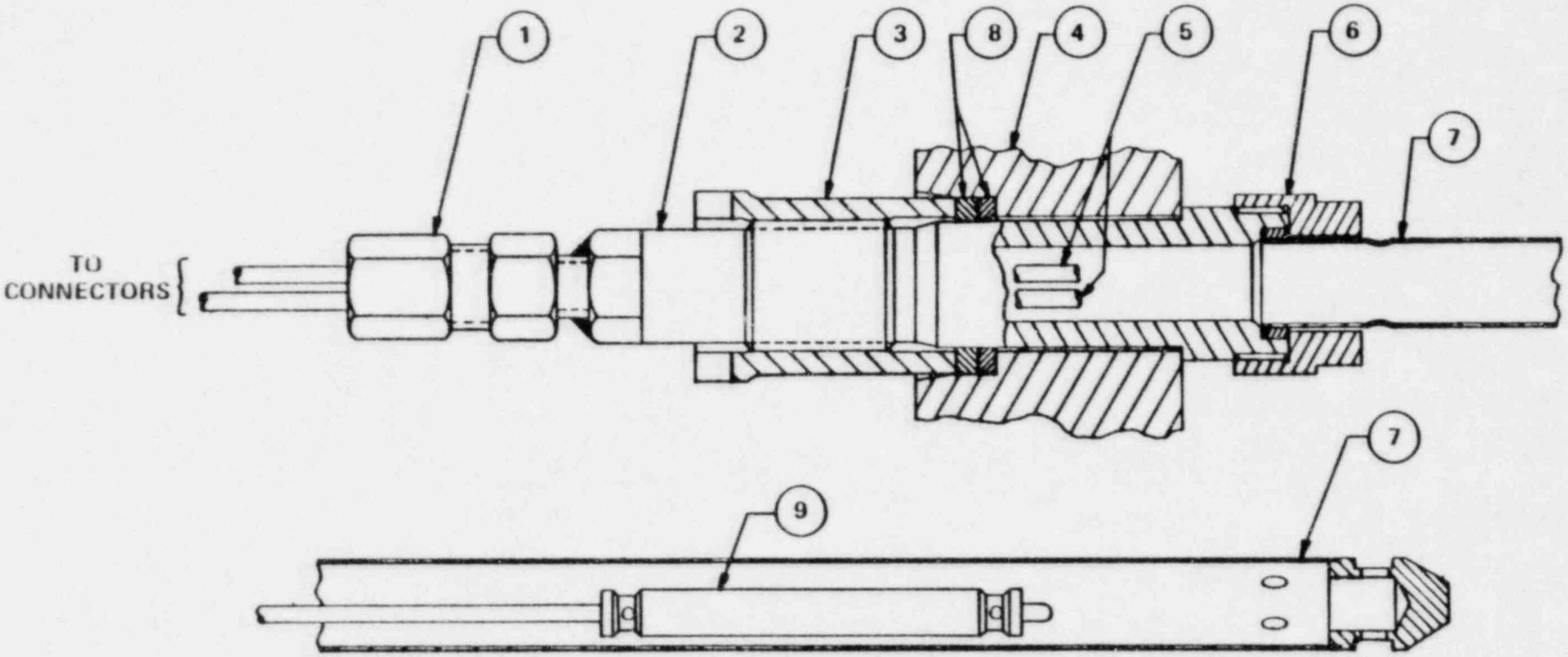


Figure 2-2

RVLMS HJTC PROBE ASSEMBLY



① CONAX SPLIT GLAND SIMILAR TO SPG-100 WITH GRAPHOIL SEALS, STAINLESS HOUSING, SEAT & FOLLOWER

② SEAL PLUG

③ DRIVE NUT

④ FLANGE

⑤ THERMOCOUPLE SHEATHS

⑥ SPANNER NUT

⑦ SEPARATOR TUBE

⑧ GRAPHOIL PACKING GRADE STN

⑨ SPLASH SHIELD

3.0 PHASE 1 HJTC TEST PROGRAM

3.1 Test 1: Autoclave Test to show HJTC (Thermocouples only) Response to Water or Steam

This test was conducted to determine if the output of a heated junction thermocouple differs sufficiently when in liquid and steam environments to be useful to determine liquid level. Several different HJTC thermocouple configurations were subjected to various temperatures and pressures in an autoclave. The test showed a large difference between the heated junction thermocouple and unheated thermocouple temperature outputs when in steam and a small difference when immersed in liquid. The difference was large enough to easily distinguish between steam and liquid.

3.2 Test 2: ORNL AIRS Test Facility: Sensitivity of the Unshielded HJTC to VOIDS

The second test was conducted to measure HJTC response to two-phase steam/water mixtures with void fractions ranging from 70 to 100 percent. This test was performed at the Oak Ridge National Laboratory (ORNL) Advanced Instruments for Reflood Studies (AIRS) 2D-3D reflood facility. An unshielded HJTC designed and fabricated at ORNL was used for this test.

This test clearly demonstrated the need for a splash shield around the area of the heated junction. The differential temperature (ΔT) signal output indicated a cooled or liquid condition at the heated junction for void fractions almost to 100 percent (See Figure 3-1). A very small amount of entrained liquid was sufficient to cool the unshielded heated junction and give a low ΔT output.

3.3 Test 3: C-E Air/Water Sensor Test: Splash Shield Development Experiments

The third test was conducted, in response to the results of the previous test, to develop a splash shield design to shield the heated junction area from spurious wettings from splashing, entrained moisture, or condensation run back, etc. Experimental HJTCs were available for this test. Various splash shield and HJTC configurations were tested. The test facility used water at atmospheric pressure and ambient temperature with air bubbles injected to produce a two-phase mixture. The test facility is shown in Figure 3-2.

The results of these experiments showed that a splash shield can effectively improve the characteristics of the HJTC for application as a RVLMS sensor. The unshielded probes quenched immediately as soon as the two-phase froth level reached the level of the heated junction. Even with the froth level 1" - 2" below the heated junction, water droplets impinging or running back down the probe sheath would reduce the temperature reading significantly. For almost all the shielded HJTC cases, the sensor output began increasing (indicating that the heated junction was uncovered) at a void fraction less than 80% and with some to as low as 20-30%. The output then rapidly increased with increasing void fraction and reached maximum output at between 80 and 100% void fraction. Typical sensor response curves are shown in Figures 3-3 and 3-4. This test demonstrates that with proper shielding of the heated junction, the HJTC output can be made to increase (thereby providing an uncovered signal) at a much lower mixture void fraction than an unshielded HJTC. Furthermore, this test demonstrates that the shielded HJTC (HJTC sensor) can function as an on/off switch. That is, the HJTC output is either high or low depending on whether the HJTC sensor is immersed in a predominantly steam or liquid environment. It should be noted that, the HJTC is to function within a separator tube so the surrounding environment of the HJTC sensor will be either all liquid or nearly dry (high void fraction)steam.

3.4 Test 4: C-E/ORNL THTF HJTC Sensor Test: High Pressure Test of HJTC Sensors

The fourth test was conducted at the Thermal Hydraulic Test Facility (THTF) at ORNL. The C-E HJTC sensor developed in test 3 was subjected to two phase flow environments considerably more severe than conditions to which the sensor will be exposed in reactor application. The objective of this test was to obtain additional data on the HJTC sensor response under various two phase flow situations.

3.4.1 Test Description

The C-E HJTC sensor was installed in the THTF upper plenum near an unused test section outlet nozzle, as shown in Figure 3-5. Water in a loop was pumped upwards through an 8 x 8 electrically heated rod bundle. Then either the power was increased (film boiling tests) or water flow decreased (boil-off tests) until the upper portion of the bundle became uncovered. Heat rates comparable to full power operation were simulated for film boiling testing and comparable to decay heat for boil-off testing.

The fluid density and flow rate measurements were made in the horizontal outlet pipe section away from the HJTC sensor locations. The sensors were on the opposite side of the electrically heated rod bundle about three feet in the horizontal direction and a half foot below the outlet pipe. The densitometer data was obtained from one beam of a three beam device that was inclined 37^{o} from the horizontal and passed through the centerline. The density measurement must be done assuming that the density along the beam path is typical of the density of the fluid flowing through the pipe. If the flow in the outlet pipe was stratified and the pipe less than half full of water, a single inclined beam would indicate a density that was too low. The HJTC sensors could therefore be covered by a two-phase mixture while the densitometer indicated a low (steam) density. Thus an analysis is necessary to provide the relationship between the indication from the densitometer and the conditions at the sensor location.

Test results were obtained for a series of film boiling and boil-off test points. Film boiling tests were conducted at simulated full reactor operating rod bundle power. Initial conditions were saturated liquid at 600 to 1800 psia. Power was then increased until the upper rod bundle area was uncovered. A data scan (THTF Heat Transfer Experiment) was taken at this point, and then the water flow increased and the rod bundle quenched. Five water input flow rates were used at several different pressure levels.

The boil-off tests were conducted at simulated decay heat rates. Instead of increasing power, the water flow input was reduced until the upper rod bundle section uncovered. This was repeated at several pressure levels.

3.4.2 Test Results

The data presented in Figures 3-6 and 3-7 were taken during the film boiling experiments and are representative of the total data at relatively low test section mass fluxes. A high mass flux (high fluid velocity) flow in the region immediately surrounding the HJTC sensor will not occur in a PWR installation. This is because the sensor will be located inside a separator tube (stand pipe) in the upper plenum away from the hot legs. Thus, the results of high fluid velocities, are not presented since they are highly atypical for PWR application.

Figure 3-6 shows the typical response of the C-E HJTC sensor. The fluid flow rate and density, as measured in the outlet pipe section, are shown as well as the sensor output. The pressure for this test ranged from 920 to 1260 psia. The density decreased indicating an increasing steam flow and void fraction in the two-phase mixture region which surrounds the sensor. Analysis of the densitometer data showed that the sensor output increased to provide an uncovered indication before the void fraction reached about 85%. The sensor output remained high until it was quenched by increasing the subcooled inlet flow.

Figure 3-7 shows the sensor response during an unexpected blowdown transient. The test was initiated from saturated conditions at about 1200 psia. The rod bundle power was quickly increased to a maximum of 11 kw/ft at 2.0 minutes, while the bundle mass flux remained constant. The rapid production of steam was indicated by both the densitometer and the HJTC sensor. At 2.5 minutes, the rod bundle power was tripped since bundle temperatures exceeded the maximum limit (1600F). The water level increased, as shown by the increase in fluid density in the outlet pipe, covering the sensor and causing the output to fall. At 3.0 minutes, a rupture disk on the THTF pressurizer burst, resulting in a rapid, uncontrolled depressurization (blowdown) of the system. The circulating pump continued to run during the transient. The HJTC sensor responded to the loss of inventory as expected. That is, when the water level dropped below the sensor elevation, the output increased to provide an uncovered indication.

The results of these high pressure tests agree with the results of low pressure tests conducted at C-E. That is, the sensor (HJTC plus splash shield) output increases to indicate an uncovered condition well before the void fraction of the surrounding two-phase mixture reaches 100%. In addition, these experiments provide preliminary evidence of the ability of the HJTC sensor to respond to blowdown depressurization transients.

3.5 Test 5: Atmospheric Air/Water Test to Show the Effect of the Separator Tube

The feasibility of the HJTC sensor to measure water level was clearly demonstrated in the previous tests. The final test in the Phase I series was conducted to investigate the ability of a separator tube to produce a collapsed water level from a surrounding two-phase mixture, and for the sensor to measure that level.

3.5.1 Test Description

A preliminary RVLMS probe assembly design consisting of a separator tube and sensor (HJTC plus splash shield) was tested in a vessel at atmospheric pressure. The probe assembly was installed inside another perforated tube to simulate installation in a PWR instrument support tube. Air was injected through a perforated manifold at the bottom of the vessel to produce a two-phase mixture (See Figure 3-8). The response of the probe assembly was determined as the water level and air injection rate were varied.

The tests were conducted by varying the water level in the test vessel and recording the output of the sensor. In the steady state tests, the output was allowed to reach its equilibrium value before the level was changed. In the transient tests, the water level was lowered by opening a drain valve and raised by adding water near the bottom of the vessel. For two-phase conditions, air was injected into the vessel at the bottom. The air flow rate could be varied to change the void fraction and the two-phase mixture level. The top of the two-phase mixture was maintained above the elevation of the HJTC sensor.

3.5.2 Test Results

The results of steady state, single phase drain and refill tests are shown in Figure 3-9. Identical curves are indicated for the drain and refill directions. Due to axial heat conduction along the sheath, the sensor started to quench or attained its maximum temperature when the collapsed water level was one inch below the heated section. The largest temperature changes, however, occurred near the lower end of the heated section. Thus, the entire transition from a covered to uncovered condition occurs over a two inch section below the top of the HJTC heater coil.

Results of the transient single phase tests with a refilling rate of 0.09 inch/sec and draining rate 0.027 inch/sec are shown in Figure 3-10. The curves show a minimal delay in quenching for the refill test with the largest temperature drop still occurring near the lower end of the heated section. The sensor output for the transient drain test is lower than the output for the refill test because the time response during drain transients is longer than for refill. That is, it takes longer for the heated junction thermocouple to increase in temperature as it becomes uncovered, than for the temperature to drop when the sensor becomes covered.

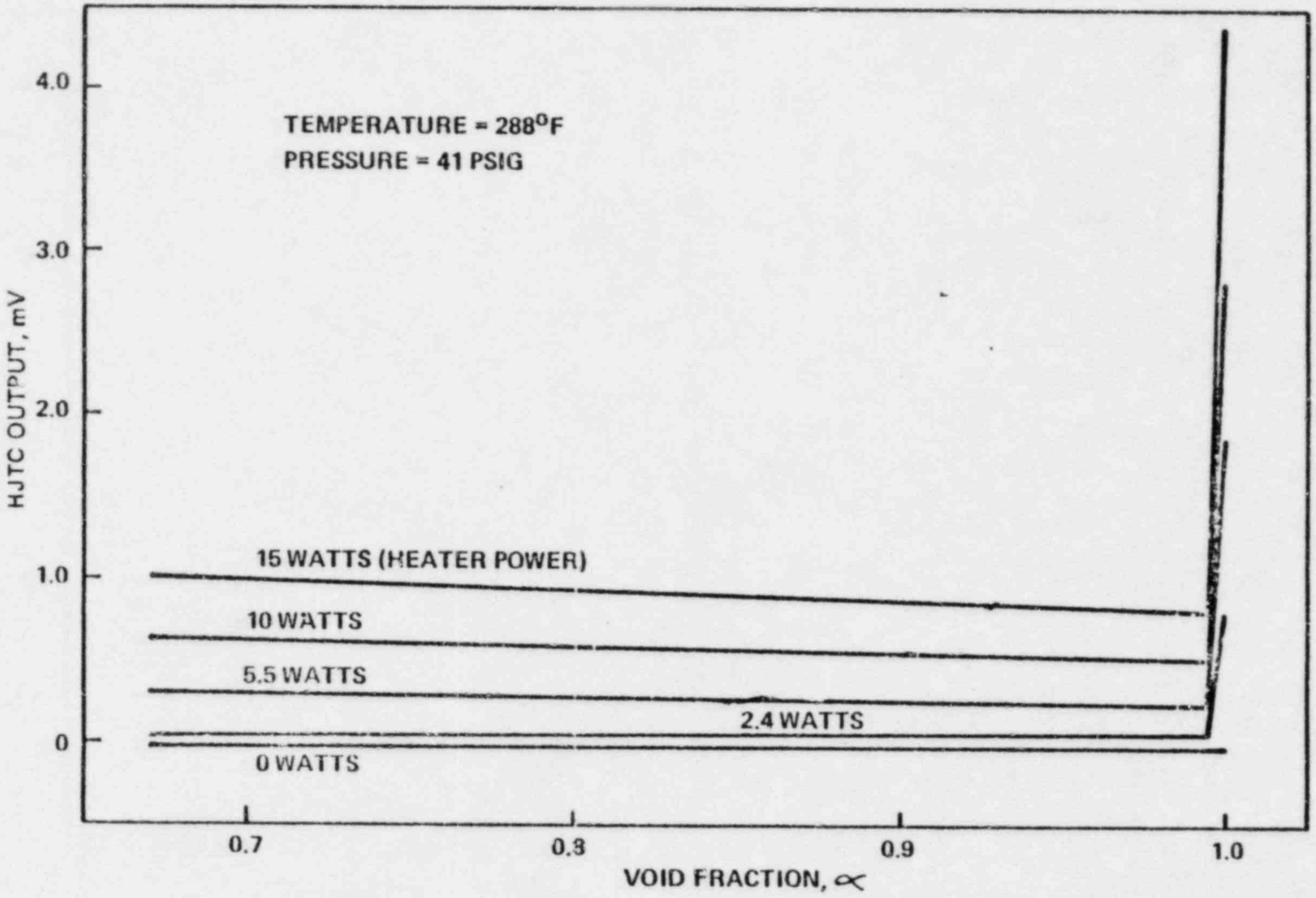
The steady state two phase tests with fixed and moderate air flow (Figure 3-11) show an identical curve as the single phase test. For each of these tests, the top of the two-phase mixture level was maintained above the sensor level. This shows that the separator tube is creating a collapsed level and that the

HJTC sensor is responding to that level. The HJTC measurement of collapsed liquid level was independently verified using a movable standpipe with flow holes positioned at the same elevation of the separator tube tap. The transient two-phase tests with the same moderate air flow (Figure 3-12) showed an essentially similar response, the difference in the quench curves being due only to the slightly higher initial differential temperatures (420F vs 400F). The transient test was repeated with a higher air flow (Figure 3-13). The results were the same in that the sensor switched when the water level reached the lower end of the heated section.

Concluding, the separator tube creates a collapsed level directly representative of the average liquid fraction in a column of fluid between its vent holes for all two-phase mixture void fractions tested, and the HJTC sensor measures that level. Furthermore, for the level transients investigated, it was demonstrated that the HJTC provides level indications (uncovered and covered) when the collapsed liquid level is within a two inch region below the top of the HJTC heater coil.

Figure 3-1

HJTC OUTPUT vs VOID FRACTION



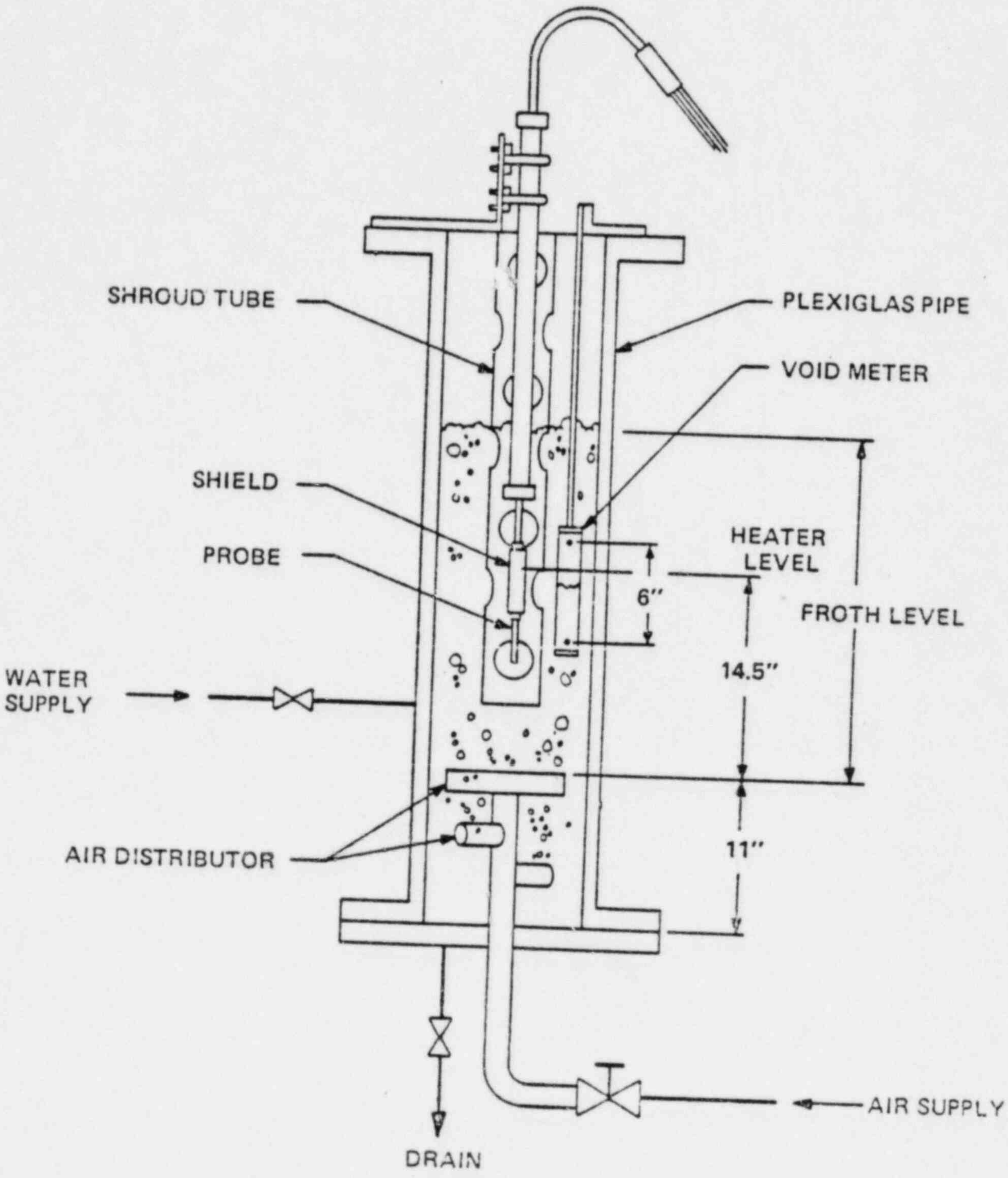


Figure 3-2
AIR-WATER TEST APPARATUS

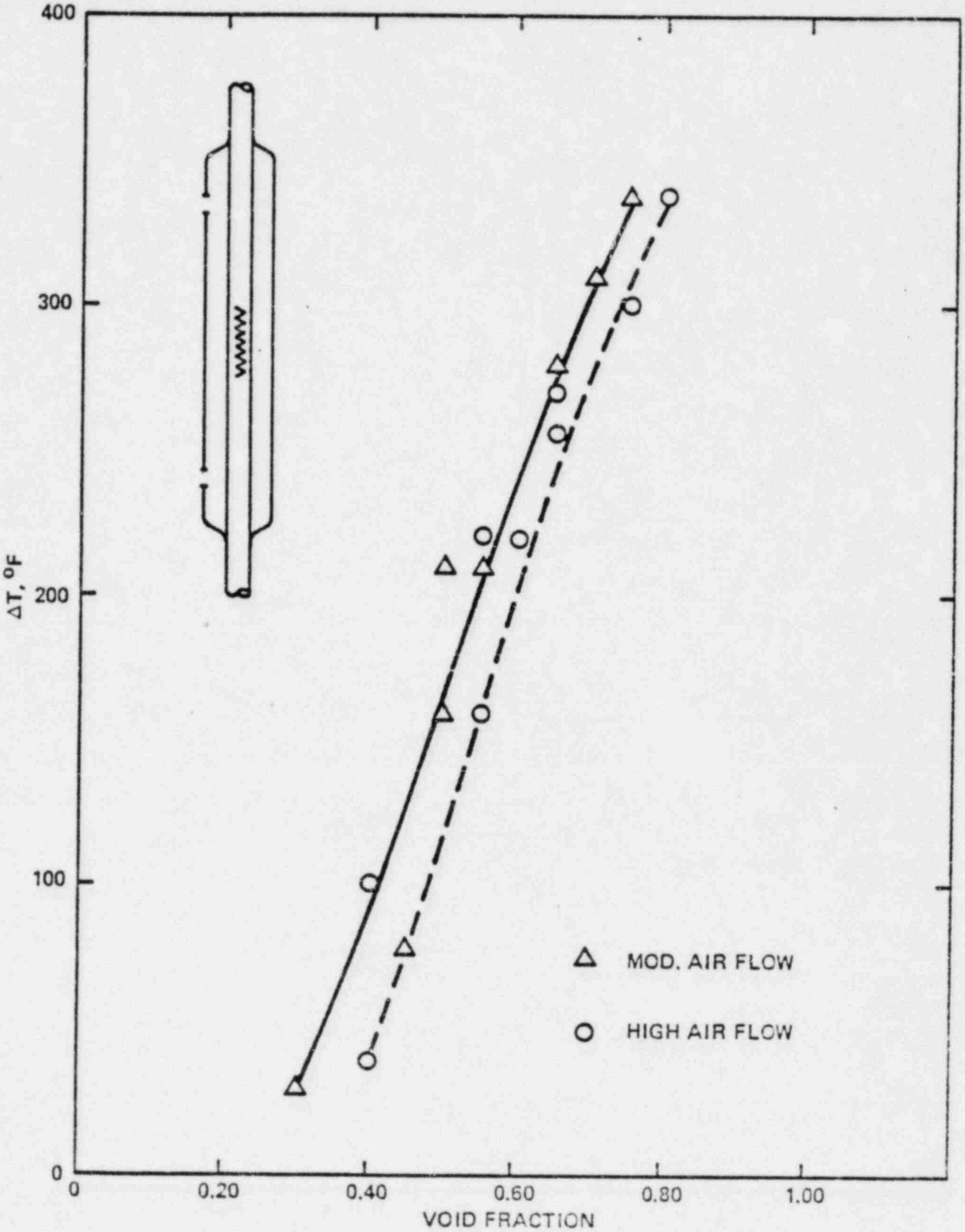


Figure 3-3
HEATER AT CENTER OF SHIELD

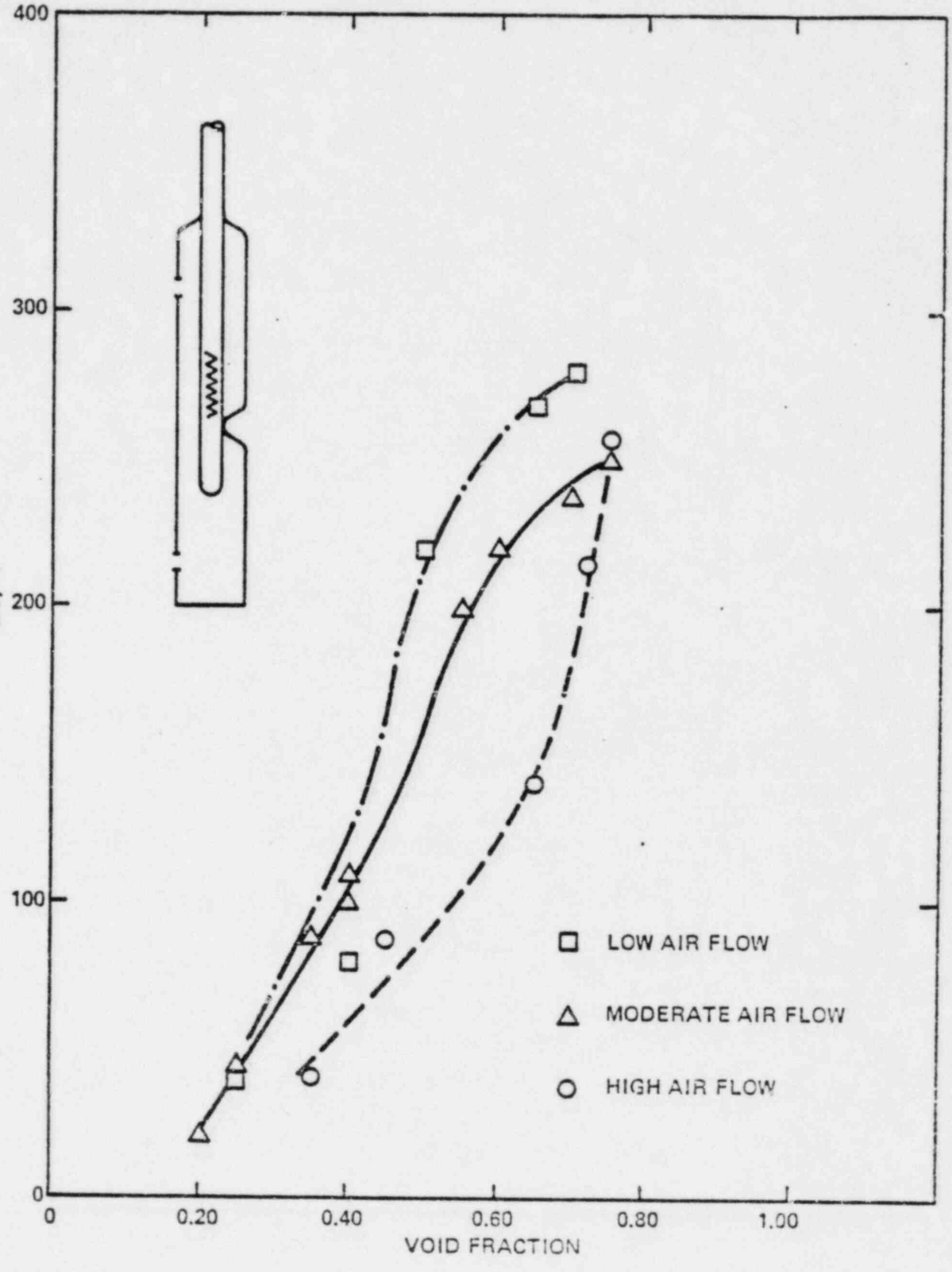


Figure 3 - 4
HEATER AT CENTER OF SHIELD

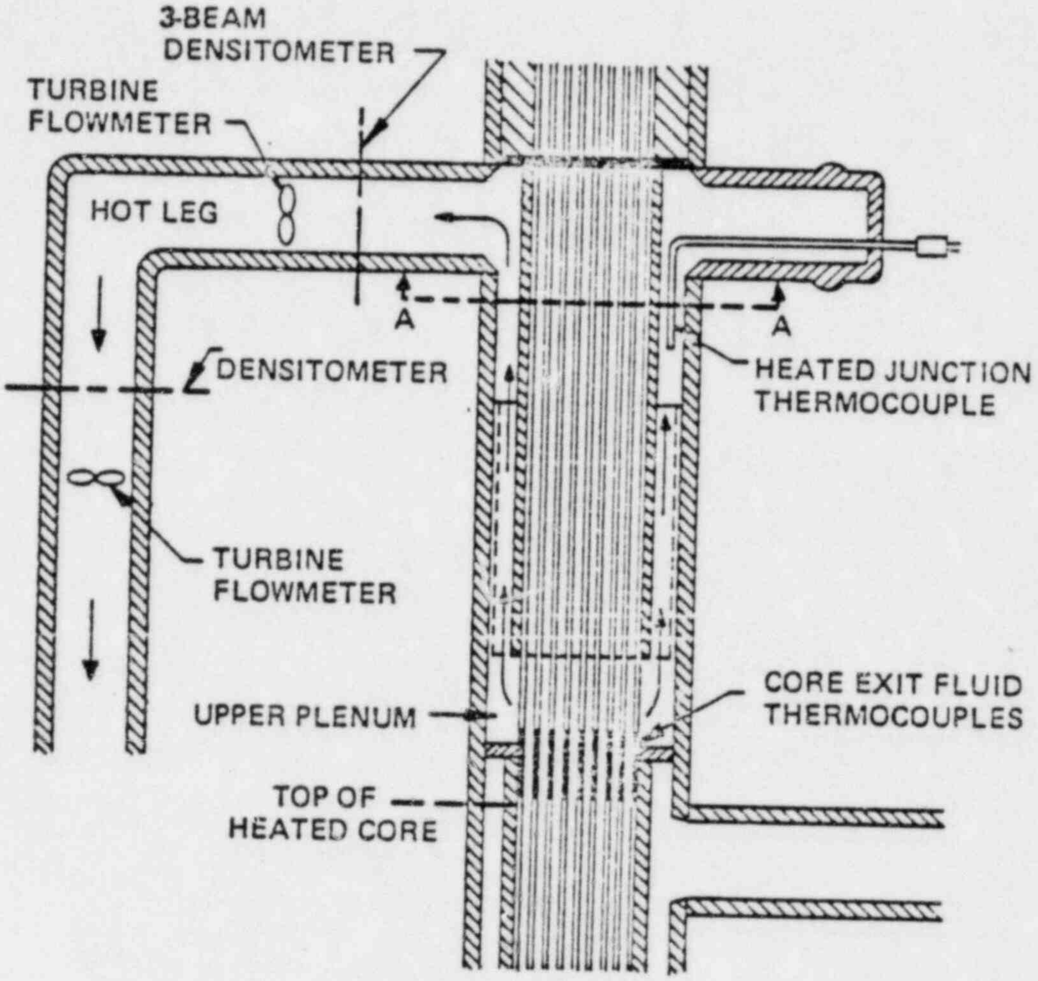


Figure 3-5

SCHEMATIC OF UPPER PART OF THTF TEST SECTION AND OUTLET PIPING SHOWING LOCATION OF HJTC

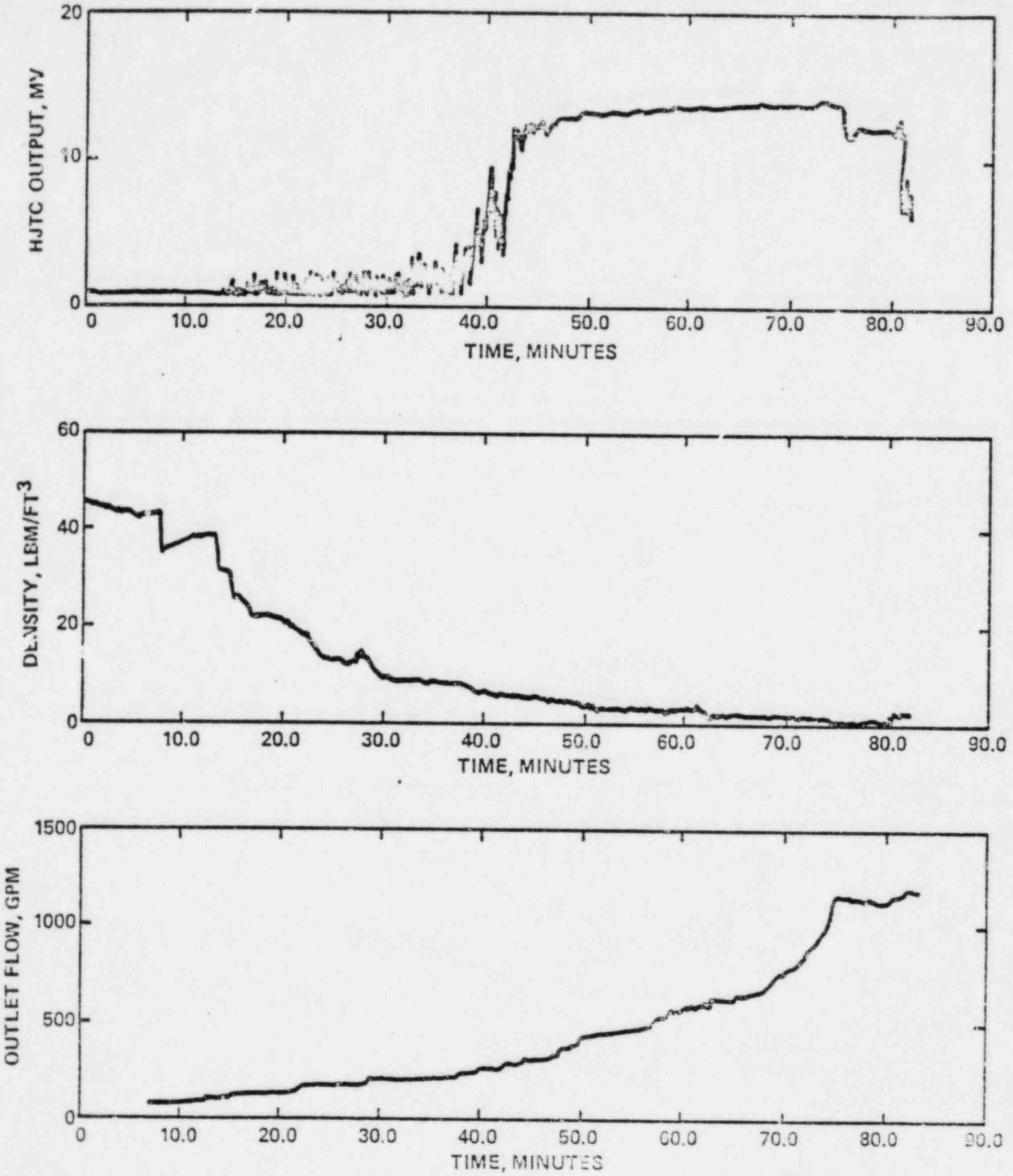


Figure 3-6
HEATED THERMOCOUPLE OUTPUT, MEASURED DENSITY, AND MEASURED VOLUMETRIC FLOW AT TEST SECTION OUTLET.

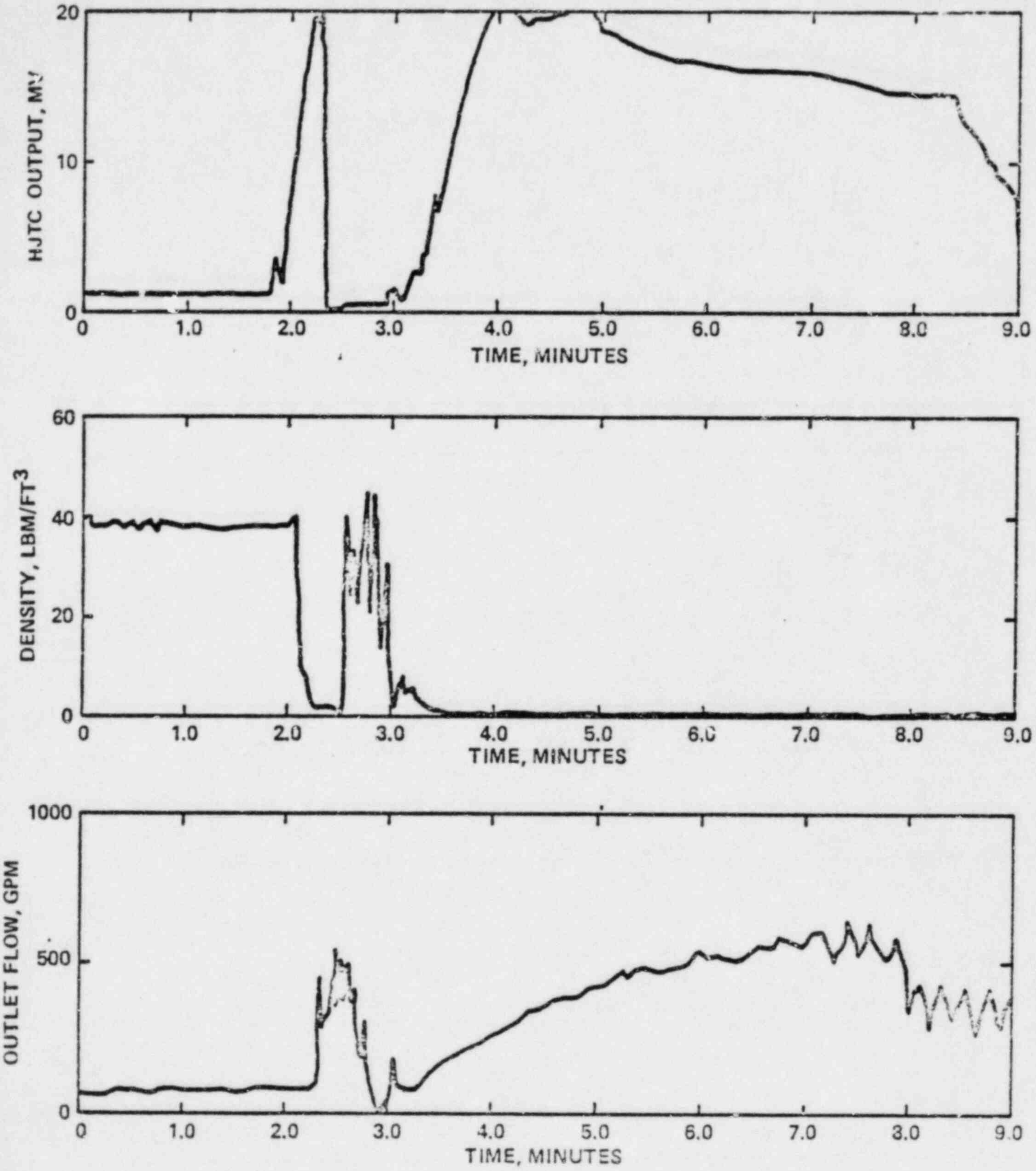


Figure 3-7

HEATED THERMOCOUPLE OUTPUT, MEASURED DENSITY, AND MEASURED VOLUMETRIC FLOW AT TEST SECTION OUTLET DURING INVERTED ANNULAR FILM BOILING TEST AND SUBSEQUENT BLOWDOWN

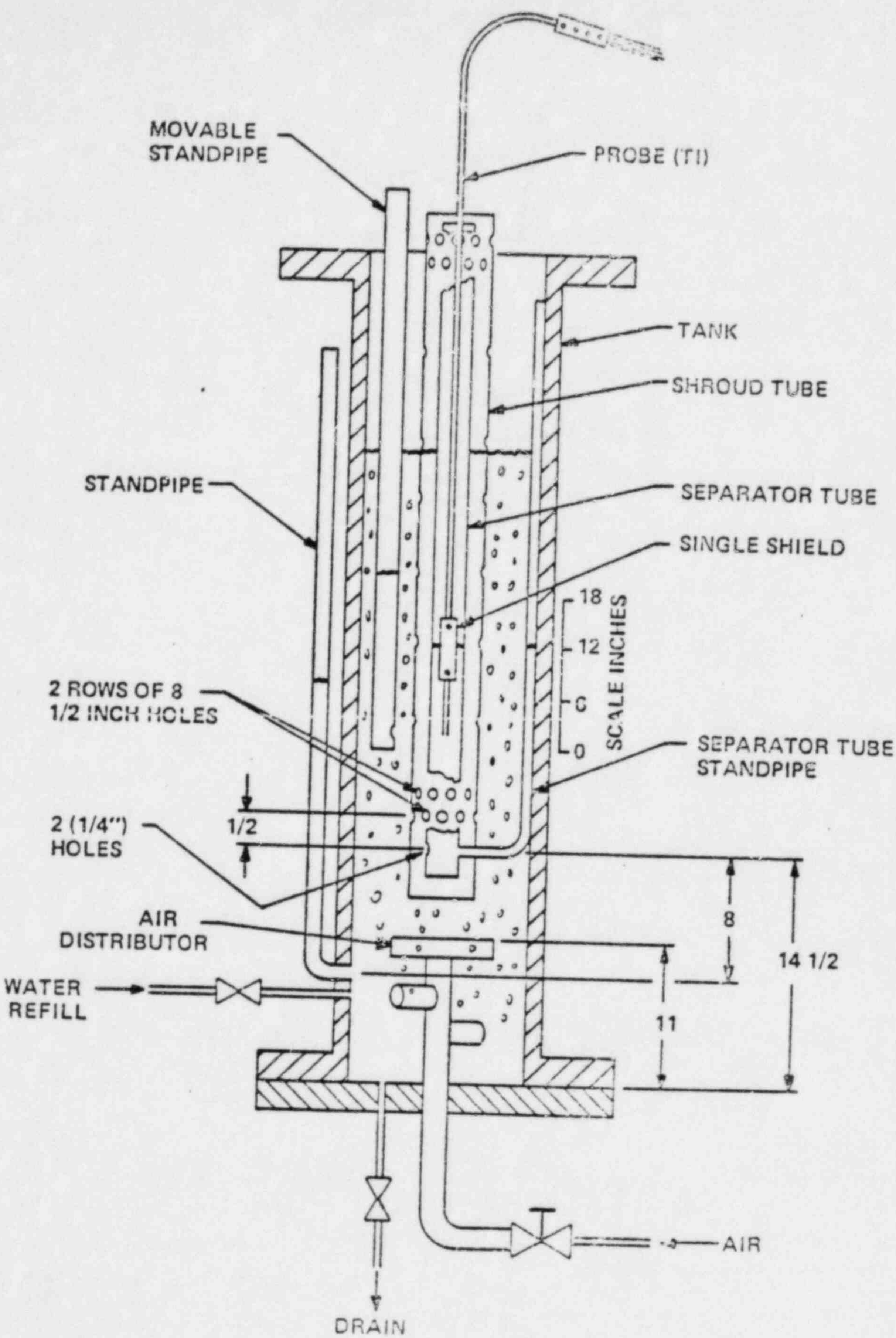


Figure 3-8
TEST APPARATUS

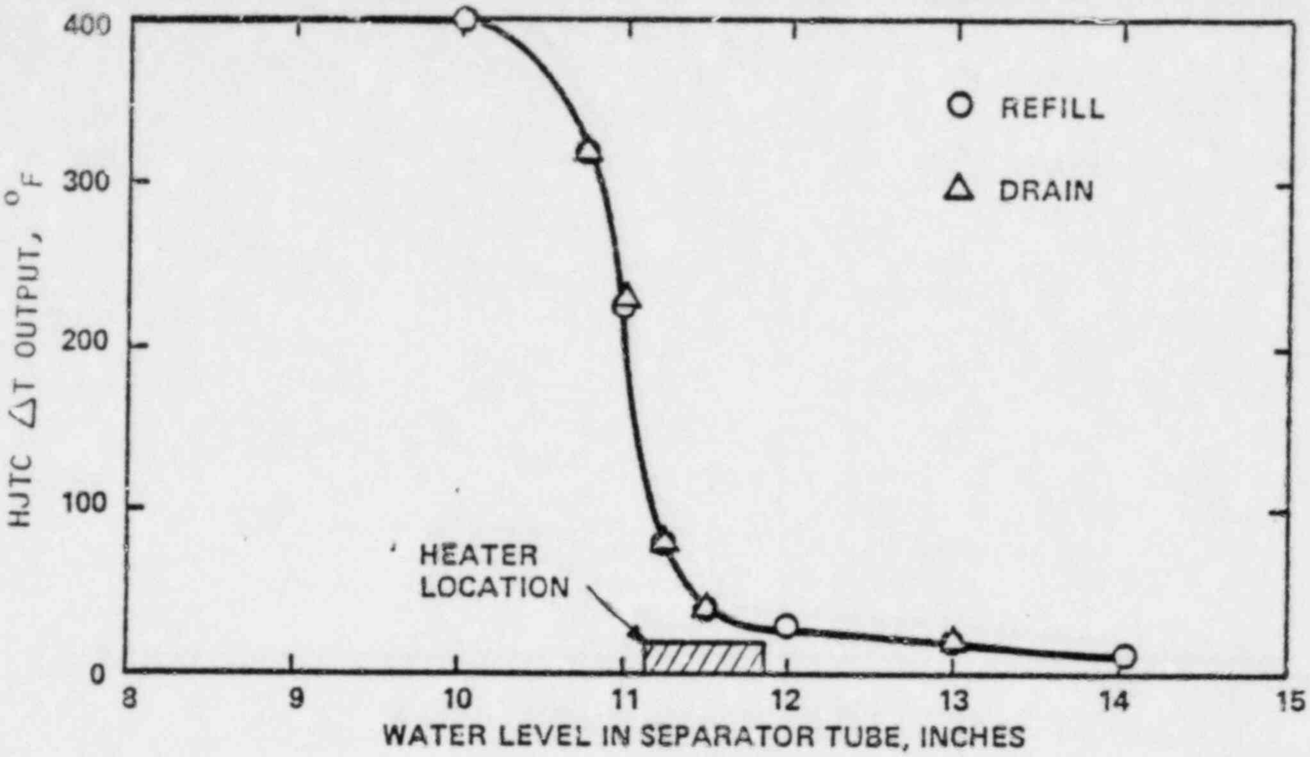


Figure 3-9
STEADY STATE SINGLE PHASE TESTS

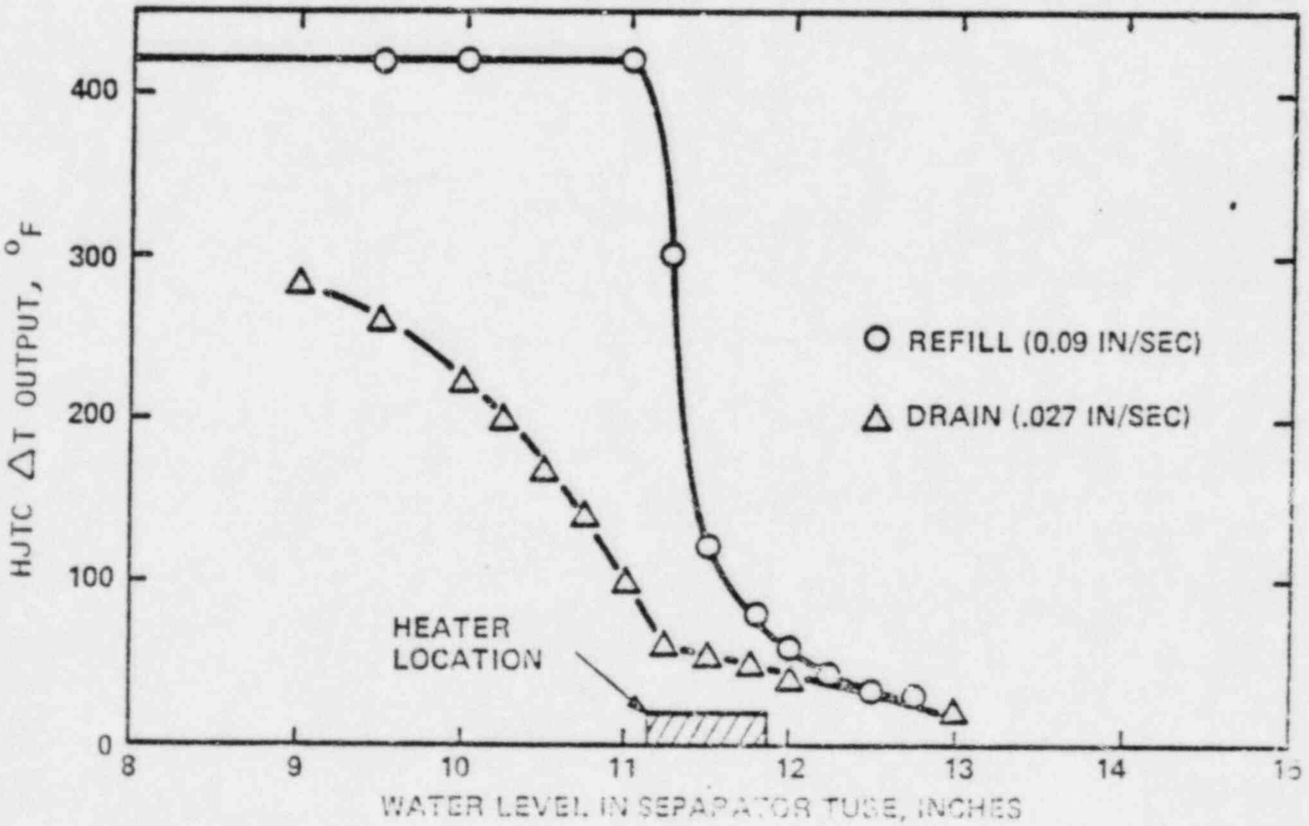


Figure 3-10
TRANSIENT SINGLE PHASE TESTS

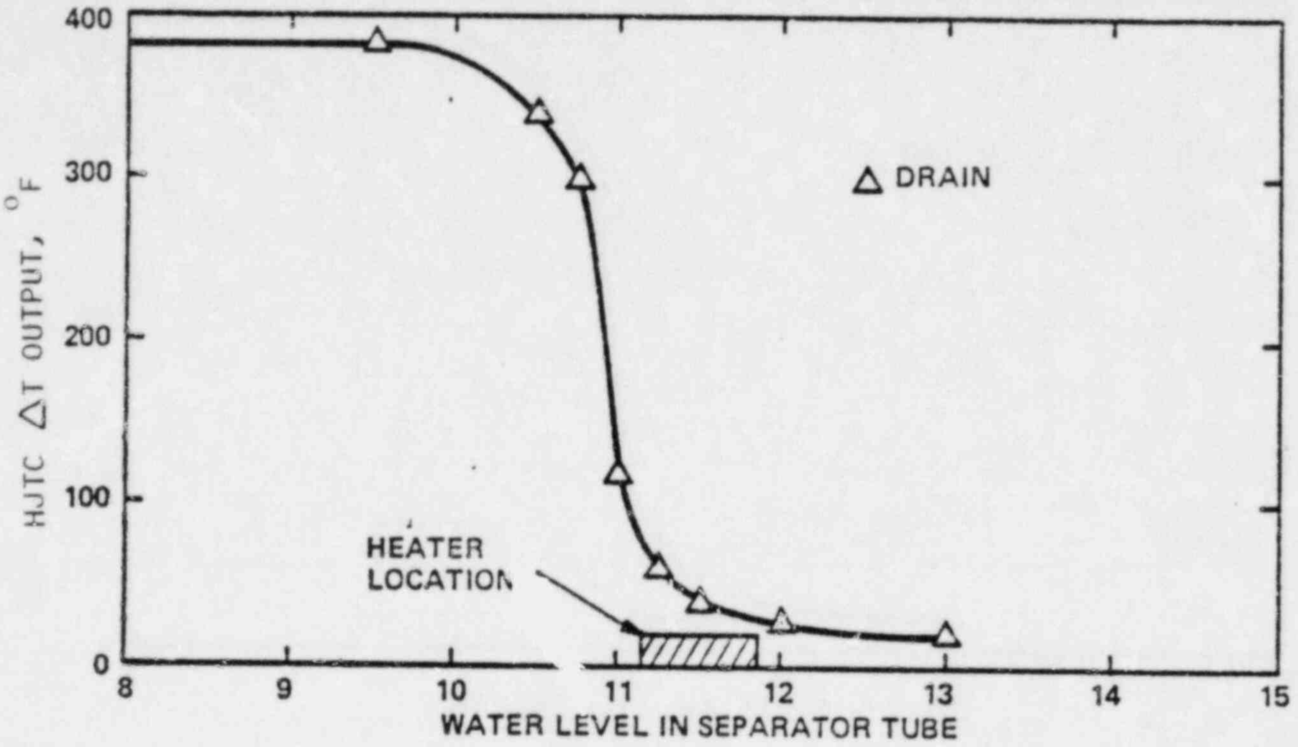


Figure 3-11
STEADY STATE TWO PHASE TESTS (MODERATE VOID FRACTION)

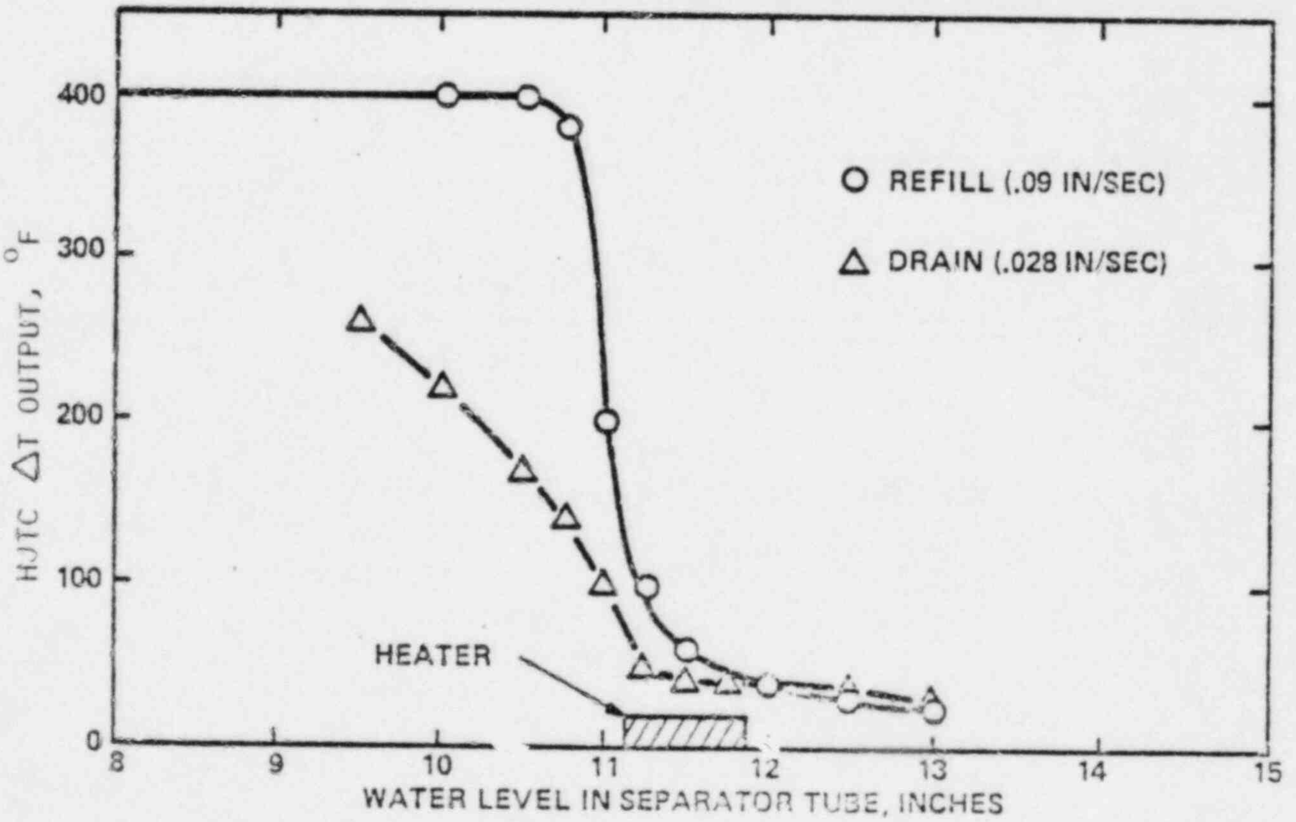


Figure 3-12
TRANSIENT TWO PHASE TESTS (MODERATE VOID FRACTION)

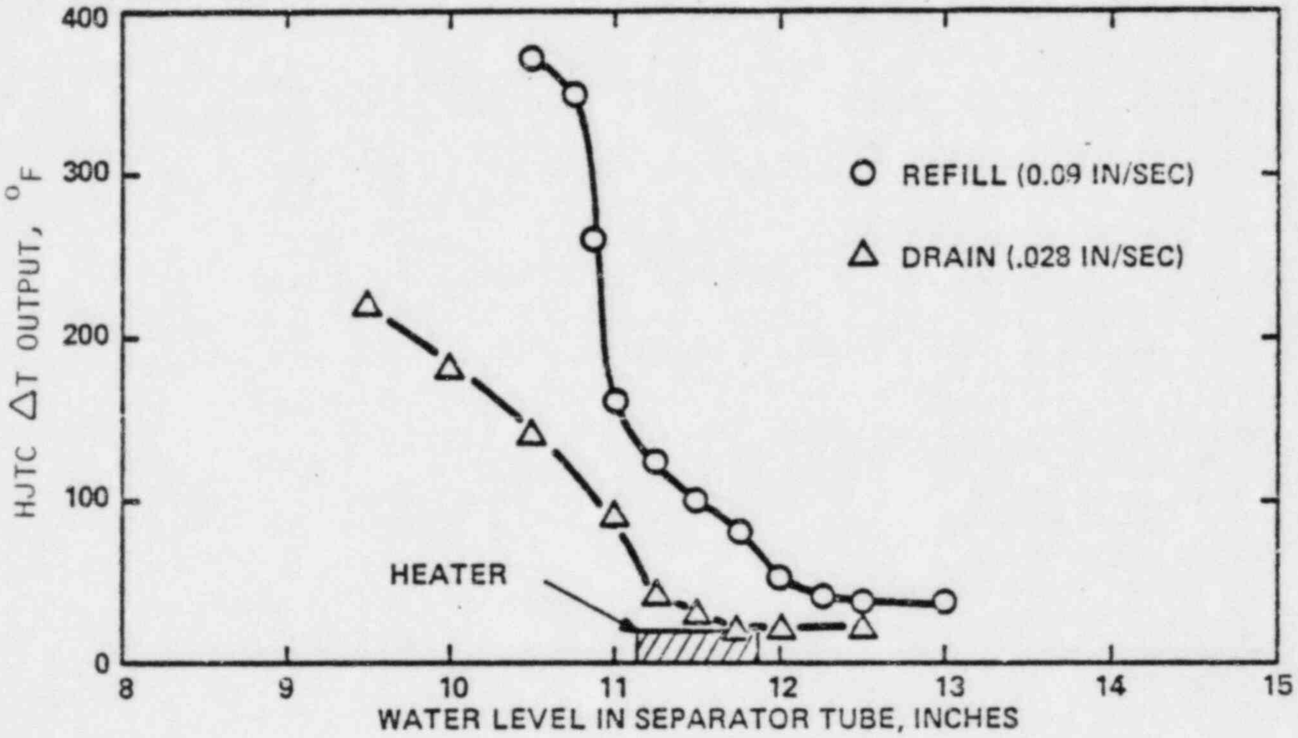


Figure 3-13
TRANSIENT TWO PHASE TESTS (HIGH VOID FRACTION)

COMBUSTION ENGINEERING, INC.

CEN - 185 - NP
Supplement 2-NP

HEATED JUNCTION THERMOCOUPLE

PHASE II Test Report

Prepared for the C-E OWNERS GROUP

November, 1981

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PDR

POWER
SYSTEMS
COMBUSTION ENGINEERING, INC.

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LEGAL NOTICE

ABSTRACT

This report provides the documentation of the Phase II tests for the Heated Junction Thermocouple, Reactor Vessel Level Monitoring System. A series of steady state and transient tests under single phase and two-phase fluid conditions were performed on a Heated Junction Thermocouple probe assembly. Fluid conditions that the probe assembly might be exposed to in a pressurized water vessel were simulated. The Phase II tests verified that a Heated Junction Thermocouple probe assembly is capable of measuring the water inventory in a reactor vessel.

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1.0 INTRODUCTION

The Reactor Vessel Level Measurement System (RVLMS) is an instrumentation system being developed by C-E as part of an Inadequate Core Cooling Instrumentation (ICCI) package. The RVLMS is intended to provide an unambiguous indication of the approach to, and recovery from ICC. The C-E design uses the Heated Junction Thermocouple (HJTC) concept to provide this indication.

1.1 HJTC/RVLMS FUNCTION

The principal function of the RVLMS is to determine and display to the operator the water inventory in the reactor vessel above the fuel alignment plate. Water inventory may be lost from the reactor vessel upper head region as a result of accidents involving the loss or shrinkage of reactor coolant system inventory. In those transients involving loss of inventory, the pressure in the reactor coolant system drops so that steam voids are formed in the coolant, resulting in a steam-water mixture. The RVLMS is specifically designed to indicate the "collapsed water level" of the steam-water mixture in the reactor vessel above the fuel alignment plate. The collapsed water level is the level the water would form if the steam-water mixture would separate completely to an all vapor (steam) region and an all liquid (water) region. Indication of the collapsed level gives the operator a measure of the water inventory above the fuel alignment plate.

The measuring portion of the RVLMS is shown schematically in Figure 1-1. It consists of a number of sensors with individual splash shields which are axially distributed inside a separator tube. This constitutes a probe assembly. The purpose of the separator tube is to create a collapsed water level inside while a steam-water mixture is outside of the tube. Thus, inside the separator tube there exists a relatively quiescent region of all liquid (collapsed water level) below a region of nearly dry steam. The sensors are Heated Junction Thermocouple (HJTC) devices. They consist of two thermocouple junctions, one of them heated by a separate heating coil. A tube with holes at the top and bottom, called a splash shield, encloses the heated junction to prevent spurious wetting by entrained water droplets. The temperature difference (ΔT) between the heated and unheated junctions provides an indication of the heat removal capability of the surrounding fluid. When the heated junction is surrounded by fluid of good cooling ability (water), the ΔT is relatively low. When the heated junction is surrounded by fluid of poor cooling ability (steam), the temperature of the heated junction becomes significantly hotter than the temperature of the unheated junction resulting in a large temperature difference between the two junctions. The change from good to poor cooling occurs when the water/steam interface falls below the heated junction. Consequently, the differential thermocouple output changes from a low value to a high value. When the output increases above a predetermined value, a signal is generated which indicates that the collapsed water level lies below the location of a particular sensor.

1.2 OVERALL TEST PROGRAM

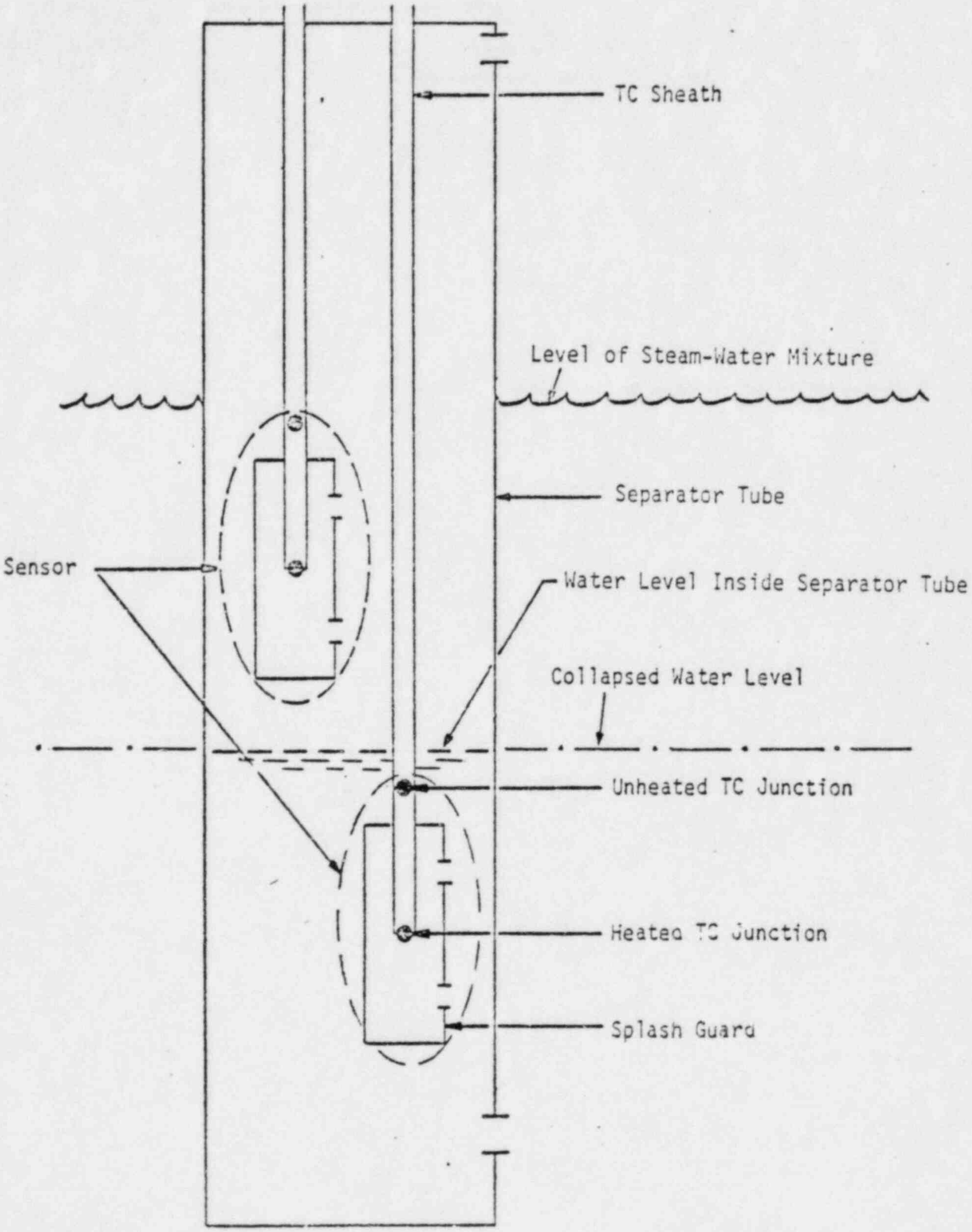
C-E has developed a comprehensive test program for the HJTC system to provide design information and to verify its capability as a RVLMS. This test program has been divided into three parts. The Phase I test series consisted of feasibility and proof-of-principle tests where the concept of using HJTCs as water level measurement devices was confirmed. Also, data useful for the initial design development of a water level sensor was obtained. The Phase I tests have been completed and the test results are documented in CEN - 185, Supplement 1.

The purpose of Phase II testing is to verify the performance of the complete HJTC probe assembly. These tests were conducted under thermal-hydraulic conditions representative of normal and accident conditions that the instrument is expected to encounter in a PWR. Phase II has been completed and the results are presented in this report.

Phase III is a prototype test. The final HJTC system design including the probe assembly and the electronics (sensor heater power controller, signal processors) will be tested. A report on the Phase III testing is scheduled for completion in June, 1982.

Figure 1-1

SCHEMATIC OF PROBE



2.0 PHASE II TEST OBJECTIVES

Phase II is a design verification test series for the probe assembly. Data obtained allows the ability of the probe assembly to indicate the collapsed water level to be determined. The objective of Phase II testing is to simulate the thermal-hydraulic conditions surrounding the HJTC probe assembly that might exist in a PWR and verify the performance of the HJTC probe assembly under these conditions. Specific objectives are given below.

1. Determine the ability of the probe assembly to establish and measure a collapsed water level when surrounded by a steam-water mixture at high pressure.

2. Determine the ability of the probe assembly to measure collapsed water level within the separator tube during rapid depressurization transients.

3. Confirm that the vent holes at the top and bottom of the separator tube are large enough so that the water level inside the separator tube closely follows the vessel water level during fast drain and refill transients.

4. Measure the response time of the HJTC sensors and probe assembly at different pressures.

5. Determine HJTC sensor output for a range of pressures for use in the design of the sensor heater power control.

3.0 SUMMARY OF HJTC PROBE PERFORMANCE

The Phase II test series evaluated the HJTC probe performance under conditions that may be expected to occur in the region of the probe during an accident in a PWR. Single-phase, two-phase, and depressurization transients were run. The tests covered a pressure range from atmospheric to 1450 psig, with blowdown tests initiated at 1875 psig. The two-phase mixture void fraction was varied from 0 to 0.52.

The results of the Phase II test series show that the separator tube is capable of creating a collapsed water level that can be detected by the HJTC sensor when the probe is immersed in a two-phase mixture. The separator tube produces a relatively quiescent region of all liquid below a region of nearly dry steam. The HJTC sensor responds to the passing of this steam/water interface. Good agreement is obtained between the water level indicated by the HJTC sensors and the collapsed water level measured independently by a DP cell.

Bottom blowdown tests at high depressurization rates (4-10 psi/sec), typical of the initial blowdown period of a small break LOCA, show that the probe responds to the top of the two-phase mixture level during the time when pressure is falling. This is due to flashing that occurs inside the separator tube. When the depressurization ends, flashing stops and a collapsed water level is formed and measured inside the separator tube. Section 8.3 describes the probe response during a fast depressurization blowdown in more detail. During blowdown tests with lower depressurization rates (1-2 psi/sec), typical of the period following the initial rapid depressurization during a small break LOCA, the probe responds more closely to the collapsed water level. Good agreement can be obtained between the water level indicated by the probe and the DP cell.

The transient drain tests show that there is a time delay between the time when the collapsed water level in the test vessel passes a sensor elevation and when the sensor indicates an uncovered condition. This time delay of the probe during drain tests is made up of several components; the drainage of water from the separator tube and splash shield, evaporation of the liquid film that remains on the sensor sheath, and heatup of the heated junction thermocouple to reach the ΔT threshold which indicates that the sensor is uncovered. The time delay is shorter at lower pressures and higher sensor heater powers. The delay due to the first two components was measured to be [ ] depending on pressure, sensor heater power, and void fraction. The time to reach a ΔT of 150°F is [ ] at 1200 psig and with a sensor heater power of 11.5 watts. Thus, the total response time of the probe for these conditions is less than [ ] The major portion of the total delay time is due to [ ] To significantly reduce the delay time, a higher sensor heater power should be used. The desired delay time will strongly contribute to the determination of the final design heater power which will be determined during the Phase III tests.

Typical HJTC sensor output was obtained for a range of pressures from atmospheric to 1450 psig. Relatively low (less than 11.5 watts) sensor heater powers were used. This data provides part of the information on sensor output at different pressures which can be used in the sensor heater power controller design. Additional data will be provided by the Phase III tests.

The response of an uncovered HJTC sensor to a sudden increase in pressure is a slight drop in output due to cooling caused by condensation and the increase in heat transfer coefficient that results from the pressure increase. The effect of condensation reduces the sensor output for only a short period of time since the condensed water droplets are quickly evaporated, leaving the heated junction dry again. In these tests, where a very high repressurization rate occurred, the output decreased by less than [ ] The duration and magnitude of the drop in sensor output depends on the sensor heater power and the repressurization transient. For PWR applications, it is not expected that condensation will cause the sensor output to drop enough to give a covered indication. This will be verified during the Phase III tests.

In conclusion, the Phase II tests demonstrate that the HJTC probe assembly functions correctly to measure the collapsed water level under thermal-hydraulic conditions which the probe might be exposed to in a PWR. These tests, therefore, verify the performance of the HJTC probe assembly as an instrument to measure the water inventory in the upper plenum of a reactor vessel.

4.0 TEST FACILITY

4.1 HJTC PROBE ASSEMBLY

The HJTC probe assembly consisted of three HJTC sensors (with splash shields) installed inside a 12 foot long separator tube (Figure 4-1). Each sensor consists of a heated and unheated Type K thermocouple. Each heated junction is protected by a splash shield. The electrical connection of the sensors allowed the measurement of each individual thermocouple temperature as well as the differential temperature between heated and unheated junctions.

The three sensors were placed at different elevations within the separator tube. The sensors were placed at 18, 72, and 134 inches below the top of the test vessel. Thus, a large axial separation between sensors existed covering the length of the vessel.

The sensor heater coils of the three sensors were connected in parallel from a single power supply source. The heater powers of each sensor were within 10% of each other, with the top sensor being at a slightly lower power. This was due to a slight difference in the heater coil resistance. The power supply was automatically tripped when the differential temperature reached 400°F.

The accuracy of each thermocouple was determined prior to testing. It was found that a variation existed in the temperature indicated by the thermocouples of each sensor. Thus, when uncovered, the output of each sensor was slightly different from the other sensors, with the middle sensor being lower by as much as 35°F. This difference in sensor outputs will not occur in the final production probe assembly due to better manufacturing quality control.

The separator tube was enclosed in a support tube similar to the way it would be in a PWR. The separator tube had[ ]holes at the bottom and[ ]holes at the top. Each hole had a[ ] diameter, thus providing an open flow area of[ ]at the bottom. Slots in the support tube[ ] This configuration

[ ] aids in preventing steam bubbles from entering the bottom of the separator tube. The support tube also had [ ] holes drilled axially between the slots on [ ] centers. Inside the separator tube, in addition to the three working sensors, tubes were added to simulate the additional sensors that would be present in the probe assembly for a PWR, thereby maintaining the same flow area.

4.2 TEST FACILITY

The test facility is shown in the isometric drawing of Figure 4-2 and a schematic diagram in Figure 4-3. The major components of the facility are a 70 gallon autoclave, test vessel, heater tube, and circulating pump. The autoclave was used as a source of hot water for injection into the test vessel and heater tube. It was also used to bring the system up to the appropriate test pressure and temperature. The pump circulated water from the autoclave to the test vessel during heat-up and refill.

The purpose of the heater tube was to produce steam which was injected into the test vessel during testing under two-phase conditions. It consisted of an electrically isolated 3/4 inch diameter, 15 foot long Inconel tube. Electric cables attached at both ends of the tube provided a direct current to heat water flowing inside the tube and generate steam. The power to the heater tube was adjustable from 0 to 250 kw. A thermocouple attached to the heater tube wall provided a high temperature safety trip for burnout protection.

The test vessel which housed the probe assembly was a 4 inch, Schedule 160 pipe, 15 feet long. Various pipe connections were made to allow filling and draining of water, steam injection at the bottom, and steam venting for pressure control. A perforated diffuser plate, located above the point of steam injection, was used to control steam bubble size and distribution. Band heaters near the bottom of the test vessel served to maintain the fluid temperature. These were not sufficient, however, to increase the test vessel fluid temperature above that of the autoclave.

4.3 TEST INSTRUMENTATION

The important parameters which relate the performance of the probe assembly were monitored on a multichannel Beckman Dynograph strip chart recorder. These parameters (given in Table 4-1) included the differential temperature output from all three HJTC sensors, test vessel water level measured by a differential pressure gauge (DP cell), pressure and temperature of the test vessel fluid, and the fluid density measured by a gamma densitometer.

The gamma densitometer was used to measure the fluid density, and hence void fraction, inside the test vessel during two-phase and blowdown testing. The device uses a 2 curie CS-137 source inside a tungsten collimator, which projects a 3/8 inch wide gamma ray beam through the vessel. The transmitted beam is then incident on a scintillation crystal. The output of the crystal is processed and displayed as digital counts per second or as a continuous signal from a rate meter. This output may be related to the fluid void fraction as follows:

$$\alpha = \frac{\ln (I/I_w)}{\ln (I_s/I_w)}$$

α = void fraction

I = transmitted beam intensity

I_w = intensity of beam with vessel filled with water

I_s = intensity of beam with vessel filled with steam.

The densitometer was positioned so that the gamma beam traversed the annulus between the support tube and the test vessel. It was located vertically at the same elevation as the heated junction of the middle HJTC sensor.

The DP cell provided an independent measurement of the collapsed water level in the test vessel to which the HJTC probe response was compared. It was calibrated in inches of water at atmospheric conditions. Since the DP cell was not recalibrated at each temperature and pressure, there was a different DP cell reading for a given water level for each pressure. This value was determined during the single phase, steady state tests and is listed for the middle sensor elevation in Table 4-2. The water level was measured from the top of the vessel. Thus, 0 inches means that the vessel is full of water and 140 inches means that it is empty.

Table 4-1

Test Instrumentation

Instrument	Parameter Measured	Range
Top HJTC Sensor	Sensor ΔT	0-400°F
Middle HJTC Sensor	Sensor ΔT	0-400°F
Bottom HJTC Sensor	Sensor ΔT	0-400°F
DP Gauge	Test Vessel Water Level	0-160 in.
Pressure Gauge	Test Vessel Pressure	0-2000 psig
Thermocouple	Test Vessel Temperature	0-800°F
Gamma Densitometer	Test Vessel Fluid Density Test Vessel Fluid Void Fraction	Liquid-Steam 0-100%

Table 4-2

DP Cell Reading When the Test Vessel Water Level is Just Below Middle Sensor Elevation

Pressure (psig)	DP Cell Reading (inches)
Subcooled Fluid*	
300	80
1450	87
Saturated Fluid*	
90	78.0
300	83.0
1300	91.0
1350	91.0
1450	91.5

---

*The DP cell reading for subcooled fluid should be used for comparison to the single phase tests in Figures 7-3 and 7-4. The saturated fluid DP cell readings should be used for comparison to the two-phase tests in the remaining figures. The DP cell reading is different for the same pressure because of the different fluid temperature.

FIGURE 4-1

HJTC PROBE ASSEMBLY

[ ]

Figure 4-2

Phase II Test Facility

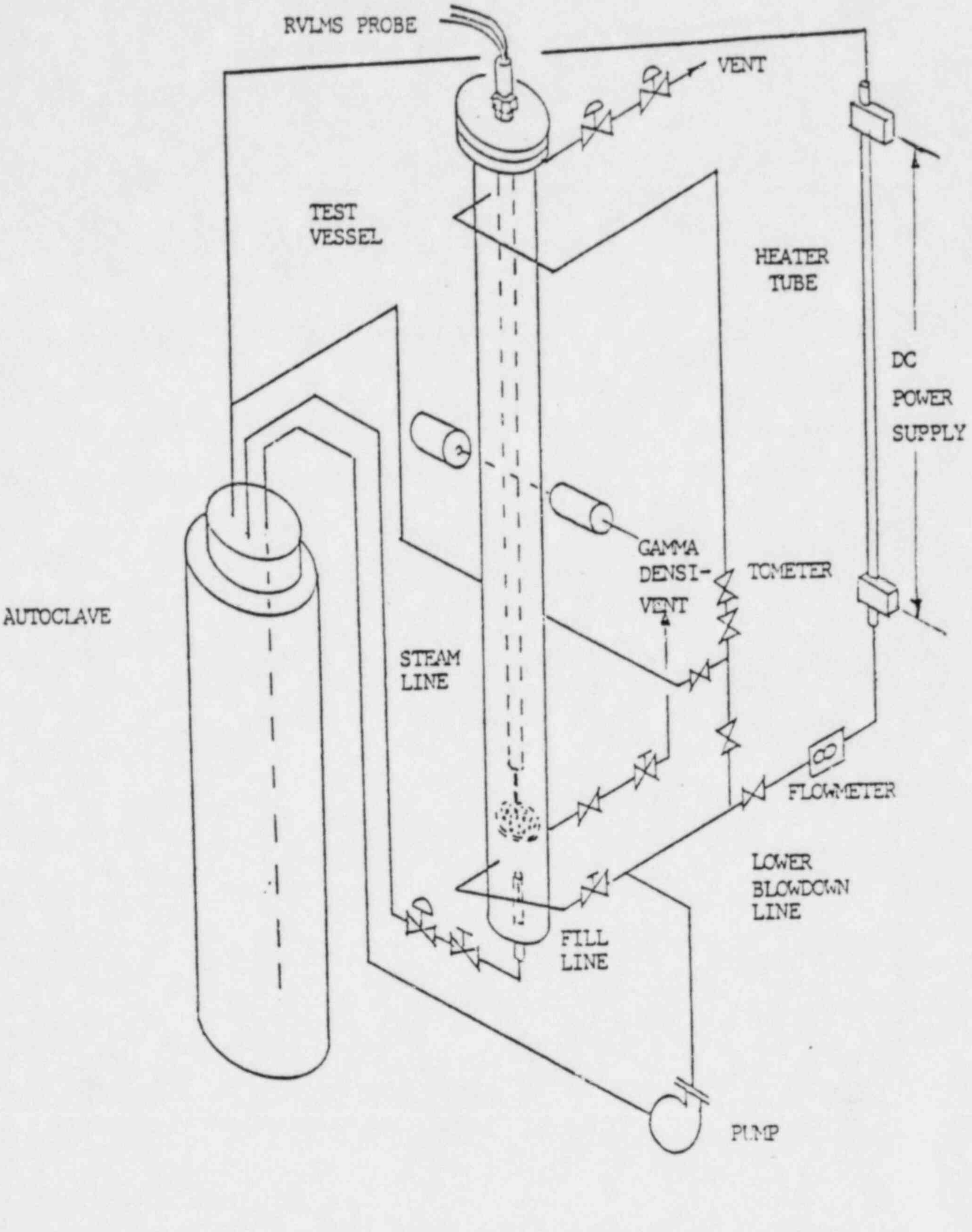
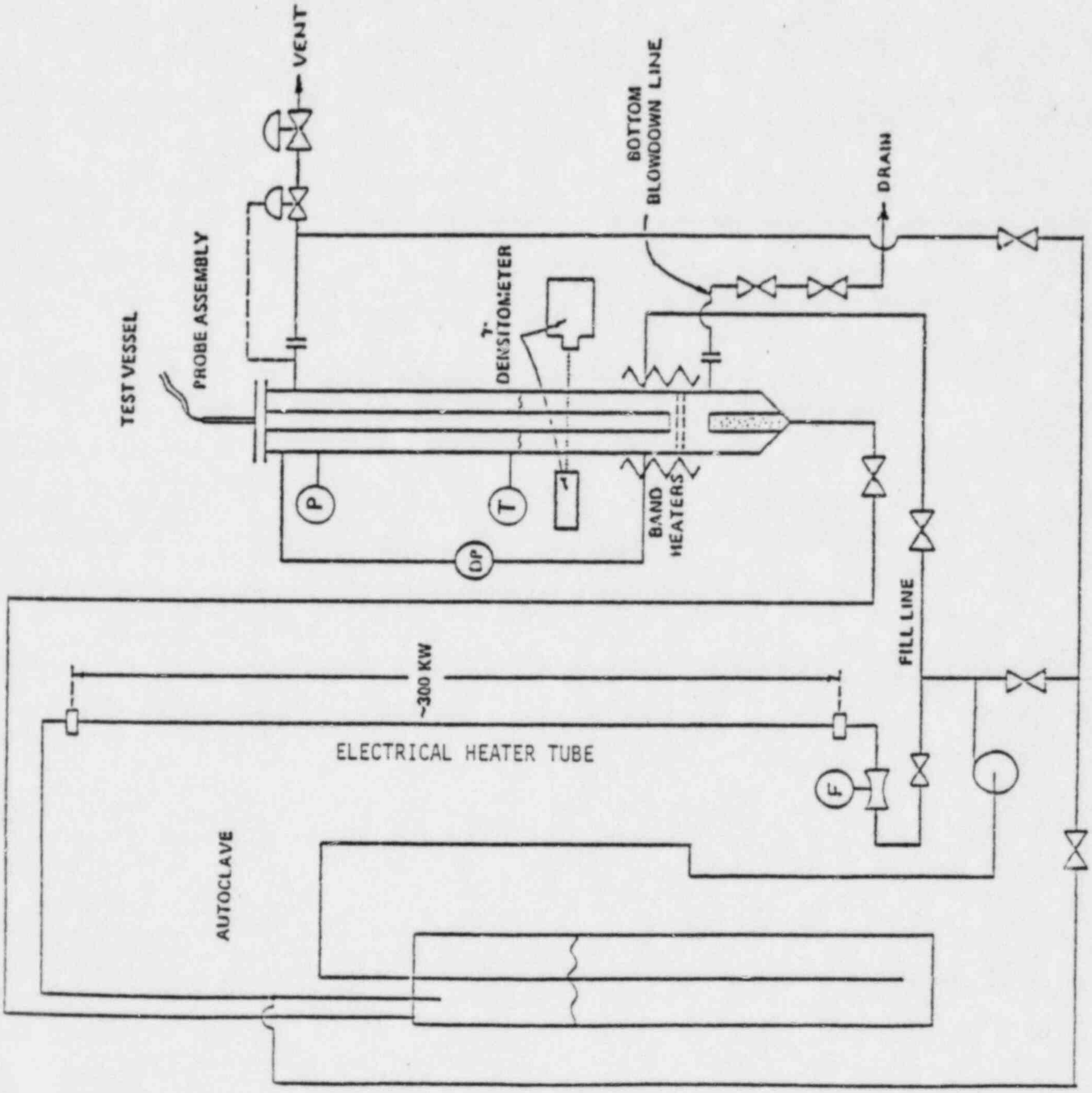


Figure 4-3

Phase II Test Facility



5.0 TEST DESCRIPTION

The HJTC probe assembly was tested under thermal-hydraulic conditions which might surround the probe during an accident in a PWR. Single phase, two-phase, and blowdown tests were performed. The pressure ranged from 0 to 1450 psig. Fluid void fractions varied from 0 to 0.52. Several different depressurization rates, from 0 to 10 psi/sec, were obtained during the blowdown tests. A list of the tests performed is given in Table 5-1.

5.1 SINGLE PHASE TESTS

Steady state and transient water level tests were performed under single phase conditions. First, the HJTC sensor output as a function of the water level was determined. The purpose of this was to demonstrate the on/off, uncovered/covered characteristic of the HJTC sensor response. The water level was varied in small increments from above the below the heated junction elevation and the equilibrium sensor output was recorded.

The second steady state test was performed to determine the covered and uncovered sensor output as a function of sensor heater power at several pressures. The purpose of this test was to obtain data for use in the heater power controller design and to show that the difference between covered and uncovered sensor outputs was greater at higher heater power. The effect of pressure on sensor output was also shown. Relatively low heater powers (less than 17 watts) were used, however, to protect against excessively high heated junction temperatures. Data at higher heater powers will be obtained in the Phase III test series.

The transient water level tests were performed to provide information on the response time of the HJTC probe assembly. The single phase transient tests also provide a comparison for judging the performance of the probe assembly during the two-phase tests, since single phase water (collapsed water level) should exist inside the separator tube in both cases.

5.2 TWO-PHASE TESTS

Two-phase, steam-water mixture tests were performed to simulate conditions which might surround the HJTC probe assembly during an inventory loss transient. The purpose of these tests was to determine the ability of the probe to create and measure the collapsed water level when immersed in a two-phase mixture. Also, data on the probe time response under two-phase conditions was obtained. Void fractions in the range of what might be expected during a small break LOCA were used. Both quasi-steady state and transient tests were performed. In the transient tests the fluid level was raised and lowered at rates similar to what occurs during small break LOCAs.

The performance of the probe assembly during two-phase conditions was compared to the single phase performance. In the single phase tests, the presence of the collapsed water level inside the separator tube was assured since there were no steam bubbles. Verification of the presence of the collapsed water level inside the separator tube during two-phase conditions would be accomplished if the probe response, after accounting for the effects of injecting steam into the test vessel at high flow velocity (described in Section 7.2), were the same as for the single phase tests. This was done in Section 7.2.

5.3 BLOWDOWN TESTS

Blowdown tests were conducted to determine the probe performance during a depressurization at rates which might be expected during a small break LOCA. The purpose was to determine the effect on the sensor response of flashing inside the separator tube while the pressure decreased. The initial pressure was greater than the saturation pressure of the test vessel fluid. The rate of depressurization was controlled by the amount that the blowdown valve was opened. It was expected that, due to flashing inside the separator tube, the HJTC sensors would respond more closely to the top of the two-phase mixture than the collapsed level, but once the pressure decrease stopped the collapsed water level would again be formed inside the separator.

Table 5-1

List of Tests Performed

Type of Test	Vessel Pressure (psig)	Sensor Heater Power (watts)	Void Fraction	Drain/Refill Rate (in/sec)
A. SINGLE PHASE				
Steady State				
Temperature Profile*	0	2.6	0	0
	800	10.0	0	0
	1450	12.1	0	0
Sensor Output vs.* Heater Power	0	2.5-17	0	0
	1200	2.5-17	0	0
	1450	2.5-17	0	0
Transient Water Level				
Drain	300	5.0	0	2,4,6
	*1450	11.5	0	0.6
Refill	300	5.0	0	0.5,1.0,1.8
	*1450	10.0	0	0.5

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*These tests were performed with a different separator tube hole area and configuration. This had a negligible effect on the results for single phase tests.

Table 5 (Continued)

Type of Test	Vessel Pressure (psig)	Sensor Heater Power (watts)	Void Fraction	Drain/Refill Rate (in/sec)
B. TWO-PHASE				
Quasi-Steady State	90	4.9	0.05,0.15,0.25,0.40	0
	1300	8.1	0.28,0.33,0.36,0.50	0
	1450	8.1	0.20,0.27,0.37,0.44,0.52	0
Transient Water Level				
Drain	300	4.9	0.40	0.50,1.2,1.8,2.9
	1350	8.1	0.35	1.0,1.2,2.6
	1450	8.1	0.27	1.6
Refill	300	4.9	0.40	0.60,1.0
	1350	8.1	0.35	0.40,0.50
	1450	8.1	0.27	0.22
C. BLOWDOWN				
	1800	8.1	-	0.57 (**0)
	1800	8.1	-	1.1 (**2)
	1875	8.1	-	2.0 (**6)
	1875	8.1	-	3.0 (**10)

**Depressurization rate, psi/sec

6.0 TEST PROCEDURE

6.1 SYSTEM HEAT-UP PROCEDURE

The test system was first filled with demineralized water from a degasifier tank. The autoclave was filled to no more than 60% of full volume. Water was circulated between the autoclave and the test vessel as it was heated up by means of the autoclave heaters. The autoclave temperature was set about 10^{o}F above the desired test vessel saturation temperature to allow for heat losses. When the desired test vessel temperature and pressure were reached, the autoclave temperature was stabilized and the test vessel band heaters were set to maintain its temperature. The test vessel was then isolated from the autoclave. Testing could then begin.

6.2 SINGLE PHASE TESTS

Steady state and transient tests were performed with single phase water. To lower the water level, a valve in the drain pipe at the bottom of the test vessel was opened. The rate at which the water level fell was controlled by the amount the valve was opened. To refill and increase the water level in the test vessel, water from the autoclave was pumped through an opened fill line valve. To prevent flashing when the water level dropped, a nitrogen overpressure bottle was connected to the top of the vessel in an attempt to maintain a constant pressure. This was successful for low drain rates, but for faster drain rates the pressure did drop slightly so some flashing may have occurred. Steady state tests were done by changing the water level a certain amount and letting the sensor output reach equilibrium.

6.3 TWO-PHASE TESTS

To perform the two-phase tests, water from the autoclave was pumped through the heater tube and electrical current was applied to the tube. The steam-water mixture produced by the electrical heating of the tube was directed back to the autoclave. The steam line that tapped into the steam space of the autoclave was then opened. This line injected the steam at the autoclave pressure, which was greater than the test vessel pressure, into the bottom of the test vessel. A control valve at the top of the vessel provided a steam vent which maintained vessel pressure. To adjust the steam flow for a higher void fraction, the heater tube power was increased and the steam line valve opened accordingly to maintain autoclave pressure. The water level in the test vessel was changed in the same way as in the single phase tests described above.

6.4 BLOWDOWN TESTS

The blowdown tests were performed by starting with the test vessel completely filled with water and isolated from the rest of the facility. The initial pressure (about 1800 - 1900 psig) was greater than the saturation pressure. The depressurization transient began when the bottom blowdown drain valve was opened. The amount the valve was opened determined the depressurization rate.

7.0 TEST RESULTS

7.1 SINGLE PHASE TESTS

Steady state and transient water level tests were conducted under single phase conditions. These tests provided information on sensor output versus heater power and pressure, sensor time response, and drainage time delay of the separator tube.

7.1.1 Steady State Tests

The output of the HJTC sensors was recorded as a function of water level. Figure 7-1 shows the output for the middle sensor for three different pressures, atmospheric, 800, and 1450 psig. The water level, as measured by the DP cell, is shown relative to the heated junction location. The output changes dramatically over a length of about one inch, which corresponds to the sensor heater coil length. This indicates the change in cooling ability of the fluid surrounding the sensor as the water/steam interface passes the heated junction elevation. The sensor is said to "switch" when its output begins to rapidly increase or decrease. Figure 7-1 shows this typical off/on, covered/uncovered characteristic of the HJTC sensor response

Figure 7-2 shows the HJTC sensor output versus heater power for several pressures. As expected, the output increases with increasing heater power. The increase in output for a covered sensor is much smaller than for an uncovered sensor. As can be seen, there is a large difference between covered and uncovered sensor outputs, which is greater at higher heater powers. This difference makes the HJTC sensor useful as a level measurement device.

The effect of pressure on sensor ΔT is also shown in Figure 7-2. For equal heater powers but a higher pressure, the uncovered sensor output is lower. This is due to the higher heat transfer coefficient for steam at higher pressures. This provides better cooling of the heated junction thermocouple. The effect of pressure on a covered sensor is small. Differences between the top and middle sensor output are, as explained in Section 4.1, due to thermocouple temperature measurement errors.

7.1.2 Transient Water Level Tests

Transient tests were conducted by draining or refilling the test vessel at different rates. These tests provide information on the time delay of the probe assembly. The total time delay is defined here as the period of time starting when the water level in the test vessel (outside of the separator tube) passes the heated junction thermocouple elevation to the time when the sensor output increases (for an uncovery transient) to a predetermined ΔT threshold value. For a PWR application, an uncovered signal is generated when the sensor output increases above this threshold value. The time delay is made up of several components. First, water must drain from the separator tube and splash shield in order to uncover the heated junction. Second is the time required to evaporate a water film which remains on the sensor sheath in the heater coil region. After this occurs, the sensor output begins to rise. The third component is the time it takes for the temperature to increase to the ΔT threshold once the output begins to rise.

Figure 7-3 shows the results of single phase transient drain and refill tests done at 300 psig. Figure 7-4 shows single phase transient results at higher pressure, 1450 psig. The differential temperature output for the top, middle, and bottom sensors is shown on the left. The vessel water level, as measured by the DP cell, is in the middle. A reading of 0 inches means the vessel is completely filled with water; 140 inches is completely empty. Pressure and temperature of the vessel fluid are recorded next. The gamma densitometer indicates when the water level in the test vessel passes the elevation of the heated junction of the middle sensor (also void fraction for two-phase tests). Time increases up the page.

For the drain tests (Figure 7-3, a-c), there is a short delay between the passage of the water level (as shown for the middle sensor by the change in the gamma densitometer output) and the time when the sensor output begins to increase. This delay is a result of the water drainage and evaporation of the water film remaining on the sensor sheath. This delay varies from [ ] depending on the drain rate. Once the sensor output starts to increase, Figure 7-3 shows that it requires about [ ] (see note on Table 7-1) for the ΔT to reach 150°F. Thus, the total time delay for the conditions in this test is less than [ ]

The first two components of the time delay, water drainage and evaporation of the water film, depend on the drain rate, pressure, and heater power. The delay is slightly longer for faster drain rates as shown in Figure 7-5. When the level outside the separator passes the middle sensor elevation for a fast drain transient, there is a greater volume of water remaining in the splash shield and separator that needs to drain than for a slow drain transient. Thus, the delay time is longer since it takes longer to drain this water. Higher heater power and pressure decrease this time delay by reducing the time required to evaporate the liquid film remaining on the sensor sheath. As shown by these tests, this time delay before the sensor output begins to increase is [ ]

[ ] The time to reach the ΔT value depends on the pressure, heater power, and threshold value. This time, starting when the sensor output begins to rapidly increase to the time when a ΔT of $150^{\circ}F$ is reached, is given in Table 7-1 for both single and two-phase drain tests. (The sensor thermal heatup time is independent of whether single phase or two-phase fluid is outside the separator.) The value of $150^{\circ}F$ has been arbitrarily selected for these tests solely to provide a comparison of the parameters which affect the time delay. Higher pressure results in a longer thermal heatup delay due to the better heat transfer coefficient to the surrounding steam. Higher heater power decreases the delay time since more heat is available to increase the heated junction temperature much faster. A higher ΔT threshold obviously results in a longer delay since the heated junction temperature must increase to a higher value.

The time response of the probe assembly for refill transients is much faster than for drain transients. When the water level rises above the heated junction, the immediate large increase in heat transfer coefficient causes the thermocouple temperature to fall very quickly. The time delay for refill depends on the refill rate, heater power, pressure, and ΔT threshold. The refill rate affects the level rise rate inside the splash shield and separator as described earlier for the drain transients. The heater power, pressure, and ΔT threshold value affect the refill time delay only in that they determine how far the sensor output must fall before the threshold is reached and a covered indication is provided. The rate at which the heated junction temperature falls is almost independent of these parameters. For the refill transients conducted in these tests, the total sensor time delay is less than [ ]

7.2 TWO-PHASE TESTS

Quasi-steady and transient water level tests were conducted under two-phase conditions. In the quasi-steady state tests, very slow vessel drain and refill rates were used to approach steady state conditions. These tests provided information on sensor output, sensor time response, and the ability of the separator tube to create a collapsed water level when surrounded by a steam-water mixture at high pressure.

The same parameters were measured and presented in the two-phase tests as in the single phase transient tests. The response of the middle sensor was tested as the collapsed water level was varied from above and below the elevation of the middle sensor. Thus, the top sensor remained uncovered and the bottom sensor remained covered. In the quasi-steady state tests, since the water level was changed at very slow rates, the DP cell reading, (which indicates the collapsed water level in the test vessel) also changed slowly and by a relatively small amount. The output of the gamma densitometer provided a measure of the fluid void fraction in the annulus between the probe assembly and the test vessel wall. It also showed when the top of the two-phase mixture passed the elevation of the middle sensor.

7.2.1 Quasi-Steady State Tests

These tests were conducted at pressures of 90, 1300, and 1450 psig. Void fractions of 0.05 to 0.52 were obtained by injecting steam at different flow rates. Figures 7-6 to 7-8 show the results of these tests and demonstrate that a collapsed water level is produced inside the separator. For the drain tests in Figures 7-6a, c, and e the DP cell reading increases slowly, indicating that water is being drained from the test vessel and that the equivalent collapsed water level outside the separator tube is falling. The sensor output increases rapidly when the water level inside the separator tube falls below the middle sensor. The densitometer shows that when the sensor becomes uncovered, the top of the two-phase mixture in the test vessel is above the middle sensor elevation. By comparing the DP cell reading when this occurs to the DP cell reading for the single phase tests (at the same pressure) it can be determined that the collapsed water level exists inside the separator. This is shown in Table 7-2. The two readings, for single phase and two-phase conditions, agree very well. This demonstrates that the collapsed water level of a two-phase mixture is created inside the separator tube and that the HJTC sensor measures that level.

Refill transients are shown in Figures 7-6b, d, f, and g. Here the DP cell reading is decreasing, indicating that water is being added to the test vessel. The densitometer shows (by a large change in output) that the top of the two-phase mixture in the test vessel rises above the middle sensor elevation before the sensor output decreases. This is as expected since the collapsed water level inside the separator tube is below the top of the two-phase mixture. When the collapsed water level inside the separator increases above the middle sensor the heated junction thermocouple is quenched and the output falls. The DP cell reading when the output begins to fall for these refill transients is also compared to the single phase tests in Table 7-2. Good agreement during refill is also obtained further demonstrating that the collapsed water level is created inside the separator tube.

A second method to confirm that the collapsed water level is created inside the separator tube is by calculating the void fraction, based on the level inside the separator, and comparing it to the value measured by the gamma densitometer. The void fraction is calculated by recording the DP cell reading when the top of the two-phase mixture level passes the densitometer. Thus, the height of the mixture region when the sensor switches can be determined. Knowing the mixture height and the DP cell reading when the sensor switches, a mean void fraction can be calculated. If a poor agreement between the calculated and measured void fractions were obtained, it would indicate that the water level inside the separator tube was not the true collapsed water level. Table 7-2 shows the comparison. Good agreement is obtained between the calculated and measured void fraction. Therefore, the separator tube does perform its function of creating a collapsed water level which can be measured by a HJTC sensor.

Examination of Table 7-2 shows an apparently increasing DP cell reading (decreasing water level outside the separator tube) at which the sensor switches as the void fraction increases. This is due to a combination of several effects; longer water drainage delay time for two-phase conditions than for single phase conditions, steam flow momentum effect on the upper DP cell tap, and the dynamic pressure contribution of the high velocity injected steam. The effect of two-phase conditions on the drainage rate is explained in Section 7.2.2. The longer delay for two-phase conditions results in slightly greater DP cell reading, i.e., lower collapsed water level outside the separator tube, when the sensor switches then for the single phase tests. The steam momentum effect is produced because of the upper DP cell tap hole is in top of the vessel head, opening downward. Thus, steam flowing upward impacts directly on the tap hole resulting in a small decrease in the collapsed water level indicated by the DP cell. These two effects, however, are small. The third effect is due to the dynamic pressure contribution of the high flow velocity of steam that is injected from the autoclave at high pressure (2000 psig). This increases the total pressure at the bottom separator tube. The dynamic pressure does not effect the DP cell as much because it has much smaller tap holes. Each of these three effects increases with higher steam flow rates (higher void fraction).

For the maximum steam flow rate, these effects cause the collapsed water level inside the separator to be higher than the collapsed water level indicated by the DP cell by about[ ] Thus, the DP cell reading when the middle sensor switches is greater by this amount than for the corresponding single phase tests due to the high velocity steam injection flow rate. Accounting for this difference yields the conclusion that the probe response is the same for two-phase conditions as for single phase conditions and that the collapsed water level is created inside the separator tube.

For some refill transients, Figures 7-7d and 7-8e, erratic covered/uncovered sensor response is shown. This occurs because the collapsed water level was held at the same elevation as the heated junction for a short period of time. Small oscillations in the separator tube water level, resulting from dynamic pressure variations in the turbulent steam/water mixture, causes the sensor output to be somewhat erratic for a short time.

7.2.2 Transient Two-Phase Level Tests

Transient two-phase level tests were conducted for drain rates varying from 0.50 to 2.9 in/sec. Refill rates varied from 0.60 to 1.0 in/sec. Pressures of 300, 1350, and 1450 psig were used and void fractions of 0.35 to 0.50 were obtained. The test results are shown in Figure 7-9 to 7-11. These figures show the same characteristics as the quasi-steady state tests. The collapsed water level inside the separator tube, to which the HJTC sensor responds, is below the elevation of the top of the two-phase mixture indicated by the densitometer. The DP cell reading at the middle sensor elevation is 83, 91, and 91.5 for the pressures 300, 1350 and 1450 psig, respectively. The DP cell reading at 300 psig is different here than in the single phase tests because of the much higher water temperature in these tests.

At the low drain and refill rates, results very similar to the quasi-steady state tests are obtained. At higher drain rates, the time delay, from the time when the collapsed level in the test vessel passes the middle sensor elevation (DP cell measurement) to the time when the sensor switches, increases. This is the same result as obtained for the single phase tests (see Figure 7-5). However, under two-phase conditions, this time delay is slightly longer than for single phase conditions (see Figure 7-12). This is due to the steam momentum effect on the DP cell, the dynamic pressure of the injected steam, and to the counter flow of steam bubbles and water draining from the separator tube through the support tube slots. The first two effects are described previously in Section 7.2.1. The third is a result of the turbulent conditions in the test vessel when steam is injected. Steam bubbles can pass through the support tube slots into the support-separator tube annulus. This flow is in the opposite direction of the water draining from the separator tube and thus slows the drainage rate by a small amount. The sensor becomes uncovered at a slightly later time since the water level inside the separator lags the water level outside the tube by a larger amount. Longer support tube slots would decrease this effect of countercurrent flow. However, as can be seen in Figure 7-12, this water drainage and evaporation time delay is still a small part of the total delay time. The higher heater power results in a shorter time delay. It causes the water film to be evaporated faster. Also, since the heated junction temperature increases faster, the sensor output reaches the ΔT threshold value earlier.

In Figure 7-10c, the effect of increasing pressure (repressurization) on an uncovered sensor output is shown for the top sensor. The top sensor was uncovered at 1300 psig with a sensor heater power of 8.1 watts. As a result of water being added to the test vessel, the pressure increases from 1300 to 1800 psig in about 8 seconds (60 psi/sec). The output of the top sensor decreases by about [ ] for a short period of time as a result of the pressure increase.

Two effects cause the decrease in the heated junction temperature (sensor output). First, the heat transfer coefficient for steam increases as the pressure increases. This provides more cooling of the heated junction, thereby reducing its temperature. Second is the effect of condensation. Liquid droplets condense on the sensor sheath inside the splash shield and also cool the heated junction thermocouple. However, these droplets are quickly evaporated by the sensor heater so the heated junction temperature, and sensor output, increases shortly after the initial fall [ ] The time it takes to evaporate the condensed liquid droplets is a function of the heater power and the pressure. The sensor output rises until it reaches a value (slightly less than the starting value) dictated by the heat transfer coefficient at the higher pressure, or until it is covered by water.

It should be noted that the decrease in sensor output resulting from repressurization is different from the drop caused by covering the sensor with water. For repressurization the output drops at a much slower rate [ ] than if it were quenched by water covering the heated junction [ ] This is one way, in addition to the DP cell indication, that the effect of condensation can be differentiated in these tests from a sensor becoming covered with water.

7.3 BLOWDOWN TESTS

Blowdown tests were conducted to test the HJTC probe assembly performance for depressurization rates expected during a small break LOCA. Depressurization rates varied from 0 to 10 psi/sec. The results are shown in Figures 7-13 to 7-15. Also, the effect of increasing pressure on sensor output is shown at the end of the blowdowns as the vessel is refilled.

In Figure 7-13 the blowdown valve was opened only a small amount. After the initial drop, the pressure remains constant (similar to the pressure plateau during a small break LOCA) due to the heat addition from the test vessel metal components and walls. The water level in the vessel decreases at a rate of 0.6 in/sec. The results show that the HJTC sensors switch in sequence. The middle sensor switches at the same DP cell reading (91 inches) as in the single and two-phase tests for the same pressure. This indicates that the collapsed water level exists in the separator tube and the sensors measure that level during this blowdown transient.

In Figure 7-14 the blowdown valve opening was slightly greater. The depressurization rate is about 2 psi/sec and the drain rate is about 1 in/sec. In this test the middle sensor switches at the same time that the gamma densitometer shows the two-phase mixture level passing the middle sensor elevation. This would tend to indicate that a two-phase mixture exists inside the separator tube due to flashing while the pressure decreases. However, it should be recalled that there is a delay time of about [ ] from when the true collapsed water level outside the separator tube passes the sensor elevation and when the sensor output begins to increase. At [ ] before the middle sensor output begins to increase, the DP cell indication of water level is 91 inches; the same value as for the single phase tests. Thus, for this depressurization transient, the fluid level inside the separator tube is more closely related to the collapsed water level than to the top of the two-phase mixture and the sensor responds to that level.

Tests with large blowdown valve openings are shown in Figure 7-15. Depressurization rates of 6 and 10 psi/sec with drain rates of 2 and 3.4 in/sec, respectively were achieved. For depressurization rates of this magnitude, a significant amount of flashing occurs inside the separator tube; more than in the previous test at a lower depressurization rate. Figure 7-15 shows that the middle sensor output increases slightly after the gamma densitometer indicates the top of the two-phase mixture passes the middle sensor elevation (by a large change in output). After accounting for the sensor delay time, it must be concluded that a two-phase fluid exists inside the separator tube for these depressurization rates and that the HJTC sensor responds to the passing of the two-phase mixture level.

These blowdown tests show that during a depressurization transient some flashing of water to steam does occur inside the separator tube. However, for depressurization rates of 2 psi/sec and less, the amount of steam bubbles produced is small and the fluid level inside the separator tube, which the HJTC sensors measure, is very close to the collapsed water level. For higher depressurization rates (6 to 10 psi/sec), the greater degree of flashing causes the fluid level inside the separator tube to be more closely related to the two-phase mixture level outside the separator. It should be noted that once the pressure decrease ends, flashing stops, and the collapsed water level is formed inside the separator. The time it takes to form the collapsed water level after the depressurization ends is related to the bubble rise velocity.

The effect of increasing pressure on an uncovered sensor output is also shown at the end of each blowdown test (Figures 7-13 to 7-15). This effect has been discussed previously in Section 7.2.2. At the end of the blowdown tests, the valve is closed and the test vessel is refilled with hot water from the autoclave. This causes the pressure to increase to near the initial test vessel pressure. The sensor output drops as described earlier. In Figures 7-13 and 7-14 the output drops by about [ ] or less, indicating that very little condensation inside the splash shield occurs. In Figure 7-15a, where the magnitude of the pressure increase is the greatest (900 psia), the top sensor output drops by about [ ] As can be seen, the output begins to increase again [ ] after the initial decrease. This time depends on the sensor heater power. The sensor is covered by water, however, before the sensor output can increase to a value more typical of a steam environment.

Table 7-1

Sensor Heat-Up Time Delay For 150°F Setpoint

Table 7-2

Comparison of Water Level When Middle Sensor Switches For Single and Two-Phase Tests

Figure 7-1

HJTC Sensor Output vs. Water Level

Figure 7-2

HJTC Sensor Output as a Function of Heater Power and Pressure

Figure 7-3 a) SINGLE PHASE TRANSIENT, 300 psig, DRAIN

SENSOR HEATER POWER = 5.0 WATTS

Figure 7-3 b) SINGLE PHASE TRANSIENT, 300 psig, DRAIN

Figure 7-3 c) SINGLE PHASE TRANSIENT, 300 psig, DRAIN

SENSOR HEATER POWER = 5.0 WATTS

Figure 7-3 d) SINGLE PHASE TRANSIENT, 300 psig, REFILL

Figure 7-3 e) SINGLE PHASE TRANSIENT, 300 psig, REFILL

SENSOR HEATER POWER = 5.0 WATTS

Figure 7-3 f) SINGLE PHASE TRANSIENT, 300 psig, REFILL

SENSOR HEATER POWER = 11.5 WATTS

Figure 7-4 a) SINGLE PHASE TRANSIENT, 1450 psig, DRAIN

SENSOR HEATER POWER = 11.5 WATTS

Figure 7-4 b) SINGLE PHASE TRANSIENT, 1450 psig, REFILL

FIGURE 7 - 5

HJTC PROBE TIME DELAY (SINGLE PHASE)

vs. DRAIN RATE

SENSOR HEATER POWER = 4.9 WATTS

Figure 7-6 a) TWO-PHASE QUASI-STEADY STATE, 90psig, DRAIN

SENSOR HEATER POWER = 4.9 WATTS.

Figure 7-6 b) TWO-PHASE QUASI-STEADY STATE, 90 psig, REFILL

SENSOR HEATER POWER = 4.9 WATTS

Figure 7-6 c) TWO-PHASE QUASI-STEADY STATE, 90 psig, DRAIN

SENSOR HEATER POWER = 4.9 WATTS Figure 7-6 d) TWO-PHASE QUASI STEADY STATE, 90 psig, REFILL

SENSOR HEATER POWER = 4.9 WATTS

Figure 7-6 e) TWO-PHASE QUASI-STEADY STATE, 90 psig, DRAIN

SENSOR HEATER POWER = 4.9 WATTS

Figure 7-6 f) TWO-PHASE QUASI-STEADY STATE, 90 psig, REFILL

SENSOR HEATER POWER = 4.9 WATTS

Figure 7-6 g) TWO-PHASE QUASI-STEADY STATE, 90 psig, REFILL

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-7 a) TWO-PHASE QUASI-STEADY STATE, 1300 psig, REFILL

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-7 b) TWO-PHASE QUASI-STEADY STATE, 1300 psig, DRAIN

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-7 c) TWO-PHASE QUASI-STEADY STATE, 1300 psig, REFILL & DRAIN

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-7 d) TWO-PHASE QUASI-STEADY STATE, 1300 psig, REFILL

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-8 a) TWO-PHASE QUASI-STEADY STATE, 1450 psig, DRAIN & REFILL

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-8 b) TWO-PHASE QUASI-STEADY STATE, 1450 psig, REFILL & DRAIN

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-8 c) TWO-PHASE QUASI-STEADY STATE, 1450 psig, DRAIN

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-8 d) TWO-PHASE QUASI-STEADY STATE, 1450 psig, DRAIN

SENSOR HEATER POWER = 8.1 WATTS FIGURE 7-8) TWO-PHASE QUASI-STEADY STATE, 1450 psig, REFILL

SENSOR HEATER POWER = 8.1 WATTS FIGURE 7-8 f) TWO-PHASE QUASI-STEADY STATE, 1450 psig, DRAIN & REFILL

SENSOR HEATER POWER = 4.9 WATTS   Figure 7-9 a) TWO-PHASE TRANSIENT, 300 psig, DRAIN

SENSOR HEATER POWER = 4.9 WATTS

Figure 7-9 b) TWO-PHASE TRANSIENT, 300 psig, DRAIN

SENSOR HEATER POWER = 4.9 WATTS Figure 7-9 c) TWO-PHASE TRANSIENT, 300 psig, DRAIN

SENSOR HEATER POWER = 4.9 WATTS Figure 7-9 d) TWO-PHASE TRANSIENT, 300 psig, REFILL

SENSOR HEATER POWER = 4.9 WATTS Figure 7-9 e) TWO-PHASE TRANSIENT, 300 psig, REFILL

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-10 a) TWO-PHASE TRANSIENT, 1350 psig, REFILL & DRAIN

SENSOR HEATER POWER = 8.1 WATTS Figure 7-10 b) TWO-PHASE TRANSIENT, 1350 psig, DRAIN & REFILL

SENSOR HEATER POWER = 8.1 WATTS Figure 7-10 c) TWO-PHASE TRANSIENT, 1350 psig, DRAIN & REFILL

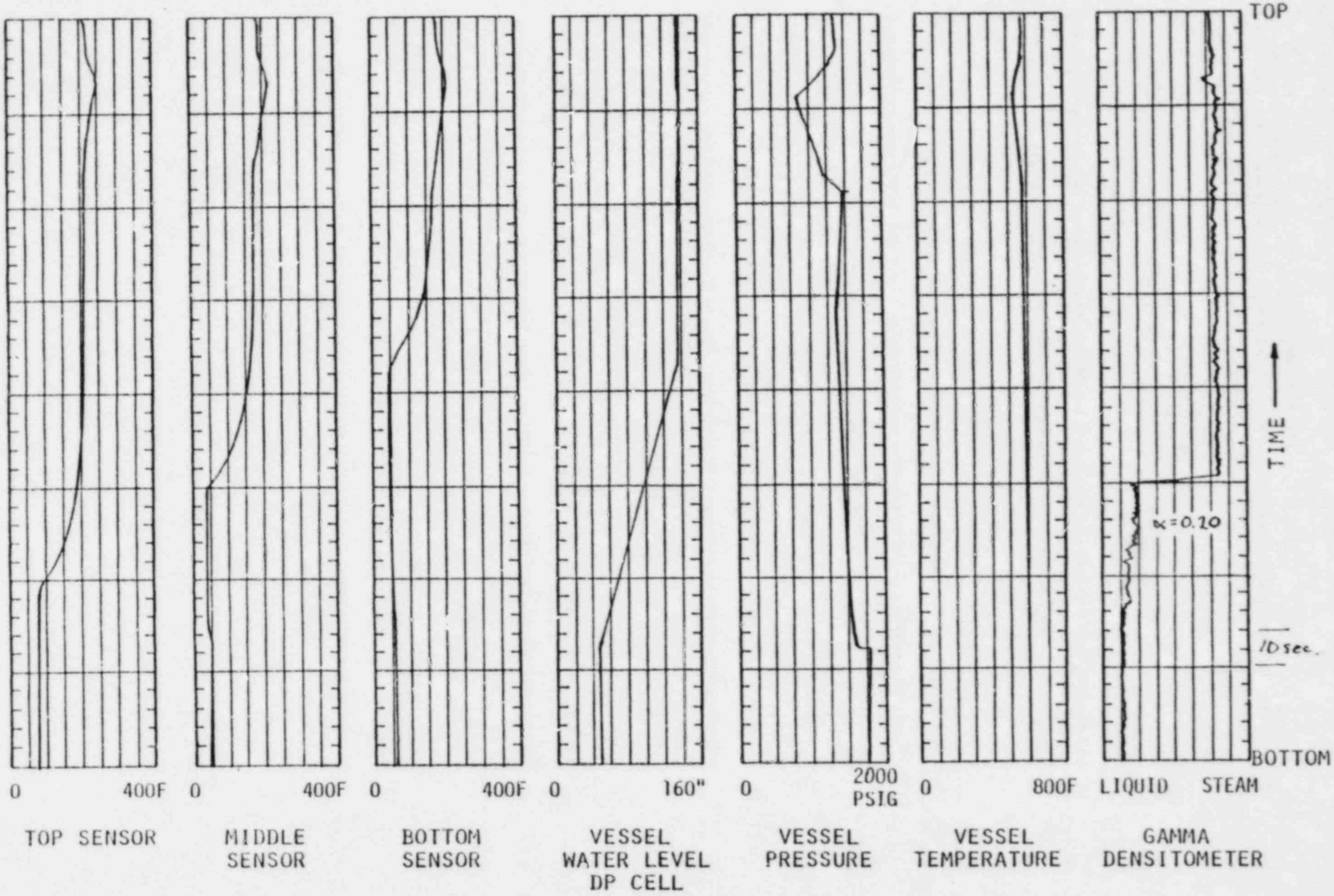
SENSOR HEATER POWER = 8.1 WATTS

Figure 7-11 a) TWO-PHASE TRANSIENT, 1450 psig, DRAIN

FIGURE 7-12

HJTC PROBE TIME DELAY (TWO-PHASE)
VS.
DRAIN RATE

SENSOR HEATER POWER = 8.1 WATTS Figure 7-13 BLOWDOWN, SMALL VALVE OPENING



SENSOR HEATER POWER = 8.1 WATTS

Figure 7-14 BLOWDOWN, MODERATE VALVE OPENING

Figure 7-15 a) BLOWDOWN, LARGE VALVE OPENING

SENSOR HEATER POWER = 8.1 WATTS

Figure 7-15 b) BLOWDOWN, LARGE VALVE OPENING

8.0 APPLICATION OF TEST RESULTS TO A PWR RVLMS INSTALLATION

The Phase II tests were conducted to verify the probe assembly design and its performance under conditions that the HJTC might be exposed to in a PWR. The previous sections present the test results. This section relates the test results to the conditions that the probe would be expected to function under in a PWR. The Phase II results are used to determine the expected performance in a PWR. It is concluded from Phase II that the C-E HJTC probe assembly can perform its function and provide reactor vessel water inventory indication to the operator during an accident.

8.1 INSTALLATION

The C-E HJTC/RVLMS is installed in a reactor vessel to measure the liquid inventory between the fuel alignment plate (FAP) and the top of the vessel head during a transient which might produce a void region in the upper head. The HJTC sensors are located inside a separator tube and measure the water level in it. The water level inside the separator is determined by a hydrostatic pressure balance that is established with the fluid outside the separator. This level, the collapsed water level, is a direct measure of the liquid mass inventory that exists between the top and bottom vent holes of the separator. Thus, during an accident when a two-phase mixture exists in the reactor vessel, inside the separator tube is a quiescent region of all liquid below a region of nearly dry steam. The HJTC sensors respond to the passing of this steam/water interface (collapsed water level). The fluid velocity inside the separator tube immediately surrounding the HJTC sensors is therefore very small, corresponding to the water drain rate or the steam bubble rise velocity. A high velocity fluid flow which might affect the sensor output, does not occur inside the separator tube.

When installed in a reactor vessel, the HJTC probe assembly is placed inside a larger support tube. This tube provides physical support against hydraulic loads and provides a guide path for insertion of the probe. The support tube also aids in preventing steam bubbles from entering the separator tube. [

] Thus, in order to get inside the separator tube, [ ]

[ ] These slots are typically longer [ ] than used in the Phase II tests, thereby providing a larger flow area and shorter drainage delay time.

8.2 TEST CONDITIONS

The Phase II tests are designed to test the performance of the HJTC probe assembly under thermal-hydraulic conditions which might surround the probe during an accident such as a small break LOCA. In a small break LOCA (0.1 ft^2) immediately after the break, the pressure falls relatively quickly (100 seconds) to the plateau pressure at 1200 to 1000 psia and remains constant for a period of time (see Figure 8-1). The pressure falls again, but at a slower rate, once the break is uncovered and steam flows out the break. Core uncovery begins at about 600 psia. The range of pressures tested in Phase II was from atmospheric to 1450 psig, with blowdown tests starting at 1800 psig. This encompasses the plateau pressure and below. It is in this pressure range where the measurement of the water inventory above the fuel alignment plate is most useful to the operator.

Typical mixture void fractions in the upper plenum for a small break LOCA range from 20 to 40 percent. The two-phase void fraction in the Phase II tests range from 0 to 52 percent. Therefore, the tests adequately simulate expected void fractions that the probe might encounter in a reactor vessel. The tests show that the separator tube does produce a collapsed water level when immersed in a two-phase mixture, and that the HJTC sensors respond to the passing of the steam-water interface inside the separator tube.

8.3 DEPRESSURIZATION AND LEVEL CHANGE RATES

The ability of the HJTC/RVLMS to respond to a change in water inventory is independent of any particular event. The HJTC probe provides an indication of water inventory for any event which results in an actual or apparent loss of inventory from the reactor vessel (loss of coolant or overcooling). The rates of change for parameters which affect the sensor response can be bounded by a small break LOCA transient.

C-E currently judges that the maximum size break for which the operator can be expected to utilize the information provided by the RVLMS is a 0.1 ft^2 break. This break proceeds slowly enough for the operator to observe the water level indication given by the RVLMS and assess its meaning. Thus, the HJTC/RVLMS is designed to provide information for small break LOCAs of 0.1 ft^2 and less. Larger breaks proceed too fast for the operator to take any action based on the RVLMS. The HJTC/RVLMS is not required to function accurately during the initial rapid blowdown depressurization period of a LOCA. It must, however, survive the blowdown for the largest mechanistic break size LOCA and provide an accurate indication during the reflood portion of the large break.

Typical depressurization and collapsed water level change rates for a 0.1 ft^2 break in the cold leg are given in Table 8-1. As can be seen, the expected depressurization and level change rates are adequately simulated by the Phase II tests. The transient can be divided into four time periods as shown in the pressure and collapsed water level Figures 8-1 and 8-2. The first period, blowdown, is characterized by rapid depressurization from normal operating pressure to the steam generator secondary side safety relief valve pressure and large water level decrease rates. During the second period, the pressure is relatively constant and the level drop rate small. The third period occurs after the break uncovers and steam flows out the break. The pressure falls off the plateau and water level drops at a slightly faster rate. The last period occurs after the minimum collapsed water level has been reached and the system begins to refill.

The HJTC/RVLMS is not required to measure the collapsed water level during the initial rapid blowdown period since it proceeds too fast for the operator to make use of the information. During the blowdown period, the depressurization rate is about 10 psi/sec. The Phase II tests show that for this depressurization rate, flashing inside the separator tube causes the HJTC sensor to respond to the passing of the two-phase mixture level. For a 0.1 ft^2 break, the blowdown period lasts for only a short period of time (about 100 seconds), after which the pressure plateau is reached. At this time the pressure remains relatively constant so no additional flashing occurs. Thus, the steam bubbles remaining inside the separator tube quickly rise and disengage from the fluid surface, thereby establishing a collapsed water level inside the separator which is measured by the sensors.

When the water level falls below the break elevation and a nearly all steam flow exits the break, the pressure begins to decrease again. The depressurization rate at this time is much lower, 1 psi/sec, than during the initial blowdown period. The Phase II results show that for this depressurization rate the fluid level inside the separator tube is very close to the collapsed water level. Since the pressure is falling, some flashing of water to steam does occur inside the separator, but the bubble production is very small. Thus, during this period of a small break LOCA (when the collapsed water level is between the bottom of the cold leg and the top of the core), the HJTC probe measures the collapsed water level.

During the refill period of the transient the collapsed water level rises as the water inventory in the reactor vessel increases. Since the pressure is relatively unchanging, a collapsed water level exists inside the separator tube during this time also, and the sensors measure that level.

Therefore it can be concluded, that the collapsed water level is measured during an accident such as a small break LOCA, except during the initial rapid depressurization (10 psi/sec) blowdown. This blowdown period, however, lasts for a relatively short time. Once the rapid depressurization ends, the collapsed water level is quickly formed and measured by the HJTC probe assembly.

8.4 TIME RESPONSE

The Phase II tests determined the time response behavior of the HJTC probe assembly. It was found that there was a time delay between when the collapsed water level outside the separator tube passes the sensor elevation and the time when the sensor output increases to a predetermined ΔT threshold value. When the threshold value is reached, an uncovered signal is given for that sensor. The largest factors affecting the time delay are the sensor heater power, pressure, and threshold value.

In Phase II relatively low heater powers, less than 11.5 watts, were used for the transient tests. In order to decrease the sensor time delay below that obtained in these tests, a higher sensor heater power of [ ] watts will be used for a PWR application. This significantly reduces the sensor delay time since the heated junction thermocouple temperature increases much faster for higher heater powers, thereby causing the ΔT threshold value to be reached more quickly. The sensor time delay is sufficiently fast so that the probe assembly response characteristics does not limit the ability of the operator to respond to the transient. Verification of the sensor heater power to be used for a PWR application will be done during the Phase III prototype tests program.

The pressure at which the HJTC sensors uncover (or recover) can vary greatly depending on the event that occurs. During a large break LOCA reflood, the system pressure can be about 30 psia. For a loss of heat sink event, water inventory can be lost from the primary coolant system at approximately 2500 psia (pressurizer safety relief valve setpoint). Phase II tests show that the sensor time response is shorter for lower pressures since the heated junction temperature rises faster. Thus, the more stringent condition concerning time response is at high pressure. The time response at high pressure and heater power will be verified during the Phase III tests.

The third major factor affecting time response is the differential temperature threshold value. For uncovery, when the sensor output increases to the threshold value, a signal is generated that indicates the sensor is surrounded by steam. In the Phase II tests a threshold of 150°F was used. This value was arbitrarily chosen to provide a comparison among the parameters which affect the time response. With higher sensor heater powers than used in Phase II the threshold can be increased above 150°F and still achieve a shorter time delay than observed in the Phase II tests. The final ΔT threshold value will be verified during the Phase III prototype tests.

8.5 REPRESSURIZATION EFFECTS

The effect of a rapid increase in pressure on an uncovered HJTC sensor output was observed during the Phase II tests. Sensor output drops slightly with increasing pressure due to a higher heat transfer coefficient to steam and condensation. Condensation decreases sensor output only temporarily since the condensed droplets are quickly evaporated, leaving the thermocouple sheath dry. The heated junction temperature then rises again to a value determined by the higher heat transfer coefficient at the higher pressure.

The rate of pressure increase in the Phase II tests was very high, 30 to 50 psi/sec. This is much greater than the approximately 1 psi/sec rate that would be expected to occur for a PWR. The higher pressure increase rate results in a larger effect on the sensor output then would be expected in a PWR. Also, at high heater powers typical of what may be used in a PWR, the effect of condensation on an uncovered sensor output is smaller. Therefore, for the pressure increase rates in a PWR, it is not expected that condensation due to repressurization would cause a misleading indication.

Table 8-1

Typical Depressurization and Collapsed Level Change Rates For a 0.1 Ft^2 LOCA

Time Period*	Depressurization Rate (psi/sec)		Collapsed Level Change Rate (in/sec)	
	PWR	Phase II Tests	PWR	Phase II Tests
Blowdown	10	2-10	3	1-3
Pressure Plateau	0	0	0.1	0.5-1.6
Break Uncovery	1.0	0-2	0.2	0.6-1.1
Refill	0	0	0.07	0.2-1.0

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*See Figures 8-1 and 8-2.

FIGURE 8-1

TYPICAL REACTOR VESSEL PRESSURE
FOR A 0.1 FT^2 SMALL BREAK LOCA

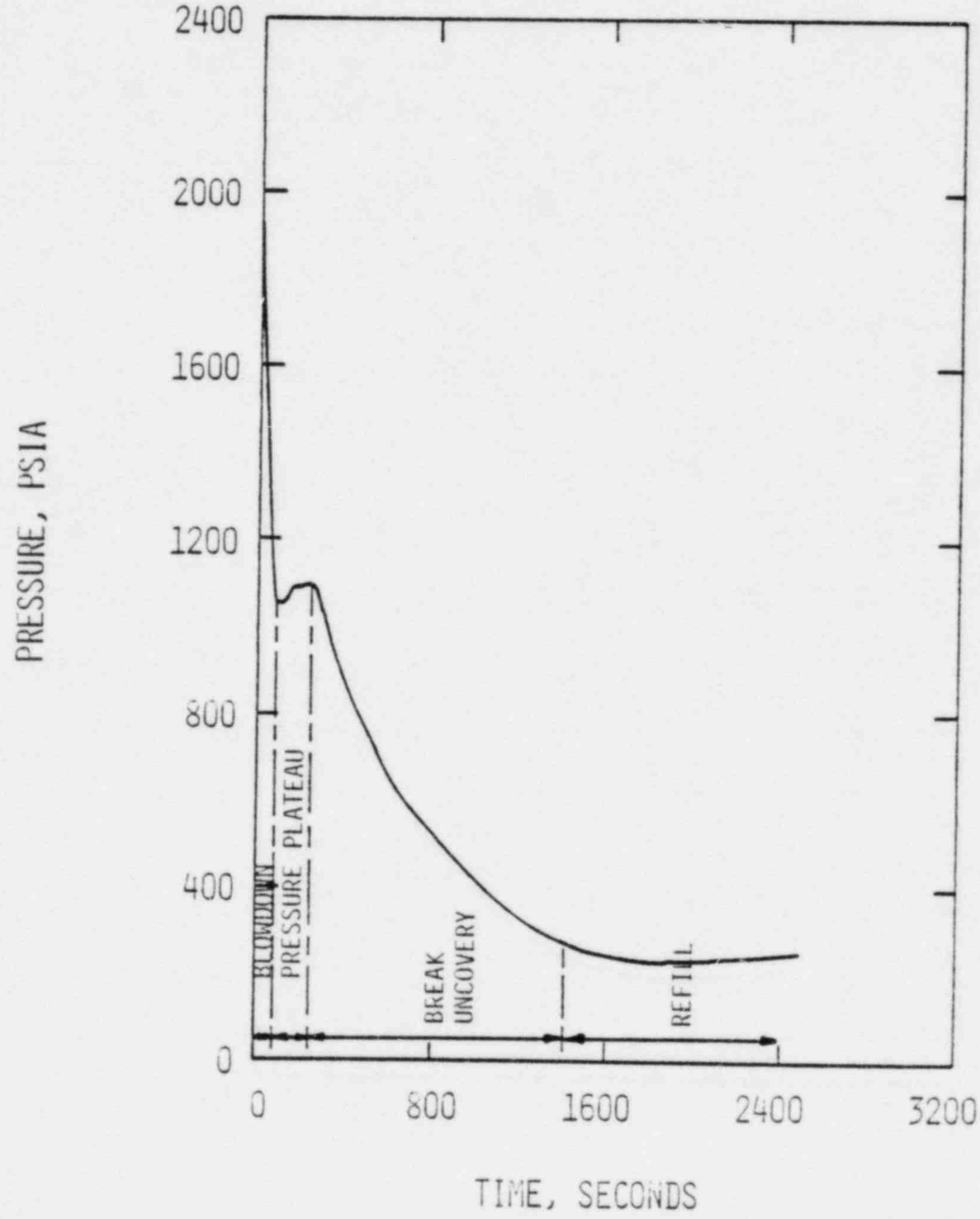
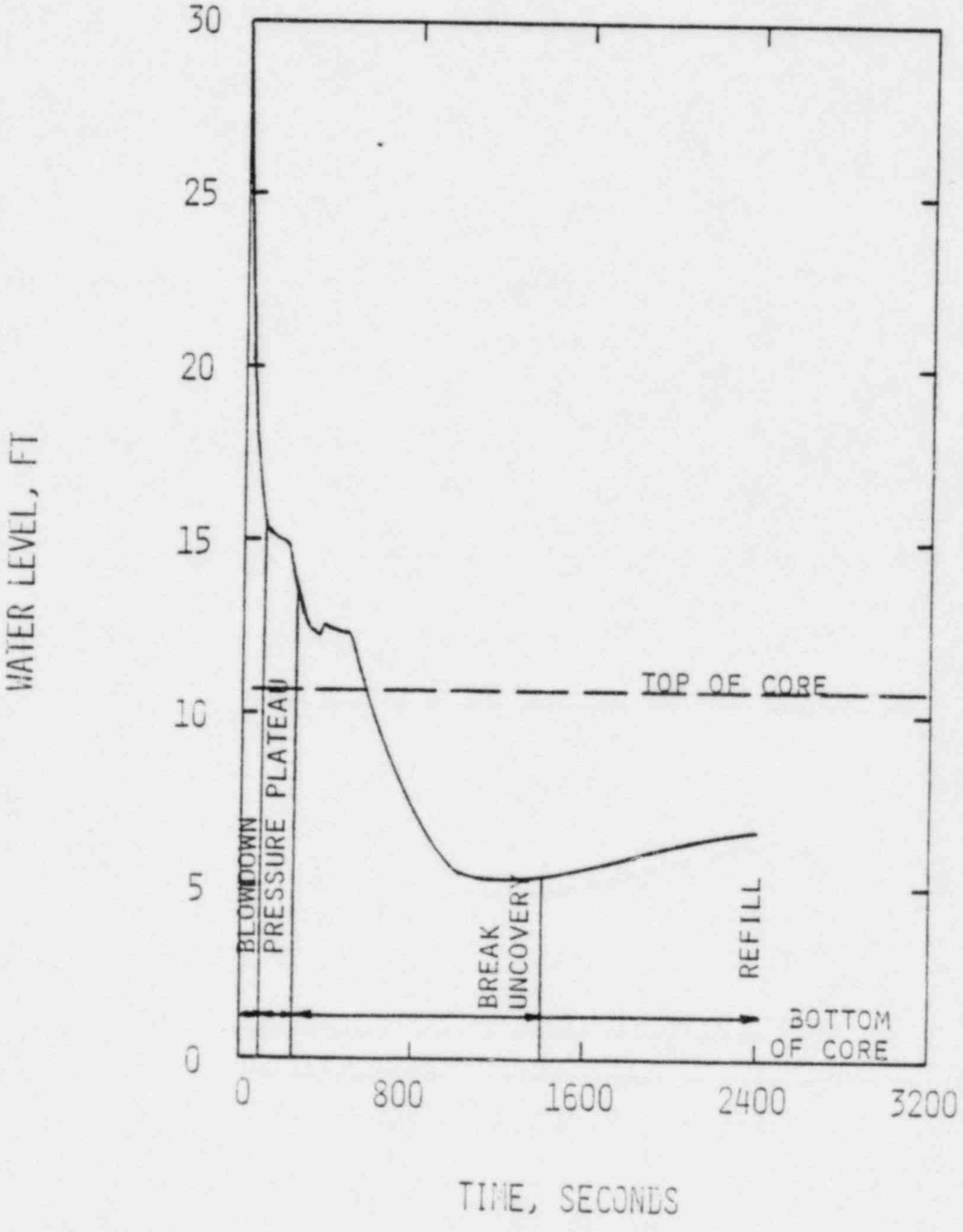


FIGURE 8-2

TYPICAL COLLAPSED WATER LEVEL IN REACTOR VESSEL FOR A 0.1 FT^2 SMALL BREAK LOCA



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