Implementation Report

Reactor Vessel Level Monitoring System

Ginna Station

Rochester Gas and Electric Corporation

89 East Avenue

Rochester, New York 14649

EWR 2799

Revision 0

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Prepared by: Richard A. Baker — 12/18/86 DATE
Electrical Engineer

Reviewed by: G.W. Daniels — 12/19/86 DATE
Manager, Electrical Engineering

Approved by: G.W. Daniels — 12/19/86 DATE
Manager, Electrical Engineering

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Revision Status Sheet

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Description of Operation

Revision 0

EWR 2799

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RVLMS Implementation Report

1.0 Summary Description of the RVLMS System

1.1 General

The Reactor Vessel Level Monitoring System (RVLMS) is designed to trend coolant inventory within the reactor vessel during all phases of plant operation, including post accident conditions with quasi-steady-state conditions, and during relatively slow developing transients. The system consists of two redundant differential pressure trending channels, each consisting of one transmitter per channel. The signals are processed to compensate for reference leg temperature differences, primary coolant flow and temperature, safety injection, and residual heat removal operation. In addition to local indication at each RVLMS instrument rack, each channel drives a remote indicator on the main control board which displays reactor vessel level and refueling level. The RVLMS differential pressure sensing lines are obtained from tubing connections to the Reactor Vessel Head Vent System (EWR 2447) and one of the Reactor Incore Instrumentation Guide Tubes.

1.2 Functions

The RVLMS system is designed to provide redundant trending of reactor vessel coolant inventory to the plant operators for the purpose of assuring adequate core cooling under all plant conditions.

1.3 Modes of Operation

The RVLMS system is designed to function during shutdown, refueling, and all normal and post accident operating conditions.

2.0 Referenced Documents

2.1 Design Criteria, EWR 2799, Revision 3, 10/2/85.

2.2 Safety Analysis, EWR 2799, Revision 2, 10/15/85.

3.0 RVLMS System Description of Components

Refer to Attachment I, RVLMS Block Diagram and Attachment II, RVLMS System Elevations.

3.1 General

The RVLMS system is a Class IE system, therefore, all components of the RVLMS system are designated Seismic Category I. All RVLMS electrical hardware is seismically qualified per IEEE 344-1974, and all conduit, tubing, piping, and electrical hardware is seismically supported to withstand the effects of a safe shutdown earthquake. All electrical components, cable, and splices located in potential harsh environment areas are environmentally qualified per IEEE 323-1974.

3.2 Reactor Vessel Upper Tap, Seal Pot and Reference Leg Sensing Line

A single RVLMS differential pressure transmitter upper tap is made at the reactor head vent piping in parallel with the head vent valves. A single run of stainless steel tubing (3/8" O.D. x .065" wall) with Swagelok fittings is run from the upper tap through the refueling cavity wall to the reference leg seal pot. The tubing inside the reactor cavity is designed to be removable to permit lifting the reactor head for refueling. The tubing is welded to the stainless steel liner as it penetrates the cavity wall to maintain the integrity of the refueling cavity. The differential pressure (DP) reference leg runs from the seal pot on the wall of the containment intermediate level to the DP transmitters on the basement level. The seal pot is designed to maintain sufficient inventory to fill the reference leg twice in the event of flashing of the reference leg due to rapid low pressure transients.

3.3 Reactor Vessel Lower Tap and Sensing Line

One RVLMS differential pressure transmitter lower tap is made in the containment Sump A below the reactor vessel by teeing off one of the neutron flux mapping guide tubes. A single run of stainless steel tubing (3/8" x .065" wall) with Swagelok fittings is run from the lower tap up through the basement floor to the DP transmitters on the basement level.

3.4 Sensing Line RTDs

The RVLMS upper tap (reference leg) sensing line has one Conax dual element 100 ohm platinum RTD installed on the intermediate level to monitor the temperature of the sensing line fluid in that region. The RTD is in direct contact with the sensing line fluid via a Swagelok tee and sends a redundant, isolated, independently routed output to each RVLMS channel to compensate for changing specific gravity of sensing line fluid as a function temperature. The lower tap sensing line has two RTDs as described above, one on the basement level and one at the Sump A level. The RVLMS system was designed to accept inputs from as many as six sensing line RTDs, but only three are actually used.

3.5 Differential Pressure Level Transmitters

Two Foxboro N-E11DM differential pressure transmitters are connected in parallel to the upper and lower tap sensing lines to provide redundant measurement of differential pressure over the height of the reactor vessel. The transmitters are sensitive to the static differential pressure due to the level of fluid in the reactor vessel plus the dynamic differential pressure due to reactor coolant flow while one or two reactor coolant pumps are running. The transmitters are located at elevation 247'11", which insures that they will remain above the worst case containment flood level.

3.6 Tcold RTDs

A Conax dual element 100 ohm RTD is installed in each reactor coolant loop cold leg to provide a redundant, isolated, independently routed Tcold output to each RVLMS channel. When reactor coolant pumps (RCPs) are running or during natural circulation, it is assumed that the temperature of fluid below the core in the reactor vessel is represented by the Tcold temperature. The Tcold signal from each loop is also input directly to an indicator on the main control board.

3.7 RVLMS Signal Processing Racks

Two Foxboro Spec 200 analog signal processing racks, one for each RVLMS channel (RVLMS1 and RVLMS2), are installed in the relay room to process signals from the DP transmitter, Tcold, sensing line RTDs and other inputs and convert them to a reactor vessel level. The RVLMS racks each contain a local reactor vessel level indicator and four status lights to indicate specific modes of operation. In addition, the RVLMS racks

generate isolated analog outputs to the Plant Process Computer System (PPCS) to enable an independent calculation of reactor vessel level to be performed.

3.8 RVLMS Main Control Board Indicator

3.8.1 A Sigma International Instruments 203 segment LED vertical scale indicator is installed on the main control board center section for each RVLMS channel (see Attachment III). The LED indicator eliminates problems common to conventional meter movement indicators such as parallax and static charge buildup, and has a full scale accuracy of ± 1%.

3.8.2 The RVLMS indicator is scaled on its right hand side for 0 to 100% reactor vessel level and has an additional upper graduation labeled "seal pot". Normally, the seal pot is physically located at the 100% level elevation and is not required to appear on the indicator, however, due to interferences in the upper tap region and sloping horizontal tubing runs, the seal pot is located 32.75 inches above the 100% vessel level, and, therefore must appear on the indicator. When the reactor coolant system is operating normally, the reactor vessel is full up to the seal pot, and vessel level will be indicated at the seal pot elevation. If vessel level decreases, the small quantity of water in the seal pot and tubing to the upper tap will drain quickly to the reactor and the indicator will then read 100% and continue trending normally from that point.

3.8.3 The left hand side of the RVLMS indicator has been scaled for refueling level (0 to 25.44 ft.). Normal full refueling level is 24.44 ft. above the refueling cavity floor, therefore, the RVLMS system was scaled to measure one foot above that mark. The containment operating floor is four inches above the 25.44 foot level (see Attachment II). The refueling level was added to the RVLMS indicator for three reasons:

3.8.3.1 There was no existing refueling level indication in the control room. The addition of the refueling range provides additional information to the operators.

3.8.3.2 During initial design of the RVLMS, there was concern that if the system were designed to function only during normal plant operating conditions, there would never be direct verification that the RVLMS would track actual known changes in vessel level. During normal operations, the RVLMS indicator always reads at the seal pot elevation. If the indicator is never observed to change, it was postulated that the control board operators

may not acquire confidence in the instrument to use it if it became necessary. Since the reactor vessel level is actually varied during shutdown from below the loop nozzles to full refueling, the RVLMS system was designed to remain operable during both normal operations and shutdown, and provide direct verification of level tracking during refueling.

3.8.3.3 The differential pressure (DP) transmitter calibrated span is 1661 inches of water while the reactor vessel/seal pot height is 483.75 inches. This means that 1177.25 inches or 70.9% of the transmitter span is required to measure the additional dynamic DP due to RCP operation. Since the dynamic DP must be compensated out of the vessel level calculation, this means that a maximum of only 29.1% of the total DP transmitter span is ever output to the indicator. The addition of the refueling range increases the indicator span to 40.6% of the DP transmitter span, therefore, more efficient use is made of the transmitter at no cost to system accuracy.

4.0 RVLMS System Inputs

Refer to Attachment I, RVLMS Block Diagram and Attachment IV, RVLMS Analog Block Diagram for description of inputs to the RVLMS racks.

4.1 Core Exit Thermocouples (0-700°F)

The average of three selected core exit thermocouples (CETs) is input to each RVLMS rack. The CET signals are read directly from each thermocouple in parallel with the CET display existing in Incore Rack #4. The CETs are used to calculate the specific gravity of reactor coolant above the core (sgt) as a function of temperature during natural circulation or RCP operation.

4.2 Tcold (0-700°F)

The Tcold RTD in each cold leg supplies one RVLMS channel and is used to calculate the specific gravity of the reactor coolant below the core (sgb) as a function of temperature during natural circulation or RCP operation. The Tcold RTDs are input directly to the RVLMS racks.

4.3 RCS Wide Range Pressure (0-3000 psig)

One RCS wide range pressure is input to each RVLMS rack from existing instrument loops for PT-420 and PT-420A in the relay room. The specific gravities of saturated vapor (sgv) and saturated liquid (sgtp) are calculated as a function of RCS pressure. The saturation temperature

of liquid (Tsat) is also calculated as a function of RCS pressure.

4.4 Differential Pressure Level Transmitter

The RVLMS DP transmitters input directly to their respective RVLMS racks and measure differential pressure due to reactor coolant level (static DP) and RCP operation (dynamic DP).

4.5 Reactor Coolant Pump (RCP) Status

On/off status for each RCP is input to both RVLMS racks to actuate dynamic DP compensation when one or two RCPs are running. RCP on/off status is obtained from existing RCP circuit breaker contact output relays in racks RB1, RB2, RY1, and RY2 in the relay room.

4.6 Safety Injection (SI) Status

Safety injection status is input to both RVLMS racks from existing instrument loops for FT-924 and FT-925 in the relay room. Safety injection on/off status is used to select the mode of operation of the RVLMS system.

4.7 Residual Heat Removal (RHR) Status

RHR status is input to both RVLMS racks from existing instrument loop FT-626 in the relay room. RHR on/off status is used to select the mode of operation of the RVLMS system.

5.0 <u>RVLMS System Function Generators</u>

Refer to Attachment IV, RVLMS Analog Block Diagram for description of function generators. The inputs described in sections 4.1, 4.2, and 4.3 are used to drive Foxboro signal characterizers (function generators) in the RVLMS racks which calculate the following parameters:

5.1 $f_1(x)$ - specific gravity of saturated vapor as function of RCS pressure (sgv)

5.2 $f_2(x)$ - saturation temperature of liquid as function of RCS pressure (Tsat)

5.3 $f_3(x)$ - specific gravity of saturated liquid as function of RCS pressure (sgtp)

5.4 $f_4(x)$ - specific gravity of subcooled liquid in reactor vessel as function of temperature (sgt, sgc, sgb)

5.5 $f_5(x)$ - specific gravity of subcooled liquid in sensing lines as function of temperature (sg1, sg2, sg3)

5.6 $f_6(x)$ - dynamic DP as function of temperature for 1 RCP running. (ΔP 1RCP)

5.7 $f_7(x)$ - dynamic DP as function of temperature for 2 RCPS running (ΔP 2 RCPS)

6.0 <u>RVLMS System Outputs</u>

Each RVLMS rack provides one output to its respective reactor vessel level indicator on the main control board in addition to several computer outputs which allow the PPCS to perform on independent calculation of reactor vessel level. Refer to Attachments I, III, and IV.

6.1 RVLMS Level Output

Reactor vessel level is output to the main control board indicator as an isolated 4-20ma signal for each channel. Since the MCB indicator output is isolated, vessel level can still be read locally at the RVLMS rack in the event of failure of the MCB indicator or its signal cable.

6.2 Computer Output - Sensing Line RTDs

An isolated analog 1-5 vdc output for each sensing line RTD is provided to the PPCS for independent calculation of vessel level.

6.3 Computer Output - Differential Pressure Transmitter

An isolated analog 1-5 vdc output for each DP transmitter is provided to the PPCS for independent calculation of vessel level.

6.4 Computer Output - Safety Injection Flow

Prior to installation of the RVLMS system, Safety Injection (SI) flow was not an existing computer parameter, therefore, it was input as part of the RVLMS system and is used to select the RVLMS calculation mode used by the PPCS for its independent RVLMS calculation. The SI computer outputs are electrically isolated from the rest of the RVLMS system.

6.5 Computer Output - RVLMS Level Output

An isolated 1-5 vdc analog RVLMS Level output is provided to the PPCS for display and for comparison with the PPCS independently calculated value of vessel level.

7.0 <u>RVLMS Modes of Operation</u>

7.1 Reactor Coolant Pumps Operating or Natural Circulation

During reactor coolant pump operation or natural circulation, reactor coolant inside the vessel is assumed to be partitioned into three temperature layers. The specific gravity of the top layer (sgt) is computed using the average of three core exit thermocouples. The specific gravity of the bottom layer (sgb) is computed using the Tcold input. The specific gravity of the central core layer (sgc) is computed using the average of the core exit and Tcold temperatures.

7.2 Safety Injection or Residual Heat Removal Mode

During safety injection (SI) or residual heat removal (RHR) phases of operation, Tcold is not considered representative of the reactor coolant bottom layer temperature, therefore, the reactor coolant is assumed to have a uniform specific gravity equal to sgt throughout the reactor vessel. When SI or RHR flow is sensed by the RVLMS system, relays automatically cut out the Tcold RTD input and the system computes vessel level using only the core exit thermocouples for reactor coolant temperature input. SI, RHR, and Tcold disabled conditions are all annunciated on the test panel in the rear of each RVLMS instrument rack.

7.3 Reactor Vessel Below Top of Core or Refueling

It is assumed that vessel level has dropped below the top of the core when the average core exit thermocouple (CET) temperature is greater than the saturation temperature (Tsat) computed from RCS wide range pressure. The RVLMS system continuously computes Tsat and compares it to the CET temperature. If reactor vessel level drops below the top of the core, the core exit thermocouples will be uncovered and no longer reliably measure reactor coolant temperature. When the CET temperature exceeds Tsat, the core exit thermocouple inputs are disabled and an annunciator on the RVLMS local test panel is actuated. In this situation, the remaining reactor coolant is assumed to be a uniform saturated fluid and its specific gravity (sgtp) is computed from RCS wide range pressure. During refueling, the CET connectors

are necessarily disconnected to permit lifting the reactor head and are, therefore, disabled. The output of each CET input module in the RVLMS racks is set to automatically fail high when the CET circuit is broken This simulates a high temperature exceeding Tsat and actuates the CET disabling feature as described above.

8.0 Differential Pressure Equations

Refer to Attachment V, Reactor Vessel Level Differential Pressure Equations.

8.1 The primary level sensing element of the RVLMS system is the differential pressure transmitter (ref. sections 3.5 and 4.4). When connected to the reactor vessel via instrument tubing as shown in Attachments I, II, and V, a change in reactor vessel level will produce a change in the differential pressure (DP) measured at the transmitter. Reactor coolant system static system pressure can be neglected because it is present on either side of the DP transmitter diaphragm and, therefore, cancels itself out of the measurement. Since level measurements usually involve relatively low differential pressures, and it is a water level which is being measured, it is convenient to express DP and head in inches of water at standard temperature and pressure. At standard temperature and pressure, the density of water is .03612 lb/cu. in, therefore, a one inch square column of water $(.03612)^{-1}$ = 27.684 inches high will weigh one pound and exert a pressure of 1 pound/sq. in. at its base. When temperature and pressure deviate from standard conditions (which is the majority of the time) the density of water and, therefore, the pressure or head resulting at the base of a column of water changes. This change is proportional to the ratio of the density of water at existing conditions to the density of water at standard conditions or:

Eq. 1 $$\text{Head (in. H2O)} = \text{Height of water column} \times \frac{\text{density H2O at existing conditions}}{\text{density H20 at STP}}$$

The density ratio is simply the specific gravity of water at the existing temperature and pressure, therefore, the head or pressure exerted by a column of any type of fluid can be expressed in terms of inches of water at standard conditions by:

Eq. 2 Head (in. H2O) = Height of fluid column (inches) x specific gravity (sg)

8.2 The RVLMS differential pressure (DP) transmitter, in effect, measures the head existing on either side of the DP diaphragm and produces an output proportional to the difference. A head is produced on side a of the DP diaphragm due to the column of water in the instrument sensing line reference leg. Likewise, a head is produced on side b of the DP diaphragm due to the height of water in the reactor vessel. The heights and lengths of the sections of the reactor vessel and sensing lines are known constants and the various fluid specific gravities are continuously calculated as described in sections 4.0 and 5.0.

8.3 Reactor Coolant Pumps Running or Natural Circulation

Using Eq. 2:

Head at a = h1sg1 + h2asg2

Likewise:

Head at b = (hr-hf)sgv + (hf-hb-hc)sgt + hcsgc + hbsgb + h3asg3 - h3bsg3 - h2bsg2

The last two terms in the latter expression are negative since the head produced by those sections is directed away from the transmitter. The transmitter actually measures DP which is:

DP = head at a - head at b

Therefore:

DP = h1sg1 + h2asg2 + h2bsg2 + h3bsg3-h3asg3-(hr-hf)sgv - (hf-hb-hc)sgt - hbsgb - hcsgc

The only quantity which is not known in the above expression is hf, which is the actual reactor vessel water level, therefore, by solving for hf:

Eq. 3 $$hf = \frac{h1sg1 + h2sg2 + h3sg3 + (hb+hc)sgt-hrsgv-hbsgb-hcsgc-D}{sgt-sgv}$$

The RVLMS system calculates vessel level, hf, in accordance with Eq. 3 during RCP operation or natural circulation.

8.4 Safety Injection or RHR

During SI or RHR, Tcold is not considered representative of the reactor coolant bottom layer temperature, therefore, the reactor coolant in the vessel is assumed to have a uniform specific gravity equal to sgt throughout the reactor vessel or:

$$sgt = sgc = sgb$$

Inserting sgt for sgc and sgb in Eq. 3 yields:

Eq. 4 $$hf = \frac{h1sg1 + h2sg2 + h3sg3 - hrsgv - DP}{sgt - sgv}$$

The RVLMS system calculates vessel level, hf, in accordance with Eq. 4 during SI or RHR operation.

8.5 Reactor Vessel Level Below Top of Core or Refueling

As described in Section 7.3, when either of the above conditions exist, the core exit thermocouples are disabled and the reactor coolant in the vessel is assumed to be a uniform fluid whose specific gravity sgtp is calculated from wide range RCS pressure. Substituting sgtp for sgt, sgc, and sgb in Eq. 3 yields:

Eq. 5 $$hf = \frac{h1sg1 + h2sg2 + h3sg3 - hrsgv - DP}{sgtp - sgv}$$

The RVLMS system calculates vessel level, hf, in accordance with Eq. 5 when vessel level is below the top of the core or during refueling.

9.0 <u>Reactor Coolant Pump Compensation</u>

9.1 In section 8.0, the RVLMS system was shown to calculate vessel level, hf, in accordance with Eq. 3, Eq. 4, or Eq. 5. In each of these equations, the DP term as measured by the level transmitter is assumed to be the "static DP" which is due only to the level of water in the reactor vessel. During natural circulation, RHR, SI, and refueling operations this assumption is valid and Eq. 3, 4, and 5 properly calculate true vessel level. However, when one or two reactor coolant pumps (RCPs) are running, the large reactor coolant flow from the vessel bottom towards the top results in a "dynamic DP" which adds to the static DP to create a "total DP".

9.2 The total DP measured when RCPs are running overwhelms the static DP and would drive the level indicator off scale, therefore, a special RCP compensation feature has been designed to extract the static DP required for the vessel level equations from the total DP. The RCP compensation feature performs the following operation:

static DP = total DP - dynamic DP,

where total DP is measured by the level transmitter, and dynamic DP is continuously calculated as a function of Tcold for both one and two RCPs running.

9.3 A discrete reactor vessel water level with separated steam and water phases is assumed to exist for natural circulation, RHR, and SI conditions, and the RVLMS level indicator indeed displays this level. When one or both RCPs are running, however, there will most likely be a nearly homogeneous mixture of steam and water phases flowing through the vessel without a discrete water level. If the reactor coolant inventory decreases during a loss of coolant accident, there will continue to be a homogeneous mixture of water and steam, but the ratio of the entrained steam volume to water volume, or void fraction will increase. The level calculated and displayed by the RVLMS system is then considered to be the "collapsed level" or the level to which the water phase would collapse if all the steam entrained in the reactor coolant was removed.

9.4 As discussed in section 9.2, the RVLMS system continuously calculates the dynamic DP as a function of Tcold, but dynamic DP is also a function of the void fraction. An increase in void fraction reduces the reactor coolant density and results in a lower dynamic DP. The actual relationship between void fraction and reactor vessel dynamic DP is a complicated thermal-hydraulic function which is not known with any degree of certainty for Ginna Station. Any attempt at modeling this relationship with the RVLMS system risks the possibility of indicating an increasing vessel level inventory when in fact it may be decreasing. To preclude this, the RVLMS system dynamic DP compensation is calculated assuming a constant zero void fraction which assures that the greatest possible dynamic DP is compensated out of the level calculation to produce an indicated level that is always conservative.

ATTACHMENT I

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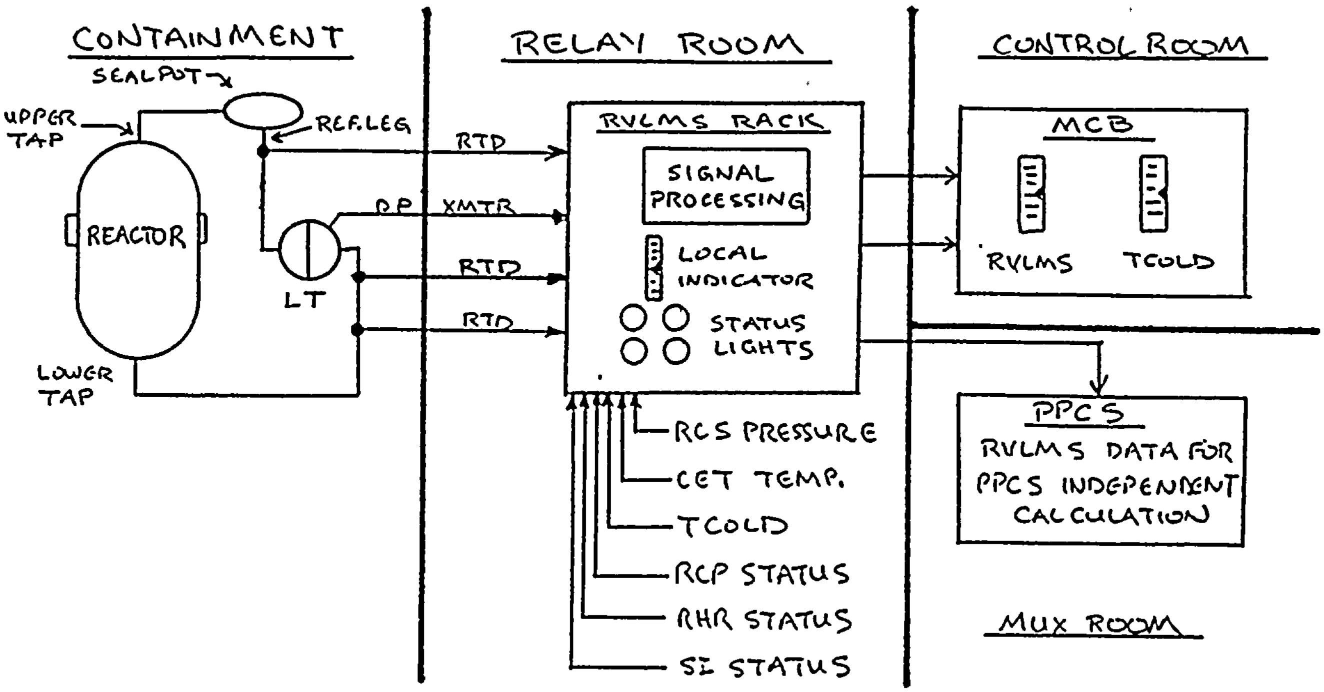
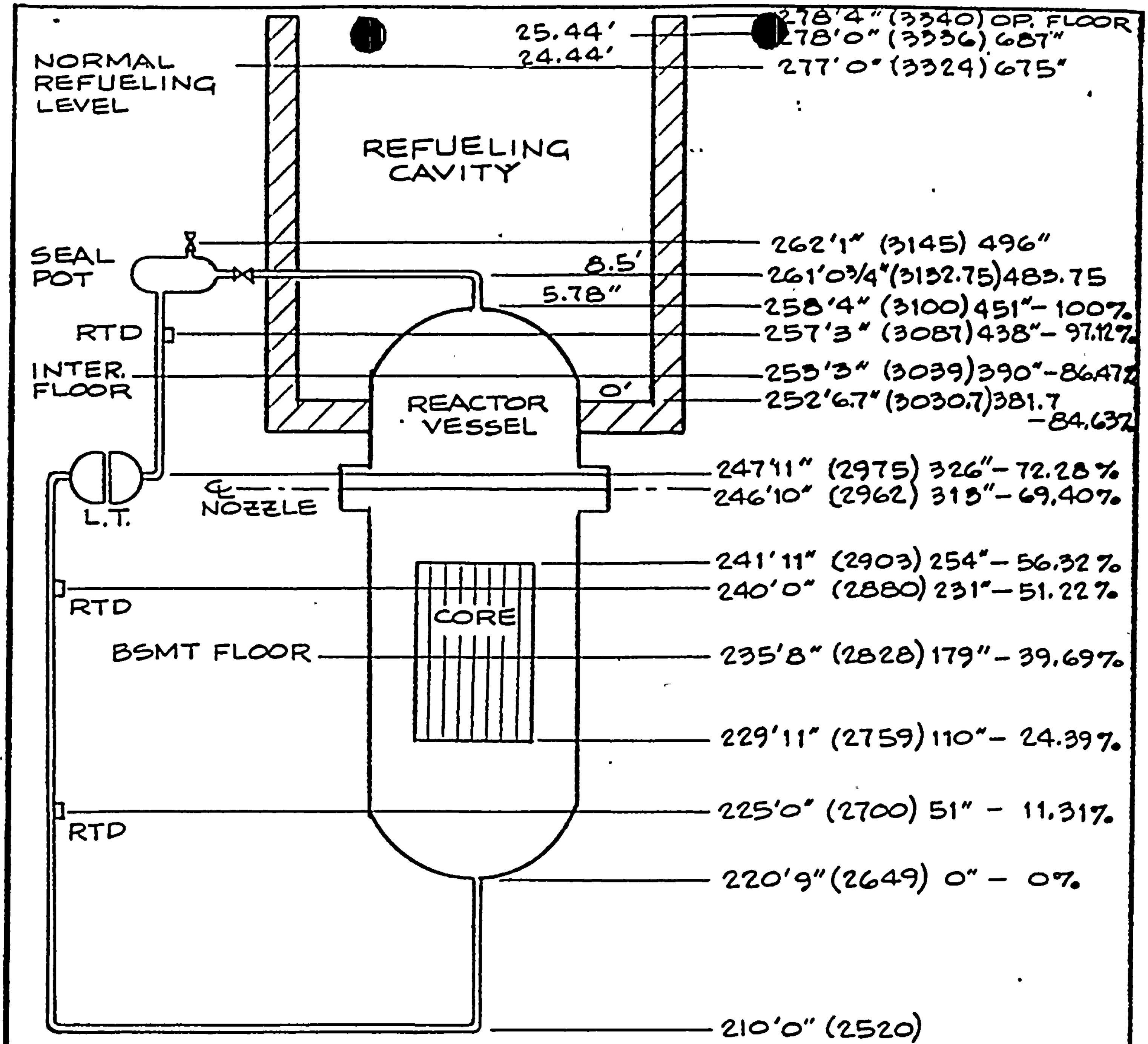
ENG. DEPT.	STATION: GINNA	DATE: 10/13/86	PAGE OF
JOB: EWR 2799- RVLMS		MADE BY: RAB	CK:

RVLMS BLOCK DIAGRAM



ATTACHMENT II



RVLMS SYSTEM ELEVATIONS

DATE	RELEASED FOR	ENGR
	CONSTRUCTION	
	LIMITED CONSTRUCTION: AS NOTED	
	PRELIMINARY NOT FOR CONSTRUCTION	
	BIDDING PURPOSES	

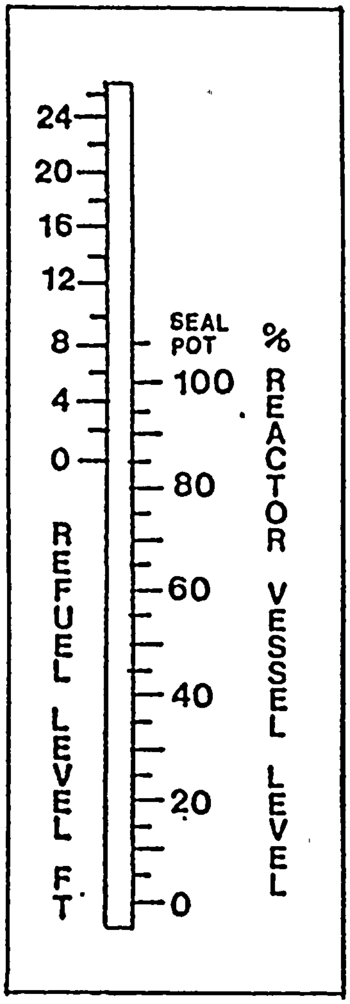
NUMBER	REVISION	DRAWN BY	CHECKED BY	RESP. ENG.	ENG. MANG'R.
0	ORIGINAL INITIAL DATE	EJD/6-9-86			

ROCHESTER GAS & ELECTRIC CORP. ROCHESTER, NEW YORK	RVLMS SYSTEM ELEVATIONS	SCALE —— NO. 03021-

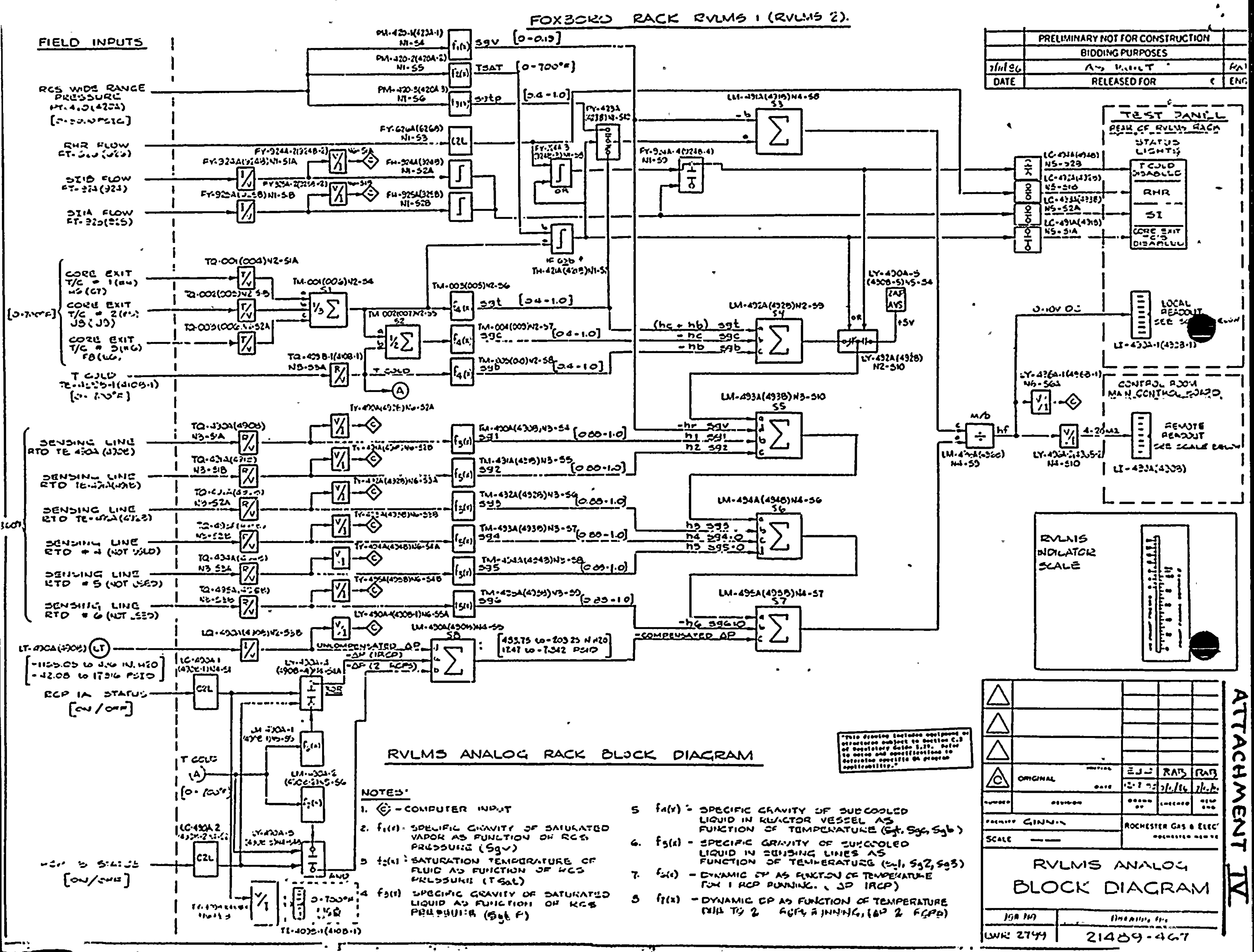
58009

HHS-191153

ATTACHMENT III

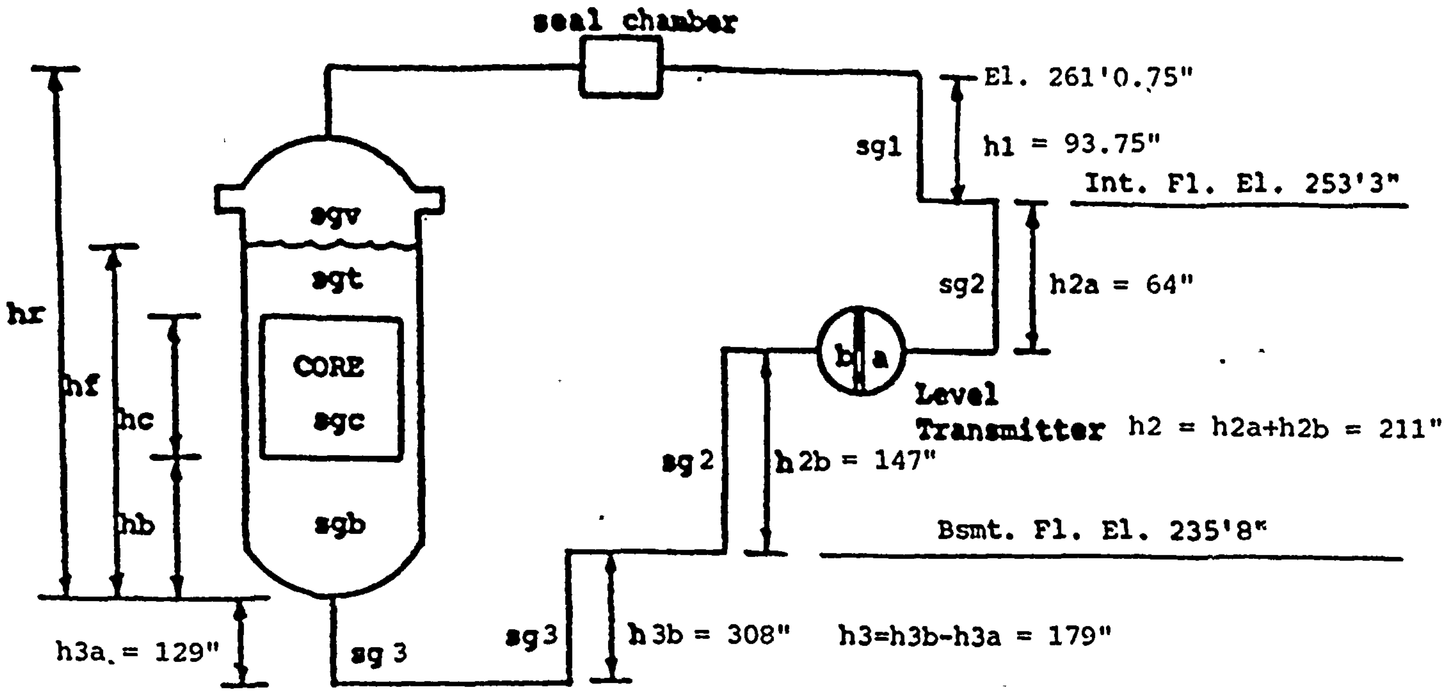


RVLMS INDICATOR SCALE



FOXBORO RACK RVLMS 1 (RVLMS 2).
PRELIMINARY NOT FOR CONSTRUCTION
BIDDING PURPOSES
DATE
RELEASED FOR
FIELD INPUTS
RCS WIDE RANGE PRESSURE
RHR FLOW
SIB FLOW
SIA FLOW
CORE EXIT
T COLD
SENSING LINE RTD
TEST PANEL
REAR OF RVLMS RACK
STATUS LIGHTS
RHR
SI
LOCAL READOUT
CONTROL ROOM MAIN CONTROL BOARD
REMOTE READOUT
RVLMS INDICATOR SCALE
RCP 1A STATUS
UNCOMPENSATED ΔP
COMPENSATED ΔP
RVLMS ANALOG RACK BLOCK DIAGRAM
NOTES:
1. © - COMPUTER INPUT
2. f1(x) - SPECIFIC GRAVITY OF SATURATED VAPOR AS FUNCTION OF RCS PRESSURE (Sgv)
3. f2(x) - SATURATION TEMPERATURE OF FLUID AS FUNCTION OF RCS PRESSURE (TSat)
4. f3(x) - SPECIFIC GRAVITY OF SATURATED LIQUID AS FUNCTION OF RCS PRESSURE (Sgt F)
5. f4(x) - SPECIFIC GRAVITY OF SUBCOOLED LIQUID IN REACTOR VESSEL AS FUNCTION OF TEMPERATURE (Sgt, Sgc, Sgb)
6. f5(x) - SPECIFIC GRAVITY OF SUBCOOLED LIQUID IN SENSING LINES AS FUNCTION OF TEMPERATURE (Sg1, Sg2, Sg3)
7. f6(x) - DYNAMIC ΔP AS FUNCTION OF TEMPERATURE FOR 1 RCP RUNNING. (ΔP 1RCP)
8. f7(x) - DYNAMIC ΔP AS FUNCTION OF TEMPERATURE DUE TO 2 RCPS RUNNING. (ΔP 2 RCPS)
ORIGINAL
GINNA
ROCHESTER GAS & ELECT
RVLMS ANALOG BLOCK DIAGRAM
21489-467
ATTACHMENT IV

REACTOR VESSEL LEVEL
DIFFERENTIAL PRESSURE EQUATION



1. Reactor Coolant Pumps Running or Natural Circulation

Head at a: $h1sg1 + h2asg2$

Head at b: $(hr - hf)sgv + (hf - hb - hc)sgt + hcsgc + hbsgb + h3asg3 - h3bsg3 - h2bsg2$

$$DP = a-b = h1sg1 + h2asg2 + h2bsg2 + h3bsg3 - h3asg3 - (hr - hf)sgv - (hf - hb - hc)sgt - hbsgb - hcsgc$$

$$DP= h1sg1 + (h2a + h2b)sg2 + (h3b - h3a)sg3 - hrsgv + hfsgv - hfsgt + hbsgt + hcsgt - hbsgb - hcsgc$$

$$DP = h1sg1 + h2sg2 + h3sg3 + hf(sgv - sgt) + (hb + hc)sgt - hrsgv - hbsgb - hcsgc$$

$$hf = \frac{h1sg1 + h2sg2 + h3sg3 + (hb + hc)sgt - hrsgv - hbsgb - hcsgc - DP}{sgt - sgv}$$

2. Safety Injection or RHR

$$hf = \frac{h1sg1 + h2sg2 + h3sg3 - hrsgv - DP}{sgt - sgv}$$

3. Reactor Vessel Level Below Top or Core or Refueling

$$hf = \frac{h1sg1 + h2sg2 + h3sg3 - hrsgv - DP}{sgtp - sgv}$$

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