STATUS SUMMARY

TMI ACTION PLAN II.F.2

"INSTRUMENTATION FOR DETECTION OF

INADEQUATE CORE COOLING"

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1.0 Regulatory Requirements

In July 1979, the TMI-2 Lessons Learned Task Force (Ref. 1) and the Office of Nuclear Reactor Regulation (Ref. 2) established requirements for instrumentation for detection of inadequate core cooling (ICC). These requirements were in two categories, A and B. The Office of Nuclear Reactor Regulation, with the approval of the Commission, required that NUREG-0578 Category A items be implemented prior to January 1, 1980, and Category B items prior to January 1, 1981. The Category A requirements for inadequate core cooling were for licensees to provide (a) descriptions of the existing instrumentation and any proposed new instrument design, (2) a schedule for installation of a subcooling meter and procedures for use of existing instrumentation for ICC. The Category B requirement was to install any new ICC instrumentation proposed by the licensee. The TMI Action Plan (NUREG-0660, Ref. 3) eventually reiterated the ICC instrumentation requirements. Somewhat later in 1980 based upon the staff's review of the state-of-the-art, and industry difficulties in the areas of design and equipment procurement, the design and qualification criteria for new and upgraded existing instrumentation comprising the final ICC monitoring system were better defined, design documentation requirements were specified, the requirement for new ICC instrumentation was strengthened and the schedule for implementation was slipped. Documentation was to be submitted by licensees by January 1, 1981 and any new instruments were required to be installed by January 1, 1982. This requirement and the new implementation schedule were approved by the Commission in NUREG-0737 (Ref. 5).

In SECY-81-582, dated October 7, 1982 (Ref. 6), the staff recommended that the implementation schedule for PWR applicants and licensees for installation of vessel water level measurement systems be further delayed and negotiated on a case-by-case basis. The indicated target date for completion of most of the level measurement installations was to be the start up following the first refueling after January 1, 1983. Actual use of the systems by plant operators is to be preceded by staff review and approval of plant specific installation and calibration data and emergency procedure guidelines relating to the ICC instrumentation system.

By memorandum from S. J. Chilk dated November 16, 1982, the schedule delay was approved by the Commission but the staff was asked to develop an option for ordering B&W plants to incorporate water level monitoring systems. Prior to that time, the B&W owners remained uncommitted and unlikely to meet the new target date. In SECY-81-582A (Ref. 8) the staff recommended to the Commission that orders be issued to B&W licensees requiring them to commit to specific designs and schedules for water level instrumentation.

In parallel with the staff and Commission reviews of technical proposals and progress towards meeting the ICC measurement requirements, the ACRS was reviewing progress. Beginning in mid 1981, the ACRS began to express concern with the reactor vessel level measurement systems that were being proposed and with the lack of a clear definition of how information obtained from these systems was to be used by the plant operators. Although the Committee has given strong support to the need for a vessel level measurement, it has been very critical of the attention being paid by the equipment designers and the staff to the need to provide unambiguous information to the operator. The matter came to a head in the ACRS letters on CESSAR and Palo Verde in late 1981.

On January 8, 1982, the staff, the industry, and the ACRS briefed the Commissioners on the capabilities and purpose of proposed water level measurement systems. This meeting was an attempt to air and resolve divergent views concerning the importance of the vessel level measurement system to plant safety, to explore the adequacy of its integration with the other instruments in the control room, and to decide upon the schedule for its implementation.

On January 19, 1982 (Ref. 9), the staff was asked by Chairman Palladino to develop a plan to address the issues and concerns identified during the January 8th, briefing. The plan was described in Reference 20 on January 29, 1982. The staff discussed the plan with the ACRS on February 19. Detailed discussions with ACRS subcommittees have been scheduled for March 31 and with the full ACRS on April 1 or 2 to present the staff's recommendations in light of reconsideration of the issues.

2.0 Instrumentation Requirements

2.1 Functional Requirements

The functional requirement for the Inadequate Core Cooling instrumentation stated in NUREG-0737 (Ref. 5) is as follows:

> "Licensees shall provide a description of any additional instrumentation or controls (primary or backup) proposed for the plant to supplement existing instrumentation (including primary coolant saturation monitors) in order to provide an unambiguous, easy-to-interpret indication of inadequate core cooling (ICC). A description

of the functional design requirements for the system shall also be included. A description of the procedures to be used with the proposed equipment, the analysis used in developing these procedures, and a schedule for installing the equipment shall be provided."

The staff, in regional meetings with the industry for pre-publication comments on NUREG-0737, emphasized that the functional requirements related to the total ICC monitoring instrumentation system, not to level monitoring instrumentation alone. The total system normally consisted of the upgraded existing instrumentation (saturation margin monitors and core exit thermocouples) plus the level measurement system.

Functional requirements of the ICC monitoring system were specified as follows:

(1) Monitoring Range - The complete ICC monitoring system must provide indication covering the full range from normal operation to complete core uncovery and must give advance warning of the approach of ICC. Core exit thermocouples and/or other systems such as differential pressure monitors are acceptable for describing conditions below the top of the fuel.

(2) Pumps On/Off - The complete ICC monitoring system should indicate the existence of ICC under high void fraction pumped flow as well as stagnant boil-off conditions.

(3) Transient Considerations - The performance of the level measurement system under the transient effects of pressure and flow variations resulting from various reactor coolant system break locations and sizes and various accident scenarios were to be evaluated by the designer of the ICC instrumentation system. Specific requirements were not specified but were understood to include transient conditions resulting from the LOCA small break spectrum.

(4) Post-Accident Monitoring Considerations - The capability of the instrumentation system to survive rapid transient conditions and effectively monitor recovery from accidents was to be evaluated by the designer. Likewise, the effects of severe core damage with flow blockage on instrumentation performance was to be evaluated.

2.2 Specific Design Requirements

Design and qualification criteria for core exit thermocouples were developed and included as Attachment 1 to NUREG-0737. Design and qualification criteria for accident monitoring instrumentation were extracted from Regulatory Guide 1.97 and included as Appendix B to NUREG-0737. In addition, NUREG-0737 required that all instrumentation in the final ICC system be evaluated for conformance to Appendix B (with stated exceptions for some accessible components of display systems) and that core exit thermocouples provided as a component of the ICC monitoring system be evaluated for conformance to Attachment 1.

The design criteria for accident monitoring instrumentation are the product of an extensive effort by the NRC and the industry. Some of these criteria are the basis for specific design requirements for ICC systems, including level monitoring instrumentation, which dictate the design configuration and equipment component quality of these systems. A summary of key design requirements stated in NUREG-0737 follows:

(1) Environmental - Environmental and seismic design requirements of NUREG-0737 Appendix B for accident monitoring instrumentation are applicable with some specified exceptions.

(2) Single failure - The single failure criterion is required of the ICC and the vessel level measurement system.

(3) Power Sources - The power supply for the ICC system is required to be Class 1E.

(4) Displays and Alarms - Specified exceptions to the criteria (1) through (3) are provided for computers and associated hardware beyond the isolater or input buffer at locations accessible for maintenance following an accident. The types and locations of displays and alarms are to be based on 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.

3.0 Description of Proposed PWR Level Measurement Concepts

3.1 Westinghouse Design

Westinghouse has proposed a level monitoring system extending over the full range of reactor coolant system inventory, from empty to full. It is supplemented by saturation margin monitors and core exit thermocouples. The Reactor Vessel Level Instrumentation System (RVLIS) (Figure 1) utilizes two sets of three differential pressure (d/p) cells. These cells measure the pressure drop from the bottom of the reactor vessel to the top of the vessel, and from the hot legs to the top of the vessel. This d/p measuring system utilizes cells of differing ranges to monitor different flow and pressure drop characteristics with and without reactor coolant pumps operating (Figure 2).

The d/p cells are located outside of the containment to eliminate the large reduction (approximately 15 percent) of measurement accuracy associated with the change in the containment environment (temperature, pressure, radiation) during an accident. The location outside of containment also facilitates system operations such as calibration, cell replacement, reference leg checks, and instrument line filling.

There are four RCS penetrations for the d/p taps, as follows: one reactor head connection at a spare penetration near the center of the head or at the reactor vessel head vent pipe, one reactor bottom connection to an incore instrument conduit at the seal table, and connections into the side of two RCS hot leg pipes.

When the reactor coolant pumps are not operating, the RVLIS readi g will be indicated on the narrow range scale. This reading corresponds to the equivalent collapsed liquid level in the vessel (i.e., if all steam bubbles were redistributed above the liquid to provide a sharp liquid/steam interface).

When the reactor coolant pumps are operating, the RVLIS reading will be indicated on the wide range scale. This reading is an indication of the void fraction of the vessel mixture. As the void content of the vessel mixture increases, the average density of the reactor coolant decreases and the RVLIS reading will decrease due to the reduction in static head and frictional pressure drop. Thus, the wide range instrument will indicate the trend of coolant inventory with the pumps running. We have required Westinghouse to examine a wide range of operating conditions for RVLIS, including operation with various combinations of idle reactor coolant pumps, to assure that unanticipated or ambiguous indications will not confuse the reactor operators. The predicted pressure drop as a function of voids is based on extensive pump degraded performance data obtained from two phase flow experiments with a 1/3 scale model. Expected pressure drop without voids for 4, 3, 2, 1 and 0 pumps running will be indicated on the instrument output display (see Figures 2 and 7) and will be verified during instrument calibration.

The upper scale provides measurement of vessel level above the hot leg pipe when the reactor coolant pump in the loop with the corresponding hot leg instrument tap is not operating. This reading will be erroneous by up to 10% with the pumps running in other loops. Effects of other abnormal operating conditions on instrument output are discussed in Section 4.2

3.2 Combustion Engineering Design

CE has proposed a level monitoring system extending from the top of the vessel to the fuel alignment plate; it is complemented by saturation margin monitors and core exit thermocouples.

The Heated Junction Thermocouple (HJTC) System (Figure 3) 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 junctions. In a fluid with relatively good heat transfer properties (e.g., liquid), the temperature difference between the adjacent thermocouples is very small. In a fluid with relatively poor heat transfer properties (e.g., steam), the temperature difference between the thermocouples is large.

Two design features ensure proper operation of the HJTC system under a wide range of 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, the string of HJTC sensors is enclosed in a tube that separates the collapsed liquid from the two phase mixture or gas that surrounds 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 when reactor coolant pumps are not operating. The eight HJTC sensors are electrically independent and located at eight levels from the reactor vessel head to the fuel alignment plate.

For recent CE designs such as St. Lucie 2, Waterford, San Onofre, and System 80 plants, the upper plenum is separated from the upper core and the upper head regions by the Upper Fuel Alignment Plate and the Upper Core Support plate, respectively. For these designs (see Figure 4), the HJTC probe extends from the upper head to the upper fuel alignment plate. However, flow holes are located at the bottom and top of the upper plenum region and at the bottom and top of the upper head region such that the separator tube will create a collapsed liquid level within both the upper head region above the Upper Guide Support Plate and the upper plenum region below the Upper Guide Support Plate. Each of these regions is to be monitored at four axial levels. Flow induced error in the upper plenum will make that reading invalid while pumps are operating.

With pumps running, approximately 1 percent bypass flow will pass from the upper core region to the upper head region . The flow is through the tie rods between the Upper Fuel Alignment and Upper Guide Support plates and back to the upper plenum through flow holes in the Upper Guide Support Plate (see Figure 4). Analyses indicate that this flow is insufficient to cause significant error in the collapsed level within the upper head separator tube and thus a valid collapsed level reading in the upper head can be obtained while the pumps are running.

Figure 5 shows a different arrangement typical of most other operating plants. For these plants, the HJTC probe extends from the upper head into a CEA shround which begins 1.5 feet above the Upper Guide Support Plate in CE plants and terminates at the Upper Fuel Alignment Plate. Flow holes in the separator tube are located at the bottom and the top of the probe. Approximately 1 percent bypass flow passes from the upper core region through the CEA shroud to the upper head region while the pumps are running. However, the CEA shroud will remain full of liquid even when the upper head level has dropped below the top of the CEA shroud with pumps running. Thus, collapsed level readings with pumps running are valid only in the region above the CEA shroud, which is the upper 5 feet in the head. When pumps are not running, the collapsed level in the separator tube is representative of the collapsed level in the upper head, and does not account for any voids which may exist below the upper guide support plate while there is liquid above that plate. Once the upper head is entirely voided, the instrument indicates the collapsed level of water in the upper plenum.

We have required CE to examine a range of conditions that could lead to errors. The results are discussed in Section 4.2

3.3 Babcock & Wilcox Design

Babcock and Wilcox has designed a d/p measurement system and discussed the concept with the staff. They have not reached a decision to recommend implementation of the system, and no detailed submittals have been received by the staff. However, various options of the system have been discussed in meetings with Duke Power (for the Oconee plant) and Washington Public

Power Supply System for WNP-1 and 4 (the latter has been cancelled). In addition, Metropolition Edison has proposed a concept for TMI-1 which consists of a single d/p measurement, over the top 10 feet of the hot leg, to detect voiding at the top of the candy cane.

The measurement system described by B&W at the February 17 meeting and presented for WNP-1 is shown in Figure 6. It consists of a narrow range instrument to monitor collapsed level over the upper ten feet of the hot leg candy cane, a wide range instrument to monitor collapsed level in the reactor vessel head down to the hot leg elevation, and a wide range instrument to monitor collapsed level from the top of the candy cane to the hot leg tap.

The B&W concept does not include a tap at the bottom of the vessel and thus can not monitor below the hot leg elevation or trend the void content of the vessel mixture with pumps running. Monitoring of pump current has been suggested as a possible alternative method to achieve the latter objective, but has not been thoroughly evaluated.

The d/p cells are located within containment and will be environmentally qualified for that location.

In the February 17 industry meeting, B&W described a range of conditions under which their system would perform. They have not made a formal submittal of this information.

3.4 NNC/EPRI Neutron Detection System

Alabama Power Company proposed this system for interim use and developmental testing on Farley Units 1 and 2. It consists of two sets of neutron detectors, one set above and the other below the reactor core. The Neutron Detector system depends on the ratio of count rates from these detectors to provide an indication of reactor water level.

The staff has reviewed test results obtained with this system and has concluded that it is unacceptable in its present form due to a very limited range of meaningful indication and its extremely slow response time required to obtain a statistically meaningful integrated count.

A technical report (Ref. 21) evaluating this system for the Electric Power Research Institute, which sponsored the development, concludes as follows: "In view of many uncertainties and inherent limitations indicated by the analysis, it does not appear prudent to implement this concept in an operating plant at this time."

3.5 Alternate Concepts

Licensees were required to evaluate alternate concepts of water level measurement systems for use in the ICC monitoring system. A number of concepts were considered and rejected for a variety of reasons. Conclusions were for the most part consistent with those of our contractor, Oak Ridge National Laboratoy (ORNL), which performed a similar study for NRC. Table 3 shows level detection methods, which were evaluated by

ORNL, including heated thermocouple, differential pressure, ultrasonic, Time Domain Reflectometry (TDR), capacitance, and microwave. Based on the results of the ORNL evaluation the torsional ultrasonic sensor is identified as one of the most promising long term solutions for reactor water level measurement. However, it would not necessarily result in a better system than those already proposed.

4.0 Reliability of Vessel Level Information

A number of important questions have been raised regarding the capability of the proposed instrumentation systems to provide reliable (unambiguous) indications of inadequate core cooling conditions. The questions involve how well the monitored parameter relates to inadequate core cooling conditions, for what accident sequences is the information pertinent, what are the specific operator action/information interfaces and the man/machine interfaces, and what conditions might result in false or misleading information that could cause the operator to take actions to worsen the situation. These issues are addressed in this section.

4.1 Relation of Coolant Level to Inadequate Core Cooling Conditions

It is well established by calculations and experiments that adequate core cooling will occur after a reactor trip so long as a two phase froth level (liquid level swollen by the presence of steam bubbles) covers the reactor core. Thus, with the possible exception of brief intervals of complex cooling conditions associated with large break LOCAs, the existence of a collapsed liquid level above the core is evidence of sufficient coolant inventory to cover the core. The large break LOCA conditions are not a detriment to the dependability of vessel level information simply because the blowdown would be over too rapidly to pose a longstanding source of confusion.

TABLE 3

Scoring of Level Detection Methods

	Reliability	Retrofit ?	In-situ verification/calibration	Survival (accident)	Survival (long-term)	Accuracy	Penetrations	Simplicity	Versalitlity	Performance history	Cost	Rating (10 max)
Multiplying Factor	10	10	10	9	8	5	5	4	4	6	3	
Methods												
1. Heated thermocouple	10	10	10	7	10	8	5	8	9	9	9	8.9
2. Diff. pressure	7	10	6	6	7	6	6	9	2	8	8	6.9
3. Ultrasonic	5	8	8	7	7	8	7	7	7	4	7	6.8
4. TDR	5	10	10	5	8	8	7	6	5	2	3	6.7
5. Capacitance	2	8	6	5	8	9	5	7	2	2	6	5.5
6. Microwave	2	6	8	7	8	5	7	3	2	1	2	5.1

When reactor coolant pumps are running, adequate core cooling by pumped two phase coolant will be maintained until depletion of coolant inventory well beyond the quantity required to cover the core after pumps have been shut off. Therefore, an indication of coolant inventory loss with pumps running is indicative of an approach to inadequate core cooling conditions.

4.2 Quality of Vessel Level Information

The staff plans a two step review of vessel level measurement systems; viz., first generic, then plant specifc. We have virtually completed review of the systems proposed by Westinghouse and by Combustion Engineering. Both vendors use the level monitoring instrumentation in conjunction with core exit thermocouples and saturation margin monitors for ICC information displays. Both level monitoring systems are designed to monitor collapsed level in the vessel during depressurization transients resulting from the complete spectrum of small break LOCAs (up to 10 psi/sec depressurization rates) with reactor coolant pumps not operating. Both systems have been functionally tested (Ref. 10 thru Ref. 17) and have demonstrated a capability to respond to such transients with a 10 to 20 second lag time. Both systems have been designed to survive rapid depressurization transients, including large break LOCA, and to effectively monitor the recovery from such events.

The Westinghouse system is designed to trend the coolant inventory with pumps running. The CE system is designed to trend the coolant inventory in the upper head (with limitations as previously discussed) with pumps running.

The proposed level monitoring systems have been evaluated for ambiguities in information displayed to the operator. Considerations included response with reactor coolant pumps on and off, various sizes and locations of small breaks, a variety of safety injection conditions, differing depressurization and repressurization scenarios, accident or operating scenarios involving steam or gas bubbles in the reactor coolant system, and flow blockage in the core subsequent to severe core damage.

The range of application of the Westinghouse and CE level monitoring systems is summarized in Table I. The limitations of the Westinghouse and CE systems which require operator training or attention in the design displays to assure proper operator interpretation are summarized in Enclosure 1.

4.3 Display of Vessel Level Information

Two types of Westinghouse RVLIS display systems are offered; the 7300 (an analog processor and panel meter display) and the microprocessor based systems (CRT or Plasma Panel display). These two systems are each offered in two versions for use with either a upper head injection (UHI) plant or a non-UHI plant since they differ only in the processor and display areas. Typical information displays of the Westinghouse analog and CRT display systems are shown in Figures 2 and 7. The display characteristics of RVLIS are two trains; separate readings for upper, narrow and wide range level; readings in percentage of level, single recorder (3-pen) for trending, and location in vicinity of other ICC parameters readily visible by the operator.

Table I

CAPABILITIES OF REACTOR VESSEL LEVEL INSTRUMENT

Parameters	Westinghouse	Combustion Engineering
Sensors	d/p Measurement	HJTC
Break Size (Functional Tests)	6 inches	4 inches
Depressurization Rate	≤ 10 psi/sec	≤ 10 psi/sec
Drain Rate	≤ 3 inch/sec	≤ 3 inch/sec
Correlation with other ICC Instrument	SMM/CET	SMM/CET
Speed of Response (sensor/transducer)	10 sec.	10 to 20 sec.
Accuracy	6% design ∼ 4% analysis	∼ 2 inches test performance for each sensor
Resolution	± ∼ 1 ft. upper range ± ∼ 2.5 ft narrow range	∼ 2 to 5 ft. depending on sensor spacing
Error Due to Flow Blockage	< 20% pumps on < 5% pumps off (under 66% flow blockage)	not applicable

Combustion Engineering offers an option for an ICC instrument display system which is part of a generic Accident Monitoring System (AMS), which is shown in Figure 8. The AMS consists of two major subsystems: (1) Critical Function Montoring System (CFMS) and (2) Qualified Safety Parameter Display System (QSPDS). Each instrument system consists 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 nonsafety grade systems. Channelized safety grade backup displays are included for each instrument system.

4.4 Uses of Vessel Level Information

Vessel level information of the quality indicated for both the Westinghouse and CE designed systems will provide useful diagnostic information to the operators. Westinghouse has integrated the level information into proposed Emergency Procedures Operator Guidelines (Ref. 19) to accomplish the following functions:

(1) Unique anticipatory diagnois of approach to ICC with reactor coolant pumps on.
(2) Detect upper head bubble with reactor coolant pumps off.
(3) Aid vessel head venting operation.

Combustion Engineering has not yet submitted their revised Emergency Procedures Operator Guidelines to include integration of vessel level information. However, they have discussed possible uses which imply an inital procedure integration similar to that of Westinghouse. CE has indicated particular reliance on the vessel level instrumentation as a more direct indication of approach to and recovery from conditions resulting in a steam bubble in the system.

In our meeting with instrument suppliers and plant operations personnel on February 16 and 17, 1982, it was generally agreed that the applications of vessel level information in Emergency Procedure Guidelines are likely to grow after experience and confidence is gained with the instrumentation. Operators will gain confidence in the instrument performance by use during normal plant operations such as venting operations associated with filling the reactor coolant system and the Pressurizer, and draining operations associated with refueling. Once operator confidence is established, potential additional applications for use of level information that will likely be phased in by utilities include the following:

(1) Provide indication of RCS liquid inventory after draining of the Pressurizer so as to permit the operator to distinguish between coolant inventory loss events and coolant shrinkage events,
(2) Unique indication of loss of inventory with reactor coolant pumps on,
(3) Indicate relative size of LOCA by trending coolant loss,
(4) Track growth or shrinkage of upper head bubble,
(5) Detect approaching loss or restoration of natural circulation, in some designs,
(6) Evaluate effectiveness of safety injection to replenish coolant inventory loss; aid decisions to depressurize the reactor coolant system faster to increase the safety injection rate,

(7) Monitor and control feed & bleed operations,

(8) Monitor and control venting operations through the new emergency reactor coolant system vents,

(9) Aid decisions to turn RCS pumps on or off,

(10) Aid decisions to turn ECC pumps on or off,

(11) In conjunction with core exit thermocouples, evaluate core damage and flow blockage,

(12) Aid offsite emergency response recommendations.

5.0 Benefits

The meeting of February 16 and 17, 1982 showed general agreement between the staff and industry that pressurized water reactors (PWRs) can be operated safely as designed; i.e., automatic safety injection actions and operator procedures based on existing signals without level information provide protection against all scenarios which have been anticipated based on the single failure criterion. Further, it is generally understood that post-TMI upgrading of existing instrumentation (including core exit thermocouples and monitors of coolant saturation margin) coupled with improved emergency operating procedures and operator training have increased the capability to respond properly to accident scenarios involving multiple failures beyond the design basis events. Therefore, the addition of vessel level information is useful only to the extent that it can provide reliable information to avoid operator confusion and to increase the proficiency of operator actions to maintain adequate core cooling over a range of possible degraded situations. There are some situations where the vessel level information is uniquely indicative of an approach to or recovery from ICC and is therefore of clear value. However, since the vessel level monitor is generally agreed to be non-essential to those operations where it is of value, there is also agreement that it should be well engineered, thoroughly tested, and carefully installed before it is phased into emergency reactor operations.

The indicated uses of vessel level information described in Section 4.4 increase the efficiency and effectiveness of emergency operations and thus contribute to plant safety. They also provide information which will aid to avoid operator confusion and thus reduce chances of operator error in response to incidents leading to steam bubble formation in the RCS (e.g., St. Lucie, Ginna). The increased efficiency in the conduct of normal system filling and draining operations and in recovery from abnormal situations, as well as the improved diagnostic information to aid in assessing core condition following coolant loss transients, should also result in economic benefits via reduced plant down time. It is difficult to quantify the economic benefits or to establish that the level information is necessary to plant safety.

6.0 Costs and Installation Progress

Estimated costs for implementation of vessel level instrumentation are provided in Table 2. The estimates were obtained from the utility owners groups with input from their suppliers. We have reviewed the estimates and found them to be reasonable.

Total cost for the Westinghouse system is estimated to be 1.4 to 1.7 million dollars on a Westinghouse reactor and 0.6 to 1.3 million dollars on a B&W

TABLE 2
ESTIMATED COSTS FOR VESSEL LEVEL INSTRUMENTATION

		COST $					
INSTRUMENT TYPE	PLANT TYPE	ENGINEERING	HARDWARE	INSTALLATION	SYSTEM CALIBRATION	SYSTEM (1) INTEGRATION	TOTAL
Westinghouse RVLIS	W	600 - 750K		(4) 650 - 750K	100 - 138K		1350K-1700K
	B&W	250 - 600K		300 - 600K	75 - 100K		630K-1300K
Combustion Engineering RVLMS	CE	710K		(Not Available Plant Specific)			~~710K~~ Not Available
B&W HLLMS	B&W	New Plant					650K-950K
		Operating Reactor(2)					1100K-1300K
Wisconsin Power (Point Beach) System	W	310K	140K	140K (3)	10K	20K	$610K
Duquesne Light (Beaver Valley Unit 1) W RVLIS	W	750K	540K	1,800K	510K		3,700 3,600K
Southern California Edison (San Onofre) CE RVLMS	CE	660K		770K	170K	1000	3,230 1600K

NOTE: (1) Systems Integration will include integration cost of the level signal into the display systems.
(2) Estimated Manrem exposure during installation is 25-50 Manrem per plant.
(3) Estimated Manrem exposure during installation is 20-40 Manrem per plant, based on number of workers involved, length of time required for installation, and rod level in area of plant.
(4) Estimated Manrem exposure during installation is 40 Manrem per plant.

reactor. In some plants, the costs could be higher. Duquesne Light Co. has completed installation of the Westinghouse system at Beaver Valley and has indicated a total cost of 3.6 million dollars for that plant. Special problems were encountered in routing and supporting the instrument tubing to meet seismic requirements. Calibration costs also appear to be higher than expected.

Point Beach has also installed a d/p measurement system. The utility designed its own system and used d/p cells located within containment. The total cost of this system was about 0.6 million dollars. The system is not redundant and does not meet the single failure criterion. This probably explains most of the cost differential compared to the Westinghouse system. The system is still under review to ascertain its conformance to other NUREG-0737 design criteria.

Total estimated cost for the installation of the CE level monitoring system in the San Onofre 2 plant (one of the two lead plants) is 1.6 million dollars. The cost of the CE system is expected to vary from plant to plant because of plant-unique installation problems.

Total estimated cost for the B&W hot leg level monitoring system is 1.1 to 1.3 million dollars. However, the estimated system does not include provisions for a tap in the vessel head, as indicated by Figure 6, or for a tap in the bottom of the vessel. Therefore, we have no cost estimate for a system that has the capability to monitor level in the reactor vessel or to trend the coolant inventory with pumps running. B&W did not supply this information when asked.

Based on the cost estimates provided, it appears that the average cost of level monitoring systems meeting NUREG-0737 requirements will be on the order of two million dollars per plant. Thus, the total cost to the industry for 45 operating PWRs plus 25 expected to become operational within the next few years would be on the order of 140 million dollars.

The estimated average manrem exposure for installation in operating reactors is on the order of 30 manrems per plant, or 1350 manrems for 45 operating PWRs. This is based on estimates provided by Wisconsin Electric Power for the Point Beach installation and estimates by Westinghouse and B&W (see Table 2).

Information provided by Westinghouse and CE indicates that 27 Westinghouse systems are on order (with 10 already installed) and 21 CE systems are on order (not yet installed). Including the Point Beach d/p system, funds have been committed for 49 of the 70 PWRs. Eight of the plants which have not ordered level monitoring systems are B&W reactors. Some of the approximately 98 million dollars already committed would be recovered if the industry were directed (or given the option) to cancel systems on order.

In understanding the costs and difficulty we expect utilities to have in installing vessel level systems, it is useful to learn how some have fared with other ICC instruments. One example is the Crystal River coolant loss in 1980 triggered by the improper installation of a circuit board in the saturation meter system. Another reference point was provided while we were obtaining cost estimates for the water level system on San Onofre. We were told that costs for upgrading the core exit thermocouple system on that plant to meet NUREG-0737 requirements are up to four times the cost of the level monitoring system. On a more general plane, we believe that most operating plants are presently in non-compliance with the NUREG-0737 upgrading requirement for existing instrumentation such as core exit thermocouples, which was to be completed on January 1, 1982.

7.0 Conclusions and Recommendations

7.1 Conclusions

Based on our review of proposed ICC monitoring systems in conjunction with results of the detailed review reported (Refs. 22, 23, and 24) by our contractors, Oak Ridge National Laboratory, the staff has concluded the following:

(1) Although an absolute need for a level monitoring system in PWRs has not been established, it seems clear that it can serve an important safety function. It will help reduce confusion during recovery from events which have been occurring with significant frequency; namely operations which result in a steam bubble in the reactor coolant system. There are many other potential applications to mitigate or help control more serious accidents involving multiple failures. The vessel level information is unique in some accident situations and confirmatory in others.

(2) Both the Westinghouse level measurement system and the Combustion Engineering system meet the intent of new ICC monitoring instrumentation required by II.F.2 of NUREG-0737, contingent upon successful completion of detailed staff review of the generic design, testing, and analysis information.

(3) Post-implementation reviews must be performed for plant specific installations before the Westinghouse and CE systems can be accepted for incorporation into emergency operating procedures. The reviews will deal with the actual installation, calibration and displays, emergency procedures guidelines, and operating procedures.

(4) Level monitoring instrumentation conforming to NUREG-0737 will cost on the order of 2 million dollars per plant for implementation.

(5) It is expected that further research and development effort would not result in significant cost reduction or improvement in PWR level monitoring capability beyond that offered by the available systems. Only one technique, ultrasonic, appears to have potential comparable to the selected methods, and it could take years to develop.

7.2 Recommendations

We recommend that the guidance in NUREG-0737 and the recommendations provided in SECY-81-582 and SECY-81-582A remain in effect except for the schedule requirements. The NRC position should be as follows:

(1) The staff should review on a plant-by-plant basis the current status and plans, including schedule, for conformance to item II.F.2 of NUREG-0737, including upgrading of existing instrumentation.

(2) The staff should renegotiate a practical schedule for implementation of level monitoring systems and upgrading of existing instrumentation for each operating reactor. Installation and instrument upgrading should be

required during the earliest refueling shutdown consistent with the existing status of the plant and practical design and procurement considerations. This is now likely to result in installation dates for several plants which will be later than that proposed in the February 19, 1982 memo from D. Eisenhut to Distribution, "Operating License Rule for NUREG-0737 Requirements".

(3) After installation, the operating utilities should be given ample time to familiarize the operators with performance characteristics of the additional instrumentation. The utilities should assure operator confidence in the new systems prior to extensive integration of the level signals into emergency operating procedures.

(4) It is recommended that d/p measurement techniques be accepted in principle with additional analyses required only when needed to resolve specific concerns relative to a specific installation.

(5) It is recommended that the B&W concept (Figure 6) for monitoring hot leg level and level in the vessel head be accepted in principle without requiring a tap in the bottom of the vessel. This will not provide inventory trending capability with the pumps running.

(6) It is recommended that the redundancy requirements be applied uniformly to all proposed level monitoring systems. However, the staff should be generous in the schedule for required modifications to systems which have already been installed, e.g., Point Beach. This will enable the operating utility to gain experience with the system, if desired, so that any indicated improvements can be incorporated into design modifications.

(7) It is recommended that the ICC monitoring systems proposed by Westinghouse and Combustion Engineering be approved as acceptable generic systems subject to satisfactory resolution of open issues identified in Refs. 22 and 23 and subject to the limitations which are to be resolved by review of plant specific installations.

ENCLOSURE 1

Limitations of Proposed Level Measurement Systems

Ambiguous or Erroneous Indications of Westinghouse RVLIS (d/p)

(1) Small breaks in the Reactor Vessel Upper Head (up to 2 3/4 inches in diameter, corresponding to a control rod ejection accident) will result in an erroneous indication of reactor level on the narrow range scale. Operators can be trained to recognize this condition by comparison with the wide range scale, and the procedures will require initiation of the ICC procedure when the selected core exit thermocouples read 1200°F.

(2) Accumulator injection when the downcomer is highly voided could result in a temporarily erratic indication. The cold accumulator water would condense some of the steam in the downcomer and result in a local depressurization. The momentary local depressurization would lower the pressure at the bottom of the vessel which would lower the d/p across the vessel causing a decrease in indicated level. The period of time when the RVLIS indication is lower than the actual collapsed liquid level will be brief. Flows within the RCS will soon compensate for the condensation and eliminate the local depressurization. Also, for most small break transients, the reactor coolant pumps will be tripped early in the transient and the downcomer mixture level will remain high. When the downcomer level is high the effect of accumulator injection on the RVLIS indication will be minor.

(3) The vessel coolant inventory may be underpredicted during relatively fast drain rates while the fluid in the upper head is flashing. This is due to a local pressurization effect. This transient condition is brief and is corrected when the mixture level in the upper head falls below the top of the guide tubes. The bigger the break the worse is the effect; but for the very rapid events the operator has no time to affect plant response before the rapid transient is over. However, use of the core exit thermocouples will preclude a premature entry to the ICC procedures.

(4) When the Reactor Coolant Pumps (RCPs) are running, the following results:

a. The wide range instrument will indicate the trend of coolant inventory in the vessel;

b. The narrow range instrument will indicate invalid (off-scale high) level readings;

c. The upper range instrument with the pump running in the same loop will indicate invalid (off-scale ~~high~~ low) level reading;

d. The upper range instrument with the pumps running in the other loop will indicate level reading with error up to 10%.

The logic of the Westinghouse display system will be designed to provide the "off-scale" indicators on the ICC panel for conditions b and c.

(5) When all or various combinations of RCP are tripped or restarted, the following will result:

a. If the RVLIS reading has dropped to the narrow range scale prior to tripping all pumps, there is significant voiding in the vessel and the core would be just covered after the pumps were tripped.

A setpoint (to be determined) will be used for the RVLIS to warn the operator that the system is approaching an uncovered core.

b. Rapid void redistribution may occur within the vessel. This will not be detected by the RVLIS, but the transition period will be brief and is of no consequence;

c. The wide range instrument will indicate an additional level reading about 33% (15% for UHI plants) of the span of the display if the vessel is full and the pumps are tripped. This provides additional information to verify the narrow range level indication.

Ambiguous or Erroneous Indications of CE RVLMS (HJTC)

1. With the RCPs running, the collapsed liquid level reading in the upper plenum region is erroneous and invalid. The staff will require that this invalid indication should be shown in the ICC display. However, operating procedures normally require that the RCPs be tripped before this low reactor vessel water level exists.

2. Repressurization of the RCS with a steam bubble in the upper head will lead to brief periods of condensation of the heated junctions. This will result in erroneous level indication during intervals when the RCS is being repressurized. The final choice of heater power input is expected to minimize the frequency of occurrence and the duration of this condition. The Phase II testing results show no concern. However, this can be studied in the CE Phase III test.

3. A break in the upper head may cause an erroneous indication of the collapsed liquid level due to the transient pressure differential between the upper head and the core region. In that circumstance, the CEA shroud may be full of liquid even when the upper head level has dropped below the top of the CEA shroud. This is an open item to be resolved, probably by operator training or by provisions in the display.

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2. "Discussion of Lessons Learned Short Term Requirements," A letter to All Operating Nuclear Power Plants from Harold R. Denton, October 30, 1979.
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6. "TMI Action Plan II.F.2 (NUREG-0737), Additional Instrumentation for Detection of Inadequate Core Cooling," SECY-81-582, W. J. Dircks, USNRC, October 7, 1981.
7. "SECY-81-582-TMI Action Plan II.F.2 (NUREG-0737); Additional Information for Detection of Inadequate Core Cooling," Memorandum for W. Dircks from S. J. Chilk, November 16, 1981.
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10. Tingle, W. W. and Golden, R. W., "Installation and Initial-Test Data Report: Westinghouse Reactor Vessel Level Indicating System Performance During Semiscale Test S-UT-3." EG/G, EGG-Semi 5494, June 1981.

11. Westinghouse Electric Corporation, "Westinghouse Reactor Vessel Level Indicating System for Monitoring Inadequate Core Cooling." December 1980.

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13. G. G. Loomis, et al., "Quick Look Report for Semiscale Mod-2A Test S-NC-2." EG/G, EGG-Semi-5507, July 1981.

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

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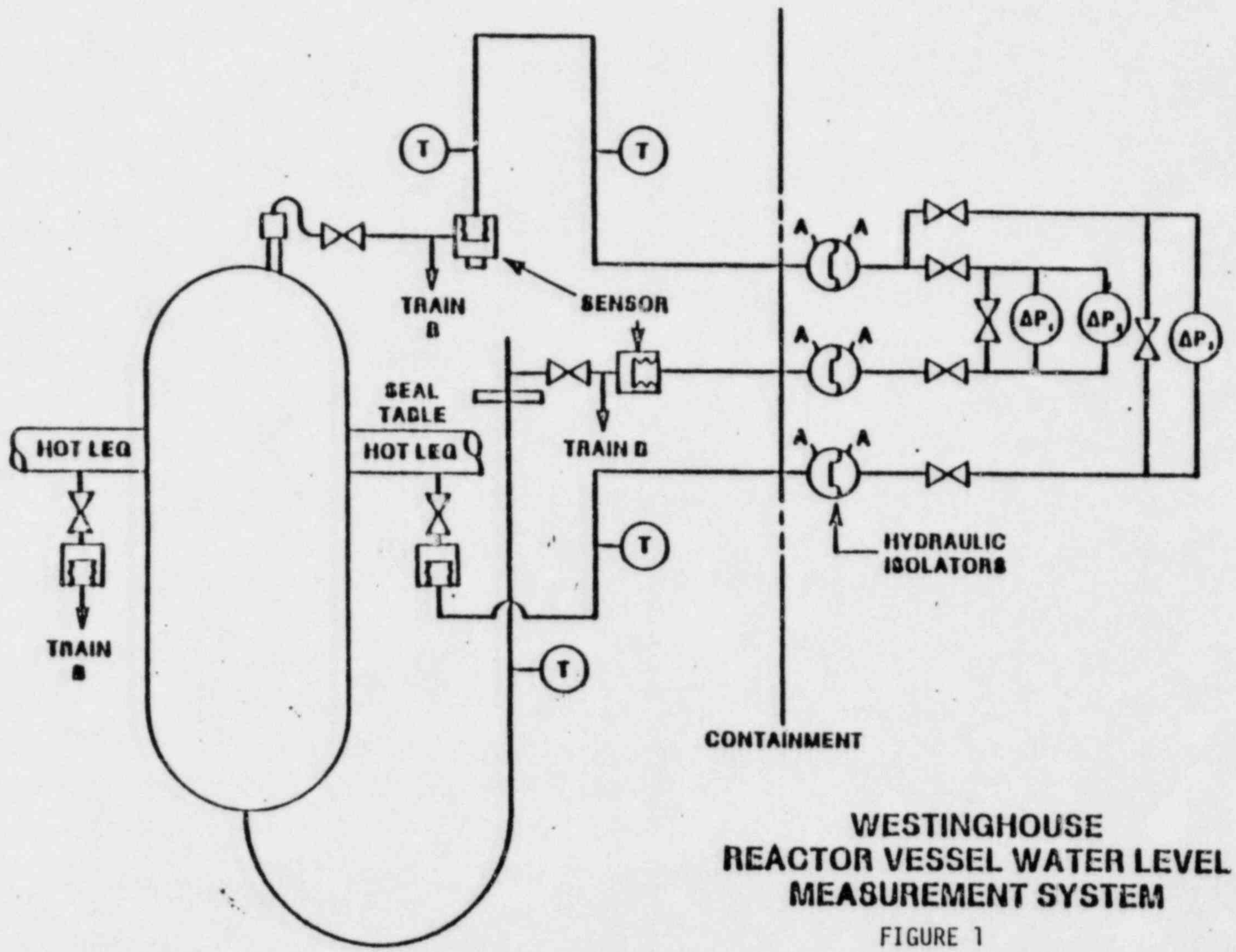


WESTINGHOUSE
REACTOR VESSEL WATER LEVEL
MEASUREMENT SYSTEM

FIGURE 1

REACTOR VESSEL LEVEL — SYSTEM B

FIGURE 2

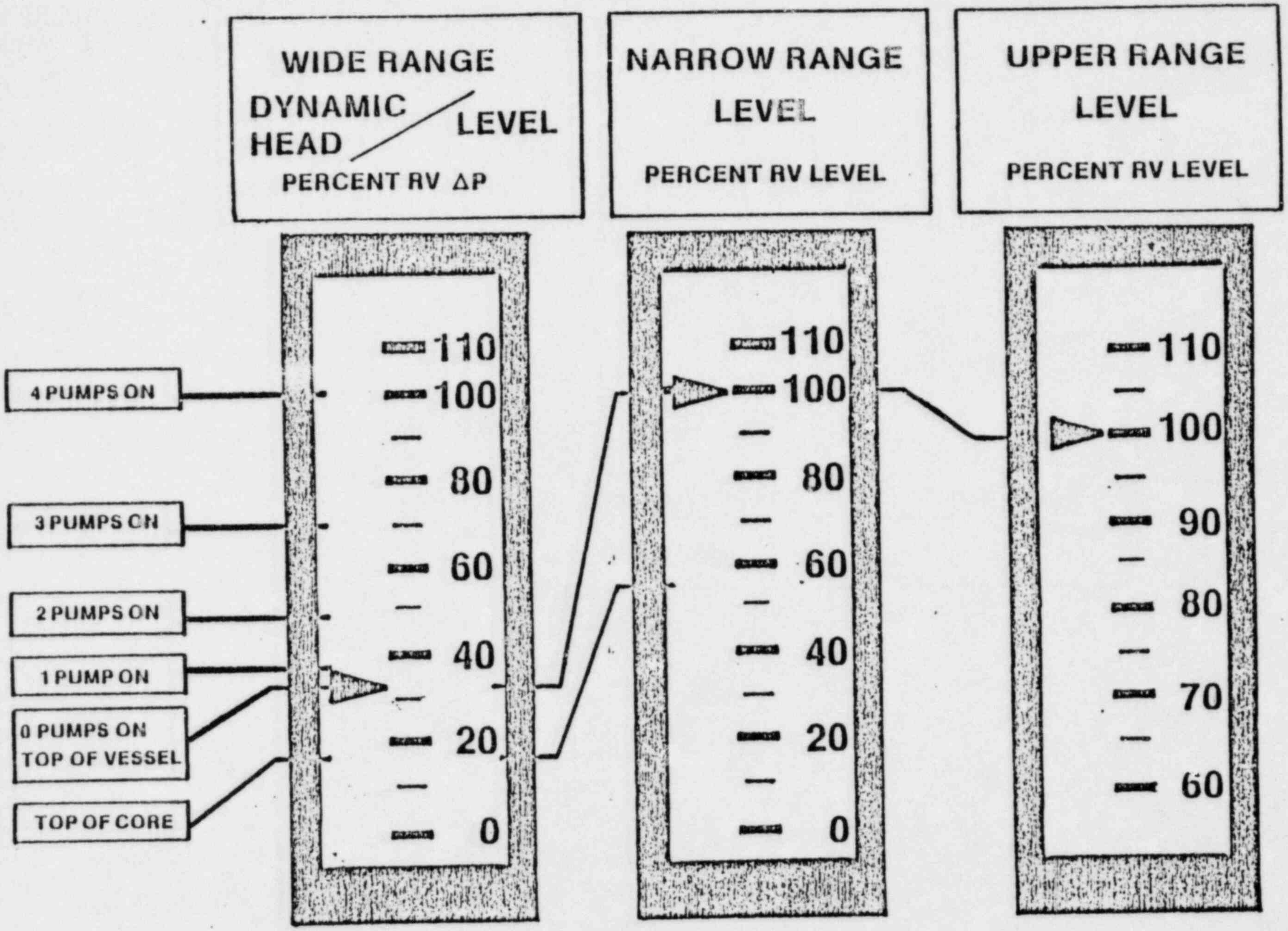


FIGURE 3

HJTC SCHEMATIC

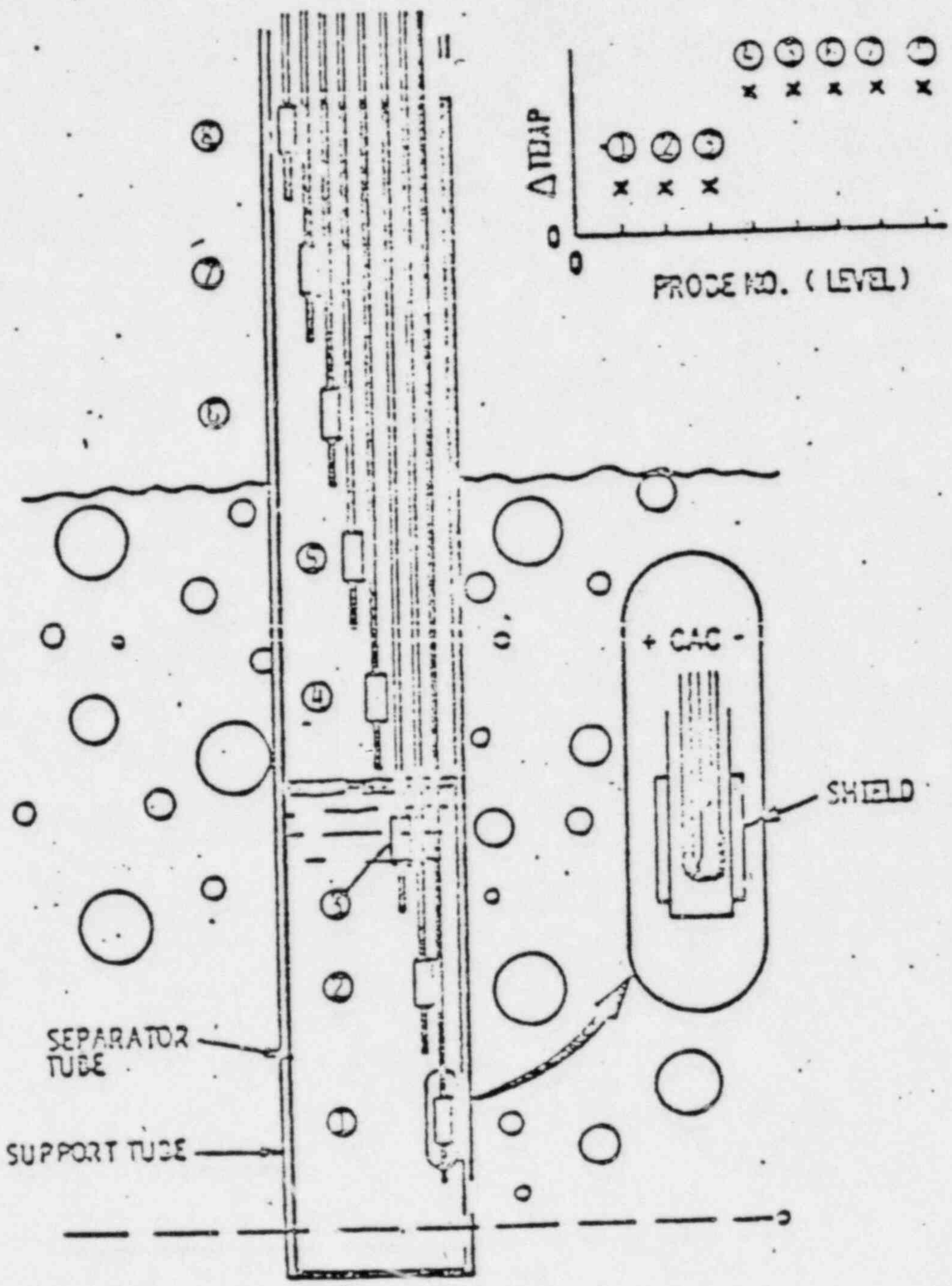
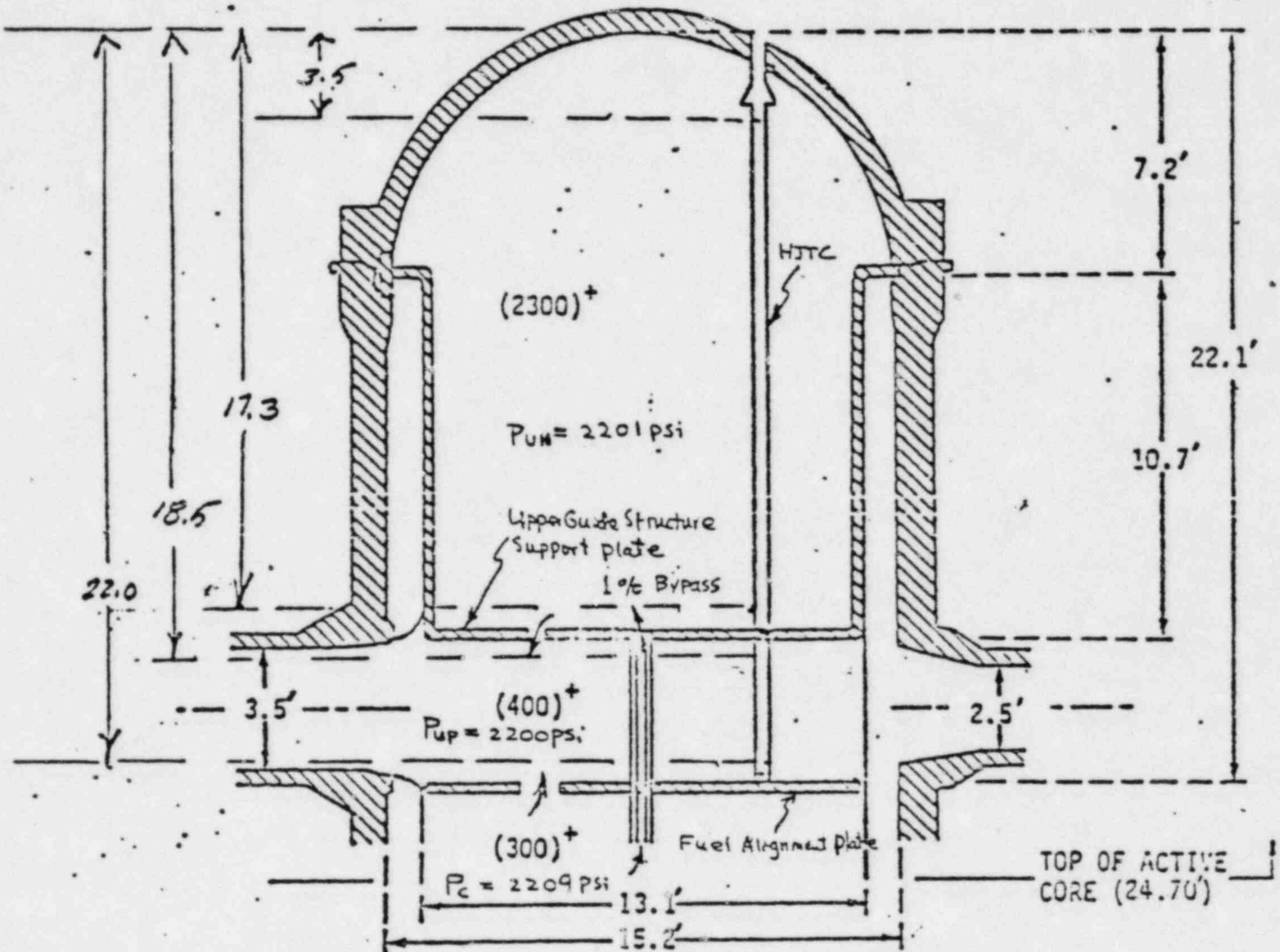


Figure 4

SYSTEM 80 UPPER HEAD AND PLENUM

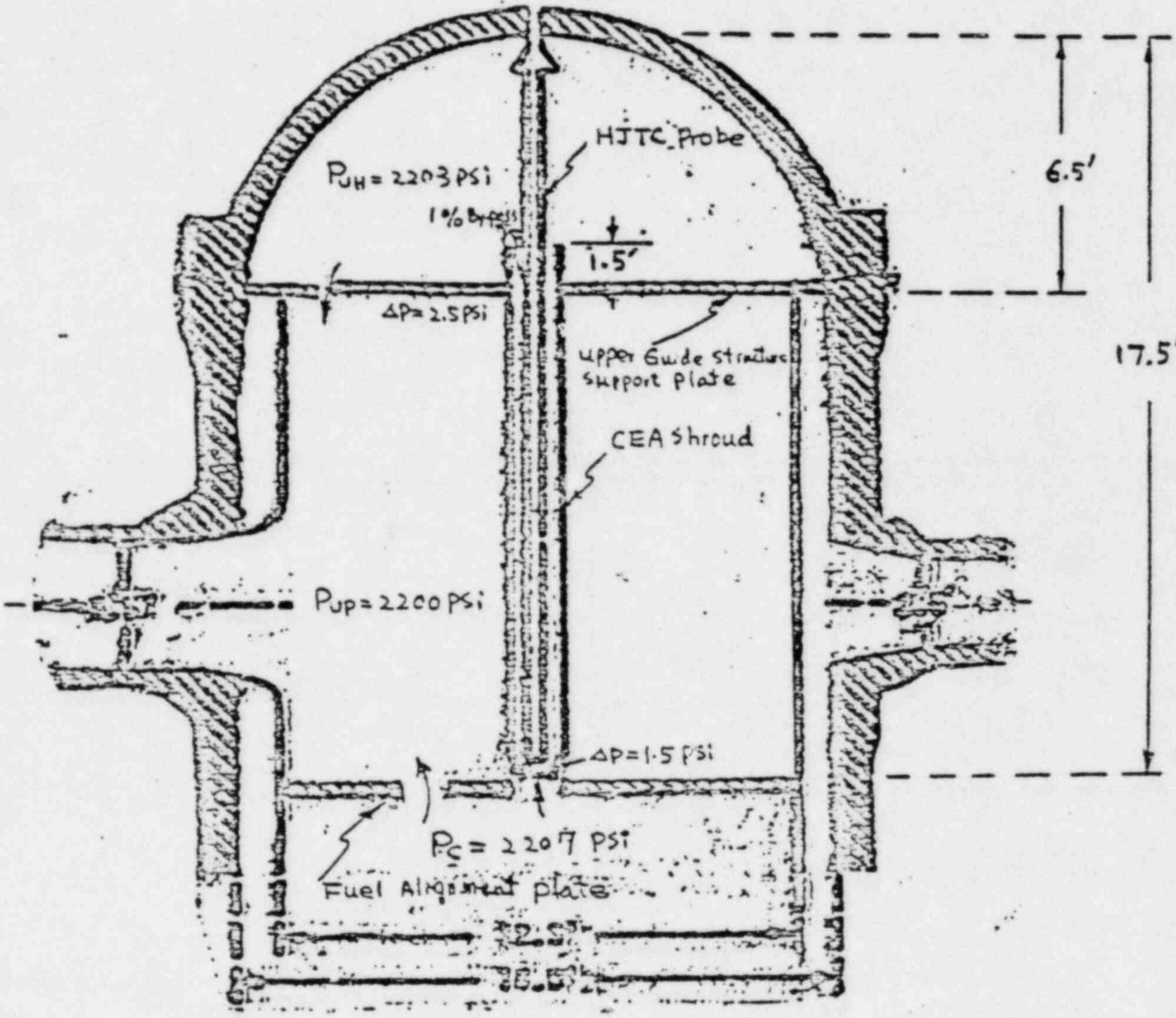


BREAK SIZE EQ DIAM.	TIME TO DRAIN U.H. (MIN.)	TIME TO SIAS (MIN.)
2"	10	5
0.5"	-	79

+FT³ AVAILABLE FOR COOLANT

Figure 5

HJTC-RVLMS INSTALLATION INSIDE CEA-SHROUD



HOT LEG LEVEL MONITORING SYSTEM (HLLMS)

TYPICAL LOOP CONFIGURATION

FIGURE 6

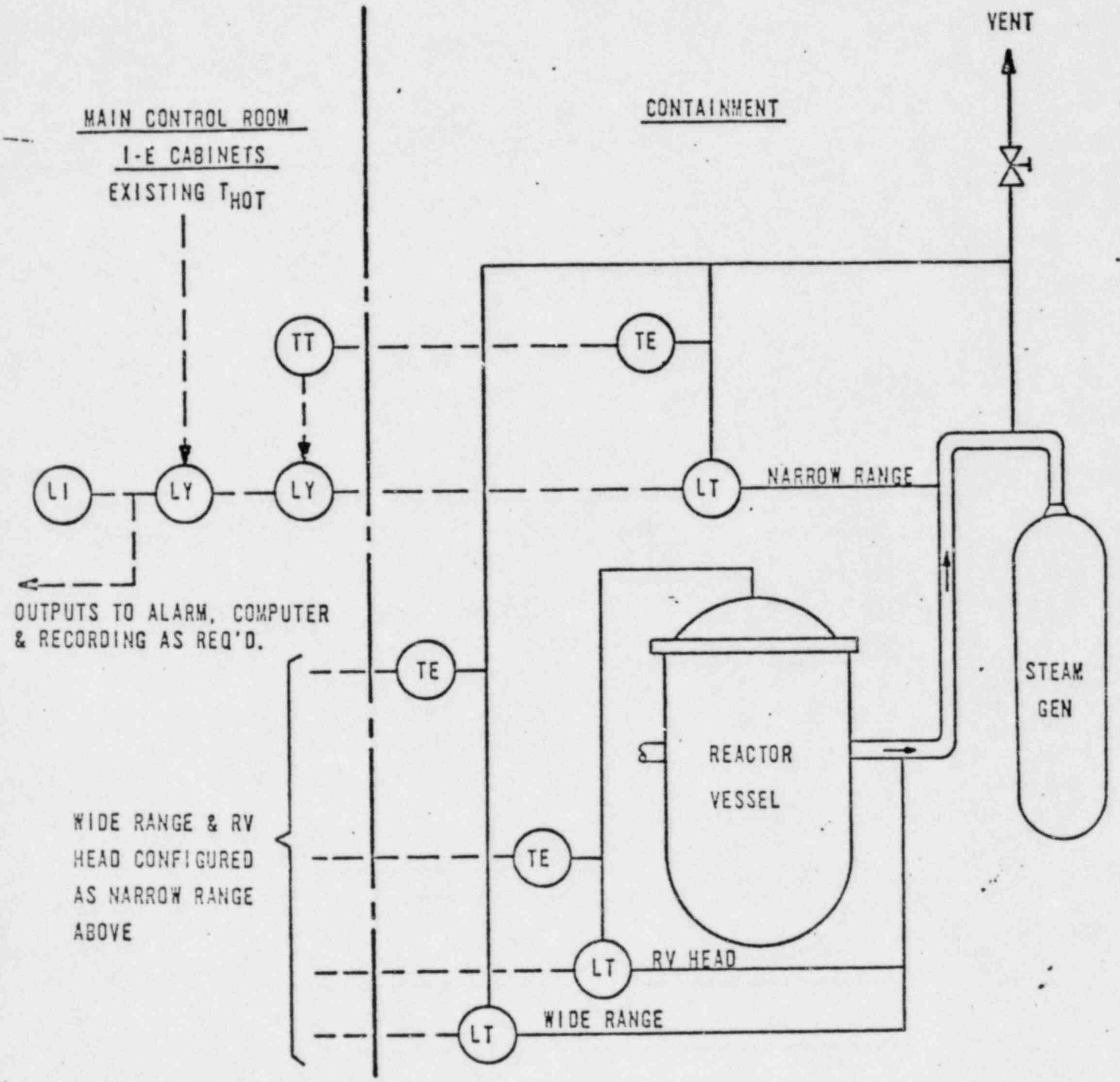
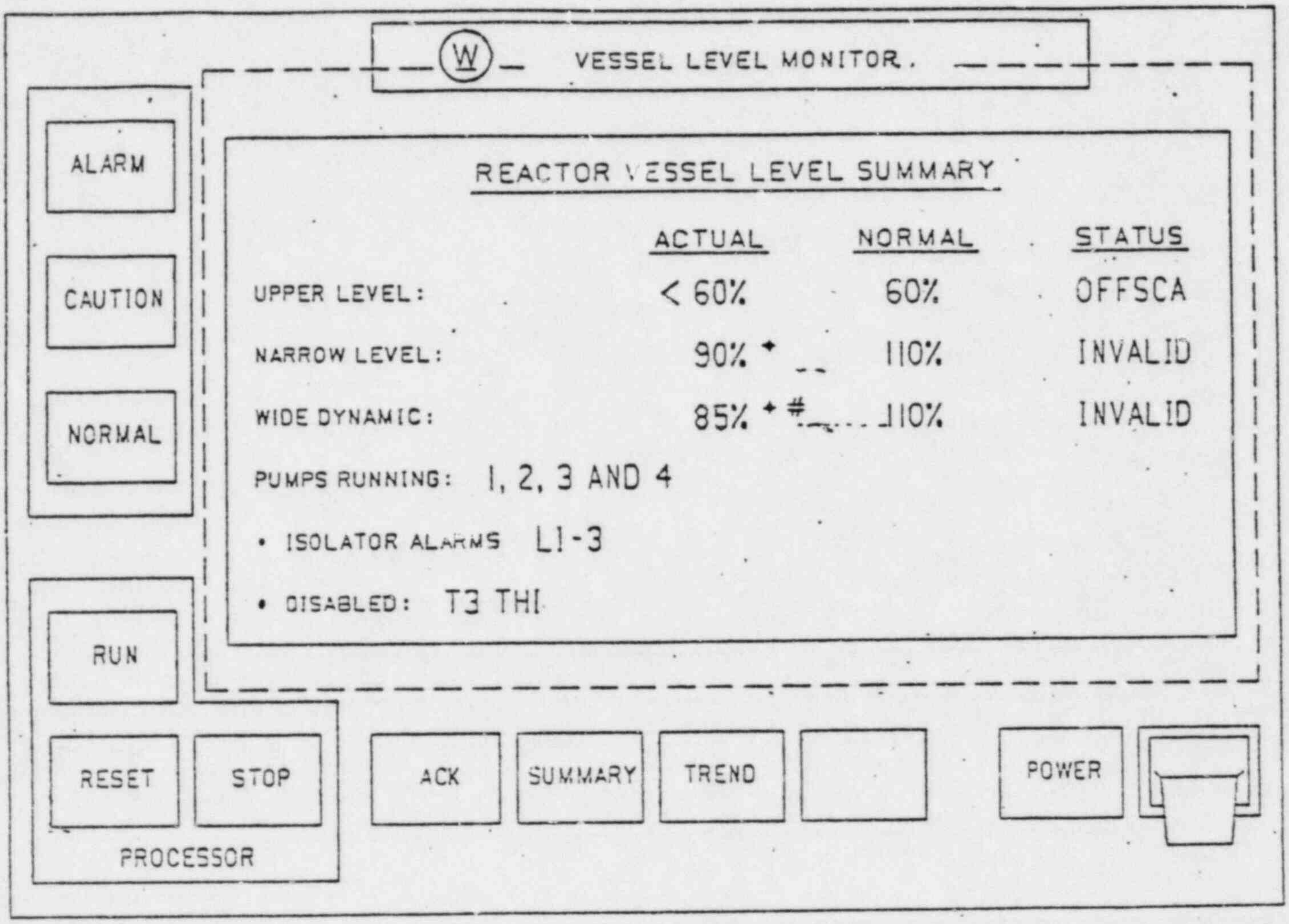


Figure 7
FULL POWER, ALL PUMPS ON



INTERACTIVE GRAPHICS
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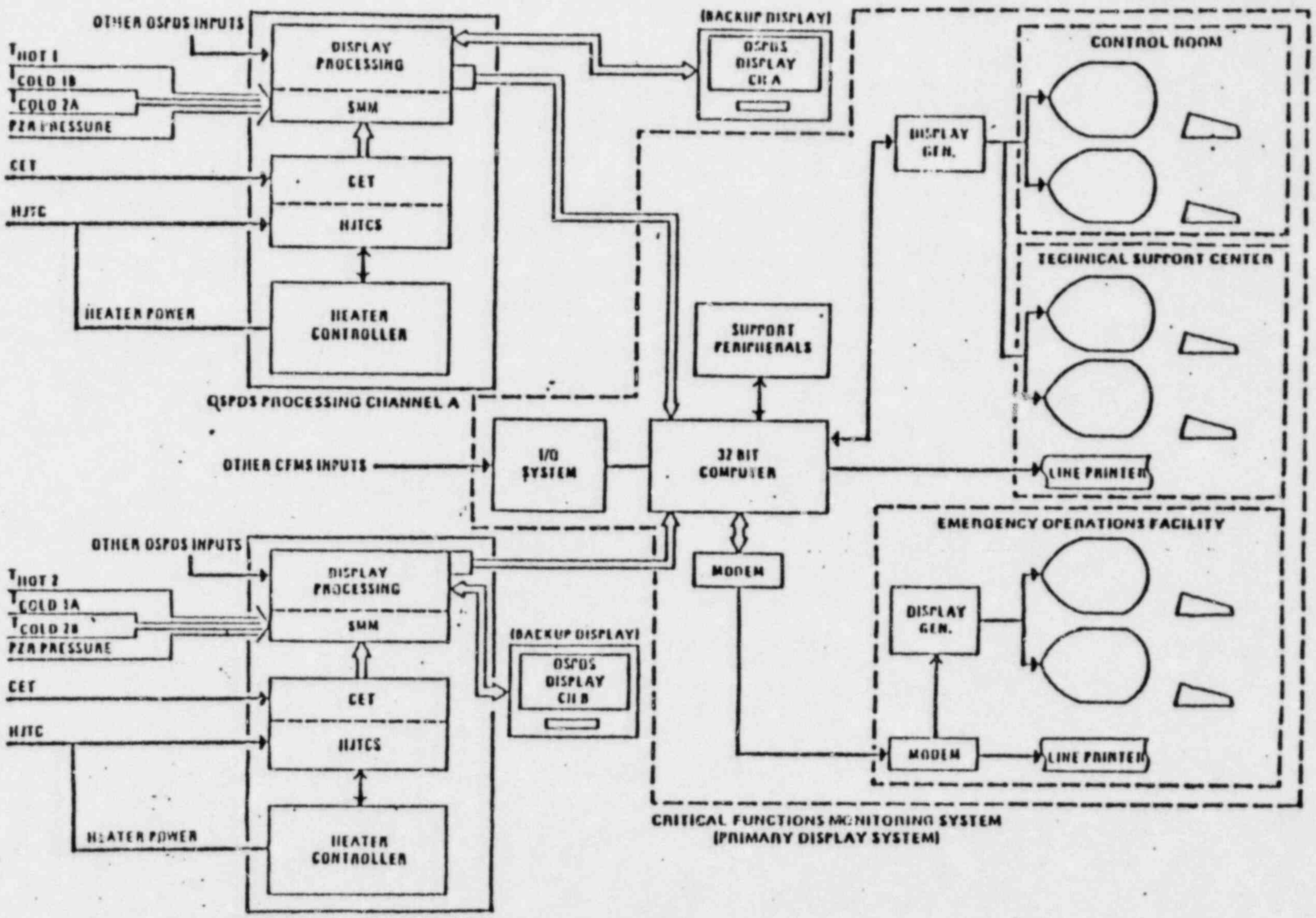

Fig. 8. Functional drawing of C-E's ICC instrumentation system including sensor, processing, and display systems

ENCLOSURE 6

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

Enclosure 6

APR 2 1982

MEMORANDUM FOR: William J. Dircks
Executive Director for Operations

FROM: Victor Stello, Jr., Chairman
Committee to Review Generic Requirements

SUBJECT: MINUTES OF CRGR MEETING NO. 11

The Committee to Review Generic Requirements met on Wednesday, March 24, 1982, from 1-5 pm. Attendance at the meeting is shown in the Enclosure. The following matters were considered:

1. Mr. Guzy of RES presented the proposed Regulatory Guide SC78-4, "Qualification and Acceptance Tests for Snubbers Used in Systems Important to Safety." The Committee requested that further information be provided on the questions below in order that the Guide can be reconsidered at a future meeting.

   (a) In view of the potential $20-40 million cost that could result from implementing the proposed Reg. Guide,

   - what safety problems would be corrected by this Guide that warrant these costs?
   - are there less costly alternatives?
   - to what degree would snubber problems still persist because of improper installation, maintenance or operational problems?

   (b) What is the expected increase in occupational exposure associated with implementing the proposed Reg. Guide?

   (c) Are there less prescriptive alternatives than Appendix A, which appear to be a purchase specification for snubbers, to achieve the goal of improved snubber performance?

   (d) Why and to what extent is 10 CFR 50 Appendix B, Quality Assurance, required by the proposed Reg. Guide?

   (e) What is the safety basis for the proposed implementation plan?

   (f) What is the design basis for the acceptance criteria in the proposed Reg. Guide (for example, water hammer loads)?

   (g) Why is rule language, "shall" and "shall not," used in the proposed Reg. Guide?

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2. Dr. Mattson of NRR presented a status summary on TMI Action Plan Task II.F.2, "Instrumentation for Detection of Inadequate Core Cooling." The discussion centered on the instrumentation systems proposed by PWR vendors for measuring reactor coolant level. The Committee did not reach a decision on a recommendation concerning the proposed systems pending further information from NRR on total ICC system costs and certain other questions regarding how the system is to be used by the operators. Nonetheless, the Committee agreed with the general approach outlined by NRR.

The impetus for considering the need for additional instrumentation to detect inadequate core cooling came from the experience of TMI. One of the most important lessons from that accident was that the operators required more information on the status of core cooling during an accident than was available in the control room at the time. This realization led to early actions by NRC to require the installation of Subcool Monitors (SM) in PWR control rooms and to upgrade the number and quality of core-exit thermocouples (TC) in PWRs. Even with this added instrumentation, however, there remained, during a small LOCA, a period of time after the system reaches saturated conditions (indicated by SM) but before the core has boiled dry (indicated by TC) when the operators have insufficient information to track the inventory of coolant in the vessel and primary system. It was to fill this gap that NRR has required extensive further studies by the industry to determine whether additional instrumentation could be provided to monitor the status of core cooling.

Based on the discussions with NRR and review of extensive material prepared by NRR and industry, the Committee reached the following preliminary conclusions:

(a) Additional instrumentation to detect ICC would be highly desirable to complement the current package of Subcool Monitors and thermocouples.

(b) Rather than requiring an unambiguous indication of water level in the vessel (which is probably not possible), it is probably sufficient to require only a void indication or inventory tracking system to aid the operators in the period between saturation and core dryout.

(c) A differential pressure system and a heated junction thermocouple system appear to be acceptable methods for void indication or tracking inventory.

(d) Other means, such as reactor coolant pump electrical current suggested by the LOFT project, may also be beneficial for tracking coolant density (and hence inventory) under pumps on condition.

(e) The instruments comprising the ICC package should be viewed as a whole, not individually, and clear guidelines should be developed on the use and limitations of each instrument in the ICC package.

(f) If a void indication or inventory tracking system is utilized, it should not be made operational until after appropriate Emergency Operating Procedure Guidelines for the overall ICC package are reviewed and approved. The system should be factored into the task analysis portion of the Detailed Control Room Design Review by the licensee, and operators should be trained in its operation and limitations.

(g) The cost-benefit assessment should be based on consideration of the costs of the overall package, including the need for redundancy and qualification requirements.

The Committee requested that this topic be reviewed again after receipt of further information from NRR.

Victor Stello, Jr., Chairman
Committee to Review Generic Requirements

Enclosure: List of Attendees

cc: CRGR Members
Office Directors
G. Cunningham, ELD
Commission (5)
Regional Administrators

ENCLOSURE 7

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D. C. 20555

Enclosure 7

April 6, 1982

The Honorable Nunzio J. Palladino
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

SUBJECT: INSTRUMENTATION FOR MONITORING WATER LEVEL OR INVENTORY

Dear Dr. Palladino:

During its 264th meeting, April 1 and 2, 1982, the Advisory Committee on Reactor Safeguards met with representatives of Babcock and Wilcox Company, Combustion Engineering, Inc., and Westinghouse Electric Corporation to discuss several proposed systems designed to indicate the approach to or the existence of inadequate core cooling (ICC). The Committee also had the benefit of comments from the NRC Staff. A Subcommittee meeting was held on March 31, 1982 to discuss the design features of these systems and their use in the management of reactor transients.

We are pleased to observe that the NRC Staff has developed an approach which will integrate the installation and use of ICC systems with that of other new systems which are being installed in response to other post-TMI-2 requirements. We were told that the scheduling of installation and use of ICC monitoring systems is expected to be done on a plant-by-plant basis, and will take into account the commercial availability of these systems as well as the schedule for installation of other backfit items.

The NRC Staff has indicated that they believe that use of the ICC monitoring system should be introduced into operating and emergency procedures very carefully and only after appropriate operator training, including experience on simulators, if feasible. We support this approach. Both the use and the testing of these systems must take into account the probability they are likely to be most useful in emergency situations. It is important that operators understand both the capabilities and the limitations of the systems in order to use them with confidence when they are needed.

The NRC Staff has concluded that the proposed Westinghouse system and the proposed Combustion Engineering system are acceptable on a generic basis, subject to further exploration of a small number of unresolved issues. The approach being taken by the Staff seems reasonable.

We agree with the following tentative conclusions of the NRC Staff:

1. Core exit thermocouples and saturation margin monitors are not sufficient for an adequate ICC monitoring system for PWRs.

2. Both the Westinghouse and Combustion Engineering vessel inventory monitoring systems correct identified deficiencies in present ICC monitoring instrumentation.

3. A multi-step review process remains to be completed to assure careful phasing-in and full integration of inventory monitors.

We believe that the current approach of the NRC Staff to dealing with the ICC problem has sufficient merit that it should continue in the proposed direction. We plan to continue our review of this area as further developments occur.

Additional comments by Members M. Bender and H. Lewis are presented below.

Sincerely,

P. Shewmon

P. Shewmon
Chairman

Additional Comments by ACRS Member M. Bender Concerning Reactor Vessel Level Indication System

Although a great deal of valuable study has clarified the use and application of the inadequate core cooling monitoring system for PWRs, the feature intended to show reactor vessel coolant level has not been shown to have great operational value. The proposed systems are not unambiguous in their response under all circumstances.

The Westinghouse RVLIS uses differential pressure to determine liquid level and measures differential pressures of 1 to 10 PSI against a background system pressure of 1500 to 2000 PSI. It must correct for density and dynamic head. The emergency operating procedures would need very thorough development to make RVLIS diagnostically useful. It would have been of doubtful value in the Ginna event or the TMI-2 accident.

The Combustion Engineering heated junction thermocouple system would be more effective under TMI-2 conditions and is less subject to ambiguity due to system operating conditions, but it, too, has some limitations.

The basic requirement is to provide guidance for operator action. The urgent need indicated by both Ginna and TMI-2 circumstances is rapid primary system depressurization and reliable shutdown cooling. I believe emphasis should be placed on being sure that such operator actions are unambiguously permissible regardless of liquid level indicating devices.

Additional Comments by ACRS Member H. Lewis Concerning "Water Level Indicators"

I see no reason to repeat all the comments I have previously made on this subject. In the interim, the Staff has commendably adopted a far more systematic and considered approach to this question, and that has mitigated but not extinguished my concerns. The remaining ones are:

1. To change the name from "water level indicators," which they are not to "inventory monitors," which they are also not, does little good. In the absence of dynamic effects, the Combustion Engineering system measures the mean void fraction in the upper plenum, no more and perhaps a bit less when dynamic effects are important. The Westinghouse system measures differential pressure, and, in the absence of dynamic effects, this is more closely but not precisely related to pressure vessel inventory. That they each give some information is indisputable.

2. Since the information they do provide depends upon many things such as pump status, flow problems and dynamic effects, etc., it is not clear to me that an operator dealing with an unfamiliar upset can know whether his upset is of such a nature that he can believe the instrument. I do wish the Staff would decide whether it is better to know partial inventory (Westinghouse) or void appearance (Combustion Engineering). This is scenario-dependent and I have not seen the issue clarified.

ENCLOSURE 8