BYRON/BRAIDWOOD STATIONS - UNITS 1 AND 2

INADEQUATE CO[illegible]NG DETECTION SYSTEM

SUMMARY STATUS REPORT

APRIL, 1982

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1.0 INTRODUCTION

1.1 SUMMARY OF ACTIVITIES

This report responds to the requirements in Section II.F.2 of NUREG-0737 (Ref. 1). The report describes the status of design and development activities being conducted by the C-E Owners Group as supplemented by plant specific efforts by Commonwealth Edison Company to define and implement a system of instrumentation to be used to detect inadequate core cooling (ICC). The report also provides information specific to Byron/Braidwood Units 1 and 2 in order to demonstrate the applicability of the generic activity to Byron/Braidwood Units 1 and 2.

Results of initial studies by the C-E Owners Group are documented in reports CEN-117 (Ref. 2) and CEN-125 (Ref. 3). All studies have been based on the requirement to indicate the approach to, the existence of, and the recovery from ICC.

The ICC system selected was specifically based on the results presented in CEN-185 (Reference 5). The basis for the instruments selected is summarized below.

1.2 BASES FOR ICC INSTRUMENT SELECTION

The ICC instrumentation sensor package described herein is designed to:
1) provide the operator with an advanced warning of the approach to ICC
2) cover the full range of ICC from normal operation to complete core uncovery.

The ICC detection system that employs this sensor package and displays, trends and logs the sensor outputs, enabling the reactor operator to monitor system conditions associated with the approach to and the recovery from ICC.

1.3. DESCRIPTION OF ICC EVENT PROGRESSION

The instrument sensor package for ICC detection provides the reactor operator a continuous indication of the thermal-hydraulic state within the Reactor Pressure Vessel (RPV) during the progression of an event leading to and away from ICC. The progression towards and away from ICC can be divided into intervals based on physical processes occurring within the RPV. These are characterized as follows:

Intervals Associated with the Approach to ICC

Interval 1 Loss of fluid subcooling prior to the first occurrence of saturation conditions in the coolant.

Interval 2 Decreasing coolant inventory within the upper plenum, (from the top of the vessel to the top of the active fuel).

Interval 3 Increasing core exit temperature produced by uncovery of the core resulting from the drop in level of the mixture of vapor bubbles and liquid below the top of the active fuel.

Intervals Associated with Recovery from ICC

Interval 4a Decreasing core exit temperature resulting from the rising of the mixture level within the core.

Interval 4b Increasing inventory above the fuel.

Interval 4c Establishment of saturation conditions followed by an increase in fluid subcooling.

These intervals encompass all possible coolant states associated with any ICC event progression. Intervals 1 thru 3 refer to fluid situations that occur during the approach to ICC. Intervals 4a, 4b and 4c refer to fluid situations which occur during the recovery from ICC.

In order to provide indicators during the entire progression of an event, an ICC instrument system should consist of instruments which provide at least one appropriate indicator for each of the physical intervals described above.

Applying this description of the "approach to", and "recovery from" ICC to ICC instrument selection:

1) provides assurance that the selected ICC system detects the entire progression.

2) demonstrates the extent of instrument diversity or redundancy which is possible with the available instruments.

Furthermore, by defining the ICC progression on a physical basis the general labels of "approach to", and "recovery from" ICC can now be associated with specific physically measurable processes. (See Section 1.3.1 and 1.3.3)

The inadequate core cooling instrument sensor package consists of (1) Reactor coolant loop and pressurizer pressure sensors, (2) reactor vessel level monitors employing the HJTC concept and (3) core exit thermocouples. The signals from the temperature and pressure sensors can be combined to indicate the loss of subcooling and occurrence of saturation (Interval 1) and the achievement of a subcooled condition following core recovery (Interval 4c). The reactor vessel level monitors provide information to the operator on the decreasing liquid inventory in the reactor pressure vessel (RPV) regions above the fuel alignment plate, as well as the increasing RPV liquid inventory above the fuel alignment plate following core recovery (Interval 2 and 4b). The core exit thermocouples (CETs) monitor the increasing steam temperatures associated with core uncovery and the decreasing steam temperatures associated with core recovery (Interval 3 and 4a).

1.3.1 Advanced Warning Of The Approach To ICC

The ICC instrumentation provides the operator with an advanced warning of the approach to ICC by providing indications of:

1) the loss of subcooling and occurrence of saturation (Interval 1) with a saturation meter receiving input from primary system temperature and pressure sensors.

2) the loss of inventory in the RPV (Interval 2) with the RVLMS.

3) the increasing core coolant exit temperature (Interval 3) with CETs.

It should be noted that the RVLMS measures inventory (collapsed liquid level) rather than two-phase level. This measurement provides the operator with an advanced indication of the coolant level should conditions arise to cause the two-phase froth to collapse via system overpressurization, or the loss of operating reactor coolant pumps.

1.3.2 Application Of The ICC Detection Instruments

Following an event leading to ICC the ICC detection instruments will provide information to the reactor operator so that he may:

1) verify that the core heat removal safety function is being met.

2) establish the potential for fission product release.

ICC instrumentation indications will be used to support the operator in helping to verify that the core heat removal safety function is being met. ICC instrumentation indications available to the operator are (1) a decreasing core exit steam superheat, (2) an increasing inventory above the fuel alignment plate or (3) an increasing subcooling in the RPV or RCS piping.

The operator is informed about the progression of an event by both static and trend displays. The trending of ICC information enables the operator to quickly assess the success of automatically or manually performed mitigating actions. A chart indicating the ICC instrumentation trending during the various ICC progression intervals associated with the approach to and recovery from ICC is presented in Table 1-1.

TABLE 1-1

ICC STATUS AS AVAILABLE TO THE OPERATOR FROM ICC INSTRUMENTATION TRENDING

I. APPROACHING AN ICC CONDITION

INTERVAL	SUBCOOLING MEASURED BY SMM	WATER INVENTORY MEASURED BY HJTC PROBE	COOLANT SUPERHEAT MEASURED BY CET
1	DECREASING	CONSTANT	CONSTANT
2	CONSTANT	DECREASING	CONSTANT
3	CONSTANT	CONSTANT	INCREASING

II. RECEDING FROM AN ICC CONDITION

INTERVAL	SUBCOOLING MEASURED BY SMM	WATER INVENTORY MEASURED BY HJTC PROBE	COOLANT SUPERHEAT MEASURED BY CET
4a	CONSTANT	CONSTANT	DECREASING
4b	CONSTANT	INCREASING	CONSTANT
4c	INCREASING	CONSTANT	CONSTANT

1.3.3 INSTRUMENT RANGE

In the ICC instrumentation sensor package saturation temperature and water inventory are used as indicators for the approach to and recovery from ICC when there is water inventory above the fuel alignment plate. These measurements characterize Intervals 1, 2, 4b and 4c of the ICC progression.

When the two-phase level is below the fuel alignment plate, the measurement of core exit fluid temperature represents a direct indication of the approach to, and recovery from ICC (Intervals 3 and 4a). Therefore, the ICC sensor package is sufficient to provide information to the reactor operator on the entire progression of an event with the potential of resulting in ICC.

1.4 SUMMARY OF SENSOR EVALUATIONS

Several sensors have been evaluated for use in an ICC Detection System. Significant conclusions about each instrument are given below.

1.4.1 Subcooled Margin Monitor

A subcooled Margin Monitor (SMM), using inputs from existing Resistance Temperature Detectors (RTD) in the hot and cold legs and from the pressurizer pressure sensors, is adequate to detect the initial occurrence of saturation during LOCA events and during loss of heat sink events.

However, the usefulness of the SMM can be significantly increased by using the signals from the fluid temperature measurements from the HJTCS and the signals from selected core exit thermocouples and by modifying the SMM to calculate and display degrees superheat (up to about 1800°F) in addition to degrees subcooling. The signals from the HJTCS temperature measurements provide information about possible local differences in temperature between the reactor vessel upper head/upper plenum (location of the HJTCS) and the hot or cold legs (location of the wide range RTDs). The core exit thermocouples respond to the coolant temperature at the core exit and their signal indicates superheat after the coolant level drops below the top of the core and, thus, provide an approximate indication of the depth of core uncovery.

With this implementation, the SMM can be used for detection of the approach to ICC, namely Interval 1 (loss of subcooling), Interval 3 (core uncovery), Interval 4b (core recovery) and Interval 4c (establishment of saturation conditions). Even with the modifications, the SMM will not be capable of indicating the existence of Interval 2 when the coolant is at saturation conditions and the level is between the top of the vessel and the top of the core.

The recovery interval may occur at low system pressure and temperature. Since the errors in the existing SMM calculations increase with lower temperature and pressure, required subcooling margins need to be revised for this situation.

1.4.2 Resistance Temperature Detectors (RTD)

The RTD are adequate for sensing the initial occurrence of saturation. Narrow range RTD are located in the hot and cold leg manifolds and the wide range RTD are located in the hot and cold legs of the reactor coolant piping. Either of the narrow or wide range RTD are sufficient to sense saturation for events initiated at power. The wide range RTD are sufficient to sense saturation for events initiated from zero power or shutdown conditions.

The RTD range is not adequate for ICC indications during core uncovery. For depressurization LOCA events, the core may uncover at low pressure, when the saturation temperature is below the lower limit of the RTD. Initial superheat of the steam will therefore not be detected by the RTD. As the uncovery proceeds, the superheated steam temperature may quickly exceed the upper limit of the RTD range. In order to be useful during the core uncovery interval, the range of RTD would have to be increased to cover a temperature range from 100°F to 1800°F.

1.4.3 Heated Junction Thermocouple System (HJTCS)

The HJTCS is being designed to show the liquid inventory of the mixture of liquid and vapor coolant above the core. It is an instrument which shows the approach to ICC and is the only one which functions in Interval 2, namely the period from the initial occurrence of saturation conditions until the start of core uncovery and Interval 4b, the period when inventory is increasing above the fuel alignment plate.

1.4.4 Core Exit Thermocouples

The core exit thermocouples are adequate to show the approach to ICC after core uncovery for the events analyzed, provided that the signal processing and display does not add substantial time delay to the thermal delay at the thermocouple junction. As mentioned above, the core exit thermocouples respond to the coolant temperature at the core exit and indicate superheat after the core is no longer completely covered by coolant. Except for a time delay, depending on event, the trend of the change in superheat corresponds to the trend of core uncovery as well as to the accompanying trend of the change in cladding temperature.

2.0 SYSTEM FUNCTIONAL DESCRIPTION

In the following sections a functional description of the instruments of the ICC Detection System is given and the function of the instruments is related to the ICC intervals which were described in Section 1.0.

2.1 SUBCOOLING AND SATURATION

The parameters measured to detect subcooling and saturation are the RCS coolant temperature and pressure. The measurement range extends from the shutdown cooling conditions up to saturation conditions at the pressurizer safety valve setpoint. The response time needs to be such that the operator obtains adequate information during those events which proceed slowly enough for him to observe and to act upon the information.

The information which is derived from the reactor vessel temperature and pressure measurements is the amount of subcooling during the initial approach to saturation conditions and the occurrence of saturation during Interval one. During Interval four, the reestablishment of subcooled conditions is obtained.

2.2 COOLANT LEVEL MEASUREMENT IN REACTOR VESSEL

The Reactor Coolant System is at saturation conditions until sufficient coolant is lost to lower the two-phase level to the top of the active core. During this interval there are no existing instruments which would measure directly the coolant inventory loss. A Reactor Vessel Level Monitoring System provides a direct measurement during this period. The parameter which is measured is the collapsed liquid level above the fuel alignment plate. The collapsed level represents the amount of liquid mass which is in the reactor vessel above the core. Measurement of the collapsed water level was selected in preference to measuring two-phase level, because it is a direct indication of the water inventory while the two phase level is determined by water inventory and void fraction.

The collapsed level is obtained over the same temperature and pressure range as the saturation measurements, thereby encompassing all operating and accident conditions where it must function. Also, it is intended to function during Interval four, the recovery interval. Therefore, it must survive the high steam temperature which may occur during the preceding core uncovery interval.

The level range extends from the top of the vessel down to the top of the fuel alignment plate. The response time is short enough to track the level during small break LOCA events. The resolution is sufficient to show the initial level drop, the key locations near the hot leg elevation and the lowest levels just above the alignment plate. This provides the operator with adequate indication to track the progression during Intervals two and four and to detect the consequences of his mitigating actions or the functionability of automatic equipment.

2.3. FUEL CLADDING HEATUP

The overall intent of ICC detection is understood to be the detection of the potential for fission product release from the reactor fuel. The parameter which is most directly related to the potential for fission product release is the cladding temperature rather than the uncovery of the core by coolant.

Since clad temperature is not directly measured, a parameter to which cladding temperature may be related is measured. This parameter is the fluid temperature at the core exit. After the core becomes uncovered, the fluid leaving the core is superheated steam and the amount of superheat is related to the fuel length exposed and to the cladding temperature.

The amount of superheat of the steam leaving the core will be measured by the core exit thermocouples. The time behavior of the superheat temperature is, with the exception of an acceptably small time delay, similar to the time behavior of the cladding temperature. Thus, from the observation of the steam superheat, the behavior of the cladding temperature can be inferred. Observation of the cladding temperature trends during an accident is considered to be of more value to the operator than information on the absolute value of the cladding temperature.

The core exit steam temperature is measured with the thermocouples located at an elevation a few inches above the fuel alignment plate. Generic calculations of a similar installation for representative uncovery events show that the thermocouples respond sufficiently fast to the increasing steam temperature.

The required temperature range of the thermocouples extends from the lowest saturation temperature at which uncovery may occur up to the maximum core average exit temperature which occurs when the peak clad temperature reaches 2200°F. The required thermocouple range is therefore 200°F to about 1800°F, which is the approximate upper service temperature limit. Thermocouples are expected to function with reduced accuracy at even higher temperatures, so the range for processing the thermocouple output extends to about 2300°F.

3.0 SYSTEM DESIGN DESCRIPTION

The following sensors have been selected as the basic instruments to meet the functional requirements described in section 2.

1. The subcooled margin monitor (SMM) (Reference 1)

2. The heated junction thermocouple (HJTC) system (Reference 2) and

3. The core exit thermocouple (CET) system.

The conceptual design of each ICC instrument is described in this section which addresses:

1. Sensors design

2. Signal processing and display design

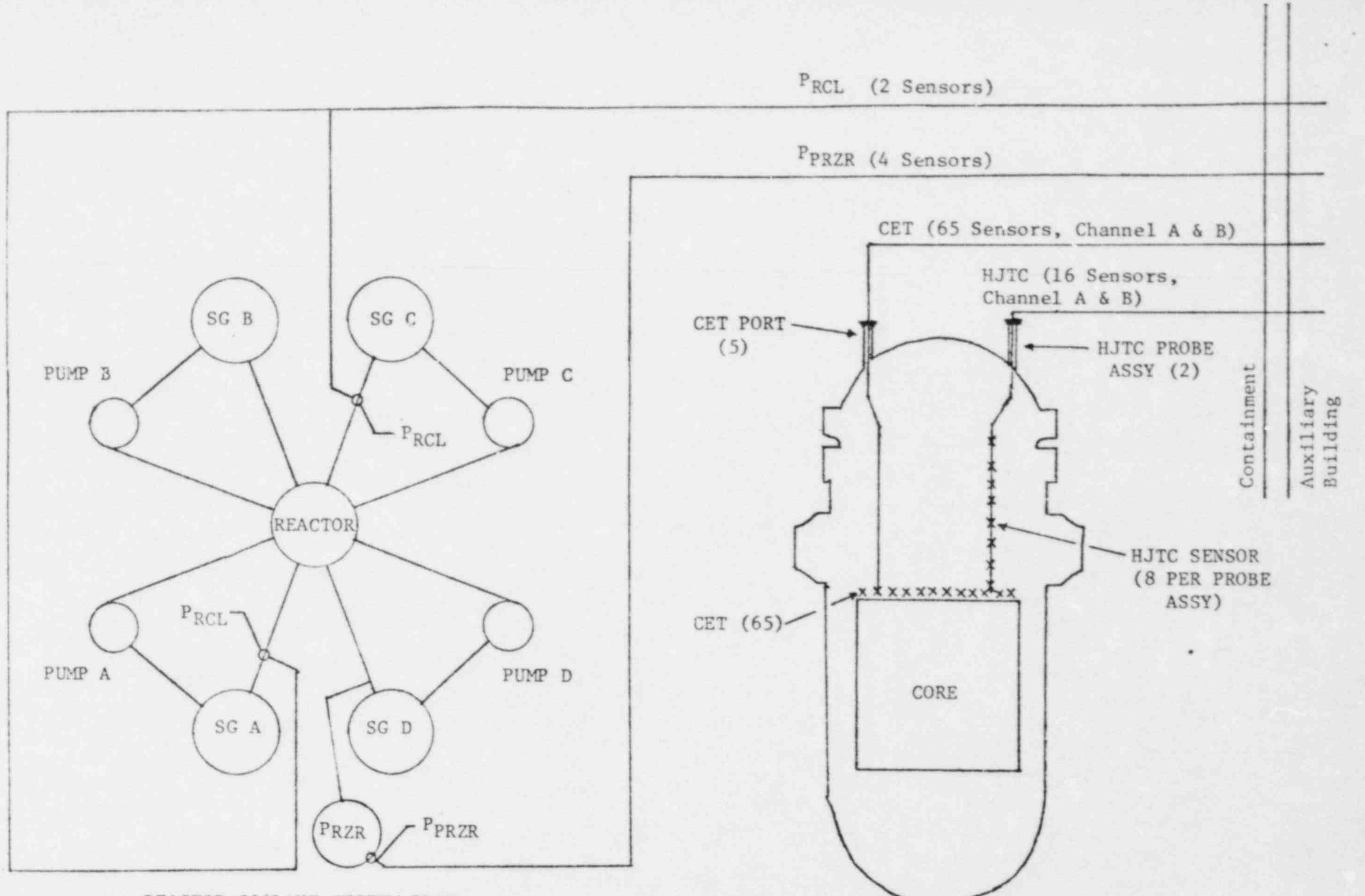
Figure 3-1 is the functional diagram for the ICC instrument systems. The HJTC and CET instrument systems consist of two safety grade channels from sensors through signal processing equipment. The outputs of processing equipment systems feeding the primary display are isolated to separate safety grade and non-safety grade systems. Channelized safety grade back-up displays are included for the two instrument systems. The SMM instrument system consists of various sensor inputs to the process computer. The generation and display of SMM is done by the process computer and is non-safety grade. The following sections present details of the design.

3.1 SENSORS DESIGN

3.1.1 Subcooled Margin Monitoring System

The subcooled margin monitor design configuration being implemented is detailed in Section 3.2.4.1. The SMM includes the maximum unheated junction thermocouple temperatures from the top three sensors of each probe (UHJTC) (Sections 3.1.2 and 3.2.2) and the representative core exit thermocouple (CET) temperature (Sections 3.1.3 and 3.2.3). The sensor inputs to the SMM are:

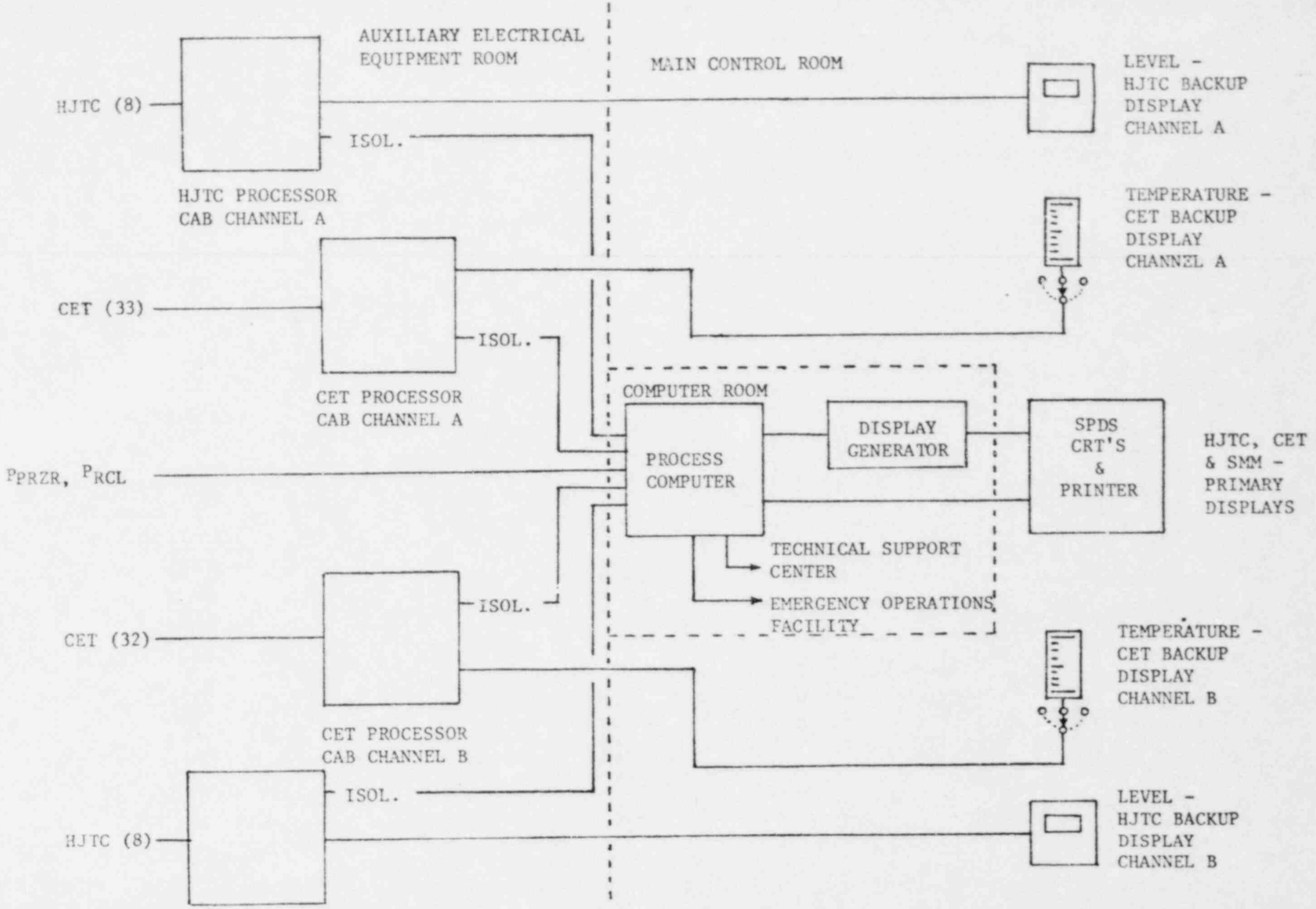
Input	Range
Pressurizer Pressure	1700-2500 psig
Reactor Coolant Loop Pressure (Wide Range, RC Hot Legs A & C)	0-3000 psig
Maximum UHJTC Temperature (from HJTC processing)	100-1800°F
Representative CET Temperature (from CET processing)	200-2300°F



REACTOR COOLANT SYSTEM PLAN

REACTOR VESSEL ELEVATION

ICC DETECTION INSTRUMENTATION
SENSORS, PROCESSING AND DISPLAY
(SHEET 1 OF 2)
FIGURE 3-1



ICC DETECTION INSTRUMENTATION
SENSORS, PROCESSING AND DISPLAY
(SHEET 2 OF 2)
FIGURE 3-1

3.1.2 Heated Junction Thermocouple (HJTC) System

The HJTC system measures reactor coolant liquid inventory with discrete HJTC sensors located at different levels within a separator tube ranging from the top of the core to the reactor vessel head. The basic principle of system operation is the detection of a temperature difference between adjacent heated and unheated thermocouples.

As pictured in Figure 3-2, the HJTC sensor consists of a Chromel-Alumel thermocouple near a heater (or heated junction) and another Chromel-Alumel thermocouple positioned away from the heater (or unheated junction). In a fluid with relatively good heat transfer properties, the temperature difference between the adjacent thermocouples is very small. In a fluid with relatively poor heat transfer properties, the temperature difference between the thermocouples is large.

Two design features ensure proper operation under all thermal-hydraulic conditions. First, each HJTC is shielded to avoid overcooling due to direct water contact during two phase fluid conditions. The HJTC with the splash shield is referred to as the HJTC sensor (See Figure 3-2). Second, a string of HJTC sensors is enclosed in a tube that separates the liquid and gas phases that surround it.

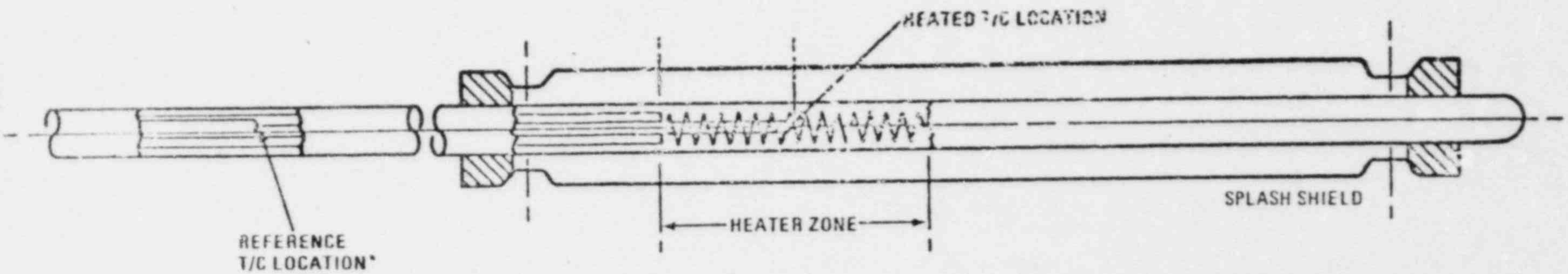
The separator tube creates a collapsed liquid level that the HJTC sensors measure. This collapsed liquid level is directly related to the average liquid fraction of the fluid in the reactor head volume above the fuel alignment plate. This mode of direct in-vessel sensing reduces spurious effects due to pressure, fluid properties, and non-homogeneities of the fluid medium. The string of HJTC sensors and the separator tube is referred to as the HJTC instrument.

The HJTC System is composed of two channels of HJTC instruments. Each HJTC instrument is manufactured into a probe assembly. The probe assembly includes eight (8) HJTC sensors, a seal plug, and electrical connectors (Figure 3-3). The eight (8) HJTC sensors are electrically independent and located at eight levels from the reactor vessel head to the fuel alignment plate.

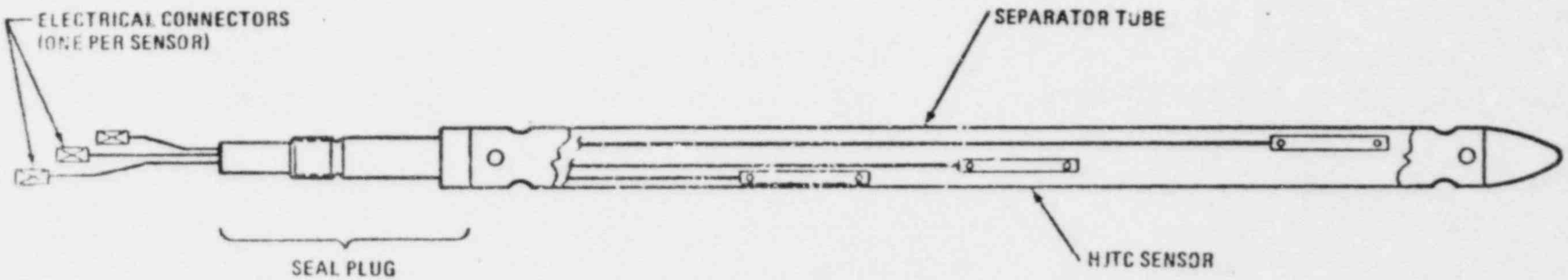
The probe assembly is housed in a stainless steel structure that protects the sensors from flow loads and serves as the guide path for the sensors. Figure 3-4 describes the locations of the HJTC probe assemblies. Installation arrangements have been developed for Byron/Braidwood Units 1 and 2.

3.1.3 Core Exit Thermocouple (CET) System

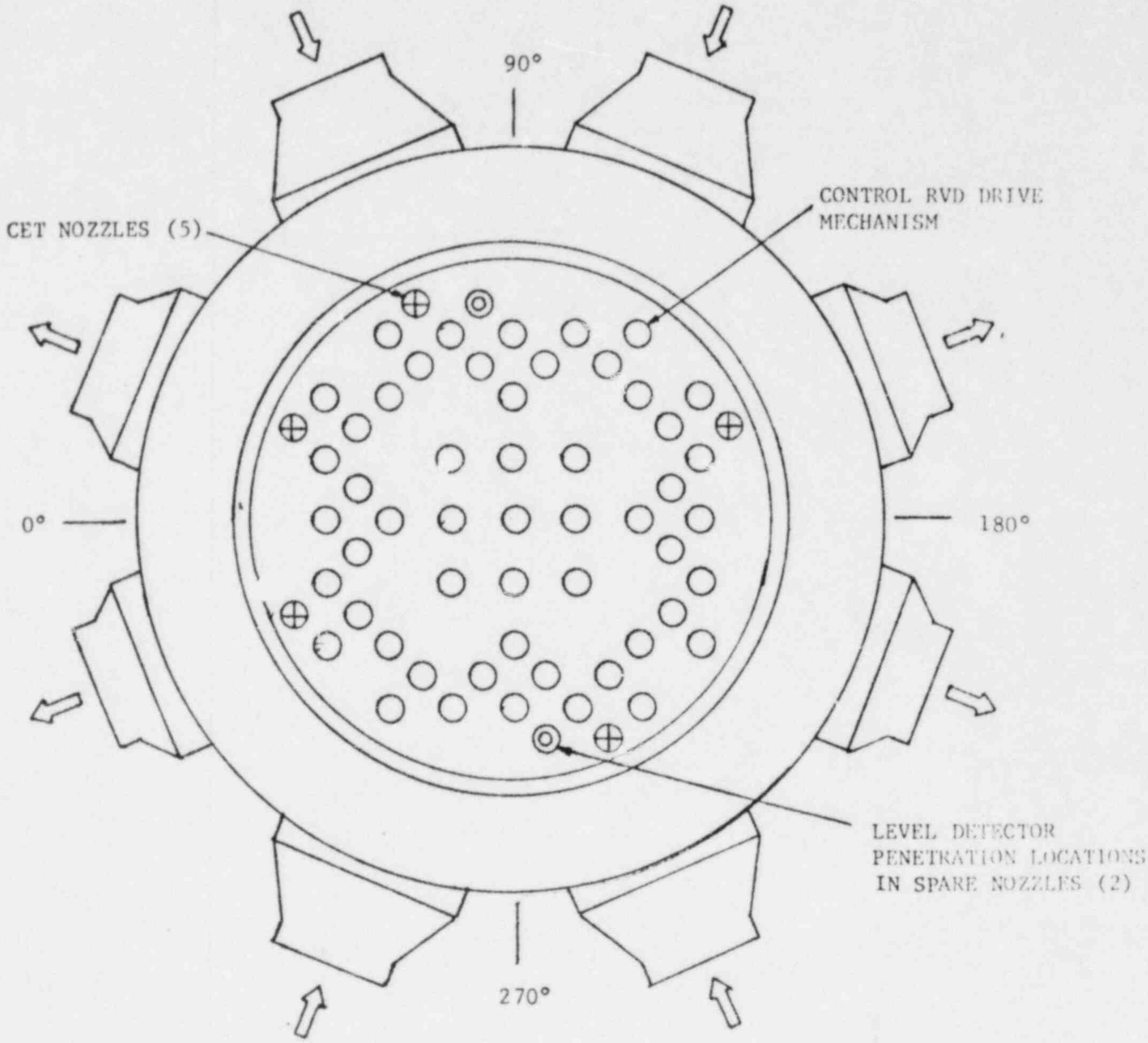
The design of the Byron/Braidwood Units 1 and 2 in-core instrumentation (ICI) system includes 65 Type K (Chromel-Alumel) thermocouples. The thermocouples are installed into guide tubes which penetrate the reactor vessel head and terminate at the exit flow end of selected fuel assemblies.



HJTC SENSOR - HJTC/SPLASH SHIELD
FIGURE 3-2



HEATED JUNCTION THERMOCOUPLE
PROBE ASSEMBLY
FIGURE 3-3



HJTC HOLDER ASSEMBLY LOCATIONS
REACTOR VESSEL PLAN
FIGURE 3-4

These core exit thermocouples (CET) monitor the temperature of the reactor coolant as it exits the fuel assemblies. The core locations of the thermocouples are shown in Figure 3-4A.

FSAR Subsection 4.4.6.1 and Section 7.7 describe the present design of the CET system. The basic design of the CET system will not change for the final ICC detection system; however, modifications will be performed to upgrade the CET to meet environmental qualification requirements. (See Section 5.0).

The CETs have a usable temperature range from 200°F to up to 2300°F (reference 4) although accuracy is reduced at temperatures above 1800°F.

The signal processing and display for the CET portion of the ICC detection instrumentation is described in paragraph 3.2.4.3 below.

3.2 SIGNAL PROCESSING AND DISPLAY EQUIPMENT DESIGN

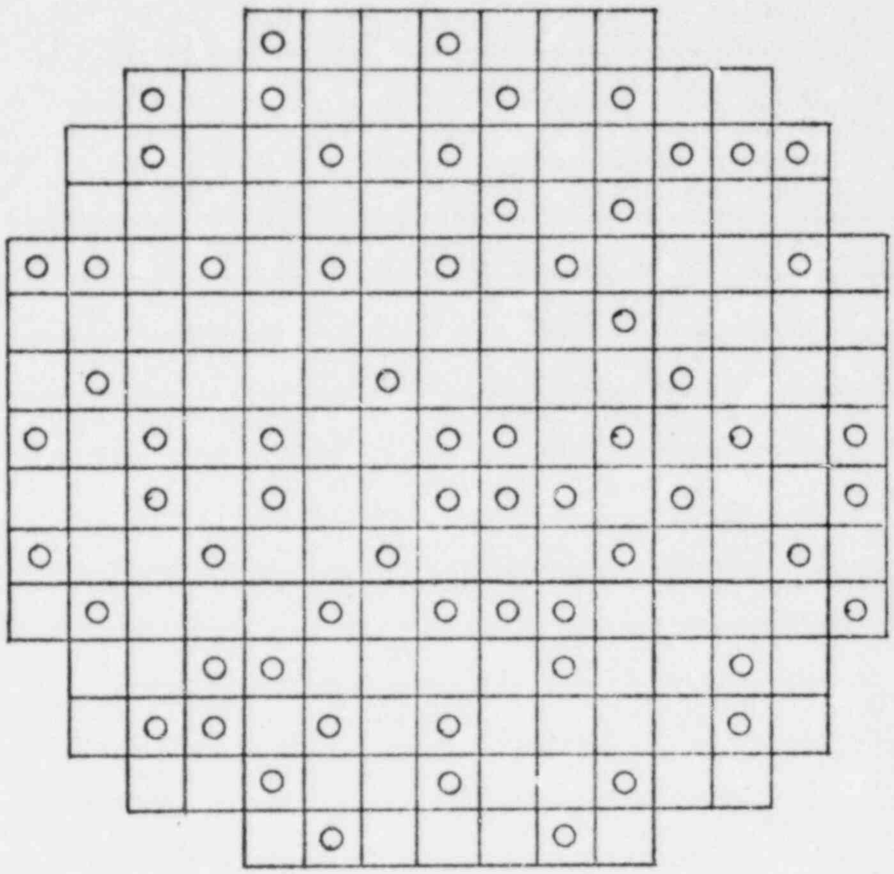
The processing and display hardware depicted in Figure 3-1 includes two subsystems of hardware - a qualified, safety related subsystem of ICC instrumentation and an unqualified, non-safety subsystem of ICC instrumentation. The equipment subsystems process and display the ICC detection sensor inputs as well as sensor inputs to meet other NRC requirements. The back-up displays for reactor level and core exit temperature are safety grade while the primary displays are non-safety grade. Human factors engineering reviews are applied to both types of display. The design objective for the equipment is to address the NUREG-0737, Item II.F.2.

3.2.1 Backup Displays

As depicted in Figure 3-1, the backup displays for reactor level and core exit temperature are driven by a two channel system. Both the HJTC and CET systems use microprocessor based designs for the signal processing function in conjunction with main control room indication, digital and analog, respectively. Each channel will accept and process ICC input signals, and provide outputs to the channel related indicator and the plant process computer. The backup displays are designed to give information to the operator in the remote chance that the primary display becomes inoperable and to confirm primary display information. Specific display descriptions for each ICC detection instrument are included in Section 3.2.4.

3.2.2 Primary Displays

The primary displays for ICC detection are generated by the plant process computer using isolated outputs from the HJTC and CET processor cabinets and NSSS protection system cabinets (for pressurizer and reactor coolant loop pressures). The main control room primary displays for ICC detection are part of the Safety Parameter Display System (SPDS). A complete description of the SPDS is included in Section E.17 for NUREG-0737, Item I.D.2. A description of specific ICC displays is included in Section 3.2.4.



THERMOCOUPLE LOCATION

CORE EXIT THERMOCOUPLES CORE LOCATIONS

FIGURE 3-4A

3.2.3 Cabling Systems

The in-containment cabling system for the CETs and HJTCs use environmentally qualified cabling and Class IE connectors. Qualified containment penetrations route the CET and HJTC signals through the containment wall to the auxiliary building.

Separation of the two CET/HJTC channels is initiated below the missile shield and maintained to the signal processing equipment in accordance with the requirements of Regulatory Guide 1.75. Section 5.0 discusses the qualification testing of the cabling.

The SMM inputs are routed from the sensors to the processing equipment via existing safety grade cabling and containment penetrations and signal isolation hardware.

3.2.4 Processing and Display Description

The following sections describe the processing and display for each of the ICC detection instruments.

3.2.4.1 Subcooled Margin Monitor

The SMM functions performed by the process computer are as follows:

1. Calculate the subcooled margin.

The saturation temperature is calculated from the average pressurizer pressure input (narrow range) unless the pressure is outside of the pressurizer pressure transmitters range in which case the average reactor coolant loop pressure input (wide range) is used. The saturation pressure is calculated from the hottest of three temperature inputs. The three inputs include: 1) average of ten hottest core exit thermocouples, 2) hottest of the top three sensors of HJTC probe-Channel A, 3) hottest of the top three sensors of HJTC probe-Channel B. The temperature subcooled margin is the difference between the saturation temperature and the hottest temperature input noted above. The pressure subcooled margin is the difference between saturation pressure and the average pressure input.

2. Process all outputs for display.

The SMM processes the temperature and pressure inputs over the following ranges: CET temperatures from 200 to 2300°F, the unheated HJTC temperatures from 100 to 1800°F, the pressurizer pressures from 1700 to 2500 psig and reactor coolant loop pressure from 0 to 3000 psig. The saturation temperature and pressure are calculated from a saturation curve and an interpolation routine.

The following information is presented on the primary display:

1. Pressure margin to saturation

2. Temperature margin to saturation

3. Trends of pressure or temperature margin to saturation

Additional information regarding the primary display, safety parameter display system (SPDS) is included in Section E.17.

Backup displays are not provided for the SMM.

3.2.4.2 Heated Junction Thermocouples - Reactor Level

The processing equipment for the HJTC performs the following functions:

1. Determine if liquid inventory exists at the HJTC positions.

   The heated and unheated thermocouples in the HJTC are connected in such a way that absolute and differential temperature signals are available. This is shown in Figure 3-5. When water surrounds the thermocouples, their temperature and voltage output are approximately equal. $V_{(A-C)}$ on Figure 3-5 is, therefore, approximately zero. In the absence of liquid, the thermocouple temperatures and output voltages become unequal, causing $V_{(A-C)}$ to rise. When $V_{(A-C)}$ of the individual HJTC rises above predetermined setpoint, liquid inventory does not exist at this HJTC position.

2. Determine the maximum upper plenum/head fluid temperature from the top three unheated thermocouples for use and a process computer input for the SMM. (The temperature processing range is from 100°F to 1800°F.) This output is an isolated signal.

3. Process all inputs and calculated outputs for display.

4. Provide an alarm output to the plant annunciator system when any of the HJTC detects the absence of liquid level.

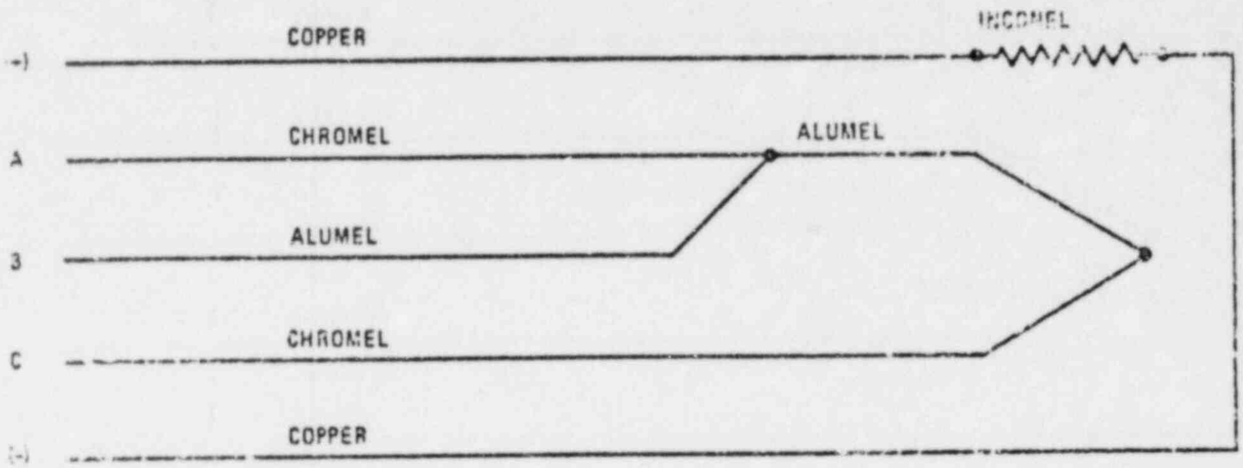
5. Provide control of heater power for proper HJTC output signal level. Figure 3-6 shows a single channel design which includes the heater power controller.

6. Provide an input to the process computer for % liquid inventory level above the fuel alignment plate. This output is an isolated signal.

The following information is presented on the primary display:

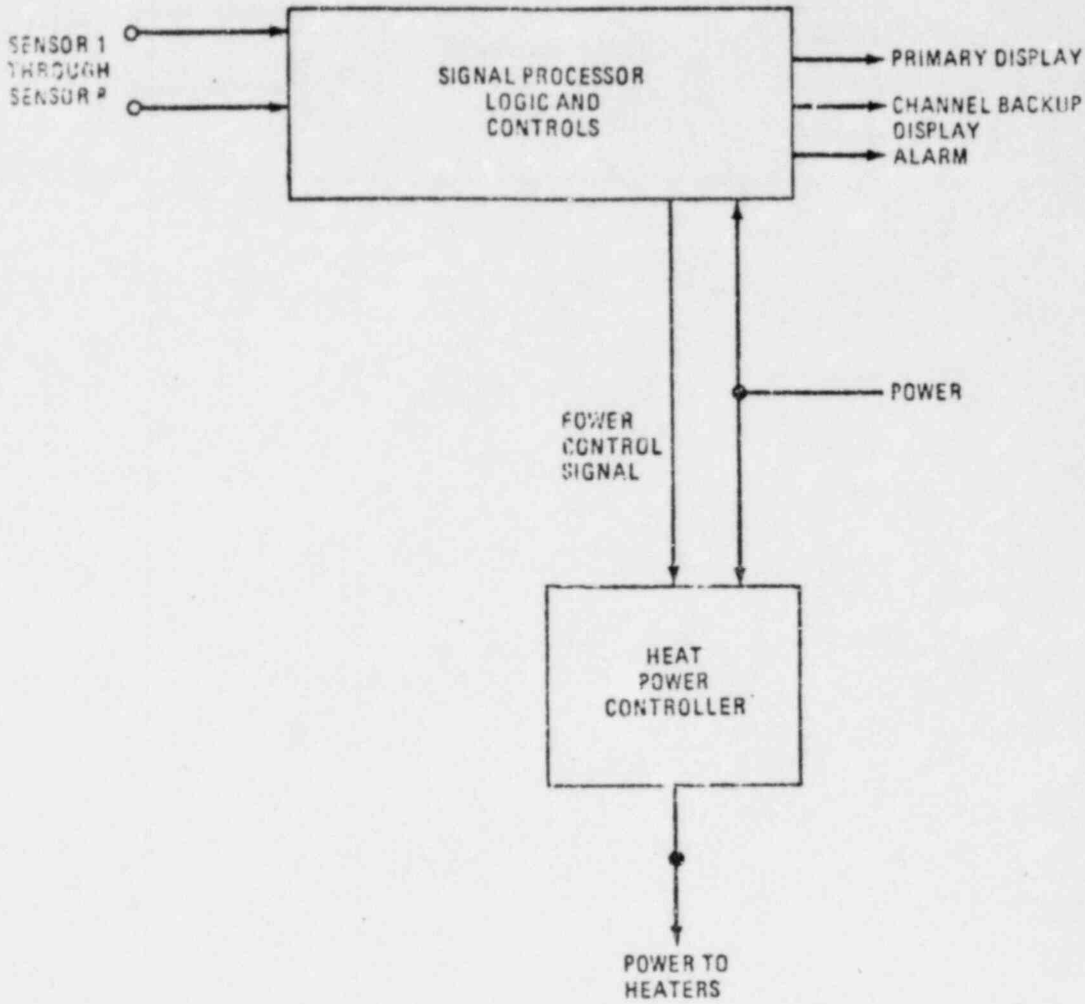
1. Liquid level inventory above the fuel alignment plate.

2. Trends of liquid level inventory.



V (A-B) = ACTUAL TEMPERATURE, UNHEATED JUNCTION
V (C-B) = ACTUAL TEMPERATURE, HEATED JUNCTION
V (A-C) = DIFFERENTIAL TEMPERATURE

ELECTRICAL DIAGRAM OF H.J.T.C.
FIGURE 3-5



HJTC SYSTEM PROCESSING CONFIGURATION
(ONE CHANNEL SHOWN)
FIGURE 3-6

Additional information regarding the primary display, safety parameter display system (SPDS) is included in Section E.17.

The following information is presented on the backup HJTC display:

1. % liquid inventory level above the fuel alignment plate derived from the eight discrete HJTC positions.

2. Unheated junction temperature at eight positions.

3. Heated junction temperature at eight positons.

3.2.4.3 Core Exit Thermocouple System

The processing equipment for the CET will perform the following functions:

1. Process all core exit thermocouple inputs. Processing of 33 CET inputs will be performed by Channel A and 32 CET inputs by Channel B.

2. Provide sixteen thermocouple (4 per quadrant) outputs, per channel, to the backup displays.

3. Provide data link outputs to the process computer for all 65 thermocouple inputs. These outputs are isolated signals.

These functions are intended to meet the design requirements of NUREG-0737, II.F.2 Attachment 1.

The following information is represented on the primary display.

1. A spacially oriented core map indicating the temperature at each of the CET locations.

2. A core exit temperature representative of the CET inputs.

3. Trends of core exit temperature.

Additional information regarding the primary display, safety parameter display system (SPDS) can be found in Section E.17.

The following information is available on the backup displays:

1. Selectable temperatures of 16 core exit thermocouples for each of the Channels A & B.

4.0 SYSTEM VERIFICATION TESTING

This section describes tests and operational experience with ICC instruments.

4.1 PRESSURE SENSORS

The hot and cold leg wide range pressure and the pressurizer pressure sensors are standard NSSS instruments which have well known responses. No special verification tests have been performed nor are planned for the future. These sensors provide basic, pressure inputs which are considered adequate for use in the SMM and other additional display functions.

4.2 HJTC SYSTEM SENSORS AND PROCESSING

The HJTC System is a new system developed to indicate liquid inventory above the core. Since it is a new system, extensive testing has been performed and further tests are planned to assure that the HJTC System will operate to unambiguously indicate liquid inventory above the core.

The testing is divided into three phases:

Phase 1 - Proof of Principle Testing (Reference 6)
Phase 2 - Design Development Testing (Reference 7)
Phase 3 - Prototype Testing

The first phase consisted of a series of five tests, which have been completed. The testing demonstrated the capability of the HJTC instrument design to measure liquid level in simulated reactor vessel thermal-hydraulic conditions (including accident conditions).

Test 1 Autoclave test to show HJTC (thermocouples only) response to water or steam.

In April 1980, a conceptual test was performed with two thermocouples in one sheath with one thermocouple as a heater and the other thermocouple as the inventory sensor. This configuration was placed in an autoclave (pressure vessel with the capabilities to adjust temperature and pressure). The thermocouples were exposed to water and then steam environments. The results demonstrated a significant output difference between steam and water conditions for a given heater power level.

Test 2 Two phase flow test to show bare HJTC sensitivity to voids.

In June 1980, a HJTC (of the present differential thermocouple design) was placed into the Advanced Instrumentation for Reflood Studies (AIRS) test facility, a low pressure two phase flow test facility at Oak Ridge National Laboratory (ORNL). The HJTC was exposed to void fractions at various heater power levels. The results demonstrated that the bare HJTC output was virtually the same in two phase liquid as in subcooled liquid. The HJTC did generate a significant output in 100% quality steam.

Test 3 Atmospheric air-water test to show the effect of a splash shield

A splash shield was designed to increase the sensitivity to voids. The splash shield prevents direct contact with the liquid in the two phase fluid. The HJTC output changed at intermediate void fraction two phase fluid. The results demonstrated that the HJTC sensor (heated junction thermocouple with the splash shield) sensed intermediate void fraction fluid conditions.

Test 4 High pressure boil-off test to show HJTC sensor response to reactor thermal-hydraulic conditions

In September 1980, a C-E HJTC sensor (HJTC with splash shield) was installed and tested at the ORNL Thermal-Hydraulics Test Facility (THTF). The HJTC sensor was subjected to various two phase fluid conditions at reactor temperatures and pressures. The results verified that the HJTC sensor is a device that can sense liquid inventory under normal and accident reactor vessel high pressure and temperature two phase conditions.

Test 5 Atmospheric air-water test to show the effect of a separator tube

A separator tube was added to the HJTC design to form a collapsed liquid level so that the HJTC sensor directly measures liquid inventory under all simulated two phase conditions. In October, 1980, atmospheric air-water tests were performed with HJTC sensor and the separator tube. The results demonstrated that the separator tube did form a collapsed liquid level and the HJTC output did accurately indicate liquid inventory. This test verified that the HJTC instrument, which includes the HJTC, the splash shield, and the separator tube, is a viable measuring device for liquid inventory.

The Phase 2 test program consisted of a series of steady state and transient tests under single phase and two phase fluid conditions with an HJTC probe assembly. Fluid conditions that the probe might be opposed to were simulated. The Phase 2 tests verified that the HJTC probe assembly is capable of measuring water inventory in a reactor vessel.

The Phase 3 test program will consist of high temperature and pressure testing of the manufactured prototype system HJTC probe assembly and processing electronics. Verification of the HJTC system prototype will be the goal of this test program. The Phase 3 test report will be published in 1982.

4.3 CORE EXIT THERMOCOUPLES

No verification testing of the CETs is planned. A study at ORNL was performed to test the response of CETs under simulated accident conditions (Reference 4). This test showed that the instruments remained functional up to 2300°F. This test along with previous reactor operating experience verifies the response of CETs.

5.0 SYSTEM QUALIFICATION

The qualification program for the ICC detection system instrumentation has not been completely defined. However, plans are being developed based on the following categories of ICC instrumentation:

1. Sensor instrumentation within the pressure vessel.

2. Instrumentation components and systems which extend from the primary pressure boundary up to and including the primary display isolator and including the backup displays.

A preliminary outline of a qualification program for each classification is given below.

The in-vessel sensors will meet the NUREG-0737, Appendix B guide to install the best equipment available consistent with qualification and schedular requirements. Design of the equipment will be consistent with the guidelines of Appendix B as well as the clarification and Attachment 1 to Item II.F.2 in NUREG-0737. Specifically, instrumentation will be designed such that they meet appropriate stress criteria when subjected to normal and design basis accident loadings. Seismic qualification to safe shutdown conditions will verify function after being subjected to the seismic loadings.

The out-of-vessel instrumentation system, up to and including the primary display isolator, and the backup displays will be environmentally qualified in accordance with IEEE-323-1974. Plant-specific containment temperature and pressure design profiles will be used where appropriate in these tests. This equipment will also be seismically qualified according to IEEE-STD-344-1975. CEN-99(S), "Seismic Qualification of NSSS Supplied Instrumentation Equipment, Combustion Engineering, Inc." (August 1978) describes the methods used to meet the criteria of this document for the heated junction thermocouple system.

Consistent with Appendix B of NUREG-0737, the out-of-vessel equipment under procurement is the best available equipment and will be qualified to meet the requirements of NUREG-0588.

The primary display will not be designed as a Class IE system, but will be designed for high reliability; thus it will not be qualified environmentally or seismically to Class IE requirements nor will it meet the single failure criteria of Appendix B, Item 2. Post-accident maintenance accessibility will be included in the design. The quality assurance provisions of Appendix B, Item 5 do not apply to the primary display according to NUREG-0737. However, the computer driven primary display system will be separated from the Class IE sensors, processing and backup display equipment by means of isolation devices which will be qualified to Class IE criteria.

Verification and Validation of the SPDS software for the primary ICC display will be performed. Additional information regarding the SPDS can be found in Section E.17.

6.0 OPERATING INSTRUCTIONS

Plant specific emergency operating procedures for use of the information from the ICC instrumentation system will be developed taking into account recommendations from the C-E generic procedures and from the Westinghouse Owners Group Generic Procedures. The Byron/Braidwood operator training program will be modified to include material associated with the use of the ICC instrumentation system.

REFERENCES

1. NUREG-0737, "Clarification of TMI Action Plan Requirements," U.S. Nuclear Regulatory Commission, November, 1980.

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3. CEN-125, "Input for Response to NRC Lessons Learned Requirements for Combustion Engineering Nuclear Steam Supply Systems," Combustion Engineering, December, 1979.

4. Anderson, R. L., Banda, L. A., Cain, D. G., "Incore Thermocouple Performance Under Simulated Accident Conditions," IEEE Nuclear Science Symposium, Vol. 28, No. 1 Page 773, Figure 81.

5. CEN-185, "Documentation of Inadequate Core Cooling Instrumentation for Combustion Engineering Nuclear Steam Supply Systems," Combustion Engineering, September, 1981.

6. CEN-185, Sup. 1, "HJTC Phase 1 Test Report," Combustion Engineering, November, 1981.

7. CEN-185P, Sup. 2-P, "HJTC Phase 2 Test Report," Combustion Engineering, November, 1981.