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June 1, 1982

Mr. Dennis M. Crutchfield, Chief
Operating Reactors Branch #5
Division of Licensing
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

SUBJECT: Response to Questions on C-E Heated Junction Thermocouple

References: (A) Letter D. M. Crutchfield to K. P. Baskin, "C-E Reactor Vessel Level Measurement System Using Heated Junction Thermocouple," April 30, 1982

(B) Letter from K. P. Baskin, C-E Owners Group, to H. R. Denton, NRC, "Communications between the Combustion Engineering Owners Group and the Nuclear Regulatory Commission," dated December 2, 1980.

Dear Mr. Crutchfield:

Enclosed are responses to questions contained in Reference A. These responses were prepared by Combustion Engineering for the C-E Owners Group.

This transmittal by the C-E Owners Group is made in order to assist you and the C-E Owners Group members in reaching resolution of requirement II.F.2. The transmittal is made according to the terms stated in Reference (B), a copy of which is attached for your convenience. In particular, this submittal is not applicable to any individual licensee or license applicant until the submittal is referenced by that licensee or license applicant for use on his docket. Furthermore, this submittal does not imply a commitment by any individual utility or group of utilities to install or use the equipment described in this submittal. Please send copies of any correspondence concerning this submittal to individuals identified in the attached list.

I hope that these responses will allow you to complete the generic portion of your review of the C-E Heated Junction Thermocouple System. If I can be of further assistance to you on this matter, please feel free to contact me at (212) 572-1401.

Very truly yours,

K P Baskin

Chairman
C-E Owners Group

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1/0

Add: NRR/DHFS/LQB
Regions: 1
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Enclosures

December 2, 1980

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Subject: Communications Between the Combustion Engineering Owners Group and the Nuclear Regulatory Commission

Dear Mr. Denton:

The Combustion Engineering Owners Group has requested that I advise you of its recently established policy regarding the subject communications. This policy will assist in reducing the uncertainty in determining the communicants on issues and thereby improve the effectiveness of all parties concerned.

Submittals made by the C-E Owners Group to the NRC will not be applicable to any individual licensee until the submittal is referenced by that licensee for use on his docket. Should the NRC have questions within the scope of any C-E Owners Group submittal, they should be addressed to the Owners Group Chairman with copies to the appropriate Owners Group Subcommittee Chairman, C-E and each Owners Group member. The individuals to whom copies should be addressed will be identified with each future Owners Group submittal.

Questions from the NRC on issues beyond the scope of previous submittals made by the C-E Owners Group should be addressed only to the individual licensees. The licensees will then consider the extent of the C-E Owners Group involvement, if any, in an appropriate response.

The C-E Owners Group feels that this communication policy serves the best interests of the Owners Group, individual licensees, and the NRC.

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If you or your Staff have any questions concerning this topic, please contact me.

Very truly yours,

KPB

K. P. Baskin
Chairman
C-E Owners Group

jkb
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Response to NRC Questions
on the C-E Heated Junction Thermocouple
System

QUESTION 1

Provide an analysis of the response (with the reactor coolant pumps running) of the heated junction thermocouple level measurement system (a) with the full length separator tube, and (b) with the split separator tube in the System 80 plants. Also discuss the instructions to the operator for interpretation of the indications.

RESPONSE

A. Introduction

The Heated Junction Thermocouple (HJTC) System is designed to measure the water inventory in the reactor vessel above the Fuel Alignment Plate (FAP) even when a steam/water two-phase mixture exists in the reactor vessel. This is accomplished by use of a separator tube which acts like an internal sight glass and creates a single-phase water level inside it when surrounded by a two-phase mixture, see Figure 1-1. The height of the water level inside the separator tube is equal to the height of the collapsed water level (water inventory) in the two-phase mixture surrounding the separator tube. Tests performed at C-E during the Phase II portion of the HJTC test program have demonstrated that a single-phase water level is created inside the separator tube when immersed in a two-phase mixture and that the HJTC sensors, which are placed inside the separator tube, measure that water level.

The reactor vessel configuration of a typical PWR reactor consists of two major regions above the Fuel Alignment Plate (FAP): (1) the upper plenum and (2) the upper head and Control Element Assembly (CEA) shrouds. The hydraulic coupling between these two regions is not very strong and occurs via a small number of flow holes in the Upper Guide Structure Support Plate (UGSSP).

During loss-of-inventory or volume-reduction accidents, the loss of water inventory proceeds somewhat independently in the two regions. The upper head, is expected to drain faster than either the CEA shrouds or the upper plenum.

B. Overall Effect of Reactor Coolant Pumps

The overall effect of Reactor Coolant Pump (RCP) operation is to circulate more vigorously and homogenize more uniformly, relative to no RCPs in operation, the two-phase mixture which is produced by flashing and/or boiling of the coolant. The capability of the separator tube to create a single-phase water level inside it is not affected by the RCP operation. Also, due to the very small flow in the upper head region of the reactor vessel (as will be discussed in more detail in the following paragraph), RCP operation will have no significant effect on the two-phase response in this region. Therefore, the HJTC response in the upper head region (above the CEA shrouds) is expected to be the same with or without the RCPs in operation.

In the upper plenum region, the forced circulation of the coolant by the RCPs together with the complex geometry of the reactor vessel above the FAP causes static pressure differences which can cause differences between the single-phase water level inside the separator tube and the equivalent collapsed water level in the surrounding region. With the Reactor Coolant Pumps (RCPs) running, the majority of the coolant flow enters the upper plenum through holes in the FAP, see Figure 1-2. This flow experiences a pressure drop across the FAP (typically 4 to 6 psi during normal, single-phase water operation, but decreasing as system voiding increases). A small portion of the coolant (about 3%) flows up the Control Element Assembly (CEA) shrouds to the upper head and then down into the upper plenum through holes in the Upper Guide Structure Support Plate (UGSSP). The pressure drop for flow in the CEA shrouds is relatively small because the holes in the UGSSP represent the governing resistance. Thus, the pressure in the upper head and CEA shrouds is greater than the pressure in the upper plenum.

In addition, there is an axial variation (beyond the one due to changing elevation heads) in the static pressure within the upper plenum region with the RCPs running. High velocity flow jets through the holes in the FAP result in a reduced static pressure immediately downstream of the FAP. Recovery of the static pressure occurs as the flow velocity decreases farther away from the FAP. Thus, there is a greater static pressure at the top of the upper plenum (just below the UGSSP) than at the bottom (just above the FAP).

These pressure differences will decrease as the void fraction in the primary coolant system increases. This is due to degradation of the pump performance that occurs as the void fraction increases and results in a decrease in mass flow rate. Thus, as water inventory is lost during a small break LOCA with the RCPs running and system voiding increases, the effect of the RCPs on the indicated collapsed level is expected to decrease. The effect of the RCPs is also smaller if fewer RCPs are running.

C. Full Length Probe

The effect of the RCPs on the measured collapsed water level is different for the two probe assembly installation designs. One design is a full length probe installed inside an empty CEA shroud, see Figure 1-3. For this installation the RCP operation has no effect on the HJTC measurement until after the collapsed water level drops below the top of the shroud (in this context, top of the CEA shroud actually refers to the large flow holes in the walls of the shroud which are located below the actual top of the shroud and above the UGSS-plate). The operating RCPs are expected to cause the collapsed level inside the CEA shroud to be higher than the collapsed level in the upper plenum. This is due to the lower pressure drop across the FAP for flow into the CEA shroud and upper head than for flow into the upper plenum. Thus, the RCPs are able to support a higher column of water inside the shrouds than outside in the upper plenum.

The HJTC probe will correctly indicate voiding in the upper head down to the elevation of the top of the CEA shrouds. The HJTC probe will also accurately measure the collapsed water level in the shrouds. However, it is expected that the measured collapsed level inside the shrouds will be higher than the collapsed level in the upper plenum.

D. Split Probe

The second installation design is a split probe which penetrates the upper head and upper plenum region. The split probe is divided at the Upper Guide Structure Support Plate (UGSSP) into two hydraulically independent separator tubes, see Figure 1-4 for a schematic of the installation in the System 80 plants. The split probe measures the collapsed water level in the upper head (above the UGSSP) separately from the collapsed water level in the upper plenum (below the UGSSP).

The HJTC measurement in the upper head is not affected by the operation of the RCPs and will correctly indicate voiding in the upper head. The HJTC measurement in the upper plenum, however, may be biased toward giving a lower indication of the collapsed level than actually exists when the RCPs are running. This is because the static pressure at the top of the upper plenum is greater than the static pressure at the bottom (see Figure 1-3) due to pressure recovery downstream of the holes in the FAP. Thus, the greater static pressure at the top holes of the upper plenum separator tube is expected to depress the collapsed water level inside the separator tube relative to the collapsed level in the upper plenum and result in a lower than actual indicated water level.

E. Operator Instructions

Instructions on how to interpret the indications from the HJTC System under all expected conditions will be provided to the operator. Based on current information, it will be recommended that the operator should disregard that portion of the collapsed water level indication that is biased when the RCPs are running.

For the full length probe it will be recommended that the operator should disregard the indicated level with the RCPs running after the level has dropped to the top of the CEA shroud and below. The placement of the HJTC sensors is such that one sensor per probe is located at the elevation of the top of the CEA shroud and one or more sensors above the top of the CEA shroud.

For the split probe, the indicated level from the upper portion of the probe in the upper head is unaffected by RCP operation. The lower portion of the probe in the upper plenum is expected to be affected by RCP operation. Based on present information, it will be recommended that the operator disregard the indicated level from the lower probe portion when the RCPs are running.

In conclusion, the readings from the full length as well as from the split probe which are unaffected by the RCP operation provide the operator with sufficient information to recognize and to track voiding in the upper head region of the reactor vessel. These readings will also continue to provide an indication whether voiding in the upper head persists.

FIGURE 1-1

SCHEMATIC OF PROBE

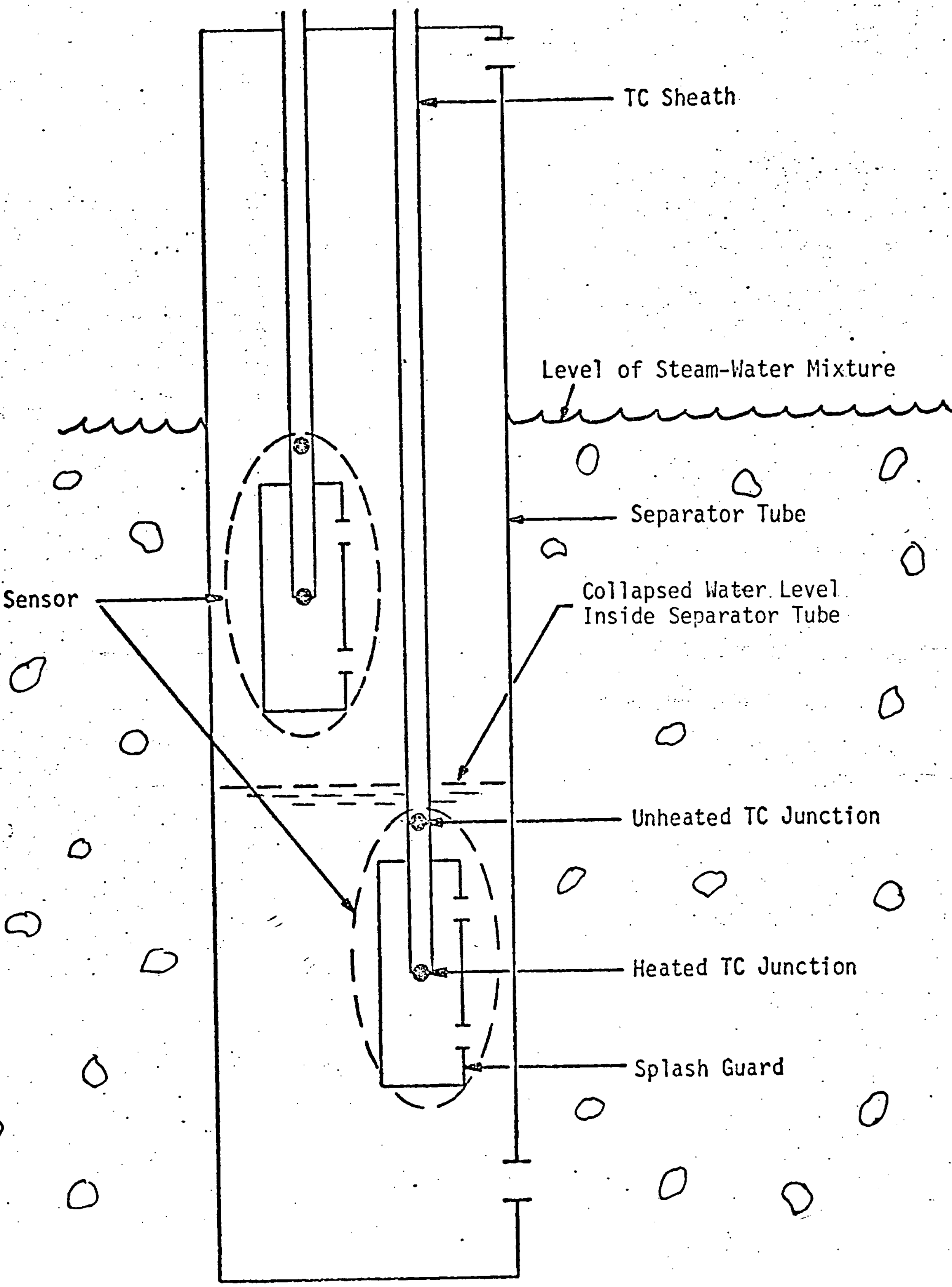


FIGURE 1-2

EFFECT OF REACTOR COOLANT PUMPS

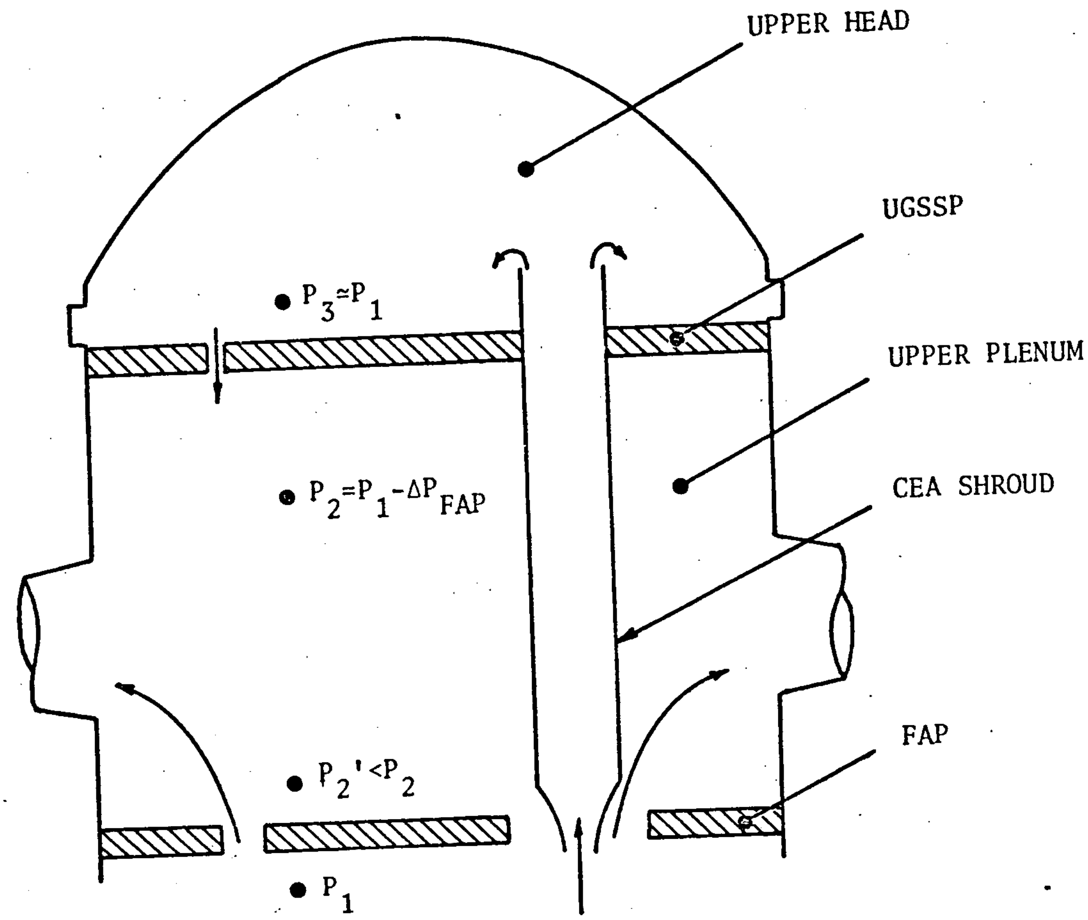


Figure 1-3
EXPECTED EFFECT OF RCPs ON HJTC MEASUREMENT FOR FULL LENGTH PROBE

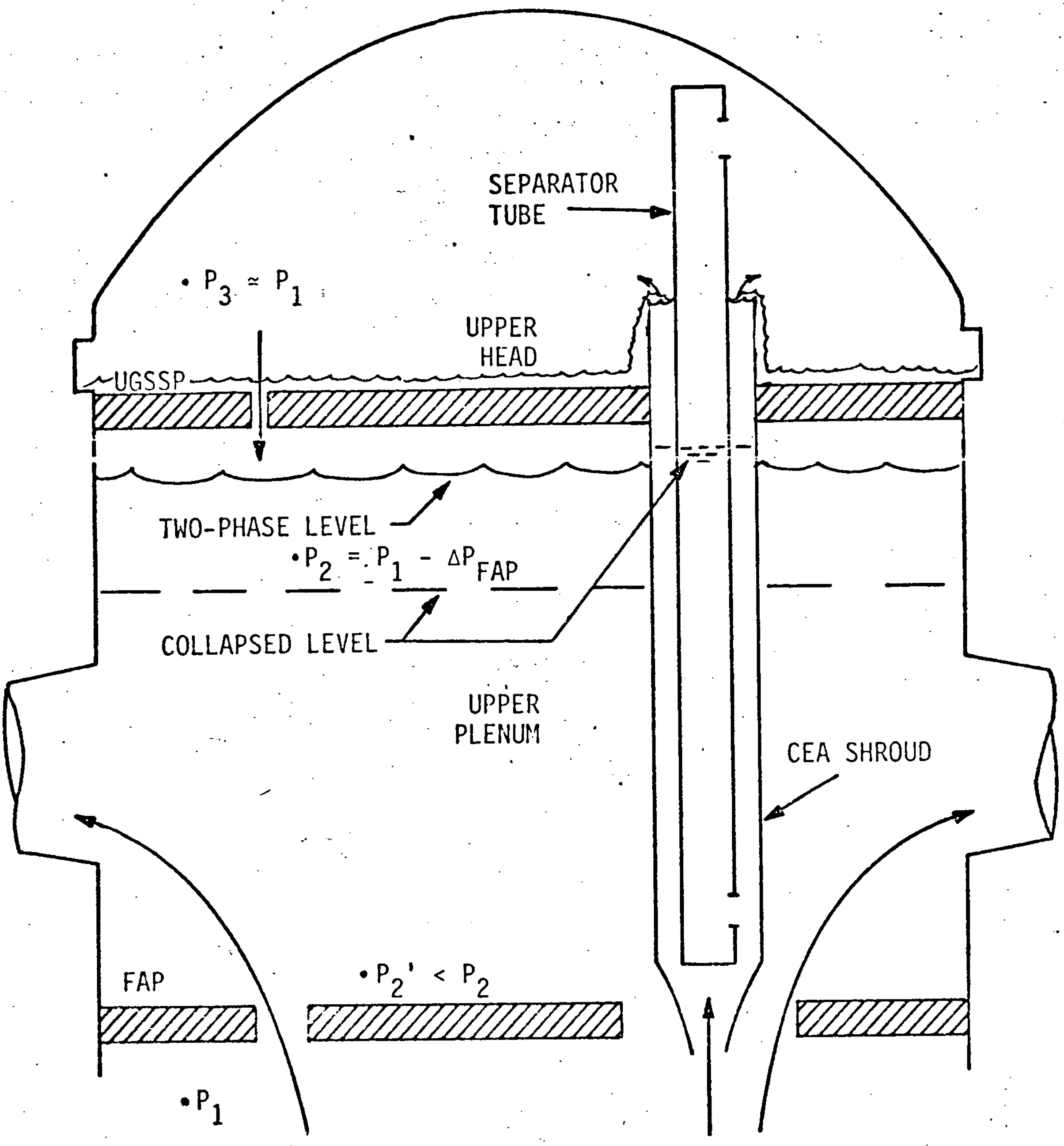
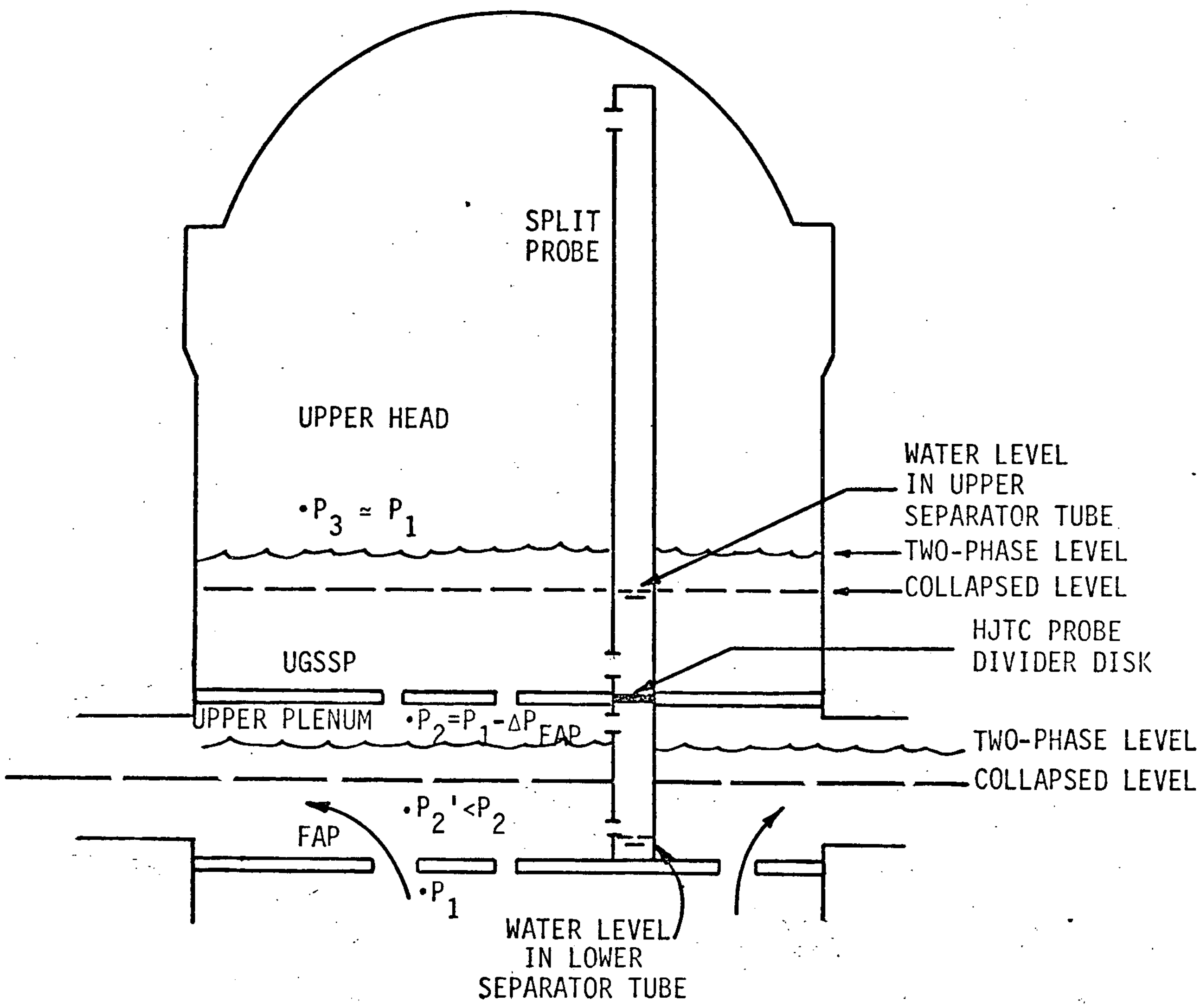


Figure 1-4

EXPECTED EFFECT OF RCPs ON
HJTC MEASUREMENT FOR SPLIT PROBE
SCHEMATIC OF SYSTEM 80 INSTALLATION



QUESTION 2

Provide an analysis of the response of the heated junction thermocouple level measurement system with a break in the upper head (a) with the full length separator tube, and (b) with the split separator tube in the System 80 plants. Also, discuss the instructions to the operator for interpretation of the indications.

RESPONSE

For a postulated break in the upper head the principal question is whether hold-up of two-phase mixture inside the separator tube might cool the HJTC sensors resulting in an indication of an unchanged water level while the water inventory outside the probe could decrease. Test results indicate that this is not the case. The separator tube provides a true indication of the collapsed level even under these conditions.

A top blowdown was simulated in the Phase II tests of the HJTC probe assembly. With the test vessel completely filled with water and at a pressure of about 1800 psig, a valve at the top of the vessel was opened. This initiated a blowdown from the top of the test vessel at a rate of about 10 psi/sec, which is about 10 times faster than during a small break. Three HJTC sensors were located about 54 inches apart at the top, middle and bottom of the separator tube which was placed inside the test vessel.

The differential temperature for the top and middle HJTC sensors increased in sequence after the blowdown valve was opened indicating that the water level in the separator tube was receding from the top down in the same manner the water inventory outside the separator tube was receding. The test ended before the bottom sensor was uncovered. This test showed that a two-phase mixture that could keep the HJTC sensors cooled did not flow up the separator tube as a result of the top blowdown.

Based on the present information, the response of the HJTC level measurement system to a break in the upper head is expected to be generally similar to the response for a break elsewhere in the primary system. Thus, the operator would not need any special instructions for this case.

QUESTION 3

Provide an analysis of the response of the heated junction thermocouple level measurement system after a large break LOCA. In particular, how will the level inside the separator tube compare with the level outside, taking into account the drain rate of the separator tube? What instructions will be provided the operator for interpretation of the indications?

RESPONSE

The HJTC System is intended to provide the operator with information that he can use in mitigating the consequences of a transient which produces a void in the reactor vessel. The blowdown portion of a large break LOCA occurs approximately during the first half minute of the transient and proceeds much too fast for the operator to take any action. Thus, the HJTC System is not designed to measure the collapsed water level during this time period. It will, however, measure the collapsed level during the reflood portion of a large break which proceeds at a much slower rate than the blowdown.

It is not expected that any substantial water hold-up will occur in the separator tube during a large break. There is one set of eight 9/32 inch diameter holes at both the bottom and at the top of the separator tube. This provides a flow area for drainage that is approximately equal to the inside area of the separator tube. The total volume inside a full-length separator tube is only about 0.05 ft^3. Thus, the flow holes in the separator tube pose no signficant restriction to the escape of flashing steam or draining water. During a rapid depressurization like in a large LOCA blowdown, the water inside the separator tube is expected to flash and escape from the separator tube in the same time period as the water in the surrounding region flashes and is discharged from the primary system.

Phase II test results show that the water level inside the separator tube lags the level outside the separator by less than four inches for an outside drain rate of 5 in/sec. This agrees with calculations that have been performed for conservatively high drain rates outside the separator. Thus, the separator tube is capable of draining fast enough so that the level inside the tube is very close to the level outside the tube.

For a large break LOCA, it will be recommended that the operator disregard the indicated level until after the initial blowdown period is over and the reactor coolant system pressure has become stable. This blowdown period will last for only a short time during the initial part of the transient.

Quest.4. Describe the effects of failure of the following components of the heated junction thermocouple level measurement system with respect to measurement system response, information presented to the operator, and effects on recovery from an abnormal transient:

General Response

The following responses are generic to either the stand alone Heated Junction Thermocouple System or Integrated Accident Monitoring System with Heated Junction Thermocouple processing. The responses are based on an engineering evaluation , since no detailed Failure Modes & Effects Analysis have been performed. An assessment of the effects of failures in recovery from abnormal transients must also take into account the operators use of the HJTC level measurements which will be plant dependent (procedures, training, tech specs, etc.).

As discussed in previous responses provided in CEN-181-P the reactor vessel level signal processing consists of two independent and redundant channels. An operator can assess system operability during plant operation by performing cross-channel checks. In addition to redundant channels and operator periodic system checks, operational availability is further enhanced by the use of automatic diagnostics performed by the processor itself. Fault indications are provided at the operator display.

Quest. A. Sensor

1) Single thermocouple failure in a single sensor. The thermocouple is assumed to fail by a break in at least one thermoelement that would result in an open circuit.

   a. Would the automatic checking procedure detect the fault before the QSPDS continued to record data?
   b. What would happen to the differential output?

2) Heater failure in a single sensor. The heater is assumed to fail by a break in the heater element that would result in an open circuit.

   a. Would the automatic checking procedure detect the fault before the QSPDS continued to record data?
   b. What would be the effect on the other heaters in the same string?

3) Assume a rupture in the sensor sheath so that coolant is admitted into the sensor.

   a. Would the automatic checking procedure detect the fault before the QSPDS continued to record data?
   b. What would be the effect on the heater in the affected area, and other heaters in the same string?

Response 4.A.1.a

The A/D circuitry uses a "flying capacitor" input isolation technique for the thermocouple (TC) inputs to the microprocessor. If a thermocouple circuit opens, an open TC detection circuit drives the capacitor to a full scale input voltage, which is detected in the microprocessor as a fault condition. The open thermocouple circuit has a fixed time constant which will take a few microprocessor cycles to drive the capacitor up to a full scale value and be detected. After detection that the thermocouple is failed, the microprocessor (μP) provides a fault indication at the operator display and disregards the TC input in all future calculations.

Response 4.A.1.b

The response of the differential output to a break in a thermocouple wire depends on which wire breaks.

1. If the chromel wire from the heated junction breaks, the differential (ΔT) output will continue to increase until the microprocessor detects a full scale heated junction temperature voltage reading. Then the thermocouple input will be recognized as faulty and disregarded.

2. If the chromel wire from the unheated junction breaks, the differential output will continue to decrease and eventually go negative. This continues until the μP detects an unheated junction voltage reaching the top of scale. The thermocouple input will be disregarded.

3. For a break in the alumel wire, common to the heated and unheated junctions, the differential output will remain essentially constant but will drift up as both heated and unheated inputs are driven to the top of scale value. The processor detects and alarms the open TC and will disregard its use.

Response 4.A.2.a

The differential (ΔT) output will decrease until a "low ΔT" fault condition is detected and alarmed at operator display. The sensor is not totally disregarded because it continues to provide measurement of local temperature.

Response 4.A.2.b

There is one probe assembly in each channel. Each probe assembly contains eight HJTC sensors which are divided into two groups of four. The four heaters are in series, each series group of four being operated by a single heater controller. Although groups of four heaters are in series, the recommended reactor installation would make all heater power leads accessible outside containment.

In the event that a single heater conductor fails by open circuiting, the result would be a decrease in the temperature of the heated thermocouple in that sensor. Similarly, the three other sensors in series with the failed heater would be temporarily non-operational and the heated thermocouples would drop in temperature to the reference junction temperature. The operator is made aware of the malfunction by a fault indication at the display panel as a result of a low ΔT alarm. Continuity checks can be performed from outside containment and would identify which heater has failed. The other three sensors of the group could be returned to operation by adding a suitable resistor in place of the failed heater. The end result is a less refined level indication in one channel of the RVLMS.

Response 4.A.3.a

Each sensor (TCs, cable and connector) is electrically and physically separate from others. Thus, a maximum of a single failed sensor could occur due to leakage as a result of sheath failure. The answer depends on the particular failure mechanism of the TCs when subjected to the various postulated water conditions associated with the question. Open TCs and loss of heaters are detected as previously described. Shorted TCs could be detected by cross channel comparisons and operator observations of erratic and decalibrated temperature indications. Also the μP could detect certain shorts where a "low ΔT" (e.g. shorted heated junction) or "high ΔT" (e.g. shorted unheated junction outside its temperature region, say at the connector, which results in a low Tref and hence high ΔT) condition occurs. Another consequence of water entering the sheath is that the connector could fail because of corrosive action or electrical shorting (see connector response).

This type of postulated failure is expected to be of very low probability as a result of quality controlled materials and fabrication of TCs which includes controlled welding procedures, routine leak testing and hydrostatic acceptance tests. In addition, Phase III testing and separate autoclave tests have demonstrated this to be an unlikely failure mechanism.

Response 4.A.3.b

If water in the thermocouple sheath results in an open heater, the same comments as in question 4.A.2 apply. If water in the thermocouple sheath results in the heater being completely or partially shorted, then the other heaters will dissipate up to 50 percent more power. A likely consequence of one heater in a string becoming shorted is a blown heater power supply fuse. This would lead to a low ΔT alarm. Resistance checks from outside containment would identify the shorted heater.

Quest. B. Probe

1. Reactor Vessel Seal Failure

Response 4.B.1

The sealing technique used for the Heated Junction Thermocouple probe assembly is similar to that widely used on C-E plants for in-core instrument assemblies. Operating experience indicates that gross seal failure is extremely unlikely. A gradual deterioration of a seal, which would permit an annoying small quantity of coolant to leak out, would have no effect on the performance of the probe. Gross failure of a sensor seal or a probe seal would fall into the category of small upper head break. However, the two probe assemblies of the Heated Junction Thermocouple System always exit the vessel in physically separate locations. Accordingly, failure of a seal on one probe has no effect on the other probe. The response of the probe during upper head breaks (in which the break is somewhat remote from the probe seal region) was recorded in tests conducted at C-E. In these tests, the sensors provided a clear indication of a loss of inventory in the sequence expected, with good agreement between the probe and independent instrumentation (see response to question 2).

Quest. C. Cables

1. Assume Failure of Connector

   a. Complete failure of connector

   b. Partial failure (only some of the connections fail)

2. Severed Cable

3. Wet Connector

4. Incorrect Wiring at Connectors (or any other location inside containment)

   A common error in large installations is the incorrect wiring of the thermocouple extension cables by connection of the alumel extension lead to the chromel thermoelement, etc. Under stable containment conditions, this could produce an offset. If the temperature of the containment were to rise, much larger temperature errors could result. This situation should be analyzed for the effect on both the thermocouple signals from the individual thermocouples and the differential signals.

Response 4.C.1.a

A complete failure of a connector by open circuiting causes the thermocouple signal voltage to go full scale, and as a result at this point ΔT is below the low ΔT fault setpoint also. A fault indication will be provided at the operator panel for the two out-of-range thermocouples and the low ΔT condition. The affected sensor can be identified by interrogating individual sensor outputs at the operator panel. The remaining three sensors in the heater string can be returned to service by installing a resistive (dummy load) jumper across the heater cable terminals outside of the containment.

Response 4.C.1.b

Partial failure of a connector would have the same effects as those discussed for open circuit thermocouples or heaters.

Response 4.C.2

A severed cable will result in open thermocouple and heater circuits. The effect of these conditions were discussed previously. Each sensor has a separate cable containing thermocouple wires and heater power leads, so that the effects of a severed cable are limited to one sensor.

Response 4.C.3

A wet connector can cause thermocouple output errors and reduced heater power. The microprocessor will detect open TCs as discussed previously, but may not automatically detect all shorted or partially shorted thermocouples conditions. An operator comparison to other thermocouples in the same channel and to the other channel indications will identify any differences in system output, which can then be traced.

Response 4.C.4

Incorrect wiring of the thermocouple extension wires can produce a variety of errors depending on the ambient temperatures and specific wiring errors. Proper plant installation procedures and testing including checking each thermocouple extension wire with a magnet before connection can minimize errors. In addition, system testing during power plant preoperational testing should provide assurance that the system is wired properly and functioning correctly. However, if an error does exist, particularly during plant operation, each thermocouple output will be observed at the operators panel. Any vague or unusual temperature indication, when compared to other thermocouples and/or RTDs, will become obvious and must be investigated further. Wiring errors which result in low ΔT fault alarms, high ΔT uncovered indications, and incorrect temperature measurements will be visable at the operators display.

Quest. D. Control Circuit

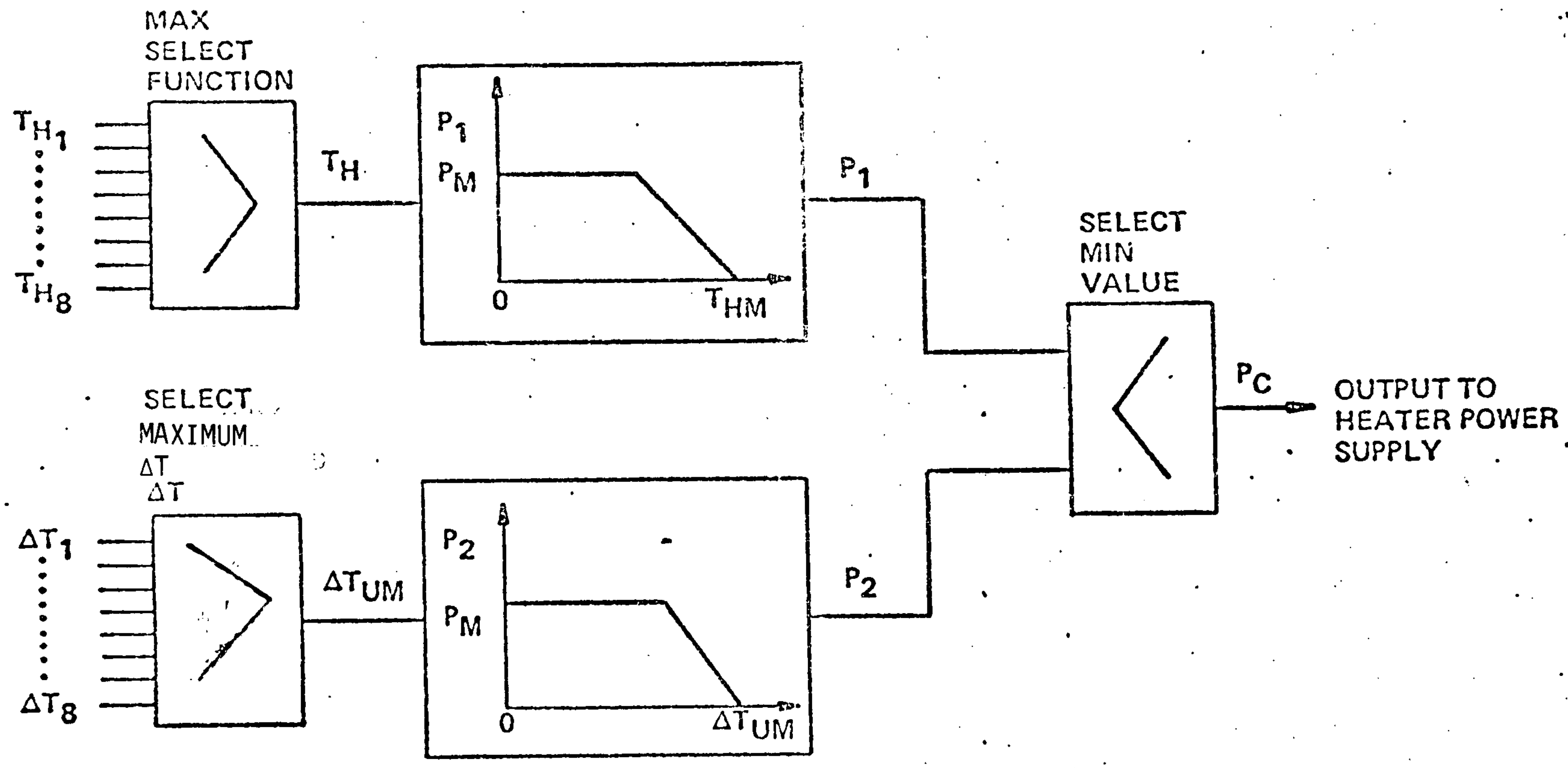
1) If the heater supply is designed for fast response, rapid fluctuations in the control signal can induce oscillations in the heater supply output. This in turn could cause heater failure by overheating or fatigue.

Response 4.D.1

The heater controller used in the RVLMS is a time modulated controller. When the control signal from the processor calls for full power, the controller delivers 100% power, 100% of the time. If the processor calls for 50% power (for example), the controller delivers 100% power for only one half of its duty cycle. The particular controllers utilized in the Heated Junction Thermocouple System have a duty cycle of 0.8 seconds. The sensor heaters and the controllers are sized such that full power is applied to all heaters during all normal operating conditions (i.e., when the sensors are covered, or at high pressure). In the event that uncovery occurs, the heater controllers may be called upon to reduce power to the heaters depending on the absolute temperature of any heated thermocouple or on the differential temperature of any sensor as shown in Figure 1.

The heater control scheme uses a proportional control law in which the microprocessor heater control signal goes from 100% to 0% over a temperature input range of 200°F. This shallow slope prevents large changes in power from being applied for small changes in input temperature. Some heater power cycling has been observed to occur because of the sampling rate of the microprocessor. During Phase III tests of the system, the fluctuations of the heated junction temperature have been observed to be relatively small, on the order of 10°F. These fluctuations are insignificant when compared to the temperature swings which result from uncovery or quenching of the sensor, and do not contribute significantly to heater fatigue.

Figure 1
HEATER POWER CONTROL LOGIC (EACH CHANNEL)



P_C - CONTROL SIGNAL TO HEATER POWER SUPPLY

P_1 - CONTROL SIGNAL BASED ON HIGH T_H

P_2 - CONTROL SIGNAL BASED ON HIGH ΔT

P_M - MAXIMUM POWER TO HEATERS

T_H - HEATED JUNCTION OUTPUT

T_{HM} - HIGHEST HEATED JUNCTION TEMPERATURE

ΔT_{UM} - MAXIMUM ΔT

SETPOINTS TO BE DETERMINED LATER