Attachment
Director of NRR
September 1, 1981

DESCRIPTION OF HEATED JUNCTION THERMOCOUPLE (HJTC) SYSTEM UNDER CONSIDERATION FOR USE AT THE PRAIRIE ISLAND NUCLEAR GENERATING PLANT TO AID IN DETECTION OF INADQUATE CORE COOLING

1.0 Description

The HJTC system measures reactor coolant liquid inventory with discrete 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.

1.1 Sensor Design

As pictured in Figure 1-1, the HJTC sensor consists of a Chromel-Alumel thermoccuple near a heater (or heated junction) and another Chromel-Alumel thermocouple positicned 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 opration 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. 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 liquid level is directly related to the average liquid fraction of the fluid in the reactor head volume above the fuel. 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 HJTC sensors, a seal plug, and electrical connectors (Figure 1-2). The eight HJTC sensors are electrically independent and located at eight levels from the reactor vessel head to the fuel.

The probe assembly is housed in a stainless steel structure that protects the sensors from flow loads and serves as a guide path for the sensors. Installation arrangements are being developed in conjunction with Westinghouse. Installation details will be provided in future documentation if NSP decides to install the HJTC System at Prairie Island.

1.2 Processing Equipment

The processing equipment for the HJTC System will perform 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 1-3. When water surrounds the thermocouples, their temperature and voltage output are approximately equal. $V_{(A-C)}$ on Figure 1-3 is, therefore, approximately

zero. In the absence of liquid, the thermocouple temperature and output voltages become unequal, causing $V_{(A-C)}$ to rise. When $V_{(A-C)}$ of the individual HJTC rises above a predetermined setpoint, liquid inventory is assumed not to exist at this HJTC position.

2. Determine the maximum upper plenum/head fluid temperature from the unheated thermocouples for use as an input to the subcooling monitors (optional).

3. Process all inputs and calculated outputs for display.

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

5. Provide control of heater power for proper HJTC output signal level. Figure 1-4 shows a single channel conceptual design which includes the heater power controller.

1.3 Display Design

The HJTC outputs will probably be displayed through a human engineered cathode ray tube (CRT) based primary display with separate backup displays.

As shown in Figure 1-5, each channel of the HJTC instrument system will also have safety grade backup displays. Both primary and backup displays are intended to be designed consistent with the criteria in NUREG-0737, Action Item II.F.2, Attachment 1, and Appendix A.

The following information is planned for the primary display:

1. Two channels of 8 discrete HJTC positions for indicated liquid inventory above the fuel.
2. Maximum unheated junction temperature of each of the two channels.

The following information is anticipated to be displayed on the backup displays:

1. Liquid inventory level above the fuel derived from the 8 discrete HJTC positions
2. Unheated junction temperature at the 8 positions
3. Heated junction temperature at the 8 positions

2.0 System Verification

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 unabiguously indicate liquid inventory above the core.

The testing is divided into three phases:

Phase 1 - Proof of Principle Testing

Phase 2 - Design Development Testing

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 under 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 base 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 CE HJTC sensor (with splash shield) was tested at the ORNL Thermal-Hydraulics Test Facility (THTF). The device is still installed and available for further tests at ORNL. The HJTC sensor was subjected to various two phase fluid conditions at reactor temperatures and presures. 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 sensors 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 3 test program will consist of high pressure and temperature tests on the HJTC instrument. These tests will provide input for the HJTC instrument design and manufacturing effort. The Phase 3 test program is expected to be completed this year.

The final processing and display design for the HJTC System has not been completed. As the design effort proceeds, design evaluations will be performed prior to installation. Correct implementation of the software and hardware will be included and documented as part of the desing effort.

3.0 System Qualification

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

1. Sensor instrumentation within the pressure vessel.

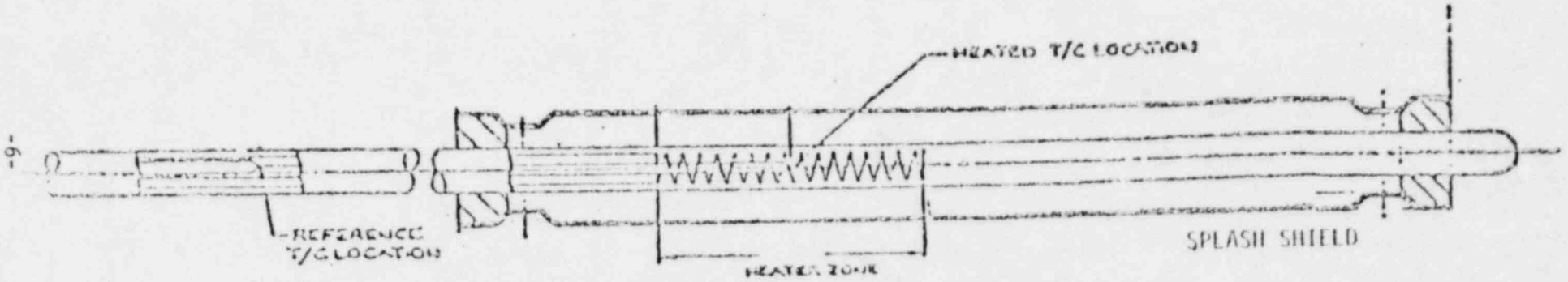
2. Instrumentation components and systems which extend from the primary pressure boundary up to and including the primary display isolator and including the backup displays.

3. Instrumentation systems which comprise the primary display equipment.

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

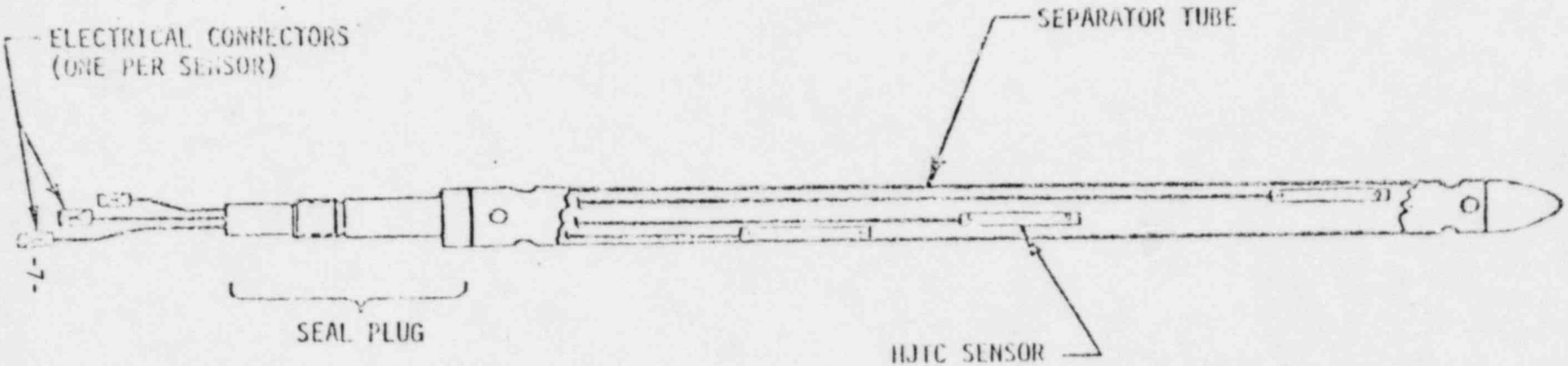
The in-vessel sensors will meet the NUREG-0737, Appendix A, requirement to install the best equipment available consistent with qualification and schedular requirements. Design of the equipment will be consistent with the guidelines of Appendix A as well as the clarification and Attachment 1 to Item II.F.2 in NUREG-0737. Specifically, components will be designed such that they meet appropriate stress criteria when subjected to normal and design basis accident loadings. Verification testing will be conducted to confirm operation at DBA pressure and temperature conditions. Seismic testing 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 as interpreted by Combustion Engineering Document, CENPD-255, "Qualification of Combustion Engineering Class IE Instruments." This document describes the metnod which will be used to qualify out-of-vessel Class IE equipment.



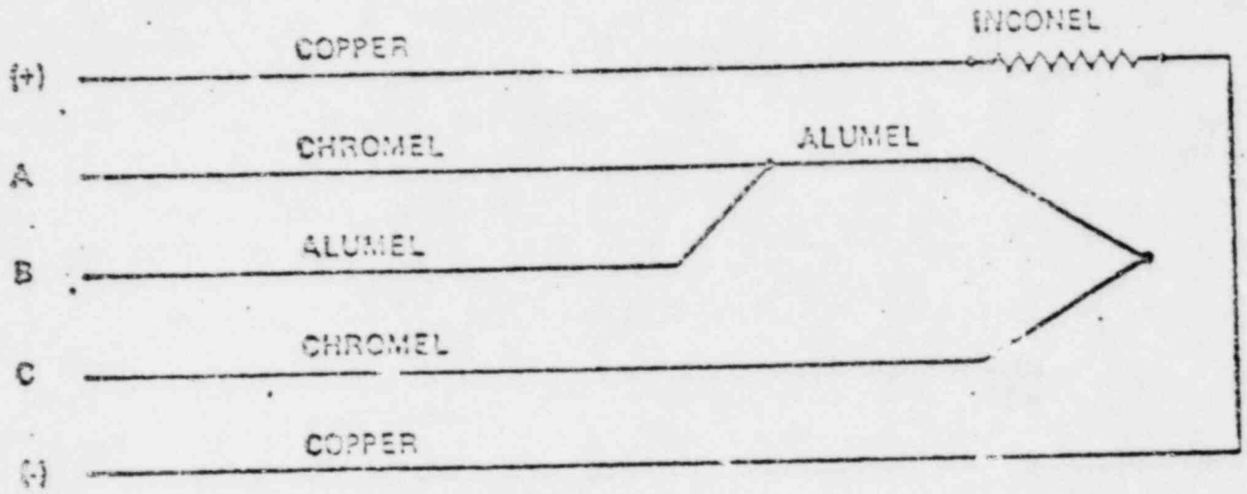
HJTC SENSOR - HJTC/SPLASH SHIELD

FIGURE 1-1



HEATED JUNCTION THERMOCOUPLE
PROBE ASSEMBLY

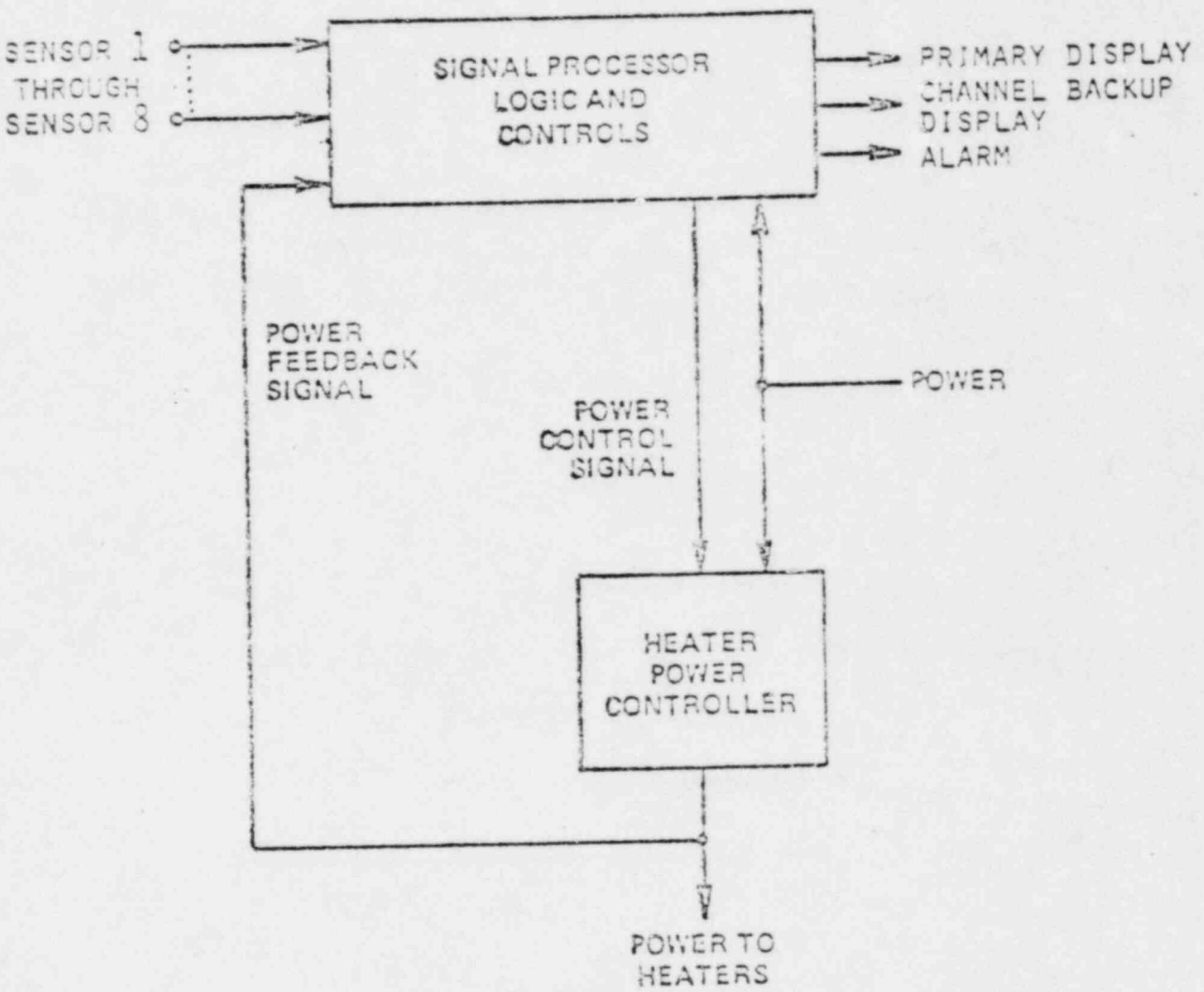
FIGURE 1-2



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

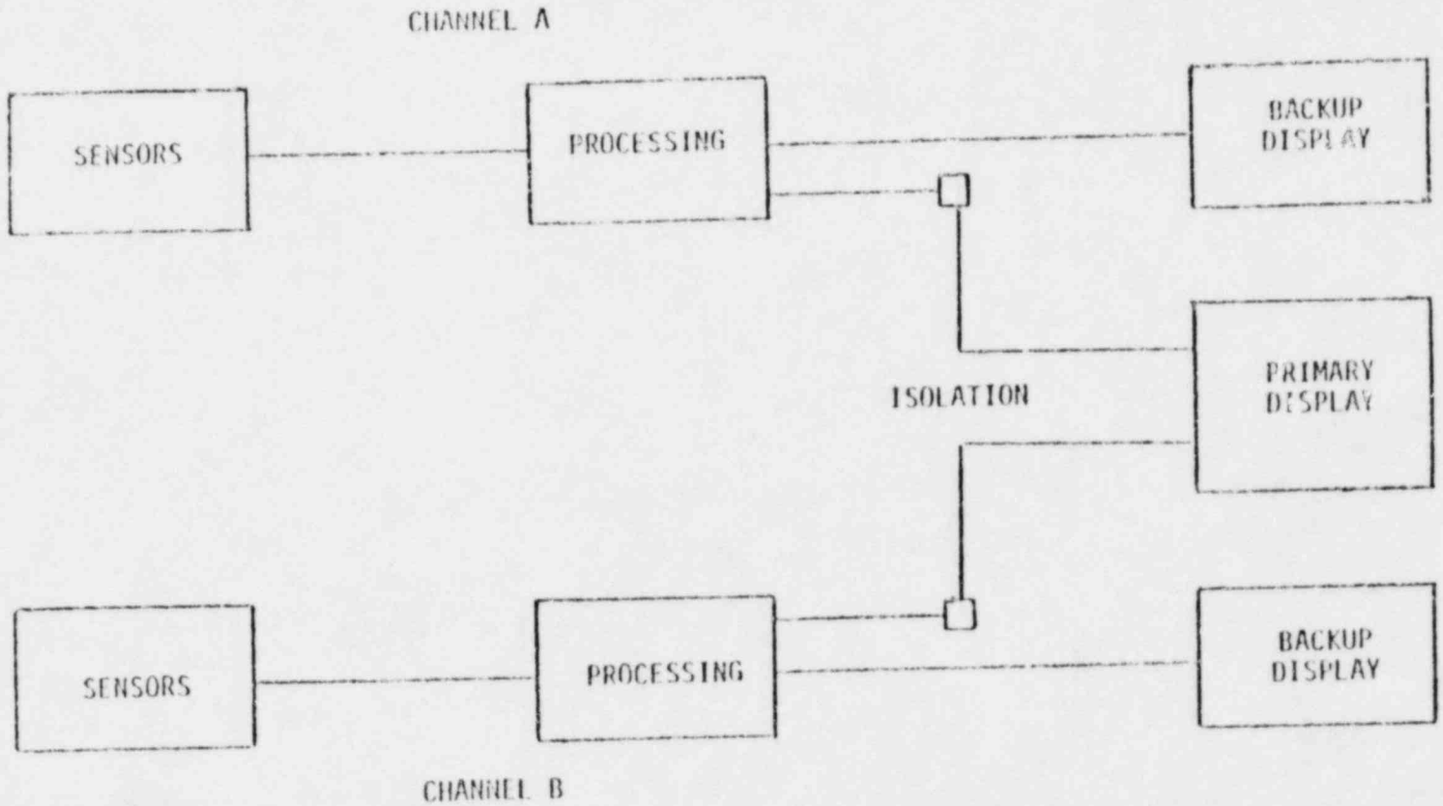
ELECTRICAL DIAGRAM OF H.J.T.C.

FIGURE 1-3



HJTC SYSTEM PROCESSING CONFIGURATION
(ONE CHANNEL SHOWN)

FIGURE 1-4



ICC INSTRUMENTS FUNCTIONAL BLOCK DIAGRAM

FIGURE 1-5