DESIGN PROPOSAL

IN RESPONSE TO NUREG 0737
SECTION II.F.2

INSTRUMENTATION TO DETECT
INADEQUATE CORE COOLING

SUBMITTED BY: DUKE POWER COMPANY
MAY 24, 1982

TABLE OF CONTENTS

1.0 BACKGROUND INFORMATION

The three principal requirements for instrumentation to detect inadequate core cooling (ICC), as most recently stated in NUREG-0737, are that the instrumentation system must be unambiguous, provide advance warning, and cover the full range of operations. The ICC detection system herein proposed meets these principal requirements. It consists of three instrumentation components: a saturation meter, a hot leg level measurement system (HLLMS) and core exit thermocouples. These three components when considered together are the ICC detection instrumentation.

1.1 DEFINITION OF INADEQUATE CORE COOLING (ICC)

In a depressurization event, the reactor coolant system (RCS) must first reach saturation conditions before there is any danger of inadequate core cooling. Subsequently, if the RCS inventory is reduced and uncovery of the core begins, temperatures in the uncovered region will increase causing superheating. It is important to note in this proposal that inadequate core cooling does not begin until reactor vessel (RV) water inventory falls below the top of the core thus resulting in an increasing fuel clad temperature.

DEFINITION OF "INADEQUATE CORE COOLING" AS USED IN NUREG 0737

INSUFFICIENT REACTOR CORE HEAT REMOVAL TO PRECLUDE CONTINUING FUEL CLAD TEMPERATURE INCREASE TO THE POINT OF SUBSTANTIAL FUEL DAMAGE.

APPROACH OF ICC INDICATED BY:

LOSS OF SUBCOOLING MARGIN

LOSS OF RC INVENTORY

INCREASE IN FUEL CLAD TEMPERATURES

ONSET OF ICC INDICATED BY:

EXCESSIVE FUEL CLAD TEMPERATURES

1.2 OPERATING GUIDES FOR DEALING WITH APPROACH TO ICC

The goals of the operator prior to ICC are different than those once ICC has occurred. Prior to an indication that ICC has occurred, the operator is taking actions which will stabilize pressure and refill the RCS. The goal is to re-establish the subcooling margin at the high pressure condition or cool down and depressurize to low pressure injection plant conditions. Indication that ICC has occurred changes the operator's guidance because the goal of refilling at the high pressure cannot be attained. The operator at this point is instructed to partially depressurize using the PORV to increase RCS inventory addition rate. If this fails, the operator is instructed to further depressurize and establish low pressure injection (LPI). These last two steps are based on conscious decisions that recovery at the higher pressure is not possible and that depressurization will cause more immediate core voiding, but in the longer term will result in improved core cooling by increased RCS inventory.

Based on this logic, it is important that the indication not be ambiguous and not occur prematurely. It is important to provide as much time as possible for recovery at the higher pressure which leads to the preferred mode of operation.

Symptoms of an overcooling transient are similar to the small break loss of coolant transient up to the point of inadequate core cooling. At this point, if the operator has taken actions for inadequate core cooling when in fact overcooling exists, an unnecessary transient would result. Thus, the operator must not proceed with the inadequate core cooling actions until inadequate core cooling is confirmed.

The following sections describe the actual operator actions taken prior to ICC and those once ICC is indicated.

Operator Actions During Approach to ICC

Operator actions during the approach to an inadequate core cooling condition are summarized as follows:

1. Initiate HPI

2. Maintain OTSG level

3. Trip RC pumps if ESFAS initiated by low RC pressure

4. Monitor incore thermocouple temperatures to determine if inadequate core cooling exists.

These actions are verified when saturation conditions exist. No further actions are taken until thermocouple temperatures reach a predetermined temperature. This indicates that superheating is occurring, that fuel clad temperature has increased above saturation, and that inadequate core cooling exists.

Operator Actions Once ICC is Indicated

Once inadequate core cooling is indicated, the operator is instructed to take the following actions:

1. Start one RCP per loop

2. Depressurize operative OTSG(s) to 400 psig as rapidly as possible

3. Open the PORV to maintain RCS pressure within 50 psi of the operative OTSG pressure

4. Continue cooldown by maintaining 100°F/hr decrease in secondary saturation temperature to achieve 150 psig RCS pressure

These actions are taken to reduce RC pressure thus increasing HPI flow and RCS inventory addition rate. If thermocouple temperature continues to rise above a higher predetermined temperature which indicates a significant increase in fuel clad temperature, the operator should:

1. Start all RCPs

2. Depressurize OTSG(s) to atmospheric pressure

3. Open the PORV to depressurize the RCS and allow LPI to restore core cooling

2.0 OBJECTIVE

The objective of this proposal is to present a system design which will provide the necessary information to assist the operator in taking actions to ensure adequate core cooling and to distinguish between conditions caused by overcooling transients and those which could lead to an approach to inadequate core cooling.

3.0 FUNCTIONAL DESCRIPTION

The condition of ICC can develop only after a well defined set of events occur. This section is intended as a functional description of an ICC detection system. The components of this ICC detection system are:

A. Subcooling Margin Monitor

B. Hot Leg Level Monitor

C. Incore/Core Exit Thermocouples

3.1 SPECIFIED CONDITIONS OF OPERATION

First, there must be a loss of RCS inventory which leads to the saturation of the RCS. Then the inventory loss must continue such that the core actually starts to become uncovered. This will result in a higher temperature generated in the core and decreased heat removal since there will be portions not covered with liquid coolant. This failure to remove the heat can then lead to high temperatures in the fuel. The ICC condition occurs when the heat removal capability of the coolant is exceeded to the extent that fuel temperatures will rise to the point of fuel damage. This does not occur until the core becomes at least partially uncovered because when it is surrounded by liquid coolant, even at saturation temperature, there is adequate cooling of the core to prevent fuel damage.

The ICC detection system monitors the prerequisite stages of ICC and the occurrence of ICC. The saturation meter will indicate when saturation conditions occur and thus provide advance warning that ICC is a possibility. However, the onset of saturation conditions does not in itself indicate that ICC will occur. There is a spectrum of LOCA events which will cause saturation conditions to occur but will not proceed to core uncovery or ICC. There are also non-LOCA events which will proceed to saturation conditions but do not have the potential for ICC. Thus the saturation meter provides warning of ICC but is not an unambiguous indication that ICC conditions could occur.

In a small break LOCA of the size which could proceed to the ICC condition, the inventory loss continuing through saturation conditions will result in the formation of liquid coolant voids in the RCS. These voids will contain steam and gases released from the coolant. The gas content will remain very small until the onset of ICC. Since there is no forced RCS flow at this point in the SB LOCA scenario, steam and gas will collect at the system high points. The high points that will become void of liquid coolant first in the B & W plant will be the upper RV head and the upper U bend of the hot leg piping (Figure 1). The formation of steam and gas bubbles in the hot leg will cause a liquid level to develop which can be inferred from the differential pressure measured by a differential pressure transmitter connected to the top of the hot leg and to an existing instrument tap at the RCS flow connection located approximately 19 feet down on the hot leg piping. This intermediate range instrument would indicate the level and thus provide additional information to the operator.

The specific nature of the information would be that the inventory loss is continuing (decreasing level) or that the inventory loss rate has been matched or exceeded by ECC injection rate (steady or increasing level). The HLLMS not only supplements the advanced warning of the saturation meter, but it also increases the range of the monitoring of the approach to ICC. The 0-19' measuring range monitors about 15% of the total RCS inventory from its hot leg positioning. This hot leg piping volume (in the 0-19' span) represents about 35% of the RCS volume left above the core which is available for cooling after the postulated transient. Thus, the HLLMS would be additional advanced warning that conditions are progressing toward the ICC condition. The HLLMS would also indicate that a level existed in the hot leg for some non-LOCA transients which do not have the potential for ICC.

However, the non-ambiguity of the HLLMS is a time related function. Early in transient time, the LOCA and non-LOCA behave similarly regarding hot leg

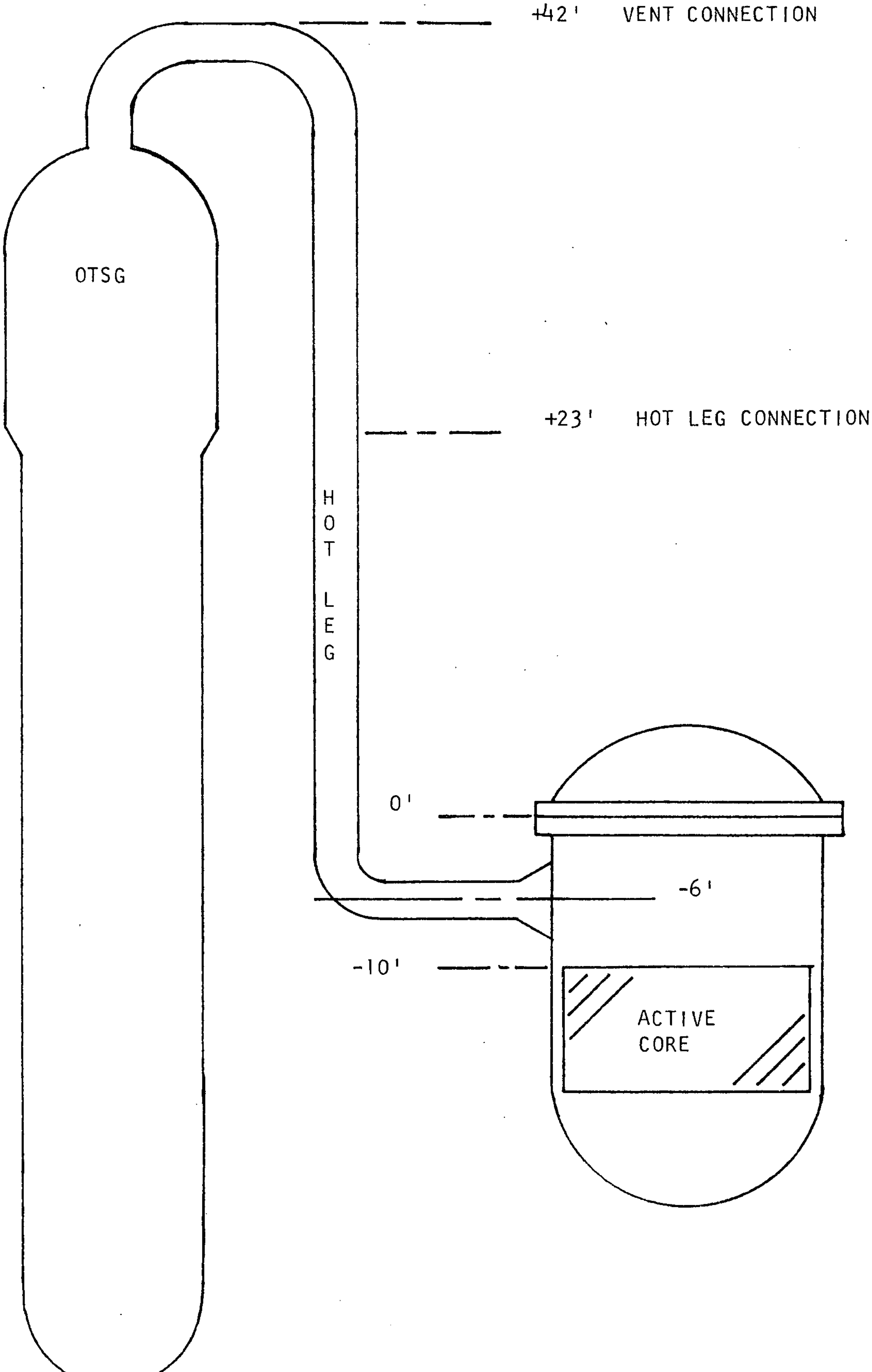

FIGURE 1

LOCATION REFERENCE DIAGRAM

level. But as the transient progresses, the level continues to decrease for the LOCA while, for the non-LOCA, the level will recover.

As the SB LOCA scenario continues, the inventory loss is such that the top of the core becomes uncovered. The core exit thermocouples will have indicated saturation temperatures since saturation conditions were reached much earlier in the transient. As inventory continues to be depleted, the core fuel region becomes uncovered and the temperature of the steam at the core exit begins to increase above saturation temperature. This superheated temperature sensed by the core exit thermocouples is additional advance indication that conditions are progressing toward ICC conditions. Ultimately, the conditions of heat transfer would be such that core exit thermocouple temperatures would increase to the thresholds for further operator actions. If for some reason, these actions were not affected, then ICC would occur and would be indicated by the core exit thermocouples.

RCS OPERATIONAL CHARACTERISTICS

Pumped Flow Conditions	2172 psig 603°F
Natural Circulation	0-2500 psig 100-650°F
Stagnant Boil-off	0-2500 psig (saturated) 212-668°F
Refueling	0 psig 70°-200°F

SYSTEM OPERATIONAL CONDITIONS

Each component of the proposed ICC system will be exposed to the above RCS operational characteristics.

The plant's operational status during which each component will operate is shown in Table 1.

3.2 QUALIFICATION

The system equipment and support hardware to be used will be designed and/or analyzed with regards to surviving and functioning under the expected design basis accident environmental conditions.

A. SUBCOOLING MARGIN MONITOR

Presently Duke has a subcooling margin monitor installed and operational at the Oconee Nuclear Station. This monitor was installed with reference to the NUREG 0578 requirements and has been accepted.

TABLE 1

SYSTEM COMPONENT	NORMAL OPERATION	NATURAL CIRCULATION	PUMPS ON	PUMPS OFF	CORE UNCOVERY
Subcooling Margin Monitor	Yes	Yes	Yes	Yes	Yes
Incore/ Core Exit Thermocouples	Yes	Yes	Yes	Yes	Yes
Hot Leg Level Monitor	Indicates Solid Hot Leg Piping	Would indicate voiding in upper hot leg	Not Operational	Would indicate loss of RCS inventory	Off Scale Low

B. INCORE/CORE EXIT THERMOCOUPLES

Recommended design for the core exit thermocouples consists of upgrading the CET instrument cable connector and cabling located within the Reactor Building to survive and function under the postulated design basis accident environmental conditions. The outside containment portion of the system would be unchanged and consists of readouts via the plant computer. No seismic requirements are considered for this design proposal.

C. HOTLEG LEVEL MONITOR

Hotleg level monitor in-containment equipment (transmitters, temperature compensation, cables, etc.) will be designed, installed and analyzed such that the proposed monitor will survive and function under the expected design basis accident environmental conditions. The HLLMS will be seismically designed and installed.

3.3 POWER SOURCES

The power sources selected for the ICC detection will be highly reliable, non-interruptible battery backed sources.

Power sources for primary and operating backup hotleg monitoring channels will be from completely separate supplies.

3.4 HUMAN FACTORS ANALYSIS

The addition of any control room indications or displays will be integrated into the control room review.

3.5 INSTALLATION CONSIDERATIONS

The proposed ICC detection system was selected with due consideration of cost effective installation.

These considerations include:

A. Requires no new reactor coolant system boundary penetrations to be installed which require expensive first-of-a-kind technologies or major structural changes to the plant as stated in NUREG 0578, Appendix A.

B. When applied as a "back-fit" on an operational plant, will result in reduced downtime and the subsequent loss of generation capability.

C. Minimizes radiological exposure to personnel and the amount of personnel to perform the modification because of exposure time.

D. Significant cost savings as demonstrated by recent cost estimates for various design proposals.

4.0 SYSTEM DESIGN

The proposed design consists of the following three Subsystems:

A. Subcooling Margin Monitor
B. Hot Leg Level Monitor
C. Incore/Core Exit Thermocouples

All three are to be considered in the total information package that will assist the operator in detecting an approach to an inadequate core cooling.

4.1 SUBCOOLING MARGIN MONITOR

The presently installed subcooling margin monitor provides the operator with the indication of loss of saturation margin. It is the first part of the ICC detection system. This monitor provides the operator with the saturation condition information of the RCS. This information in itself does not indicate that an ICC event is imminent but does warn the operator to examine the other sources of information available, in a confirmatory/ discerning action. Thus, the subcooling margin monitor performs an advance warning role in the ICC detection system.

4.2 HOT LEG LEVEL MONITOR SYSTEM (HLLMS)

The hot leg level monitor (HLLMS) provides the operator with indication that voiding is/has occurred in the RCS and alerts him to the potential for inadequate core cooling via core uncovery.

The B & W NSS System utilizes a once-through steam generator (OTSG) which offers a unique design difference in comparison to other PWR designs which employ a U-tube steam generator. The B & W NSS incorporates a long, vertical section of hot leg piping in order to accommodate the OTSG design. This vertical hot leg piping provides an optimum location for RC level indication in the B & W NSS. The HLLMS would provide the operator with an early indication of voided conditions in the RCS and would alert the operator to the potential for core uncovery.

The proposed HLLMS design will not be operational when the RC pumps are operating and the fluid in the hot leg is not in a saturated condition. When any RC pump is operating, the differential pressure between the level sensing line connections will not correlate to level measurement because of the flow induced differential pressure between the sensing line connections. Also, with pumps operating under accident conditions, the presence of voids and their distribution would preclude accurate inventory indications. The proposed HLLMS design will include simple and clear indication to control room operator that the HLLMS is not in use or is erroneous under these conditions. However, during emergency or SB LOCA conditions with RCP's tripped and hot leg voiding, the HLLMS will provide hot leg level indication to the operator.

The following is a description for the proposed design of the HLLMS described in Section 3.1 and above:

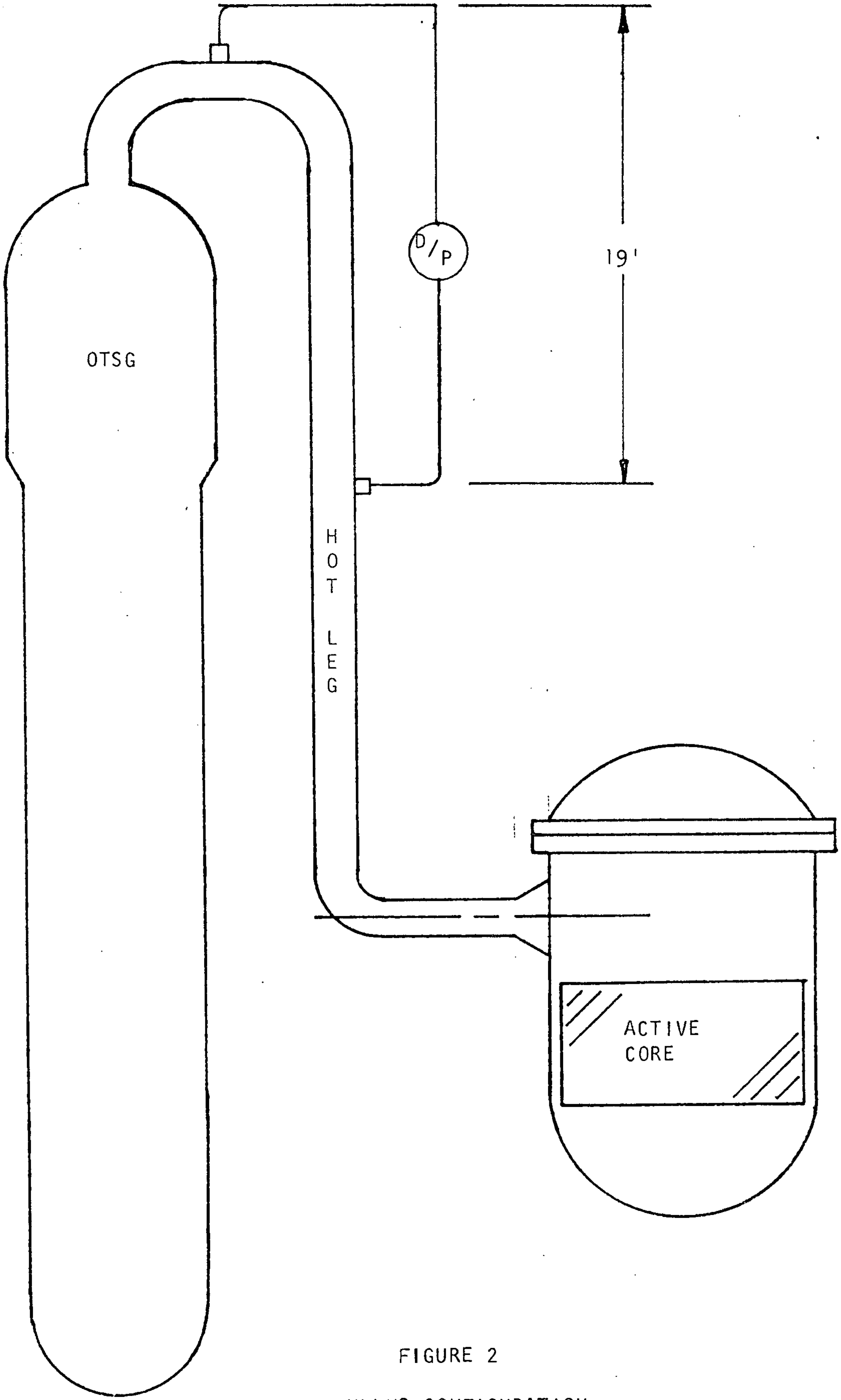

FIGURE 2

HLLMS CONFIGURATION

The proposed HLLMS will consist of two differential pressure measuring channels, one on each hot leg, with each performing a confirmatory/backup role to the other. Both channels will normally be operational such that maintenance or failure considerations would not result in loss of system performance.

System Layout

Schematic of the system layout for the Hot Leg Level Monitor System is by Figure 2. For each hot leg, there are two reactor coolant system connections for the d/p cell reference lines, one connection at the hot leg vent point, and one connection at the hot leg 19 foot tap. Each d/p cell measures the pressure drop from the top of each hot leg piping to the 19 foot tap on the hot leg piping. The cells will have the same range since elevation dimensions will be nearly the same and the cells will be used under the same RCS flow behavior (without pump operation).

The differential pressure cells are located within containment to eliminate the need of additional mechanical containment penetrations. The measurement accuracies associated with in-containment d/p cells for post-accident conditions will be consistent with demonstrated available equipment. The location of d/p cells within containment will be such to facilitate calibration, d/p cell replacement and maintenance.

To eliminate inaccuracies of the hot leg level measurement, temperature measurements of the vertical sections of impulse lines inside containment are provided. These measurements, together with the existing reactor coolant temperature measurement and wide range RCS pressure, compensate the d/p transmitter outputs for differences in reactor coolant density and impulse line density. These density differences may occur, for example, during changes in containment environment accompanying an accident.

The process electronics performs the necessary computations to display hot leg level readings based on signals from the d/p transmitters. The reactor coolant temperature (T_{hot}), wide range RCS pressure and impulse line temperature are used to provide density compensation for the hot leg level readings. The calculation for the compensation is performed by the process electronics.

Hot leg level readings will be displayed on the Main Control Board.

Plant Operator Interface

Control board displays provide an indication of reactor coolant system hot leg upper range coolant level in percent from 0 to 100 for each loop after compensation.

Additional level output signals will be available to the

Plant Computer - Analog

Alarm Display Panel (Statalarm) - Digital

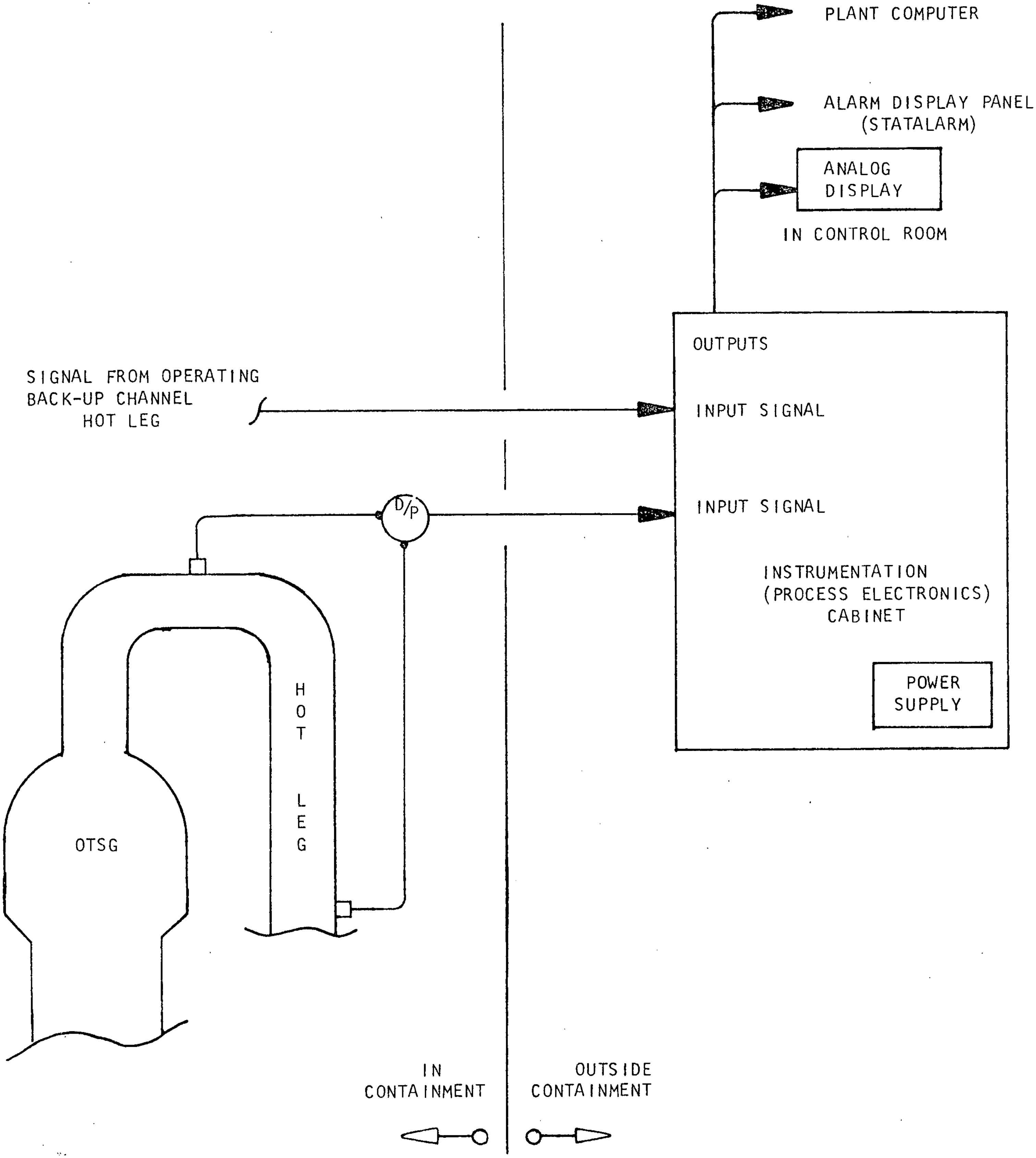

FIGURE 3 SIMPLIFIED HOT LEG LEVEL MONITORING SYSTEM BLOCK DIAGRAM

from the process electronics and employ suitable isolation methods where required. The above outputs will be standard industry signals of ranges suitable to existing input capability.

Set points for alarms will be determined from analysis provided in existing documents and information as required from the NSSS vendor such that the operator will be alerted to conditions that may proceed towards an ICC event.

See Figure 3 for a simplified diagram of the proposed HLLMS.

4.3 INCORE/CORE EXIT THERMOCOUPLES

The incore/core exit thermocouples in conjunction with the two preceding subsystems make up the ICC detection system. The incore/CET's are the actual indicators of the developing inadequate core cooling transient. Their increase in temperature reflects the possibility for excessive fuel clad temperatures.

The proposed system design for the incores/CET's consists of upgrading the connectors and cabling to survive the postulated design basis accident environmental conditions in the reactor building containment. This will insure that the information the incores/CET's provide to the plant computer survive and function under the above postulated conditions.

The remainder of the outside containment subsystem would remain unchanged as previously described in Section 3.2 Item B.

5.0 SUMMARY

Hot leg level will be a determining parameter in the LOCA versus non-LOCA decision process. Given evidence of a LOCA transient, the operator will be forewarned of, and will then be able to take confirmatory actions to prevent, a possible ICC event. Particular operator actions involve HPI maximization and steam generator depressurization. The HLLMS provides valuable feedback to the operator concerning hot leg inventory conditions and the effectiveness of ECC injection to mitigate the transient.

The HLLMS is designed to aid in the determination of RCS conditions by being coupled with information from other plant indications such as primary and secondary temperatures and pressures. It is not to be used as a sole indicator of RCS conditions.

The saturation meter, the HLLMS and core exit thermocouples (exceeding saturation temperature) satisfy the requirement for advanced warning of the potential for ICC at various stages of the accident.

The requirement that the ICC detection instrument system be unambiguous is satisfied by the core exit thermocouples, since the actual high temperature in the fuel region is the only direct measure of whether or not inadequate core cooling is occurring.

Operator actions are required based on indications from the saturation monitor and core exit thermocouple temperatures to preclude the onset of the ICC. There are no direct actions that the operator would take based soley on HLLMS. However, if the inventory trend is down (level decreasing) the operator would verify that actions to be taken at saturation conditions were taken and that these actions had the expected results (e.g., actual HPI flow indicated after starting an HPI pump). The role of the HLLMS is to provide the operator information on the progress of the transient and confirm that the actions taken to preclude ICC are actually initiated.

Taken in conjunction, the saturation meter, HLLMS, and core exit thermocouples provide advanced warning and an unambiguous ICC detection system.

6.0 REFERENCES

B & W Report "Evaluation of Instrumentation to Detect ICC", August, 1980, Document No. 86-1120838-00.

Letter from R. J. Mattson to J. Mattimoe, chairman B & W Owner's Group "Cost Estimates and Design Options", April, 1982.

B & W Report "Reactor Coolant System Level", prepared for Duke Power Company, June, 1981, Document No. 77-1126635-00.

B & W Report "An Evaluation of the Use and Application of a Hot Leg Level Measurement System", January, 1982, Document No. 77-1130541-00.