TEC Report No. R-84-011-NP

SUMMARY REPORT
PHASE I OF AP&L ICC MONITORING SYSTEM PROGRAM TEST SERIES

Revision 1

Submitted to:

Arkansas Power and Light Company
P.O. Box 551
Little Rock, Arkansas 72203

Contract No. T-064-G, Task No. 001A

TEC Project Team
Wayne Garber, Project Manager
R. K. Mobley, Project Engineer

Prepared by:

Technology for Energy Corporation
One Energy Center, Pellissippi Parkway
Knoxville, Tennessee 37922
(615) 966-5856

January 1985

Approved: F. W. Garber R. A. Hedrick
R. K. Mobley R. D. Moore

54.1.84011

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANO	- Arkansas Nuclear One
AP&L	- Arkansas Power & Light Company
CDC	- Control Data Corporation
DOE	- Department of Energy
dp	- Differential Pressure
ETD	- Engineering Technology Division
FCTF	- Forced Convection Test Facility
FRS	- Fuel Rod Simulators
FSAR	- Final Safety Analysis Report
IC	- Incore
ICC	- Inadequate Core Cooling
I.D.	- Inside Diameter
INEL	- Idaho National Engineering Laboratory
LOCA	- Loss of Coolant Accident
LWR	- Light Water Reactor
NRC	- Nuclear Regulatory Commission
O.D.	- Outside Diameter
ORNL	- Oak Ridge National Laboratory
P&ID	- Piping and Instrumentation Diagram
PWR	- Pressurized Water Reactor
RELAP5	- Reactor Linearized Analysis Program, Version 5
RIM	- Radcal Inventory Meter
RTD	- Resistance Temperature Detector
TEC	- Technology for Energy Corporation
UH	- Upper Head

Section 1

INTRODUCTION

Technology for Energy Corporation (TEC) has contracted w'th Arkansas Power and Light (AP&L) Company to supply an inadequate ccre cooling (ICC) system for Arkansas Nuclear One (ANO), Units 1 and 2. TEC and AP&L designed and conducted an extensive experimental test program on the Radcal Inventory Meter (RIM) to verify ICC capability and compliance with regulatory requirements, and to provide licensing suport and design data for the system hardware.

A two-phase test program was conducted at the Oak Ridge National Laboratory (ORNL). Phase I utilized the atmospheric Air/Water Test Facility. The overall objectives of Phase I were to:

- Provide basic design data on the performance of various manometer/RIM assembly combinations,
- Select prototype manometer/RIM assembly configurations for additional testing,
- Demonstrate that the final prototype manometer/RIM assembly can make level measurements in a variety of air/water mixtures and flows, and
- Determine the domain of flow and void fraction boundary conditions under which the manometer/RIM assembly can provide unambiguous ICC determination.

Section 2 provides a detailed description of Phase I testing and a summary of the Air/Water Test Series results.

Phase II utilized the pressurized-water Forced Convection Test Facility (FCTF) at Oak Ridge. The FCTF is a typical reactor simulation facility and has been used for several Nuclear Regulatory Commission

(NRC) programs. It has both blowdown and reflood capabilities with sufficient control and instrumentation to simulate a reactor under small break, loss-of-coolant (LOCA) conditions. Phase II testing was conducted in two parts:

- Upper Head Test Series and
- In-Core Test Series.

Two separate test series were required to simulate the different upper head and in-core thermal-hydraulic boundary conditions in a nuclear reactor during a LOCA.

The objectives for both the Upper Head and In-core Test Series were to:

- Demonstrate that the selected prototype manometer/RIM assembly can supply accurate, reliable monitoring of liquid level in the upper head and upper plenum of a reactor;
- Demonstrate that the selected prototype manometer/RIM assembly can supply accurate, reliable monitoring of the in-core liquid level under low power conditions;
- Provide data to determine the boundary conditions (i.e. depressurization rates, flow rates, repressurization rates, etc.) for accurate, reliable, above and in-core monitoring performance;
- Confirm that the absolute temperature measurements provide a reliable indication of above-core coolant temperature in an ICC event;
- Provide data on how accurately a RIM monitors fuel thermal performance; and
- Provide data to finalize the sensor geometry, sensor arrangement, and manometer design for ANO, Units 1 and 2.

Section 3 provides a detailed description of the Upper Head Test Series; Section 4 describes the In-core Test Series. Each section also provides a summary of the appropriate test results.

Section 5 discusses the tested RIM compliance to regulatory requirements. Section 6 provides the results of the three-part RIM test program. The overall conclusions are that all three types of tested RIM sensors meet or exceed the regulatory requirements. Any one sensor type or a combination of two or all three sensor types in conjunction with the tested manometer should:

- Maintain their mechanical/electrical integrity, operability, and performance under small break, loss-of-coolant events;
- Respond accurately and reliably to both blowdown and reflood transients and be usable as an ICC warning system when coupled to a data processing system;
- Indicate inventory loss or gain rates as well as inventory itself;
- Produce a predictable response;
- Trend fuel clad temperatures (via absolute thermocouples); and
- Indicate fuel surface heat transfer conditions.

The test data confirms that a complete, RIM-based ICC system in full compliance with regulatory requirements can be provided for ANO, Units 1 and 2.

Section 2

AIR/WATER TEST SERIES

2.1 OVERALL OBJECTIVES OF THE AIR/WATER TEST SERIES

The overall objectives of the Air/Water Test Series were to:

- Provide basic design data on the manometer/RIM assembly performance,
- Demonstrate that the final prototype manometer/RIM assembly can make level measurements in a variety of air/water mixtures and flows,
- Obtain basic performance data, response time, and fill and drain rates of the manometer/RIM assembly, and
- Determine the domain of flow and void fraction boundary conditions under which the manometer/RIM assembly can provide unambiguous data.

2.2 AIR/WATER EXPERIMENTAL CONFIGURATION AND TEST MATRIX FOR MANOMETER EQUALIZING PORT TESTING

Figure 2-1.

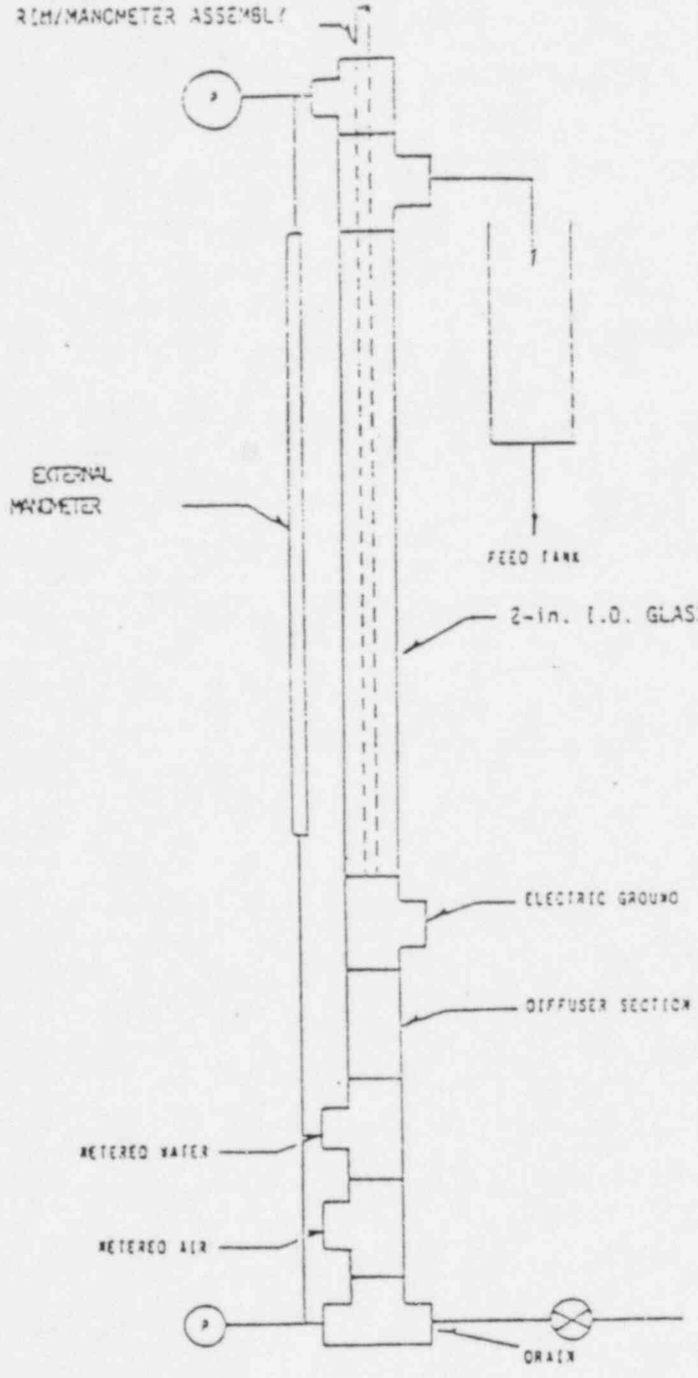

Figure 2-2. ORNL Air/Water Test Facility Schematic.

2.3 AIR/WATER RESULTS AND CONCLUSIONS FOR MANOMETER EQUALIZING PORT TESTING

Table 2-1

MANOMETER PORT PATTERNS TESTED IN
THE AIR/WATER TEST SERIES

Pattern Number	Number of Slots	Number of Rows	Height (in.)	Width (in.)	Row-to-Row Centerline Spacing (in.)

Figure 2-3:

Figure 2-4.

Figure 2-5.

Figure 2-6.

2.4 AIR/WATER EXPERIMENTAL CONFIGURATION AND TEST MATRIX FOR MANOMETER/RIM ASSEMBLY TESTING

The air/water testing of the manometer/RIM tube assembly was performed in the experimental facility shown in Figure 2-2. Water and air were metered into a vertical test section that housed the RIM and its manometer. The test section was transparent to allow visual observations. The external manometer (shown in Figure 2-2) was designed so that when air was bubbled into the test section, no air was induced in the internal manometer.

Figure 2-7. Bottom Manometer Equalizing Port Design Chosen in the Air/Water Test Series.

Figure 2-8. Air/Water Test Series Sensor Types and Locations.

Figure 2-9. Air/Water Test Series Sensor Designs.

2.5 AIR/WATER RESULTS AND CONCLUSIONS FOR MANOMETER/RIM ASSEMBLY TESTING

2.5.1 Results and Conclusions for AW2100

Table 2-2

Table 2-3

Section 3

UPPER HEAD TEST SERIES

3.1 OVERALL OBJECTIVES OF THE UPPER HEAD TEST SERIES

The overall objectives of the Upper Head Test Series were to:

- Demonstrate that the prototype manometer/RIM assembly can supply measurements to provide effective ICC monitoring of the upper head and upper plenum of the reactor,
- Provide data to determine the domain of the boundary conditions [i.e., depressurization rates (break size), initial flow rate sensitivity, and refill repressurization rates] of unambiguous manometer/RIM assembly ICC monitoring performance,
- Confirm that the manometer/RIM assembly absolute temperature measurement provides a good indication of coolant temperature above the core in an ICC event, and
- Provide data to select the optimum sensor types and arrangements in the manometer/RIM assembly for ANO, Units 1 and 2.

3.2 UPPER HEAD EXPERIMENTAL CONFIGURATION AND TEST MATRIX

Depressurization tests of the RIM were conducted in the ORNL FCTF, which can simulate a large PWR during a small break event. The test facility is a high-pressure, high-temperature, forced-circulation water loop configured as shown in Figure 3-1. The loop can be operated at temperatures and pressures up to 650°F and 2250 psig, with a water flow through the test section of up to 50 gpm at variable test-section power inputs of up to about 30 kW.

The FCTF is a typical blowdown test facility composed of a circulating pump (with bypass for flow control), a test section, pressurizer, heat exchanger, and blowdown line connected to the test section. The test

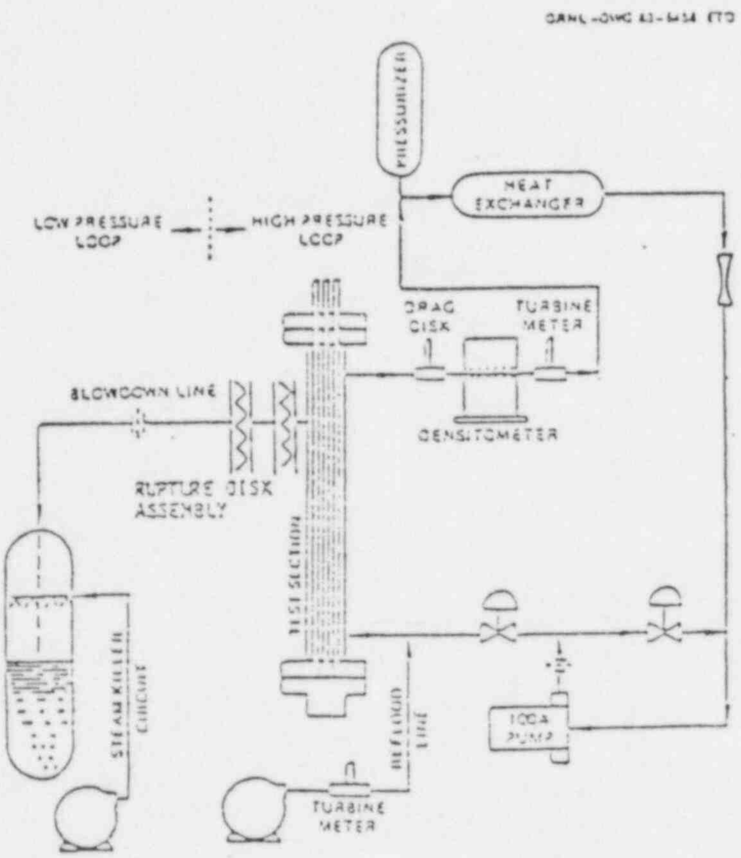

Figure 3-1. ORNL FCTF Schematic.

section was configured with the inlet piping connected near the bottom of the test section (i.e., no internal downcomer was simulated). The blowdown line was connected to the top of the test section to simulate hot leg breaks. Two rupture disks with a nitrogen buffer were used to create primary system breaks. An orifice assembly downstream of the rupture disks determined the break size.

The FCTF has the necessary instrumentation to monitor a small break LOCA. The major instruments monitoring the loop and test section are shown in Figures 3-2 and 3-3. The following standard instrument designations are used:

PE - Pressure

PDE - Differential Pressure

TE - Temperature

FE - Flow.

The FCTF data acquisition system records 135 instrument signals every 0.025 seconds.

In the Upper Head Test Series, four manometer/RIM assemblies were tested in a bundle configuration as shown in Figure 3-4. This simultaneous testing allowed direct comparison of sensor types and chamber variations during the testing sequence and enabled a smaller number of tests to determine the most effective manometer/RIM assembly design to be utilized in ANO, Units 1 and 2.

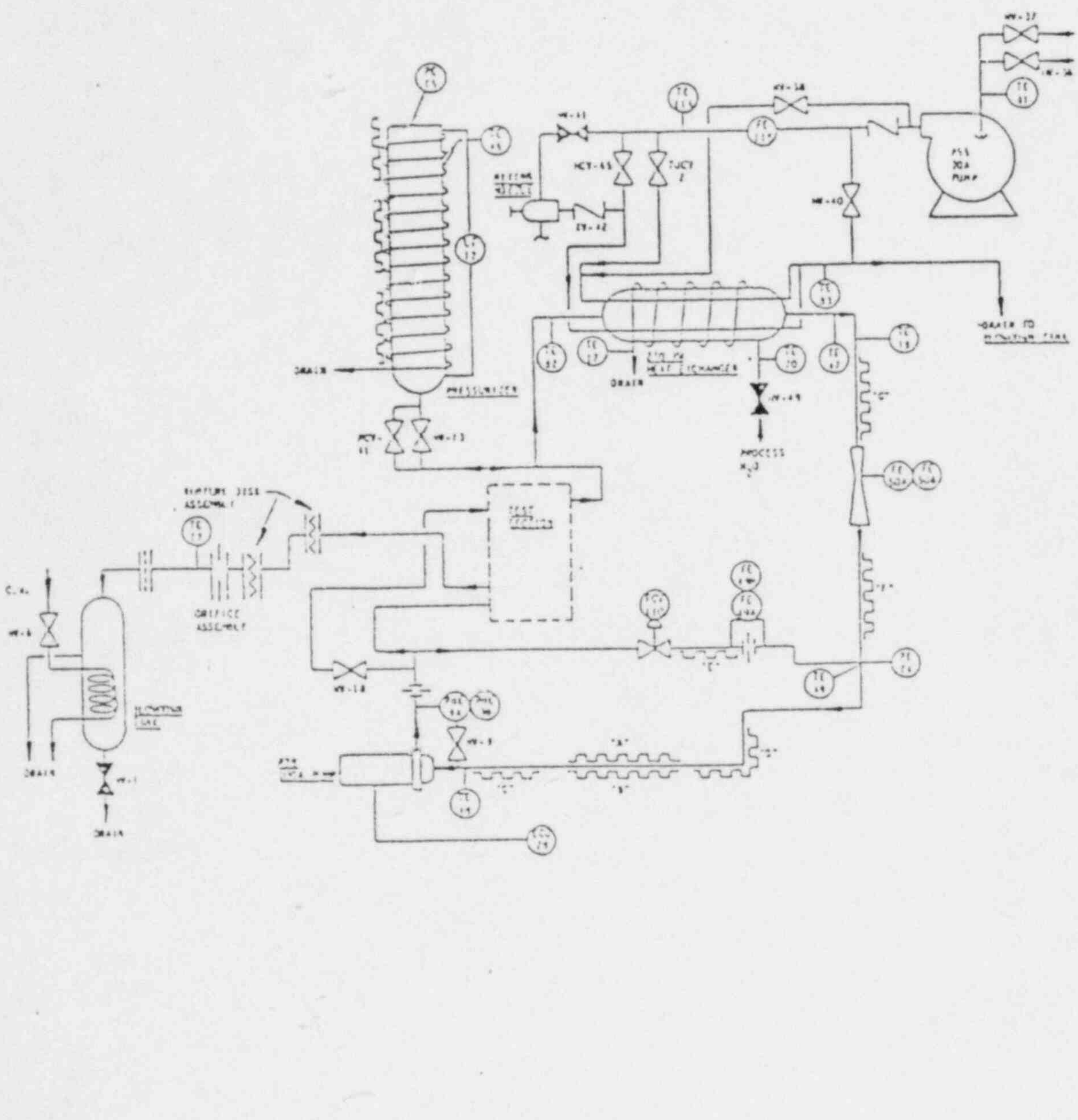

Figure 3-2. Major FCTF Loop Instrumentation.

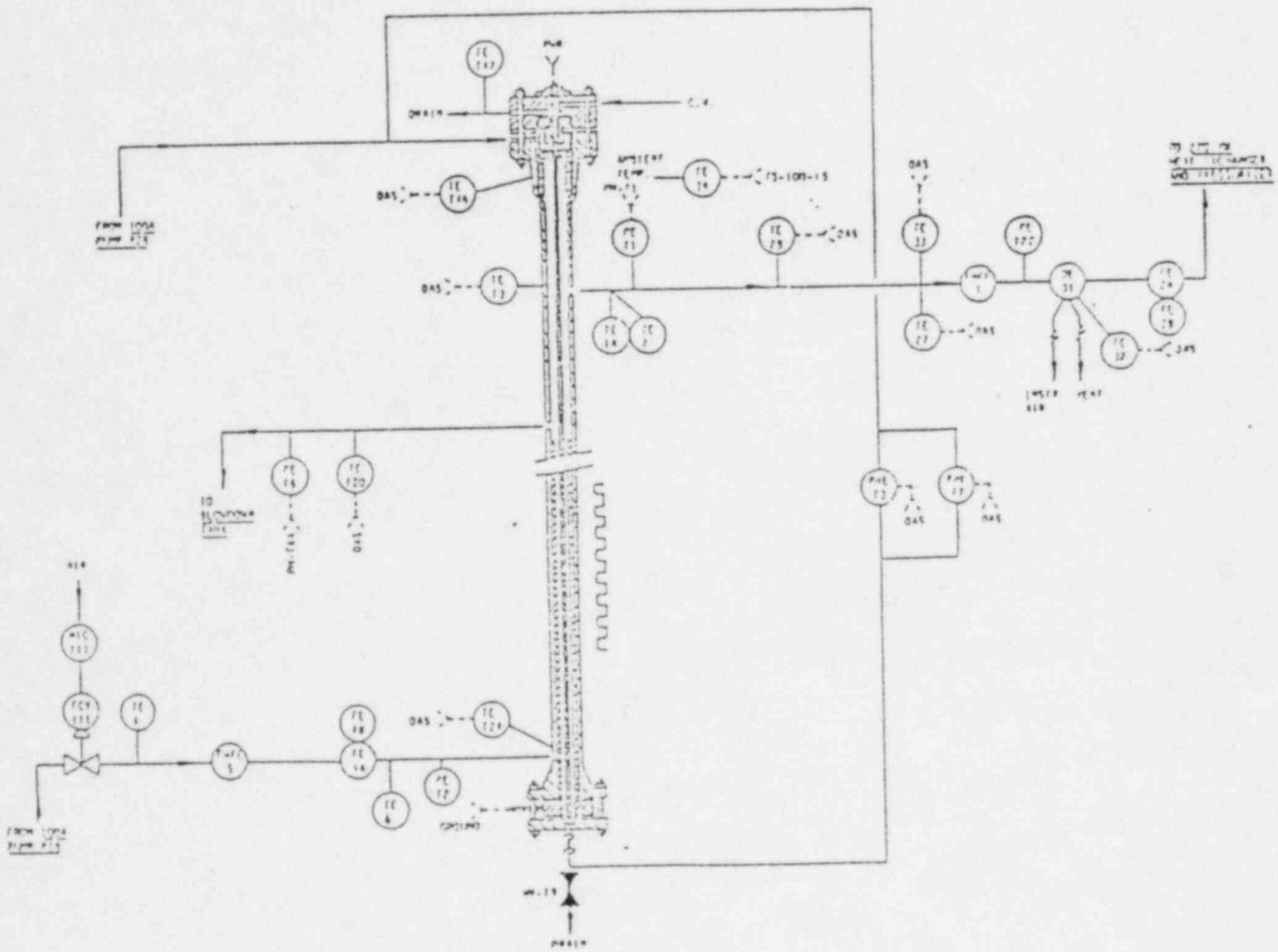

Figure 3-3. Major FCTF Test Section Instrumentation.

Figure 3-4.

Figure 3-5.

Table 3-1

SUMMARY OF UPPER HEAD TEST SERIES SENSOR ARRANGEMENT

(S - Slow, F - Fast, SU - Signature of Uncovery)

		Rod 2			Rod 3		Rod 4			Rod 5		
Upper Head Bundle Level	Approximate Hot Junction Elevation* (ft)	Sensor Type	Approximate Cold Junction Elevation* (ft)	Gas Gap Length (in)	Sensor Type	Approximate Cold Junction Elevation* (ft)	Sensor Type	Approximate Cold Junction Elevation* (ft)	Gas Gap Length (in)	Sensor Type	Approximate Cold Junction Elevation* (ft)	Gas Gap Length (in)

*Zero is the centerline of the stainless steel bundle ground plate.

54.2.84011

Figure 3-6.

3.3 UPPER HEAD RESULTS AND CONCLUSIONS

3.3.1 Basic Response Patterns During Blowdown

The fundamental phenomenon in the test section during blowdown is a loss of inventory from a two-phase regime covered by single-phase steam. The primary parameter is rate-of-loss of inventory. The RIMs are separated from the test section mixture by the manometers which permit water to flow into the instrument region while inhibiting steam entrance. This construction provides a better indication of water inventory with the mixture quality inside the manometer during blowdown being primarily a function of depressurization rate.

The response of each sensor type (slow, fast, and signature of uncovery) to loss of inventory is indicated in Figures 3-7 through 3-9. (As with all unfiltered experimental data, these figures have noise spikes that should be disregarded.)

Figure 3-7 shows the response of a slow sensor to a medium rate, loss-of-inventory case. At this rate, the different time constants of the differential thermocouple junctions and the decreasing absolute

Table 3-2

MAJOR UPPER HEAD TEST SERIES PARAMETERS

Test Number	(PE-T2) Initial Pressure (psia)	(TE-T4) Initial Temperature (Deg. F)	(FE-4A) Initial Test Section Flow (gpm)	Equivalent Reactor Break (in-dia.)	Average Level Fall Rate* (ft/min)	Average Level Rise Rate* (ft/min)	Comments

NOTE:

*These were calculated from the pretest calibrated PDE-T7 differential pressure transducer output.

54.1.84011

Figure 3-7.

Figure 3-8.

Figure 3-9.

3.3.2 Differential Pressure Transducer Comparisons During Blowdown

Figure 3-10.

Figure 3-11.

Table 3-3

DELAY TIMES UNTIL INITIATION OF UNCOVERY SIGNAL DURING UPPER HEAD TEST SERIES FOR SLOW AND FAST SENSORS USING DIFFERENTIAL PRESSURE TRANSDUCERS AS THE BASIS FOR COLLAPSED LIQUID LEVEL SENSOR CROSSING TIMES

		Slow Sensors		Fast Sensors	
Test Number	Average Level Fall Rates* (ft/min)	Maximum Delay Time (s)	Minimum Delay Time (s)	Maximum Delay Time (s)	Minimum Delay Time (s)

3.3.3 Basic Response Patterns During Reflood

Figure 3-12.

Figure 3-13.

Figure 3-14.

3.3.4 Differential Pressure Transducer Comparisons During Reflood

Figure 3-15.

Figure 3-16.

Table 3-4

DELAY TIMES UNTIL INITIATION OF RECOVERY SIGNAL DURING UPPER HEAD TEST SERIES FOR SLOW AND FAST SENSORS USING DIFFERENTIAL PRESSURE TRANSDUCERS AS THE BASIS FOR COLLAPSED LIQUID LEVEL SENSOR CROSSING TIMES

		Slow Sensors		Fast Sensors	
Test Number	Average Level Fall Rates* (ft/min)	Maximum Delay Time (s)	Minimum Delay Time (s)	Maximum Delay Time (s)	Minimum Delay Time (s)

* Calculated from the pretest calibrated PDE-T7 differential pressure transducer output.

Section 4

IN-CORE TEST SERIES

4.1 OVERALL OBJECTIVES OF THE IN-CORE TEST SERIES

The overall objectives of the In-core Test Series were to:

- Demonstrate that the prototype RIM sensors can supply measurements to provide effective ICC monitoring of the reactor core under low-power conditions,
- Provide data to determine the boundary conditions on unambiguous RIM ICC monitoring performance - depressurization rates (break size), initial flow rate sensitivity, and refill repressurization,
- Confirm that the absolute temperature measurement provides a good indication of coolant temperature above the core in an ICC event, and obtain data on how closely the RIM reflects fuel thermal performance, and
- Provide data to select the optimum sensor types and arrangements in the RIM probe for ANO, Units 1 and 2.

4.2 IN-CORE EXPERIMENTAL CONFIGURATION AND TEST MATRIX

Figure 4-1.

Figure 4-2.

Table 4-1

MAJOR IN-CORE TEST SERIES PARAMETERS

Test Number	(PE-T2) Initial Pressure (psia)	(TE-4) Initial Test Section Temp. (Deg. F)	(FE-4A) Initial Test Section Flow (gpm)	Equivalent Reactor Break (in-dia.)	Average Level Fall Rate* (ft/min)	Average Level Rise Rate* (ft/min)	Comments

*These were calculated from the pretest calibrated PDE-T7 differential pressure transducer output.

4.3 IN-CORE RESULTS AND CONCLUSIONS

4.3.1 FPS Sheath Thermocouple Comparisons During Blowdown

Figure 4-3.

Figure 4-4.

Figure 4-5.

4.3.2 Differential Pressure Transducer Comparisons During Blowdown

Figure 4-6.

Figure 4-7.

Figure 4-8.

4.3.3 FPS Sheath Thermocouple Comparisons During Reflood

4.3.4 Differential Pressure Transducer Comparisons During Reflood

Figure 4-10.

Figure 4-11.

Figure 4-12.

Figure 4-13.

Section 5

REGULATORY REQUIREMENTS COMPLIANCE

There are two major documents with which the TEC ICC monitoring system must comply: (1) NUREG-0737, "Classification of TMI Action Plan Requirements" and (2) Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident." The test program described in this document does not address all of the requirements in these documents because some of the requirements are related to items other than system performance. The following sections address directly those requirements related to system performance with which this test report shows compliance and indicate how the TEC ICC monitoring system complies totally with both documents.

5.1 COMPLIANCE WITH SECTION II.F.2 OF NUREG-0737

The following classification of requirements are from Section II.F.2, "Instrumentation for Detection of Inadequate Core Cooling," of NUREG-0737.

1. Requirement: "Design of new instrumentation should provide an unambiguous indication of ICC. This may require new measurements or a synthesis of existing measurements which meet design criteria (item 7)."

   Compliance:

2. Requirement: "The evaluation is to include reactor-water-level indication."

Compliance:

3. Requirement: "Licensees and applicants are required to provide the necessary design analysis to support the proposed final instrumentation system for inadequate core cooling and to evaluate the merits of various instruments to monitor water level and to monitor other parameters indicative of core-cooling conditions."

Compliance:

4. Requirement: "The indication of ICC must be unambiguous in that it should have the following properties: (a) It must indicate the existence of inadequate core cooling caused by various phenomena (i.e., high-void fraction-pumped flow as well as stagnant boil-off), and (b) It must not erroneously indicate ICC because of the presence of an unrelated phenomenon."

Compliance:

(a)

(b)

5. Requirement: "The indication must give advanced warning of the approach of ICC."

Compliance:

6. Requirement: "The indication must cover the full range from normal operation to complete core uncovery. For example, water-level instrumentation may be chosen to provide advanced warning of two-phase level drop to the top of the core and could be supplemented by other indicators such as in-core and core-exit thermocouples provided that the indicated temperatures can be correlated to provide indication of the existence of ICC and to infer the extent of core uncovery. Alternatively, full-range level instrumentation to the bottom of the core may be employed in conjunction with other diverse indicators such as core-exit thermocouples to preclude misinterpretation due to any inherent deficiencies or inaccuracies in the measurement system selected."

Compliance:

7. Requirement: "All instrumentation in the final ICC system must be evaluated for conformance to Appendix B, Design and Qualification Criteria for Accident Monitoring Instrumentation, as clarified or modified by the provisions of items 8 and 9 that follow. This is a new requirement."

   Compliance:

8. Requirement: "If a computer is provided to process liquid-level signals for display, seismic qualification is not required for the computer and associated hardware beyond the isolator or input buffer at a location accessible for maintenance following an accident. The single-failure criteria of item 2, Appendix B, need not apply to the channel beyond the isolation device if it is designed to provide 99% availability with respect to functional capability for liquid-level display. The display and associated hardware beyond the isolation device need not be Class 1E, but should be energized from a high-reliability power source which is battery backed. The quality assurance provisions cited in Appendix B, item 5, need not apply to this portion of the instrumentation system. This is a new requirement."

   Compliance:

9. Requirement: "Incore thermocouples located at the core exit or at discrete axial levels of the ICC monitoring system and which are part of the monitoring system should be evaluated for conformity with Attachment 1, Design and Qualification Criteria for PWR Incore Thermocouples, which is a new requirement."

   Compliance:

10. Requirement: "The types and locations of displays and alarms should be determined by performing a human-factors analysis taking into consideration: (a) the use of this information by an operator during both normal and abnormal plant conditions, (b) integration into emergency procedures, (c) integration into operator training, and (d) other alarms during emergency and need for prioritization of alarms."

    Compliance:

5.2 COMPLIANCE WITH REGULATORY GUIDE 1.97

Although not addressed directly in this test program, the TEC ICC system will meet the requirements of Regulatory Guide 1.97. Other qualification program reports are required to document compliance. The following is included to give an overview of how the TEC ICC monitoring system will comply with the Design and Qualification Criteria for Instrumentation given in Table 1 (Category 1) of Regulatory Guide 1.97.

1. Equipment Qualification

    Requirement: "The instrumentation should be qualified in accordance with Regulatory Guide 1.89, Qualification of Class 1E Equipment for Nuclear Power Plants, and the methodology described in NUREG-0588, Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment.

    Instrumentation whose ranges are required to extend beyond those ranges calculated in the most severe design basis accident event for a given variable should be qualified using the guidance provided in Paragraph 6.3.6 of ANSI-4.5.

Qualification applies to the complete instrumentation channel from sensor to display where the display is a direct-indicating meter or recording device. If the instrumentation channel signal is to be used in a computer-based display, recording, or diagnostic program, qualification applies from the sensor up to and including the channel isolation device.

The seismic portion of qualification should be in accordance with Regulatory Guide 1.100, Seismic Qualification of Electric Equipment for Nuclear Power Plants. Instrumentation should continue to read within the required accuracy following, but not necessarily during a safe shutdown earthquake."

Compliance:

2. Redundancy

Requirement: "No single failure within either the accident-monitoring instrumentation, its auxiliary supporting features, or its power sources concurrent with the failures that are a condition or result of a specific accident should prevent the operators from being presented the information necessary for them to determine the safety status of the plant and to bring the plant to and maintain it in a safe condition following that accident. Where failure of one accident-monitoring channel results in information ambiguity (that is, the redundant displays disagree) that could lead operators to defeat or fail to accomplish a required safety function, additional information should be provided to allow the operators to deduce the actual conditions in the plant. This may be accomplished by providing additional independent channels of information of the same variable (addition of an identical channel) or by providing an independent channel to monitor a different variable that bears a known relationship to the multiple channels (addition of a diverse channel). Redundant or diverse channels should be electrically independent and physically separated from each other and from equipment not classified important to safety in accordance with Regulatory Guide 1.75, Physical Independence of Electric Systems, up to and including any isolation device. Within each redundant division of a safety system, redundant monitoring channels are not needed except for steam generator level instrumentation in two-loop plants."

Compliance:

3. Power Supply

Requirement: "The instrumentation should be energized from station standby power sources as provided in Regulatory Guide 1.32, Criteria for Safety-Related Electric Power Systems for Nuclear Power Plants, and should be backed up by batteries where momentary interruption is not tolerable."

Compliance:

4. Channel Availability

Requirement: "The instrumentation channel should be available prior to an accident except as provided in Paragraph 4.11, Exception, as defined in IEEE Std 279-1971, Criteria for Protection Systems for Nuclear Power Generating Stations, or as specified in the technical specifications."

Compliance:

5. Quality Assurance

Requirement: "The recommendations of the following regulatory guides pertaining to quality assurance should be followed:

- Regulatory Guide 1.28 - Quality Assurance Program Requirements (Design and Construction)
- Regulatory Guide 1.30 (Safety Guide 30) - Quality Assurance Requirements for the Installation, Inspection, and Testing of Instrumentation and Electric Equipment
- Regulatory Guide 1.38 - Quality Assurance Requirements for Packaging, Shipping, Receiving, Storage, and Handling of Items for Water-Cooled Nuclear Power Plants
- Regulatory Guide 1.58 - Qualification of Nuclear Power Plant Inspection, Examination, and Testing Personnel
- Regulatory Guide 1.64 - Quality Assurance Requirements for Design of Nuclear Power Plants
- Regulatory Guide 1.88 - Collection, Storage, and Maintenance of Nuclear Power Plant Quality Assurance Records
- Regulatory Guide 1.123- Quality Assurance Requirements for Control of Procurement of Items and Services for Nuclear Power Plants
- Regulatory Guide 1.144- Auditing of Quality Assurance Programs for Nuclear Power Plants
- Regulatory Guide 1.146- Qualification of Quality Assurance Program Audit Personnel for Nuclear Power Plants

Reference to the above regulatory guides (except Regulatory Guides 1.30 and 1.38) is being made pending issuance of a revision to Regulatory Guide 1.28 that is under development (Task RS 002-5) and that will endorse ANSI/ASME NQA-1-1979, Quality Assurance Program Requirements for Nuclear Power Plant.

Compliance:

6. Display and Recording

Requirement: "Continuous real-time display should be provided. The indication may be on a dial, digital display, CRT, or stripchart recorder.

Recording of instrumentation readout information should be provided for at least one redundant channel.

If the direct and immediate trend or transient information is essential for operator information or action, the recording should be continuously available on redundant dedicated recorders. Otherwise, it may be continuously updated, stored in computer memory, and displayed on demand. Intermittent displays such as data loggers and scanning recorders may be used if no significant transient response information is likely to be lost by such devices."

Compliance:

7. Range

Requirement: "If two or more instruments are needed to cover a particular range, overlapping of instrument span should be provided. If the required range of monitoring instrumentation results in a loss of instrumentation sensitivity in the normal operating range, separate instruments should be used."

Compliance:

8. Equipment Identification

Requirement: "Types A, B, and C instruments designed as Categories 1 and 2 should be specifically identified with a common designation on the control panels so that the operator can easily discern that they are intended for use under accident conditions."

Compliance:

9. Interfaces

Requirement: "The transmission of signals for other use should be through isolation devices that are designated as part of the monitoring instrumentation and that meet the provisions of this document."

Compliance:

10. Servicing, Testing, and Calibrations

Requirement: "Servicing, testing, and calibration programs should be specified to maintain the capability of the monitoring instrumentation. If the required interval between testing is less than the normal time interval between plant shutdowns, a capability for testing during power operation should be provided.

Whenever means for removing channels from service are included in the design, the design should facilitate administrative control of the access to such removal means.

The design should facilitate administrative control of the access to all setpoint adjustments, module calibration adjustments, and test points.

Periodic checking, testing, calibration, and calibration verification should be in accordance with the applicable portions of Regulatory Guide 1.118, Periodic Testing of Electric Power and Protection Systems, pertaining to testing of instrument channels. (Note: Response time testing not usually needed.)

The isolation of the isolation device should be such that it would be accessible for maintenance during accident conditions."

Compliance:

11. Human Factors

Requirement: "The instrumentation should be designed to facilitate the recognition, location, replacement, repair, or adjustment of malfunctioning components. It is designed to be highly reliable with minimal repair or adjustment. Faults are readily identified through the sensor functional checks and the DAS self-diagnostic software. The DAS modules and equipment cabinet are designed for easy replacement or repair."

Compliance:

12. Direct Measurement

Requirement: "To the extent practicable, monitoring instrumentation inputs should be from sensors that directly measure the desired variables. An indirect measurement should be made only when it can be shown by analysis to provide unambiguous information."

Compliance:

Section 6

OVERALL CONCLUSIONS

The breadth of the parameter space in the Air/Water, Upper Head, and Incore Test Series was significant. Variations in blowdown rate, reflood rate, initial temperature, and initial flow were included. Furthermore, three sensor types and three chamber length variations within two of the sensor types were tested. The overall conclusions are:

- All RIM probes maintained their mechanical integrity, operability, and performance throughout the tests,
- All RIM sensor types respond well to blowdown and reflood transients and could be utilized as ICC warning devices with relatively simple type-specific data processing,
- Inventory loss or gain rate can be determined in addition to inventory,
- There is no practical difference in response of RIM rods containing different numbers of sensor locations
- The response of the sensors is predictable, including variations in absolute temperature and flow,
- Absolute thermocouples in the RIM rods can be used to trend fuel clad temperature, and
- RIM sensors in the instrument guide tube can be used to indicate fuel surface heat transfer conditions.

All the sensors tested meet the NRC Regulatory Requirements on performance (Section 5). The "best" sensor design can, therefore, be selected from all the types tested on the basis of optimizing the combination of performance parameters for a particular application. The performance parameters to be considered are:

Tracking Collapsed Liquid Level: - The capability of the sensor to respond dramatically and quickly to the passage of a liquid/vapor interface.

Splashing Sensitivity: - The capability of the sensor to maintain a stable uncovered alarm state under surface splashing phenomena.

Signal Doubling Time: - The time it takes for the signal to double in magnitude after uncovery. This is the alarm generation time delay (fast and slow sensors) after liquid level passage.

Uncovery (Blowdown) Signal/Initial Signal: The ratio of the dry output signal to the initial wet signal. The greater the ratio, the more obvious the uncovered state and the easier it is to interpret.

Recovery (Reflood) Signal/Initial Signal: The ratio of the wet output signal after the sensor has been dry to the initial wet signal. After having gone through a blowdown and reflood transient, the temperature of the sensor will be decreased and this ratio is an indication of how closely the final wet state approaches the pre-transient wet state.

Magnitude of Initial Signal: The larger the initial signal, the easier it is to process and the less the uncertainty (%) in its magnitude.

Accuracy as a Rate Monitor: The capability of a sensor to be used as a rate of level fall or rate of level rise meter. This capability would allow an operator to calculate the amount of time he had to take action before ICC occurred or to calculate the amount of time it would take to reflood a portion of the vessel.

Absolute Temperature Sensitivity: The change in the output signal due to changes in absolute temperature. An instrument which was very sensitive could give unreliable information in temperature transients. The worst effect on any RIM sensor type is about 27% of signal.

Flow Sensitivity: The change in the output signal due to changes in flow. An instrument which was very flow sensitive could give unreliable information in flow transients. The flow sensitivity of the RIM sensors is that which is related to flow-induced changes in heat transfer coefficient. These changes are orders of magnitude smaller than those related to uncovery from a wet state.

Since all the sensor variations tested meet the regulatory requirements, only a relative scale is needed for optimization. Best in a performance parameter category is indicated by a 1 and worst by a 3. Utilizing all the data from the tests and this relative scale, the comparison of the performance of the sensor types is presented in Table 6-1. The comparison of the performance of the chamber lengths is presented in Table 6-2. The categories are ordered in importance from the most important at the top to the least important at the bottom of the tables. Based on

Table 6-1

PERFORMANCE OF SENSOR TYPES

(1 = Best, 2 = Middle, 3 = Worst)

Category	Slow	Fast	Signature of Uncovery
Tracking Collapsed Liquid Level			
Splashing Sensitivity			
Signal Doubling Time			
Uncovery (Blowdown) Signal/Initial Signal			
Recovery (Reflood) Signal/Initial Signal			
Magnitude of Initial Signal			
Accuracy as a Rate Monitor			
Absolute Temperature Sensitivity			
Flow Sensitivity			

Table 6-2

PERFORMANCE OF CHAMBER LENGTHS

(1 = Best, 2 = Middle, 3 = Worst)

Category	Length (inches) 0.75	1.00	1.25
Tracking Collapsed Liquid Level			
Splashing Sensitivity			
Signal Doubling Time			
Uncovery (Blowdown) Signal/Initial Signal			
Recovery (Reflood) Signal/Initial Signal			
Magnitude of Initial Signal			
Accuracy as a Rate Monitor			
Absolute Temperature Sensitivity			
Flow Sensitivity			