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GENERIC RESPONSES TO NRC QUESTIONS ON THE C-E INADEQUATE CORE COOLING INSTRUMENTATION

Prepared for the C-E OWNERS GROUP

NUCLEAR POWER SYSTEMS DIVISION
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C-E POWER SYSTEMS
COMBUSTION ENGINEERING, INC.

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GENERIC RESPONSES TO

NRC QUESTIONS ON THE

C-E INADEQUATE CORE COOLING

INSTRUMENTATION

Nuclear Power Systems
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TABLE OF CONTENTS

1.0 INTRODUCTION

This document contains generic responses to the questions 1 through 13 of Reference 1.0-1. These questions are concerned with those items of the inadequate core cooling instrumentation and test program which are common for all C-E Nuclear Steam Supply Systems (NSSS).

Requested information relating to the specific system to address ICC, including ICC signal transmission, processing and display hardware and display software will be provided on plant specific dockets.

REFERENCES FOR SECTION 1.0

1.0-1 Letter from D. M. Crutchfield (Chief Operating Reactors Branch No. 5, Division of Licensing, NRC) to K. Baskin (Chairman, C-E Owners Group), Subject: C-E Reactor Vessel Level Measurement System, July 31, 1981.

2.0 RESPONSES TO NRC REQUEST FOR ADDITIONAL INFORMATION ON THE C-E INADEQUATE CORE COOLING INSTRUMENTATION

This section responds to questions 1 through 13 of Reference 1.0-1. These questions are concerned with those items of the Inadequate Core Cooling Instrumentation (ICCI) and test program which are common to all C-E Nuclear Steam Supply Systems.

QUESTION 1

In the discussion of a suitable definition of Inadequate Core Cooling, the definition is constrained to fall within bounds of certain core conditions. Please discuss your approach to defining "inadequate core cooling". What are the limiting conditions for the applicability of the heated junction thermocouple level system?

RESPONSE

C-E's approach to defining the condition of Inadequate Core Cooling (ICC) is consistent with that given by the NRC staff. In a previous evaluation the staff has written:

> "The staff considers the core to be in a state of inadequate core cooling whenever the two phase froth level falls below the top of the core and the core heatup is well in excess of conditions that have been predicted for calculated small break scenarios for which some uncovery with successful recovery from the accident have been predicted. Possible indicators of such a condition are core exit superheat temperature and/or the rate of coolant loss or level drop prior to core uncovery and the extent and duration of uncovery."

The progression toward this "state of ICC" begins with a reduction in subcooling leading to the occurrence of saturation conditions in the primary system. It continues with a decrease in coolant inventory. If the inventory continues decreasing, the active fuel region could become uncovered and the fuel rods could heat up and superheat the steam exiting the core. Each of these three conditions will occur prior to the occurrence of ICC, but the functioning of the ICC instrumentation is independent of the sequence of the progression. The instrumentation is designed to monitor the conditions and to indicate the condition to the operator. The rate of the progression of each condition and the severity of the core heatup determine the requirements on the ICC instruments.

The limiting condition for applicability of the Heated Junction Thermocouple (HJTC) may be expressed by the maximum rate of decreasing level indication which it can provide. During the initial depressurization to the saturation pressure, following a small break, the level change can be very rapid. The level change and the HJTC indication will be more rapid than the operator can reasonably follow. After the initial depressurization, for a class of small breaks, the HJTC will provide an accurate indication of the decreasing level. For larger breaks, the event progresses too rapidly for operator action and automatic equipment alone is relied upon to provide the initial system response. The ICC instruments can be used to provide information during the refill portion of these events.

The HJTC is designed to follow decreasing level rates of 1 in/sec. For example, this is equivalent to the rate for a 0.1 ft^2 break with the primary pumps running and with one high pressure safety injection pump.

QUESTION 2

Identify the maximum size break for which the system will still allow the operator to take corrective action under ICC procedures. Please include a discussion of the response capabilities of the heated junction thermocouple instrumentation with respect to the system dynamics. These questions should be answered for a small break, such as 3 inch.

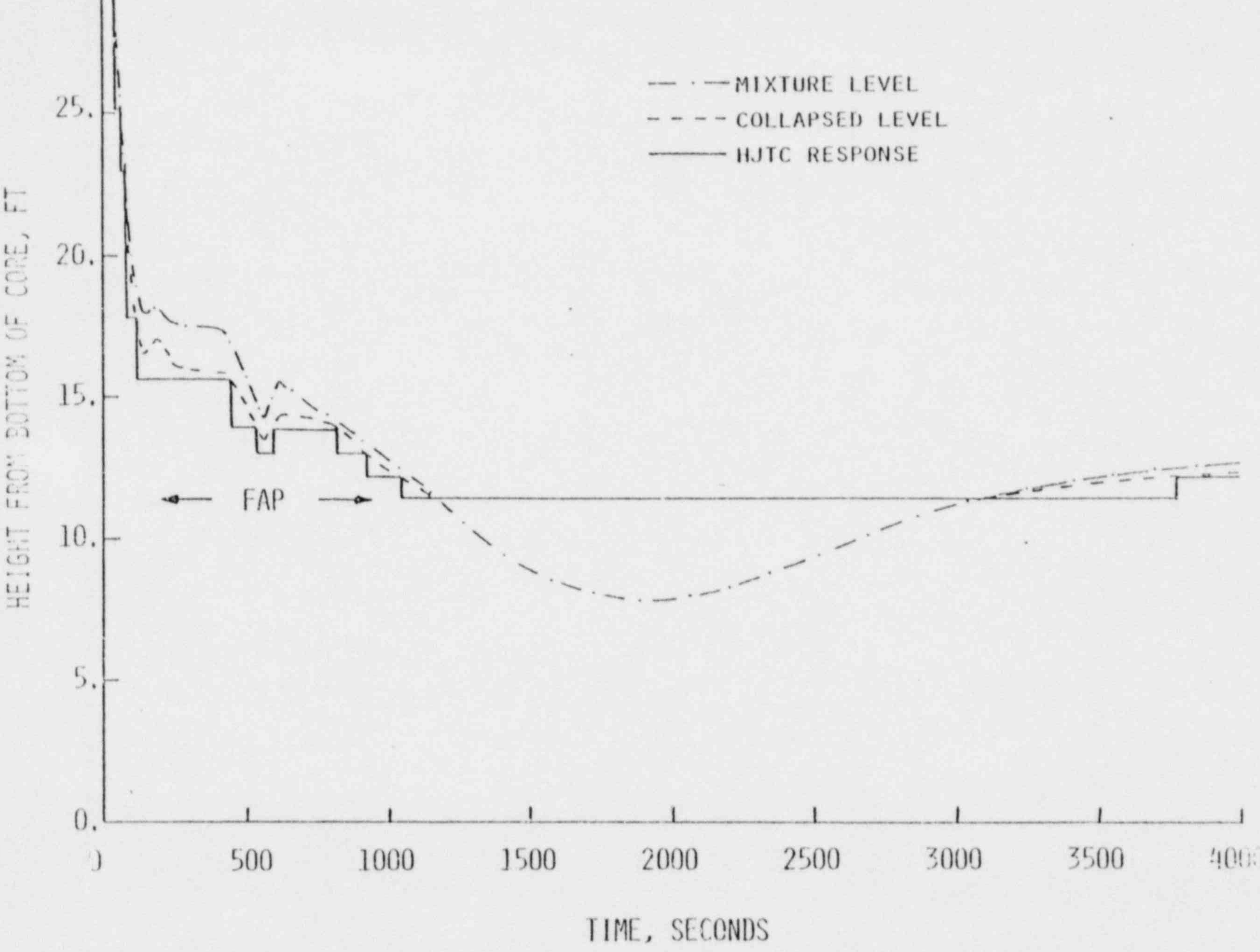
RESPONSE

C-E currently judges that the maximum size break for which the operator can be expected to take corrective action under the ICC procedures is a 0.1 ft^2 (4 inch) break. This small break proceeds slowly enough for the operator to assess and act on the indications from the ICC instrumentation. The instrumentation, i.e. HJTC System, responds to the change in water level faster than the operator can reasonably follow the transient. Thus, the response of the HJTC system does not limit the operator's ability to take prompt corrective action. Larger breaks may proceed too fast for the operator to take any action during the transient. Automatic systems function to replenish lost inventory and mitigate the consequences of the large break accidents. The HJTC system is therefore designed to provide information during small breaks (less than 0.1 ft^2) and during the reflood portion of a large break.

The HJTC system measures the collapsed water level (liquid inventory) at discrete elevations in the reactor vessel above the fuel alignment plate. When the collapsed water level falls below an individual sensor, the sensor output increases and gives an uncovered (high differential temperature) indication. The collapsed water level is therefore displayed in steps as each successive sensor is uncovered. The actual collapsed water level is equal to or greater than the level displayed by the HJTC system. Figure 2-1 shows the typical response of the HJTC system for a 0.05 ft^2 break in the cold leg with the reactor coolant pumps tripped and flow from one high pressure safety injection pump (HPSIP). The response follows the collapsed water level above the fuel alignment plate in steps. Sensor elevations typical of the generic design have been used here. These exact elevations do not apply to any specific plant, however.

Figure 2-1 shows that the core starts to uncover at about 20 minutes. Thus, the operator has sufficient time to observe the decrease in water level and take corrective actions. For example, in this case where the flow from only one HPSIP is credited, the operator could attempt to establish safety injection flow from a second HPSIP. The flow from two HPSIPs equals the break flow at 17 minutes. After this time, the water level would start to increase, thereby avoiding an inadequate core cooling condition.

FIGURE 2-1
HJTC RESPONSE FOR A 0.05 FT^2 COLD LEG BREAK



QUESTION 3

Describe the Phase II test program, or programs used in the evaluation of the heated junction thermocouple level measurement system. Please provide representative test · ults including anomolous results. Explain the results with respect to exp. l behavior in operating reactors.

RESPONSE

The Phase I and Phase II test programs have been completed. These test reports will be submitted to the NRC in November.

QUESTION 4

Discuss the survivability and outputs of the heated junction thermocouple level system during and after a large break LOCA and support with test results.

RESPONSE

The components of the heated junction thermocouple (HJTC) system which would experience sudden and/or sustained changes in the environment during and following a large break LOCA may be divided into several categories as follows:

a. HJTC Probe Assembly.

b. Supporting structures internal to the vessel which support the probe.

c. Pressure boundary components which seal and also support the HJTC probe.

d. Electrical connectors and cabling which supply power to the HJTC heaters and transmit thermocouple signals back to signal processing equipment located outside of containment.

Figure 4-1 is a schematic representation of the HJTC system components within containment.

A. HJTC Probe Assembly

The sensors of the HJTC probe assembly are constructed using Inconel clad hermetically sealed mineral insulated cable, which is typical of thermocouples and other instrumentation used in reactor environments. Each sensor is electrically and physically separate from other sensors and is located above the active core region. Initial large break LOCA pressure and temperature transients would not directly damage such cable. Later in the accident, the temperature in the region of the HJTC sensors may increase above the saturation temperature due to core clad heat up. For LOCA's analyzed to date, the temperature in the region of the HJTC sensors is less than 1500^{o}F. At this temperature, HJTC sensors can be expected to operate and endure the loss of inventory and to provide an indication of the recovery of inventory in the region above the core if and when such a recovery is effected.

B. Support Structures Internal to the Vessel

The hardware within the reactor vessel which supports the HJTC probe assembly is designed to meet the intent of Subsection NG and Appendix F of the ASME Boiler and Pressure Vessel Code. As such, the stress limits for core support structures are adhered to in the design analysis of the HJTC support structures. The deflection of the HJTC support structure is also limited prevent damage to the HJTC instrumentation. The stresses and deflections are evaluated for a large break LOCA based on a blowdown analysis and appropriate mecnanical normal operating loads, to assure the stress and deflection limits are not exceeded.

C. Pressure Boundary Components

All pressure retaining components suppl ed for the HJTC system are designed in accordance with Section III of the 1980 Edition of the ASME Boiler and Pressure Vessel Code*. As sucn, normal operating,

* In some cases, the utility may require that an alternate edition be employed.

transient, and faulted conditions are considered and applied to the design of the HJTC pressure boundary components. The physical position of the flanges used for the HJTC system, i.e., on the reactor head, is such that a large break in the primary piping would not directly affect the mechanical integrity of the HJTC flange.

D. Electrical Connectors and Cabling

The sensor cables leading up to the electrical connectors, and the connectors, will be qualified in accordance with IEEE Std 323-1974 and IEEE Std 344-1975. These standards cover the environmental and seismic qualification of Class IE equipment for nuclear power generating stations. The environmental qualification encompasses the ex-vessel conditions expected following a large break LOCA.

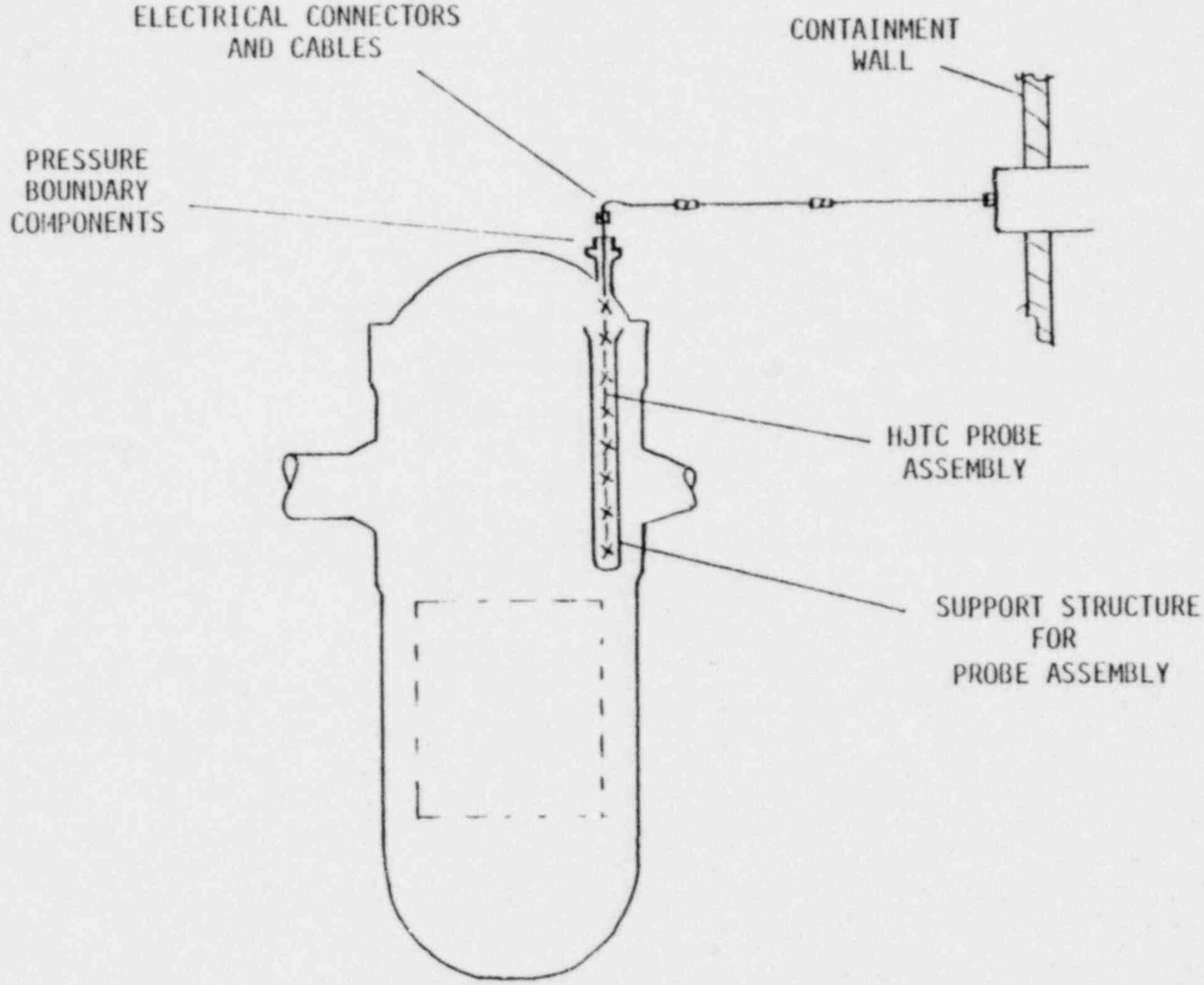


FIGURE 4-1

HJTC SYSTEM COMPONENTS
IN CONTAINMENT

QUESTION 5

Provide an analysis to determine if voiding can occur in the core of a C-E reactor while the upper head is still filled with water. Discuss the extent of voiding which can occur and whether or not it can lead to inadequate core cooling. Please analyze the effect on the core-exit thermocouples should such an event occur and discuss how inadequate core cooling conditions would be determined under these conditions. There is experimental evidence that this can occur, i.e. in tests SUT-2 (10% break), SUT-5 (2.5% break), SUT-7 (5% break) at Semiscale, these effects were observed.

RESPONSE

Background

Figure 5-1, is a vessel diagram for a typical C-E PWR. The location of the core exit thermocouple (CET) is shown in relation to the upper head, upper plenum, and core. An instrument thimble assembly is routed through the upper head, through the instrument support plate and into an instrument tube. The instrument tube extends from the upper head through the upper guide structure support plate and surrounds the thimble in the upper plenum region. Figure 5-2 illustrates the details of the CET position and the paths for communication of core coolant. The CET is located just above the fuel alignment plate inside the instrument thimble which is inside the instrument tube.

Of concern is the possibility that there may be coolant held in the upper head due to slow draining during a time when the core is experiencing inadequate core cooling (ICC). Upper head draining occurs through the CEA shrouds, instrument tubes, and holes in the upper guide structure support plate. Liquid draining from the upper head mixes with steam and water exiting from the core and is swept through the upper plenum to the hot legs.

In the following discussions, it will be shown that in a C-E PWR, the upper head drains well in advance of core uncovery or ICC, and therefore would have a minimal effect on the response of the CET during ICC.

Analysis of S-UT Semiscale Tests

The S-UT Semiscale test series was designed to determine the effect of upper head injection (UHI) on core cooling for small break loss-of-coolant accidents. Tests were conducted with and without UHI for comparison of system mass distributions and core cooling. The test system was modified to include vessel upper head internals that simulate the upper head flow paths in a PWR equipped with UHI capability. These internals included a perforated ECC injection tube, a bypass line from the top of the downcomer, a simulated control rod guide tube, and two simulated support columns. (Refer to Figures 5-3 and 5-4 for details of the Semiscale design.)

The following seven tests were conducted:

Test # S-UT-X	Break Size % of cold leg area	Break Size C-E PWR ft^2	UHI On/Off	Comments
1	10%	0.5	Off	Results can be compared to S-07-10, and 10D
2	10%	0.5	On	
3	2½%	0.125	Off	(Results not reviewed)
4	2½%	0.125	Off	Band heaters powered on all further tests
5	2½%	0.125	On	
6	5%	0.25	Off	
7	5%	0.25	On	

C-E reactors do not have UHI. Therefore, tests S-UT-2, -5, and -7 do not apply to C-E reactors due to the injection of ECC fluid in the upper head. The other tests, S-UT-1, -4, and -6, which were run without UHI to establish baseline response of the system, have been examined to determine their applicability to C-E PWR designs. (Test S-UT-3 was the same as S-UT-4 except for the use of band heaters. S-UT-3 was not reviewed.)

A. Test Geometry Evaluation

It was observed in one of the tests (S-UT-1) that core voiding and core uncovery occurred while the upper head was still in the process of draining. Since the draining characteristics of the upper head are geometry dependent, the Semiscale (S-S) design is compared to the typical C-E PWR design. Relevant data are given in Table 5-1. Upper head draining depends on elevation head or height of fluid, volume, and flow area. If S-S is to simulate a PWR, then these geometry items must be similar.

Review of the designs shows that the elevation heads or height of fluid columns for S-S and C-E are similar. However, the volume and flow area arrangements are quite different. In S-S, only 33% of the upper head volume occurs above the guide tube outlet elevation. In a C-E PWR, roughly 73% of the upper head volume occurs above the elevation which corresponds to the CEA shroud outlet. Also in S-S, the guide tube flow area represents only 57% of the total area available for draining. In a C-E PWR, the CEA shroud flow area represents 97% of the total area for draining.

If these geometry differences are overlooked for the moment, the key question concerns the time of draining of the upper head. The upper head draining time is approximately equal to the volume of the upper head divided by the average liquid outlet volumetric flow rate*. Assuming that proper scaling requires that fluid velocities be the same in S-S as in the full scale PWR, the upper head draining time then is proportional to the ratio of the upper head volume to the exit flow area. Values of the volume to area ratio are given in Table 5-1. Either a larger volume or a smaller exit flow area will produce a longer time for draining.

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*This approximate relationship can be checked by using data from test S-UT-1 (Ref: EG&G-SEMI-5333, "Quick Look Report for Semiscale MOD-2A Test S-UT-2.) The average outlet flow from one support column is 50 ml/sec (see Figure 27 from the Reference) and from the other 70 ml/sec (see Figure 28), for a total of 120 ml/sec. This test showed that the bypass and guide tube uncovered quickly, providing a path for steam flow into the upper head (Figures 25 and 26). Draining time = 0.495 $(ft^3)*28.3x10^3$ (ml/ft^3)/ 120 (ml/sec) = 117 seconds. This agrees very well with the draining time from Figure 21 of about 120 seconds.

For the condition where the level is above the guide tube outlet, the volume to flow area ratio for S-S is roughly four times larger than the ratio for a C-E PWR. The C-E upper plenum would therefore be expected to drain faster than S-S. When the level drops below the elevation of the guide tube outlet, the volume to flow area ratios are not as drastically different, but the conclusion is the same, that the C-E design would drain faster than S-S.

B. Test Data Evaluation

The S-S upper head draining times are given in Figure 5-5 as a function of break size. Only the three S-S tests without UHI are presented (S-UT-1, -4, -6). The end of upper head draining is marked by the uncovery of the two support columns in the S-S design. From the test data, this is observed to be the time of strong steam flow venting from the core into the upper head through one or both of the support tubes.

Also plotted in Figure 5-5, are the times for the start of core uncovery. It is clear from this data, that upper head draining is completed well in advance of core uncovery for all small break LOCA conditions tested, except for the 10% break (S-UT-1).

For the 10% break, S-UT-1, uncovery of the core begins roughly 50 seconds after initiation of the LOCA due to loop seal blowout. The extent of voiding in this case was not extensive, in fact the peak clad temperature did not exceed the initial clad temperature prior to the LOCA. Loop seal blowout may initiate a momentary depression of the core mixture level for C-E plants as well. This uncovery is not related to the extensive voiding and loss of coolant inventory which leads to ICC. A better example of ICC for this break size is, S-S test S-07-10, which is also shown on Figure 5-5. Upper head draining was virtually identical to S-UT-1 but core uncovery due to loss of inventory did not occur until 100 seconds later. In test S-07-10, the CET's were observed to respond immediately to the onset of core uncovery and were unaffected by the earlier upper head draining as can be seen by examining traces of cladding temperatures and core exit temperature on Figure 5-6.

One of the assumptions in the analysis of ICC, is that a specific LOCA event progress slowly enough for the operator to use the instrument displays to observe the progression. For the 10% break discussed above, this progression is too rapid. As described in the C-E responses to Questions 1 and 2 above, the acceptable range of break sizes for LOCA events is 0.1 ft^2 or less. Therefore, all of the S-S small break LOCA's discussed above fall outside this range.

Figure 5-5, shows the range of predicted time of uncovery for C-E plants, for the 0.1 ft^2 break LOCA. Core uncovery occurs between 700 and 800 seconds for this break size. The smallest break size S-S test, S-UT-4, resulted in an upper head draining time of 400 seconds. Realizing that the geometry differences discussed earlier indicate that the C-E upper head will drain faster than S-S, these results show that upper head draining will preceed core uncovery by more than five minutes.

Table 5-1

Semiscale and C-E PWR

Geometry Comparisons

	S-S		C-E		S-S/C-E
Elevations (in)					
height of upper head	105		95		
distance from top of core to top of vessel	210		215		
Volume of upper head (ft^3)	.495		490		
above guide tube outlet (ft^3 and % of total)	.164	33%	356	73%	
below guide tube outlet (ft^3 and % of total)	.331	67%	134	27%	
Flow areas (ft^2)					
guide tube/shrouds (ft^2 and % of total)	.00196	57%	27.8	97%	
support tubes/instrument tubes	.00098	29%	.267	1%	
bypass/UGS P.	.00049	14%	.534	2%	
total	.00343		28.6		
total without guide tube/shrouds	.00147		.801		
Volume/Flow area (ft)					
above guide tube outlet	47.8		12.4		3.85
below guide tube outlet	225		167		1.34

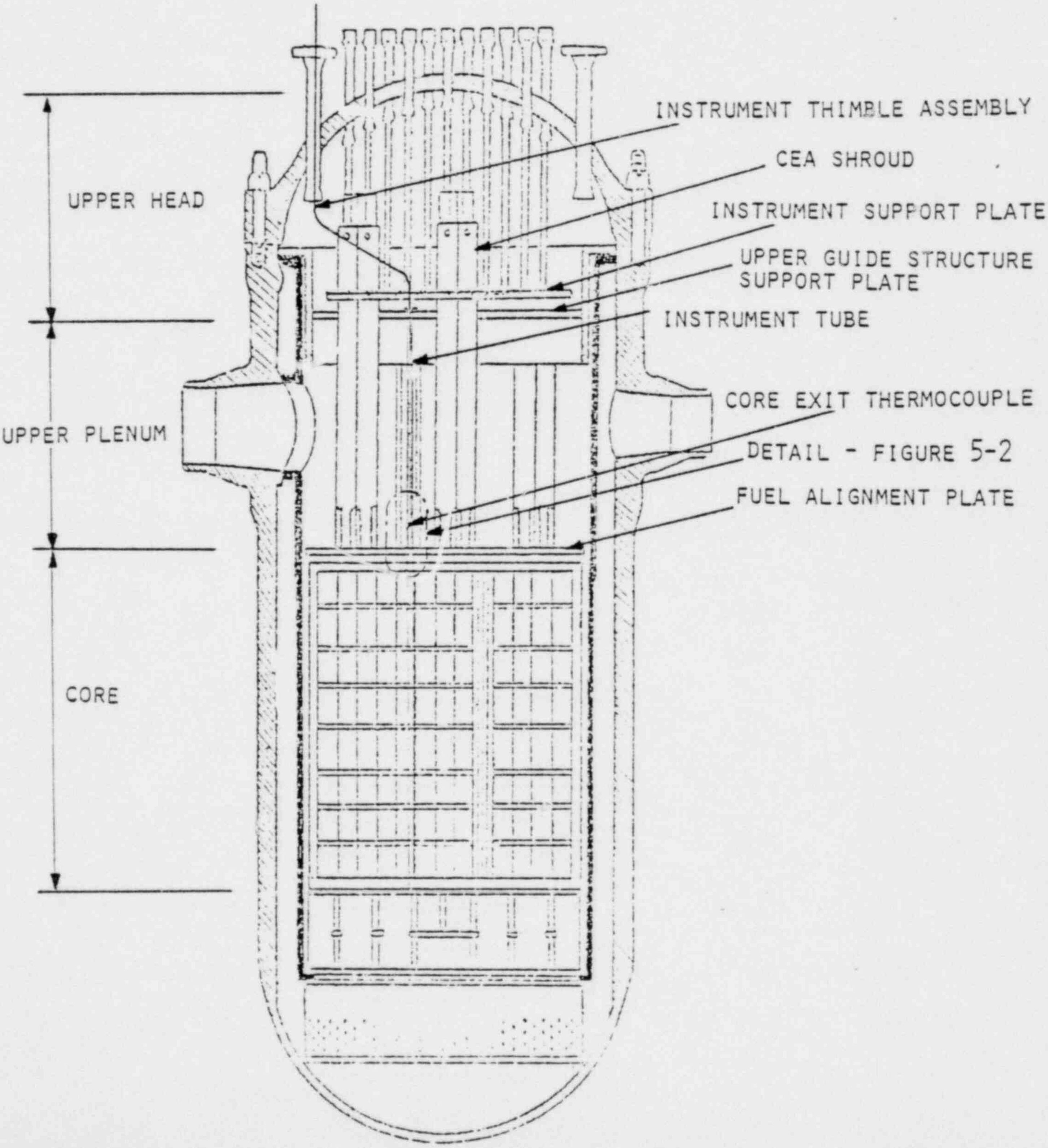
Drain time = Mass/$\dot{m}$ = ρ Vol/ ρ VA

Assuming ρ V to be constant for proper scaling

Then drain time = Vol/A

FIGURE 5-1

TYPICAL C-E VESSEL DIAGRAM LOCATING CORE EXIT THERMOCOUPLE



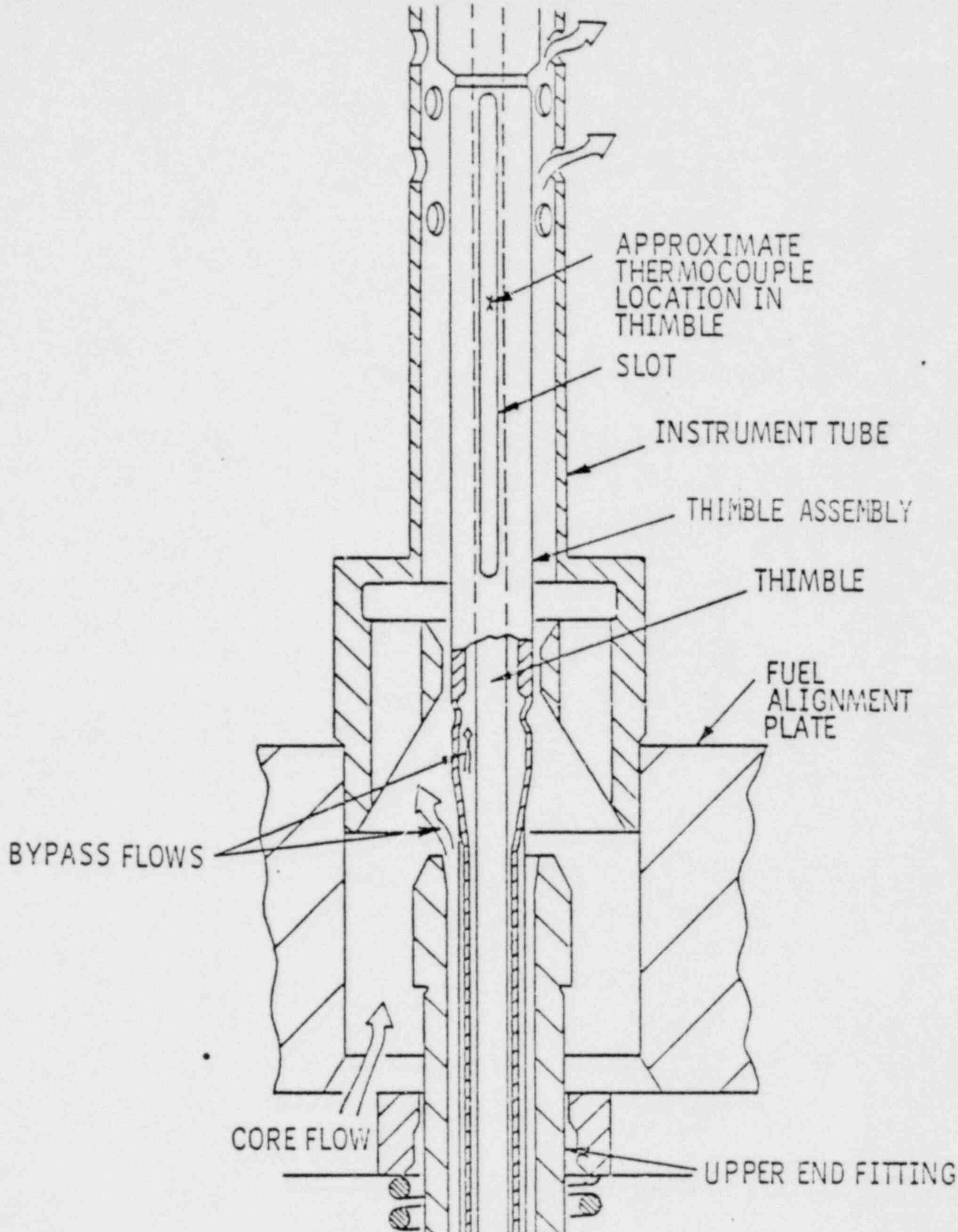


FIGURE 5-2

REPRESENTATIVE CORE EXIT THERMOCOUPLE SCHEMATIC

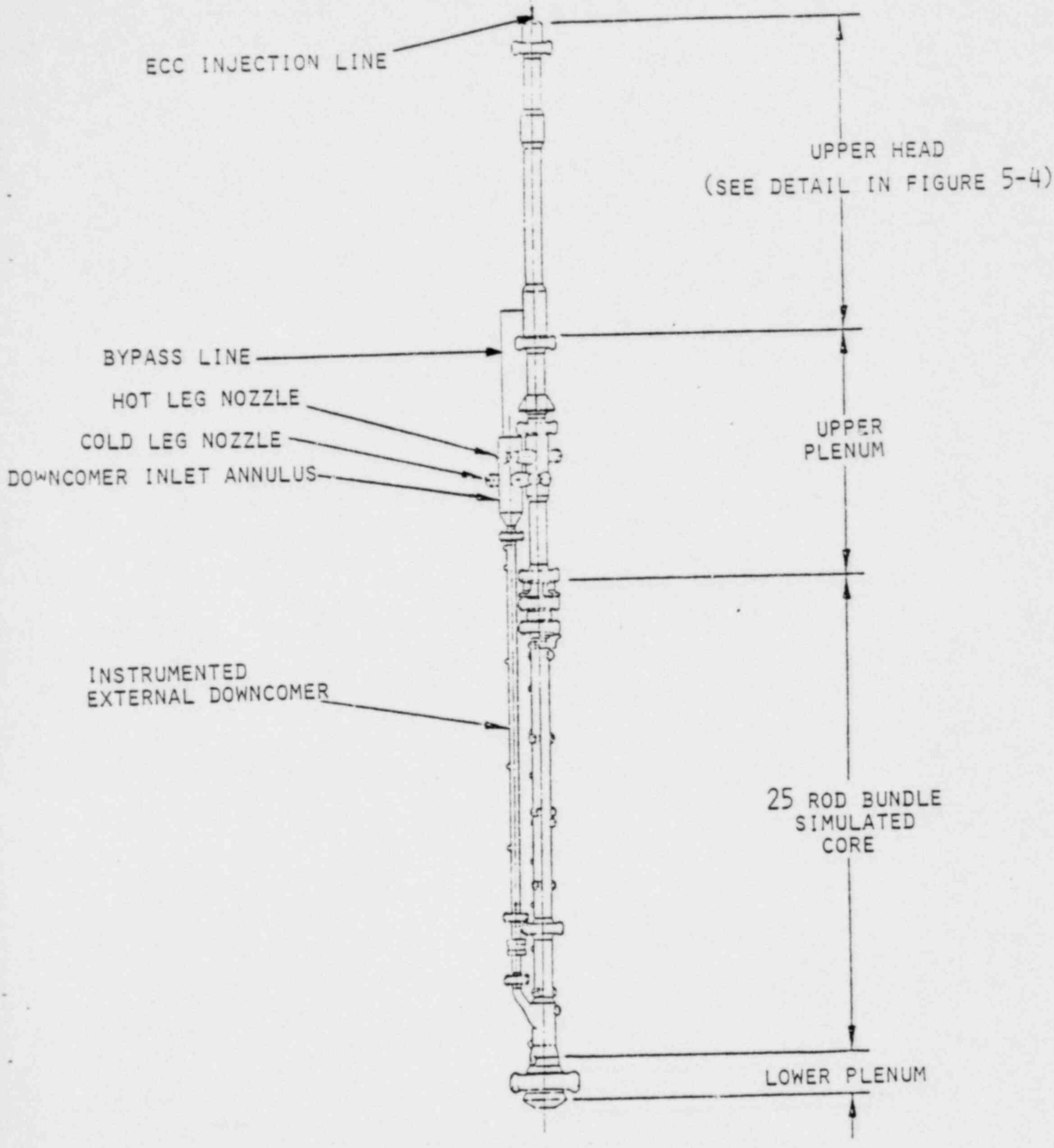


FIGURE 5-3

SEMISCALE MOD-2A PRESSURE VESSEL

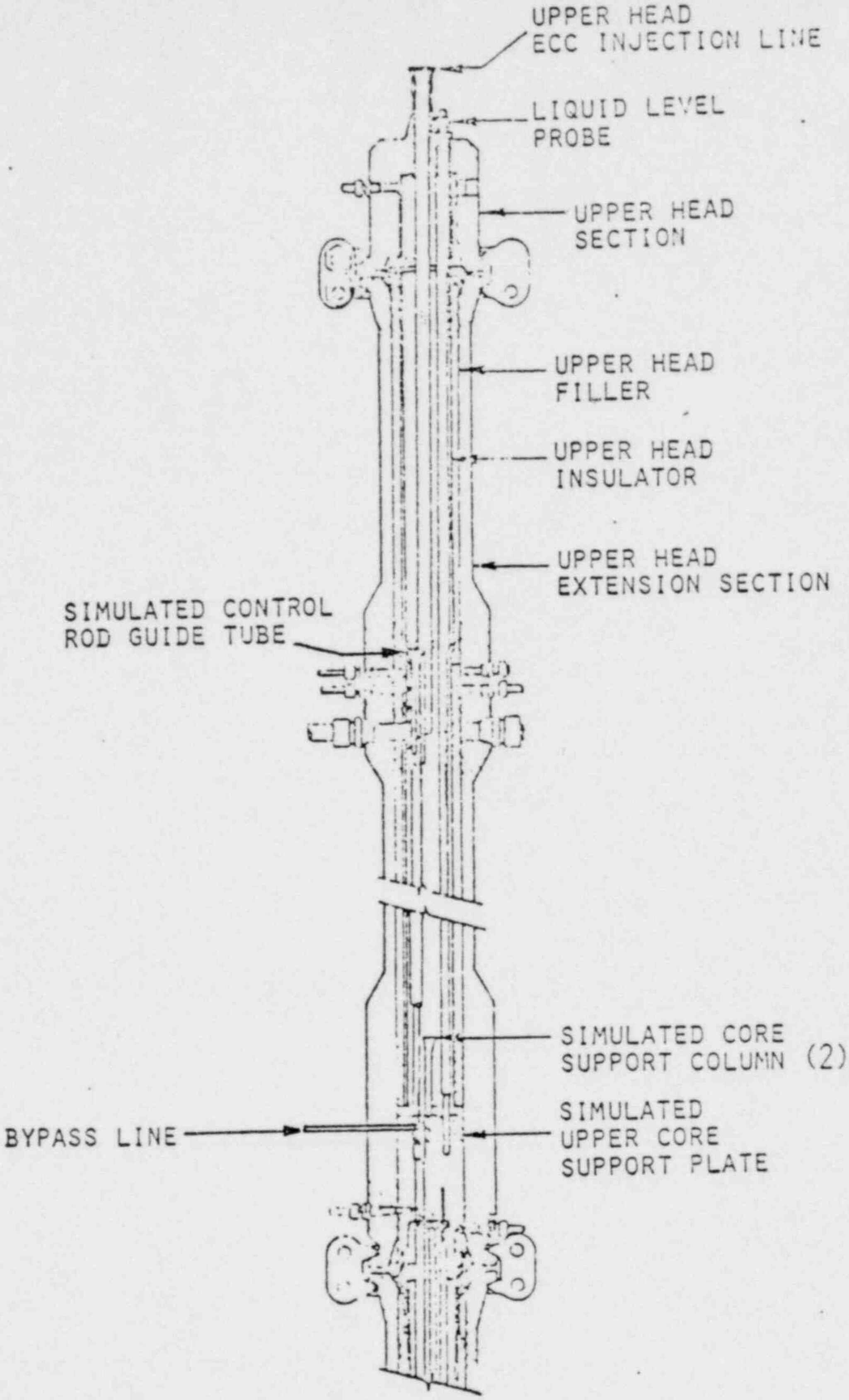


FIGURE 5-4

UPPER HEAD CONFIGURATION FOR THE
SEMISCALE MOD-2A VESSEL

FIGURE 5-5

COMPARISON OF UPPER HEAD DRAINING TIMES TO CORE UNCOVERY TIMES FOR A RANGE OF BREAK SIZES

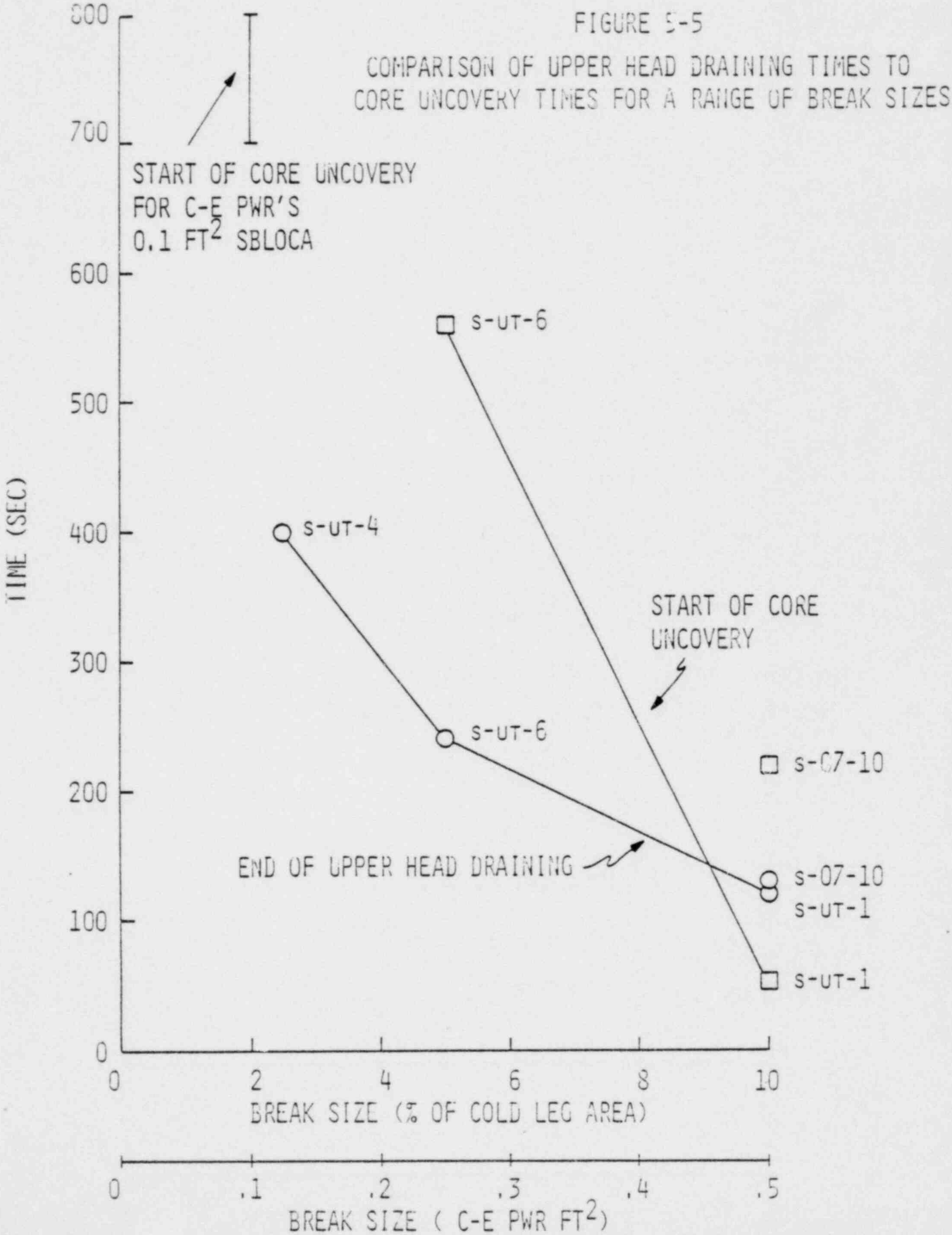
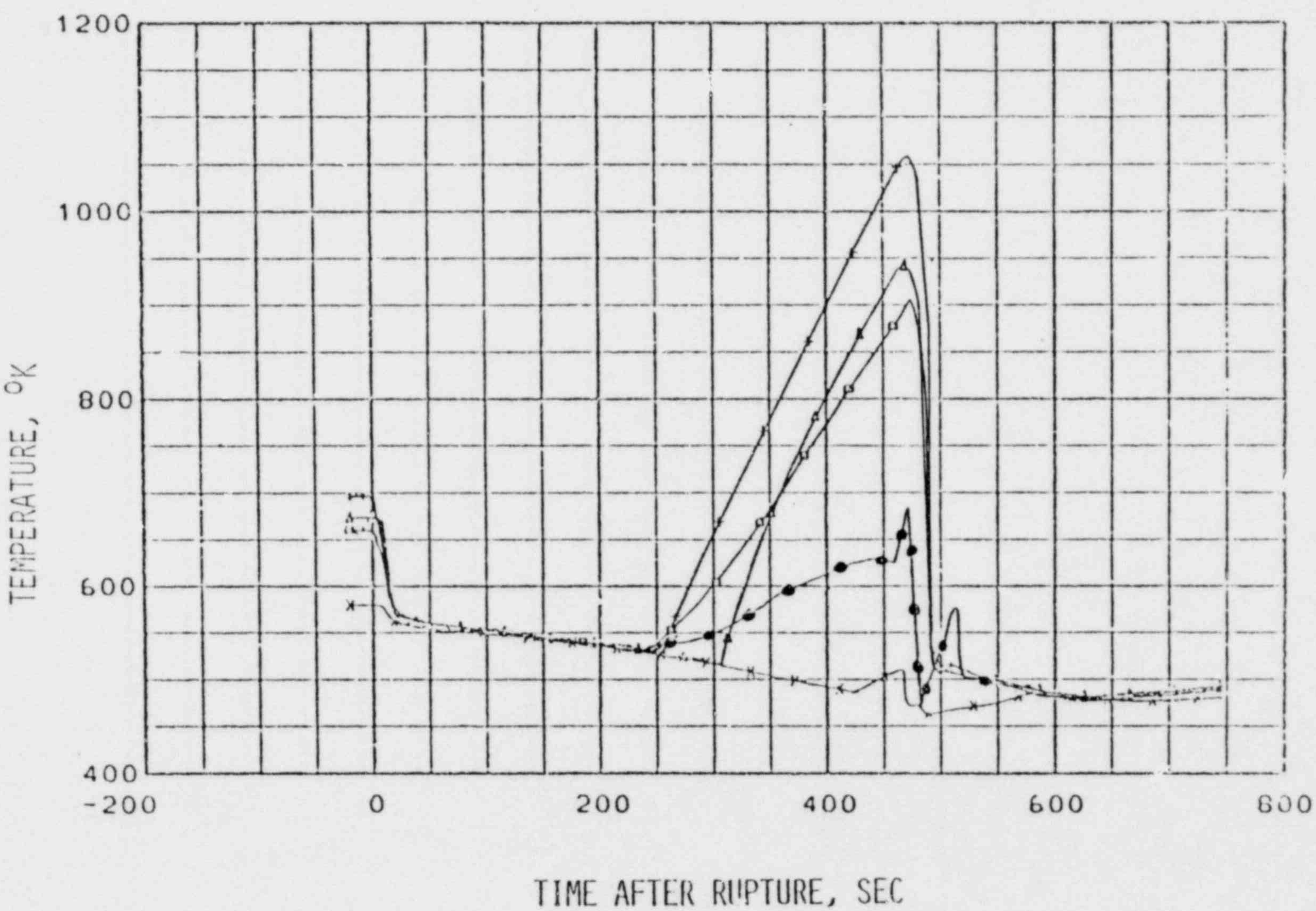


FIGURE 5-3

RESPONSE OF CORE EXIT THERMOCOUPLE IN SEMISCALE TEST S-07-10D

× CLADDING TEMPERATURE, ROD C-2, 0.3 FEET ABOVE BOTTOM OF ACTIVE CORE
Δ CLADDING TEMPERATURE, ROD C-2, 4.4 FEET ABOVE BOTTOM OF ACTIVE CORE
+ CLADDING TEMPERATURE, ROD C-2, 9.1 FEET ABOVE BOTTOM OF ACTIVE CORE
□ CLADDING TEMPERATURE, ROD C-2, 10.5 FEET ABOVE BOTTOM OF ACTIVE CORE
● CORE EXIT THERMOCOUPLE 2.2 FEET ABOVE TOP OF ACTIVE CORE



QUESTION 6

Discuss the expected response of the heated thermocouple level sensors during a repressurization with the water level below the sensor and the possible effects of condensation on the response of the sensors. Could this sequence of events lead to an indication which would imply that the sensor is covered when it is not? Please provide representative test data.

RESPONSE

There are two primary effects which cause the output of an uncovered sensor to change as the pressure increases. These are the change in heat transfer coefficient and condensation. As the pressure increases, the heat transfer coefficient for steam at the heated junction thermocouple increases also. Thus, more heat is removed from the sensor heater coil causing the temperature of the heated junction to decrease. This in turn results in a reduction of the sensor output. The second effect is due to droplets of condensed water collecting on the sensor sheath inside the splash guard. These droplets are evaporated by heat from the sensor heater coil, thereby decreasing the temperature of the heated junction thermocouple and sensor output. The mass of liquid condensate is limited to that within the splash guard since the splash guard prevents water from running down the sensor sheath from above. Also, the effect of condensation is only temporary. That is, after the condensed water droplets have been evaporated, the sensor output increases to the value governed by the heat transfer coefficient to steam at the existing pressure. The time that it takes to evaporate the condensed droplets depends on the sensor heater power.

During the Phase II test program on the HJTC system, the effect of changing pressure on sensor output was determined. Transients with both increasing and decreasing pressure were evaluated. Initially, the test vessel was completely filled with steam at 1400 psia and the sensor uncovered. A valve at the top of the vessel was opened to vent steam and allow the pressure to decrease. As the pressure dropped, sensor output increased (by about 20%) due to the decrease in heat transfer coefficient. The valve was closed and the pressure increased (due to vessel wall heat) about 600 psi in 10 seconds. The sensor output dropped by about 15% of the change in output from uncovered to covered in response to the increase in pressure. Thus, this lower sensor output was still well above the covered sensor output. Therefore, the sensor output remained high enough so that a misleading indication was not given.

It should be noted that the repressurization rate observed in this test was much greater than would be expected in a reactor vessel for refilling after a small break LOCA. Also, the sensor heater power used in the test was much lower than would be used in a reactor vessel. For repressurization rates and sensor heater powers more typical of reactor vessel applications the effect of increasing pressure would be even less than observed in the Phase II test program. Additional data on the effect of pressure on sensor output is given in the Phase II test report.

Question 7

Discuss the expected time response of the system with respect to the individual components and as a whole. Identify and discuss the factors which limit the time response.

Response

The following are the expected time responses of indivirua' components:

1. HJDTC - The Heated Junction Differential Thermocouple (HJDTC) response time is the time starting at sensor uncovery until the ΔT output reaches the ΔT setpoint value signaling an uncovered condition. Based on the results of Phase II testing, the response time is expected to be from 2 to 20 seconds, depending on vessel pressure and whether the sensor is covering or uncovering. The response time may be longer under extreme conditions when heater power has been reduced to protect the HJDTC from overheating.
2. Cabling time constants will be less than one second.
3. The signal processing electronics time delay will not be greater than 4.0 seconds.
4. The operator display (RVLMS panel) response time will be less than one second.

Overall system response time will range from 8 to 26 seconds. Response time when covering is much shorter than when uncovering because of the higher heat transfer coefficient of liquid as opposed to steam. When uncovered, response time is primarily a function of pressure, because the heat transfer coefficient increases with pressure. Another factor which increases response time response when uncovering is a film of liquid remaining on the HJDTC cladding which must be evaporated or boiled off as the heated junction temperature increases.

Question 8

No specific information has been given for the spacing of the sensors in each of the heated junction thermocouple instrument strings. Are the sensors to be spaced evenly from the core alignment plate to the top of the reactor vessel head? Discuss the spacing chosen. Will the spacing be the same in both instrument strings? If not, how would the decrease in resolution due to the loss of a single sensor affect the ability of the system to detect an approach to inadequate core cooling? (i.e., how is the redundancy of the system affected if dissimilar spacings are used in the two detector strings?).

Response

Actual dimensions will be provided on a plant specific basis. For all installations, sensor locations in both probe assemblies will be identical.

The following sensor locations are examples of typical sensor placement:

Sensor	Location
1	Near the top of the vessel head.
2	Midway between sensors 1 and 3.
3	Above the upper guide structure support plate.
4	Top of the hot leg lip.
5	Midway between sensors 4 and 6.
6	Bottom of the hot leg.
7	Midway between sensors 6 and 8.
8	Above the fuel alignment plate.

The primary reason for choosing identical spacing was to provide the operator with the means to quickly observe system faults by any difference in the level indication between the two channels. With eight sensors, the probe assembly provides indications of the collapsed liquid level at intervals ranging from approximately one to four feet. This resolution will be sufficient to adequately determine the level and trending of liquid inventory above the core.

QUESTION 9

Discuss how the core-exit thermocouples might be used to estimate the depth of core uncovery. Also discuss how the rate of loss of coolant may affect the core-exit thermocouple response. Provide an evaluation of the pro's and con's of using the indications of the core-exit thermocouples as a measure of the liquid inventory in the vessel if the coolant level is below the top of the core.

RESPONSE

The C-E requirement on Core Exit Thermocouples (CET) to monitor ICC is limited to the trending of steam superheat at the exit of the core. This provides an indication of when the core starts to uncover, of the direction of the event progression while the core is partially uncovered and of the recovery of the core. The magnitude of the steam temperature or superheat might be used to infer more about the conditions within the core, but C-E believes that more information is not needed for the reactor operator at the time of an event in order for him to take appropriate mitigating actions and to monitor their effectiveness. To obtain more information about core level or vessel inventory from the measurement of steam temperature would require an extensive on-line algorithm which would be dependent on several empirical relations. These relations include the transient heat transfer coupling of the fuel rod and the steam and the heat produced by clad oxidation. C-E believes that such analyses are properly left until after an event is terminated, when the data stored during the event can be analyzed for the unique set of event conditions.

Once the two-phase level drops below the top of the core, it is the steam temperature which is of immediate concern to the operator. Higher steam temperature means higher clad temperature and a greater potential for fission product release, so the operator needs an indication of whether the steam temperature is increasing or decreasing. This indication is provided by the CET measurement of steam temperature.

An analysis was made, for two different rates of core uncovery, of the relation among clad temperature, core exit steam temperature and two phase level. The conditions at the start of uncovery were typical of small break analyses conditions; i.e. 600 psia, 1180 seconds after reactor trip, top peak axial power distribution and core uncovery rates of 0.014 and 0.14 in/sec. Figure 9-1 shows the results. The upper plot gives the maximum clad temperature at any instant vs. the steam temperature at the core exit, for the two uncovery rates. The lower plot gives the same clad temperature vs. the two-phase level in the core.

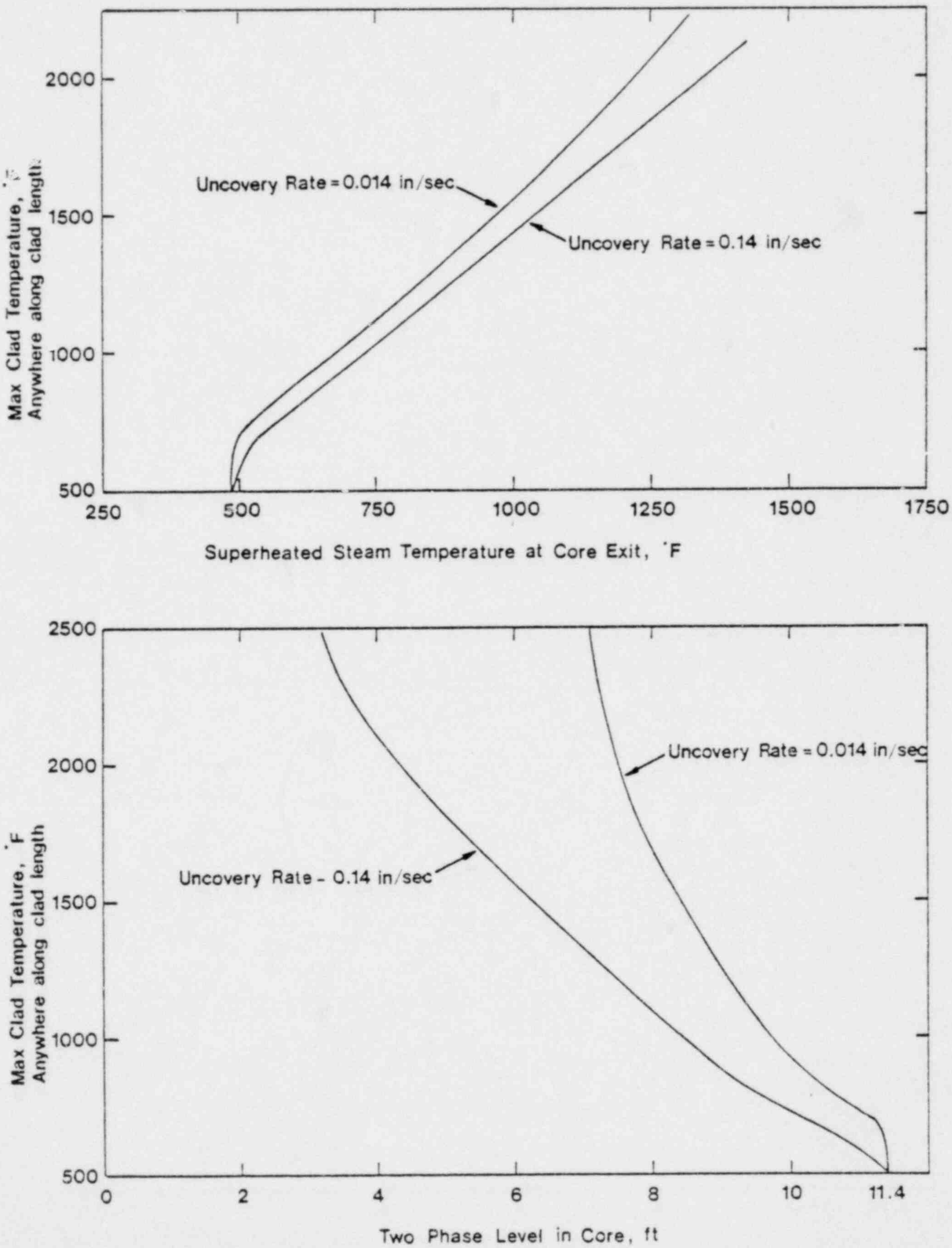
The upper plot shows that there is a relatively small difference in the maximum clad temperature for a given value of core exit steam temperature when the core uncovers at two different rates. As long as there is a two phase level to boil off steam and to provide a steam flow at the core exit, there is a strong thermal coupling between the clad temperature and the exit steam temperature. Even though the two phase levels may differ, the variation in exit steam temperature is representative of the variation in clad temperature.

The lower plot shows that there can be a large difference in the maximum clad temperature when the core uncovers to a given level, depending on the rate of uncovery. As the two phase level falls and uncovers a given clad location, the surface heat transfer coefficient decreases by about a factor of 100 from that for boiling to that for superheated steam. This lowered film coefficient causes a decrease in heat flux while the fuel and clad temperature rise. For a rapid uncovery to a given level, the fuel does not have as much time to heat up as it does for a slower uncovery to the same level. Hence, for any given transient two phase level there are large differences in the possible instantaneous clad temperatures, depending on how long the clad has been uncovered.

The conclusions are that a measurement of core exit steam temperature is much better than a measurement of two phase level for indicating the clad temperature behavior, and that clad temperature is the proper parameter for evaluating the potential for fission product release.

Figure 9-1

Relation Between Temperature and Level



QUESTION 10

Discuss the expected behavior of the level sensor shroud surrounded by a high velocity two-phase mixture. In particular, discuss how the system is protected from the effects of high velocity steam entering the bottom ports of the shroud and creating a two-phase mixture within the shroud. If restrictions are placed in the bottom of the shroud to block the bottom drain paths, discuss or show experimental evidence that there is still adequate drainage and response time.

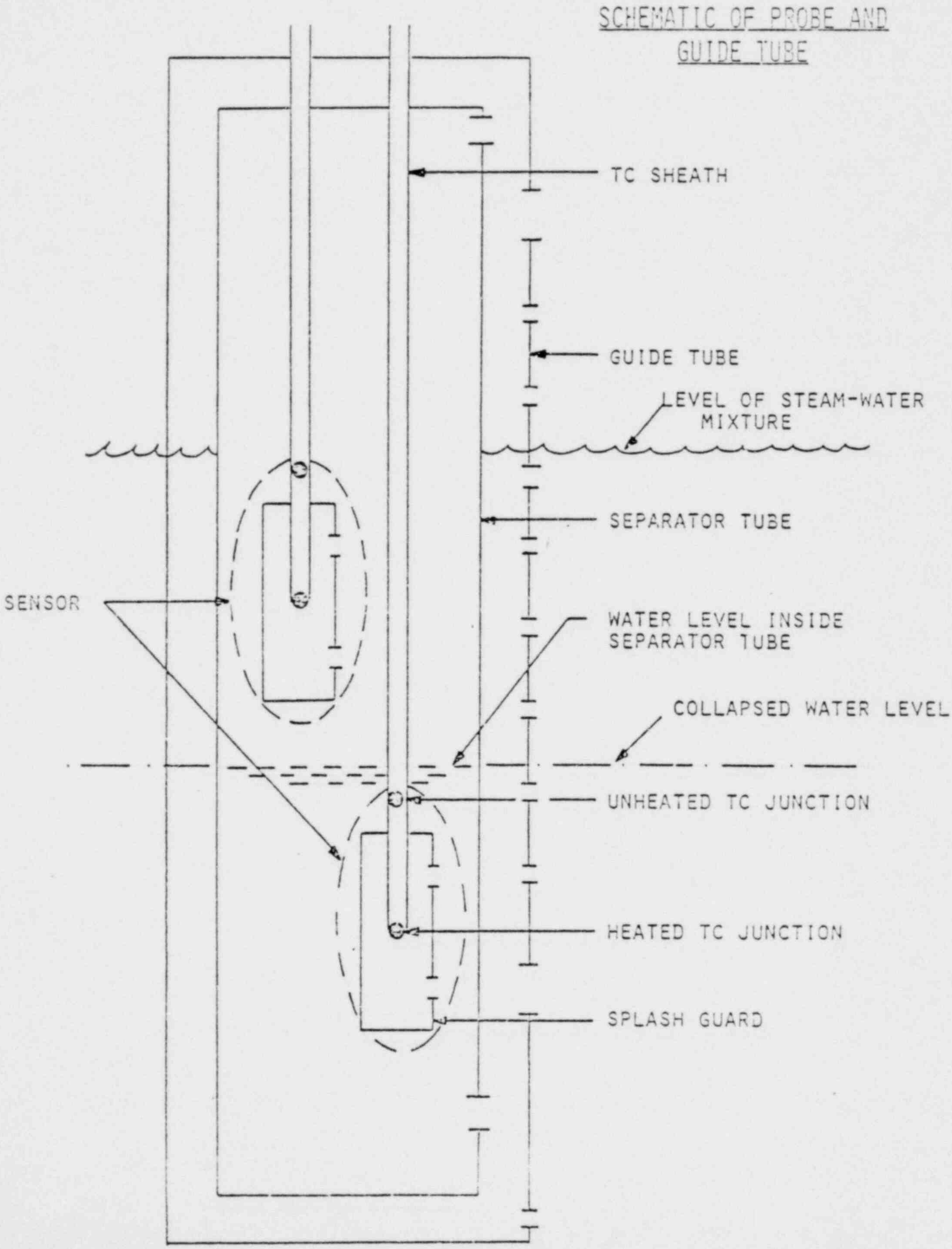
RESPONSE

The C-E water level measurement device consists of a number of HJTC sensors axially distributed inside a standpipe, called a separator tube. A functional schematic of the instrument probe is shown in Figure 10-1. A sensor is made up of a heated junction, unheated junction, and a splash guard surrounding the heated junction thermocouple. The separator tube has holes at the bottom and top to allow water and steam to flow in and out. The purpose of the separator tube is to separate the steam and water phases and create a collapsed water level inside the tube when a two-phase mixture exists outside the tube. Thus, a region of nearly dry steam exists inside the separator above a region of all liquid. The sensors inside the separator tube measure the location of this steam-liquid interface as it passes the heated junction thermocouple elevation.

The separator tube is surrounded by another tube which provides a guide path and physical support for the instrument. It also aids in preventing steam bubbles from entering the separator tube. This guide tube is perforated along its entire length to enhance drainage. Slots in the guide tube at the top and bottom are offset axially from the holes in the separator. That is, the guide tube slots are slightly above the holes in the bottom of the separator tube so that they do not overlap (see Figure 10-1). Thus, steam bubbles which may pass through the guide tube slots, are prevented from entering the separator since they would have to turn 180^0 downward in the separator - guide tube annulus to reach the separator tube holes. This would be particularly effective in a high velocity two-phase mixture. Small holes at the very bottom of the guide tube allow water below the slots to drain, but are too small to allow a significant amount of steam to pass through.

Tests (HJTC Phase II Test Program) have demonstrated the ability of the separator tube with the above described configuration to create a collapsed water level when surrounded by a two-phase mixture. The void fraction of the two-phase mixture ranged from 0 to 50%. These tests have also shown that drainage of the separator tube is not significantly impaired. The Phase II Test Report describes these tests and provides additional information. Therefore, steam is prevented from entering the bottom holes of the separator tube and creating a two-phase mixture without significantly affecting the drain rate or response time of the instrument.

FIGURE 10-1
C-E HJTC SYSTEM



Question 11

Question 11 has been broken down into a series of individual questions (11-a through 11-h) to facilitate a more comprehensive response.

Question 11-a

Describe the choice of heater power or range of heater powers to be used with the heated junction thermocouple sensors.

Response

Heater power will be chosen from test data taken from prototype probe assemblies to give a clear difference between uncovered and covered states. Heater power will be kept at a constant level except when reduced by the heater power control system to prevent excessively higher heated junction temperatures, as discussed in response to Question 11-b.

Question 11-b

Describe the heater power supply or heater power control system.

Response

Figure 11-1

HEATER POWER CONTROL LOGIC (EACH CHANNEL)

Question 11-c

Are separate supplies provided for each sensor heater?

Response

No, each of the two probe assemblies will have two heater power supplies. Each heater power supply will provide heater power for four heaters connected in series. The four HJDTC sensors supplied by one heater power supply will occupy alternating level positions with the other four sensors in a probe assembly.

Question 11-d

Discuss the heater supply system with respect to NUREG 0737 "single failure" criterion.

Response

The RVLMS utilizes two electrically independent channels. Each channel consists of one probe assembly (eight sensors), one signal processing unit, two heater power supplies, one operator display, cabling and connectors. The two channels are identical including sensor locations The two independent operator displays will continuously display percentage of reactor vessel level above the fuel alignment plate.

Most power supply failures, capable of causing an erroneous or ambiguous indication will be automaticaly detected and a fault signal provided to the operator. Any failure which causes an error in level indication will result in a difference in the level indications on the two operator displays. The operator will then be able to obtain individual thermocouple junction temperatures for operability checking and diagnostic purposes upon manual command at the operator module. This will enable the operator to determine which channel is operating correctly.

Question 11-e

Discuss how uncovered sensors are protected from overheating while covered sensors are supplied with sufficient power for a clear indication of uncovery.

Response

The heater power control logic, discussed in Question 11-b, ensures that an uncovered sensor will always signal an uncovered condition either by a high ΔT or by a high unheated junction temperature, while preventing excessive HJDTC temperatures. Covered sensors, when uncovered, will be subjected to the same heater power and environmental conditions as previously uncovered sensors, and will provide the same uncovered indication.

Question 11-f

Will AC or DC power be used?

Response

AC power will be used for the heaters.

Question 11-q

Dis.'ss the possible effects of leakage, particularly at high temperatures on the level measurement with both AC and DC heater power.

Response

Figure 11-2 presents a schematic of the HJDTC including leakage paths. A single leakage resistance, A or B, will have no effect on the temperature measurement. The thermocouple is connected to a floating circuit, consisting of a capacitor which is not connected to the input of the signal processing equipment except when sampling. During sampling, the capacitor is disconnected from the thermocouple and connected to the signal processor input.

Two leakage resistances, A and B should have a negligible affect on the thermocouple signals because the capacitor used for the signal processing input will filter at a considerable lower frequency than 60 Hertz.

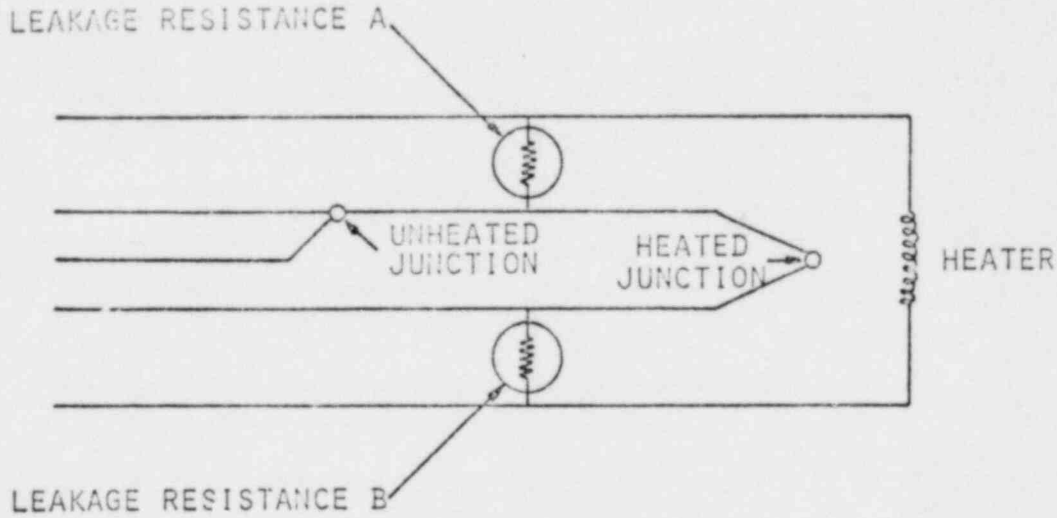


FIGURE 11-2: HJDTC WITH LEAKAGE RESISTANCES

Question 11-h

Discuss the possible effects of AC pick-up on the instrumentation system.

Response

AC pick-up is not anticipated to be a problem. Both legs of the heater wire are contained in the insulation material, therefore, much of the AC field will cancel out. A capacitance at the cold junction end of the thermocouple will be chosen to effectively filter 60 cycle voltage.

Question 12

Question 12-a Describe the on-line test procedures for the heated junction thermocouple sensors. One test mentioned is based on a change in indication, observed by varying heater power.

Response

Because the system is computer based, it has the capability to perform operability self testing. The following automatic on-line sensor tests have been incorporated into the RVLMS. Failed tests will result in a fault indication at the operator display.

1. Computer software will be self-tested using a cyclical redundancy check.
2. A sensor high (top-of-scale, 2300°F) thermocouple measurement will indicate an open thermocouple circuit.
3. A low thermocouple measurement will indicate an improper cable connection or a shorted thermocouple.
4. A low ΔT output is provided to indicate loss of heater power. Excessive heater power current will be fuse protected, which will in turn result in loss of heater power and a low ΔT output alarm.

In addition, access for test inputs will be provided for manual testing.

Question 12

Question 12-b Discuss how the operator or person testing the system will decide that the sensors are operating.

Response

An operator can assess system operability during plant operation by performing cross-channel comparisons. Excessive differences in thermocouple outputs between the two channels will be taken as a fault indication.

In any condition resulting in a reduced liquid level, any persistant difference in level output will also be a fault indication. The operator will be able to observe all thermocouple outputs on demand from the display to diagnose the failure. If further checking or confirmation is desired, diverse plant temperature measurements can be analyzed, (i.e., RTD, core exit thermocouples, etc.).

In addition to redundant channels, and operator system checks, operational availability is further enhanced by the on-line tests described in response to question 12-a. These will result in a fault indication at the operator display for the channel containing the fault. A diagnostic code will be provided at the operator display upon manual command by the operator.

Question 12

Question 12-c Discuss the effectiveness of the test procedures under various reactor conditions. i.e. cold shutdown, full power, and post accident.

Response

The tests described for questions 11-a and 11-b will work under the full range of operating conditions.

Question 13

Describe how the operational availability will be determined. What criteria are used? Describe the servicing, testing, and calibration programs.

Response

Determination of operational availability and the criteria used are addressed in Questions 12-a and 12-b. Servicing, periodic testing, and calibration requirements will be addressed in the plant installation and maintenance procedures and plant Technical Specifications as appropriate.