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MFN 08-313

Docket No. 52-010

April 11, 2008

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Subject: **Response to Portion of NRC Request for Additional Information Letter No. 152 - Related to ESBWR Design Certification Application – RAI Number 4.3-12**

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) response to the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) sent by the Reference 1 NRC letter. GEH response to RAI Number 4.3-12 is addressed in Enclosures 1 and 2.

Verified DCD changes associated with this RAI response are identified in the enclosed DCD markups by enclosing the text within a black box. The marked-up pages may contain unverified changes in addition to the verified changes resulting from this RAI response. Other changes shown in the markups may not be fully developed and approved for inclusion in DCD Revision 5.

If you have any questions or require additional information, please contact me.

Sincerely,

James C. Kinsey

James C. Kinsey
Vice President, ESBWR Licensing

DO68
NRO

Reference:

1. MFN 08-121, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, *Request for Additional Information Letter No. 152 Related to the ESBWR Design Certification Application*, dated February 11, 2008

Enclosures:

1. MFN 08-313 – Response to Portion of NRC Request for Additional Information Letter No. 152 - Related to ESBWR Design Certification Application – RAI Number 4.3-12
2. MFN 08-313 – Response to Portion of NRC Request for Additional Information Letter No. 152 - Related to ESBWR Design Certification Application – DCD Markups from the Response to RAI Number 4.3-12

cc:	AE Cubbage	USNRC (with enclosures)
	GB Stramback	GEH/San Jose (with enclosures)
	RE Brown	GEH/Wilmington (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)
	eDRF	0000-0080-6894

Enclosure 1

MFN 08-313

Response to Portion of NRC Request for

Additional Information Letter No. 152

Related to ESBWR Design Certification Application

RAI Number 4.3-12

NRC RAI 4.3-12

NRC Summary: Describe the Feedwater Temperature Control System

NRC Full Text:

Provide a description of the FWT control system design and logic. Provide a figure showing the location of the relevant sensors important to the operation of the FWT control system. Describe how the design meets the requirements for the condensate and feedwater system specified in Subsection 10.4.7.1.1 of DCD Rev.4.

GEH Response

Description of FWT Control System Design and Logic

Independent of FW level control, triple redundant FW Temperature (FWT) control is also designed for the ESBWR to allow reactor power maneuvering without moving control rods. The ESBWR High Pressure (HP) Feedwater Heater Temperature Control Diagram is provided in DCD, Tier 2, Figure 7.7-7. FWT control is accomplished by either manipulating the main steam flow to the #7 FW heaters to increase FWT above the temperature normally provided by the FW heaters with turbine extraction steam (normal FWT) or by directing a portion of the FW flow around the high pressure FW heaters to decrease FWT below the normal FWT. An increase in FWT decreases reactor power and a decrease in FWT increases reactor power. At 100% Rated Thermal Power (RTP) conditions, the addition of seventh stage FW heaters in full service provides approximately 36.7°C (66°F) increase in the FWT, which corresponds to approximately 15% core power reduction. ESBWR reactor power versus FW temperature map (Power-FWT Map) is described in LTR NEDO-33338 Figure 4.2-1. The figure is reproduced here and will be included in DCD, Tier 2, Revision 5, Section 4.4.

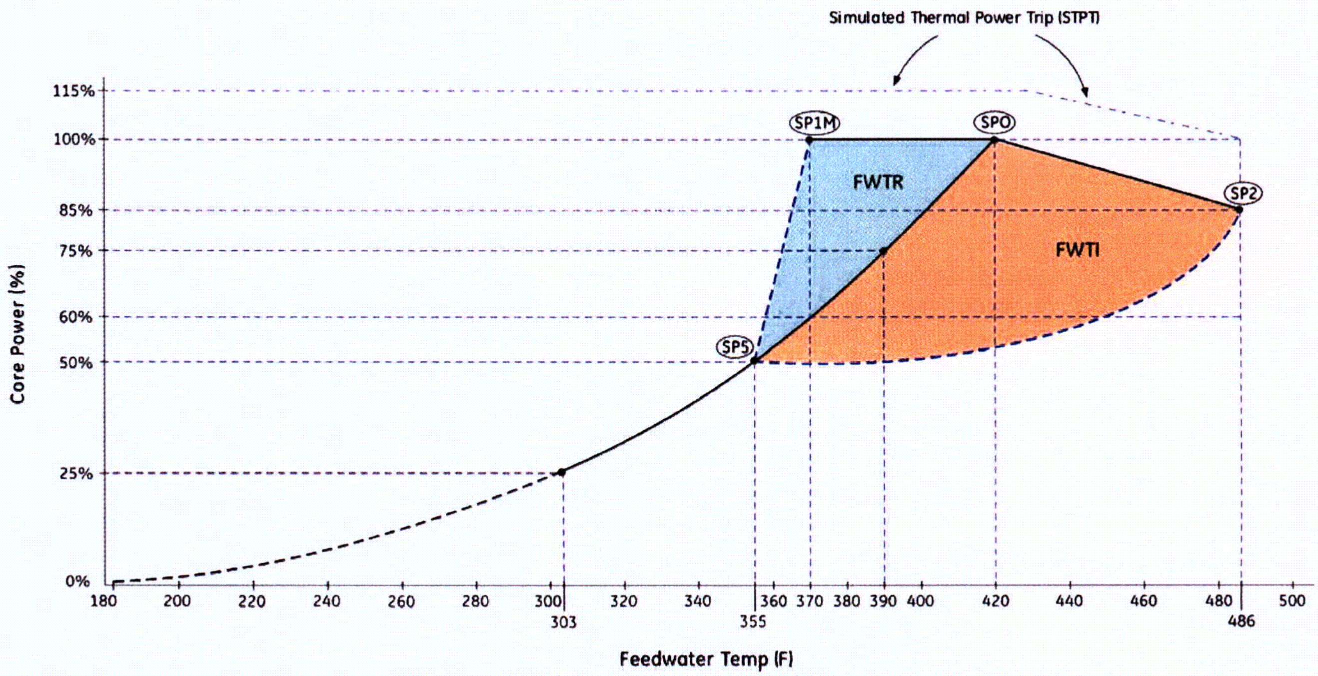


Figure 4.2-1 from NEDO-33338.
ESBWR Power – Feedwater Temperature Operating Domain/Map

The following operating modes are provided for the FW temperature control system:

- Manual – the FW temperature setpoint is controlled by the operator, and
- Automatic – the FW temperature setpoint is controlled by the Plant Automation System (PAS).

Both modes of FWT control use eight FW temperature measurements, four per FW line. These redundantly measured temperatures are compared to the temperature setpoint and the error signal is used by a PID (proportional, integral, derivative) controller. The PID controller output range is between –100% to +100% depending on whether heating or cooling of the FW is required. The output signals are used to generate the position demands for the HP FW heater bypass valves and seventh FW heater steam heating valves.

Both modes of FWT control include the following features:

- Neither the operator nor the PAS can input a setpoint outside the area allowed by Power-FWT Map (adjustable per fuel cycle).
- Neither the operator nor the PAS can change the setpoint faster than an allowable rate (nominally 55.6 °C (100 °F) per hour).
- No FW temperature control mode can be entered unless the controller has passed all its self-diagnostic tests, and the operator has actively selected the control mode.
- The FWT controller is unable to decrease FW temperature if the reactor thermal power is greater than 100%. The validated reactor thermal power signal is provided by the NMS.

- Individual temperature control valves are "locked up" if they are not at their demanded position within a predetermined time or one-way "locked up" if there is an Automated Thermal Limit Monitor (ATLM) one-way block (to prevent FW temperature from additional decrease (increase). The steam heating valves are blocked from further closing (opening), the bypass valves are blocked from further opening (closing)).
- The heating valves to the 7th FW heater and the high pressure FW heater bypass valves are not open simultaneously.

A loss of FW heating that results in a significant decrease in FW temperature is independently detected by the ATLMs and by the DPS (Diverse Protection System), either of which will mitigate the event by initiating SCRRI/SRI functions. These interlocks mitigate the effects of a reactor power increase due to reduced FWT. Although no credit is taken for the function in the safety analysis, the FW temperature control system mitigates inadvertent FW temperature changes in either direction by manipulating its control valves to maintain the setpoint temperature. The temperature difference between FW lines A and B is monitored and alarmed if it exceeds the allowable value.

If reactor thermal power versus FWT is outside of the area allowed by the Power-FWT Map, the RC&IS initiates a control rod withdrawal block and FWT control valve one-way block. If reactor thermal power versus feedwater temperature further departs from the area allowed by the Power-FWT Map, the Reactor Protection System (RPS) initiates a reactor shutdown. The RPS uses eight safety-related measurements of FW temperature (two per division) and implements a reactor scram using two-out-of-four logic based on a validated reactor thermal power.

A combined FW temperature change and FW flow/reactor water level change caused by controller failure is precluded by implementing the two control schemes in physically different cabinets and processors.

No single failure or operator error of the FWT control system results in more than a 55.6°C (100°F) decrease in the final FWT. The design meets the requirements for the condensate and feedwater system specified in DCD Tier 2 Subsection 10.4.7.1.

DCD Impact

DCD Tier 1: Table 2.2.1-2, Subsection 2.2.3, Table 2.2.3-1, Table 2.2.3-3, Table 2.2.7-2 and Table 2.2.14-2 will be revised as shown in the markups in enclosure 2.

DCD Tier 2: Subsection 7.1.5.2.3.3, Subsection 7.2.1.2.4.2, Subsection 7.2.1.2.4.3, Subsection 7.2.2.2.1, Table 7.2-1, Figure 7.2-2, Subsection 7.7.2.2.7.7, Subsection 7.7.3, Subsection 7.7.3.1.2, Subsection 7.7.3.2.1 Subsection 7.7.3.2.3, Subsection 7.7.3.3, Subsection 7.7.4.2, Figure 7.7-3, and Subsection 7.8.1.1.3 will be revised and Figure 7.7-7 will be added as shown in the markups in enclosure 2.

No changes to the subject LTR (NEDO-33338) will be made in response to this RAI.

No changes to DCD Subsections 10.4 or 4.4 will be made in response to this RAI.

Enclosure 2

MFN 08-313

Response to Portion of NRC Request for

Additional Information Letter No. 152

Related to ESBWR Design Certification Application

DCD Markups from the Response to RAI Number 4.3-12

Verified DCD changes associated with this RAI response are identified in the enclosed DCD markups by enclosing the text within a black box. The marked-up pages may contain unverified changes in addition to the verified changes resulting from this RAI response. Other changes shown in the markups may not be fully developed and approved for inclusion in DCD Revision 5.

Table 2.2.1-2

RC&IS Major Functional Groups

Major Functional Group	Functions
RAPI SIU	Handles RAPI inter-channel communication between ATLM, RWM, and RAPI A and B channels and external communication with the nonsafety-related NMS MRBM.
RWM	Enforces absolute rod pattern restrictions, called the Ganged Withdrawal Sequence Restrictions (GWSR) when reactor power is below the low power setpoint (LPSP) and the RPS RMS is in either the STARTUP or RUN position. Supports shutdown margin testing
ATLM	Microprocessor-based subsystem of the RC&IS Enforces Operating Limit Minimum Critical Power Ratio (OLMCPR) Enforces the Operating Limit ~~Minimum~~ Maximum Linear Heat Generation Rate (OLMLHGR) Issues rod withdrawal block signals Issues high-pressure FW heater bypass valves one-way block signal. Issues seventh FW heater steam heating valves one-way block signal. Initiates SCRRI/SRI functions on Loss of FW Heating
Remote Communication Cabinets (RCCs)	Houses the redundant microprocessor-based communication system that interfaces with the RAPI, MCC, and RBCC.
Motor Controller Cabinets (MCCs)	Houses the CRDS FMCRD motor controllers ~~(MC)~~. Interfaces with RCC, RBCC and Emergency Rod Insertion Panel (ERIP)
Rod Brake Controller Cabinets (RBCCs)	Operates the CRDS FMCRD holding brakes Interfaces with RCC.
ERICP	Located in CB. Relay-hardware based, nonsafety-related control system that alternatively commands scram follow, ARI, and SCRRI.
ERIP	Interface with the MCC FMCRD MCs.

2.2.3 Feedwater Control System

Design Description

The Feedwater Control System (FWCS), automatically or manually, controls RPV water level by modulating the supply of feedwater flow to the RPV, the low flow control valve (LFCV), individual reactor feed pump ASD, or the RWCU/SDC system overboard control valve (OBCV).

The FWCS changes reactor power by automatically or manually controlling FW temperature by modulating the 7th FW heater steam heating valves or the high-pressure FW heater bypass valves.

Functional Arrangement

(1) FWCS functional arrangement is defined in Table 2.2.3-1.

Functional Requirements

(2) FWCS automatic functions, initiators, and associated interfacing systems are defined in Table 2.2.3-2.

(3) FWCS controls are defined in Table 2.2.3-3.

(4) FWCS minimum inventory of alarms, displays, and status indications in the main control room are addressed in Section 3.3.

(5) Single failure modes of fault tolerant digital controllers (FTDC) are defined in Table 2.2.3-4.

(6) FWCS software is developed in accordance with the software development program described in Section 3.2.

Inspections, Tests, Analyses and Acceptance Criteria

Table 2.2.3-54 defines the inspections, tests, and/or analyses, together with associated acceptance criteria for the FWCS.

Table 2.2.3-1

~~Feedwater Control Modes~~FWCS Functional Arrangment

FWCS is nonsafety-related.
FWCS ~~is a~~uses triple-redundant, fault tolerant digital controllers (FTDC)

Table 2.2.3-2

FWCS Automatic Functions, Initiators, and Associated Interfacing Systems

Functions	Initiators	Interfacing System
Perform FW runback	RPV water level high (Level 8)	NBS
~~Send signal to N-DCIS to initiate SCRRI / SRI function~~	~~FW temperature low.~~	~~RC&IS~~
Reduce speed of other FW pumps	FW flow high on one FW pump run-out	-
Start standby reactor feed pump	Reactor feed pump trip	-
Open the steam line condensate drain valves	Steam flow less than predefined value of rated flow	-
~~Perform FW runback.~~	~~FW temperature low~~	-
Trip all FW pumps	RPV water level high-high (Level 9)	-DPS
~~Perform FW runback.~~	~~RPV water level high (Level 8)~~	-
Perform FW runback and close the LFCV and the RWCU/SDC overboard flow control valve	ATWS trip signal	~~DICS~~DPS
One-way block high-pressure FW heater bypass valves	ATLM issues high-pressure FW heater bypass valves one-way block signal	RC&IS

One-way block seventh FW heater steam heating valves	ATLM issues seventh FW heater steam heating valves one-way block signal	RC&IS

Table 2.2.3-3

FWCS Controls

Parameter	Description
RPV Level Control	Manual speed control (reactor feed pump) Manual start/stop (reactor feed pump) Automatic / manual mode (reactor feed pump control) Manual control (~~No. 7~~ high pressure FW heater string bypass valves and isolation valves) • Automatic Control Modes: Single element control: (enable at predefined value below rated reactor power) RPV water level: • Modulate either the low flow control valve (LFCV) or individual reactor feed pump ASD. • Modulate RWCU/SDC system overboard control valve (OBCV) Three element control: (enable during normal power operation) Three process variables generate master feedwater flow demand signal (for output to individual reactor feed pump loop trim controller): • Total steam flow • Total FW flow • RPV water level Reactor feed pump loop trim controller modulates individual reactor feed pump ASD: • Master FW flow demand signal • Individual reactor feed pump flow signals
FW Temperature Control	Manual mode: FW temperature setpoint set by operator Automatic mode: FW temperature setpoint is provided by PAS • Modulate FW heater No. 7 steam inlet valves • Modulate HP FW Heaters bypass valves

Table 2.2.7-2

RPS Automatic Functions, Initiators, and Associated Interfacing Systems

Function	Initiator	Interfacing System
Reactor scram	NMS PRNM trip condition	NMS
	NMS SRNM trip condition	NMS
	CRD charging header pressure low	CRDS
	Turbine stop valve closed position	-
	Turbine control valve control oil pressure low	-
	Condenser pressure high	-
	Power Generation Bus Loss	-
	MSIV closed position	NBS
	Reactor Pressure high	NBS
	RPV reactor level low (Level 3)	NBS
	RPV reactor level ~~low~~ high (Level 8)	NBS
	Drywell pressure high	CMS
	Suppression pool average temperature high	CMS
	High simulated thermal power (feedwater temperature biased)	NBS, NMS

Table 2.2.14-2

DICS Functions, Initiators, and Interfacing Systems

Function	Initiator	Interfacing System
SCRRI/SRI (DPS)	RC&IS SCRRI signal.	RC&IS, RPS
	ATLM SCRRI/SRI signal	RPS, RC&IS
	Generator load rejection signal.	TGCS, RPS, RC&IS
	Loss of FW heating.	~~FWCS~~C&FS, NMS, RPS, RC&IS
	Turbine trip signal.	TGCS, RPS, RC&IS
	OPRM thermal neutron flux oscillation	NMS, RPS, RC&IS
Delayed FWRB (DPS)	SCRRI/SRI signal and power levels remain elevated	NMS, RC&IS, FWCS
	RPS scram command and power levels remain elevated	RPS, NMS, FWCS
DPS Scram (DPS)	RPV dome pressure high	NBS, RPS
	RPV water level high (Level 8)	NBS, RPS
	RPV water level low (Level 3)	NBS, RPS
	Drywell pressure high	CMS, RPS
	Suppression pool temperature high	CMS, RPS
	MSIV closure	NBS, RPS
	RPS Scram	RPS
	SCRRI/SRI command with power levels remaining elevated	NMS, RC&IS, RPS
	~~Manual scram~~	-
ADS initiation (DPS)	RPV water level low (Level 1)	NBS

7.1.5.2.3.1 Nuclear Boiler System Instrumentation

Nonsafety-related NBS instrumentation provides indication of reactor coolant and vessel temperatures, RPV water level, and ~~reactor vessel~~RPV pressure. Refer to Subsection 7.7.1 for additional information.

7.1.5.2.3.2 Rod Control and Information System

The nonsafety-related RC&IS is able to control reactor power level by controlling the movement of the control rods in the reactor core during manual, semi-automated, and automated modes of plant operations. The ATLM automatically enforces fuel operating thermal limits ~~M~~minimum ~~C~~critical ~~P~~power ~~R~~ratio (MCPR) and ~~M~~maximum ~~L~~linear ~~H~~heat ~~G~~generation ~~R~~rate (MLHGR) when reactor power is above the ~~L~~low ~~P~~power ~~S~~setpoint (LPSP). Refer to Subsection 7.7.2 for additional information.

7.1.5.2.3.3 Feedwater Control System

~~A~~ The nonsafety-related FWCS has two sets of highly reliable and triple redundant ~~nonsafety-related FWCS~~controllers. The FW level controller automatically and manually regulates the flow of feedwater into the ~~reactor pressure vessel~~RPV. ~~This~~ It maintains a predetermined water level ~~limits~~ for all modes of reactor operation, including heatup and cooldown. The FW temperature controller allows reactor power maneuvering without moving control rods. Refer to Subsection 7.7.3 for additional information.

7.1.5.2.3.4 Plant Automation System

The nonsafety-related PAS:

- Provides automatic startup/shutdown algorithms and controls,
- Regulates reactivity during criticality control,
- Provides heatup and pressurization control,
- Regulates reactor power, and
- Provides automatic power generation control during power operation. Refer to Subsection 7.7.4 for additional information.

~~The PAS does not involve safety-related systems.~~ The PAS is the ~~first of two~~plant-wide automation schemes implemented by the N-DCIS~~, plant-wide automation and system level automation~~. The PAS coordinates the action of multiple systems ~~for plant-wide automation~~ using system level controllers to automate the operation, maintenance, testing, and inspection functions. It uses ~~A~~automated ~~P~~program ~~F~~functions (APF) to coordinate the ~~A~~automatic ~~P~~power ~~R~~regulator (APR) and ~~the~~ its ~~P~~power ~~G~~generation and ~~C~~control ~~S~~systems (PGCS)~~ of the PAS~~.

The PAS provides the capability for supervisory control of the entire plant by supplying set-point commands to independent nonsafety-related automatic control systems as changing load demands and plant conditions dictate. Safety-related systems are never controlled or tasked by

Divisions of Scram Logic Circuitry: The two divisions of primary scram logic circuitry are powered from independent and separate power sources. One of the two divisions of scram logic circuitry distributes Division 1 safety-related 120 VAC power to the A solenoids of the HCUs. The other division of scram logic circuitry distributes Division 2 safety-related 120 VAC power to the B solenoids of the HCUs. The HCUs (including the scram pilot valves and the scram valves) are components of the CRDS. A full scram of control rods associated with a particular HCU occurs when both A and B solenoids of the HCU are de-energized. The arrangement of equipment groups within the RPS from sensors to actuator loads is shown in Figure 7.2-1. The RPS ~~functional block diagram showing the RPS~~ interfaces and boundaries ~~diagram~~ with other systems ~~is~~ are shown in Figure 7.2-2.

7.2.1.2.4.2 Initiating Circuits

The RPS logic initiates a reactor scram in the individual sensor channels when any one or more of the conditions listed below exist (IEEE Std. 603, Section 4.1, 4.2 and 4.4). The system monitoring the process condition is indicated in ~~parenthesis~~parentheses. These conditions are:

- High ~~Drywell~~ drywell ~~Pressure~~ pressure (CMS),
- Turbine ~~S~~stop ~~V~~valve (TSV) ~~Closure~~ closure (RPS),
- Turbine ~~C~~control ~~V~~valve (TCV) ~~Fast~~ fast ~~Closure~~ closure (RPS),
- NMS-monitored SRNM and APRM conditions exceed acceptable limits (NMS),
- High ~~Reactor~~ reactor ~~Pressure~~ pressure (NBS),
- Low ~~R~~reactor pressure vessel (RPV) ~~W~~water ~~L~~level (Level 3) decreasing (NBS),
- High ~~Reactor~~ RPV ~~W~~water ~~L~~level (Level 8) increasing (NBS),
- Main ~~S~~steam ~~L~~line ~~I~~isolation ~~V~~valve (MSIV) ~~Closure~~ closure (Run mode only) (NBS),
- Low ~~C~~control ~~R~~rod ~~D~~drive HCU ~~A~~accumulator ~~C~~charging ~~H~~header ~~P~~pressure (CRDS),
- High s~~S~~uppression ~~P~~pool ~~T~~temperature (CMS),
- High ~~C~~condenser ~~P~~pressure (RPS),
- Power ~~G~~generation ~~B~~bus ~~L~~loss (Loss of ~~F~~feedwater ~~F~~flow)(Run mode only) (RPS),
- High simulated thermal power (Feedwater temperature biased) (NBS and NMS),
- Operator-initiated manual scram (RPS), and
- Reactor Mode Switch in "Shutdown" position (RPS).

With the exception of the NMS outputs, the MSIV closure, TSV closure and TCV fast-closure, loss of feedwater flow due to loss of power generation bus, main condenser pressure high, and manual scram outputs, ~~the other~~ systems provide sensor outputs through the RPS RMU.

The MSIV Closure, TSV closure and TCV fast-closure, loss of power generation bus, manual scram output, and main condenser pressure high signals are provided to the RPS through hardwired connections. The NMS trip signal is provided to the RPS through fiber optic cable. The systems and equipment providing trip and scram initiating inputs to the RPS for these conditions are discussed in the following subsections.

Neutron Monitoring System

The separate and isolated NMS digital Startup Range Neutron Monitor (SRNM) trip signals, and Average Power Range Monitor (APRM) trip signals from each of the four divisions of the NMS equipment are provided to their divisions of RPS trip logic as shown on Figure 7.2-1.

SRNM Trip Signals: The safety-related SRNM subsystem provides trip signals to the RPS to cover the range of plant operation from source range through startup range (more than 10% of reactor-rated power). Three SRNM conditions, monitored as a function of the NMS, comprise the SRNM trip logic output to the RPS. These conditions are:

- SRNM upscale (high count rate or high thermal neutron flux level),
- Short (fast) period, and
- SRNM inoperative.

The three trip conditions from every SRNM associated ~~in~~ with a NMS division are combined into a single SRNM trip signal for that division. The specific condition causing the SRNM trip output state is identified by the NMS, and is not detectable within the RPS. The SRNM trip functions are summarized in Table 7.2-2. SRNM trip signals are summarized in Table 7.2-3.

APRM Trip Signals: The APRMs ~~provide~~ trip signals ~~to the RPS to~~ cover the range of plant operation from a few percent of reactor-rated power to greater-than-rated power. Three APRM conditions, monitored as a function of the NMS, comprise the APRM trip logic output to the RPS. These conditions are:

- APRM high thermal neutron flux,
- High simulated reactor thermal power, and
- APRM inoperative.

The APRM trip functions are summarized in Table 7.2-4.

Within the safety-related APRM subsystem there is the Oscillation Power Range Monitor (OPRM) function, which is capable of generating a trip signal in response to core thermal neutron flux oscillation conditions, and thermal-hydraulic instability fast enough to prevent cladding thermal limit violation and fuel damage. This OPRM trip signal is combined with the other three APRM trip signals to form the final APRM trip signal to the RPS. The NMS also provides the RPS with a simulated reactor thermal power signal to support the load rejection bypass algorithm.

Nuclear Boiler System

Reactor Pressure: _Reactor pressure is measured by four physically separate pressure transmitters mounted on separate divisional local racks in the safety envelope within the Reactor Building (RB). Each transmitter is on a separate instrument line and is associated with a separate RPS electrical division. Each transmitter provides an analog output signal to the RPS RMU, which digitizes and conditions the signal before sending it to the appropriate RPS DTM in one of the four RPS divisional sensor channels. The four pressure transmitters and associated instrument lines are components of the NBS.

Reactor Pressure Vessel ~~(RPV)~~ Water Level:_ RPV water level is measured by four physically separate level (differential pressure) transmitters mounted on separate divisional local racks in the safety envelope within the RB. Each transmitter is on a separate pair of instrument lines and is associated with a separate RPS electrical division. Each transmitter provides an analog output signal to the RPS RMU, which digitizes and conditions the signal before sending it to the appropriate DTM in one of the four RPS divisional sensor channels. The four separate level transmitters and associated instrument lines are components of the NBS.

Main Steamline Isolation Valve Closure: _Each of the four Main Steam Lines (MSLs) can be isolated by closing either its inboard or outboard isolation valve. Position (limit) switches are mounted on both isolation valves of each MSL. These switches provide output to the appropriate DTM in one of the four RPS divisional trip channels using ~~hard wired~~hard-wired connections. On each MSL, two position switches are mounted on each inboard isolation valve and each outboard isolation valve. Each of the two position switches on any one MSL isolation valve is associated with a different RPS divisional sensor channel. A reactor scram is initiated by either the inboard or outboard valve closure on two or more of the MSLs. The eight MSIVs and the 16 position switches supplied with these valves (for RPS use) are components of the NBS.

Feedwater Temperature Biased Simulated Thermal Power: Feedwater temperature (FWT) is measured by four separate temperature sensors mounted on each feedwater line in the MSL tunnel area within the RB. Each sensor is connected to a separate channel and is associated with a separate RPS electrical division. Each sensor provides a temperature signal to the RPS RMU, which digitizes and conditions the signal before sending it to the appropriate RPS DTM. The eight temperature sensors (four on each feedwater line) are components of the NBS. The RPS uses FWT from NBS and simulated thermal power (STP) from the NMS to develop a STP setpoint that is a function of FWT. The analytical limit for this setpoint varies linearly between 115% STP at 222.2 °C (432 °F) FWT and 100% STP at 254.4 °C (490 °F) FWT.

Control Rod Drive System

Locally mounted pressure transmitters measure the CRDS accumulator charging header pressure at four physically separate locations. Each transmitter is associated with a separate RPS division and is on a separate instrument line. Each transmitter provides an analog output signal to the RMU, which digitizes and conditions the signal before sending it to the appropriate DTM (in one of the four RPS divisional trip channels). The four pressure transmitters and associated instrument lines are components of the CRDS. This is an anticipatory scram because it initiates a scram before the HCUs have time to depressurize the reactor.

Reactor Protection System

signal to be enabled, 12 of the 16 assigned thermocouples are required to be operable. When the established limits of high temperature are exceeded in two of the four divisions, scram initiation is generated.

Each temperature sensor provides an analog output signal to the RMU, which digitizes and conditions the signal before sending it to the appropriate DTM. The temperature sensors and associated instrument lines are components of the CMS. The suppression pool water level signals also are provided. When water level drops below ~~selected~~ any of the temperature sensors, the exposed sensors are logically bypassed, so only the sensors below water level are used to determine the averaged temperature signal to the RPS.

7.2.1.2.4.3 Reactor Protection System Outputs to Interfacing Systems

Scram Signals to the CRD System: Reactor trip conditions existing in any two or more of the four RPS automatic trip channels and/or in both RPS manual trip channels cause power to the output circuits of the RPS (normally supplying power to the solenoids of the scram pilot valves of the CRD system) to be disconnected ~~from power~~, resulting in insertion of all control rods and reactor shutdown.

When the scram pilot valve solenoids are disconnected from power by the RPS trip signals, the two scram air header dump valves of the CRD system (backup scram valves) are actuated by the RPS trip signals to exhaust the air from the scram air header, resulting in backup scram action.

RPS Status Outputs to the NMS: Two types of RPS status condition signals (four combined signals each, one per division) are provided to the NMS by the RPS. Isolated output signals, indicating that the Reactor Mode Switch is in the Run position, are provided to the four divisions of the NMS whenever the mode switch is in that position. These signals are used by the NMS to bypass the NMS SRNM alarm and trip function, whenever the Reactor ~~m~~Mode ~~s~~Switch is in the Run position.

Scram Follow Signals to the RC&IS: Upon the occurrence of any full reactor scram condition the RPS provides isolated output signals to the RC&IS. This enables automatic rod run-in (scram-follow) logic in the RCIS to cause full insertion (or "run-in") of the fine motion control rod drives subsequent to scram. The RPS also provides the RC&IS with both scram test switch status, indicating the start of a rod pair scram test and the position of the Reactor Mode Switch.

Rod Block Signals to the RC&IS: Rod withdrawal inhibit signals (one for each channel) are provided by the RPS via isolated output signals sent to the RC&IS whenever there is a "Low CRD Charging Water Header Pressure" trip signal or when any CRD charging pressure trip bypass switch is in the Bypass position.

Outputs to the LD&IS: ~~The drywell pressure output signals are sent to the LD&IS for RCPB and primary containment leakage alarm and isolation functions. The drywell pressure output signals are obtained from the RPS sensors (one for each division) and provided to the LD&IS via the Q-DCIS. Also,~~The Reactor Mode Switch status signals from each division are provided to the LD&IS for RCPB isolation function. The RPS also provides an interlock to the LD&IS for bypassing the MSIV isolation (when the Reactor Mode Switch is not in the Run ~~mode~~position) that otherwise would result from high main condenser vacuum-pressure and/or low inlet-pressure to the turbine during startup and shutdown.

Outputs to Main Control Room Panels:

Safety-related status and alarm signals are sent from the RPS to the ~~main control~~MCR console.

Displays: Instrument channel sensor checks are capable of being performed at the ~~main control~~MCR console. Displays exist for readout and comparison of the current values of the variables or separate processes being monitored for each set of four (one per division). Displays related to RPS scram variables include the following minimum set of signals. These signals are:

- Reactor vessel pressure,
- RPV water levels,
- Containment drywell pressures,
- CRD HCU accumulator charging header pressures,
- Suppression pool (local or bulk) temperatures,
- Power generation bus voltages,
- Feedwater temperature,
- TSV position,
- Hydraulic Trip System oil pressure,
- MSIV position,
- Main condenser pressure, and
- NMS outputs.

The values of all scram parameters are continuously sent through isolated gateways to the N-DCIS where displays of the scram parameters from all divisions are integrated to allow easy comparison between divisions. Additionally, the ~~plant computers~~PCF and alarm systems ~~will~~ alarm if any divisional parameter value differs from the value in the other three divisions by more than a predetermined amount. The intent is that channel sensor checks be performed continuously.

Alarms: Alarms are provided at the ~~main control~~MCR console by the trip condition of any of the four sensor trip channels, by the trip condition of each automatic or manual trip system, and when bypassing a scram function. The alarm function is provided through isolated gateways to the ~~plant computer functions (~~PCF~~)~~.

The ~~following~~ provided alarms / indications related to RPS status are ~~provided~~:

- RPS NMS trip (generated in NMS),

- Reactor vessel pressure high,
- RPV water level low (≤ Level 3),
- RPV water level high (≥ Level 8),
- Containment (drywell) pressure high,
- MSIV closure trip,
- TSV closure,
- TCV fast closure,
- Main condenser pressure high,
- Power generation bus loss (~~Loss~~ loss of feedwater flow),
- Feedwater temperature biased STP trip,
- CRD HCU accumulator-charging-header-pressure low,
- Suppression pool temperature high,
- RPS divisional automatic trip (auto-scram) (each of the four: Div. 1, 2, 3, 4 automatic trip),
- RPS divisional manual trip (each of the four: Div. 1, 2, 3, 4 manual trip),
- Manual scram trip (two: both Manual A and Manual B),
- Reactor Mode Switch in Shutdown position,
- Shutdown mode trip bypassed,
- Non-coincident NMS trip mode in effect (in NMS),
- NMS trip mode selection switch still in ~~N~~non-coincident position, with Reactor Mode Switch in Run position (in NMS),
- Division in which channel A (B, C, or D) sensors are bypassed (four),
- Trip conditions in Channel A (B, C, or D) and Channel A (B, C, or D) sensors bypassed (four),
- Division 1 (2, 3, or 4) TLU out-of-service bypass (four),
- CRD accumulator-charging-header-pressure low trip bypass,
- Any CRD accumulator-charging-header trip with bypass switch still in ~~B~~bypass position and the Reactor Mode Switch in Startup or Run mode,
- Auto-scram test switch in ~~T~~test mode (manual trip of automatic logic) (four),

- TSV closure trip bypassed,
- TCV fast closure trip bypassed,
- MSIV closure trip bypassed,
- NMS SRNM trip bypassed with the Reactor Mode Switch in ~~Run mode~~Run position,
- Non-coincident NMS trip bypassed with the Reactor Mode Switch in Run ~~mode~~position,
- RPV water level high trip bypassed,
- Condenser pressure high trip bypassed,
- Feedwater temperature biased STP trip bypassed,
- Special MSIV operationa~~l~~ bypassed, and
- Power generation bus loss trip bypassed.

The above RPS displays and alarms meet the information display requirements of IEEE Std. 603, Section 5.8.

Outputs to Nonsafety-Related DCIS ~~(N-DCIS) (~~Plant Computer Function~~s~~): The PCF maintains lo~~s~~gs of the tripped, bypassed, and reset conditions of the RPS instrument channels, divisions of logic, divisions of trip actuators, and scram logic circuitry as well as tripped and reset conditions of RPS automatic and manual trip systems through isolated gateway connections from the RPS to the N-DCIS. For conditions causing reactor trip the N-DCIS identifies the specific trip variable, the affected divisional channel identity, and the specific automatic or manual trip system. These signals also are provided to the sequence of events (SOE) function of the PCF.

Outputs to the Isolation Condenser System~~-(ICS)~~: Reactor Mode Switch status (that is, Run/~~NOT~~Not-Run indications) from the four divisions is provided by the RPS to the ICS to be used as automatic operation signal permissives or inhibits. Automatic operation signal permissives are generated whenever the Reactor Mode Switch is placed in the Run position, and automatic operation signal inhibits are generated whenever the Reactor Mode Switch is placed in any of its remaining three positions. The RPS also provides the loss of power generation bus voltage signal (Loss of ~~F~~feed ~~W~~water ~~F~~flow) for automatic initiation of the ICS.

Outputs to the Plant Automation System~~-(PAS)~~: The RPS provides the ~~Plant Automation System (~~PAS~~)~~ with separate signals to indicate the position of the Reactor Mode Switch. The RPS also provides the auto scram signal from the OLU to the PAS.

Uninterruptible AC Power Supply: The AC electric power required by the four divisions of RPS logic is delivered from four pairs of physically separate and electrically independent uninterruptible safety-related 120 VAC buses. The power circuits of the "A" and "B" solenoids of the scram pilot valves are powered from two of the four divisional ~~vital AC power supplies~~120 VAC UPS.

- Provides a continuously available LPRM/APRM display for detection of any neutron flux oscillation in the reactor core.

7.2.2.1.4 Oscillation Power Range Monitor

7.2.2.1.4.1 Safety-Related Design Bases

The general OPRM safety-related functional requirements are as follows:

- Design ~~T~~the OPRM ~~is designed~~ to safety-related standards. The general functional requirements specify that, under the worst permitted input LPRM bypass conditions, the OPRM is capable of generating a timely trip signal in response to core neutron flux oscillation conditions and thermal-hydraulic instability to prevent violation of the thermal safety limit. The independence and redundancy incorporated into the design of the OPRM is consistent with the safety-related design bases of the RPS.
- ~~The~~ Provide OPRM ~~provides~~ monitoring and protection function for core-regional and core-wide neutron flux oscillation monitoring using the LPRM signals sent to the associated APRM channel in which the OPRM channel resides. The OPRM is capable of generating a timely trip signal to scram the reactor in response to an excessive and unacceptable neutron flux oscillation to prevent fuel damage. Scram functions are ensured when the minimum LPRM input requirement to the OPRM is fulfilled. Independence and redundancy requirements are incorporated into the design and are consistent with the safety-related design basis of the RPS.

7.2.2.1.4.2 Nonsafety-Related Design Bases

The OPRM provides core neutron flux oscillation information for the ~~plant computer~~PCF and MCR display, and alarms when the OPRM is inoperative or has an insufficient number of LPRM inputs.

7.2.2.2 System Description

The safety-related functions of the NMS consist of the SRNM and PRNM ~~S~~subsystems. (The LPRM, APRM, and OPRM collectively are called the PRNM ~~S~~subsystem.) The nonsafety-related ~~Automated Fixed In-Core Probe (~~AFIP~~)~~ ~~S~~subsystem of the NMS and the ~~Multi-channel Rod Block Monitor (~~MRBM~~)~~ are discussed in Subsection 7.7.6.

7.2.2.2.1 System Identification

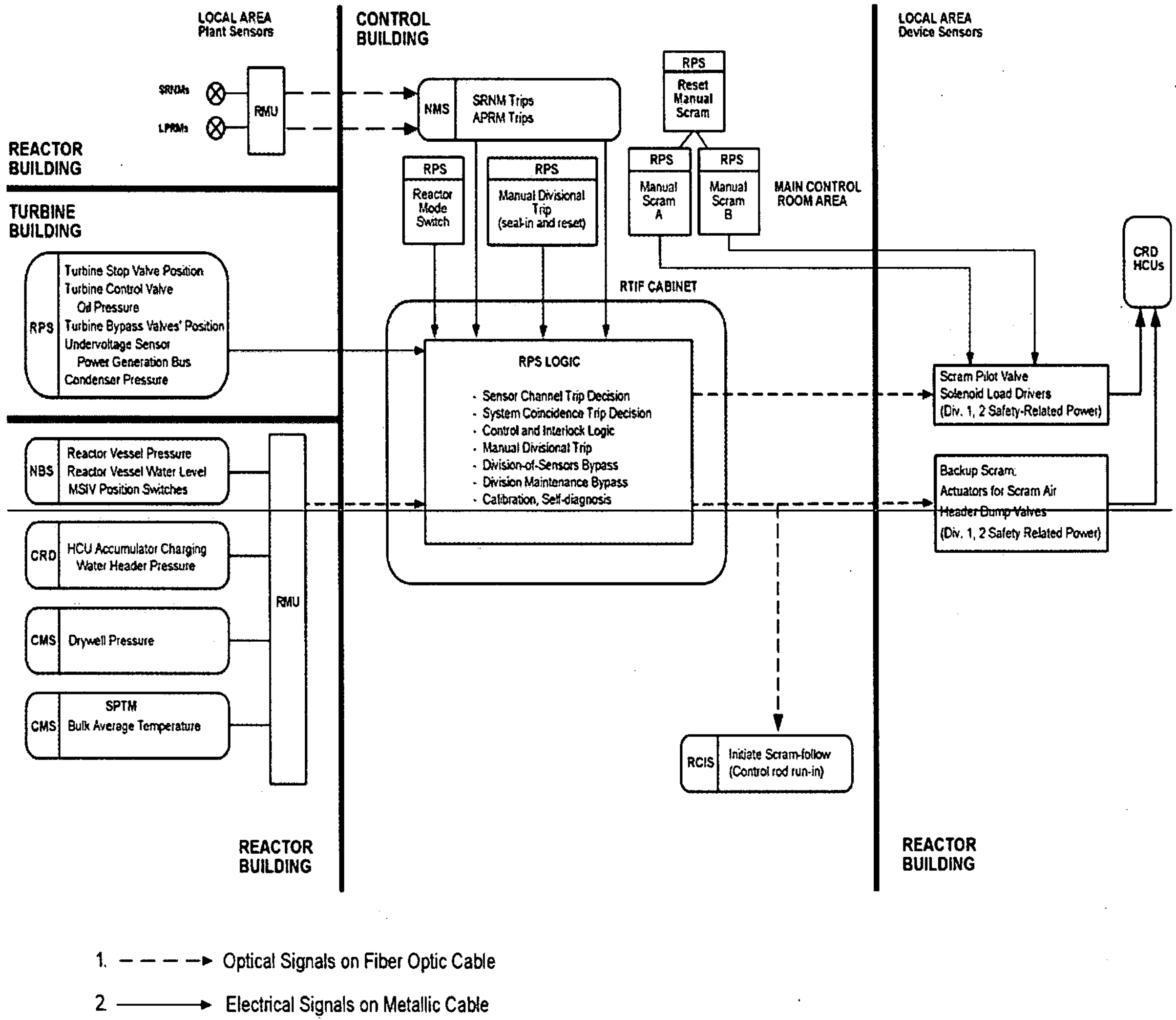
The purpose of the NMS is to monitor reactor power generation and, for the safety-related aspects of the NMS, to provide trip signals to the RPS initiating a reactor scram whenever there is an excessive neutron flux (and thermal power) level, excessive neutron flux oscillation, or excessive rate of change in neutron flux (short period). In addition, it provides power information to the ~~plant computer~~PCF and the Automated Thermal Limit Monitor (ATLM) in the RC&IS, for control of the rod withdrawal block ~~function~~and feedwater temperature control valve one-way block functions. The operating range of the various detectors is shown in

Table 7.2-1

~~Channels~~Sensors Used in Functional Performance of RPS

Channel Description	Number ~~of Channels~~ of Sensors
NMS (APRM)	4
NMS (SRNM) [1]	4
NBS reactor vessel pressure	4
Drywell pressure	4
RPV narrow range water level	4
Low charging pressure to control rod hydraulic unit accumulator	4
MSIV position switches	16
TSV closure	4
TCV fast closure	4
Loss of ~~P~~power ~~G~~generation ~~B~~bus (Loss of FW ~~F~~flow)	4
High ~~C~~condenser ~~P~~pressure	4
SPTM	4
Feedwater temperature	8

1. In modes other than Run


LOCAL AREA
Plant Sensors
CONTROL BUILDING
LOCAL AREA
Device Sensors
SRNMs
LPRMs
RMU
NMS
SRNM Trips
APRM Trips
RPS
Reset Manual Scram
REACTOR BUILDING
RPS
Reactor Mode Switch
RPS
Manual Divisional Trip (seal-in and reset)
RPS
Manual Scram A
RPS
Manual Scram B
MAIN CONTROL ROOM AREA
TURBINE BUILDING
CRD HCUs
RPS
Turbine Stop Valve Position
Turbine Control Valve
Oil Pressure
Turbine Bypass Valves' Position
Undervoltage Sensor
Power Generation Bus
Condenser Pressure
RTIF CABINET
RPS LOGIC
- Sensor Channel Trip Decision
- System Coincidence Trip Decision
- Control and Interlock Logic
- Manual Divisional Trip
- Division-of-Sensors Bypass
- Division Maintenance Bypass
- Calibration, Self-diagnosis
Scram Pilot Valve
Solenoid Load Drivers
(Div. 1, 2 Safety-Related Power)
Backup Scram
Actuators for Scram Air
Header Dump Valves
(Div. 1, 2 Safety Related Power)
NBS
Reactor Vessel Pressure
Reactor Vessel Water Level
MSIV Position Switches
CRD
HCU Accumulator Charging
Water Header Pressure
RMU
CMS
Drywell Pressure
CMS
SPTM
Bulk Average Temperature
RCIS
Initiate Scram-follow
(Control rod run-in)
REACTOR BUILDING
REACTOR BUILDING
1. Optical Signals on Fiber Optic Cable
2 Electrical Signals on Metallic Cable

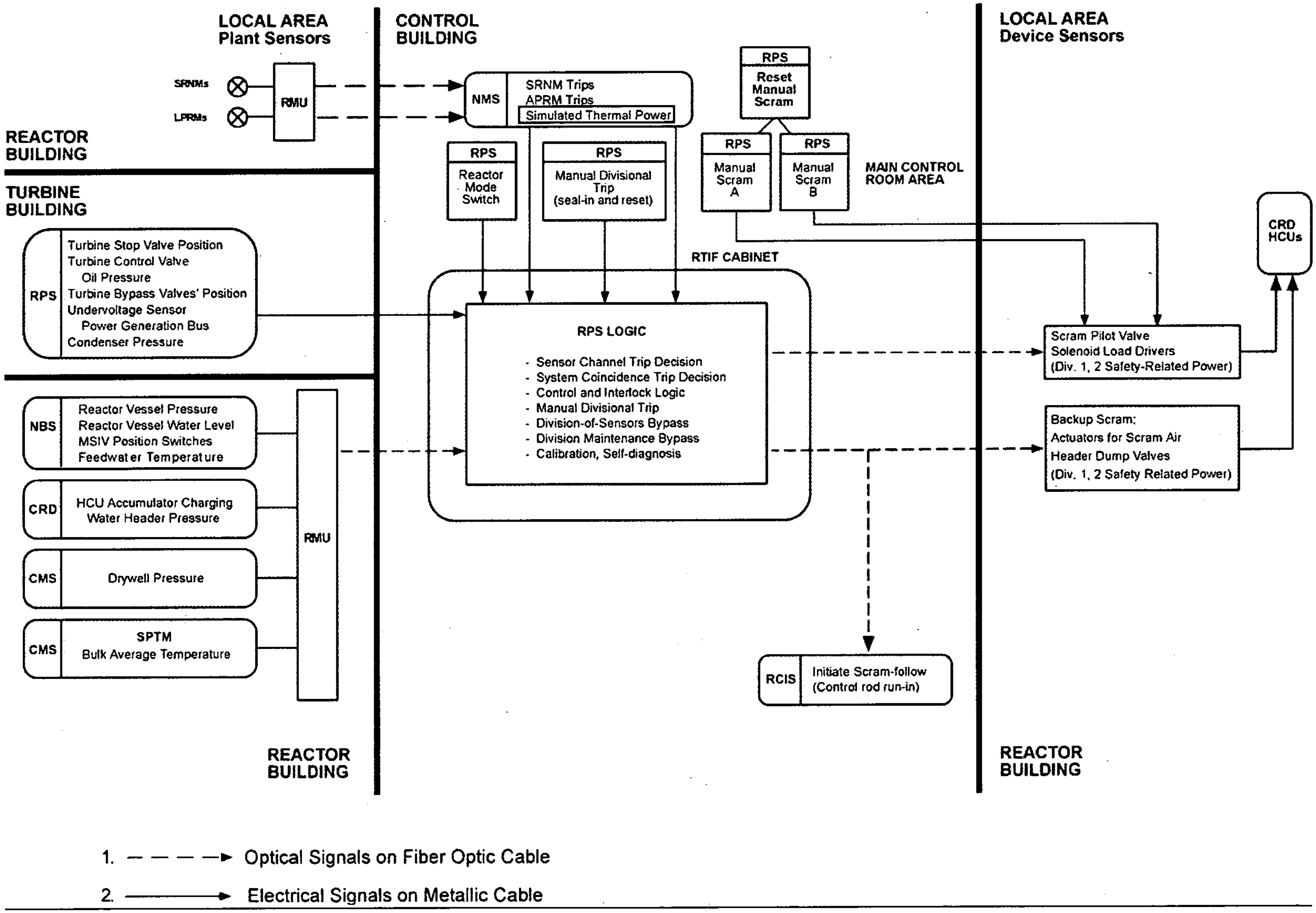


Figure 7.2-2. RPS Interfaces and Boundaries Diagram

Bypass conditions generally allow continuation of normal rod movement capability by bypassing failed equipment in one RC&IS channel. After repair or replacement of the failed equipment is completed, the operator can restore the system or subsystem to a full two-channel operability. The operator has the capability to establish single-channel bypass conditions within the following. These system ~~or~~/ subsystems are:

- RSPC channel A or B bypass,
- FCM channel A or B bypass,
- ATLM channel A or B bypass,
- RWM channel A or B bypass, or
- RAPI channel A or B bypass.

7.7.2.2.7.7 Automated Thermal Limit Monitor Algorithm Description

The ATLM is a microprocessor-based subsystem of the RC&IS that executes two different algorithms for enforcing fuel operating thermal limits when reactor power is above the low power setpoint. One algorithm enforces Operating Limit Minimum Critical Power Ratio (OLMCPR), and the other enforces the Operating Limit ~~Minimum~~ Maximum Linear Heat Generation Rate (OLMLHGR). For the OLMCPR algorithm, the core is divided into multiple regions, each region consisting of 16 fuel bundles. For the OLMLHGR algorithm, each region is further vertically divided into four segments. During a calculation cycle, ATLM Rod Block Setpoints (RBS) are calculated for OLMCPR monitoring and for OLMLHGR monitoring. The calculated setpoints are compared with the real time averaged LPRM readings for each region/segment. The ATLM issues a trip signal if any regionally averaged LPRM reading exceeds the calculated RBS. This trip signal causes a rod block within the RC&IS. The ATLM provides a FW temperature (FWT) control valve one-way block and a rod withdrawal block if reactor thermal power versus FWT is outside of the area allowed by the reactor power versus FWT map, or if the FWT decrease causes thermal limit violations. The ATLM provides a FWT control valve one-way block, rod withdrawal block, and SCRRI/SRI initiation, if the FWT decreases by more than 16.7°C (30°F) from the current value within a predefined time.

The ATLM algorithm is also based upon control rod positions and status data and other plant data from the RAPI. The ATLM operating limit setpoints may be updated based upon calculated inputs from the core monitoring function of the N-DCIS. Updates of the ATLM setpoints can occur either automatically or by operator request.

7.7.2.2.7.8 Operational Considerations

RC&IS DOI in the MCR, along with associated ~~hard~~control switches located close to the RC&IS DOI such as withdrawal and insertion pushbuttons, are the main interfaces for the operator to perform manual or semi-automatic control rod movements, activate and deactivate the RC&IS automatic rod movement mode, and activate and deactivate RC&IS bypass conditions. In addition, the operator can determine the details of the RC&IS status and related FMCRD status information at this interface. Dedicated ~~hard~~control switches are also provided on the main control panel for manual initiation of an ARI function and for manual initiation of an SCRRI/SRI system in Subsection 4.6.1. The primary output of the RC&IS to accomplish the RC&IS related rod movement functions is the 3-phase AC power to the FMCRD motors, and associated AC power to the ~~motor built-in brakes~~MBBs, and the holding brakes of the CRD system.

The RC&IS modules that interface with FMCRD instrumentation include the appropriate signal conditioning and conversion components (for example, RDC, discrete contact closure or reed switch input circuitry, and excitation power sources/supplies) for acquisition of~~ the following~~:

- Resolver A and B position feedback signals (continuous signals);
- Coupling check (overtravel-out) position reed switch (discrete signal);
- Latched full-in and full-in position reed switches (discrete signal; these two reed switches are wired in parallel);
- Buffer contact reed switch (discrete signal); and
- Scram ~~T~~timing position reed switches (discrete signals) at the following positions:
  - 0% insertion,
  - 10% insertion,
  - 40% insertion,
  - 60% insertion, and
  - 100% insertion.

The induction motor controllers provide the proper 3-phase power to the FMCRD motor, the directly associated ~~motor built-in brake~~MBB, and the holding brakes of the CRD system to accomplish the RC&IS rod movement functions.

The RC&IS does not directly interface with any other basic plant instrumentation. The other inputs to the RC&IS are by hardwired signal interfaces, data communication links with other systems, or from the RC&IS DOI.

7.7.3 Feedwater Control System

The FWCS accomplishes both RPV water level control and FWT control. RPV water level control is accomplished by manipulating the speed of the FW pumps. FWT control is accomplished by manipulating the heating steam flow to the seventh stage FW heaters or directing a portion of the FW flow around the high- pressure FW heaters. The two functions are performed by two sets of triple redundant controllers located in separate cabinets. The ESBWR HP FW Heater Temperature Control Diagram is provided in Figure 7.7-7.

7.7.3.1 System Design Bases

7.7.3.1.1 Safety-Related Design Basis

The FWCS is not a safety-related system and is not required for safe shutdown of the plant. Therefore, the FWCS has no safety-related design basis. In the ~~P~~power ~~O~~operation ~~M~~mode, only one of the triply~~e~~ redundant controllers can be removed from service.

~~The safety-related feedwater isolation function is not included in the FWCS.~~

The safety-related LD&IS performs isolation of the ~~feedwater~~FW system following a ~~feedwater~~FW line break inside containment by closing the ~~feedwater~~FW containment isolation valves. ~~and tripping the reactor feedwater pump Adjustable Speed Drive (ASD) motor circuit breaker.~~

7.7.3.1.2 Power Generation (Non-safety) Design Bases

The FWCS is designed so that the functional capabilities of safety-related systems are not inhibited (IEEE Std. 603, Subsection 5.6.3). The FWCS regulates the flow of ~~feedwater~~FW into the RPV to maintain predetermined water level limits during transients and normal plant operating modes; additionally the FWCS controls FWT to allow reactor power control without moving control rods. The desired range of water level during normal power operation is based on steam separator performance. The requirements include limiting carryover, which can affect turbine performance, and limiting carryunder, which can affect overall plant efficiency. FWT control allows independent control of temperature either above or below the temperature normally provided by the FW heaters with turbine extraction steam. An increase in FWT decreases reactor power and a decrease in FWT increases reactor power. FWT is normally set manually by the operator. The setpoint can also be adjusted by the Plant Automation System (PAS). There is a maximum allowable FWT setpoint change that cannot be exceeded. FWT cannot be decreased when the reactor thermal power exceeds 100%. The system does not accept a temperature setpoint outside of the area allowed by the reactor power versus FWT map which is described in Subsection 4.4.4.3.

If the RPV water rises to Level 8, ~~then~~ equipment protective action trips the main turbine and reduces ~~feedwater~~FW demand to zero. The DPS trips ~~T~~the ~~feedwater~~FW pumps ~~trip~~ if the water continues to rise to Level 9. Upon receipt of a FW isolation signal from the Q-DCIS the FWCS will trip the breakers for the reactor FW pumps and place the running FW booster pumps (FBP) into minimum flow recirculation for asset protection and water hammer mitigation. If the water falls to Level 3, ~~then~~ the RPS, ~~shuts down the reactor. The RPS is~~ a fully independent safety-related system (Subsection 7.2.1), shuts down the reactor. If the water level continues to drop and reaches Level 2, the high-pressure make-up function of the CRD system ~~initiates~~ is initiated (Reference Figure 7.7-1, Water Level Range Definition). The CRD system is fully independent of other plant delivery or injection systems. If the reactor thermal power versus FWT is outside of the area allowed by the reactor power versus FWT map, the RC&IS/ATLM initiates a control rod withdrawal block and a FWT control valve one-way block. If the reactor thermal power versus FWT further departs from the area allowed by the reactor thermal power versus FWT map, the RPS initiates a reactor shutdown.

7.7.3.2 System Description

7.7.3.2.1 General Description

The FWCS is a power generation (control) system that maintains proper RPV water level in the operating range from high (Level 9) to low (Level 2). During normal operation, ~~feedwater~~FW flow is delivered to the RPV through three Reactor Feed Pumps (RFPs~~) which~~), which operate in parallel. Each RFP is driven by an adjustable-speed induction motor that is controlled by an adjustable speed drive (ASD). In normal operation, the fourth RFP is in standby mode and starts automatically if any operating ~~feedwater~~FW pump trips while at power. In abnormal operation, the fourth RFP can be set in manual mode or can be removed from service for maintenance. The reactor FW pumps receive suction from the FW booster pump discharge header. The FW booster pumps draw suction from the fourth open FW heater tank and increase FW pressure to the required suction pressure of the reactor feed water pumps. There are four booster pumps with three in service during normal operation and the fourth in standby. Upon failure of any of the running booster pumps the standby pump is started by the FWCS. The FWCS places the running FW booster pumps in minimum flow recirculation mode upon receipt of a FW isolation signal. In normal operation, FWT is controlled by FW heaters one through six using turbine extraction steam. If increased FWT is demanded, modulating valves admit steam from the main steam header to the seventh FW heater. If decreased FWT is demanded, modulating valves direct a part of the FW flow around the fifth, sixth, and seventh FW heaters.

Both functions of ~~T~~the FWCS are~~is~~ implemented on the triply~~e~~ redundant, Fault-Tolerant Digital Controllers (FTDC) including power supplies and input/output signals. The controller is designed for a Mean Time to Failure (MTTF) of no less than 1000 years. ~~The~~ Each FTDC consists of three parallel processing channels, each containing the hardware and software for execution of the control algorithms. Each FTDC channel executes the control software for the control modes. Additional information is provided in Mark VIe Control System Guide, N-DCIS Design Documents, GEH-6721B, Vol. 1, Rev C, Chapter 2, System Architecture (Reference 7.7-2). At the operator's discretion, the system operation mode can be selected from the main control console. The FWCS functional diagram is provided ~~as~~ in Figure 7.7-3.

During normal operation the FWCS sends three speed-demand signals, each of which reflects a voted FWCS processor output, to each feed pump ASD. The ASD performs a mid value vote and uses it to control the speed/frequency of the feed pump motor. The mid value vote is also returned to the FWCS as an analog input and compared with the speed demands sent by the FWCS. If an FTDC channel detects a discrepancy between the field voter output and the FTDC channel output, a "lock-up" signal is sent to a "lock-up" voter which causes the feed pump ASD to maintain the current pump speed and ~~an~~ activates an alarm ~~is activated~~ in the MCR.

During FWT control, the FWCS sends a voted (median selected) position demand to either the modulating valves admitting steam to the seventh FW heater or the modulating valves directing a part of the FW flow around the fifth, sixth, and seventh FW heaters. The actual received position demand and actual valve position are returned to the FWCS as analog inputs and compared with the position demands sent by the FWCS. If an FTDC channel detects a discrepancy between the field voter output and the FTDC channel output, a lock-up signal is sent to a lock-up voter that maintains the valve position and activates an alarm in the MCR. For drawings of the FW system, FW heater, pump and valve configuration, see Section 10.4.

7.7.3.2.2 Operation Modes (Level Control)

The following modes of RPV water~~feedwater flow provide~~ level control are provided.~~:~~

- **Single Element Control** - At less than 25% of rated reactor power~~s,~~ the FWCS uses single-element control based on RPV water level. In this mode the conditioned level error from the master level (proportional + integral, or PI) controller is used to determine the demand to either the Low Flow Control Valve (LFCV) or to an individual feed pump ASD. The ASDs control feed -pump -motor -speed and thus ~~feedwater~~FW flow rate. In addition, the FWCS can regulate the RWCU/SDC system Overboard Flow Control Valve (OBCV) flow demand to counter the effects of density changes and purge flows into the reactor during heatup when the steam flow rate is low.
- **Three-Element Control** - During normal power range operation, the three-element control mode uses water level, total ~~feedwater~~FW flow rate, total steam flow rate, and individual feed pump suction flow rate and pressure signals to determine the feed pump speed demand. The total ~~feedwater~~FW flow rate is subtracted from the total steam flow rate signal to yield the ~~vessel~~ RPV flow rate mismatch. The flow rate mismatch signal is summed with the conditioned level error signal from the master level PI controller to provide the input signal for the master flow rate (PI) controller. The master flow controller provides the demand signal to the individual RFP loop trim controllers that use the discharge flow rate signals to balance RFP flow rates. The trim controllers provide the speed demand signal to the ASDs that control feed pump motor speed and thus ~~feedwater~~FW flow rate.
- **Manual Feed Pump Control** - Each RFP can be controlled manually from the main control console through the FTDC by selecting the manual mode for that ~~feed~~ pump. In manual mode, the RFP speed demand signal that is sent directly to the ASD of the selected feed pump ~~may~~ has the capability of being increased or decreased. Each feed pump is controlled manually at the manual/automatic transfer station. Each FBP can be started or stopped manually from the main control console through the FTDC by selecting the manual mode for the desired FBP.

The FWCS also provides interlocks and control functions to other systems. If the reactor water reaches Level 8, ~~then~~ the FWCS simultaneously activates a control room alarm and sends a zero-speed demand signal to the feed pump ASDs and the three operating FBPs are placed into recirc mode. At reactor water setpoint Level 8 the main turbine is tripped by the FWCS and at Level 9, a trip signal is sent to the ~~feedwater~~FW pump ASD control breakers by the DPS.

The worst case of a FW Pump ASD controller failure in the FW system would cause a run-out of one FW pump to its maximum capacity. In the event of a one pump run-out (detected by FW flow high), the FWCS would respond by reducing the demand to the other pumps, automatically compensating for the excessive flow from the failed pump.~~Additional feedwater temperature controls, monitoring, and alarms are provided to assist in power maneuvering using the number~~

~~seven high-pressure feedwater heater and bypass around the high-pressure feedwater heaters. Refer to Section 10.4.~~

~~A loss of feedwater heating that results in a significant decrease in feedwater temperature generates a signal that FWCS sends to N-DCIS to initiate SCRRI and SRI functions. This interlock limits the consequences of a reactor power increase due to cold feedwater. The temperature difference between feedwater lines A and B is monitored and alarmed if excessive.~~

In addition, the FWCS initiates the signal to open the steam line condensate drain valves when steam flow rate falls below 40% of rated flow rate~~. —~~, ~~Finally,~~and the FWCS sends a zero-flow demand signal to the feed pump ASDs on identification of an ATWS condition.

7.7.3.2.3 Operation Modes (Temperature Control)

The modes of FWT control are as follows.

- Manual – the FWT setpoint is controlled by the operator.
- Automatic – the FWT setpoint is controlled by the PAS.

Both modes of FWT control use eight FWT measurements, four per FW line. These redundantly measured temperatures are compared to the temperature setpoint and the error signal is used by a proportional, integral, derivative (PID) controller. The PID controller output range is between –100% to +100% depending on whether heating or cooling of the FW is required. The output signals are used to generate the position demands for both the FW heater bypass valves and the seventh FW heater steam heating valves.

Both the manual and automatic modes of FWT control include the following features.

- Neither the operator nor the automation system can input a setpoint outside the area allowed by the ESBWR reactor power versus FWT operating map (Power-FWT Map) which is adjustable per fuel cycle and described in DCD subsection 4.4.4.3 .
- Neither the operator nor the automation system can change the setpoint faster than an allowable rate (nominally 55.6°C (100°F) per hour).
- No FWT control mode can be entered unless the controller has passed all its self-diagnostic tests and unless the operator has actively selected the control mode.
- The FWT controller is unable to decrease FWT if the reactor thermal power is greater than 100%. The validated reactor thermal power signal is provided by the NMS.
- Individual temperature control valves are "locked up" if they are not at their demanded position within a prespecified time or one-way "locked up" if there is an ATLM one-way block (to prevent FWT from additional decrease (increase), the steam heating valves are blocked from further closing (opening), the bypass valves are blocked from further opening (closing)).
- The heating valves to the seventh FW heater and the high pressure FW heater bypass valves are not open simultaneously.

7.7.3.3 Safety Evaluation

The FWCS is ~~not safety-related and is not required for safe shutdown of the plant. It is~~ a power generation system that maintains proper RPV water level and FWT. Its ~~operation~~ level control range is from high water level (Level 9) to low water level (Level 2) and its nominal FWT control range at 100% rated power is from 188°C (370°F) to 215.6°C (420°F). FWT has the capability of being increased up to 252.2°C (486°F) which reduces the rated reactor power by approximately 15%. If the ~~vessel~~ RPV water level rises too high (Level 8), then the main turbine trips and the feed pump ASD flow demand is reduced to zero. Continued rising water level to Level 9 results in a trip of all ASD feed pumps by the DPS and running FBPs placed into recirc mode. The ~~vessel~~ RPV water level rising to Level 8 or falling to Level 3 results in the shutdown of the reactor by the RPS. If the reactor thermal power versus FWT is outside of the area allowed by the reactor power versus FWT map, the RC&IS initiates a control rod withdrawal block and FWT control valve one-way block. If reactor thermal power versus FWT further departs from the area allowed by the reactor power versus FWT map, the RPS initiates reactor shutdown. The RPS uses eight safety-related measurements of FWT (two per division) and implements a reactor scram using two-out-of-four logic based on a validated reactor thermal power. Refer to Subsection 7.2.1 for the RPS description.

The FWCS initiates a runback of ~~feedwater~~FW pump ~~feedwater~~FW demand to zero, places the running FBPs into recirc mode, and closes the LFCV and RWCU/SDC ~~overboard flow control valve~~OBCV when it receives an ATWS trip signal from the ATWS/SLC Logic. Refer to Subsection 7.8.1.1.

A combined FWT change and FW flow/reactor water level change caused by controller failure is precluded by implementing the two control schemes in physically different cabinets and processors.

A loss of FW heating that results in a significant decrease in FWT is independently detected by the ATLMs and by the DPS, either of which will mitigate the event by initiating SCRRI and SRI functions. These interlocks mitigate the effects of a reactor power increase due to reduced FWT. Although no credit is taken for the function in safety analysis, the FWT control system also mitigates inadvertent FWT changes in either direction by manipulating its control valves to maintain the setpoint temperature. The temperature difference between FW lines A and B is monitored and alarmed if it exceeds the allowable value.

A total failure of the triple redundant FWT control system such that the outputs all fail downscale (or upscale), and the heating steam valves close (or open), or the bypass valves close (or open) is highly unlikely. No single failure or operator error of the FWT control system results in more than a 55.6°C (100°F) decrease in the final FWT. The design meets the requirements for the condensate and FW system specification in Subsection 10.4.7.1.

Table 7.1-1 identifies the FWCS and the associated codes and standards applied, in accordance with the SRP. This subsection addresses conformance ~~with~~ to regulatory requirements, guidelines, and industry standards.

to give the total ~~feedwater~~FW flow rate into the ~~vessel~~RPV. The total ~~feedwater~~FW flow rate is indicated on the main control console in the MCR.

Feed pump flow rate is sensed at a single flow element, which is part of the C&FS, downstream of each feed pump. The discharge line flow element differential pressure is sensed by a single transmitter, which is part of the FWCS, and sent to the FTDC through the N-DCIS multiplexing function. The FWCS multiplexing function signal conditioning algorithms take the square root of the differential pressure and provide the discharge flow rate measurements to the FTDC. The feed pump discharge flow rate is compared with the demand flow rate for that pump and the resulting error is used to adjust the speed demand to the ASD to reduce that error and balance RFP flow rate between operating pumps.

7.7.4 Plant Automation System

7.7.4.1 System Design Bases

7.7.4.1.1 Safety Design Basis

The PAS has no safety-related design basis, but is designed so that the functional capabilities of safety-related systems are not hindered. Abnormal events requiring control rod scrams are sensed and controlled by the safety-related RPS, which is fully independent of the PAS. Discussions of the RPS are provided in Subsection 7.2.1.

This system provides the capability for supervisory control of the entire plant. It does this by supplying set-point commands to independent nonsafety-related automatic control systems as changing load demands and plant conditions dictate.

7.7.4.1.2 Power Generation (Non-Safety) Design Bases

The power generation basis of this system is to provide supervisory control that regulates reactivity during criticality control, provides heatup and pressurization control, regulates reactor power, controls turbine/generator output, controls secondary nonsafety-related systems, and provides reactor startup / shutdown controls.

7.7.4.2 System Description

The primary purposes of the PAS are reactivity control, heatup and pressurization control, reactor power control, generator power control (MWe control), and plant shutdown control. The PAS consists of triple redundant process controllers. The functions of the PAS are accomplished by suitable algorithms for different phases of reactor operation which include approach to criticality, heatup, reactor power increase, automatic load following, reactor power decrease, and shutdown. The N-DCIS accepts one-way communication from the Q-DCIS so that the safety-related information can be monitored, archived, and alarmed seamlessly with the N-DCIS data (IEEE Std. 603, Subection 5.6.3).

Through the N-DCIS, the PAS receives input from the following major safety-related systems: NMS (Section 7.2.2) and the RPS (Subsection 7.2.1~~2~~). Through the N-DCIS, the PAS receives input from the following major non-safety systems: the RC&IS (Subsection 7.7.2), SB&PC (Subsection 7.7.5), FWCS (Subsection 7.7.3), RWCU/SDC (Subsection 7.4.3), and the Turbine

Generator Control System (TGCS)(Subsection 10.2.2). The output demand request signals from the PAS are sent to the RC&IS to position the control rods, to the SB&CS for pressure setpoints, and to the TGCS for load following operation. A simplified functional block diagram of the PAS is provided in Figure 7.7-4.

The PAS interfaces with the operator's control console to perform its designed functions. From the operator's control console for automatic plant startup, power operation, and shutdown functions, the operator uses the PAS to issue supervisory control commands to nonsafety-related systems. The operator also uses the PAS to adjust set-points of lower level controllers to support automation of the normal plant startup, shutdown, and power range operations. In the automatic mode, the PAS also issues command signals to the turbine master controller, which contains appropriate algorithms for automated sequences of turbine and related auxiliary systems. The PAS presents the operator with a series of break point controls on the main control console nonsafety-related VDUs for a prescribed plant operation sequence.

When all the prerequisites are satisfied for a prescribed breakpoint in a control sequence, a permissive is requested and upon operator acceptance, the prescribed control sequence is initiated or continued. The PAS then initiates demand signals to various system controllers to carry out the predefined control functions. For non-automated operations that are required during normal startup or shutdown (such as a change of Reactor Mode Switch status), automatic prompts are provided. Automated operations continue after the prompted actions are completed manually. The functions associated with reactor power control are performed by the PAS.

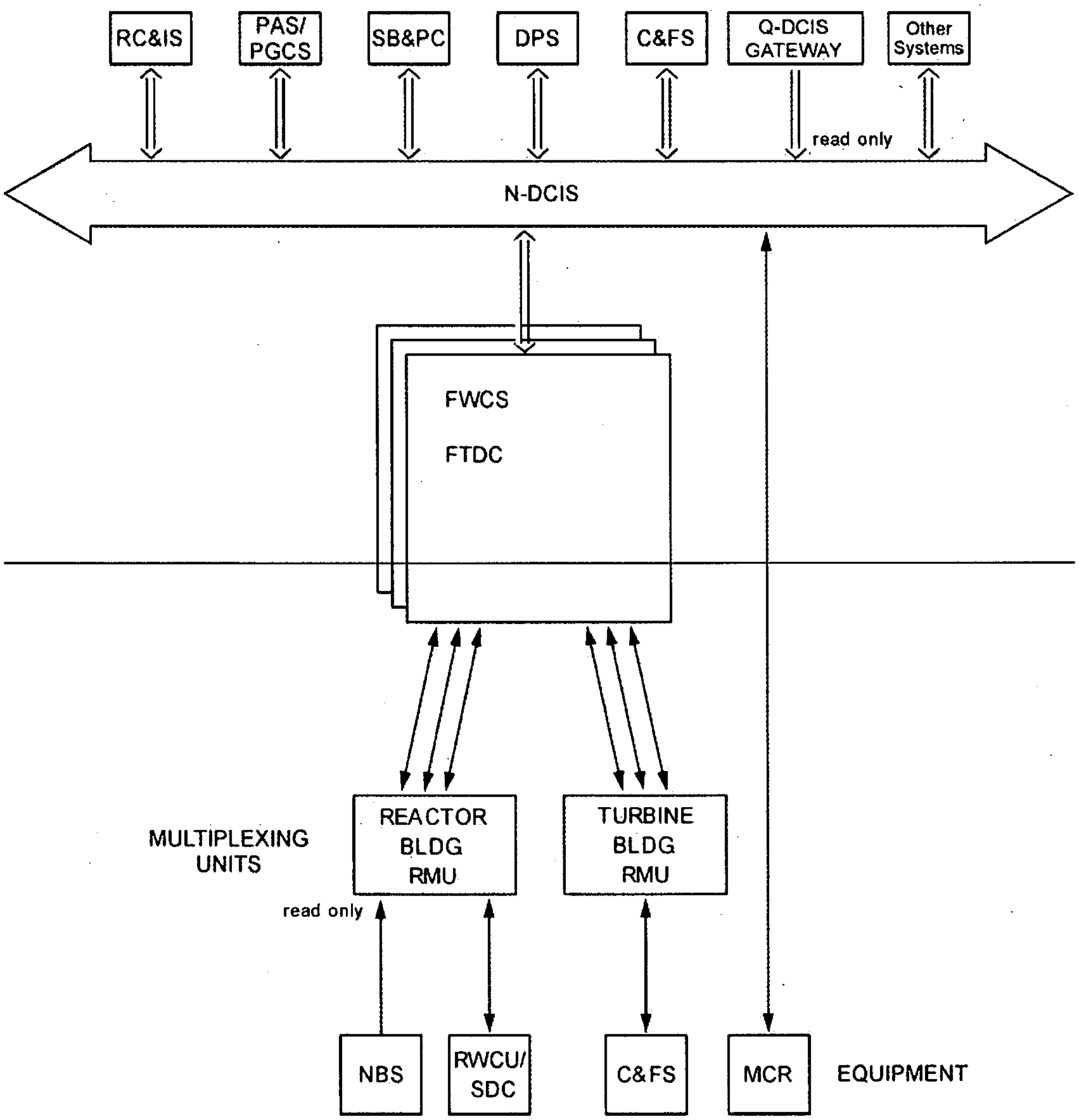
For reactor power control by control rod motion, the PAS contains algorithms that can change reactor power by control rod motions. A prescribed control rod sequence is followed when manipulating control rods for reactor criticality, heatup, power changes, and automatic load following. For reactor power control by FWT change, the PAS can provide the FWT control setpoint to allow reactor power maneuvering without moving control rods. Each of these functions has its own algorithm to achieve its designed objective. In combination, the two reactor power control methods are utilized to form a sequential step-by-step power maneuvering strategy for the control rod pattern/movement and FWT change. During automatic load following operation, the PAS interfaces with the TGCS to coordinate main turbine and reactor power changes for stable operation and performance.

The normal mode of operation of the PAS is automatic. If any system or component conditions are abnormal during execution of the prescribed sequences, the PAS automatically switches into the manual mode. With the PAS in the manual mode, any in-progress operation stops and alarms are activated in the MCR. Also with the PAS in manual mode, the operator can manipulate control rods through the normal controls. A failure of the PAS does not prevent manual control of reactor power, and does not prevent safe shutdown of the reactor.

The triple redundant FTDC and redundant system controllers perform the PAS control functional logic.

7.7.4.3 Safety Evaluation

The PAS does not perform or ensure any safety-related function. This system is designed so that functionalities of safety-related systems in the plant are not affected by it.


RC&IS
PAS/ PGCS
SB&PC
DPS
C&FS
Q-DCIS GATEWAY
Other Systems
read only
N-DCIS
FWCS
FTDC
MULTIPLEXING UNITS
REACTOR BLDG RMU
TURBINE BLDG RMU
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EQUIPMENT

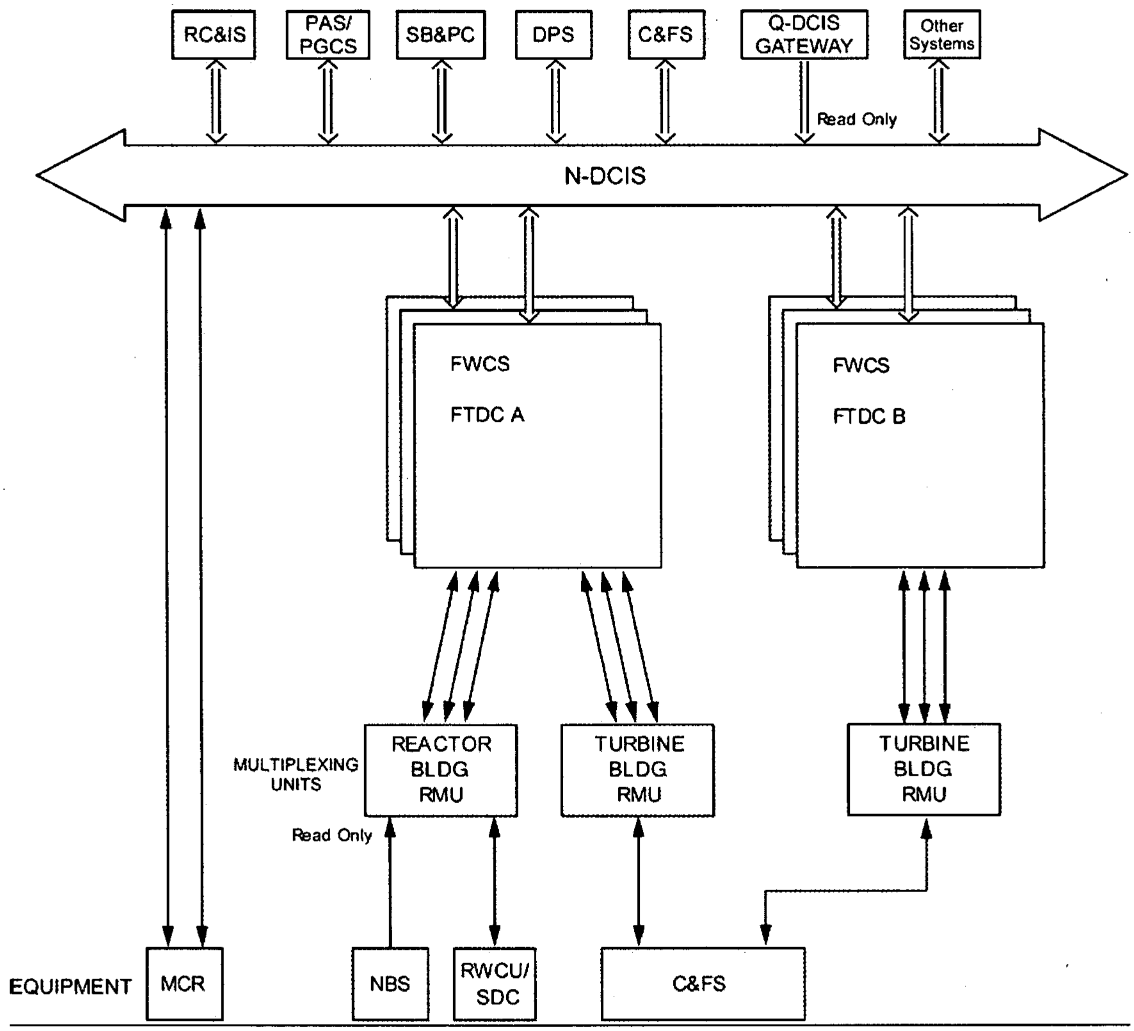

Figure 7.7-3. Feedwater Control System Functional Diagram

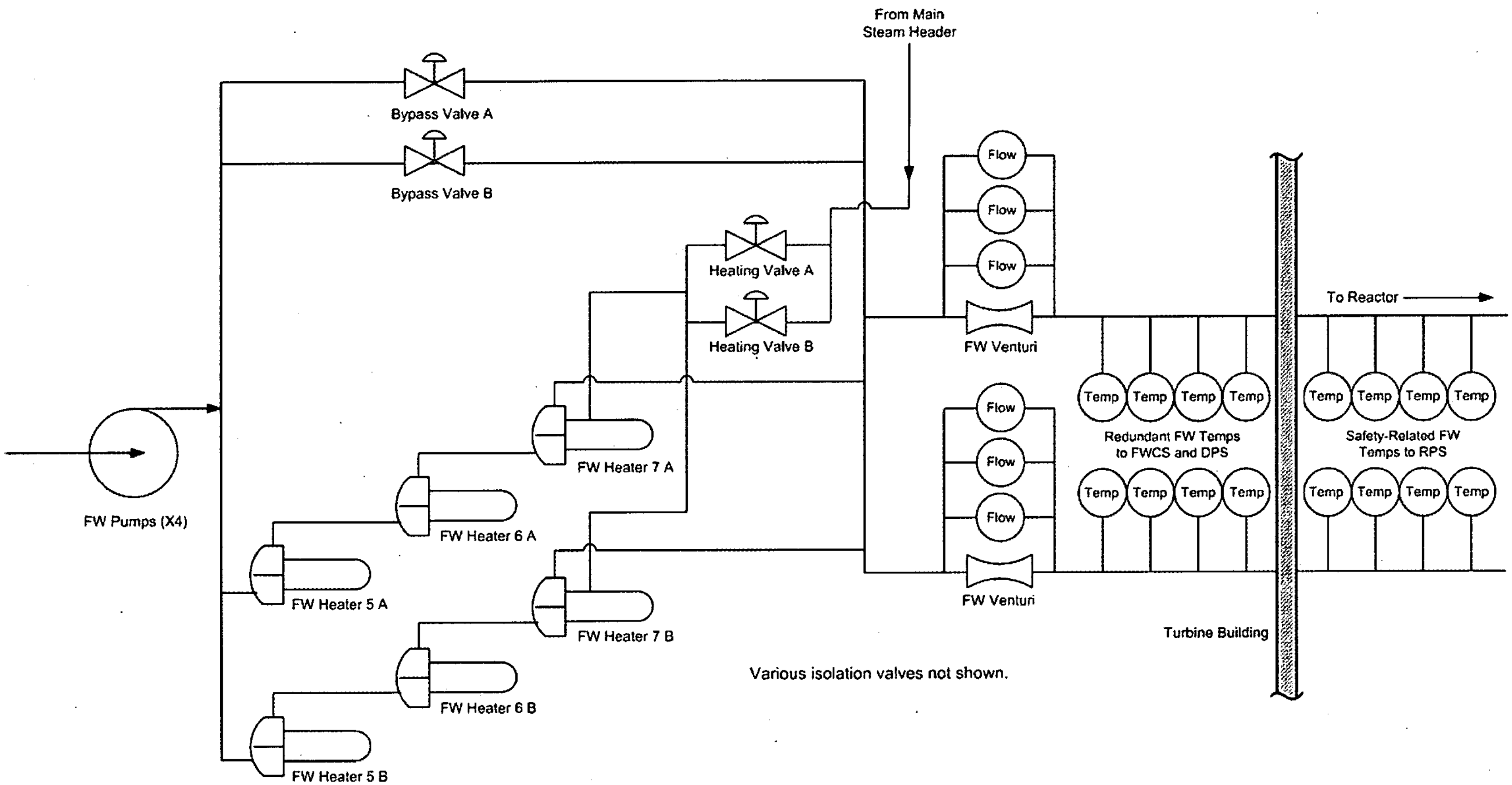

Figure 7.7-7. HP Feedwater Heater Temperature Control Diagram

7.8.1.1.1.2 ATWS Mitigation Logic to Inhibit the ADS

~~For ATWS mitigation, the ADS, which is part of the Nuclear Boiler System (NBS), is inhibited automatically.~~ Automatic initiation of the Automatic Depressurization System (ADS) by SSLC/ESF is inhibited by the ATWS/SLC system logic using the following signals.~~:~~

- A coincident low RPV water level (Level 2) signal and Average Power Range Monitor (APRM) ATWS permissive signal (i.e., an APRM signal that is above a specified setpoint from the NMS).
- A coincident high RPV pressure and APRM ATWS permissive signal that persists for 60 seconds.

MCR ~~switches~~ controls manually inhibit the ADS under ATWS conditions. The same inhibit conditions apply~~ies~~ to the GDCS function.

7.8.1.1.2 DPS ARI ATWS Mitigation Logic

The ARI function of the ATWS mitigation logic is implemented as nonsafety-related logic that is processed by the DPS. The DPS generates the signal to open the ARI air header dump valves in the CRD system based on any of the following command signals:

- High RPV dome pressure signal, a low RPV water level signal (Level 2), or a manual ATWS mitigation (ARI/SLC/FWRB initiation) signal;
- D~~R~~PS scram command;
- SCRRI/SRI command and power levels remaining elevated;
- Manual DPS scram signal;
- On receipt of signals initiating ARI, described above, the DPS generates an additional signal to the Rod Control and Information System (RC&IS) to initiate electrical insertion (that is, FMCRD Run-~~I~~in) of all operable control; and
- A safety-related manual ATWS mitigation signal initiates the SLC system, ARI and FWCS runback of feedwater flow. It is sent to the nonsafety-related portions of the ATWS mitigation logic through qualified isolation devices.

The ARI and FMCRD Run-~~I~~in logic resides in the DPS, which is totally separate and independent from the Q-DCIS with diverse hardware and software. The RPV pressure and level input sensors for the ARI logic are independent and separate from the sensors used in the Q-DCIS.

7.8.1.1.3 DPS ~~Scram and~~ SCRRI/SRI ~~ATWS Mitigation~~ Logic

The DPS processes a SCRRI/SRI signal to hydraulically scram selected control rods and to command RC&IS to perform the SCRRI function based on any of the following initiators:

- Generator load rejection signal from the Turbine Generator Control System (TGCS) (two-out-of-three logic),
- Turbine trip signal from TGCS (two-out-of-three logic),
- Loss of feedwater heating based on C&FS and NMS signals (two-out-of-four logic),
- SCRRI/SRI signal from ATLM (two-out-of-three logic),
- SCRRI signal from RC&IS (two-out-of-three logic), and
- OPRM thermal neutron flux oscillation signal from NMS (two-out-of-four logic).

It is also possible to initiate SRI and SCRRI manually from the MCR.

7.8.1.1.4 DPS Scram ATWS Mitigation Logic

On either SCRRI/SRI command with power remaining elevated (two-out-of-three logic) or RPS scram command (two-out-of-four logic) the DPS ~~will perform the following~~:

- Initiates a diverse scram (and ARI as indicated previously); and
- Initiates a delayed FWRB if the elevated power levels persist.

~~For conditions that require SCRRI (processed as two-out-of-three logic) and power levels that remain elevated, the DPS processes an SRI signal to hydraulically scram selected control rods. The DPS will also process an SRI signal if an OPRM trip signal is received from the NMS. It is also possible to initiate SRI and SCRRI manually from the MCR.~~

7.8.1.2 Diverse Instrumentation and Control

In addition to the ATWS mitigation functions described previously, other DICS functions are included in the DPS.

The DPS has a set of diverse reactor protection and diverse ESF logics that are implemented using hardware and software separate and independent from that of the RPS and SSLC/ESF.

The DPS transmits the ~~feedwater runback~~FWRB signal from the ATWS mitigation logic to the FWCS. The DPS trips the feedwater pumps on high RPV water level (Level 9) after they have been run back to zero flow on high RPV water level (Level 8).

Additionally, the DPS provides diverse monitoring and indication of critical safety functions and process parameters required to support manual operations and assessment of plant status.

7.8.1.2.1 Diverse Reactor Trip Functions

The DPS reactor trip functions provide a diverse means of reactor shutdown and serve as backups to the RPS. A subset of the RPS scram signals is selected for inclusion in the DPS scope, which provides acceptable diverse protection results. This set of diverse protection logics for reactor scram, combined with the ATWS mitigation features, other diverse backup scram