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SPECIFICATION FOR
NUCLEAR POWER PLANT
TRAINING SIMULATOR

Babcock & Wilcox

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SPECIFICATION FOR NUCLEAR POWER PLANT TRAINING SIMULATOR

BABCOCK & WILCOX
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NUCLEAR POWER PLANT SIMULATOR

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1. GENERAL

1.1 Scope

This specification describes a Nuclear Power Plant Simulator. The control room equipment, including the plant control console and the instructor's console, shall be duplicated in appearance and function so as to train operators as if they were operating an actual control room. The system is flexible, permitting expansion or modification of the hardware and software to reflect advances in design, technology, and the size of future plants, or to allow for universal or condensed training programs applicable to several different plants. The simulator shall be designed for 24-hour operation for extended periods with minimum maintenance down-time.

1.2. Purpose

The simulator will be used to train personnel in the technology needed for operation of nuclear power generating plants, comprising:

a. All modes of operation including startup, maneuvering, normal and emergency conditions and shutdowns.

b. Qualification for the Atomic Energy Commission Reactor Operator licensing examination.

1.3. Applicable Documents

1.3.1. Sacramento Municipal Utility District, Rancho Seco Nuclear Station, Unit 1 Preliminary Safety Analysis Report Volume 1, 2, 3, 4, and 5

1.3.2. JIC Electrical Standards for Industrial Equipment

1.3.3. Standards of NEMA, ISA, and USASI.

2. CONTRACT PERFORMANCE

2.1. The Vendor shall supply and install the complete system. The Vendor accepts full responsibility for all design, development, and system integration to comply with this specification.

2.2. The Vendor shall supply the hardware and software listed below, except as otherwise noted.

a. Consoles with their respective instrumentation, except (1) console and instrumentation which duplicate that of the actual nuclear plant control room, and (2) the integrated control system as specified in 5.16.

b. Computing equipment.

c. Input/Output system to mate computer with panels and consoles.

d. Instruction console.

e. All hardware required to complete the integrity of the system including local signal-generators and conditioners for integration of instrumentation not controlled directly by the computer and all necessary cable and connectors.

f. An integrated package of real-time programs (software) for the simulation of the logic, dynamic and spatial characteristics required for the nuclear power plant involved.

g. All design and development details and modeling techniques to be used in the system. In addition, documentation relating to fabrication, system assembly, inspection, installation and checkout shall be supplied, as defined by the purchase order terms and conditions.

h. Performance and acceptance test procedures which demonstrate compliance with this specification to the satisfaction of the customer.

3. HARDWARE FUNCTIONAL REQUIREMENTS

3.1. Computer System

3.1.1. General Requirements

The simulator system shall utilize general purpose computational equipment, unless special purpose equipment has a demonstrated advantage.

The power plant simulator shall consist of a plant control console, (B&W will provide), an instructor's console, a computer system including computer peripherals, the integrated control system (B&W will provide), and the necessary data and control interfaces to couple these components together. A block diagram of the power plant simulator is shown in Appendix C.

The computer(s) shall be new machines (not previously used) and all solid state preferably consisting of integrated circuits where practical. Digital computers should be of the binary, parallel, single address-type with indexing and indirect and direct addressing.

3.1.2. Accuracy

The Vendor shall include in his proposal specifications for the accuracy of: (1) individual component accuracies (e.g., operational amplifier analog-to-digital converter), and (2) computer(s); overall computer accuracy.

3.1.3. Reliability

The computer hardware shall be designed and constructed to provide reliable operation for long periods of time. The system shall be capable of providing greater than 95% up time (continuous service). Modular construction methods should facilitate short downtime requirements for component failure troubleshooting and repair. In this manner the circuit board containing the failed component may be diagnosed (preferably by computer program), a new one put in service, and the repair made in the maintenance facility after the system is fully operable. The Vendor shall include in his proposal techniques to be used to provide a reliable system.

3.1.4. Computer Peripherals

Peripheral (input/output) devices shall be provided which allow the user to rapidly and efficiently communicate with the computer(s). These devices shall be representative of present day computer technology. Examples for the digital system would include, but not be limited to, magnetic tape transports, card readers, high speed paper tape handlers, magnetic drums and/or discs, line printers and heavy duty typewriter. The Vendor shall include in his proposal complete specifications on the peripheral devices to be used.

3.1.5. I/O Control System

The input/output control system shall permit fast and efficient data transfer into and out of the computer. In a digital computer this would include multi-channel transfer through the accumulator, and one or more channels of direct memory access for the high speed transfer of blocks of data.

The digital computer shall contain a facility which, under program control, sends signals to peripheral devices to initiate a transfer of data (set lines), and a facility which monitors the status of external devices (sense lines). It would also be desirable for the digital computer to contain a hardware priority interrupt facility for the purpose of interrupting program execution to service a high priority device or mode signal from one of the operator consoles.

3.1.6. Data Conversion

Data conversion equipment will be required between computer(s) and the plant control console, instructor's console, and integrated control system. The data conversion equipment will include a high speed multiplexer, an analog-to-digital converter, and digital-to-analog converter. The quantity of these components will be determined by the modeling requirements of the simulation and the number of inputs and outputs to the control consoles and integrated control system. The effective speed of the data conversion equipment must be in keeping with computer and problem solution speed so as to not be a limiting factor in the system. Requirements for double buffering of the D/A converters, and sample-and-hold amplifiers on the multiplexer input may be considered to permit simultaneous update to eliminate skew. The work length of the conversion equipment should provide a resolution that is in keeping with the resolution of the computer.

3.1.7. Interfaces

Data and control interfaces shall be provided as shown in the block diagram of the plant simulator (Appendix C). These interfaces which are an integral part of the simulator shall provide signal conditioning, signal buffering and amplification. Examples would be voltage/current conversion impedance matching, and signal isolation. Meters, recorders and manual controls on the plant control console, integrated control system, and instructors console will utilize the interfaces to communicate with the computer simulator.

3.1.8. Expandability and Extra Capacity

The memory cycle time of the digital computer shall be sufficiently fast to permit the real-time solution of the system once through the loop, plus having 25% spare time, i.e., only 80% of the real time cycle shall be used for the initial design.

The memory of the digital computer shall be oversized and/or expandable by 50% of the storage required for solution of the original power plant system.

The input/output data and control channels of the digital computer shall be expandable by 25%.

3.2. Consoles

3.2.1. Instructor Console

This component shall:

A. Centralize all energizing operations for plant control consoles and other equipment, together with operating mode and malfunction control.

B. Contain all malfunction selection switches specified in section 5.20.

C. Contain all mode selection switches specified in section 4.2. All switches shall be back-lighted pushbuttons and operate with the computer in a duplex mode. In this manner the computer turns on the light when the command has been acknowledged.

3.2.2. Computer Console

The computer consoles shall contain all the necessary controls to efficiently operate the computer. All controls shall be clearly and permanently labeled to identify their function.

3.2.3. Plant Control Console and Integrated Control System

The plant control console shall contain the same controls as that used in the power plant. Both the plant control console and integrated control system will be furnished by B&W. Complete data on the input/output of these systems will be furnished to the Vendor.

4. COMPUTER OPERATION REQUIREMENTS

4.1. General

This nuclear plant simulator is to operate on a real-time basis whether the computer(s) are of analog, digital or hybrid design. Programming methods must indicate clearly that all worst case simulations are completed without response time compromise. Also, in accordance with the general philosophy that the simulator be capable of 25% expansion, the computation cycle time of digital machines must be capable of handling 25% more calculations than the largest computation string envisioned from the specified equations. Therefore, bid responses should clearly indicate the general approach to programming and how real-time operation is to be achieved. Included should be a discussion of basic instruction set, machine language assembler, program debugging sub routines, editors, loaders and compilers, diagnostic routines, and startup initialization for any proposed digital or hybrid machines. For analog or hybrid machines, information should include ways to best utilize equipment capability, methods for minimizing over and undershoot, time responses, etc. Discussion should include proposed documentation (refer to section 10) of programs, source tapes, instruction manuals, complete program flow charts and listings, etc.

4.2. Overall Performance

The ranges of operating performance required from the nuclear plant simulator include, but are not limited to: subcritical operation, operation at nuclear criticality, zero power to full power ascension, steady-state operation at any level, controlled shutdowns, emergency shutdowns and special perturbations. Selection by the instructor from the instructor's console of an initial condition shall command the computer to generate and distribute appropriate plant parameters for a particular mode of operation. Resetting from one condition to another -

will be accomplished by the computer which will inform the instructor if switch positions and/or meters, dials, etc., on the plant control console do not correspond to the new condition. When initialization to the new mode has been accomplished, the computer will so inform the instructor. Modes of operation for which the simulator may be initialized shall include those in the table below.

I.C. No.	Control rod or criticality status	Approx system temp, F	Power status	Source status	Xenon status	Burnup status
1	All in core	70	Zero	Original	Zero	Zero
2	All in core	300	Zero	Original	Zero	Zero
3	All in core	580	Zero	Original	50%	Zero
4	All in core	580	Zero	Original	100%	Zero
5	$1 subcritical	500	Zero	Original	Zero	Zero
6	$1 subcritical	580	Zero	Original	100% +	Zero
7	--	580	1%	--	Zero	Zero
8	--	580	100%	--	100%	Zero
9	All in core	300	Zero	Original	Zero	30%
10	$1 subcritical	300	Zero	Original	Zero	30%
11	$1 subcritical	580	Zero	Photon	100%	30%
12	--	580	1%	--	100% +	30%
13	--	580	100%	--	100%	30%
14	$1 subcritical	500	Zero	Photon	Zero	80%
15	--	580	1%	--	Zero	80%
16	--	580	100%	--	100%	80%

Note 1: In the "xenon status" column all values refer to equilibrium conditions except for I.C. Nos. 6 and 12 which show "100+". In these two cases the Xenon is to be initialized in the transient condition at a few hours after shutdown from the equilibrium condition.

Note 2: For all initial conditions the decay heat shall be set at equilibrium for the power indicated.

The simulator shall provide simulation of prestartup preparation ranging from complete verification, test and inspection of all critical equipment to assure all systems are in proper condition for startup (cold or hot), to a simple check of a single system and its critical equipment following a reactor trip, owing to a known and readily-corrected malfunction.

The simulator shall generate all plant parameters corresponding to hot or cold startup to full power and load, including heating, synchronizing, loading of the turbine generator, transient responses to changes in pressure and flow, moderator temperature, rod position, fission product inventory, coolant density, etc. The system shall display, on appropriate instrumentation, parameters relating to a specific mode of operation and include over limit protection for out-of-tolerance operation.

The simulator shall provide realistic simulation of full power operation, loading, maneuvering, response to control rod adjustment, coolant flow, pressure regulation, and chemical shim adjustment.

Simulation of actual plant system or equipment failure shall be accomplished by digital program or analog circuits, selectable at the discretion of the instructor. Once a malfunction is initialized, the simulator shall reproduce the same logical sequence of events through which an actual plant/plants would progress under the same failure or malfunction conditions, including initiation and subsequent effects of corresponding protective system response.

The simulated malfunction shall be removable only by proper trainee action or by system initialization by the instructor. Unless action is taken, the simulator shall proceed through the sequence of events to produce the same result as would be experienced in the actual plant/plants.

The simulator shall be capable of simulating all function and operation of a completely controlled shutdown. For any out-of-tolerance operation, the simulated protection systems shall exhibit the same response as an actual plant (e.g. fast rod insertion, reactor trip). A manual reactor trip which allows the operator to override the automatic protective systems shall be provided.

4.3. Diagnostics and Calibrations

Programs and instructions shall be provided for diagnosing system malfunctions. Such programs should be directed at both preventive maintenance and breakdown maintenance servicing of the computer(s), interfaces, peripherals and consoles. Diagnostic and calibration programs should be identified as to whether they are on-line or down-time oriented, and as to the stage of development, i.e., whether operational and proven, being debugged, or conceptual.

Debugging aids should be identified.

4.4. Method of Programming

Programming method is most important to the overall mission of this simulator. All simulation and control must be real-time. Depending on the computer configuration proposed, programming techniques and languages shall be consistent with the real-time concept and allow for 25% increased computations without major programming rewrite.

Bid responses should discuss how the following functions are to be performed: (1) integration, (2) multiplication related to integration, (3) multiplication not related to integration, (4) division (note what happens as divisor approaches zero), (5) how logic operations are performed, (6) generations of linear and non-linear functions, (7) time delays (both variable and non-variable), and (8) how high precision calculations are to be made. Special attention should be paid to reactor kinetic simulations below one (1) percent power level.

5. MODEL FUNCTIONAL REQUIREMENTS

5.1. Introduction

This section of the specification is intended to indicate the depth and scope of the anticipated modeling requirements for the Nuclear Power Plant Simulator. In some cases, the detailed requirements given may be modified if an equally faithful simulation can be provided by means other than that indicated.

5.2. Reactor Core

The reactor core simulation shall consist of at least eight spatial regions each with lumped parameters for 1/8 of the core at nodal points which are located in two axial planes in groups of four at 90-degree spacing.

"Point" type neutron kinetics shall be simulated for each of the eight spatial regions and shall include modeling for at least four delay groups. Coupling between two regions shall consist of a "diffusion" coefficient which is a function of the difference between neutron power (or level) of these regions. The kinetics equation for each region shall be coupled to all other regions.

The thermal node for each of the eight regions shall reflect the cylindrical pin geometry and shall consist of one fuel node, one clad node, and one fluid sink node. The moderator and Doppler reactivity feedbacks shall each be independently simulated in each of the eight core spatial regions. Simulation shall be provided in each of the eight spatial regions for the xenon phenomenon, including iodine and xenon production and decay, xenon "burnup," and reactivity poison effects.

The vertical projection of each of the two groups of four regions in each axial plan shall be radially symmetrical so that essentially four vertical flow channels for reactor coolant are simulated. The axial flow transport lag shall be simulated by four parallel channels of two series nodes each which coincide with the eight spatial regions which have already been discussed.

The eight flow nodes shall have lumped coolant parameters. Because of the relatively short core transit time, the flow may be simulated as two series time constants rather than pure transport delays. The fuel pin surface heat transfer coefficient shall be a function of the primary flow.

5.3. Nuclear Instrumentation System

This system consists of two source channels, two intermediate channels and four power range channels. All detectors are located out of the core and multiple units are located in pairs with 180° spacing in the plan view.

The detectors are installed in "strings" in the axial direction, but discrimination of axial flux variation beyond the sensor is not provided.

The simulation of the detector string in each channel shall provide for discrimination of azimuthal flux variations and programming and/or modeling capacity shall be committed for later provision of axial discrimination simulation. Detection of neutron level from each of the eight core spatial regions shall include individual inputs from the eight kinetics models each with an "attenuation" coefficient.

Provision shall be made for the instructor to fail each detector string.

5.4. Rod Drive System

Simulation shall provide for reactivity changes from any and all rods as a function of (1) the group or rod selected, (2) motion commands from the operator, the automatic control system, or the reactor protection system, or (3) the true lags and/or time constants of the drive mechanism and/or gravity insertion. Rod worth simulation shall reflect the true shape of the rod worth versus position curve and the relative distance between rods and the eight core spatial regions which were described in section 5.2.

Simulation shall further provide for single rods sticking or lagging and for an asymmetric rod pattern signal or a shim rod not out signal to the integrated control system.

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5.5 Reactor Coolant System

This is the main pressurized water system that provides the means for transporting the heat from the reactor core through the primary piping to the heat exchanger where heat is transferred to the secondary side to make steam. From the steam generator the reactor coolant flows back through pumps and piping to the reactor vessel and core.

Simulation shall be provided for two loops, including one reactor vessel, one pressurizer, two steam generators, and four primary pumps and connecting piping.

The model for the reactor coolant side of the boilers shall have two axial segments.

The loop flow simulation shall provide for appropriate flow variations and combination as a function of the logic of the number of pumps running, and the pressure drop of piping, components, and flow area transitions. All pumps are single speed.

Transport delay simulation shall be provided between the core outlet and the boiler tube inlet, including the reactor outlet plenum, piping, and the boiler inlet plenum. In a similar manner, transport delay simulation between the boiler tube outlets and the core inlet shall include the boiler outlet plenum, piping, and plenums and channels within the reactor vessel. The delay simulation for the reactor plenums is included in the heat balance equations.

The pressurizer fluid simulation shall consist of at least three regions. The pressurizer spray system shall be simulated by the appropriate mass flow and assumed thermal equilibrium between the spray and the steam above the water. The five electric pressurizer heaters shall each be simulated as a single point source with heat transferred to the water. In the case of transient inflow to the pressurizer from the reactor coolant system, incomplete mixing (non-thermal equilibrium) shall be simulated.

For the reactor coolant system and pressurizing systems combined, an overall mass inventory shall be simulated as a function of the net temperature change throughout the loop. This mass inventory simulation shall have incorporated with it provision for letdown and makeup flow from the auxiliary systems as specified in section 5.7

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For the heatup mode of operation provision shall be made for the heat capacitance of the reactor coolant system metal as well as the water.

Simulation shall be provided for the specific concentration and inventory of boron as a function of letdown and makeup flow and concentration. The specific concentration shall constantly be reflected in the core moderator reactivity coefficient.

Pressurizer level shall control makeup to reactor coolant system.

The average (of two loops) reactor outlet pipe pressure shall control in sequence five banks of pressurizer heaters and the three pressurizer relief valves. Low-low pressurizer level shall inhibit heater operation.

5.6. Steam and Power Conversion

The steam generator is a unique once through-type, the secondary side of which consists essentially of a continuous moving stream of water from the point of feedwater inlet to superheated steam outlet with partial recirculation of steam to heat the incoming feedwater. The feedwater, after entering and mixing with the heating steam, passes through the downcomer and starts up the riser where it begins to receive heat through the tubes from the reactor coolant.

Saturated steam generation in a low quality mixture initially occurs and then, as the fluid continues moving up, the quality becomes progressively higher until superheated steam is produced at the upper end of the riser section.

The pressure loss due to flow is relatively small within the steam generator, the main forces being the static head exerted by the denser feedwater in the downcomer in balance with the column in the riser which is made up of lighter fluid varying from saturated water to superheated steam. The variable length section varies from 85% to 10% of the riser length. A minimum of two axial regions shall be simulated for the riser section and one for the downcomer section.

The integrated plant control system to be described later requires that the piping and steam volume of the boiler be simulated to include mass inventory pressure, pressure drop, and flow. Relief valves shall be simulated based on header pressure and shall have at least four staggered relief points. The four governing valves and four stop valves shall be simulated and shall be tied in with the automatic turbine control system.

A temperature compensated boiler level signal shall be provided by boiler dynamic simulation and made available to the integrated plant controller system.

Simulation for the turbines (see Figure C-7) shall include torque effects from flow, inertia of rotating parts, frequency phase angle between generator and electrical grid, electrical losses, and mechanical losses.

The turbine-generator electrohydraulic control system (EHC) simulation (see Figure C-7) shall include the effects of the components listed below.

1. Two servo actuators.
2. Two automatic valve controllers (ACVC and ATVC).
3. Two manual valve controllers (MGVC and MTVC).
4. Speed and load error and error bias.
5. Load level, rate, and limit control.
6. Speed level, rate, and limit control.
7. Mode transfer—stop valve to governor valve.
8. Mode transfer—local or remote (ICS)
9. Turbine trips—overspeed, low vacuum, low oil, high thrust, manual.

Condenser hot well simulation shall include the proper mass balance and automatic level control. Condenser vacuum shall be simulated as a function of circulation water flow rate, circulation water temperature, and air ejector capacity.

The three parallel condensate pumps shall be simulated by the appropriate change in condensate flow as a function of head capacity data and flow resistance. These pumps are electric motor driven (single speed).

The low pressure heaters shall be simulated with a one-lumped parameter node heat balance including the effects of thermal time constants and fluid flow on both sides of the tubes.

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The pressure drop in the condensate chain of piping, filter, and heaters shall be simulated as a function of flow and fluid inertia.

The steam feedpumps shall be simulated as steam turbine driven devices with speed varying as a function of feedwater demand as determined by the integrated control system. Pump inertia and speed changer characteristics shall be included.

The high pressure heaters shall be simulated in a manner similar to that described above for the low pressure heaters.

The emergency feedpump shall be simulated separately, but in a manner similar to that of the main feedpump.

The feedwater regulating valve shall be simulated as an adjustable resistance depending upon position, which is being dictated by the integrated control system.

The pressure drop in the feedwater chain piping, heaters, and regulating valves shall be simulated as a function of flow and fluid inertia.

The condenser bypass shall simulate approximately 15% of full load as dictated by the control valve position.

The condensate storage tank shall have variable water inventory simulation.

For purposes of warmup simulation, the heat capacitance of the water and steel of the piping, turbine, boilers, and condenser shall be simulated. Differential expansion shall be simulated as a function of the temperature difference between the turbine shaft and casing.

The auxiliary boiler shall be simulated with variable pressure and with variable flow as demanded by the heatup simulation. The heat removal in the cooling towers shall be simulated, including the effects of the number of fans and pumps running and a variable input efficiency factor. The flow as a function of sequential fan operation shall be simulated. Point type heat transfer in the condenser shall be simulated as a function of the circulating water flow and temperature.

Partial simulation shall be provided for the basic cooling water systems, which provide for rejection of heat to the canal water or cooling tower from such equipment as the generator hydrogen coolers, turbine oil coolers, exciter air coolers, and EHC oil coolers. The temperature in each of these components shall be proportional to a reference temperature, which may be simulated by a single time constant and the logic of operational pumps.

5.7. Makeup and Purification System

The letdown coolers shall be simulated with a point type heat balance between the reactor coolant letdown flow and the component cooling water, including simulation for variable flow and temperature.

The manual position switch for the letdown flow control valve and the component cooling water flow valve has an interlock such that the cooling water flow path is open before the letdown valve can be opened. High letdown temperature shall shut down letdown flow.

The letdown control valve simulation shall include pressure drop characteristics combined with position and flow. The demineralizer shall be simulated by constant ΔP of either one or two values depending upon whether one or two demineralizers are on the line.

The three-way valve simulation shall provide for flow switching and tie in with the flow integrators of the deborating and demineralizer supplies. Automatic positioning of valves for the moderator dilution cycle shall be inhibited if control rods are not at the 95% withdrawn position, or if the integrated flow of deborated return water reaches a preset amount, or if the makeup tank level reaches a low-low value.

The makeup tank simulation shall include water inventory balance reflecting the input from the letdown demineralizer, seals, deborated supply, demineralized supply, boric acid solution, and the output to the makeup pumps. Hydrogen overpressure shall be simulated.

The emergency borated supply simulation shall include emergency valve operation and mass depletion from the tank. Both the demineralized makeup and the deborated makeup shall be simulated to include the effects of valve position, pressure drop, and the inhibit function of the flow integrator.

The flow from the makeup tank shall be simulated as a function of tank pressure, pump head capacity data, pressure drop characteristics of piping and variable position of the control valves in the three branch lines, and the downstream pressure in the reactor coolant system.

The differential pressure between the reactor coolant outlet piping and the seal supply header shall control the valve which regulates flow to the header. Direct makeup flow shall be controlled by pressurizer level.

5.8. Decay Heat Removal System (Emergency Low Pressure Injection System)

This system has the dual function of providing decay heat removal during normal shutdown and providing low pressure injection in the event of a maximum credible accident.

The system mass flow inventory shall be simulated including the storage in the borated water storage tank, the spray flow, the flooding supply flow, and the reactor building sump mass accumulation after an MCA. The spray flow provides cooling to the reactor building following an MCA and is discussed elsewhere.

For the pumps, the simulation shall include the head capacity curve. Head pressure simulation shall include the downstream pressure in the reactor coolant system. The cooler simulation shall provide for transient cooling following a power failure and reactor coolant pump coastdown.

Heat transferred in the coolers shall be simulated as a function of total flow and temperature. The final cooler sink temperature simulation shall include the effects of stopping and starting the nuclear service water pumps and the position of stop valves.

The decay heat removal function and the emergency injection function of this system need not be simulated continuously during normal operation.

5.9. Core Flooding Tanks

This simulation is required as part of the emergency action following the maximum credible accident. The pressure and volume of the gas above the water shall be simulated according to the perfect gas laws. The water volume simulation shall reflect the outflow which in turn is the function of overpressure and the ΔP in the pipeline.

5.10. Chemical Addition and Sampling System

The boron concentration and makeup flow into the makeup tank of the previously mentioned purification and letdown system shall be simulated.

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* 5.11. Plant Component, Turbine Plant, and Nuclear Service Cooling Water Systems

The water volume in the surge tanks shall be simulated as a function of temperature and mass inventory (where applicable). Flows shall be simulated as a function of the logic of pump and valve status plus simple time constants. Zero level in the surge tanks shall call for zero pump flow. Heat transferred in the coolers shall be simulated as a function of total flow and temperature.

5.12. Reactor Building Simulation

Following a simulated Maximum Credible Accident (MCA), the reactor building model together with the reactor coolant system shall include a pressure, energy, and mass balance as affected by reactor coolant leak rate, spray rate, core flooding rate, fan cooler heat removal rate, passive heat sinks, decay heat generation, and fluid recirculation rate. A "saturated" heat balance model may be assumed, i.e., superheated vapor will not be simulated.

5.13. Waste Disposal System

The simulation of this system supplements the simulation of the purification and makeup system and shall include the deborating demineralizer ΔP, the water inventory in the bleed holdup tank, and station demineralized water tank, and the pump flow.

In connection with waste disposal and abnormal radioactive waste transport, a radiation monitoring system (RMS) of approximately 20 individual channels may be installed, for which partial simulation shall be provided. Six channels shall have simulation of a radiation level proportional to the value of an initiating event or variable that is buffered through a simple time constant. All other channels shall be simulated only by a static analog signal.

5.14. Electrical System

* Simulation shall be provided for the 22 kv station bus and the two 230 volt kilovolt busses including the ability for the instructor to arbitrarily add and reject loads, the ability to separate the plant from the rest of the system, and the complete loss of all power. Individual simulation shall be provided for each of the primary pump loads and other

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major station loads. Simulation shall be provided for frequency synchronization computation, control, and display.

For cases of loss of all power, auxiliary diesel generator startup and cut-in to the 4160 volt emergency busses shall be simulated. Simulation shall be provided for battery supply to the vital instrumentation while all power is off, while the non-vital loads have been rejected and while the diesels are coming on the line. Provide loss of load signal to the integrated control system mentioned later.

The functions described above require at least the simulation for the following specific components: Station generator, 2 main 230 kv busses with connecting breakers, two 6900 volt reactor busses, four 4160 volt turbine plant busses, two 4160 volt engineered safeguard busses, two 4160 volt engineered safeguard busses, two 4160 volt 2000 kw diesel generators, two 480v engineered safeguard busses, two 250-125 dc busses, four 120v vital instrumentation busses, and the batteries.

Provide individual simulation for each component listed in the table in Appendix A. For normal operation, i.e., not on diesel generator power, simulation shall include display of variations in parameter readings.

For the casualty simulation of reactor trip and separation from the power system grid, power shall be interrupted to all loads except vital instrumentation and emergency lighting.

A delay for cranking of diesel generators (D-G) simulated, after which D-G frequency and voltage shall come up according to a time constant.

After synchronization and cutting into the 4160v engineered safeguards busses is accomplished, the subsequent restarting of equipment shall be simulated as mentioned above and as indicated by the equations in Appendix A.

For large components, the simulation of load switching shall include the effects of fluctuations in power, voltage, and frequency display plus the visual effect on lighting in the simulator training room.

5.15. Reactor Protection System

This system has inputs from 4 protection channels with 2 out of 4 coincidence required to provide a trip. These trip signals open the breakers in each of two rod drive power supplies. Each of the 4 protection channels has inputs from high flux, high temperature, high pressure, low pressure, high startup rate, and loss of pumps. Simulation shall provide logic for individual channel representation and coincidence switching. Provision shall be made for failing a protection channel distinct from failing a sensor input. Simulation shall tie into the rod drive power source breakers.

5.16. Safeguards Actuation System

This system provides for starting the emergency safeguard system following an MCA. Two out of three coincidence from pressure sensors on low pressure starts the high pressure injection system. Two out of three coincidence on another low pressure signal starts the low pressure injection system. Two out of three coincidence of the reactor building pressure sensors on high pressure starts the emergency cooling system and actuates the isolation system for the reactor building. Two out of three coincidence on the reactor high pressure starts the spray pumps mentioned in the decay heat system above. Two out of three coincidence on high pressure in the reactor building opens the valves in the spray line. Simulation shall include sensors, setpoints, coincidence, failure capability of sensors, and shall provide appropriate tie-ins to the computer model of each system mentioned.

5.17. Reactor Building Isolation System

This system, when actuated by a pressure of 4 psig in the reactor building, is designed to close a valve or valves in all lines which penetrate the reactor building and which do not serve an accident-consequence limiting function.

Also, the 4 psig pressure signal actuates the opening of normally closed valves in systems that serve an accident-consequence limiting function.

5.18. Integrated-Boiler-Turbine-Reactor Control System (Simulation Not Required)

5.18.1. Turbine Speed Control

Provision shall be made for the instructor to act as load dispatcher and add and reject loads as mentioned in the electrical

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description above. Simulation shall be provided for manual adjustment of the load demand according to the maximum load limit, the minimum load limit, and the rate limit.

Also, simulation shall be provided for the runback limiter which accommodates input signals from the shim safety rod not out signal, asymmetric rod signal, loss of load signal, and the reactor coolant pump capability runback signal. The runback limiter shall provide an output megawatt demand signal which feeds the reactor control system and the turbine and steam generator control.

The megawatt demand shall be compared with the true reactor megawatt output and this resulting megawatt error signal shall be summed with the secondary pressure setpoint to provide an adjusted pressure setpoint signal which shall feed to the turbine control. The adjusted pressure setpoint signal shall be compared with the true steam pressure and the resulting difference, or error signal, shall be fed to the turbine speed control.

5.18.2. Boiler Control

Simulation for the steam generator controls shall provide for accepting the megawatt demand signal from the runback limiter, previously mentioned, and inputting this to a feedwater demand calculation simulation. The feedwater demand calculator modifies the megawatt demand by the difference in set pressure and actual pressure and outputs a total feedwater demand.

The total feedwater demand signal is inputted to a steam generator load ratio control which shall have inputs from a manual ratio adjustment and logic signals indicating the number of primary pumps which are running. The steam generator low ratio control outputs a signal to each of the feedwater control chains of the 2 loops.

This feedwater control shall include simulation for modifying the steam generator load ratio control output signal by the reactor coolant pump limiter, the reactor coolant temperature limiter, the low feedwater temperature limiter, and the steam generator level limiter.

The finally modified feedwater flow demand signal is compared with the actual feedwater flow and then the resulting signal

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positions the feedwater control valve and/or the steam supply valve for the variable speed feedwater pumps of each loop.

5.18.3. Reactor Control

The reactor control system simulation shall include inputs from the hot and cold leg temperatures of each loop, averaging of these two temperatures, averaging of the two averages, and comparison with a temperature set point. The temperature error from the averaging and compare simulator shall feed into the demand computer which, with the proper weighting coefficients, adds integrated temperature error to the straight temperature error, and then adds the megawatt demand obtained from the runback limiter, which was described in 5.18.1. The sum of these three is compared with the actual reactor power, thus producing an error signal which, after passing through a deadband unit, feeds into the rod control automatic sequencing logic and thence to the control rod drive motors.

5.19. Summary and Allocation of Model Requirements

5.19.1. General

This section (5.19) is intended to summarize the major phenomena that require simulation and to allocate functions qualitatively to either of two categories—long and short time constants.

Particular attention should be given to the numerical method used for solving the reactor kinetics equations because the value of "l^*" is about 25 microseconds and solution instability may occur. Traditional digital technique may require 1000 solutions per second. More modern techniques may require 100 solutions per second. However, there are still other techniques with which 5 solutions per second, or fewer, are satisfactory.

It should be noted that the kinetics equations must be solved over a dynamic range of approximately 10 decades during reactor startup. Probably, digital solutions of less than five per second will be adequate for the remainder of the plant. The phenomena with extremely long time constants, such as xenon buildup and decay, may not change noticeably over a period of minutes.

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5.19.2. Long Time Constant Category

A. Reactor coolant, letdown and makeup water inventory model and boron concentration model.

B. Reactor building pressure and temperature.

C. Water inventory and mass balance requirement following a MCA including reactor building, high and low pressure injection, and borate storage tank.

D. Steam and power conversion system water inventory including volume of piping and miscellaneous components plus the condenser hotwell and condensate storage.

E. Heat storage modeling of reactor coolant system and steam and power conversion water and steel during plant warmup.

F. Reactivity model for xenon.

5.19.3. Short Time Constant Category

A. Boiler thermal model.

B. Boiler secondary mass, density, level, and pressure balance simulation.

C. Steam supply pressure, mass, and flow model.

D. Steam turbines and controls.

E. Feedwater supply pressure drop, pump head, pump speed, and flow model.

F. Reactor kinetics.

5.20. Casualty Simulation

1. Intercept signal from ICS to control rod drive panel (via CP-4) and provide for defeating signal.

2. Provide for "locking" in whatever logic signal (insert or withdraw) is being sent from operator's console to CRDS.

3. Provide for individual rod casualties by programmable access to select which rod and by instructor console switching to defeat motion, retard motion (P.O.).

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4. Degrade one uncompensated ion chamber.

* 5. Fail one compensated ion chamber.

6. Fail one proportional counter.

7. Fail one reactor protection channel.

* 8. Initiate xenon tilt (P.O.).

* 9. Insert false reactor outlet temperature (P.O.).

* 10. Insert false reactor inlet temperature (P.O.).

* 11. Insert false RC flow signal (P.O.).

12. Trip off RCP1AA.

13. Trip off RCP1BA.

14. Trip off RCP1AB.

15. Trip off RCP1BB.

* 16. Insert false RC pressure (P.O.).

* 17. Initiate pressurizer spray valve failure.
   (a) Opens spontaneously.
   (b) Will not open.

18. Freeze pressurizer level signal (P.O.).

* 19. Initiate "weeping" pressurizer relief.

20. Simulate RC leak.

21. Simulate letdown cooler leak.

22. Simulate MU leak.

23. Simulate boiler tube leak.

24. Simulate steam leaks (3).

25. False main steam header pressure signal (P.O.).

* 26. Fail one turbine bypass valve (initiate open signal)(P.O.).

* 27. Fail one auxiliary steam exhaust valve (initiate open signal) (P.O.).

* 28. Defeat integrated control system input to turbine electro hydraulic control (EHC).

* 29. Insert error into EHC speed feedback.

* 30. Fail integral of EHC automatic governor valve control.

* 31. Freeze mode transfer relay (MT2) of EHC.

* 32. Trip main turbine.

* 33. Cut off one cooling tower fan (P.O.).

34. Cut off one circulation pump (P.O.).

35. Cut off one air ejector (P.O.).

36. Cut off one condensate pump (P.O.).

* 37. Degrade one LP heater (P.O.).

38. Intercept ICS feedflow signal to one loop between controller and limit box.

* 39. Trip one feedpump (P.O.).

40. Degrade one feedpump.

* 41. Degrade HP heater (P.O.).

* 42. Fail letdown valve.

43. Freeze 3-way valve.

44. Freeze valve in combined makeup and deboration return.

* 45. Block boron addition.

46. Fail one high pressure makeup pump (P.O.).

* 47. Fail normal makeup valve.

* 48. Fail RC pump seal control.

* 49. Fail one decay heat pump (P.O.).

* 50. Fail one nuclear services pump (P.O.).

* 51. Fail one nuclear services raw water pump (P.O.).

52. Fail one plant cooling water pump (P.O.).

* 53. Fail one component cooling water pump (P.O.).

* 54. Fail one turbine plant water pump (P.O.).

55. Fail one reactor building emergency cooler (P.O.).

56. Fail one reactor building spray pump (P.O.).

57. Drop all load.

58. Separate plant from network.

59. Defeat start of one diesel generator.

60. Drop out 6900V Bus 1A.

61. Drop out 230 KV transformer.

Where "(P.O.)" is shown above, provide multiple casualty capability via programmable option, i.e., where there are multiple components of the same kind it shall be possible for the instructor to preselect, by instructions directly to the computer, any of the multiple components for failure. However, the failure shall be effective only when the instructor actuates a push button.

The notation "degrade" indicates that a potentiometer is required to vary the intensity of a given casualty. The potentiometer, however, shall not be effective until a push button is activated.

In addition to the switches and potentiometers which are specifically committed to casualty simulation, the instructors console shall also have (1) the following meters which provide indication of the most critical plant parameters for normal monitoring and for feedback of casualty effects and (2) the following remote controls - some of which may also be used for introducing casualties.

62. Megawatt demand meter.

63. Megawatt actual meter.

64. Grid frequency meter.

65. Steam pressure meter.

66. RC average temperature meter.

67. RC pressure meter.

68. Dispatch load demand to integrated control system.

69. Set or perturb grid frequency.

70. Make up hydrogen to MU tank.

71. Make up to component cooling water surge tank.

72. Bleed from component cooling water surge tank.

73. Make up water core flooding tank B.

74. Make up N_2 to CFT1B core flooding tank B.

75. Make up water to CFT1A core flooding tank A.

76. Make up N_2 to CFT1A core flooding tank A.

77. Fire up (or fail) auxiliary boiler.

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6. HARDWARE DESIGN REQUIREMENTS

6.1 General

6.1.1. The purpose of this document is to describe the general standards of construction for electronic equipment for nuclear power plants.

6.1.2. The objective of these standards is to provide quality equipment which will promote:

(a) Personnel safety.

(b) Reliable service.

(c) Long life.

(d) Easy and low cost maintenance.

6.1.3. Information listing voltage, phase, frequency and volt-ampere requirements shall be shown on the main equipment nameplate. Nameplate shall be durable thermosetting plastic.

6.1.4. Because of special or recent developments in the state of the art of computing equipment manufacturing, there may be exceptions to this specification that will be acceptable, provided that adequate justification is furnished by the vendor.

6.2. Component Standards

6.2.1. Standard components shall be used wherever possible. If special components are used; type, number, name of manufacturer and other pertinent information shall be shown on the stock list.

6.2.2. All composition resistors shall have the resistance value and tolerance indicated either by means of the Electronic Industries Association (EIA) color code, or by printing on the resistor body, whichever is preferred.

6.2.3. Wire-wound resistors shall have resistance value and power rating plainly marked on resistor body in a location where this information is plainly visible.

6.2.4. When resistors with adjustable taps are used, the taps shall be in an accessible location for adjustment.

6.2.5. All capacitors shall be plainly marked with voltage, capacity, polarity and terminal identification. Capacitors shall be installed with this information visible where practical.

6.2.6. All capacitors shall have working voltage ratings in excess of applied peak voltages.

6.2.7. If selected components are used, this information shall be indicated on the schematic diagram and parts list in the instruction book.

6.3. <u>Construction Practice</u>

6.3.1. The use of sub-chassis construction is recommended.

6.3.2. Sub-chassis which have the same function and rating and are electrically identical shall be interchangeable.

6.3.3. Test points shall be brought out for checking essential wave forms and voltages where terminals are not otherwise provided.

6.3.4. Equipment enclosures shall be designed and constructed to provide accessibility.

6.3.5. All parts should be accessible for visual inspection and replacement.

6.3.6. All hardware shall be plated or of a non-corrodible material.

6.3.7. Lockwashers or other locking devices shall be used.

6.3.8. Resilient washers shall be used whenever brittle materials are bolted in assembly.

Control knobs shall be fastened securely.

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6.4. Metal Work

6.4.1. All sharp edges and burrs shall be removed.

6.4.2. Self-tapping screws shall not be used where occasional removal of a part is required.

6.4.3. Front panels shall not be secured to the chassis solely by circuit components.

6.4.4 Devices for retaining panels and cover plates should preferably be of the captive type.

6.5. Soldering and Electrical Connections

6.5.1. A solder with a non-corrosive flux, such as resin, should be used.

6.5.2. All parts shall be "tinned" before soldering unless the part is specifically plated to insure a good soldered joint (e.g., "AN" type connectors having gold-plated contacts).

6.5.3. All parts shall be cleaned prior to soldering.

6.5.4. A proper amount of solder shall be used on all connections.

6.5.5. Insulation shall not be damaged by soldering.

6.5.6. Components which may be damaged by heat when soldering shall be suitably shielded from the heat during the soldering operation.

6.5.7. Connections shall be made with solder, compression type lugs, or wire-wrapping technique for which reasonable assurance can be given that high compression, metal-to-metal contact in excess of the cross-sectional area of the wire is permanently provided.

6.6. Interconnection Cables and Connectors

6.6.1 The external covering on the cable shall be oil-resistant such as polyvinyl chloride, or equivalent.

6.6.2. When connection from the shield to both connector pin and the cable clamp is indicated, the shield shall be connected directly to the pin and the pin connected to the cable clamp by hook-up wire. Connection to the clamp shall be made by a lug.

6.6.3. The cable clamp of the connector shall be clamped on the outer insulated covering of the cable. The cable shall be built up if necessary, to insure good clamping.

6.6.4. Connectors and clamps shall be sufficiently tight to prevent damage to the connections during assembly and normal use.

6.6.5. Where cable is terminated with connector, cable clamp shall be used.

6.6.6. All separable connectors shall have a device for holding them firmly in place.

6.6.7. The energized portion of the circuit shall be connected to the female end of plugs and receptacles.

6.7. Wiring

6.7.1. General purpose hook-up wire shall consist of stranded tinned copper not less than AWG No. 24, with plastic insulation consistent with 6.5.5 above.

6.7.2. Shielded cable, single or multiple conductor, shall consist of stranded tinned copper not less than AWG No. 25 size for single conductor wire used in sub-assemblies and not less than AWG No. 22 for all other uses. The wire or wires shall have thermoplastic insulation, metallic shield, and an oil and moisture resistant covering, such as vinyl plastic.

6.7.3. Special wiring, such as RG/U coaxial cables and twin-lead, may be used when necessary for proper functioning of equipment.

6.7.4. All conductors and multi-conductor cable used on industrial equipment shall have insulation rated at 600 volts, except that the internal wiring on electronic panels shall have insulation adequate for the voltage on that wire.

6.7.5. All wires and cables shall be secured and protected to prevent breaking of the wire connection or fraying of the insulation.

6.7.6. All connections to terminals shall be readily accessible when screwed type terminals are used.

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6.7.7. Wires shall be continuous and shall be supported at their termination if the wire weight exceeds the appropriate hanging weight limit.

6.7.8. The internal wiring of electronic equipment with the exception of automatic wire-wrapping applications, shall be color-coded.

6.8 Printed Circuits

6.8.1. Plastic boards with copper laminate on one or both sides and plated through holes, if necessary, may be used in place of conventional wires within electronic units.

6.8.2. The base material of the plastic board shall be at least grade G10 or equivalent.

6.8.3. Plastic boards shall not be less than 1/16 inch thick.

6.8.4. Copper shall be 100 percent International Annealed Copper Standard (IACS), Mil P-13949 or recognized equivalent, and no thinner than 2 oz per sq ft (copper 0.0027 in. thick) except for plated through holes which shall be at least 0.001 in. thick.

6.8.5. Bond strength shall meet peel strength requirements in accordance with NEMA Standard for boards in accordance with 6.8.2 above.

6.8.6. Currents of 0.0027 inch thick copper shall not exceed values shown in Table I.

Table I

Line width in.	Amperes	Ohms/in.
1/4	3	0.0009
1/8	1.5	0.0018
1/16	0.75	0.0035
1/32	0.40	0.007

6.8.7. Line width and separation shall not be narrower than 0.010 inch.

6.8.8. Sharp corners should be avoided.

6.9. Mounting and Clamping

6.9.1. All components shall be securely mounted in a manner so as not to cause damage to any portion of the equipment nor affect its performance.

6.9.2 Mounting hardware shall be designed to facilitate replacement of parts and assemblies.

6.9.3. Rivets and welds shall not be used to mount components.

6.9.4. Pilot lamp holders shall be of the bayonet type or similar. Lamps shall be replaceable from front of panel.

6.10. Identification

6.10.1. Terminal barrier strips and terminals shall be identified on, or adjacent to, the barrier strip with the same designation that appears on the diagrams.

6.10.2 All controls shall be clearly and permanently labeled to identify their function.

6.10.3. Red warning labels or tags shall be provided on enclosures shielding exposed points of dangerously high voltages.

6.11. Power Source

The power supply to the electronic equipment shall be obtained from a transformer with an isolated secondary winding. The primary of the transformer shall be connected to the load side of the main disconnect device of the equipment.

6.12. Overcurrent Protection

An overcurrent protective device (fuse or circuit breaker) shall be placed in the ungrounded conductor of each branch circuit.

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6.13. Equipment Grounding

6.13.1. All exposed metal parts shall be at earth ground potential.

6.13.2. A copper or other corrosion-resistant conductor shall be used for grounding purposes.

6.13.3. The size of the ground conductor shall be at least equal to the power carrying conductors to the equipment.

7. TEST REQUIREMENTS

7.1 Subsystem Evaluation Tests

The vendor shall perform and record an evaluation test program on each component, subassembly or subsystem of the simulator system in keeping with good engineering practice to assure overall system reliability and to isolate potential problem areas.

7.2. System Tests

7.2.1. The vendor shall conduct a testing sequence at its facility to demonstrate system compliance with this specification prior to delivery. The sequence shall include:

a. Operation of all consoles and panels to applicable requirements.

b. Test of all vendor supplied peripheral hardware not included in 7.2.1 a.

c. Demonstration of software performance to specification.

d. Performance of all special and operational computer programs

7.2.2. Adequate test data shall be recorded and maintained by the vendor to permit analysis for compliance to the system requirements.

7.3 Acceptance Tests

7.3.1. Preliminary acceptance test shall be performed before shipment of equipment from the vendor's factory. Final acceptance tests shall be performed at the B&W designated delivery point.

7.3.2. The tests shall demonstrate completely all phases of simulator operation so as to provide B&W with evidence that the system meets all specifications.

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8. DOCUMENTATION REQUIREMENTS

8.1. Engineering Drawings

The vendor shall provide B&W with a list of all drawings, sketches and related documents to be supplied with the equipment.

8.2. Engineering Reports

The vendor shall report all engineering design and development analyses in sufficient detail to permit the customer to thoroughly review and evaluate the system.

8.3 Computer Program Documentation

Documentation shall include, but not be limited to, the following items, or the equivalent detail as appropriate to the type system being furnished, i.e., digital, analog, hybrid, etc:

a. Program code edit or listing.
b. Schematic diagram or program flow sequence and logic.
c. Description of equation solution technique.
d. Description of special transfer functions, approximation methods, or other special techniques.

8.4. Recommended Spare Parts List

Upon completion of the final definition of all hardware requirements the vendor shall provide B&W with a list of all recommended spare parts. The following information shall be included:

a. Item number.
b. Part identification.
c. Total quantity in system.
d. Recommended quantity for 1 year operation.
e. Recommended quantity for 5 years operation.
f. Unit price.

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- e. Recommended quantity for 5 years operation.
- f. Unit price.

8.5. Test Reports

The vendor shall provide at least one reproducible copy of the test reports for all testing requirements of paragraphs 7.2 and 7.3.

8.6. Maintenance Requirements

The vendor shall provide maintenance requirements for all equipment used in the simulator system, whether proprietary or purchased.

Appendix A

Mathematical Models for Simulator

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1. REACTOR CORE, NUCLEAR INSTRUMENTATION AND CONTROL ROD MODELS

(Reference Figures C-3, C-4, and C-5 and Sections 5.2, 5.3, 5.4, and 5.5 of Main Specification)

1.1. Neutron Kinetics Equations

$$\frac{dn_i}{dt} = \frac{\rho_i n_i}{\ell^*} - \frac{\Sigma \beta_i n_i}{\ell^*} + \sum_{i=1}^{4} \lambda_i C_i + S_1 + S_2 + D_i(n_{i+2} + n_{i+4} - 2n_i) + D_{i+1}(n_{i+6} - n_i) + D_{i+2}(n_{i+1} - n_i) + D_{i+3}(n_{i+3} + n_{i+5} - 2n_i) + D_{i+4}(n_{i+7} - n_i)$$

(typical for eight equations)

$$\frac{dC_i}{dt} = \frac{\beta_i n_i}{\ell^*} - \lambda_i C_i$$ (typical for 32 equations)

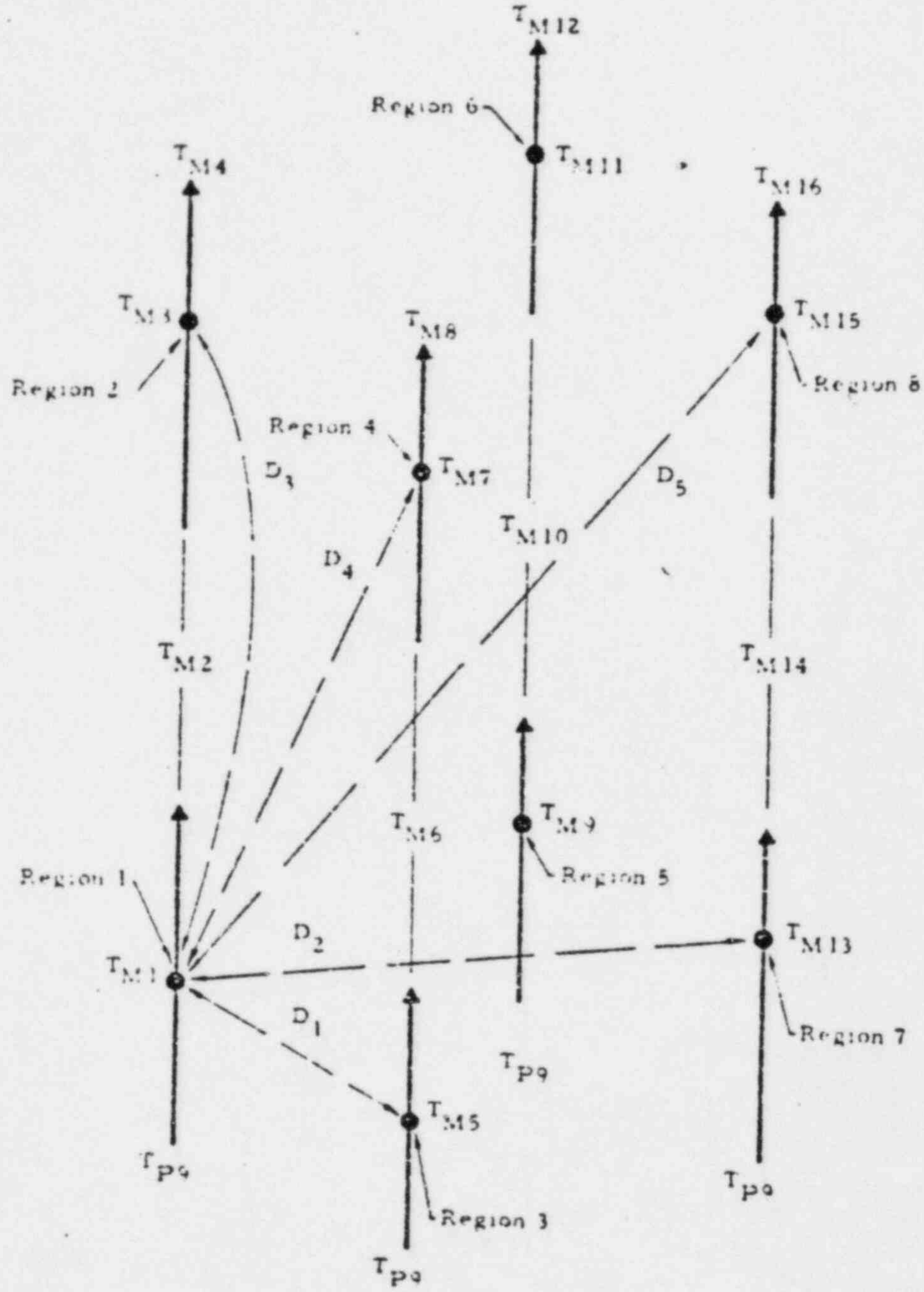
$$n = \frac{n_1 + n_2 + n_3 + n_4 + n_5 + n_6 + n_7 + n_8}{8}$$

1.2. Reactivity Equations

$\rho_i = \rho_{Ri} + \rho_{Di} + \rho_{Mi} + \rho_B + \rho_{Xi} + \rho_L$ (typical for 8 equations)

ρ_{Ri} = function control rod positions (typical for 8 equations)

$\rho_{Di} = c_D T_{Fi} + K_{1.1}$ (typical for 8 equations)


T M12
Region 6
T M11
T M4
T M16
T M3
T M8
T M15
Region 2
Region 4
Region 8
D 3
T M7
D 5
T M10
D 4
T M2
T M14
T M6
T M9
Region 1
Region 5
D 2
T M13
T M1
D 1
Region 7
T P9
T M5
T P9
T P9
Region 3
T P9

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$\rho_{Mi} = c_M T_{Mi} + K_{1.2}$ (typical for 8 equations)

$\rho_B = c_B C_{Bi} + K_{1.3}$ (typical for 8 equations)

$\rho_{Xi} = f(X_i)$ (typical for 8 equations)

$\frac{dX_i}{dt} = \lambda_I I_i + (\gamma_X \Sigma_f - \sigma_X X_i)\phi_i - \lambda_X X_i$ (typical for 8 equations)

$\frac{dI_i}{dt} = \gamma_I \Sigma_f \phi_i - \lambda_I I_i$ (typical for 8 equations)

$\phi_i = K_{1.4} n_i$ (typical for 8 equations)

$\rho_L = f_1(t)$ (same for all core regions)

1.3. Decay Heat Model (Same for All Eight Core Regions)

$$q_{DH} = C_{F1}\lambda_{F1} + C_{F2}\lambda_{F2} + C_{F3}\lambda_{F3}$$

$$\frac{dC_{F1}}{dt} = K_{1.5} n - C_{F1}\lambda_{F1}$$

$$\frac{dC_{F2}}{dt} = K_{1.6} n - C_{F2}\lambda_{F2}$$

$$\frac{dC_{F3}}{dt} = K_{1.7} n - C_{F3}\lambda_{F3}$$

1.4. Thermal Model

$K_{1.8} \frac{dT_{Fi}}{dt} = K_{1.9} n_i + q_{DH} - K_{1.10}(T_{Fi} - T_{Zi})$ (typical for 8 equations)

$$K_{1.11} \frac{dT_{Zi}}{dt} = K_{1.10}(T_{Fi} - T_{Zi}) - (U_1)(T_{Zi} - T_{Mi}) \quad \text{(typical for 8 equations)}$$

$$K_{1.12} \frac{dT_{Mi}}{dt} = (U_1)(T_{Zi} - T_{Mi}) - K_{1.13}(T_{M(i+1)} - T_{P9}) \frac{w_{RC1}}{4}$$

(typical for 8 equations)

$$T_{Mi} = \frac{T_{Mi-1} + T_{Mi+1}}{2}$$

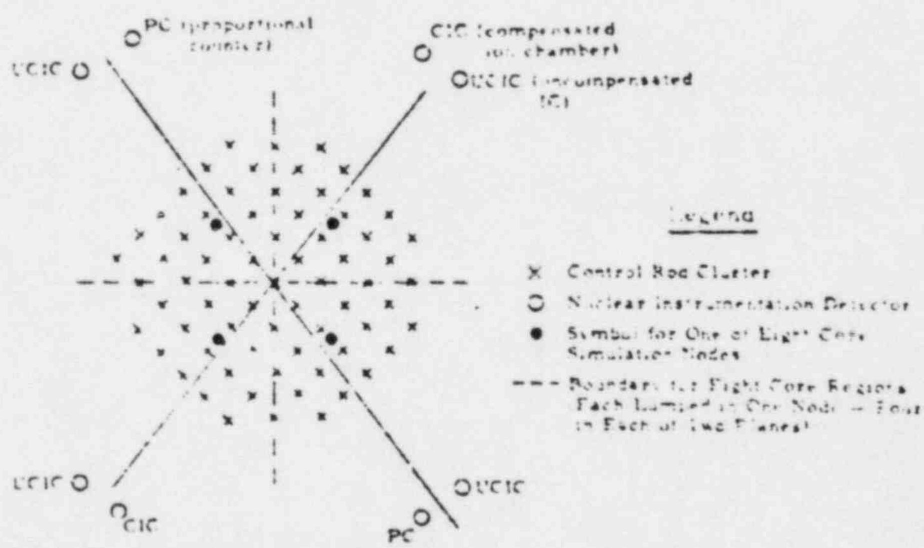
<u>Note:</u> ($T_{Mi-1} = T_{P9}$ for regions 1, 3, 5, and 7.)

$$h_1 = K_{1.14} \left(\frac{w_{RC1}}{4}\right)^{.8}$$

$$U_1 = \frac{1}{\frac{1}{K_{1.15}} + \frac{1}{h_1}}$$

1.5. Conceptual Design of Nuclear Instrumentation and Control Rod Model

<u>Core Plan</u>



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1.5.1. Assign a reference worth to each of 69 rod clusters according to radial position in the above plan and according to the standard withdrawal sequence.

1.5.2. Use one standard "S shape," worth versus axial distance for all full rods and one equivalent worth curve for all partial rods.

1.5.3. Subdivide the axial worth curve into two overlapping functions of axial position (function A & B). "A" functions should affect reactivity only for the four lower core nodes and "B" functions should affect reactivity only for the four upper core nodes.

1.5.4. The total reactivity should be the product of the reference worth times each of the two "A" and "B" functions.

1.5.5. Provide for neutron detection by means of eight pseudo sensors each in symmetry with, and each detecting neutrons only from, one of the eight core kinetics nodes.

1.5.6. Provide for simulating more than two detectors in a given instrument string by using the values from the two pseudo detectors to select a stored axial flux shape curve which best fits the two points. Thus instrumentation readout can be obtained for a detector located anywhere along the string which is assigned to a given quadrant of the core in order to simulate different types of detectors, e.g., proportional counters, uncompensated ion chambers, compensated ion chambers, incore detectors. Provide six different attenuating coefficients.

1.6. Control Rod Drive Conceptual Model

The 69 control rod clusters will be subdivided into 7 control rod groups and 1 xenon (partial) rod group. Provision will be made to allow the instructor to designate the number and radial position of rods within each of the 7 control rod groups (programmable option).

Selection of rods for movement will be initiated by pushbuttons and selector switches on the console. Provision will be made to move the rods in a preprogrammed sequence in response to ICS or manual withdraw/insert signals. The rods can also be moved singly or by groups in manual mode. The position of each rod and group will be displayed on the console.

Actual control rod drive response will be the same for all rods except that an instructor initiated malfunction shall cause the velocity of any selected rod to differ from the standard value by a fixed amount or to equal zero.

Normal rod response shall be modeled by a fixed pure delay, a time constant and one of two steady state velocities.

Rod response to a scram shall be modeled by a pure delay plus a time dependent function.

Symbols for Section 1

β_i = constant section 1

β_1 = constant section 1

β_2 = constant section 1

β_3 = constant section 1

β_4 = constant section 1

γ_X = constant section 1

γ_I = constant section 1

λ_i = constant section 1

λ_1 = constant section 1

λ_2 = constant section 1

λ_3 = constant section 1

λ_4 = constant section 1

λ_{F1} = constant section 1

λ_{F2} = constant section 1

λ_{F3} = constant section 1

λ_I = constant section 1

λ_X = constant section 1

ρ_i = total reactivity for typical core region

ρ_1 = total reactivity for core region 1

ρ_2 = total reactivity for core region 2

ρ_3 = total reactivity for core region 3

ρ_4 = total reactivity for core region 4

ρ_5 = total reactivity for core region 5

ρ_6 = total reactivity for core region 6

ρ_7 = total reactivity for core region 7

ρ_8 = total reactivity for core region 8

ρ_B = reactivity effect of boron

ρ_{Di} = reactivity effect of fuel temperature for typical core region

ρ_{D1} = reactivity effect of fuel temperature for core region 1

ρ_{D2} = reactivity effect of fuel temperature for core region 2

ρ_{D3} = reactivity effect of fuel temperature for core region 3

ρ_{D4} = reactivity effect of fuel temperature for core region 4

ρ_{D5} = reactivity effect of fuel temperature for core region 5

ρ_{D6} = reactivity effect of fuel temperature for core region 6

ρ_{D7} = reactivity effect of fuel temperature for core region 7

ρ_{D8} = reactivity effect of fuel temperature for core region 8

ρ_L = reactivity effect of fuel burnup

ρ_{Mi} = reactivity effect of moderator temperature for typical core region

ρ_{M1} = reactivity effect of moderator temperature for core region 1

ρ_{M2} = reactivity effect of moderator temperature for core region 2

ρ_{M3} = reactivity effect of moderator temperature for core region 3

ρ_{M4} = reactivity effect of moderator temperature for core region 4

ρ_{M5} = reactivity effect of moderator temperature for core region 5

ρ_{M6} = reactivity effect of moderator temperature for core region 6

ρ_{M7} = reactivity effect of moderator temperature for core region 7

ρ_{M8} = reactivity effect of moderator temperature for core region 8

ρ_{Ri} = reactivity effect of control rods for typical core region

ρ_{R1} = reactivity effect of control rods for core region 1

ρ_{R2} = reactivity effect of control rods for core region 2

ρ_{R3} = reactivity effect of control rods for core region 3

ρ_{R4} = reactivity effect of control rods for core region 4

ρ_{R5} = reactivity effect of control rods for core region 5

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ρ_{R6} = reactivity effect of control rods for core region 6

ρ_{R7} = reactivity effect of control rods for core region 7

ρ_{R8} = reactivity effect of control rods for core region 8

ρ_{Xi} = reactivity effect of xenon for typical core region

ρ_{X1} = reactivity effect of xenon for core region 1

ρ_{X2} = reactivity effect of xenon for core region 2

ρ_{X3} = reactivity effect of xenon for core region 3

ρ_{X4} = reactivity effect of xenon for core region 4

ρ_{X5} = reactivity effect of xenon for core region 5

ρ_{X6} = reactivity effect of xenon for core region 6

ρ_{X7} = reactivity effect of xenon for core region 7

ρ_{X8} = reactivity effect of xenon for core region 8

ϕ_i = neutron flux for a typical core region, neutrons/sec-cm^2

ϕ_1 = neutron flux for core region 1, neutrons/sec-cm^2

ϕ_2 = neutron flux for core region 2, neutrons/sec-cm^2

ϕ_3 = neutron flux for core region 3, neutrons/sec-cm^2

ϕ_4 = neutron flux for core region 4, neutrons/sec-cm^2

ϕ_5 = neutron flux for core region 5, neutrons/sec-cm^2

ϕ_6 = neutron flux for core region 6, neutrons/sec-cm^2

ϕ_7 = neutron flux for core region 7, neutrons/sec-cm^2

ϕ_8 = neutron flux for core region 8, neutrons/sec-cm^2

σ_X = constant section 1

Σ_f = constant section 1

α_B = constant section 1

α_D = constant section 1

α_M = constant section 1

C_i = neutron precursor concentration for typical delay group

C_1 = neutron precursor concentration delay group 1 - region 1

C_2 = neutron precursor concentration delay group 2 - region 1

C_3 = neutron precursor concentration delay group 3 - region 1

C_4 = neutron precursor concentration delay group 4 - region 1

C_5 = neutron precursor concentration delay group 1 - region 2

C_6 = neutron precursor concentration delay group 2 - region 2

C_7 = neutron precursor concentration delay group 3 - region 2

C_8 = neutron precursor concentration delay group 4 - region 2

C_9 = neutron precursor concentration delay group 1 - region 3

C_{10} = neutron precursor concentration delay group 2 - region 3

C_{11} = neutron precursor concentration delay group 3 - region 3

C_{12} = neutron precursor concentration delay group 4 - region 3

C_{13} = neutron precursor concentration delay group 1 - region 4

C_{14} = neutron precursor concentration delay group 2 - region 4

C_{15} = neutron precursor concentration delay group 3 - region 4

C_{16} = neutron precursor concentration delay group 4 - region 4

C_{17} = neutron precursor concentration delay group 1 - region 5

C_{18} = neutron precursor concentration delay group 2 - region 5

C_{19} = neutron precursor concentration delay group 3 - region 5

C_{20} = neutron precursor concentration delay group 4 - region 5

C_{21} = neutron precursor concentration delay group 1 - region 6

C_{22} = neutron precursor concentration delay group 2 - region 6

C_{23} = neutron precursor concentration delay group 3 - region 6

C_{24} = neutron precursor concentration delay group 4 - region 6

C_{25} = neutron precursor concentration delay group 1 - region 7

C_{26} = neutron precursor concentration delay group 2 - region 7

C_{27} = neutron precursor concentration delay group 3 - region 7

C_{28} = neutron precursor concentration delay group 4 - region 7

C_{29} = neutron precursor concentration delay group 1 - region 8

C_{30} = neutron precursor concentration delay group 2 - region 8

C_{31} = neutron precursor concentration delay group 3 - region 8

C_{32} = neutron precursor concentration delay group 4 - region 8

C_{B1} = refer to section 9

C_{F1} = concentration of empirical isotope No. 1, Btu

C_{F2} = concentration of empirical isotope No. 2, Btu

C_{F3} = concentration of empirical isotope No. 3, Btu

D_i = constant section 1

D_1 = constant section 1

D_2 = constant section 1

D_3 = constant section 1

D_4 = constant section 1

D_5 = constant section 1

h_1 = variable surface coefficient of fuel pins

I_i = concentration of I-135 in typical core region, atoms/cc

I_1 = concentration of I-135 in core region 1, atoms/cc

I_2 = concentration of I-135 in core region 2, atoms/cc

I_3 = concentration of I-135 in core region 3, atoms/cc

I_4 = concentration of I-135 in core region 4, atoms/cc

I_5 = concentration of I-135 in core region 5, atoms/cc

I_6 = concentration of I-135 in core region 6, atoms/cc

I_7 = concentration of I-135 in core region 7, atoms/cc

I_8 = concentration of I-135 in core region 8, atoms/cc

l^* = constant section 1

n = neutron concentration for whole core, neutrons/cc

n_i = neutron concentration in typical core region, neutrons/cc

n_1 = neutron concentration in core region 1, neutrons/cc

n_2 = neutron concentration in core region 2, neutrons/cc

n_3 = neutron concentration in core region 3, neutrons/cc

n_4 = neutron concentration in core region 4, neutrons/cc

n_5 = neutron concentration in core region 5, neutrons/cc

n_6 = neutron concentration in core region 6, neutrons/cc

n_7 = neutron concentration in core region 7, neutrons/cc

n_8 = neutron concentration in core region 8, neutrons/cc

q_{DH} = decay heat generation in core region

S_1 = constant section 1

S_2 = constant section 1

T_{Fi} = temperature of fuel in typical core region, F

T_{F1} = temperature of fuel in core region 1, F

T_{F2} = temperature of fuel in core region 2, F

T_{F3} = temperature of fuel in core region 3, F

T_{F4} = temperature of fuel in core region 4, F

T_{F5} = temperature of fuel in core region 5, F

T_{F6} = temperature of fuel in core region 6, F

T_{F7} = temperature of fuel in core region 7, F

T_{F8} = temperature of fuel in core region 8, F

T_{Mi} = average moderator temperature in typical core region, F

T_{Mi+1} = outlet moderator temperature in typical core region, F

T_{Mi-1} = inlet moderator temperature in typical core region, F

T_{M1} = average moderator temperature in core region 1, F

T_{M2} = moderator temperature - outlet region 1; inlet region 2, F

T_{M3} = average moderator temperature in core region 2, F

T_{M4} = outlet moderator temperature in core region 2, F

T_{M5} = average moderator temperature in core region 3, F

T_{M6} = moderator temperature - outlet region 3, inlet region 4, F

T_{M7} = average moderator temperature in core region 4, F

T_{M8} = outlet moderator temperature in core region 4, F

T_{M9} = average moderator temperature in core region 5, F

T_{M10} = moderator temperature - outlet region 5; inlet region 6, F

T_{M11} = average moderator temperature core region 6, F

T_{M12} = outlet moderator temperature core region 6, F

T_{M13} = average moderator temperature core region 7, F

T_{M14} = moderator temperature - outlet region 7, inlet region 8, F

T_{M15} = average moderator temperature core region 8, F

T_{M16} = outlet moderator temperature core region 8, F

T_{D9} = refer to section 2

T_{Zi} = clad temperature for typical core region, F

T_{Z1} = clad temperature for core region 1, F

T_{Z2} = clad temperature for core region 2, F

T_{Z3} = clad temperature for core region 3, F

T_{Z4} = clad temperature for core region 4, F

T_{Z5} = clad temperature for core region 5, F

T_{Z6} = clad temperature for core region 6, F

T_{Z7} = clad temperature for core region 7, F

T_{Z8} = clad temperature for core region 8, F

U_i = coefficient for heat transfer between clad center and average moderator for 1/8 core region, Btu/sec-F

w_{RC1} = refer to section 2

X_i = xenon concentration for typical core region, atoms/cc

X_1 = xenon concentration for core region 1, atoms/cc

X_2 = xenon concentration for core region 2, atoms/cc

X_3 = xenon concentration for core region 3, atoms/cc

X_4 = xenon concentration for core region 4, atoms/cc

X_5 = xenon concentration for core region 5, atoms/cc

X_6 = xenon concentration for core region 6, atoms/cc

X_7 = xenon concentration for core region 7, atoms/cc

X_8 = xenon concentration for core region 8, atoms/cc

Constants for Reactor Core Equations

α_B = boron reactivity coefficient, ρ/C_{B1}

α_D = Doppler reactivity coefficient, ρ/T_F

α_M = moderator reactivity coefficient, ρ/T_{MA}

β_i = neutron fraction in typical delay group

β_1 = neutron fraction in delay group 1

β_2 = neutron fraction in delay group 2

β_3 = neutron fraction in delay group 3

β_4 = neutron fraction in delay group 4

γ_I = fractional yield of I-135

γ_X = fractional yield of xenon

λ_i = decay constant for typical delay group, sec^{-1}

λ_1 = decay constant for delay group 1, sec^{-1}

λ_2 = decay constant for delay group 2, sec^{-1}

λ_3 = decay constant for delay group 3, sec^{-1}

λ_4 = decay constant for delay group 4, sec^{-1}

λ_{F1} = decay constant for empirical isotope #1, sec^{-1}

λ_{F2} = decay constant for empirical isotope #2, sec^{-1}

λ_{F3} = decay constant for empirical isotope #3, sec^{-1}

λ_I = decay constant for I-135, sec^{-1}

λ_X = decay constant for xenon, sec^{-1}

Σ_f = macroscopic fission cross section of fuel, cm^{-1}

σ_X = microscopic thermal neutron absorption cross section of xenon, cm^2

D_i = typical diffusion term between core regions

D_1 = empirical neutron diffusion term between horizontally adjacent regions

D_2 = empirical neutron diffusion term between horizontally opposite regions

D_3 = empirical neutron diffusion term between vertical pairs of regions

D_4 = empirical neutron diffusion term between vertically adjacent regions

D_5 = empirical neutron diffusion term between vertically opposite regions

$K_{1,1}$ = fuel temperature reference reactivity

$K_{1,2}$ = moderator temperature reference reactivity

$K_{1,3}$ = boron reference reactivity

$K_{1,4}$ = proportionality constant for ϕ

$K_{1,5}$ = yield of empirical DH isotope No. 1, Btu/sec-neutron level

$K_{1,6}$ = yield of empirical DH isotope No. 2, Btu/sec-neutron level

$K_{1,7}$ = yield of empirical DH isotope No. 3, Btu/sec-neutron level

$K_{1,8}$ = thermal capacity of 1/8 of fuel, Btu/F

$K_{1,9}$ = neutron heat generation in 1/8 of fuel, Btu/sec-neutron

$K_{1,10}$ = thermal coefficient—fuel to clad, Btu/sec-F-region

$K_{1,11}$ = thermal capacity of 1/8 of clad, Btu/F

$K_{1,12}$ = thermal capacity of moderator, Btu/F-region

$K_{1,13}$ = moderator flow thermal transport factor, Btu/lb-F

$K_{1,14}$ = thermal coefficient across clad surface film at full flow (Btu/sec-F-region) divided by (full flow)$^{.8}$

$K_{1,15}$ = thermal coefficient between clad node center and outer surface per region, Btu/sec-F

l^* = neutron lifetime, sec

S_1 = original neutron source

S_2 = photoneutron source

2. REACTOR COOLANT SYSTEM MODEL

(Reference Figure C-6 and Section 5.5 of Main Specification)

2.1 Flow Model

$$\tau_{RC} \frac{dw_{RC2}}{dt} = \left(w'_{RC2} - w_{RC2}\right)$$

$$\tau_{RC} \frac{dw_{RC3}}{dt} = \left(w'_{RC3} - w_{RC3}\right)$$

$$\tau_{RC} = K_{2.1}$$

$$w_{RC1} = w_{RC2} + w_{RC3}$$

$$N_{RC} = N_{RCA} + N_{RCB}$$

Flow mode	Reactor coolant pumps running	N_{RCA}	N_{RCB}	w'_{RC2}	w'_{RC3}
1	RCP1AA and RCP1BA RCP1AB and RCP1BB	2	2	$K_{2.2}$	$K_{2.3}$
2	RCP1AA and RCP1BA RCP1AB or RCP1BB	2	1	$K_{2.4}$	$K_{2.5}$
3	RCP1AA or RCP1BA RCP1AB and RCP1BB	1	2	$K_{2.5}$	$K_{2.4}$
4	RCP1AA or RCP1BA RCP1AB or RCP1BB	1	1	$K_{2.6}$	$K_{2.6}$
5	RCP1AA and RCP1BA	2	0	$K_{2.7}$	0
6	RCP1AB and RCP1BB	0	2	0	$K_{2.7}$
7	RCP1AA or RCP1BA	1	0	$K_{2.8}$	0
8	RCP1AB or RCP1BB	0	1	0	$K_{2.8}$
9	None	0	0	$K_{2.47}$	$K_{2.47}$

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2.2 Heat Transport Model

$$K_{2.9}\frac{dT_{P1}}{dt} = w_{RC1}\left[\frac{T_{M4} + T_{M8} + T_{M12} + T_{M16}}{4} - T_{P1}\right]$$

$$T_{P2} = T_{P1} \text{ @ t minus} \left(\frac{K_{2.10}}{w_{RC2}}\right) \text{ sec}$$

$$T_{P12} = T_{P1} \text{ @ t minus} \left(\frac{K_{2.10}}{w_{RC3}}\right) \text{ sec}$$

$$T_{P7} = T_{P6} \text{ @ t minus } K_{2.15}\left(\frac{N_{RCA}}{w_{RC2}}\right) \text{ sec}$$

$$T_{P17} = T_{P16} \text{ @ t minus } K_{2.15}\left(\frac{N_{RCB}}{w_{RC3}}\right) \text{ sec}$$

$$T_{P8} = T_{P7} \text{ @ t minus } K_{2.16}\left(\frac{N_{RCA}}{w_{RC2}}\right) \text{ sec}$$

$$T_{P18} = T_{P17} \text{ @ t minus } K_{2.16}\left(\frac{N_{RCB}}{w_{RC3}}\right) \text{ sec}$$

$$K_{2.17}\frac{dT_{P9}}{dt} = w_{RC2}(T_{P8} - T_{P9}) + w_{RC3}(T_{P18} - T_{P9})$$

(See 3.1 for remainder of heat transport model.)

2.3. Reactor Coolant Mass and Heat Inventory Model

$$\frac{dM_{RC}}{dt} = w_{P12} + w_{P18} - w_{P1} + w_{P21} + w_{P22} + w_{D3}$$
$$+ w_{D4} + w_{DH1} + w_{DH2} - w_{D7} - w_{D8} - w_{P20} - w_{P31}$$

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$$\frac{dQ_{RC}}{dt} = U_1\Sigma(T_{Zi} - T_{Mi}) - K_{3.32}w_{RC2}(T_{P4} - T_{P2})$$

$$- K_{3.32}w_{RC3}(T_{P14} - T_{P12}) - K_{3.33}\left(\frac{dT_{P5}}{dt} + \frac{dT_{P15}}{dt}\right)$$

$$- K_{2.48}(w_{P21} + w_{P22} + w_{D3} + w_{D4}) - q_P + h_{MU}(w_{P12}$$

$$+ w_{P18}) - h_{RC}(w_{P1} + w_{D7} + w_{D5} + w_{P20} + w_{P21})$$

$$- h_{DH}(w_{DH1} + w_{DH2}) - (T_{RC} - T_{PM1})K_{2.18}$$

$$T_{RC} = \frac{2T_{P1} + T_{P7} + T_{P17}}{4}$$

$$h_{RC} = f(T_{RC})$$

$$\frac{dT_{PM1}}{dt} = \frac{1}{K_{2.49}}(T_{RC} - T_{PM1}) - \frac{1}{K_{2.50}}(T_{PM1} - K_{2.51})$$

$$q_P = K_{2.52}N_{RC}$$

2.4. Pressurizer

If $M_{PW2} \geq K_{2.19}$:

$$\frac{dM_{PW1}}{dt} = Z_1\frac{dQ_{RC}}{dt} - \frac{dM_{RC}}{dt} \quad \text{and} \quad \frac{dM_{PW2}}{dt} = 0$$

If $M_{PW2} < K_{2.19}$:

$$\frac{dM_{PW1}}{dt} = 0 \quad \text{and} \quad \frac{dM_{PW2}}{dt} = Z_1\frac{dQ_{RC}}{dt} - \frac{dM_{RC}}{dt}$$

$$K_{2.20}M_{PW1}\frac{dT_{PW1}}{dt} = K_{2.21}(T_{PW2} - T_{PW1}) + q_{PS}$$

$$q_{PS} = K_{2,20} T_{PW1} \frac{dM_{PW1}}{dt} \quad \text{if} \quad \frac{dM_{PW1}}{dt} \quad \text{is negative}$$

$$q_{PS} = K_{2,20} T_{P1} \frac{dM_{PW1}}{dt} \quad \text{if} \quad \frac{dM_{PW1}}{dt} \quad \text{is positive}$$

$$P_{P2} = P_{P1} + (N_{RCA} - N_{RCB}) K_{2,59}$$

$$K_{2.22} M_{PW2} \frac{dT_{PW2}}{dt} = q_h - K_{2.23}(T_{PW2} - T_{PS}) - K_{2.21}(T_{PW2} - T_{PW1}) - K_{2.24} w_B - K_{2.22} T_{PW2} \frac{dM_{PW2}}{dt}$$

$$L_P = K_{2.25}(M_{PW1} + M_{PW2}) - K_{2.26}$$

$$V_{PW} = K_{2.27}(M_{PW1} + M_{PW2})$$

$$V_{PS} = K_{2.28} - V_{PW}$$

$$w_B = K_{2.29}(T_{PW2} - T_{PS})$$

$$\frac{dM_{PS}}{dt} = \frac{w_{SP} \Delta h_P}{h_{Fg1}} + w_B - w_{SR} - K_{2.30}(T_{PS} - T_{PM2})$$

$$\frac{dT_{PM2}}{dt} = \frac{1}{K_{2.31}} (T_{PS} - T_{PM2}) - \frac{1}{K_{2.32}} (T_{PM2} - T_E)$$

$$\rho_{PS} = \frac{M_{PS}}{V_{PS}}$$

$$T_{PS} = f(\rho_{PS})$$

$$P_{P1} = f(\rho_{PS}) \quad \text{if} \quad L_P \geq 0$$

$$P_{P1} = f(T_{RC}) \quad \text{if} \quad L_P < 0$$

$q_h = 0$ if $L_P < K_{2.36}$

$q_h = q_{h1} + q_{h2} + q_{h3} + q_{h4} + q_{h5}$ if $L_P > K_{2.36}$

$$\begin{cases} q_{h1} = 0 \text{ if } P_{P1} > K_{2.2} \text{ or if } K_{2.2} > P_{P1} > K_{2.35} \text{ and } q_{h1} = 0 \\ q_{h1} = K_{2.38} \text{ if } P_{P1} < K_{2.35} \text{ or if } K_{2.2} > P_{P1} > K_{2.35} \text{ and } q_{h1} = K_{2.38} \end{cases}$$

$$\begin{cases} q_{h2} = 0 \text{ if } P_{P1} > K_{2.11} \text{ or if } K_{2.11} > P_{P1} > K_{2.37} \text{ and } q_{h2} = 0 \\ q_{h2} = K_{2.40} \text{ if } P_{P1} < K_{2.37} \text{ or if } K_{2.11} > P_{P1} > K_{2.37} \text{ and } q_{h2} = K_{2.40} \end{cases}$$

$$\begin{cases} q_{h3} = 0 \text{ if } P_{P1} > K_{2.12} \text{ or if } K_{2.12} > P_{P1} > K_{2.39} \text{ and } q_{h3} = 0 \\ q_{h3} = K_{2.42} \text{ if } P_{P1} < K_{2.39} \text{ or if } K_{2.12} > P_{P1} > K_{2.39} \text{ and } q_{h3} = K_{2.42} \end{cases}$$

$$\begin{cases} q_{h4} = 0 \text{ if } P_{P1} > K_{2.13} \text{ or if } K_{2.13} > P_{P1} > K_{2.41} \text{ and } q_{h4} = 0 \\ q_{h4} = K_{2.43} \text{ if } P_{P1} < K_{2.41} \text{ or if } K_{2.13} > P_{P1} > K_{2.41} \text{ and } q_{h4} = K_{2.43} \end{cases}$$

$$\begin{cases} q_{h5} = 0 \text{ if } P_{P1} > K_{2.14} \text{ or if } K_{2.14} > P_{P1} > K_{2.55} \text{ and } q_{h5} = 0 \\ q_{h5} = K_{2.56} \text{ if } P_{P1} < K_{2.55} \text{ or if } K_{2.14} > P_{P1} > K_{2.55} \text{ and } q_{h5} = K_{2.56} \end{cases}$$

$$\begin{cases} w_{SR} = 0 \text{ if } P_{P1} < K_{2.33} \text{ or if } K_{2.33} < P_{P1} < K_{2.44} \text{ and } w_{SR} = 0 \\ w_{SR} = K_{2.45} SV_{91} \text{ if } K_{2.34} > P_{P1} > K_{2.44} \text{ or if } K_{2.44} > P_{P1} > K_{2.33} \\ \quad \text{and } w_{SR} = K_{2.45} SV_{91} \\ w_{SR} = K_{2.45} SV_{91} + K_{2.54} \text{ if } P_{P1} > K_{2.53} \text{ or if } K_{2.53} > P_{P1} > K_{2.34} \\ \quad \text{and } w_{SR} < K_{2.54} \end{cases}$$

$$w_{SP} = K_{2.46} \frac{N_{RC}}{4} S_{38} SV_{90}$$

initiate or maintain setting of:

$S_{38} = 0$ if $P_{P1} < K_{2.56}$ or if $K_{2.58} < P_{P1} < K_{2.57}$ and $S_{38} = 0$

$S_{38} = 1$ if $P_{P1} > K_{2.57}$ or if $K_{2.58} < P_{P1} < K_{2.57}$ and $S_{38} \neq 0$

Note on pressurizer heater and spray valve equations:

The spray valve and 5 heaters are controlled by ON, OFF, AUTO type PB's. The equations supplied on page A-22 reflect the system operation with all PB's in "AUTO." Listed below are additional equations for "OFF" and "ON" operation.

$q_{h1} = 0$, if "OFF"; $q_{h1} = K_{2.38}$, if "ON"; as given if "AUTO"

$q_{h2} = 0$, if "OFF"; $q_{h2} = K_{2.40}$, if "ON"; as given if "AUTO"

$q_{h3} = 0$, if "OFF"; $q_{h3} = K_{2.42}$, if "ON"; as given if "AUTO"

$q_{h4} = 0$, if "OFF"; $q_{h4} = K_{2.43}$, if "ON"; as given if "AUTO"

$q_{h5} = 0$, if "OFF"; $q_{h5} = K_{2.56}$, if "ON"; as given if "AUTO"

final value of $S_{38} = 0$, if 'CLOSE'

final value of $S_{38} = 1$, if 'OPEN'

value of S_{38} as given if "AUTO"

q_{h1} control listed in SIMOR as RC125

q_{h2} control listed in SIMOR as RC129

q_{h3} control listed in SIMOR as RC135

q_{h4} control listed in SIMOR as RC141

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q_{n5} control listed in SIMOR as RC147

S_{38} control listed in SIMOR as RC153

Symbols for Section 2

ρ_{PS} = density of steam in pressurizer

τ_{RC} = variable time constant for reactor coolant flow transients, sec

h_{DH} = refer to section 7

h_{fg1} = constant section 2

h_{MU} = refer to section 6

h_{RC} = enthalpy of reactor coolant, Btu/lb

Δh_P = enthalpy difference between pressurizer water and spray water, Btu/lb (constant)

L_P = water level in pressurizer tank

M_{PS} = mass of pressurizer steam, lb

M_{PW1} = mass of water in pressurizer surge region, lb

M_{PW2} = mass of water in pressurizer saturated region, lb

M_{RC} = mass of water in reactor coolant system, lb

N_{RC} = total number of reactor coolant pumps on-line

N_{RCA} = number of RC pumps in loop A on-line

N_{RCB} = number of RC pumps in loop B on-line

P_{P1} = reactor outlet pressure in loop A, psig

P_{P2} = reactor outlet pressure in loop B, psig

q_h = total heat input from pressurizer heaters, Btu/sec

q_{h1} = heat input by pressurizer heater 1, Btu/sec

q_{h2} = heat input by pressurizer heater 2, Btu/sec

q_{h3} = heat input by pressurizer heater 3, Btu/sec

q_{h4} = heat input by pressurizer heater 4, Btu/sec

q_{h5} = heat input by pressurizer heater 5, Btu/sec

q_P = heat gain of RC pumps, Btu/sec

q_{PS} = heat transported by mass change in pressurizer

Q_{RC} = heat content or reactor coolant, Btu

S_{38} = position of pressurizer spray control valve

SV_{90} = position of pressurizer spray stop valve

SV_{91} = position of stop valve in pressurizer pilot relief line

T_E = pressurizer ambient sink temperature, F

T_{M1} = refer to section 1

T_{M4} = refer to section 1

T_{M8} = refer to section 1

T_{M12} = refer to section 1

T_{M16} = refer to section 1

T_{P1} = temperature of coolant at reactor vessel outlet, F

T_{P2} = temperature of reactor coolant at boiler tube inlet, loop A, F

T_{P4} = refer to section 3

T_{P5} = refer to section 3

T_{P6} = refer to section 3

T_{P7} = temperature of reactor coolant at pump suction, loop A, F

T_{P8} = temperature of coolant at reactor vessel inlet, loop A, F

T_{P9} = temperature of reactor coolant at core inlet, F

T_{P10} = (not used)

T_{P11} = (not used)

T_{P12} = temperature of reactor coolant at boiler tube inlet, loop B, F

T_{P14} = refer to section 3

T_{P15} = refer to section 3

T_{P16} = refer to section 3

T_{P17} = temperature of reactor coolant at pump suction, loop B, F

T_{P18} = temperature of reactor coolant at vessel inlet, loop B, F

T_{PM1} = average RC system metal temperature, F

T_{PM2} = average pressurizer metal temperature, F

T_{PS} = pressurizer steam temperature, F

T_{PW1} = pressurizer water temperature in surge region, F

T_{PW2} = pressurizer water temperature in saturated region, F

T_{RC} = average temperature of reactor coolant, F

T_{Zi} = refer to section 1

U_1 = refer to section 1

V_{PS} = volume of steam in pressurizer, ft³

V_{PW} = volume of water in pressurizer, ft³

w_B = pressurizer water boiling rate, lb/sec

w_{D3} = refer to section 6

w_{D4} = refer to section 6

w_{D7} = refer to section 7

w_{D8} = refer to section 7

w_{DH1} = refer to section 7

w_{DH2} = refer to section 7

w_{P1} = refer to section 6

w_{P12} = refer to section 6

w_{P15} = refer to section 6

w_{P20} = refer to section 8

w_{P21} = refer to section 8

w_{P22} = refer to section 8

w_{P31} = refer to section 8

w_{RC1} = total reactor coolant flow, lb/sec

w_{RC4} = flow in RC loop 1 (dynamic), lb/sec

w_{RC2} = flow in RC loop 1 (steady state), lb/sec

w_{RC3} = flow in RC loop 2 (dynamic), lb/sec

w_{RC2} = flow in RC loop 2 (steady state), lb/sec

w_{SP} = pressurizer spray flow, lb/sec

w_{SR} = pressurizer relief flow, lb/sec

Z_1 = variable swell coefficient for RC, lb/Btu

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Constants for Reactor Coolant System Equations

T_E = ambient sink temperature

$K_{2.1}$ = time constant for RC flow transients, sec

$K_{2.2}$ = cut off point for pressurizer heater group No. 1, psig

$K_{2.3}$ = flow in RC loop A, mode 1, or loop B, mode 1, lb/sec

$K_{2.4}$ = flow in RC loop A, mode 2, or loop B, mode 3, lb/sec

$K_{2.5}$ = flow in RC loop B, mode 2, or loop A, mode 3, lb/sec

$K_{2.6}$ = flow in RC loop A, mode 4, or loop B, mode 4, lb/sec

$K_{2.7}$ = flow in RC loop A, mode 5, or loop B, mode 6, lb/sec

$K_{2.8}$ = flow in RC loop A, mode 7, or loop B, mode 8, lb/sec

$K_{2.9}$ = mass factor for reactor upper plenum, lb

$K_{2.10}$ = mass factor reactor vessel outlet to boiler tube inlet, lb

$K_{2.11}$ = cut off point for pressurizer heater group No. 2, psig

$K_{2.12}$ = cut off point for pressurizer heater group No. 3, psig

$K_{2.13}$ = cut off point for pressurizer heater group No. 4, psig

$K_{2.14}$ = cut off point for pressurizer heater group No. 5, psig

$K_{2.15}$ = mass factor boiler tube outlet to pump inlet, lb

$K_{2.16}$ = mass factor pump inlet to reactor vessel inlet, lb

$K_{2.17}$ = mass factor for reactor entrance annulus and lower plenum, lb

$K_{2.18}$ = thermal constant for RC system metal, Btu/sec-F

$K_{2.19}$ = normal mass in upper region of pressurizer water, lb

$K_{2.20}$ = specific heat of pressurizer insurge, Btu/lb-F

$K_{2.21}$ = thermal coefficient of mixing between pressurizer water and insurge, Btu/sec-F

$K_{2.22}$ = specific heat of pressurizer water, Btu/lb-F

$K_{2.23}$ = thermal coefficient between pressurizer water and steam, Btu/sec-F

$K_{2.49}$ = thermal time constant between reactor coolant and metal, sec

$K_{2.50}$ = thermal time constant between RC metal and RB, sec

$K_{2.51}$ = RB sink temperature, F

$K_{2.52}$ = RC pump heat gain factor, Btu/sec per pump

$K_{2.53}$ = cut on point for pressurizer code relief, psig

$K_{2.54}$ = flow through pressurizer code relief valve, lb/sec

$K_{2.55}$ = cut on point for fifth pressurizer heater group, Btu/sec

$K_{2.56}$ = capacity of fifth pressurizer heater group, Btu/sec

$K_{2.57}$ = set point for initiating opening of pressurizer spray valve, psig

$K_{2.58}$ = set point for initiating closing of pressurizer spray valve, psig

$K_{2.59}$ = RC pressure bias factor

~~[illegible] ter, [illegible]~~

$K_{2.60}$ = RECIPROCAL OF SPECIFIC HEAT REACT. LOW. PLEN., #-F/BTU

$K_{2.65}$ = HEAT TRANSFER FACTOR IN REACTOR BTWN STEAM AND WATER, BTU/F

$K_{2.66}$ = AVERAGE ENTHALPY OF STEAM IN REACTOR SYSTEM, BTU/#

$K_{2.67}$ = BOILING COEFFICIENT IN REACTOR, #/SEC PER F

$K_{2.68}$ = CONDENSING COEFFICIENT IN REACTOR, #/SEC PER F

$K_{2.69}$ = VOLUME OF REACTOR SYSTEM LESS PRESSURIZER, FT^3

$K_{2.70}$ = TOTAL VOLUME OF REACTOR SYSTEM INCL. PRZR, FT^3

$K_{2.71}$ = AVERAGE ENTHALPY OF STEAM IN PRESSURIZER, BTU/#

$K_{2.72}$ = CONDENSING COEFFICIENT FOR STEAM IN PRZR, #/SEC PER F

$K_{2.73}$ = PRZR SPRAY CONDENSING FACTOR, #/SEC PER #/SEC

$K_{2.74}$ =

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~~$K_{2.24}$ = latent heat of boiling pressurizer water, Btu/lb~~

$K_{2.25}$ = pressurizer level constant, in./lb

$K_{2.26}$ = level correction factor for pressurizer lower head, in.

~~$K_{2.27}$ = specific volume of pressurizer water, ft³/lb~~

$K_{2.28}$ = total pressurizer volume, ft^3

$K_{2.29}$ = empirical boiling constant for pressurizer water, lb/sec-F

$K_{2.30}$ = thermal constant for pressurizer metal divided by condensation effect, lb/sec-F

$K_{2.31}$ = thermal time constant between pressurizer steam and metal, sec

$K_{2.32}$ = thermal time constant between pressurizer metal and environmental sink, sec

$K_{2.33}$ = cut off point for pressurizer pilot relief valve, psig

$K_{2.34}$ = cut off point for pressurizer code relief valves, psig

$K_{2.35}$ = cut on point for first pressurizer heater group, psig

$K_{2.36}$ = Lo-Lo pressurizer level set-point, in.

$K_{2.37}$ = cut on point for second pressurizer heater group, psig

$K_{2.38}$ = total capacity of pressurizer heater group 1, Btu/sec

$K_{2.39}$ = cut on point for third pressurizer heater group, psig

$K_{2.40}$ = capacity of pressurizer heater group No. 2, Btu/sec

$K_{2.41}$ = cut on point for fourth pressurizer heater group, psig

$K_{2.42}$ = capacity of pressurizer heater group No. 3, Btu/sec

$K_{2.43}$ = capacity of pressurizer heater group No. 4, Btu/sec

$K_{2.44}$ = cut on point for pressurizer pilot relief, psig

$K_{2.45}$ = flow through pressurizer pilot relief valve, lb/sec

$K_{2.46}$ = pressurizer spray flow at rated conditions, lb/sec

$K_{2.47}$ = flow in RC loop A, or in RC loop B, mode 9, lb/sec

$K_{2.48}$ = enthalpy of water in core flooding tanks or in borate storage tank, Btu/lb

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3. STEAM GENERATOR MODEL

(Reference Section 5.6 of Main Specification)

(For RCH1A)

3.1. Reactor Coolant Side Thermal Model

$$T_{P4} = T_{P2} - K_{3.1} \frac{w_{S1}}{w_{RC2}} (T_{B3} - T_{B1})$$

$$\frac{dT_{P5}}{dt} = K_{3.2} \frac{w_{RC2}}{L_{B2}} (T_{P4} - T_{P5}) + \frac{dL_{B2}}{dt} \left(\frac{T_{P4} - T_{P5}}{L_{B2}} \right)$$

$$- K_{3.3} (T_{P5} - T_{B2})$$

$$T_{P6} = 2T_{P5} - T_{P4}$$

3.2. Steam Side Flow and Mass Model

$$\frac{dL_{B1}}{dt} = K_{3.4} (w_{F7} + w_{B3} - w_{B1})$$

$$\rho_{B4} = f(T_{FD1})$$

$$\frac{dw_{B1}}{dt} = \frac{K_{3.6}}{L_{B1}} \Big[K_{3.7} L_{B1} - K_{3.8} \rho_{B1} L_{B2} + K_{3.9} w_{F7}^2 - K_{3.10} w_{B2}^2$$

$$- K_{3.11} w_{B1}^2 - K_{3.12} w_{B3}^2 - K_{3.13} L_{B2} \frac{dw_{B2}}{dt} \Big]$$

$$\frac{dL_{B2}}{dt} = \frac{w_{B1} - w_{B2} - K_{3.14} L_{B2}\left(\frac{dP_{S1}}{dt}\right)}{K_{3.16}\rho_{B1}}$$

$$\frac{dL_{B3}}{dt} = -\frac{dL_{B2}}{dt}$$

$$w_{B2} = w_{B3} + w_{S1} + K_{3.16}\rho_{B2}\left(\frac{dL_{B3}}{dt}\right) + K_{3.16} L_{B3}\left(\frac{d\rho_{B2}}{dt}\right)$$

$$w_{B3} = \frac{w_{F7}(h_{B1} - h_{B4})}{K_{3.17}}$$

3.3. Steam Side and Tube Metal Thermal Model

$$\frac{dh_{B1}}{dt} = K_{3.18}\left[f(P_{S1}) - h_{B1}\right]$$

$$\frac{dP_{S1}}{dt} = K_{3.19}\left(\frac{w_{B1}h_{B1}}{L_{B2}}\right) + K_{3.20}(T_{B2} - K_{3.21}) - K_{3.22}P_{S1}$$

$$- K_{3.23}\left(\frac{w_{B2}}{L_{B2}}\right) + K_{3.24}\left(\frac{w_{B2}P_{S1}}{L_{B2}}\right) - \frac{K_{3.25}}{L_{B2}}\left(\frac{dL_{B2}}{dt}\right)$$

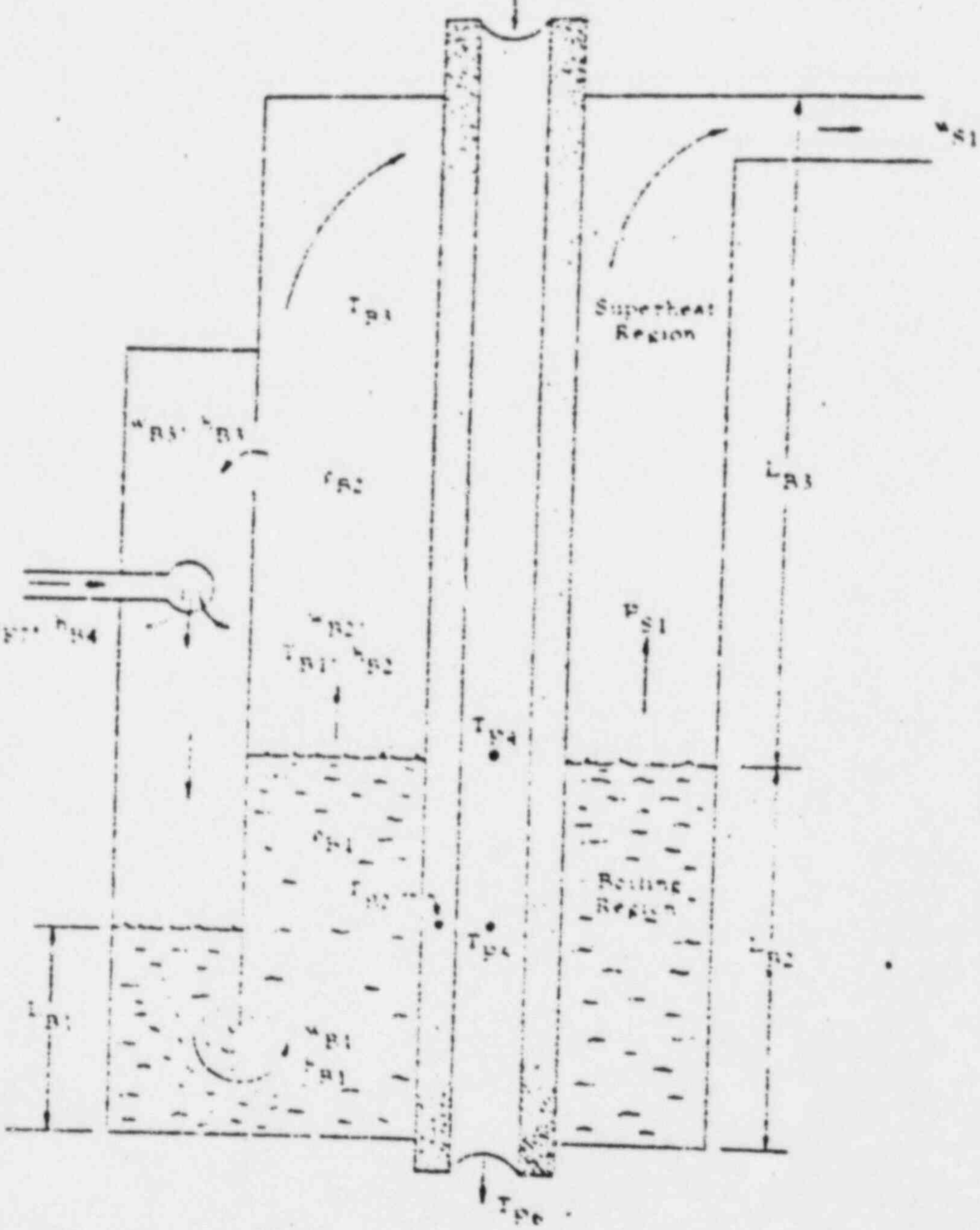
$$- \frac{P_{S1}}{L_{B2}}\left(\frac{dL_{B2}}{dt}\right)$$

$$h_{B2} = f_1(P_{S1})$$

$$\rho_{B1} = f_2(P_{S1})$$

$$T_{B1} = f_3(P_{S1})$$

(Symbols refer to RCH1A)



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Symbols for Section 3

ρ_{B1} = average density in boiling region, RCH1A, Btu/lb

ρ_{B2} = superheated steam density, RCH1A, Btu/lb

ρ_{B3} = average density in boiling region, RCH1B, Btu/lb

ρ_{B4} = superheated steam density, RCH1B, Btu/lb

h_{B1} = enthalpy at entrance of boiling region, RCH1A, Btu/lb

h_{B2} = enthalpy of saturation in RCH1A, Btu/lb

h_{B3} = enthalpy of aspirator flow in RCH1A, Btu/lb

h_{B4} = enthalpy of feedwater into RCH1A, Btu/lb

h_{B5} = enthalpy at entrance of boiling region, RCH1B, Btu/lb

h_{B6} = enthalpy of saturation in RCH1B, Btu/lb

h_{B7} = enthalpy of aspirator flow in RCH1B, Btu/lb

h_{B8} = enthalpy of feedwater into RCH1B, Btu/lb

L_{B1} = length in downcomer of RCH1A, in.

L_{B2} = length in boiling region of RCH1A, in.

L_{B3} = length in superheat region of RCH1A, in.

L_{B4} = length in downcomer of RCH1B, in.

L_{B5} = length in boiling region of RCH1B, in.

L_{B6} = length in superheat region in RCH1B, in.

P_{S1} = outlet pressure at steam generator RC-H1A, psig

P_{S2} = outlet pressure at steam generator RC-H1B, psig

T_{B1} = saturation temperature in RCH1A, F

T_{B2} = average tube metal temperature in RCH1A, F

T_{B3} = superheat temperature in RCH1A, F

T_{B4} = saturation temperature in RCH1B, F

T_{B5} = average tube metal temperature in RCH1B, F

T_{B6} = superheat temperature in RCH1B, F

T_{FD1} = refer to section 5

T_{P2} = refer to section 2

T_{P4} = temperature of reactor coolant at boundary of superheat region and boiling region, RCH1A

T_{P5} = temperature of reactor coolant, average in boiling region, RCH1A, F

T_{P6} = temperature of reactor coolant at outlet of tubes, RCH1A, F

T_{P12} = refer to section 2

T_{P14} = same as T_{P4} for RCH1B

T_{P15} = same as T_{P5} for RCH1B

T_{P16} = same as T_{P6} for RCH1B

U_{2A} = coefficient for heat transfer from reactor coolant to boiler tube, Btu/sec-F-region (loop A)

U_{2B} = coefficient for heat transfer from reactor coolant to boiler tube, Btu/sec-F-region (loop B)

w_{B1} = flow out of downcomer into boiling region, RCH1A, lb/sec

w_{B2} = flow out of boiling region into superheat region, RCH1A, lb/sec

w_{B3} = aspirator flow, RCH1A, lb/sec

w_{B4} = flow out of downcomer into boiling region, RCH1B, lb/sec

w_{B5} = flow out of boiling region into superheat region, RCH1B, lb/sec

w_{B6} = aspirator flow, RCH1B, lb/sec

w_{F7} = refer to section 5

w_{F8} = refer to section 5

w_{RC2} = refer to section 2

w_{RC3} = refer to section 2

w_{S1} = refer to section 4

w_{S2} = refer to section 4

γ = log ΔT ratio superheat to boiling region

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Constants for Steam Generator Model

$K_{3.1}$ = ratio of specific heat of steam/water

$K_{3.2}$ = units conversion times reciprocal of time constant for reactor coolant in boiler, ft/lb

$K_{3.3}$ = thermal factor for heat transfer between reactor coolant and boiler tube, ft^2-°F/Btu

$K_{3.4}$ = reciprocal of downcomer area times fluid density, ft/lb

$K_{3.5}$ = reciprocal of latent heat of steam, lb/Btu

$K_{3.6}$ = units conversion times gravitational factor times downcomer area, ft-$in.^2$/sec^2

$K_{3.7}$ = units conversion times downcomer fluid density, lb/$in.^2$-ft

$K_{3.8}$ = units conversion, ft^2/$in.^2$

$K_{3.9}$ = inertia factor for feedflow, sec^2/lb-$in.^2$

$K_{3.10}$ = inertia factor for saturated steam flow, sec^2/lb-$in.^2$

$K_{3.11}$ = inertia factor for saturated water, sec^2/lb-$in.^2$

$K_{3.12}$ = inertia factor for aspirator flow

$K_{3.13}$ = units conversion times reciprocal of boiling section area and gravitational constant, sec^2/$in.^2$-ft

$K_{3.14}$ = flow kinetics factor No. 1 in boiling region, $in.^2$/ft

$K_{3.15}$ = flow kinetics factor No. 2 in boiling region, lb/ft

$K_{3.16}$ = area in superheater region, ft^2

$K_{3.17}$ = latent heat of steam, Btu/lb

$K_{3.18}$ = reciprocal of downcomer density times downcomer volume, lb^{-1}

$K_{3.19}$ = thermal factor No. 1 for boiling region heat balance, ft-lb/Btu-$in.^2$

$K_{3.20}$ = thermal factor No. 2 for boiling region heat balance, lb/F-$in.^2$

$K_{3.21}$ = thermal factor No. 3 for boiling region heat balance, F

$K_{3.22}$ = thermal factor No. 4 for boiling region heat balance, lb^{-1}

$K_{3.23}$ = thermal factor No. 5 for boiling region heat balance, ft-$in.^2$

$K_{3,24}$ = thermal factor No. 6 for boiling region heat balance, ft-lb

$K_{3,25}$ = thermal factor No. 7 for boiling region heat balance, lb-in.^{2}

$K_{3,26}$ = thermal factor for boiler tube heat balance, F-ft^2/Btu

$K_{3,27}$ = thermal flow factor for boiler tube heat balance, sec^{-1}

$K_{3,28}$ = thermal factor No. 1 for log ΔT model, ft^{-1}

$K_{3,29}$ = thermal factor No. 2 for log ΔT model, ft^{-1}

$K_{3,30}$ = conductance factor for RC side boiler tube surface film

$K_{3,31}$ = conductance factor for steam side boiler tube surface film

4. STEAM SUPPLY PIPING AND TURBINE GENERATOR MODEL

(Reference Figure C-6 and C-7 and Section 5.6 of Main Specification)

4.1. Main and Auxiliary Steam Supply

$w_{S1} = K_{4.1}\sqrt{P_{S1} - P_{S3}}$ $\qquad$ $w_{S2} = K_{4.1}\sqrt{P_{S2} - P_{S4}}$

$w_{S3} = \sqrt{K_{4.2}SV_1(P_{S3} - P_{S5})}$

$w_{S4} = \sqrt{K_{4.2}SV_2(P_{S4} - P_{S10})}$

$w_{S7} = \sqrt{K_{4.3}(0.9SV_3 + 0.9SV_{83} - 0.8SV_3SV_{83})(P_{S3} - P_{S6})}$

$w_{S8} = \sqrt{K_{4.3}(0.9SV_4 + 0.9SV_{84} - 0.8SV_4SV_{84})(P_{S4} - P_{S6})}$

$w_{S9} = K_{4.4}A_{S1}$ $\qquad$ $w_{S10} = K_{4.4}A_{S2}$

$w_{S5} = 0 \quad \text{if} \quad P_{S3} < K_{4.5}$

$w_{S5} = K_{4.6} \quad \text{if} \quad K_{4.5} < P_{S3} < K_{4.7}$

$w_{S5} = K_{4.8} \quad \text{if} \quad K_{4.7} < P_{S3} < K_{4.9}$

$w_{S5} = K_{4.10} \quad \text{if} \quad K_{4.9} < P_{S3} < K_{4.11}$

$w_{S5} = K_{4.12} \quad \text{if} \quad K_{4.11} < P_{S3}$

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$w_{S6} = 0$ if $P_{S4} < K_{4.5}$

$w_{S6} = K_{4.6}$ if $K_{4.5} < P_{S4} < K_{4.7}$

$w_{S6} = K_{4.8}$ if $K_{4.7} < P_{S4} < K_{4.9}$

$w_{S6} = K_{4.10}$ if $K_{4.9} < P_{S4} < K_{4.11}$

$w_{S6} = K_{4.12}$ if $K_{4.11} < P_{S4}$

$\left.\begin{array}{l} w_{S15} = 0 \\ w_{S31} = 0 \end{array}\right\}$ if $P_{S5} < K_{4.14}$

$\left.\begin{array}{l} w_{S37} = 0 \\ w_{S38} = 0 \end{array}\right\}$ if $P_{S10} < K_{4.14}$

$\left.\begin{array}{l} w_{S15} = K_{4.15} \text{ (ICS 49)} \\ w_{S31} = 0 \end{array}\right\}$ if $P_{S5} \geq K_{4.14}$ and if $P_{SC} \geq K_{4.75}$ or bypass permit signal is present (SP 102)

$\left.\begin{array}{l} w_{S37} = K_{4.15} \text{ (ICS 50)} \\ w_{S38} = 0 \end{array}\right\}$ if $P_{S10} \geq K_{4.14}$ and if $P_{SC} \geq K_{4.75}$ or bypass permit signal is present (SP 102)

$\left.\begin{array}{l} w_{S15} = 0 \\ w_{S31} = K_{4.74} \text{ (ICS 49)} \end{array}\right\}$ if $P_{S5} \geq K_{4.14}$ and if $P_{SC} < K_{4.75}$ and if bypass signal is not present (SP 102)

$\left.\begin{array}{l} w_{S37} = 0 \\ w_{S38} = K_{4.74} \text{ (ICS 50)} \end{array}\right\}$ if $P_{S10} \geq K_{4.14}$ and if $P_{SC} < K_{4.75}$ and if bypass signal is not present (SP 102)

$w_{S14} = K_{4.16} w_{S19}$ $\quad$ $w_{S16} = K_{4.13} w_{S19}$

$P_{S3} = f(\rho_{S1})$ $\quad$ $P_{S4} = f(\rho_{S2})$

$P_{S5} = f(\rho_{S3})$ $\quad$ $P_{S6} = f(\rho_{S4})$

$P_{S10} = f(\rho_{S6})$

$w_{S11} = 0$ if $S_{27} \neq 0$

$w_{S11} = f_1(w_{F1})$ if $S_{27} = 0$

$w_{S12} = 0$ if $S_{26} \neq 0$

$w_{S12} = f_1(w_{F2})$ if $S_{26} = 0$

$w_{S22} = 0$ if $S_{27} \neq 0$

$w_{S23} = f_2(w_{F1})$ if $S_{27} = 0$

$w_{S24} = 0$ if $S_{26} \neq 0$

$w_{S24} = f_2(w_{F2})$ if $S_{26} = 0$

$w_{S13} = 0$ if FP3 is off or if $S_{19} \neq 0$

$w_{S13} = 5$ if FP3 is on and if $S_{19} = 0$

$w_{S29} = 0$ if FP3 is off or if $S_{19} = 0$

$w_{S29} = 5$ if FP3 is on and if $S_{19} \neq 0$

$$w_{S32} = S_{27}[f_1(w_{F1}) + f_2(w_{F1})]$$

$$w_{S33} = S_{26}[f_1(w_{F2}) + f_2(w_{F2})]$$

$$\rho_{S1} = \frac{M_{S1}}{K_{4.17}} \qquad \rho_{S2} = \frac{M_{S2}}{K_{4.17}} \qquad \rho_{S6} = \frac{M_{S6}}{K_{4.18}}$$

$$\rho_{S3} = \frac{M_{S3}}{K_{4.18}} \qquad \rho_{S4} = \frac{M_{S4}}{K_{4.19}}$$

$$\frac{dM_{S1}}{dt} = w_{S1} - w_{S3} - w_{S5} - w_{S7} - w_{S9} - \frac{w_{S14}}{2}$$

$$\frac{dM_{S2}}{dt} = w_{S2} - w_{S4} - w_{S6} - w_{S8} - w_{S10} - \frac{w_{S14}}{2}$$

$$\frac{dM_{S3}}{dt} = w_{S3} - w_{S11} - w_{S13} - w_{S15} - w_{S31}$$

$$\frac{dM_{S6}}{dt} = w_{S4} - w_{S12} - w_{S37} - w_{S38}$$

$$\frac{dM_{S4}}{dt} = w_{S7} + w_{S8} - w_{S17} - w_{S18}$$

$$w_{S18} = \frac{q_{W1}}{K_{4.33}}$$

4.2. Turbine Electro-Hydraulic Control (EHC)

4.2.1. Basic EHC Signal Generation

$S_{14} = .5$ momentarily after OCB is initially energized

$S_{14} = 10$ momentarily after OCB is initially de-energized

$S_{14} = \omega_S/K_{4.90}$ if TURBINE MANUAL is energized

$$\begin{cases} S_{14} = (K_{4.101})(\text{ICS input}) & \text{if OPER IC is energized} \\ \dfrac{dS_{14}}{dt} = R_E + R_B & \text{if OPER AUTO is energized} \end{cases}$$

$$\begin{cases} R_E = 0 & \text{if } -K_{4.91} < E_2 < +K_{4.91} \\ R_E = -K_{4.58} & \text{if } E_2 \leq -K_{4.91} \\ R_E = +K_{4.58} & \text{if } E_2 \geq +K_{4.91} \end{cases}$$

$$\begin{cases} R_B = 0 & \text{if GO is not energized or} \\ & \text{if } S_{14} = S_{17} \\ R_B = +K_{4.92} R_C & \text{if GO is energized,} \\ & \text{if } S_{14} < S_{17}\text{, and} \\ & \text{if OCB is not energized} \\ R_B = -K_{4.92} R_C & \text{if GO is energized,} \\ & \text{if } S_{14} > S_{17}\text{, and} \\ & \text{if OCB is not energized} \end{cases}$$

$$\begin{cases} R_B = +R_D & \text{if GO is energized,} \\ & \text{if } S_{14} < S_{17}\text{, and} \\ & \text{if OCB is energized} \\ R_B = -R_D & \text{if GO is energized,} \\ & \text{if } S_{14} > S_{17}\text{, and} \\ & \text{if OCB is energized} \end{cases}$$

R_C = acceleration setting from console

$$\begin{cases} R_D = K_{4.102} & \text{if STAND loading rate is energized} \\ R_D = K_{4.104} & \text{if FAST loading rate is energized} \end{cases}$$

$$
\begin{cases}
S_{17} = .5 & \text{momentarily when OCB is energized} \\
S_{17} = S_{14} & \text{if OPER AUTO is not energized} \\
\dfrac{dS_{17}}{dt} = 0 & \text{if both "setter" RAISE and LOWER are de-energized} \\
\dfrac{dS_{17}}{dt} = +K_{4.47} & \text{if "setter" RAISE is energized} \\
\dfrac{dS_{17}}{dt} = -K_{4.47} & \text{if "setter" LOWER is energized}
\end{cases}
$$

$$
\begin{cases}
S_{13} = K_{4.57} & \text{if OCB is energized} \\
S_{13} = K_{4.99}S_{14} & \text{if OCB is not energized}
\end{cases}
$$

$$E_5 = S_{13} - \omega_S$$

4.2.2. Automatic Throttle Valve Controller

$$
\begin{cases}
E_1 = E_5 & \text{if TRANSFER is not energized} \\
E_1 = K_{4.49} & \text{if TRANSFER is energized}
\end{cases}
$$

$$S_5' = K_{4.48}E_1 \quad \text{if TURBINE MANUAL is not energized}$$

4.2.3. Manual Throttle Valve Controller

$$
\begin{cases}
S_5' = 0 & \text{if LATCH is not energized and if TURBINE MANUAL is energized} \\
\dfrac{dS_5'}{dt} = K_{4.43}S_{11} & \text{if TURBINE MANUAL is energized and if LATCH is energized}
\end{cases}
$$

$$
\begin{cases}
S_{11} = -K_{4.94} & \text{if manual throttle valve LOWER is energized and if FAST is not energized} \\
S_{11} = +K_{4.94} & \text{if manual throttle valve RAISE is energized and if FAST is not energized}
\end{cases}
$$

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$$\begin{cases} S_{11} = -K_{4.95} & \text{if manual throttle valve LOWER and FAST are both energized} \\ S_{11} = +K_{4.95} & \text{if manual throttle valve RAISE and FAST are both energized} \end{cases}$$

4.2.4. Throttle Valve Actuator

This may be driven by either the automatic or the manual throttle valve controller. The actuator output in turn determines the actual throttle valves positions—subject to individual valves test modes. The combined throttle valves hydraulic characteristic is simulated independently of the individual valves positions and is a direct function of the actuator output.

$S_5 = 0$ if LATCH is deenergized

$$K_{4.39}\frac{dS_5}{dt} = K_{4.40}S_5' - S_5 \quad \text{if LATCH is energized}$$

track meter position = $\Delta S_5'$

$$\Delta S_5' = \int K_{4.43}S_{11}\,dt - K_{4.46}E_1$$

4.2.5. Automatic Governor Valve Controller

$$K_{4.90}\frac{dP_{S7}'}{dt} = P_{S7} - P_{S7}'$$

$$\begin{cases} E_4 = E_5/K_R + S_{14} - K_{4.56}P_{S7}' & \text{if OCB is energized and if IMPI is energized} \\ E_4 = E_5/K_R + S_{14} & \text{if OCB is energized and if IMPO is energized} \\ E_4 = E_5/K_R & \text{if OCB is not energized} \end{cases}$$

$E_3 = E_4$ if TRANSFER is energized

[illegible] $= K_{4.55}$ if TRANSFER is not energized

$$\begin{cases} S_{12} = K_{4.51} E_3 & \text{if IMPO is energized} \\ K_{4.52}\, dS_{12}/dt = K_{4.53} \dfrac{dE_3}{dt} + E_3 & \text{if IMPI is energized} \end{cases}$$

Set $S_9 = 0$ if LATCH is not energized

Hold S_9 and Set $S_7 = S_9$ } if MT2 is energized and TURBINE MANUAL is not energized and LATCH is energized

$\frac{dS_9}{dt} = K_{4.44} E_2$ and Set $S_7 = S_{12}$ } if MT2 is not energized and TURBINE MANUAL is not energized and LATCH is energized

$$E_2 = K_{4.50}(S_9 - S_{12})$$

4.2.6. <u>Manual Governor Valve Controller</u>

$$\begin{cases} S_9 = 0 & \text{if MANUAL is energized and LATCH is not energized} \\ \dfrac{dS_9}{dt} = K_{4.44} S_{10} & \text{if MANUAL is energized and if LATCH is energized} \end{cases}$$

$$\begin{cases} S_{10} = -K_{4.86} & \text{if manual governor valve LOWER is energized and FAST is not energized} \\ S_{10} = +K_{4.88} & \text{if manual governor valve RAISE is energized and FAST is not energized} \\ S_{10} = -K_{4.86} & \text{if manual governor valve LOWER is energized and FAST is energized} \\ S_{10} = +K_{4.89} & \text{if manual governor valve RAISE is energized and FAST is energized} \\ S_{10} = 0 & \text{if neither manual LOWER nor manual RAISE is energized} \end{cases}$$

$S_7 = S_6$ if MANUAL is energized

4.2.7. Governor Valve Actuator

(See note in 4.2.4.)

$$\begin{cases} \text{Hold } S_6' & \text{if throttle pressure limit is activated and} \\ & \text{if } \dfrac{P_{S3} + P_{S4}}{2} \le P_{set} \\ S_6' = K_{4.97} S_7 & \text{if throttle pressure limit is not activated,} \\ & \text{or if } \dfrac{P_{S3} + P_{S4}}{2} > P_{set}\text{, and if } S_7 < S_8 \\ S_6' = K_{4.97} S_8 & \text{if throttle pressure limit is not activated,} \\ & \text{or if } \dfrac{P_{S3} + P_{S4}}{2} > P_{set}\text{, and if } S_7 > S_8 \end{cases}$$

$$\begin{cases} \dfrac{dS_8}{dt} = 0 & \text{if neither POSITION LIMIT RAISE nor POSITION LIMIT LOWER is on} \\ \dfrac{dS_8}{dt} = +K_{4.96} & \text{if POSITION LIMIT RAISE is on} \\ \dfrac{dS_8}{dt} = -K_{4.96} & \text{if POSITION LIMIT LOWER is on} \end{cases}$$

$$\begin{cases} S_6 = 0 & \text{if } OST_1 \text{ is energized or if LATCH is not energized} \\ K_{4.41} \dfrac{dS_6}{dt} = K_{4.42} S_6' - S_6 & \text{if LATCH is energized and } OST_1 \text{ is not energized} \end{cases}$$

4.2.8. Throttle Valve Position Logic

The combined effective throttle valve position is simulated in the turbine torque equations as S_5. However, the four throttle valves have individual position indication and testing capability. Also, the effect of individual valve action on flow must be simulated as shown in section 4.1.

$$\begin{cases} SV_3 = 0 & \text{if } TV_1 \text{ test is energized and if no other TV is in test} \\ SV_3 = S_5 & \text{if } TV_1 \text{ test is not energized or if any other TV is in test} \end{cases}$$

$$\begin{cases} SV_{83} = 0 & \text{if } TV_2 \text{ test is energized and if no other TV is in test} \\ SV_{83} = S_5 & \text{if } TV_2 \text{ test is not energized and if any other TV is in test} \end{cases}$$

$$\begin{cases} SV_4 = 0 & \text{if } TV_3 \text{ test is energized and if no other TV is in test} \\ SV_4 = S_5 & \text{if } TV_3 \text{ test is not energized and if any other TV is in test} \end{cases}$$

$$\begin{cases} SV_{84} = 0 & \text{if } TV_4 \text{ test is energized and if no other TV is in test} \\ SV_{84} = S_5 & \text{if } TV_4 \text{ test is not energized and if any other TV is in test} \end{cases}$$

Each of the four throttle valve position signals SV_3, SV_{83}, SV_4, SV_{84}, drive analog position meters and also energize open and close limit lights. If the valve is in mid stroke, both the open and close light are energized.

4.2.9. Governor Valve Position Logic

The combined effective governor valve position is simulated in the turbine torque equation as S_e. In order to produce a linear effect the four governor valves are programmed to open in a prescribed sequence— except in the mode where TRANSFER is not energized, when all governors open together. Individual position simulation must, therefore, be provided for each valve.

$S_{15A} = S_6$ if TRANSFER is not energized

$S_{15B} = S_6$ if TRANSFER is not energized

$S_{16A} = S_6$ if TRANSFER is not energized

$S_{16B} = S_6$ if TRANSFER is not energized

$S_{15A} = 0$ if TRANSFER is energized and if $S_6 < K_{4,79}$

$S_{15B} = 0$ if TRANSFER is energized and if $S_6 < K_{4,81}$

$S_{16A} = 0$ if TRANSFER is energized and if $S_6 < K_{4,83}$

$S_{16B} = 0$ if TRANSFER is energized and if $S_6 < K_{4,85}$

$S_{15A} = 1$ if TRANSFER is energized and if $S_6 > K_{4,80}$

$S_{15B} = 1$ if TRANSFER is energized and if $S_6 > K_{4,82}$

$S_{16A} = 1$ if TRANSFER is energized and if $S_6 > K_{4,84}$

$S_{16B} = 1$ if TRANSFER is energized and if $S_6 > K_{4,86}$

$$S_{15A} = \frac{S_6 - K_{4,79}}{K_{4,80} - K_{4,79}}$$ if TRANSFER is energized and if $K_{4,79} < S_6 < K_{4,80}$

$$S_{15B} = \frac{S_6 - K_{4,81}}{K_{4,82} - K_{4,81}}$$ if TRANSFER is energized and if $K_{4,81} < S_6 < K_{4,82}$

$$S_{16A} = \frac{S_6 - K_{4,83}}{K_{4,84} - K_{4,83}}$$ if TRANSFER is energized and if $K_{4,83} < S_6 < K_{4,84}$

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$$S_{16B} = \frac{S_6 - K_{4.85}}{K_{4.86} - K_{4.85}} \quad \begin{array}{l} \text{if TRANSFER is energized and} \\ \text{if } K_{4.85} < S_6 < K_{4.86} \end{array}$$

The logic for governor valve position indication is identical to that for throttle valves.

4.2.10. Reheat Stop Valve Position Logic (RSV)

These valves, which are located at the reheater outlet, are not used to control flow. Neither does the momentary testing of one valve noticeably effect steam flow. Their flow stop action following a turbine trip is included in the transfer function for turbine torque.

The testing of each RSV is done simultaneously with the testing of a companion Intercept Valve (IV).

$RSV_1 = 1$ if LATCH is energized and
[if MAINTENANCE TEST is not energized, or
if MAINTENANCE TEST is energized but
$(RSV - IV)_1$ is not in TEST, or
if MAINTENANCE TEST is energized and
$(RSV - IV)_1$ is in TEST but some other (RSV - IV) is in TEST]

$RSV_1 = 0$ if LATCH is not energized or
[if MAINTENANCE TEST is energized and
$(RSV - IV)_1$ TEST is energized and if no
other (RSV - IV) TEST is energized]

RSV_2, RSV_3, and RSV_4 have the same type logic. If any RSV is "zero", its close light is energized. If any RSV is "one", its open light is energized.

4.2.11. Intercept Valve Logic (IV)

These valves, which are located immediately downstream from the RSV, have a function which is similar to the RSV. The difference is that the IV may be closed by the lowest overspeed condition which does not affect the RSV. Also, the IV opening stroke time is longer than the RSV.

$IV_1 = 0$ if LATCH is not energized or
if OST_1 is energized or
[if MAINTENANCE TEST is energized and
$(RSV - IV)_1$ is in TEST and no other RSV - IV is in TEST]

$\frac{d(IV)_1}{dt} = +K_{4.67}$ if LATCH is energized; and if OST$_1$ is not energized; and if IV$_1$ ≠ 1; and

- if MAINTENANCE TEST is not energized, or
- if MAINTENANCE TEST is energized but (RSV − IV)$_1$ is not in TEST, or
- if MAINTENANCE TEST is energized and (RSV − IV)$_1$ is in TEST but some other (RSV − IV) is in TEST

Hold IV$_1$ = 1 — if IV$_1$ = 1 and d(IV)$_1$/dt would otherwise equal $+K_{4.67}$

Energize IV$_1$ close light — if IV$_1$ = 0

Energize IV$_1$ open light — if IV$_1$ = 1

Energize IV$_1$ open and close light — if $0 < IV_1 < 1$

The three other IV have logic which is similar to that for IV$_1$.

4.2.12. Requirements for Energizing EHC Modes, Signals, and Lights

4.2.12.1. EHC Modes

Item	Prerequisites (loss of which also releases)	Initiated by	Released by
TURCR		ON and ENGAGE PB	OFF or GO or DISENGAGE
LATCH	OST_1 not energized EXTHR not energized LOIL not energized LOVAC not energized	LATCH PB	MAN TRIP
MAN		TURBINE MANUAL, SET, or LET PB	OPER AUTO or OPER IC
OPER AUTO		OPER AUTO PB	MANUAL or OPER IC
OPER IC	OCB energized	OPER IC PB	MANUAL or OPER AUTO
OPER AUTO SYNC	$n_S = K_{4.[illegible]} \pm K_{4.69}$	OPER AUTO SYNC PB	
SET	OCB not energized	$\left\lvert\frac{E_4}{S_{13}}\right\rvert > K_{4.66}$	$\left\lvert\frac{E_4}{S_{13}}\right\rvert < K_{4.66}$
LET	OCB energized and OPER IC not energized	$\left\lvert\frac{E_4}{S_{14}}\right\rvert > K_{4.67}$	$\left\lvert\frac{E_4}{S_{14}}\right\rvert < K_{4.67}$
GO	LATCH energized OPER AUTO energized	GO PB	HOLD or $S_{14} = S_{17}$
HOLD		HOLD PB	GO
MT1	LATCH energized	TRANSFER PB	
OCB	None ——— if ——→	Manual action	$n_S < K_{14.[illegible]}$ or MANUAL TRIP or Manual OPEN OCB
	OPER AUTO SYNC if ——→	$n_S = K_{4.[illegible]} \pm K_{4.[illegible]}$	
MT2	$E_2 = 0$ (within $\pm K_{4.61}$)	OPER AUTO or OPER IC PB	($E_2 \neq 0$)
OST_1	OST_2 TEST not energized	$n_S > K_{4.60}$ or OST_1 TEST SW	$n_S < K_{4.60}$ and OST_1 TEST not energized
OST_2		$n_S > K_{4.73}$	$n_S < K_{4.73}$
EXTHR		$E_T > K_{4.61}$	$E_T < K_{4.61}$
LOIL		$P_{01} < K_{4.62}$	$P_{01} > K_{4.62}$
LOVAC		$P_{SC} < K_{4.75}$	$P_{SC} > K_{4.75}$
IMPI	OCB energized	IMPI PB	IMPO or OPER IC
IMPO		IMPO PB	IMPI

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4.2.12.2. EHC Console Input Signals

R_C	Maintained by console acceleration rate setting
R_D	Initiated by STND and released by FAST, or initiated by FAST and released by STND
$\frac{dS_{17}}{dt}$	Maintained by console "Setter Raise" or "Setter Lower" pushbuttons
$\frac{dS_8}{dt}$	Maintained by console VALVE POSITION LIMITER Raise or Lower Pushbuttons
S_{10}	Maintained by Console Manual Governor Control Raise or Lower pushbuttons (with or without FAST)
S_{11}	Maintained by Console Manual Throttle Control Raise or Lower Pushbuttons (with or without FAST)
TV_1 TEST	Maintained by Console (Throttle Test)$_1$ PB
TV_2 TEST	Maintained by Console (Throttle Test)$_2$ PB
TV_3 TEST	Maintained by Console (Throttle Test)$_3$ PB
TV_4 TEST	Maintained by Console (Throttle Test)$_4$ PB
$(RSV - IV)_1$ TEST	Maintained by Console $(RSV - IV)_1$ Test PB
$(RSV - IV)_2$ TEST	Maintained by Console $(RSV - IV)_2$ Test PB
$(RSV - IV)_3$ TEST	Maintained by Console $(RSV - IV)_3$ Test PB
$(RSV - IV)_4$ TEST	Maintained by Console $(RSV - IV)_4$ Test PB
OST_1 TEST	Maintained by Console Switch
OST_2 TEST	Maintained by Console Switch
MAINT TEST	Maintained by Console Switch
THR PRESS IN	Initiated by momentary TPC IN Released by momentary TPC OUT
THR PRESS OUT	Initiated by momentary TPC OUT Released by momentary TPC IN

The following input signals are initiated by momentary console pushbuttons and have been previously included in 4.12.2.1:

LATCH, MANUAL TRIP, TURBINE MANUAL, OPER AUTO, GO, HOLD, OPER AUTO SYN, OPER ICS, TRANSFER.

4.2.12.3. EHC Lights and Displays

UNIT TRIP: energized by LATCH deenergized

SPEED CONTROL: energized by OCB deenergized

LOAD CONTROL: energized by OCB energized

THROTTLE CONTROL: energized by MTI deenergized

GOVERNOR CONTROL: energized by MTI energized

VALVE POSITION LIMIT: energized by $S_7 \geq S_8$

THROT PRESS LIMIT: energized by $\frac{P_{S3} + P_{S4}}{2} < P_{set}$

TV, GV, RSV, and IV status lights and meters are energized by logic and equations in 4.2.6, 4.2.7, 4.2.10, and 4.2.11. SETTER display indicates $K_{4.98}S_{17}$ if OCB is not energized and $K_{4.99}S_{17}$ if OCB is energized.

REFERENCE display indicates $K_{4.98}S_{14}$ if OCB is not energized and $K_{4.99}S_{14}$ if OCB is energized.

4.3. Turbine Torque, Speed, Power, and Temperature Equations

$$P_{S7} = f(\rho_{S5})$$

$$\rho_{S5} = \frac{M_{S5}}{K_{4.23}}$$

$$\frac{dM_{S5}}{dt} = w_{S17} - w_{S19}$$

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$$w_{S19} = K_{4.24}P_{S7}$$

$$w_{S17} = K_{4.21}S_5S_6(P_{S6} - P_{S7})$$

$$w_{S20} = w_{S19} - w_{S16} - w_{S21}$$

$$K_{4.77}\frac{dw_{S25}}{dt} = w_{S20} - w_{S23} - w_{S24} - w_{S25}$$

$$w_{S26} = w_{S25} - w_{S22}$$

$$K_{4.77}\frac{dM_S}{dt} = K_{4.78}(w_{S17} - w_{S19}) + K_{4.27}w_{S19} - M_S$$

$$M_d = K_{4.28}w_{S19}$$

$$\begin{cases} \omega_S = K_{4.26} & \text{if TURGR is energized} \\ \dfrac{d\omega_S}{dt} = K_{4.25}(M_s - M_g - M_w - M_e - M_d) & \text{if TURGR is not energized} \end{cases}$$

$$M_w = K_{4.29}\omega_S$$

$$\begin{cases} \left.\theta = 0 \text{ and } \dfrac{d\theta}{dt} = 0\right\} & \text{if OCB is not energized} \\ \dfrac{d\theta}{dt} = (\omega_S - \omega_0)K_{4.30} & \text{if OCB is energized} \end{cases}$$

$$M_e = K_{4.32}\frac{d\theta}{dt}$$

$$MW_E = E_X\left(K_{4.31}\sin\theta + \frac{W_1}{1000}\right)$$

$M_g = K_{4.72} MW_E$

Equations for Excitation (E_X) and other electrical modeling may be found in section 14.

$$K_{4.35} \frac{dT_{SM1}}{dt} = (T_{S1} - T_{SM1})$$

$$T_{S1} = \frac{T_{B3} + T_{B6}}{2}$$

$$q_{W1} = K_{4.34}(T_{S1} - T_{SM1})$$

$$K_{4.36} \frac{dT_{SM2}}{dt} = (T_{S2} - T_{SM2})$$

$$K_{4.37} \frac{dT_{SM3}}{dt} = (T_{S2} - T_{SM3})$$

$$E_T = K_{4.38}(T_{SM2} - T_{SM3})$$

$$T_{S2} = f(P_{S8})$$

$$P_{S8} = f(\omega_{S20})$$

$P_{O1} = K_{4.63}\omega_S$ { if auxiliary ac or dc oil pump is off or if $K_{4.63}\omega_S > K_{4.65}$

$P_{O1} = K_{4.65}$ { if auxiliary ac or dc oil pump is on and if $K_{4.65} > K_{4.63}\omega_S$

Symbols for Section 4

θ = electrical phase angle, deg

ρ_{S1} = density of steam in RC-H1A header, lb/ft^3

ρ_{S2} = density of steam in RC-H1B header, lb/ft^3

ρ_{S3} = density of steam in auxiliary supply header A, lb/ft^3

ρ_{S4} = density of steam in main supply header, lb/ft^3

ρ_{S5} = density of steam in main turbine chest, lb/ft^3

ρ_{S6} = density of steam in auxiliary supply header, B, lb/ft^3

ω_S = main turbine generator shaft speed, cps

ω_L = line frequency, cps

A_{S1} = area of leak in RC-H1A header, ft^2

A_{S2} = area of leak in RC-H1B header, ft^2

E_1 = speed/load error signal to automatic throttle (stop) valve controller

E_2 = error signal from tracking amplifier of automatic governor valve controller mode transfer system

E_3 = speed/load error signal to automatic governor valve controller

E_4 = non-biased speed/load error signal to automatic governor valve controller

E_5 = non-regulated and non-biased speed error signal

E_T = excess thrust in main turbine

E_X = refer to section 14

IV_1 = intercept valve No. 1

IV_2 = intercept valve No. 2

IV_3 = intercept valve No. 3

IV_4 = intercept valve No. 4

K_R = constant section 4

M_d = main turbine damping torque, ft-lb

M_e = main turbine generator electrical torque losses, ft-lb

M_g = main turbine generator load torque, ft-lb

M_S = main turbine driving torque (from steam), ft-lb

M_{S1} = steam mass in RC-H1A header, lb

M_{S2} = steam mass in RC-H1B header, lb

M_{S3} = steam mass in auxiliary supply header, lb (A)

M_{S4} = steam mass in main supply header, lb

M_{S5} = steam mass in main turbine chest, lb

M_{S6} - steam mass in auxiliary supply header, lb (B)

M_w = main turbine generator mechanical loss torque, ft-lb

MW_E = generator electrical megawatt output

P_{O1} = main turbine oil pressure, psig

P_{S1} = refer to section 3

P_{S2} = refer to section 3

P_{S3} = steam header pressure at STOP valve inlet for header A, psig

P_{S4} = steam header pressure at STOP valve inlet for header B, psig

P_{S5} = pressure in auxiliary steam header A, psig

P_{S6} = pressure at governor valve inlet, psig

P_{S7} = main turbine first stage pressure, psig (STATIC)

P'_{S7} = main turbine first stage pressure, psig

P_{S8} = pressure at reheater outlet

P_{S10} = pressure in auxiliary steam header B, psig

P_{SC} = refer to section 5

P_{set} = constant section 4

q_{W1} = heat absorbed by steam supply piping, Btu/sec

R_B = speed/load rate signal from input controls, cps/sec

R_C = speed rate signal from input rate set, cps/sec

R_D = load rate signal from input load rate set, %/sec

R_E = reference load rate from MT, %/sec

R_F = load rate from ICS, %/sec

R_{SV1} = reheat stop valve No. 1

R_{SV2} = reheat stop valve No. 2

R_{SV3} = reheat stop valve No. 3

R_{SV4} = reheat stop valve No. 4

S_5 = master throttle valve position from actuator

S_5' = master throttle valve position demand to actuator

$\Delta S_5'$ = throttle valve track meter position

S_6 = master governor valve position from actuator

S_6' = master governor valve position demand to actuator

S_7 = demand governor valve position signal without load limit

S_8 = demand governor valve position signal from load limit setter (input)

S_9 = demand governor valve position signal from manual governor valve controller (MGVC)

S_{10} = input to MGVC from manual input

S_{11} = input to manual throttle valve controller from manual input

S_{12} = output demand governor valve position signal from automatic governor valve controller (AGVC)

S_{13} = speed demand signal

S_{14} = speed/load demand signal, cps or %

S_{15A} = actual position of governor valve No. 1

S_{15B} = actual position of governor valve No. 2

S_{16A} = actual position of governor valve No. 3

S_{16B} = actual position of governor valve No. 4

S_{17} = input speed/load setting

S_{19} = FFP No. 2 turbine valve position

S_{26} = refer to section 5

S_{27} = refer to section 5

SV_1 = position of valve between steam header A and auxiliary header

SV_2 = position of valve between steam header B and auxiliary header

SV_3 = position of throttle valve No. 1

SV_4 = position of throttle valve No. 2

SV_{83} = position of stop valve No. 2 in steam header A

SV_{84} = position of stop valve No. 2 in steam header B

T_{B3} = refer to section 3

T_{B6} = refer to section 3

T_{S1} = temperature of steam at turbine stop valve inlet, F

T_{S2} = temperature of steam at crossover between high and low pressure turbines, F

T_{SM1} = temperature of steam supply piping, F

T_{SM2} = temperature of turbine casing, F

T_{SM3} = temperature of turbine shaft, F

V_S = refer to section 14

w_I = refer to section 14

w_{F1} = refer to section 5

w_{F2} = refer to section 5

w_{S1} = steam flow from steam generator RC-H1A, lb/sec

w_{S2} = steam flow from steam generator RC-H1B, lb/sec

w_{S3} = steam flow to auxiliary header from RC-H1A, lb/sec

w_{S4} = steam flow to auxiliary header from RC-H1B, lb/sec

w_{S5} = steam flow through relief valves from RC-H1A, lb/sec

w_{S6} = steam flow through relief valves from RC-H1B, lb/sec

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w_{S7} = steam flow from RC-H1A header to governor valves, lb/sec

w_{S8} = steam flow from RC-H1B header to governor valves, lb/sec

w_{S9} = flow through leak in RC-H1A header, lb/sec

w_{S10} = flow through leak in RC-H1B header, lb/sec

w_{S11} = flow to main feed pump No. 1, lb/sec

w_{S12} = flow to main feed pump No. 2, lb/sec

w_{S13} = flow to emergency feed pump No. 1, from H.P. header, lb/sec

w_{S14} = flow to reheater from main steam header, lb/sec

w_{S15} = turbine bypass flow, lb/sec (Loop A)

w_{S16} = flow to reheater from H.P. extraction, lb/sec

w_{S17} = flow from main header to H.P. turbine chest, lb/sec

w_{S18} = steam flow for warming piping, lb/sec

w_{S19} = steam flow at main turbine first stage, lb/sec

w_{S20} = steam flow out of H.P. turbine, lb/sec

w_{S21} = refer to section 5

w_{S22} = refer to section 5

w_{S23} = steam flow to main feed pump No. 1 from reheaters, lb/sec

w_{S24} = steam flow to main feed pump No. 2 from reheaters, lb/sec

w_{S25} = steam flow into L.P. turbines

w_{S26} = steam flow out of L.P. turbines

w_{S31} = steam flow through auxiliary header exhaust valves (A), lb/sec

w_{S32} = flow to feed pump No. 1 from auxiliary boiler, lb/sec

w_{S33} = flow to feed pump No. 2 from auxiliary boiler, lb/sec

w_{S37} = turbine bypass flow (B), lb/sec

w_{S38} = steam flow through auxiliary header exhaust valves (B), lb/sec

Constants for Steam Supply Piping and Turbine Generator Equations

$K_{4.1}$ = conversion factor for flow in boiler supply headers, section 1

$K_{4.2}$ = conversion factor for flow in auxiliary supply headers

$K_{4.3}$ = conversion factor for flow in boiler supply headers, section 2

$K_{4.4}$ = conversion factor for flow through leak in boiler headers

$K_{4.5}$ = first threshold of steam supply relief, psig

$K_{4.6}$ = steam relief flow mode 1, lb/sec

$K_{4.7}$ = second threshold of steam supply relief, psig

$K_{4.8}$ = steam relief flow mode 2, lb/sec

$K_{4.9}$ = third threshold of steam supply relief, psig

$K_{4.10}$ = steam relief flow mode 3, lb/sec

$K_{4.11}$ = fourth threshold of steam supply relief, psig

$K_{4.12}$ = steam relief flow mode 4, lb/sec

$K_{4.13}$ = fraction of steam from H.P. extraction to reheaters

$K_{4.14}$ = set point for turbine bypass flow, psig

$K_{4.15}$ = turbine bypass flow, lb/sec

$K_{4.16}$ = fraction of H.P. steam to reheaters

$K_{4.17}$ = volume of each boiler steam supply header, ft^3

$K_{4.18}$ = volume of auxiliary steam supply header, ft^3

$K_{4.19}$ = volume of lumped steam supply header between isolation and stop valves, ft^3

$K_{4.21}$ = factor for combined main turbine governor valve flow simulation

$K_{4.23}$ = volume of main turbine inlet chest, ft^3

$K_{4.24}$ = "gain" factor for pressure drop-flow simulation through turbines

$K_{4.25}$ = overall turbine-generator inertia constant cycles/sec^2-ft-lb

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$K_{4.26}$ = turbine speed with turning gear, cps

$K_{4.27}$ = factor for converting steam flow to driving torque in L.P. turbine

$K_{4.28}$ = steam flow torque damping loss factor, ft-sec

$K_{4.29}$ = T-G mechanical loss constant, lb-ft/cps

$K_{4.30}$ = power phase-angle conversion for main generator, degree/cps

$K_{4.31}$ = phase-angle to torque conversion

$K_{4.32}$ = generator electrical loss constant, lb-ft-sec/degree

$K_{4.33}$ = heat of condensation in steam header, Btu/lb

$K_{4.34}$ = thermal transfer factor for heat loss to steam header piping, Btu/sec-F

$K_{4.35}$ = thermal time constant for steam header piping, sec

$K_{4.36}$ = thermal time constant for turbine casing, sec

$K_{4.37}$ = thermal time constant for turbine shaft, sec

$K_{4.38}$ = turbine expansion factor, inches/F

$K_{4.39}$ = time constant for main throttle (stop) valve actuator, sec

$K_{4.40}$ = gain factor for main throttle valve actuator

$K_{4.41}$ = time constant for governor valve actuator, sec

$K_{4.42}$ = gain factor for governor valve actuator

$K_{4.43}$ = gain factor for manual throttle valve controller (MTVC)

$K_{4.44}$ = gain factor for manual governor valve controller (MGVC)

$K_{4.47}$ = rate factor for setting turbine speed or load on setter

$K_{4.48}$ = gain factor for ATVC

$K_{4.49}$ = ATVC input error in TRANSFER mode

$K_{4.50}$ = gain factor for governor valve tracking amplifier

$K_{4.51}$ = gain factor for AGVC in OPER IC mode

$K_{4.52}$ = time constant for AGVC, sec

$K_{4.53}$ = reset factor for AGVC, sec

$K_{4.54}$ = H.P. extraction to reheater/1st stage flow

$K_{4.55}$ = AGVC input error prior to TRANSFER mode

$K_{4.56}$ = gain factor for first stage pressure feedback (IMPI mode)

$K_{4.57}$ = synchronous speed reference, cps

$K_{4.60}$ = turbine overspeed trip No. 1 set point, cps

$K_{4.61}$ = turbine excess thrust trip set point, in.

$K_{4.62}$ = low turbine oil trip set point, psig

$K_{4.63}$ = proportionality factor for pressure of turbine shaft oil pump, psig/cps

$K_{4.65}$ = steady-state output pressure of auxiliary turbine oil pump, psig

$K_{4.66}$ = speed error trip set point, cps

$K_{4.67}$ = load error trip set point, %

$K_{4.69}$ = maximum frequency error for initiating "OCB" energizing, cps

$K_{4.72}$ = factor for converting electrical torque to electrical megawatts

$K_{4.73}$ = set point for OST No. 2

$K_{4.74}$ = flow through auxiliary header exhaust valves, lb/sec

$K_{4.75}$ = set point for low condenser vacuum trip, in. Hg

$K_{4.77}$ = reheater time constant, sec

$K_{4.78}$ = factor for converting steam flow to torque in H.P. turbine

$K_{4.79}$ = signal fraction at which governor valve No. 1 starts to open

$K_{4.80}$ = signal fraction at which governor valve No. 1 is wide open

$K_{4.81}$ = signal fraction at which governor valve No. 2 starts to open

$K_{4.82}$ = signal fraction at which governor valve No. 2 is wide open

$K_{4.83}$ = signal fraction at which governor valve No. 3 starts to open

$K_{4.84}$ = signal fraction at which governor valve No. 3 is wide open

$K_{4.85}$ = signal fraction at which governor valve No. 4 starts to open

$K_{4.86}$ = signal fraction at which governor valve No. 4 is wide open

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$K_{4.87}$ =

$K_{4.88}$ = rate factor for governor valve motion in normal manual mode

$K_{4.89}$ = rate factor for governor valve motion in fast manual mode

$K_{4.90}$ = factor for scaling EHC base signal to speed

$K_{4.91}$ = dead band limit (±) for track error to initiate automatic signal correction on first stage pressure feedback mode transfer

$K_{4.92}$ = gain factor for turbine speed rate setting

$K_{4.94}$ = rate factor for throttle valve motion in normal manual mode

$K_{4.95}$ = rate factor for throttle valve motion in fast manual mode

$K_{4.96}$ = rate for changing governor valve position limit

$K_{4.97}$ = factor for converting "10 range" signal to "1 range"

$K_{4.98}$ = scale factor for displaying target speed on setter meter

$K_{4.99}$ = scale factor for displaying target load on setter meter or actual load on reference meter

$K_{4.100}$ = scale factor for displaying actual speed on reference meter

$K_{4.101}$ = scale factor for ICS input to EHC

$K_{4.102}$ = scale factor for standard turbine loading rate

$K_{4.103}$ = scale factor for fast turbine loading rate

K_R = 0.3

P_{set} = set point for EHC throttle pressure limit, psig

5. CONDENSATE AND FEEDWATER MODEL

(Reference Figure C-6 and Section 5.6 of Main Specification)

5.1 Condenser and Hotwell Model

$$\frac{dM_{SC}}{dt} = w_{S26} + w_{S15} - w_{C2} + w_{S37}$$

$$q_C = K_{5.1} w_{C1} (T_{SC} - T_{C2})$$

$$w_{C1} = K_{5.2} N_{CW}$$

$$K_{5.3} \frac{dT_{C2}}{dt} = K_{5.4} w_{C1} (T_{C1} - T_{C2}) + q_C$$

$T_{C2} - T_{C1} = K_{5.65} N_{TF}$; N_{TF} = instructor input to program

$$\frac{dM_{WC}}{dt} = w_{C2} + w_{C3} + w_{C4} + w_{C5} + w_{C6} + w_{C7} + w_{C10} - w_{C8} - w_{C9} - w_{C11}$$

$$w_{C2} = q_C / K_{5.66}$$

$$V_{SC} = K_{5.6} - K_{5.7} M_{WC}$$

$$\rho_{SC} = M_{SC} / V_{SC}$$

$$T_{SC} = f(\rho_{SC})$$

$$P_{SC} = [K_{5.8} - f(\rho_{SC}) - P_{AC}]K_{5.9}$$

$$K_{5.10} dP_{AC}/dt = K_{5.11}(w_{S15} + w_{S26} + w_{S37}) - w_{AE} + K_{5.56} S_{37}(K_{5.8} - P_{AC})$$

$$w_{AE} = K_{5.12} f_1(P_{AC})(SV_{158} + SV_{159})(P_{S3} + P_{S4})(S_{34} + S_{35}) + K_{5.5} f_2(P_{AC})[N_{VP1}(1 - S_{34}) + N_{VP2}(1 - S_{35})]$$

$$P_{WC} = f(\rho_{SC}) + P_{AC} + P_{HY} - K_{5.8}$$

$$P_{HY} = K_{5.14} M_{WC}$$

$$w'_{C7} = 0 \quad \text{if} \quad L_{WC} > K_{5.17} \quad \text{or if} \quad L_{CT} = 0$$

$$w'_{C7} = K_{5.18}(K_{5.60} - L_{WC}) \begin{cases} \text{if} \quad K_{5.61} \le L_{WC} \le K_{5.17} \quad \text{and} \\ \text{if} \quad L_{CT} > 0 \end{cases}$$

$$w'_{C7} = K_{5.62} \quad \text{if} \quad L_{WC} < K_{5.61} \quad \text{if} \quad L_{CT} > 0$$

$$w_{C7} = K_{5.57} P_{SC} w'_{C7}$$

$$w'_{C12} = 0 \quad \text{if} \quad L_{WC} < K_{5.19}$$

$$w'_{C12} = K_{5.20}(L_{WC} - K_{5.19}) \quad \text{if} \quad K_{5.19} < L_{WC} \le K_{5.63}$$

$$w'_{C12} = K_{5.64} \quad \text{if} \quad L_{WC} > K_{5.63}$$

$$w_{C12} = K_{5.15} N_{CP} w'_{C12}$$

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$$\frac{dM_{CT}}{dt} = w_{C12} - w_{C7} - w_{C20} - w_{C21}$$

$$L_{WC} = K_{5.58} M_{WC}$$

$$L_{CT} = K_{5.59} M_{CT}$$

$$w_{C5} = w_{S11} + w_{S22} + w_{S23}$$

$$w_{C6} = w_{S12} + w_{S33} + w_{S24}$$

$$w_{C8} = w_{F13}$$

$$w_{C9} = w_{F14}$$

5.2. Condensate and Feedwater Flow Model

$$\left\{ \begin{array}{l} \Delta P_{FP1} = \omega_{FP1}^{2} f\left(\frac{w_{F1}}{\omega_{FP1}}\right); \text{ do not use this equation and set } w_{F1} = 0 \\ \text{if} \quad \omega_{FP1} = 0, \quad \text{or if} \quad SV_{11} = 0, \quad \text{or if} \quad P_{C3} \le 0 \end{array} \right.$$

$$\left\{ \begin{array}{l} \Delta P_{FP2} = \omega_{FP2}^{2} f\left(\frac{w_{F2}}{\omega_{FP2}}\right); \text{ do not use this equation and set } w_{F2} = 0 \\ \text{if} \quad \omega_{FP2} = 0, \quad \text{or if} \quad SV_{10} = 0, \quad \text{or if} \quad P_{C3} \le 0 \end{array} \right.$$

$$w_{F3} = \sqrt{K_{5.32} SV \, \Delta P_{FP1}}$$

$$P_{F1} - P_{C3} = \Delta P_{FP1} = \Delta P_{FP2}$$

$$P_{F2} = \left(\frac{A_{S3} P_{S1} + A_{S4} P_{S2}}{A_{S3} + A_{S4} + 10^{-3}}\right) + (w_{F1} + w_{F2} + w_{F3} + w_{F13} + w_{F14})^{2} R_{1}$$

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$$P_{F1} = P_{F2}\left(\frac{SV_{12} + SV_{13} + SV_{14}}{SV_{12} + SV_{13} + SV_{14} + 10^{-3}}\right) + (w_{F1} + w_{F2} + w_{F3})^2 R_2$$

$$P_{C3} = P_{C2}\left(\frac{SV_6 + SV_7 + SV_8}{SV_6 + SV_7 + SV_8 + 10^{-3}}\right) - w_{C17}^2 R_3$$

$$w_{C17} = w_{F1} + w_{F2} + w_{F3} - w_{C16}$$

$$P_{C2} = P_{C1} - (w_{C11} - w_{C12})^2 \left(\frac{1}{\sqrt{K_{5.43}} + \sqrt{K_{5.55}S_{36}}}\right)^2$$

$$P_{C1} = P_{WC} + f\left(\frac{w_{CP}}{N_{CP}}\right); \quad N_{CP} = SP228 + SP232 + SP236$$

$$w_{CP} = w_{F1} + w_{F2} + w_{F3} - w_{C16} + w_{C3} + w_{C12}$$

$$w_{C11} = w_{CP}$$

$$w_{C3} = 0 \quad \text{if} \quad N_{CP} = 0$$

$$w_{C3} = K_{5.22}SV_5 \quad \text{if} \quad N_{CP} \neq 0$$

$$w_{C10} = \sqrt{K_{5.24}(SV_{15} - 10^{-3})P_{F2}}$$

$$SV_{15} = f(w_{F1} + w_{F2}) \cdot [1 - (SV_{18} + SV_{19} - SV_{18}SV_{19})]$$

$$w_{F5} = \sqrt{K_{5.16}SV_{13}(P_{F1} - P_{F2})}$$

$$w_{F6} = \sqrt{K_{5.21}SV_{14}(P_{F1} - P_{F2})}$$

$$w_{F7} = [\sqrt{K_{5.25}S_{20}(SV_{19} - SV_{157})} + \sqrt{K_{5.26}S_{21}SV_{37}}]\sqrt{P_{F2} - P_{S1}}$$

$$w_{F8} = \left[\sqrt{K_{5.27}S_{22}(SV_{18} + SV_{156})} + \sqrt{K_{5.28}S_{23}SV_{38}}\right]\sqrt{P_{F2} - P_{S2}}$$

$$w_{C14} = \sqrt{K_{5.13}SV_{6}(P_{C2} - P_{C3})}$$

$$w_{C13} = \sqrt{K_{5.43}(P_{C1} - P_{C2})}$$

[illegible]

$$R_2 = \left[\frac{1}{\sqrt{K_{5.29}SV_{12}} + \sqrt{K_{5.30}(SV_{13} + SV_{14} + 10^{-3})}}\right]^2$$

$$R_3 = \left[\frac{1}{\sqrt{K_{5.31}SV_{6}} + \sqrt{K_{5.32}(SV_{7} + SV_{8} + 10^{-3})}}\right]^2$$

$$A_{S3} = S_{20}(SV_{19} + SV_{157}) + S_{21}SV_{37}$$

$$A_{S4} = S_{22}(SV_{18} + SV_{156}) + S_{23}SV_{38}$$

$$\left.\begin{aligned} w_{C8} &= w_{F13} \\ w_{C20} &= 0 \\ w_{C9} &= w_{F14} \\ w_{C21} &= 0 \end{aligned}\right\} \text{ if } \quad M_{WC} \neq 0$$

$$\left.\begin{array}{l} w_{C8} = 0 \\ w_{C20} = w_{F13} \\ w_{C9} = 0 \\ w_{C21} = w_{F14} \end{array}\right\} \text{ if } M_{WC} = 0$$

$$w_{F13} = \omega_{FP3}\, f\left(\frac{\Delta P_{FP3}}{\omega^2_{FP3}}\right) \quad \begin{cases} \text{if } & W_{C17} = 0 \text{ and} \\ \text{if } & SV_{17}(A_{S3} + A_{S4})(M_{WC} + M_{CT}) \neq 0 \end{cases}$$

$$\Delta P_{FP3} = P_{F2}$$

$$w_{F13} = 0 \quad \text{and do not compute } \Delta P_{FP3} \quad \begin{cases} \text{if } & W_{C17} \neq 0 \text{ or} \\ \text{if } & SV_{17}(A_{S3} + A_{S4})(M_{WC} + M_{CT}) = 0 \end{cases}$$

$$w_{F14} = f(\Delta P_{FP4}) \quad \begin{cases} \text{if } & W_{C17} = 0 \text{ and} \\ \text{if } & SV_{16}(A_{S3} + A_{S4})(M_{WC} + M_{CT}) \neq 0 \\ \text{and if FP4 "RUN" is on} \end{cases}$$

$$\Delta P_{FP4} = P_{F2}$$

$$w_{F14} = 0 \quad \text{and do not compute } \Delta P_{FP4} \quad \begin{cases} \text{if } & W_{C17} \neq 0 \text{ or} \\ \text{if } & SV_{16}(A_{S3} + A_{S4})(M_{WC} + M_{CT}) = 0 \\ \text{or if FP4 "STOP" is on} \end{cases}$$

5.3. Feed Pump Turbine Models

$$K_{5.37} \frac{d\omega_{FP1}}{dt} = (\omega_{FP1})_D - \omega_{FP1}$$

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$$(\omega_{FP1})_D = [1 - (IC135)(IC217)][K_{5.38}P_{S5}(ICS63)(SP216)$$

$$+ K_{5.39}P_{S5}(SP217)\int_t (SP224 - SP225)\,dt$$

$$+ K_{5.40}S_{27}P_{S9}]SP220$$

$$K_{5.37}\frac{d\omega_{FP2}}{dt} = (\omega_{FP2})_D - \omega_{FP2}$$

$$(\omega_{FP2})_D = [K_{5.38}P_{S10}(ICS64)(SP272)$$

$$+ K_{5.39}P_{S10}(SP273)\int_t (SP280 - SP281)\,dt$$

$$+ K_{5.40}S_{26}P_{S9}]SP276$$

$$K_{5.44}\frac{d\omega_{FP3}}{dt} = (\omega_{FP3})_D - \omega_{FP3}$$

$$(\omega_{FP3})_D = K_{5.47}(SP321)(S_4P_{S5} + S_{19}P_{S9})\begin{pmatrix}\text{TRIP}\\ \text{RESET}\\ \text{SIGNAL}\end{pmatrix}$$

<u>Note</u>: Symbols of the form IC135, ICS63, SP216, etc., used in the above equations refer to GP4 computer input system numbers listed in program SIMOR.

5.4. Condensate and Feedflow Thermal Model

$$K_{5.50}\frac{dT_{C3}}{dt} = f(w_{C17} - w_{C14}) + SV_{160}f_1(P_{S9}) - T_{C3}$$

$$K_{5.53}\frac{dT_{FD1}}{dt} = f(w_{F5} + w_{F6}) - T_{FD1}$$

$$w_{C4} = K_{5.51}(w_{C17} - w_{C14})(T_{C3} - T_{SC})$$

$$\left.\begin{aligned} w_{S22} &= w_{C4} \\ w_{S34} &= 0 \end{aligned}\right\} \quad \text{if} \quad SV_{160} = 0$$

$$\left.\begin{aligned} w_{S22} &= 0 \\ w_{S34} &= w_{C4} \end{aligned}\right\} \quad \text{if} \quad SV_{160} \neq 0$$

$$\left.\begin{aligned} w_{S21} &= K_{5.23}(w_{F5} + w_{F6})(T_{FD1} - T_{C3}) \\ w_{C18} &= w_{S21} + w_{S14} + w_{S16} \end{aligned}\right| \quad \begin{aligned} &\text{if} \quad N_{HD} \neq 0 \\ &\quad w_{S21} = w_{C18} = 0 \\ &\text{if} \quad N_{HD} = 0 \\ &\quad (N_{HD} = SP325 + SP329) \end{aligned}$$

5.5. Auxiliary Boiler Model

$$w_{S35} = w_{S29} + w_{S32} + w_{S33} + w_{S34}$$

$$K_{5.54} \frac{dP_{S9}}{dt} = w_{S36} - w_{S35}$$

$$w_{S36} = f(P_{S9})(IC182)$$

Symbols for Section 5

ρ_{SC} = density of steam in condenser

ω_{FP1} = main feed pump No. 1 shaft speed, cps

ω_{FP2} = main feed pump No. 2 shaft speed, cps

ω_{FP3} = emergency feed pump No. 1 shaft speed, cps

$(\omega_{FP1})_D$ = main feed pump No. 1 shaft speed demand, cps

$(\omega_{FP2})_D$ = main feed pump No. 2 shaft speed demand, cps

$(\omega_{FP3})_D$ = emergency feed pump No. 1 shaft speed demand, cps

A_{S3} = admittance factor loop A feed valves

A_{S4} = admittance factor loop B feed valves

F_5 = constant section 5

L_{CT} = condensate storage tank level, in.

L_{WC} = condenser water level, in.

M_{CT} = mass of water in condensate storage tank, lb

M_{SC} = mass of steam in main condenser, lb

M_{WC} = mass of water in main condenser, lb

N_{CP} = number of condensate pumps on line

N_{CW} = number of circ water pumps on line

N_{HD} = number of heater drain pumps on line

N_{TF} = number of cooling tower fans on line

N_{VP1} = vacuum pump 1 on signal

N_{VP2} = vacuum pump 2 on signal

P_{AC} = partial pressure of air in condenser, psi

P_{C1} = pressure at condensate pump discharge, psig

P_{C3} = pressure at polisher outlet, psig

P_{C3} = pressure at main feed pump suction, psig

P_{F1} = pressure in discharge of main feed pumps, psig

P_{F2} = pressure in discharge of H. P. heater, psig

P_{HY} = hydrostatic pressure in condenser, psi

P_{SC} = condenser vacuum, in Hg

P_{S1} = refer to section 3

P_{S2} = refer to section 3

P_{S3} = refer to section 4

P_{S4} = refer to section 4

P_{S5} = refer to section 4

P_{S9} = pressure in auxiliary boiler, psig

P_{S10} = refer to section 4

P_{WC} = total pressure at condenser outlet, psig

ΔP_{FB} = feed pump bypass pressure drop, psi

ΔP_{FP1} = pressure differential across main feed pump No. 1, psi

ΔP_{FP2} = pressure differential across main feed pump No. 2, psi

ΔP_{FP3} = pressure differential across emergency feed pump No. 1, psi

ΔP_{FP4} = pressure differential across emergency feed pump No. 2, psi

q_C = heat transfer across condenser tubes, Btu/sec

R_1 = parallel resistance factor for all normal feed valves

R_2 = parallel resistance factor for H. P. heaters, valves, and bypass

R_3 = parallel resistance factor for L. P. heaters, valves, and bypass

R_4 = resistance factor for main feed pumps bypass

S_4 = position of H. P. throttle EFP No. 1

S_{19} = emergency feed pump No. 2 turbine valve position

S_{20} = RC-H1A low load feed valve position

S_{21} = RC-H1A high load feed valve position

S_{22} = RC-H1B low load feed valve position

S_{23} = RC-H1B high load feed valve position

S_{26} = main feed pump No. 2 auxiliary throttle position

S_{27} = main feed pump No. 1 auxiliary throttle position

S_{34} = position of 3-way valve in condenser exhaust line No. 1 (SP293)

S_{35} = position of 3-way valve in condenser exhaust line No. 2 (SP297)

S_{36} = polisher bypass control (SP284)

S_{37} = vacuum breaker valve position (SP240)

SV_5 = condensate pump recirculation valve position

SV_6 = L. P. heater bypass valve position

SV_7 = L. P. heater No. 1 inlet valve position

SV_8 = L. P. heater No. 2 inlet valve position

SV_9 = main feed pump bypass valve position

SV_{10} = main feed pump No. 2 discharge valve position

SV_{11} = main feed pump No. 1 discharge valve position

SV_{12} = H. P. heater bypass valve position

SV_{13} = H. P. heater No. 1 inlet valve position

SV_{14} = H. P. heater No. 2 inlet valve position

SV_{15} = position of valve in recirculation, H. P. heater to condenser

SV_{16} = position of valve in emergency F. P. No. 2 discharge

SV_{17} = position of valve in emergency F. P. No. 1 discharge

SV_{18} = position of emergency feed valve to RC-H1B

SV_{19} = position of emergency feed valve in RC-H1A

SV_{37} = RC-H1A high load feedwater stop valve position

SV_{38} = RC-H1B high load feedwater stop valve position

SV_{156} = stop valve for start up feed line B pos

SV_{157} = stop valve for start up feed line A pos

SV_{158} = stop valve 1 for main steam to air ejector pos SP335

SV_{159} = stop valve 2 for main steam to air ejector pos SP337

SV_{160} = stop valve for auxiliary boiler feed pos

T_{C1} = temperature of circulating water entering condenser, F

T_{C2} = temperature of circulating water leaving condenser, F

T_{C3} = temperature of condensate at L. P. heater exit, F

T_{FD1} = temperature of feedwater at H. P. heater outlet, F

T_{SC} = temperature of steam in main condenser, F

V_{SC} = volume of steam in main condenser, ft³

w_{AE} = total air ejector flow, lb/sec

w_{C1} = total condenser circulating water flow, lb/sec

w_{C2} = rate of steam condensation in main condenser, lb/sec

w_{C3} = condensate pump recirculation flow, lb/sec

w_{C4} = L. P. heater drain flow, lb/sec

w_{C5} = condensate flow from main feed pump No. 1 condenser, lb/sec

w_{C6} = condensate flow from main feed pump No. 2 condenser, lb/sec

w_{C7} = vacuum drag make-up, lb/sec

w'_{C7} = demand vacuum drag make-up, lb/sec

w_{C8} = flow from condenser to emergency feed pump No. 1, lb/sec

w_{C9} = flow from condenser to emergency feed pump No. 2, lb/sec

w_{C10} = recirculation flow from H. P. heater discharge to condenser, lb/sec

w_{C11} = total flow to condensate pumps, lb/sec

w_{C12} = condensate flow from condensate pumps to storage tanks, lb/sec

w'_{C12} = demand condensate flow from condensate pumps to storage tanks, lb/sec

w_{C13} = total flow through polisher, lb/sec

w_{C14} = L. P. heater bypass flow, lb/sec

w_{C17} = total flow at L. P. heater discharge header, lb/sec

w_{C18} = H. P. heater drain pump flow, lb/sec

w_{C20} = flow to EFP1 from cond stg tk, lb/sec

w_{C21} = flow to EFP2 from cond stg tk, lb/sec

w_{CP} = total flow through condensate pumps, lb/sec

w_{F1} = flow through main feed pump No. 1, lb/sec

w_{F2} = flow through main feed pump No. 2, lb/sec

w_{F3} = main feed pump bypass flow, lb/sec

w_{F5} = flow through H. P. heater No. 1, lb/sec

w_{F6} = flow through H. P. heater No. 2, lb/sec

w_{F7} = main feed flow to steam generator RC-H1A, lb/sec

w_{F8} = main feed flow to steam generator RC-H1B, lb/sec

w_{F13} = flow from emergency feed pump No. 1, lb/sec

w_{F14} = flow from emergency feed pump No. 2, lb/sec

w_{S11} = refer to section 4

w_{S12} = refer to section 4

w_{S14} = refer to section 4

w_{S15} = refer to section 4

w_{S16} = refer to section 4

w_{S21} = steam flow to H.P. heater, lb/sec

w_{S22} = steam flow to L.P. heater, lb/sec

w_{S23} = refer to section 4

w_{S24} = refer to section 4

w_{S26} = refer to section 4

w_{S29} = steam flow from auxiliary boiler to EFP1, lb/sec

w_{S32} = refer to section 4

w_{S33} = refer to section 4

w_{S34} = flow from auxiliary boiler to L.P. heaters, lb/sec

w_{S35} = total flow from auxiliary boiler, lb/sec

w_{S36} = steam generation in auxiliary boiler, lb/sec

w_{S37} = refer to section 4

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Constants for Condensate and Feedwater Model

$K_{5.1}$ = thermal factor for heat transfer in condenser, Btu/lb-F

$K_{5.2}$ = hydraulic factor for circulating water flow, lb/sec-pump

$K_{5.3}$ = thermal conversion factor for circulating water mass within condenser, Btu/F

$K_{5.4}$ = thermal factor for heat transport by flowing circulating water, Btu/lb-F

$K_{5.5}$ = exhaust rate factor for vacuum pumps

$K_{5.6}$ = total condenser shell free volume, ft^3

$K_{5.7}$ = condenser water volume factor, ft^3/lb

$K_{5.8}$ = atmospheric pressure, $lb/in.^2$

$K_{5.9}$ = pressure conversion, $in.^3$-Hg/lb

$K_{5.10}$ = air partial pressure factor, $in.^2$

$K_{5.11}$ = partial air flow factor, lb/in.-Hg-sec

$K_{5.12}$ = exhaust rate factor for air ejector

$K_{5.13}$ = admission factor for L. P. heater bypass valve, $lb\text{-}in.^2/sec^2$

$K_{5.14}$ = combined hydrostatic pressure and area factor for condenser, $in.^{-1}$

$K_{5.15}$ = rejection flow factor, $pump^{-1}$

$K_{5.16}$ = admission factor for H. P. heater No. 1 stop valve, $lb\text{-}in.^2/sec^2$

$K_{5.17}$ = set point for condenser makeup, in.

$K_{5.18}$ = "pumping" factor for condenser makeup, lb/sec-in.

$K_{5.19}$ = set point for condenser water rejection, lb

$K_{5.20}$ = flow factor for condenser water rejection, lb/sec-in.

$K_{5.21}$ = admission factor for H. P. heater No. 2 stop valve, $lb\text{-}in.^2/sec^2$

$K_{5.22}$ = factor for cond pump recirculation, lb/sec

$K_{5.23}$ = ratio factor—H. P. heater drain flow to condensate flow, $°F^{-1}$

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$K_{5.24}$ = factor for recirculation flow from H. P. heaters to condenser, lb²/sec²

$K_{5.25}$ = admission factor for low load feed valve to RCH1A, lb-in.²/sec²

$K_{5.26}$ = admission factor for high load feed valve to RCH1A, lb-in.²/sec²

$K_{5.27}$ = admission factor for low load feed valve to RCH1B, lb-in.²/sec²

$K_{5.28}$ = admission factor for high load feed valve for RCH1B, lb-in.²/sec²

$K_{5.29}$ = admission factor for H. P. heater bypass valve, lb-in.²/sec²

$K_{5.30}$ = admission factor for both H. P. heater stop valves, lb-in.²/sec²

$K_{5.31}$ = admission factor for L. P. heater bypass valve, lb-in.²/sec²

$K_{5.32}$ = admission factor for both L. P. heater stop valves, lb-in.²/sec²

$K_{5.33}$ = admission factor for main feed pumps bypass valve, lb-in.²/sec²

$K_{5.34}$ = static condensate system pressure, psig

$K_{5.37}$ = main feed pump inertia constant, sec

$K_{5.38}$ = feed pump ICS control conversion factor, in.²-cps/lb

$K_{5.39}$ = feed pump manual control conversion factor, in.²/lb

$K_{5.40}$ = feed pump auxiliary boiler control conversion factor, in.²-cps/lb

$K_{5.43}$ = admission factor for polisher, lb-in.²/sec²

$K_{5.44}$ = emergency feed pump inertia constant, sec

$K_{5.47}$ = emergency feed pump steam valve factor, in.²-cps/lb

$K_{5.50}$ = thermal time constant for L. P. heater, sec

$K_{5.51}$ = thermal factor for L. P. heater steam flow, F⁻¹

$K_{5.53}$ = thermal time constant for H. P. heater, sec

$K_{5.54}$ = auxiliary boiler pressure factor, in.²

$K_{5.55}$ = main feed pump bypass factor, lb-in.²/sec²

$K_{5.56}$ = air flow constant, in.³/sec

$K_{5.57}$ = condensate injection flow factor, in.⁻¹ Hg⁻¹

$K_{5.58}$ = combined height/mass for hotwell, in./lb

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$K_{5.59}$ = combined height/mass for cond storage tk, in./lb

$K_{5.60}$ = condenser level, in.

$K_{5.61}$ = condensate emergency injection point, in.

$K_{5.62}$ = maximum injection flow, lb/sec

$K_{5.63}$ = condensate emergency rejection point, in.

$K_{5.64}$ = maximum rejection flow, lb/sec

$K_{5.65}$ = coding tower fan effectiveness

$K_{5.66}$ = latent heat in condenser, Btu/lb

6. MAKEUP, PURIFICATION, CHEMICAL ADDITION, AND WASTE DISPOSAL FLUID FLOW AND THERMAL MODEL

(Reference Figure C-6 and Sections 5.7, 5.10, 5.13 of Main Specification)

6.1. Letdown, Purification and Deboration Flow Model

(Drop any term in which the denominator approaches zero unless otherwise noted.)

$$w_{P1} = \frac{\sqrt{P_{P1} - P_{MU}}}{\sqrt{R_5}}$$

$$R_5 = \frac{1}{A_1} + \frac{1}{A_2} + \frac{1}{A_3} + \frac{1}{A_4} + \frac{1}{A_5}$$

$$A_1 = \left(\frac{SV_{20}SV_{23}}{2} + \frac{SV_{21}SV_{39}}{2}\right) SV_{22}K_{6.8} \text{ (coolers)}$$

$$A_2 = K_{6.2}S_{28} + K_{6.3}S_{29} \text{ (orifice and valves)}$$

$$A_3 = \left(\frac{SV_{24} + SV_{25}}{2}\right) K_{6.4} \text{ (demin)}$$

$$A_4 = S_{30}K_{6.7} + (1 - S_{30})\left[\left(\frac{SV_{26} + SV_{27} + SV_{28}}{3}\right)K_{6.9} + SV_{34}\left(\frac{SV_{32} + SV_{33}}{2}\right) K_{6.10}\right]$$

$$A_5 = \left(\frac{SV_{35} + SV_{36}}{2}\right) K_{6.11}$$

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If A_1 or A_2 or A_3 or A_4 or A_5 is zero, set $w_{P1} = 0$ and do not calculate R_5.

if $SV_{64} = 0$ then activate "closed" digital input for SV_{20}

if $SV_{65} = 0$ then activate "closed" digital input for SV_{21}

if $T_{P19} > K_{6.32}$ then activate "closed" digital input for SV_{22}

$$P_{P5} = P_{P1} - \left(\frac{1}{A_1} + \frac{1}{A_2}\right) w_{P1}^2 \quad \text{if} \quad A_1A_2 \neq 0$$

$$P_{P5} = K_{6.5} \quad \text{if} \quad A_1A_2 = 0$$

$$P_{WT} = K_{6.49} \quad \text{if} \quad N_{WT} \neq 0$$

$$P_{WT} = 0 \quad \text{if} \quad N_{WT} = 0$$

$$P_{DW} = K_{6.50} \quad \text{if} \quad N_{DW} \neq 0$$

$$P_{DW} = 0 \quad \text{if} \quad N_{DW} = 0$$

$$w_{P4} = w_{P1} - w_{W1} + w_{W2} + w_{W3} + w_{CA}$$

$$w_{W1} = 0 \quad \text{if} \quad S_{30} \neq 0 \quad \text{or if} \quad SV_{26} + SV_{27} + SV_{28} = 0$$

$$w_{W1} = w_{P1} \quad \text{if} \quad S_{30} = 0 \quad \text{and if} \quad SV_{26} + SV_{27} + SV_{28} \neq 0$$

$$w_{W2} = 0 \quad \text{if} \quad SV_{29} + SV_{30} + SV_{31} = 0$$

$$w_{P2} = 0 \quad \text{if} \quad S_{30} + SV_{26} + SV_{27} + SV_{28} \neq 0 \quad \text{or if} \quad SV_{32} + SV_{33} = 0$$

$w_{P2} = w_{P1}$ if $S_{30} + SV_{26} + SV_{27} + SV_{28} = 0$ and if $SV_{32} + SV_{33} \neq 0$

$w_{W2} = K_{6.12} SV_{55} N_{WT} SV_{34}$ if $SV_{29} + SV_{30} + SV_{31} \neq 0$

$w_{W3} = K_{6.13} SV_{56} N_{DW}$

$w_{CA} = K_{6.14} N_{CA}$

$P_{CAD} = K_{6.48}$ if $N_{CA} \neq 0$

$P_{CAD} = 0$ if $N_{CA} = 0$

$MU71 = w_{P2} + w_{W3}$

$$\frac{dM_{B1}}{dt} = w_{W1}\left(\frac{SV_{26}}{SV_{26} + SV_{27} + SV_{28}}\right) - w_{W2}\left(\frac{SV_{29}}{SV_{29} + SV_{30} + SV_{31}}\right)$$

$$\frac{dM_{B2}}{dt} = w_{W1}\left(\frac{SV_{27}}{SV_{26} + SV_{27} + SV_{28}}\right) - w_{W2}\left(\frac{SV_{30}}{SV_{29} + SV_{30} + SV_{31}}\right)$$

$$\frac{dM_{B3}}{dt} = w_{W1}\left(\frac{SV_{28}}{SV_{26} + SV_{27} + SV_{28}}\right) - w_{W2}\left(\frac{SV_{31}}{SV_{29} + SV_{30} + SV_{31}}\right)$$

$$\frac{dM_{DM}}{dt} = w_{W4} - w_{W3}$$

w_{W4} is instructor input

$L_{DM} = K_{6.45} M_{DM}$

6.2. Makeup Surge Tank Model

$$\frac{dM_{MU}}{dt} = w_{P5} - w_{P7} - w_{P6}$$

$$\frac{dH}{dt} = w_H - \lambda_H H$$

w_H = instructor adjusted input

$$L_{MU} = K_{6.46} M_{MU}$$

$$P_{MU} = \frac{K_{6.15} H}{V_M - K_{6.16} M_{MU}} - K_{5.8}$$

$$w_{P5} = w_{P4} + w_{P13}$$

$$w_{P6} = \sqrt{K_{6.32} F_5 (P_{P1} - P_{CC})} \quad (F_5 \text{ is instructor input})$$

6.3. Normal Makeup Flow Model

$$P_{P8} = P_{MU} + K_{6.17} L_{MU}$$

$$P_{P9} = P_{P8} + f\left(\frac{w_{P7}}{N_{MU}}\right)$$

$$w_{P7} = SV_{40}\left(\sqrt{K_{6.18} S_{33} SV_{41} \Delta P_{P1}} - w_{P11}\right)$$

$$\Delta P_{P1} = P_{P9} - \frac{P_{P1} + P_{P2}}{2}$$

$$w_{P11} = \sqrt{\frac{K_{6.19} K_{6.20} S_{32} SV_{45} \Delta P_{P1}}{K_{6.19} + K_{6.20} S_{32} SV_{45}}}$$

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$$w_{P12} = K_{6.22} w_{P11}$$

$$w_{P13} = (w_{P11} - w_{P12}) SV_{54} SV_{46}$$

$$S_{33} = K_{6.25}(L'_P - L_P) + K_{6.26} \int (L'_P - L_P)\,dt$$

$$L'_P = f(T_{RC})$$

$$S_{32} = K_{6.27}(\Delta P_{P2} - K_{6.21}) + K_{6.28} \int (\Delta P_{P2} - K_{6.21})\,dt$$

$$\Delta P_{P2} = P_{P11} - \frac{P_{P1} + P_{P2}}{2}$$

$$P_{P11} = P_{P9} - \frac{w_{P11}^2}{K_{6.20} S_{32} SV_{45}} \qquad \left(\begin{matrix} \text{if} \quad S_{32} \quad \text{or} \quad SV_{45} = 0, \quad \text{then} \\ P_{P11} = K_{6.44} \end{matrix} \right)$$

$$w_{P18} = w_{P7} - w_{P11} - w_{P19}$$

$$w_{P19} = \sqrt{K_{6.42} F_6 (P_{P9} - P_{RB})} \qquad (F_6 \text{ is instructor input})$$

6.4. Emergency High Pressure Injection

$$w_{P9} = U_3 \left(\frac{2}{3} SV_{77} + \frac{2}{3} SV_{78} - \frac{1}{3} SV_{77} SV_{78} \right) f_1 \left(\frac{P_{P1} + P_{P2}}{2} \right)$$

$$U_3 = \left(\frac{SV_{43}}{1 + SV_{61} SV_{62}} + \frac{SV_{61} SV_{62}}{1 + SV_{43}} \right) \left\{ \text{if} \quad M_{BW} \neq 0 \quad \text{and} \quad w_{RB1} \neq 0 \right.$$

$$U_3 = SV_{43} \left\{ \text{if} \quad M_{BW} \neq 0 \quad \text{and} \quad w_{RB1} = 0 \right.$$

$$U_3 = SV_{61} SV_{62} \left\{ \text{if} \quad M_{BW} = 0 \quad \text{and} \quad w_{RB1} \neq 0 \right.$$

$$U_3 = 0 \left\{ \text{if} \quad M_{BW} = 0 \quad \text{and} \quad w_{RB1} = 0 \right.$$

$$w_{D3} = \frac{w_{P6}}{1 + SV_{61}SV_{62}} \left\{ \text{if} \quad M_{BW} \neq 0 \quad \text{and} \quad SV_{43} \neq 0 \right.$$

$$w_{D3} = 0 \left\{ \text{if} \quad M_{BW} = 0 \quad \text{or if} \quad SV_{43} = 0 \right.$$

$$w_{P8} = U_4 \left(\frac{2}{3} SV_{79} + \frac{2}{3} SV_{80} - \frac{1}{3} SV_{79} SV_{80} \right) f_1 \left(\frac{P_{P1} + P_{P2}}{2} \right)$$

$$U_4 = \left(\frac{SV_{42}}{1 + SV_{59}SV_{60}} + \frac{SV_{59}SV_{60}}{1 + SV_{42}} \right) \quad \text{if} \quad M_{BW} \neq 0 \quad \text{and if} \quad w_{RB2} \neq 0$$

$$U_4 = SV_{42} \left\{ \text{if } M_{BW} \neq 0 \quad \text{and} \quad w_{RB2} = 0 \right.$$

$$U_4 = SV_{59}SV_{60} \left\{ \text{if} \quad M_{BW} = 0 \quad \text{and if} \quad w_{RB2} \neq 0 \right.$$

$$U_4 = 0 \left\{ \text{if} \quad M_{BW} = 0 \quad \text{and} \quad w_{RB2} = 0 \right.$$

$$w_{D4} = \frac{w_{P8}}{1 + SV_{59}SV_{60}} \left\{ \text{if} \quad M_{BW} \neq 0 \quad \text{and if} \quad SV_{42} \neq 0 \right.$$

$$w_{D4} = 0 \left\{ \text{if} \quad M_{BW} = 0 \quad \text{or if} \quad SV_{42} = 0 \right.$$

6.5. Thermal Model

$$\frac{dT_{P19}}{dt} = \frac{K_{6.33} w_{P1}}{N_{LC}} (T_{P17} - T_{P19}) - (T_{P19} - T_{CC1}) K_{6.34}$$

$$\frac{dT_{P23}}{dt} = \frac{K_{6.36} w_{P13}}{N_{SC}} (T_{P22} - T_{P23}) - (T_{P23} - T_{CC3}) K_{6.38}$$

$$T_{P21} = \frac{(w_{P1} - w_{W1})T_{P19} + w_{P13}T_{P23} + (w_{W2} + w_{W3} + w_{CA})K_{6.39}}{w_{P5}}$$

$$h_{MU} = K_{6.40} + K_{6.41}T_{P24}$$

$$M_{MU}\frac{dT_{P24}}{dt} = w_{P5}T_{P21} - w_{P7}T_{P24}$$

$$T_{P22} = T_{P24} + K_{6.47}(T_{RC} - T_{P24})$$

Symbols for Section 6

λ_H = constant section 6

A_1 = letdown cooler admittance factor

A_2 = letdown orifice admittance factor

A_3 = purif demin admittance factor

A_4 = debor demin and bleed tk admittance factor

A_5 = filter admittance factor

F_5 = area factor for leak in letdown coolers

F_6 = area factor for leak between MU and RB

H = hydrogen content of make-up tank, lb

h_{MU} = enthalpy of reactor make up water, Btu/lb

L_{DM} = level in demineralized water tank, in.

L_{MU} = water level in make up tank, in.

L_P = refer to section 2

L'_P = operator adjusted pressurizer level set point, in.

M_{B1} = mass of water in bleed tank No. 1, lb

M_{B2} = mass of water in bleed tank No. 2, lb

M_{B3} = mass of water in bleed tank No. 3, lb

M_{BW} = refer to section 7

M_{DM} = mass of water in demin water tank, lb

M_{MU} = mass of water in make-up tank, lb

N_{CA} = number of chemical add pumps on line

N_{DW} = number of demin water pumps on line

N_{LC} = number of letdown coolers on line

N_{MU} = number of make-up pumps on line

N_{SC} = number of seal return coolers on line

N_{WT} = number of waste transfer pumps on line

P_{CAD} = pressure in chemical addition discharge header, psig

P_{CC} = refer to section 11

P_{DW} = pressure at demin water pump discharge, psig

P_{MU} = pressure in makeup tank, psig

P_{P1} = refer to section 2

P_{P2} = refer to section 2

P_{P5} = pressure downstream of all letdown valves, psig

P_{P8} = pressure at makeup tank outlet, psig

P_{P9} = pressure at H.P. injection pump B discharge, psig

P_{P11} = pressure at R.C. pump seal supply hdr, psig

P_{RB} = refer to section 12

P_{WT} = pressure at waste transfer pump discharge, psig

ΔP_{P1} = pressure drop between MU pumps and RC system, psi

ΔP_{P2} = pressure drop between RC pump seal header and RC system, psi

R_5 = resistance factor for letdown system

S_{28} = H.P. letdown control valve position

S_{29} = L.P. letdown control valve position

S_{30} = three way deboration valve position

S_{32} = RC pumps seal supply control valve position

S_{33} = normal make-up control valve position

SV_{20} = letdown cooler A inlet valve position

SV_{21} = letdown cooler B inlet valve position

SV_{22} = combined letdown stop valve position

SV_{23} = letdown cooler A outlet valve position

SV_{24} = letdown demineralizer A inlet valve position

SV_{25} = letdown demineralizer B inlet valve position

SV_{26} = RC bleed tank A inlet valve position

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SV_{27} = RC bleed tank B inlet valve position

SV_{28} = RC bleed tank C inlet valve position

SV_{29} = RC bleed tank A outlet valve position

SV_{30} = RC bleed tank B outlet valve position

SV_{31} = RC bleed tank C outlet valve position

SV_{32} = deborating demineralizer A inlet valve position

SV_{33} = deborating demineralizer B inlet valve position

SV_{34} = MU system combined return and feed valve position

SV_{35} = MU filter A inlet valve position

SV_{36} = MU filter B inlet valve position

SV_{39} = letdown cooler B outlet valve position

SV_{40} = makeup tank outlet valve position

SV_{41} = normal RC makeup isolation valve position

SV_{42} = emergency H. P. injection pump A suction valve position

SV_{43} = emergency H. P. injection pump C suction valve position

SV_{45} = RC pump seal supply isolation valve position

SV_{46} = combined seal return isolation valve position

SV_{54} = RC pump seal return isolation valve position

SV_{55} = combined bleed tank outlet valve position

SV_{56} = demineralized water supply valve position

SV_{59} = DH-MU crossover A1 isolation valve position

SV_{60} = DH-MU crossover A2 isolation valve position

SV_{61} = DH-MU crossover B1 isolation valve position

SV_{62} = DH-MU crossover B2 isolation valve position

SV_{64} = MUC1A IC inlet valve position

SV_{65} = MUC1B IC inlet valve position

SV_{77} = position of stop valve in loop B,H.P. injection line

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SV_{78} = position of stop valve in loop B H. P. injection line

SV_{79} = position of stop valve in loop A H. P. injection line

SV_{80} = position of stop valve in loop A H. P. injection line

T_{CC1} = refer to section 11

T_{CC3} = refer to section 11

T_{P17} = refer to section 2

T_{P19} = temperature at letdown cooler outlet, F

T_{P21} = temperature of fluid entering MU tank, F

T_{P22} = temperature of combined seal return, F

T_{P23} = temperature at seal return cooler exit, F

T_{P24} = temperature of fluid within and leaving MU tank, F

T_{RC} = refer to section 2

U_3 = admission factor for H. P. injection, loop B

U_4 = admission factor for H. P. injection, loop A

V_M = constant section 6

w_{CA} = flow from boron poison tank, lb/sec

w_{D3} = emergency flow through H. P. injection pump C, lb/sec

w_{D4} = emergency flow through H. P. injection pump A, lb/sec

w_H = rate of hydrogen makeup, lb/sec

w_{P1} = letdown flow, lb/sec

w_{P2} = flow to deborating demineralizers, lb/sec

w_{P4} = total flow upstream of MU filters, lb/sec

w_{P5} = total flow into MU storage tank, lb/sec

w_{P6} = flow through leak between letdown coolers and IC system, lb/sec

w_{P7} = flow out of makeup tank, lb/sec

w_{P8} = flow through H. P. injection pump A, lb/sec

w_{P9} = flow through H. P. injection pump C, lb/sec

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w_{P11} = flow in RC pump seal supply header, lb/sec

w_{P12} = in seal leakage for RC pumps, lb/sec

w_{P13} = return flow from RC pump seals, lb/sec

w_{P18} = normal make-up to RC system, lb/sec

w_{P19} = flow through leak between makeup system and RB, lb/sec

w_{RB1} = refer to section 7

w_{RB2} = refer to section 7

w_{W1} = flow to RC bleed tanks, lb/sec

w_{W2} = flow from RC bleed tanks, lb/sec

w_{W3} = flow from demineralized water tank, lb/sec

w_{W4} = makeup flow to demineralized water tank, lb/sec

Constants for Makeup, Purification, Chemical Addition, and Waste Disposal System Model

λ_H = decay constant for hydrogen absorption, sec^{-1}

$K_{6.2}$ = admission factor for letdown orifices

$K_{6.3}$ = admission factor for letdown valve

$K_{6.4}$ = admission factor for purification demineralizer stop valves

$K_{6.5}$ = static reference valve of P_{P5} and P_{P6} and P_{P7}

$K_{6.6}$ =

$K_{6.7}$ = resistance factor for three-way valve with full normal flow direct to make-up

$K_{6.8}$ = admission factor for letdown coolers

$K_{6.9}$ = admission factor for bleed tank stop valves

$K_{6.10}$ = admission factor for deborated demineralizer stop valves

$K_{6.11}$ = admission factor for make-up filters

$K_{6.12}$ = reference flow rate of one waste transfer pump, lb/sec

$K_{6.13}$ = reference flow rate of one distilled water pump, lb/sec

$K_{6.14}$ = reference flow rate of chemical addition

$K_{6.15}$ = gas law constant for hydrogen, $lb\text{-}ft^3/in.^2$

$K_{6.16}$ = specific volume of water in MU tank, ft^3/lb

$K_{6.17}$ = hydrostatic pressure factor, $lb/in.^3$

$K_{6.18}$ = admission factor for make-up supply control valve

$K_{6.19}$ = admission factor for RC pump seal supply piping, etc.

$K_{6.20}$ = admission factor for RC pump seal supply control valve

$K_{6.21}$ = reference ΔP for RC pump seal supply control, psi

$K_{6.22}$ = admission factor for RC pump in seal leakage

$K_{6.23}$ =

$K_{6.25}$ = gain constant for pressurizer level controller, $in.^{-1}$

$K_{6.26}$ = integration constant for pressurizer level controller, sec^{-1}

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$K_{6.27}$ = proportionality constant for RC pump seal supply control, in.²/lb

$K_{6.28}$ = integration constant for RC pump seal supply control, in.²/lb-sec

$K_{6.32}$ = admission factor for leak between letdown coolers and IC system

$K_{6.33}$ = thermal constant for mass in letdown coolers, lb^{-1}

$K_{6.34}$ = conductivity factor for letdown cooler tube metal, sec^{-1}

$K_{6.36}$ = thermal constant for mass in seal return coolers, lb^{-1}

$K_{6.38}$ = conductivity factor for seal return cooler tube metal, sec^{-1}

$K_{6.39}$ = reference temperature for water in bleed tanks, demineralized water tank, and chemical addition tank, and core flooding tanks, F

$K_{6.40}$ = enthalpy base for RC make-up, Btu/lb

$K_{6.41}$ = specific heat for RC make-up, Btu/lb-F

$K_{6.42}$ = admission factor for leak from make-up line to RB

$K_{6.44}$ = static pressure reference, psig

$K_{6.45}$ = factor for converting DWT mass to level, in./lb

$K_{6.46}$ = factor for converting MU tank mass to level, in./lb

$K_{6.47}$ = thermal factor for combined seal return water heat pickup

$K_{6.48}$ = dynamic pressure in CA header, psig

$K_{6.49}$ = dynamic pressure in waste transfer header, psig

$K_{6.50}$ = dynamic pressure in demineralized water header, psig

7. DECAY HEAT AND LOW PRESSURE INJECTION FLUID FLOW AND THERMAL MODEL — INCLUDING BORATE TANK MASS BALANCE

(Reference Figure C-6 and Section 5.8 of Main Specification)

7.1. Flow Model

$w_{DH1} = 0,$ if DHP1B is off

$w_{DH2} = 0,$ if DHP1A is off

$w_{DH1} = U_5 [SV_{57} f_2 (P_{P2}) + SV_{61} SV_{62} (w_{P9} - w_{D3})]$ if DHP1B is on

$w_{DH2} = U_7 [SV_{58} f_2 (P_{P1}) + SV_{59} SV_{60} (w_{P8} - w_{D4})]$ if DHP1A is on

$w_{RB1} = U_9 w_{DH1}$

$w_{RB2} = U_{12} w_{DH2}$

$w_{D5} = U_{10} w_{DH1}$

$w_{D6} = U_{13} w_{DH2}$

$w_{D7} = U_{11} w_{DH1}$

$w_{D8} = U_{14} w_{DH2}$

$$\left.\begin{aligned} U_5 &= 0 \\ U_7 &= 0 \end{aligned}\right] \quad \begin{aligned} &\text{if} \quad M_{BW} = 0 \quad \text{and} \\ &\text{if} \quad M_{RBW} = 0 \end{aligned}$$

$$\left.\begin{aligned} U_5 &= U_9 + U_{10} + U_{11} \\ U_7 &= U_{12} + U_{13} + U_{14} \end{aligned}\right] \quad \text{if both } M_{RW} \text{ and } M_{RBW} \neq 0$$

$$U_6 = SV_{66}SV_{49}SV_{50}SV_{69}$$

$$U_8 = SV_{68}SV_{49}SV_{50}SV_{70}$$

$$\left.\begin{aligned} U_9 &= SV_{51}/(1 - SV_{87} + U_6) \\ U_{10} &= SV_{87}/(1 + SV_{51} + U_6) \\ U_{11} &= U_6/(1 + SV_{87} + SV_{51}) \\ U_{12} &= SV_{52}/(1 - SV_{68} + U_8) \\ U_{13} &= SV_{68}/(1 - SV_{52} + U_8) \\ U_{14} &= U_8/(1 + SV_{88} + SV_{52}) \end{aligned}\right\} \quad \begin{aligned} &\text{if} \quad M_{BW} \neq 0 \quad \text{and} \\ &\text{if} \quad M_{RBW} \neq 0 . \end{aligned}$$

$$\left.\begin{aligned} U_9 &= SV_{51}/(1 - U_6) \\ U_{10} &= 0 \\ U_{11} &= U_6/(1 + SV_{51}) \\ U_{12} &= SV_{52}/(1 + U_8) \\ U_{13} &= 0 \\ U_{14} &= U_8/(1 + SV_{52}) \end{aligned}\right\} \quad \begin{aligned} &\text{if} \quad M_{BW} = 0 \quad \text{and} \\ &\text{if} \quad M_{RBW} \neq 0 \end{aligned}$$

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$$
\left.
\begin{aligned}
U_9 &= 0 \\
U_{10} &= SV_{87}/(1 + U_6) \\
U_{11} &= U_6/(1 + SV_{87}) \\
U_{12} &= 0 \\
U_{13} &= SV_{88}/(1 + U_8) \\
U_{14} &= U_8/(1 + SV_{88})
\end{aligned}
\right\}
\begin{aligned}
&\text{if} \quad M_{BW} \neq 0 \quad \text{and} \\
&\text{if} \quad M_{RBW} = 0
\end{aligned}
$$

$$\frac{dM_{BW}}{dt} = w_{D11} - w_{D3} - w_{D4} - w_{D5} - w_{D6} - w_{D1} - w_{D2}$$

SV_{69}, SV_{70}, and w_{D11} are instructor inputs

$$L_{BW} = K_{7.9} M_{BW}$$

7.2 Thermal Model

$$T_{D3} = \frac{w_{D5}T_{BW} + w_{RB1}T_{RBW} + w_{D7}T_{P1}}{w_{DH1}} \qquad \text{if} \quad w_{DH1} \neq 0$$

$$T_{D3} = T_{BW} \qquad \text{if} \quad w_{DH1} = 0$$

$$T_{D2} = \frac{w_{D6}T_{BW} + w_{RB1}T_{RBW} + w_{D8}T_{P1}}{w_{DH2}} \qquad \text{if} \quad w_{DH2} \neq 0$$

$$T_{D2} = T_{BW} \qquad \text{if} \quad w_{DH2} = 0$$

$$\frac{dT_{D5}}{dt} = K_{7.1} w_{DH1}\left(T_{D3} - T_{D5}\right) - \left[K_{7.2} + K_{7.3}\left(w_{DH1}\right)^{.8}\right] \left[\left(\frac{T_{D3} + T_{D5}}{2}\right) - T_{NB2}\right]$$

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$$\frac{dT_{D4}}{dt} = K_{7.1} w_{DH2} \left(T_{D2} - T_{D4}\right) - \left[K_{7.2} + K_{7.3} \left(w_{DH2}\right)^{.8}\right] \left[\left(\frac{T_{D2} + T_{D4}}{2}\right) - T_{NA2}\right]$$

$$\frac{dT_{BW}}{dt} = K_{7.4}(q_{BH} - K_{7.5})$$

$q_{BH} = 0$ if $T_{BW} > K_{7.6}$ or if $L_{BW} < K_{7.10}$

$q_{BH} = K_{7.8}$ if $T_{BW} < K_{7.6}$ and if $L_{BW} \geq K_{7.10}$

$$h_{DH} = \left(\frac{T_{D2} w_{DH2} + T_{D3} w_{DH1}}{w_{DH2} + w_{DH1}}\right) K_{7.11} + K_{7.12}$$

Symbols for Section 7

h_{DH} = enthalpy of reactor fluid at DH cooler exit, Btu/lb

L_{BW} = level in borate storage tank, in.

M_{BW} = mass of water in borate water tank, lb

M_{RBW} = refer to section 12

P_{P1} = refer to section 2

P_{P2} = refer to section 2

q_{BH} = heat output of borate tank heater, Btu/sec

SV_{49} = normal DH pump suction isolation valve No. 1 position

SV_{50} = normal DH pump suction isolation valve No. 2 position

SV_{51} = D.H. pump B RB suction valve position

SV_{52} = D.H. pump A RB suction valve position

SV_{57} = DHC1B outlet isolation valve position

SV_{58} = DHC1A outlet isolation valve position

SV_{59} = refer to section 6

SV_{60} = refer to section 6

SV_{61} = refer to section 6

SV_{62} = refer to section 6

SV_{68} = normal DH pump suction isolation valve No. 3 position

SV_{69} = DHP1B normal suction stop valve position

SV_{70} = DHP1A normal stop valve position

SV_{87} = position of stop valve at BSP1A suction

SV_{88} = position of stop valve at BSP1B suction

T_{BW} = temperature of water in borate storage tank, F

T_{D2} = temperature at L.P. injection pump A suction, F

T_{D3} = temperature at L.P. injection pump B suction, F

T_{D4} = temperature at D.H. cooler A exit, F

T_{D5} = temperature at D.H. cooler B exit, F

T_{NA2} = refer to section 11

T_{NB2} = refer to section 11

T_{P1} = refer to section 2

T_{RBW} = refer to section 12

U_5 = admission factor No. 1 for DHP1B suction

U_6 = admission factor No. 2 for DHP1B suction

U_7 = admission factor No. 1 for DHP1A suction

U_8 = admission factor No. 2 for DHP1A suction

U_9 = RB sump DH flow factor loop B

U_{10} = borated water DH flow factor loop B

U_{11} = coolant return DH flow factor loop B

U_{12} = RB sump DH flow factor loop A

U_{13} = borated water DH flow factor loop A

U_{14} = coolant return DH flow factor loop A

w_{D1} = refer to section 12

w_{D2} = refer to section 12

w_{D3} = refer to section 6.

w_{D4} = refer to section 6

w_{D5} = borate flow to L.P. injection pump B, lb/sec

w_{D6} = borate flow to L.P. injection pump A, lb/sec

w_{D7} = RC DH flow to L.P. injection pump B, lb/sec

w_{D8} = RC DH flow to L.P. injection pump A, lb/sec

w_{D11} = makeup flow to borate water storage tank, lb/sec

w_{DH1} = flow through DHP1B and DHC1B, lb/sec

w_{DH2} = flow through DHP1A and DHC1A, lb/sec

w_{P8} = refer to section 6

w_{pc} = refer to section 6

w_{RB1} = flow from RB sump to DHP1B, lb/sec

w_{RB2} = flow from RB sump to DHP1A, lb/sec

Constants for Decay Heat and L. P. Injection Model

$K_{7.1}$ = thermal constant for mass in one DH cooler, lb^{-1}

$K_{7.2}$ = time constant for DH cooler tube metal, sec

$K_{7.3}$ = thermal constant for heat transfer across fluid films in DH coolers

$K_{7.4}$ = thermal factor borate water tank, F/Btu

$K_{7.5}$ = heat loss from borate water tank, Btu/sec

$K_{7.6}$ = set point for borate water tank heater operation, F

$K_{7.8}$ = capacity of borate tank heater, Btu/sec

$K_{7.9}$ = factor for converting mass to level in borate water tank, in. /lb

$K_{7.10}$ = lo-lo level heater cut out for borate water tank, in.

$K_{7.11}$ = specific heat factor for DH water, Btu/lb-F

$K_{7.12}$ = enthalpy base, Btu/lb

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8. CORE FLOODING TANKS AND RC SYSTEM LEAK MODEL

(Reference Figure C-6 and Section 5-9 of Main Specification)

$$w_{P20} = \sqrt{K_{8.1}F_7\left[\left(\frac{P_{P1} + P_{P2}}{2}\right) - P_{RB}\right]}$$

$$w_{P31} = \sqrt{K_{8.10}F_8\,(P_{P1} - P_{S2})}$$

$$w_{P32} = \sqrt{K_{8.10}F_9\,(P_{P2} - P_{S1})}$$

$$w_{P21} = 0 \quad \text{if} \quad P_{CF1} \le P_{P1}$$

$$w_{P21} = SV_{81}\sqrt{K_{8.2}\,(P_{CF1} - P_{P1})} \quad \text{if} \quad P_{CF1} > P_{P1}$$

$$w_{P22} = 0 \quad \text{if} \quad P_{CF2} \le P_{P2}$$

$$w_{P22} = SV_{82}\sqrt{K_{8.2}\,(P_{CF2} - P_{P2})} \quad \text{if} \quad P_{CF2} > P_{P2}$$

$$\frac{dM_{CF1}}{dt} = w_{P23} - w_{P25} - w_{P21}$$

$$w_{P25} = K_{8.3}SV_{73}$$

$$\frac{dM_{CF2}}{dt} = w_{P24} - w_{P26} - w_{P22}$$

$$w_{P26} = K_{8.3}SV_{74}$$

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$$L_{CF1} = K_{8.4} + K_{8.5}M_{CF1}$$

$$L_{CF2} = K_{8.4} + K_{8.5}M_{CF2}$$

$$V_{CF1} = K_{8.6} - K_{8.7}M_{CF1}$$

$$V_{CF2} = K_{8.6} - K_{8.7}M_{CF2}$$

$$P_{CF1} = \frac{K_{8.8}M_{N1}}{V_{CF1}} - 14.7$$

$$\frac{dM_{N1}}{dt} = w_{P29} - w_{P27}$$

$$w_{P27} = K_{8.9}SV_{75}$$

$$P_{CF2} = \frac{K_{8.8}M_{N2}}{V_{CF2}} - 14.7$$

$$\frac{dM_{N2}}{dt} = w_{P30} - w_{P28}$$

$$w_{P28} = K_{8.9}SV_{76}$$

(F_7, F_8, F_9, w_{P23}, w_{P24}, w_{P29}, and w_{P30} are instructor inputs)

Symbols for Section 6

F_7 = area factor for leak flow between RC and RB

F_8 = area factor for leak flow across RCH1B tubes

F_9 = area factor for leak flow across RCH1A tubes

L_{CF1} = level in CFT1B, in.

L_{CF2} = level in CFT1A, in.

M_{CF1} = mass of water in CFT1B above level reference, lb

M_{CF2} = mass of water in CFT1A above level reference, lb

M_{N1} = mass of nitrogen in CFT1B, lb

M_{N2} = mass of nitrogen in CFT1A, lb

P_{CF1} = pressure in CFT1B, psig

P_{CF2} = pressure in CFT1A, psig

P_{P1} = refer to section 2

P_{P2} = refer to section 2

P_{RB} = refer to section 12

P_{S1} = refer to section 3

P_{S2} = refer to section 3

SV_{73} = position of drain valve for CFT1B

SV_{74} = position of drain valve for CFT1A

SV_{75} = position of vent valve for CFT1B

SV_{76} = position of vent valve for CFT1A

SV_{81} = position of stop valve in CFT1B H. P. injection line

SV_{82} = position of stop valve in CFT1A H. P. injection line

V_{GF1} = volume of gas in CFT1B, ft^3

V_{GF2} = volume of gas in CFT1A, ft^3

w_{P20} = flow through leak between RC system and RB, lb/sec

w_{P21} = injection flow from CFT1B, lb/sec

w_{P22} = injection flow from CFT1A, lb/sec

w_{P23} = water makeup to CFT1B, lb/sec

w_{P24} = water makeup to CFT1A, lb/sec

w_{P25} = drain flow from CFT1B, lb/sec

w_{P26} = drain flow from CFT1A, lb/sec

w_{P27} = vent flow from CFT1B, lb/sec

w_{P28} = vent flow from CFT1A, lb/sec

w_{P29} = nitrogen makeup to CFT1B, lb/sec

w_{P30} = nitrogen makeup to CFT1A, lb/sec

w_{P31} = flow through boiler tube leak, loop B, lb/sec

w_{P32} = flow through boiler tube leak, loop A, lb/sec

Constants for Core Flooding Tanks and RC System Leak Model

$K_{8.1}$ = admission factor for RC leak

$K_{8.2}$ = admission factor for injection flow

$K_{8.3}$ = reference flow for CF tank drains, lb/sec

$K_{8.4}$ = reference level in CF tanks, in.

$K_{8.5}$ = level conversion factor for CF tanks, in./lb

$K_{8.6}$ = total volume of one CF tank, ft^3

$K_{8.7}$ = volume conversion factor for CF tanks, ft^3/lb

$K_{8.8}$ = gas law constant for CF tank nitrogen, $ft^3/in.^2$

$K_{8.9}$ = reference flow for nitrogen venting, lb/sec

$K_{8.10}$ = admission factor for boiler tube leak

9. BORON MODEL

(Reference Figure C-6 and Section 5.10 of Main Specification)

$$C_{B1} = (B_{RC}/M_{RC})10^6$$

$$(10^6)\frac{dB_{RC}}{dt} = C_{B2}(w_{P18} + w_{P12}) + K_{9.1}(w_{D3} + w_{D4} + w_{DH1} + w_{DH2}) + K_{9.2}(w_{P21} + w_{P22}) - C_{B1}(w_{P1} + w_{P20} + w_{P31} + w_{P32} + w_{D7} + w_{D8})$$

$$C_{B2} = (B_{MU}/M_{MU})10^6$$

$$(10^6)\frac{dB_{MU}}{dt} = C_{B1}S_{30}w_{P1} + C_{B1}K_{9.4}w_{P2} + \left(\frac{C_{B3}SV_{29} + C_{B4}SV_{30} + C_{B5}SV_{31}}{SV_{29} + SV_{30} + SV_{31}}\right)w_{W2} - K_{9.3}w_{CA} - C_{B2}(w_{P13} - w_{P7})$$

$$C_{B3} = (B_{B1}/M_{B1})10^6$$

$$C_{B4} = (B_{B2}/M_{B2})10^6$$

$$C_{B5} = (B_{B3}/M_{B3})10^6$$

$$(10^6)\frac{dB_{B1}}{dt} = \left(\frac{C_{B1}SV_{26}w_{W1}}{SV_{26} + SV_{27} + SV_{28}}\right) - \left(\frac{C_{B3}SV_{29}w_{W2}}{SV_{29} + SV_{30} + SV_{31}}\right)$$

(10c) $\frac{dB_{B2}}{dt} = \left(\frac{C_{B1} SV_{27} * W1}{SV_{26} + SV_{27} + SV_{28}}\right) - \left(\frac{C_{B4} SV_{30} * W2}{SV_{29} + SV_{30} + SV_{31}}\right)$

(10d) $\frac{dB_{B3}}{dt} = \left(\frac{C_{B1} SV_{28} * W1}{SV_{26} + SV_{27} + SV_{28}}\right) - \left(\frac{C_{B5} SV_{31} * W2}{SV_{29} + SV_{30} + SV_{31}}\right)$

If $SV_{26} + SV_{27} + SV_{28} = 0$ set the entire expression in which it appears equal to zero. Handle $SV_{29} + SV_{30} + SV_{31}$ in the same manner.

Symbols for Section 9

B_{B1} = total boron in bleed tank No. 1, lb

B_{B2} = total boron in bleed tank No. 2, lb

B_{B3} = total boron in bleed tank No. 3, lb

B_{MU} = total boron in makeup tank, lb

B_{RC} = total boron in RC system, lb

C_{B1} = boron concentration in reactor coolant, ppm

C_{B2} = boron concentration in makeup tank, ppm

C_{B3} = boron concentration in bleed tank No. 1, ppm

C_{B4} = boron concentration in bleed tank No. 2, ppm

C_{B5} = boron concentration in bleed tank No. 3, ppm

M_{B1} = refer to section 6

M_{B2} = refer to section 6

M_{B3} = refer to section 6

M_{MU} = refer to section 6

M_{RC} = refer to section 2

S_{30} = refer to section 6

SV_{26} = refer to section 6

SV_{27} = refer to section 6

SV_{28} = refer to section 6

SV_{29} = refer to section 6

SV_{30} = refer to section 6

SV_{31} = refer to section 6

w_{CA} = refer to section 6

w_{D3} = refer to section 6

w_{D4} = refer to section 6

w_{D7} = refer to section 7

w_{D8} = refer to section 7

w_{DH1} = refer to section 7

w_{DH2} = refer to section 7

w_{P1} = refer to section 6

w_{P2} = refer to section 6

w_{P7} = refer to section 6

w_{P12} = refer to section 6

w_{P13} = refer to section 6

w_{P18} = refer to section 6

w_{P20} = refer to section 8

w_{P21} = refer to section 8

w_{P22} = refer to section 8

w_{P31} = refer to section 8

w_{P32} = refer to section 8

w_{W1} = refer to section 6

w_{W2} = refer to section 6

Constants for Boron Model

$K_{9.1}$ = boron concentration in borate water tank, ppm

$K_{9.2}$ = boron concentration in CF tanks, ppm

$K_{9.3}$ = boron concentration in CA tank, ppm

$K_{9.4}$ = deborating demineralizer effectiveness

10. INTERMEDIATE COOLING SYSTEM MODEL

(This section has been combined with section 11.)

11. BASIC HEAT REMOVAL SYSTEMS

11.1. Plant Cooling System (PC)

$$N_{PC1} = (2/3\ SV_{143} + 2/3\ SV_{144} - 1/3\ SV_{143}SV_{144})U_{25}$$

$$N_{PC2} = U_{25}SV_{146}$$

$N_{CPF} = 0$ if no canal pump is ON

$N_{CPF} = 2/3$ if 1 canal pump is ON

$N_{CPF} = 1$ if 2, 3, or 4 canal pumps are ON

$$U_{22} = SV_{131} + SV_{142} - SV_{131}SV_{142}$$

$$U_{23} = N_{CPF}SV_{130}U_{22}$$

$$U_{24} = P_{CA}SV_{136}SV_{139} + P_{CB}SV_{135}SV_{140} - P_{CA}P_{CB}SV_{136}SV_{139}SV_{135}SV_{140}$$

$$U_{25} = U_{23} + U_{22}U_{24}SV_{141} - U_{22}U_{23}U_{24}SV_{141}$$

$P_{CA} = 0$ if plant cooling pump A is OFF

$P_{CA} = 1$ if plant cooling pump A is ON

$P_{CB} = 0$ if plant cooling pump B is OFF

$P_{CB} = 1$ if plant cooling pump B is ON

$$K_{11.20} \frac{dT_{PC}}{dt} = K_{11.21}[1 + 24(1 - U_{26})] - T_{PC}$$

$$U_{26} = U_{26} + U_{23} SV_{141} - U_{24} U_{25} SV_{142}$$

$$T_{HC} = K_{11.22} MW_E + T_{PC}$$

$$T_{TOC} = K_{11.4} TS + T_{PC}$$

11.2. Reactor Component Cooling (CC) System

$$K_{11.1} \frac{dT_{CC1}}{dt} = (T_{P19} - K_{11.2} X U_{15} + K_{11.} [illegible]) + K_{11.2} - T_{CC1}$$

$$K_{11.5} \frac{dT_{CC2}}{dt} = \left(\frac{T_{P7} - T_{P17}}{2} - K_{11.2}\right) U_{16} + \left(\frac{T_{P7} - T_{P17}}{2}\right) K_{11.7}$$
$$+ K_{11.8} N_{RC} + K_{11.2} - T_{CC2}$$

$$K_{11.4} \frac{dT_{CC3}}{dt} = (T_{P23} - K_{11.2} X U_{17} + K_{11.5} T_{P15}) + K_{11.2} - T_{CC3}$$

$$U_{16} = 1 - U_{18} U_{19} U_{20} (0.25 - 0.75\, N_{PC})$$

$$U_{15} = 1 - U_{18} U_{14} (0.25 - 0.75\, N_{PC})$$

$$U_{17} = 1 - U_{19} (0.25 - 0.75\, N_{PC})$$

$U_{18} = 1$ if $N_{CC} = 0$

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$U_{18} = 0 \quad \text{if} \quad N_{CC} = 0$

$U_{19} = SV_{63}SV_{66}SV_{67}$

$U_{20} = SV_{64} + SV_{65} - SV_{64}SV_{65}$

$L_{CC} = K_{11.8}T_{CC} + K_{11.9}\int w_{CC}dt + K_{11.10}$

(w_{CC} is an instructor input ±)

$$T_{CC} = K_{11.20}U_{18}(K_{11.11}U_{19}U_{20}T_{CC1} + K_{11.12}U_{19}T_{CC2} + K_{11.13}T_{CC3}) + K_{11.14}(1 - 0.25\ N_{PC1})$$

$$P_{CC} = K_{11.15}U_{18}[K_{11.16} + K_{11.17}(1 - U_{19}) + K_{11.18}(1 - U_{20})]$$

$T_{P01} = T_{CC3}$

$T_{P02} = T_{CC3}$

$T_{P03} = T_{CC3}$

$T_{P04} = T_{CC3}$

$T_{PM3} = T_{CC3}$

$T_{PM4} = T_{CC3}$

$T_{PM5} = T_{CC3}$

$T_{PM6} = T_{CC3}$

11.3. Turbine Plant Cooling System (TP)

$$T'_{TP} = 95 + 120(1 - N_{TP}N_{PC2})$$

$$K_{11.25}\left(\frac{dT_{TP}}{dt}\right) = T'_{TP} - T_{TP}$$

$$T_{EX} = T_{EHO} = 17\ MW_E$$

$$P_{TP} = K_{11.23}N_{TP}$$

$$L_{TP} = K_{11.24}T_{TP}$$

11.4. Nuclear Service Raw Water System (NR)

$$L_{NRA} = K_{11.26}$$

$$L_{NRB} = K_{11.27}$$

$$P_{NRA} = 0 \quad \text{if} \quad N_{NRA} = 0$$

$$P_{NRA} = K_{11.28} \quad \text{if} \quad N_{NRA} = 1$$

$$P_{NRB} = 0 \quad \text{if} \quad N_{NRB} = 0$$

$$P_{NRB} = K_{11.28} \quad \text{if} \quad N_{NRB} = 1$$

11.5. Nuclear Services Cooling Water System (NS)

$$T'_{NA1} = K_{11.29}[1 - (N_{NRA})(N_{NSA})(SV_{92})] + K_{11.30}$$

$$T'_{NB1} = K_{11.29}[1 - (N_{NRB})(N_{NSB})(SV_{93})] + K_{11.30}$$

$$K_{11.31} \frac{dT_{NA1}}{dt} = T'_{NA1} - T_{NA1}$$

$$K_{11.31} \frac{dT_{NB1}}{dt} = T'_{NB1} - T_{NB1}$$

$$T_{NA2} = T_{NA1} + (K_{11.24} + K_{11.30} - T_{NA1})(1 - SV_{94}SV_{95})$$

$$T_{NB2} = T_{NB1} + (K_{11.29} + K_{11.30} - T_{NB1})(1 - SV_{96}SV_{97})$$

$$F_{12} = \left(1 - \frac{T_{NA1}}{K_{11.29} + K_{11.30}}\right) SV_{98}SV_{99}K_{11.32}$$

$$F_{13} = \left(1 - \frac{T_{NA1}}{K_{11.29} + K_{11.30}}\right) SV_{102}SV_{103}K_{11.32}$$

$$F_{14} = \left(1 - \frac{T_{NB1}}{K_{11.29} + K_{11.30}}\right) SV_{100}SV_{101}K_{11.32}$$

$$F_{15} = \left(1 - \frac{T_{NB1}}{K_{11.29} + K_{11.30}}\right) SV_{104}SV_{105}K_{11.32}$$

$$w_{NA1} = K_{11.33}N_{NSA}SV_{98}SV_{99}\left(1 - \frac{SV_{102}SV_{103}}{3}\right)SV_{92}$$

$$w_{NA2} = K_{11.33}N_{NSA}SV_{102}SV_{103}\left(1 - \frac{SV_{98}SV_{99}}{3}\right)SV_{92}$$

$$w_{NB1} = K_{11.33}N_{NSB}SV_{100}SV_{101}\left(1 - \frac{SV_{104}SV_{105}}{3}\right)SV_{93}$$

$$w_{NB2} = K_{11.33}N_{NSB}SV_{104}SV_{105}\left(1 - \frac{SV_{100}SV_{101}}{3}\right)SV_{93}$$

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$$L_{NSA} = K_{11.24} T_{NA1}$$

$$L_{NSB} = K_{11.24} T_{NB1}$$

$$P_{NSA} = K_{11.23} N_{NSA}$$

$$P_{NSB} = K_{11.23} N_{NSB}$$

Symbols for Section 11

ω_S = refer to section 4

F_{12} = effectiveness factor for RB emergency cooler No. A1

F_{13} = effectiveness factor for RB emergency cooler No. A2

F_{14} = effectiveness factor for RB emergency cooler No. B1

F_{15} = effectiveness factor for RB emergency cooler No. B2

L_{CC} = level in CC system surge tank, in.

L_{NRA} = constant section 11

L_{NRB} = constant section 11

L_{NSA} = level in NS system A surge tank, in.

L_{NSB} = level in NS system B surge tank, in.

L_{TP} = level in TP system surge tank, in.

M_e = refer to section 4

MW_E = refer to section 4

N_{CC} = number of CC system pumps on line

N_{CPF} = canal pump factor

N_{NRA} = number of nuclear raw water pumps in NRA ON

N_{NRB} = number of nuclear raw water pumps in NRB ON

N_{NSA} = number of nuclear services pumps in NSA ON

N_{NSB} = number of nuclear services pumps in NSB ON

N_{PC1} = PC system raw water pump factor

N_{PC2} = PC system canal pump factor

N_{RC} = refer to section 2

N_{TP} = number of turbine plant circ pumps on line

P_{CA} = plant raw water pump A factor

P_{CB} = plant raw water pump B factor

P_{CC} = component coolant system pressure

P_{NRA} = nuclear raw water coolant system pressure loop A

P_{NRB} = nuclear raw water coolant system pressure loop B

P_{NSA} - nuclear service water coolant system pressure loop A

P_{NSB} = nuclear service water coolant system pressure loop B

P_{TP} = turbine plant coolant system pressure

SV_{63} = component cooling discharge valve position

SV_{64} = refer to section 6

SV_{65} = refer to section 6

SV_{66} = component cooling isolation valve position

SV_{67} = component cooling isolation valve position

SV_{92} = NSCW pump A discharge valve position ES340

SV_{93} = NSCW pump B discharge valve position ES433

SV_{94} = NSCW to DH cooler A valve position ES146

SV_{95} = NSCW from DH cooler A valve position ES150

SV_{96} = NSCW to DH cooler B valve position ES234

SV_{97} = NSCW from DH cooler B valve position ES238

SV_{98} = NSCW to emergency cooler A1 valve position ES283

SV_{99} = NSCW from emergency cooler A1 valve position ES291

SV_{100} = NSCW to emergency cooler A2 valve position ES377

SV_{101} = NSCW from emergency cooler A2 valve position ES385

SV_{102} = NSCW to emergency cooler B1 valve position ES307

SV_{103} = NSCW from emergency cooler B1 valve position ES315

SV_{104} = NSCW to emergency cooler B2 valve position ES401

SV_{105} = NSCW from emergency cooler B2 valve position ES409

SV_{130} = PRW to unit 1 valve position PC145

SV_{131} = PRW ret to cooling tower valve position PC110

SV_{135} = PCW pump suction from cooling tower valve position PC76

SV_{136} = PCW pump suction from cooling tower valve position PC94

SV_{139} = PCW pump discharge to plant CW header valve position PC106

SV_{140} = PCW pump discharge to plant CW header valve position PC90

SV_{141} = PRW to cooling water sup. header cross tie valve position PC 118

SV_{142} = PRW to cooling water ret. header cross tie valve position PC 114

SV_{143} = CCW heat exchanger block valve position PC138

SV_{144} = CCW heat exchange block valve position PC141

SV_{146} = CCW heat exchange block valve position PC134

T_{CC} = component cooling water temp, F

T_{CC1} = CC temp at letdown cooler exit, F

T_{CC2} = CC temp at RC pump and oil cooler exit, F

T_{CC3} = CC temp at seal cooler exit, F

T_{EHO} = temp of EHC oil, F

T_{EX} = temp at exciter, F

T_{HC} = temp at hydrogen coolers, F

T_{NA1} = dynamic temp of NS sys A supply, F

T'_{NA1} = static temp of NS sys A supply, F

T_{NA2} = temp of NS supply to DH cooler A, F

T_{NB1} = dynamic temp of NS sys B supply, F

T'_{NB1} = static temp of NS sys B supply, F

T_{NB2} = temp of NS supply to DH cooler B, F

T_{P7} = refer to section 2

T_{P17} = refer to section 2

T_{P19} = refer to section 6

T_{P23} = refer to section 6

T_{PC} = temp of plant cooling system, F

T_{PM3} = temperature of RCP1AA motor, F

T_{PM4} = temperature of RCP1BA motor, F

T_{PM5} = temperature of RCP1AB motor, F

T_{PM6} = temperature of RCP1BB motor, F

T_{PO1} = temperature of RCP1AA oil, F

T_{PO2} = temperature of RCP1BA oil, F

T_{PO3} = temperature of RCP1AB oil, F

T_{PO4} = temperature of RCP1BB oil, F

T_{TOC} = temperature of turbine oil coolers, F

T_{TP} = turbine plant dynamic temp, F

T'_{TP} = turbine plant static temp, F

U_{15} = flow factor for CC water to LD cooler

U_{16} = flow factor for CC water to RC oil cooler

U_{17} = flow factor for CC water to seal cooler

U_{18} = CC pump factor

U_{19} = ES valve CC cooling flow factor

U_{20} = LD cooler valve CC cooling flow factor

U_{22} = canal pump flow return factor

U_{23} = canal pump flow supply factor

U_{24} = plant cooling pump supply factor

U_{25} = canal pump— plant cooling pump factor

U_{26} = canal pump—plant cooling pump factor

w_{CC} = feed/bleed flow in CC system, lb/sec

w_{NA1} = flow of NS water to RB emergency cooler A1, lb/sec

w_{NA2} = flow of NS water to RB emergency cooler A2, lb/sec

w_{NB1} = flow of NS water to RB emergency cooler B1, lb/sec

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w_{NB2} = flow of NS water to RB emergency cooler B2, lb/sec

w_{P1} = refer to section 6

w_{P15} = refer to section 6

Constants for Section 11

$K_{11.1}$ = time constant for letdown cooler, sec

$K_{11.2}$ = temperature of plant cooling water, F

$K_{11.3}$ = flow factor for letdown cooler heat transfer, sec/lb

$K_{11.4}$ = time constant for seal cooler, sec

$K_{11.5}$ = flow factor for seal cooler heat transfer, sec/lb

$K_{11.6}$ = time constant for RC pump oil cooler, sec

$K_{11.7}$ = RC pump oil temperature factor

$K_{11.8}$ = CC surge tank level/temperature conversion factor, in./F

$K_{11.9}$ = CC surge tank level/flow factor, in.-sec/lb

$K_{11.10}$ = CC surge tank level reference, in.

$K_{11.11}$ = relative flow fraction; CC water to letdown coolers

$K_{11.12}$ = relative flow fraction; CC water to RC oil coolers

$K_{11.13}$ = relative flow fraction; CC water to seal coolers

$K_{11.14}$ = temperature bias factor for RC pump

$K_{11.15}$ = CC system overall pressure factor

$K_{11.16}$ = CC system seal flow pressure factor

$K_{11.17}$ = CC system ES pressure factor

$K_{11.18}$ = CC system letdown flow pressure factor

$K_{11.19}$ = RC pump heat factor for CC system

$K_{11.20}$ = overall temperature factor for CC system

$K_{11.21}$ =

$K_{11.22}$ =

$K_{11.23}$ = pressure factor, TP pump, lb/in.^{2}

$K_{11.24}$ = level factor, TP surge tank, in./F

$K_{11.25}$ = overall time constant for TP cooler, sec

$K_{11.26}$ = static level factor for NR spray pond A, in.

$K_{11.27}$ = static level factor for NR spray pond B, in.

$K_{11.28}$ = pressure factor for NS pumps

$K_{11.29}$ = temperature excursion factor for NS systems malfunction, F

$K_{11.30}$ = normal temperature for NS systems, F

$K_{11.31}$ = overall time constant for NS systems coolers, sec

$K_{11.32}$ = factor in RB cooler effectiveness

$K_{11.33}$ = factor for relating NS system valve configuration to flow

12. REACTOR BUILDING MODEL – INCLUDING SPRAY

(Reference Figure C-6 and Section 5-12 of Main Specification)

$$P_{RB} = f_1(\rho_{RB}) + P_{RBA}$$

$$\rho_{RB} = \frac{M_{RBS}}{V_{RBS}} \quad \text{if} \quad F_7 \neq 0$$

$$\text{or} \quad F_6 \neq 0$$

$$\text{or} \quad A_{S1} \neq 0$$

$$\text{or} \quad A_{S2} \neq 0$$

$$\rho_{RB} = K_{12.1} \quad \text{if} \quad F_7 = 0$$

$$\text{and} \quad F_6 = 0$$

$$\text{and} \quad A_{S1} = 0$$

$$\text{and} \quad A_{S2} = 0$$

$$\frac{dM_{RBS}}{dt} = K_{12.2}(w_{P19} + w_{P20}) - w_{S9} - w_{S10} + K_{12.3}$$

$$(q_{DH} - q_L - q_{FL} - q_S)$$

$$T_{RBS} = f_2(\rho_{RB})$$

$$q_L = K_{12.4}(T_{RBS} - T_{RBL})$$

$$K_{12.13} \frac{dT_{RBL}}{dt} = q_L$$

$$q_{FC} = (T_{RBS} - K_{12.6})(F_{12} + F_{13} + F_{14} + F_{15})$$

$$q_S = K_{12.7}(w_{D1} + w_{D2})(T_{RBS} - T_{BW})$$

$$P_{RBA} = K_{12.8}(T_{RBS} + 460) - 14.7$$

$$\frac{dM_{RBW}}{dt} = \frac{q_L + q_{FC} + q_S}{K_{12.3}} + (1 - K_{12.2})(w_{P19} + w_{P20}) + w_{D1} + w_{D2} + w_{OV} - w_{RB1} - w_{RB2}$$

$$L_{RB} = K_{12.5} M_{RBW}$$

$w_{OV} = 0$ if $M_{RC} \leq K_{12.9}$

$w_{OV} = w_{P21} + w_{P22} - w_{D3} - w_{D4} - w_{DH1} - w_{DH2}$ if $M_{RC} > K_{12.9}$

$$V_{RBS} = K_{12.10} - K_{12.11} M_{RBW}$$

$$T_{RBW} = T_{RBS}$$

$\left.\begin{array}{l} w_{D1} = 0 \\ P_{D1} = 0 \end{array}\right\}$ if BSP1B is off or if $M_{BW} = 0$

$\left.\begin{array}{l} w_{D1} = K_{12.12} SV_{71} SV_{87} \\ P_{D1} = K_{12.14} \end{array}\right\}$ if BSP1B is on and if $M_{BW} \neq 0$

$$\left.\begin{array}{l} w_{D2} = 0 \\ P_{D2} = 0 \end{array}\right\} \quad \text{if BSP1A is off or if } M_{BW} = 0$$

$$\left.\begin{array}{l} w_{D2} = K_{12.12} SV_{72} SV_{88} \\ P_{D2} = K_{12.14} \end{array}\right\} \quad \text{if BSP1A is on and if } M_{BW} \neq 0$$

Symbols for Section 12

ρ_{RB} = density of steam in reactor building, lb/ft³

A_{S1} = refer to section 4

A_{S2} = refer to section 4

F_6 = refer to section 6

F_7 = refer to section 8

F_{12} = refer to section 11

F_{13} = refer to section 11

F_{14} = refer to section 11

F_{15} = refer to section 11

L_{RB} = level of water in reactor building, in.

M_{RBS} = mass of steam in main reactor building, lb

M_{RBW} = mass of water in reactor building, lb

M_{RC} = refer to section 2

P_{D1} = discharge pressure of building spray pump B, psi

P_{D2} = discharge pressure of building spray pump A, psi

P_{RB} = pressure in reactor building, psig

P_{RBA} = partial pressure of RB air, psi

q_{DH} = refer to section 1

q_{FC} = heat removal by RB fan coolers, Btu/sec

q_L = rate of heat absorption by RB liner, Btu/sec

q_S = heat absorbed by RB spray, Btu/sec

SV_{71} = position of valve in RB spray line B

SV_{72} = position of valve in RB spray line A

SV_{87} = refer to section 7

SV_{88} = refer to section 7

T_{BW} = refer to section 7

T_{RBL} = temperature of RB liner, F

T_{RBS} = temperature of reactor building steam, F

T_{RBW} = temperature of reactor building water, F

V_{RBS} = volume of steam in RB, ft^3

w_{D1} = flow through RB spray pump B, lb/sec

w_{D2} = flow through RB spray pump A, lb/sec

w_{D3} = refer to section 6

w_{D4} = refer to section 6

w_{DH1} = refer to section 7

w_{DH2} = refer to section 7

w_{OV} = overflow of water through RC leak, lb/sec

w_{P19} = refer to section 6

w_{P20} = refer to section 8

w_{P21} = refer to section 8

w_{P22} = refer to section 8

w_{RB1} = refer to section 7

w_{RB2} = refer to section 7

w_{S6} = refer to section 4

w_{S10} = refer to section 4

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Constants for Reactor Building Model

$K_{12.1}$ = normal vapor density in RB, lb/ft³

$K_{12.2}$ = fraction of RC which is steam

$K_{12.3}$ = heat of vaporization, Btu/lb

$K_{12.4}$ = thermal factor for RB liner, Btu/sec-F

$K_{12.5}$ = factor for converting RB water mass to level, in. /lb

$K_{12.6}$ = sink temperature for RB fan coolers, F

$K_{12.7}$ = thermal factor for RB spray, Btu/lb-F

$K_{12.8}$ = gas law constant for RB air, lb/in.²-F

$K_{12.9}$ = mass in RC system below leak, lb

$K_{12.10}$ = normal free volume of RB, ft³

$K_{12.11}$ = specific volume of RB water, ft³/lb

$K_{12.12}$ = RB spray flow in each system, lb/sec

$K_{12.13}$ = thermal factor for RB liner, Btu/F

$K_{12.14}$ = discharge pressure of RB spray pumps, psig

13. RADIATION MONITORING SYSTEM MODEL

(Reference Section 5.13 of Main Specification)

$$K_{13.1}\left(\frac{dC_{M1}}{dt}\right) = K_{13.3}C_{M2}\int w_{P6}dt - C_{M1}$$

$$C_{M2} = K_{13.5} + F_4$$

$F_4 = 0$ if no failed fuel casualty is in

$F_4 = f(t)$ if the failed fuel casualty is in

$$C_{M3} = K_{13.8} + K_{13.9}C_{M6}$$

$$K_{13.10}\frac{dC_{M4}}{dt} = K_{13.12}C_{M2}\int (w_{P19} + w_{P20})dt + K_{13.13}C_{M6}\int (w_{S9} + w_{S10} + w_{S16})dt - C_{M4}$$

$$C_{M5} = K_{13.15} + K_{13.16}C_{M4}$$

$$K_{13.2}\left(\frac{dC_{M6}}{dt}\right) = K_{13.4}C_{M2}\int (w_{P31} + w_{P32})dt - C_{M6}$$

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Symbols for Section 13

C_{M1} = meter reading, RMS C. C. channel, cpm

C_{M2} = meter reading, RMS letdown channel, cpm

C_{M3} = meter reading, RMS air ejector channel, cpm

C_{M4} = meter reading, RMS RB channel, cpm

C_{M5} = meter reading, RMS station vent channel, cpm

C_{M6} = concentration of radioactivity in steam system

F_4 = radiation factor for failed fuel

w_{P6} = refer to section 6

w_{P19} = refer to section 6

w_{P20} = refer to section 8

w_{P31} = refer to section 8

w_{P32} = refer to section 8

w_{S9} = refer to section 4

w_{S10} = refer to section 4

Constants for Radiation Monitoring System Model

$K_{13.1}$ = conversion and time factor for C.C. channel, sec

$K_{13.2}$ = conversion and time factor for concentration in steam

$K_{13.3}$ = factor for radiation buildup from leaking letdown cooler

$K_{13.4}$ = factor for radiation buildup in steam

$K_{13.5}$ = background for letdown channel, cpm

$K_{13.6}$ =

$K_{13.7}$ =

$K_{13.8}$ = background for air ejector channel, cpm

$K_{13.9}$ = radiation buildup factor for leaking steam generator tubes

$K_{13.10}$ = time constant for RB channel, sec

$K_{13.11}$ =

$K_{13.12}$ = radiation buildup factor for RC leak

$K_{13.13}$ = radiation buildup factor for steam leak

$K_{13.14}$ =

$K_{13.15}$ = background for station vent channel, cpm

$K_{13.16}$ = gain factor for station vent channel

$K_{13.17}$ =

14. ELECTRICAL SYSTEM MODEL

14.1. Turbine Exciter

$$E_X = K_{14.11} I_{11}$$

$$I_{11} = K_{14.12}(I_{12} + I_{13})$$

$I_{12} = 0$ if Exciter Supply Power is OFF

$I_{12} = \int R_G dt$

$R_G = +K_{14.14}$ if Base Adjust RAISE PB is depressed

$R_G = -K_{14.14}$ if Base Adjust LOWER PB is depressed

$R_G = 0$ if neither Base Adjust PB is depressed

$I_{13} = 0$ if Exciter Supply Power is OFF

$I_{13} = \int R_H dt + K_{14.13} V_G$

$R_H = +K_{14.15}$ if MANUAL VOLT REG is energized and if manual RAISE is depressed

$R_H = -K_{14.15}$ if MANUAL VOLT REG is energized and if manual LOWER PB is depressed

$R_H = 0$ if MANUAL VOLT REG is energized and neither RAISE nor LOWER is depressed

$R_H = K_{14.16}(V_S - 14.17\ V_G)$ if AUTO VOLT REG is energized

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Exciter Mode Logic and Inputs from Console.

Mode	Energized by PB	Deenergized by PB	Momentary or maintained
Exciter Supply ON	ON	OFF	MOM
Base Adjust RAISE	RAISE		MAIN
Base Adjust LOWER	LOWER		MAIN
Auto Volt Reg	AUTO REG		MOM
Manual Volt Reg	MAN REG		MOM
Manual Reg Raise	RAISE REG		MAIN
Manual Reg Lower	LOWER REG		MAIN

14.2. Description of Electrical Plant (Refer to Figure C-9)

For normal operation with the nuclear unit generator and a significant power level, the unit electrical system is connected with the utilities system power grid via the OCB breaker(s) and the nuclear unit own electrical load being supplied directly from the unit generator. MGB_1 and MGB_2 would be closed but the subbreakers, e.g., B_2 would be open— with the exception that the 4160V nuclear service bus 1B and 1C (ES_1 and ES_2) are connected to the grid through B_{10}, B_{12}, B_{13}, B_{14} and MGB_2. With this normal hookup the nuclear units own loads (w_1) would probably be a minor part of the total unit generator load.

During startup all plant loads are connected to the main grid through MGB_1 and MGB_2.

On any condition of a drooping voltage supply automatic bus transfer is provided for individual busses to transfer to the alternate source. In the case of ES_1 and ES_2 busses the alternate source is ultimately the two emergency diesel generators EDG, but the breakers B_{15} and B_{16} will not close until the EDG are up to speed. No plant loads except those on ES_1 and ES_2 will be applied to the EDG. Furthermore the EDG will never be paralleled with any external source and, normally, not with each other.

Upon loss of voltage source and breaker opening or automatic transfer, all loads drop out and must be restarted manually—with the exception of the ES loads which have an automatic restart and sequencing feature. Manual "live-bus" transfer does not drop loads.

All loads and main bus breakers have individual dynamic simulation with the exception that loads on 480 V normal bus 1A and 1D may be lumped into two constant loads of 700 hp each.

The electric mimic panel display meters require that individual bus loads be summed in order to generate amperage indication.

All combinations of OCB and MGB breaker connections to the five grid tie lines will not be simulated but will be shifted from time to time by instructor initiated reprogramming, i.e., the instructor (acting as load dispatcher) will dictate to the operators which OCB or MGB he should close on a given day.

In synchronizing two independent power sources prior to breaker closure or live transfer, a key lock switch is used to display the two frequencies on a synchroscope. However, the frequency comparison is always between ω_G and ω_S.

14.3. Bus, Breaker and Electrical Parameter Tabulation

Table 1. Symbols

Bus name	Voltage symbol	Current symbol	Frequency symbol	Normal breaker status N.C.	Normal breaker status N.O.
6900 V 1A	V_1	I_{15}	ω_1	B_1	B_2
6900 V 1B	V_2	I_{16}	ω_2	B_3	B_4
4160 V 1E	V_3	I_{17}	ω_3	B_5	--
4160 V 1F	V_4	--	ω_4	B_6	B_7
4160 V 1A	V_5	I_{18}	ω_5	B_8	B_9
4160 V 1B	V_{ES1}	I_{20}	ω_{ES1}	B_{12}, B_{13}	B_{14}
4160 V 1C	V_{ES2}	I_{21}	ω_{ES2}	B_{15}, B_{14}	B_{16}
4160 V 1D	V_6	I_{19}	ω_6	B_{17}	B_{18}
480 V 1A	--	--	--	--	--
480 V 1B	--	--	--	--	--
480 V 1C	--	--	--	--	--
480 V 1D	--	--	--	--	--
Grid 1	V_S	I_{22}	ω_S	OCB	--
Grid 2	V_S	I_{23}	ω_S	MGB_1	--
Grid 3	V_S	I_{24}	ω_S	MGB_2	--
Gen	V_G	I_{14}	ω_G	None	--

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The following breaker pairs are interlocked so that both cannot be closed or open at the same time: $B_1 - B_2$, $B_3 - B_4$, $B_5 - B_7$, $B_8 - B_9$, $B_{10} - B_{11}$, $B_{17} - B_{18}$

Table 2. Potential Loads

Bus	Loads, hp		Symbol
6900 V 1A	RC pump	6950	W_2
	RC pump	6950	
6900 V 1B	RC pump	6950	W_3
	RC pump	6950	
4160 V 1E	Circ pump	4000	W_4
	Circ pump	4000	
4160 V 1F	Circ pump	4000	
	Circ pump	4000	
	Cond pump	3500	
4160 V 1A	RC H.P. MU pump	700	W_5
	Lgt (always connected), kVA	400	
	Cool tower	2500	
	Plant raw water pump	500	
	Cond pump	3500	
	HTR drain pump	800	
480 V 1A	Lumped (constant)	700	
4160 V 1D	Cool tower	2500	W_6
	Cond pump	3500	
	HTR drain pump	800	
	Lgt (always connected)	400	
	Plant raw water pump	500	
480 V 1B	Lumped	700	
4160 V 1B	RC H.P. MU pump	700	W_7
	DH pump	400	
	NS raw water pump	450	
480 V 1B	Lumped (comes on with ES)	450	
	NS cool water pump	200	
4160 V 1C	RC H.P. MU pump	700	W_8
	Emerg (aux) feed pump	1000	
	DH pump	400	
	NS raw water pump	450	
480 V 1C	Lumped (comes on with ES)	450	
	NS cool water pump	200	

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14.4. Load Model

Except for those loads that are lumped, the load levels in the groups W_1 through W_8, fluctuate as individual loads are switched. The lumped lighting loads and the two lumped 700 hp loads are always connected. The two lumped 450 hp loads come on the safeguards actuation trip of high reactor building pressure. In converting power units:

- Multiply horsepower (hp) by 0.83 to get kW
  Multiply horsepower (hp) by 1 to get kVA

W_1 = W_2 (if B_1 is closed) + W_3 (if B_3 is closed)
+ W_4 (if B_5 is closed) + W_5 (if B_8 is closed)
+ W_6 (if B_{17} is closed)

W_9 = (MW_E − W_1) (if OCB is closed)

W_9 = 0 (if OCB is open)

W_{10} = [W_2(if B_2 is closed) + W_3(if B_4 is closed)
+ (W_7 + W_8)(if B_{11} is closed)] [if MGB_1 is closed]

W_{10} = 0 (if MGB_1 is open)

W_{11} = [W_4(if B_7 is closed) + (W_7 + W_8)(if B_{10} is closed)]
[if MGB_1 is closed]

W_{11} = 0 (if MGB_2 is open)

(See section 14.6 for emergency diesel loading)

14.5. Voltage Model

$V_S = K_{14.24}\omega_o$

V_7 = 0 if MGB_1 is not energized

V_7 = V_S if MGB_1 is energized

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$V_8 = 0$ if MGB_2 is not energized

$V_8 = V_S$ if MGB_2 is energized

MGB opens manually or automatically if $V_S \leq K_{14.26}$

$V_G = K_{14.19} V_S$ if OCB is energized

$V_G = K_{14.16} \omega_S I_{11}$ if OCB is not energized

$V_1 = K_{14.25} V_G$ if B_1 is closed

$V_1 = K_{14.23} V_7$ if B_2 is closed

$V_2 = K_{14.25} V_G$ if B_3 is closed

$V_2 = K_{14.23} V_7$ if B_4 is closed

B_1 and B_2 and B_3 and B_4 may be operated manually in pairs or a closed breaker will open if its supply voltage $V_7 \leq K_{14.26}$

$V_3 = K_{14.29} V_G$ if B_5 is closed

$V_4 = K_{14.28} V_8$ if B_7 is closed

$V_3 = V_4$ if B_6 is closed

$V_3 = 0$ if B_5 and B_6 are open

$V_4 = 0$ if B_7 and B_6 are open

B_6 is controlled manually.

B_5 and B_7 may be controlled manually in pairs or will open automatically if the appropriate supply voltage is drooping. i.e.,

$V_G \leq K_{14.27}$; $V_8 \leq K_{14.26}$

$V_5 = K_{14.29}V_G$ if B_8 is closed

$V_5 = K_{14.28}V_8$ if B_9 is closed

$V_6 = K_{14.29}V_G$ if B_{17} is closed

$V_6 = K_{14.28}V_8$ if B_{18} is closed

B_8 and B_9 and B_{17} and B_{18} operate as pairs either manually or automatically to open if the appropriate supply voltage is drooping, i.e., $V_G \leq K_{14.27}$; $V_8 \leq K_{14.26}$

$V_{ES1} = K_{14.28}V_7$ if B_{11} is closed

$V_{ES1} = K_{14.28}V_8$ if B_{12}, B_{13}, and B_{10} are closed

$V_{ES1} = K_{14.1}V_{D1}$ if B_{15} is closed

$V_{ES1} = 0$ if B_{11}, B_{15}, and (B_{12} or B_{13} or B_{10}) are open

$V_{ES2} = K_{14.28}V_8$ if B_{10} and B_{14} are closed

$V_{ES2} = K_{14.28}V_7$ if B_{11}, B_{12}, B_{13}, and B_{14} are closed

$V_{ES2} = K_{14.1}V_{D2}$ if B_{16} is closed

B_{10}, B_{11}, B_{12}, B_{13}, B_{14} may be operated manually or automatically:

if $V_8 \leq K_{14.26}$ B_{10} opens, B_{11} closes;
if $V_7 \leq K_{14.26}$ B_{10} closes, B_{11} opens;
if both V_7 and $V_8 \leq K_{14.26}$, B_{10}, B_{11}, B_{12}, B_{13} all open.

Following this, the events are dictated by the emergency operation of the diesel generators.

14.6. Emergency Diesel Generator Model

This mode may be defeated by an instructor imposed casualty, or the operator may impose a manual defeat from the console.

If no defeat is imposed the mode may be initiated by any of the following three conditions:

If manual starting is initiated

or

If emergency injection has been initiated

or

If $V_S < K_{14.26}$

$$K_{14.2}\frac{d\omega_{D1}}{dt} = K_{14.8}(60 - \omega_{D1}) + K_{14.9}\int(60 - \omega_{D1})dt - K_{14.10}\omega_{D1}$$

$$K_{14.2}\frac{d\omega_{D2}}{dt} = K_{14.8}(60 - \omega_{D2}) + K_{14.9}\int(60 - \omega_{D2})dt - K_{14.10}\omega_{D2}$$

after an initial delay of $K_{14.3}$ sec

The manual defeat, whether a casualty by the instructor or an operator action could be introduced by replacing the 60 in the last two equations with zero.

When ω_{D1} and/or ω_{D2} become $> K_{14.22}$, and if the respective breakers B_{11} and B_{10} plus B_{12} and B_{13} have opened, then the diesel generator(s) connect with their respective busses via closing of B_{15} and B_{16}.

The equations above for ω_{D1} and ω_{D2} still apply with the following additions:

To the right side of the equation for ω_{D1} and ω_{D2} subtract $K_{14.4}W_7$ and $K_{14.4}W_8$ respectively.

14.7. Frequency and Current Modeling

ω_S and its relation to ω_o is covered in section 4.3.

ω_o is set from the instructor's console

$\omega_7 = 0$ if MGB_1 is open

$\omega_8 = 0$ if MGB_2 is open

$\omega_7 = \omega_0$ if MGB_1 is closed

$\omega_8 = \omega_0$ if MGB_2 is closed

$\omega_1 = \omega_S$ if B_1 is closed

$\omega_1 = \omega_7$ if B_2 is closed

$\omega_2 = \omega_S$ if B_3 is closed

$\omega_2 = \omega_7$ if B_4 is closed

$\omega_3 = \omega_S$ if B_5 is closed

$\omega_4 = \omega_8$ if B_7 is closed

$\omega_3 = \omega_4$ if B_6 is closed

$\omega_5 = \omega_S$ if B_8 is closed

$\omega_5 = \omega_8$ if B_9 is closed

$\omega_6 = \omega_S$ if B_{17} is closed

$\omega_6 = \omega_8$ if B_{18} is closed

$\omega_{ES1} = \omega_7$ if B_{11} is closed

$\omega_{ES1} = \omega_{ES2}$ if B_{12}, B_{13}, B_{14} are closed

$\omega_{ES1} = \omega_{D1}$ if B_{15} is closed

$\omega_{ES2} = \omega_{8}$ if B_{10} and B_{14} are closed

$\omega_{ES2} = \omega_{D2}$ if B_{16} is closed

$I_{14} = K_{14.20}(MW_E/0.8\ V_G)$

$I_{15} = K_{14.30}W_2$

$I_{16} = K_{14.30}W_3$

$I_{17} = K_{14.31}W_4$

$I_{18} = K_{14.31}W_5$

$I_{19} = K_{14.31}W_6$

$I_{20} = K_{14.31}W_7$

$I_{21} = K_{14.31}W_8$

$I_{22} = K_{14.32}W_9$

$I_{23} = K_{14.32}W_{10}$

$I_{24} = K_{14.32}W_{11}$

14.8. Control Room Light Fluctuations

The attached sketch indicates the layout for the simulator control room lighting.

Since all fixtures will be fluorescent, simulated voltage dips need only involve a momentary interruption or flicker— in contrast to variable voltage level.

Power to all main control room lighting shall be interrupted for the following conditions and for the following intervals:

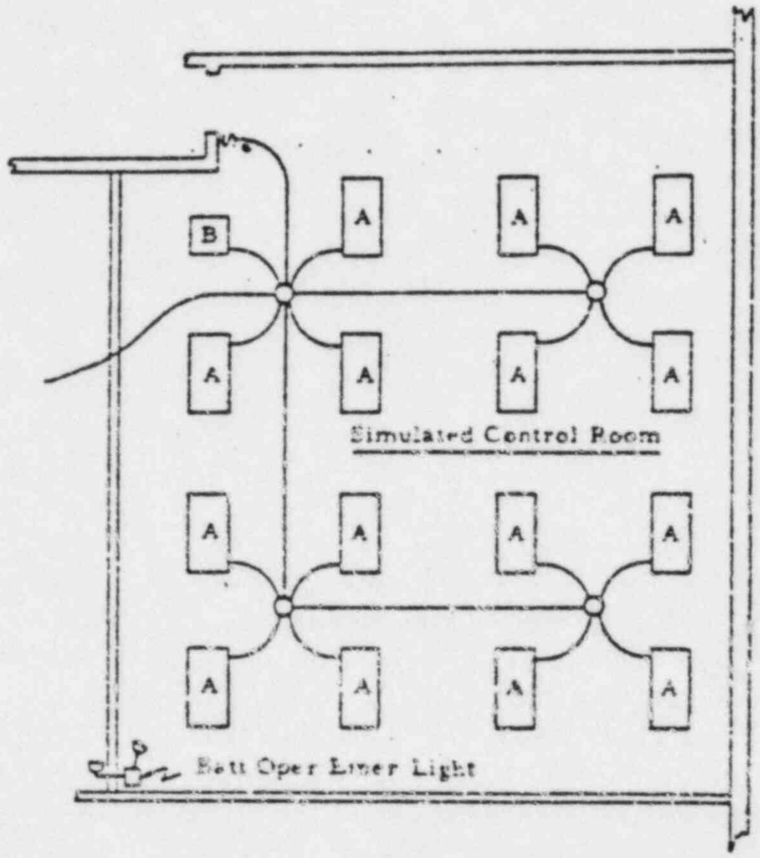
1. Any time the following components are started:

Component	Interrupt time
RC pump No. 1	$K_{14.33}$
RC pump No. 2	$K_{14.33}$
RC pump No. 3	$K_{14.33}$
RC pump No. 4	$K_{14.33}$
Circulation pump No. 1	$K_{14.34}$
Circulation pump No. 2	$K_{14.34}$
Circulation pump No. 3	$K_{14.34}$
Circulation pump No. 4	$K_{14.34}$
Condensate pump No. 1	$K_{14.34}$
Condensate pump No. 2	$K_{14.34}$
Condensate pump No. 3	$K_{14.34}$

2. Any time breaker B_{10} or B_{11} open automatically, i.e., $V_8 < K_{14.26}$ or $V_7 < K_{14.26}$, an interrupt of $K_{14.35}$ sec shall occur.

3. Any time B_{15} or B_{16} are already closed, as described in 14.6, an interruption shall exist whenever $V_L < K_{14.36}$

$$V_L = \frac{V_{ES1} + V_{ES2}}{2}$$



Type "A" lighting fixtures 2'-0" × 4'-0" fluor with four (4) 40 W lamps
Type "B" 2'-0" × 2'-0" four (4) 20 W lamps
Voltage - 120 V
All fixtures are rapid start and have Acrylic pyramidal lens

Total illumination -
15 type "A" fixtures at 160 W = 2400 W
1 type "B" at 80 W = 80 W
2480 W fluorescent

Symbols for Section 14

ω_0 = refer to section 4

ω_1 = frequency on 6900 V bus 1A, cps

ω_2 = frequency on 6900 V bus 1B, cps

ω_3 = frequency on 4160 V bus 1E, cps

ω_4 = frequency on 4160 V bus 1F, cps

ω_5 = frequency on 4160 V bus 1A, cps

ω_6 = frequency on 4160 V bus 1D, cps

ω_7 = frequency on start up transformer No. 1, cps

ω_8 = frequency on start up transformer No. 2, cps

ω_{D1} = emergency diesel 1A speed, cps

ω_{D2} = emergency diesel 1B speed, cps

ω_{ES1} = frequency on engineered safeguards bus 1E, cps

ω_{ES2} = frequency on engineered safeguards bus 1F, cps

ω_S = refer to section 4

B_1 = 6900 V bus 1A to aux transformer No. 1

B_2 = 6900 V bus 1A to start-up transformer No. 1

B_3 = 6900 V bus 1B to aux transformer No. 1

B_4 = 6900 V bus 1B to start-up transformer No. 2

B_5 = 4160 V bus 1E to aux transformer No. 2

B_6 = 4160 V bus 1E to elect bus 1F

B_7 = 4160 V bus 1F to start-up transf No. 2

B_8 = 4160 V bus 1A to aux transformer No. 2

B_9 = 4160 V bus 1A to start-up transf No. 2

B_{10} = start up transf No. 2 to tie point

B_{11} = 4160 V bus 1B to start-up transf No. 1

B_{12} = 4160 V bus 1B breaker No. 1 to tie point

B_{13} = 4160 V bus 1B breaker No. 2 to tie point

B_{14} = 4160 V bus 1C to tie point

B_{15} = 4160 V bus 1B to emerg gen No. 1

B_{16} = 4160 V bus 1C to emerg gen No. 2

B_{17} = 4160 V bus 1D to aux transformer No. 2

B_{18} = 4160 V bus 1D to start-up transf No. 2

E_X = excitation factor

I_{11} = exciter field amps

I_{12} = exciter base adjust amps

I_{13} = exciter regulator amps

I_{14} = generator output amps

I_{15} = 6900 V bus 1A amps

I_{16} = 6900 V bus 1B amps

I_{17} = 4160 V bus 1E and 1F amps

I_{18} = 4160 V bus 1A amps

I_{19} = 4160 V bus 1D amps

I_{20} = 4160 V bus 1B amps

I_{21} = 4160 V bus 1B amps

I_{22} = OCB amps

I_{23} = MGB_1 amps

I_{24} = MGB_2 amps

MGB_1 = start-up transf No. 1 power breaker

MGB_2 = start-up transf No. 2 power breaker

MW_E = refer to section 4

OCB = main circuit breaker

R_G = exciter base adjust rate

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R_E = exciter voltage regulation rate

V_1 = voltage on 6900 V bus 1A

V_2 = voltage on 6900 V bus 1B

V_3 = voltage on 4160 V bus 1E

V_4 = voltage on 4160 V bus 1F

V_5 = voltage on 4160 V bus 1A

V_6 = voltage on 4160 V bus 1D

V_7 = voltage on station side of MGB_1

V_8 = voltage on station side of MGB_2

V_{ES1} = voltage on engineered safeguards bus 1B

V_{ES2} = voltage on engineered safeguards bus 1C

V_G = main unit generator voltage

V_L = factor for control room lighting simulation

V_S = grid voltage

W_1 = total plant electrical load, kW

W_2 = reactor coolant pump bus 1A load, kW

W_3 = reactor coolant pump bus 1B load, kW

W_4 = 4160 V bus 1E load, kW

W_5 = 4160 V bus 1A load, kW

W_6 = 4160 V bus 1D load, kW

W_7 = engineered safeguards 4160 V bus 1B (connected load), kW

W_7' = engineered safeguards 4160 V bus 1B (transient load), kW

W_8 = engineered safeguards 4160 V bus 1C (connected load), kW

W_8' = engineered safeguards 4160 V bus 1C (transient load), kW

W_9 = total load carried by unit generator through OCB to system grid, kW

W_{10} = total load of plant carried by system grid through MGB_1

W_{11} = total load of plant carried by system grid through MGB_2

Constants for Electrical System Model

$K_{14.1}$ = proportionality factor, volts per cps

$K_{14.2}$ = time constant for diesel start-up, sec

$K_{14.3}$ = time delay for diesel start-up, sec

$K_{14.4}$ = proportionality factor for relating load changes to frequency lag, cps/watt

$K_{14.5}$ = time constant for load transient, sec

$K_{14.6}$ = equivalent voltage with emergency lighting on battery power

$K_{14.7}$ = set point for RB pressure trip, psig

$K_{14.8}$ = proportional gain factor for emergency diesel control

$K_{14.9}$ = integration factor for emergency diesel control

$K_{14.10}$ = load torque factor for emergency diesel control

$K_{14.11}$ = factor for converting exciter field amps to exciter effectiveness

$K_{14.12}$ = factor for converting exciter regulator and base amps to field amps

$K_{14.13}$ = factor for converting generator voltage in regulation controller

$K_{14.14}$ = change rate factor for exciter base adjuster

$K_{14.15}$ = change rate factor for exciter manual voltage regulation

$K_{14.16}$ = factor for converting voltage error to control rate in exciter automatic regulator

$K_{14.17}$ = scale factor for converting generator voltage to network system voltage

$K_{14.18}$ = factor for generating generator voltage from speed and exciter field current

$K_{14.19}$ = $1/K_{14.17}$

$K_{14.20}$ = scale factor for calculating generator amps from power and voltage

$K_{14.21}$ =

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$K_{14.22}$ = EDG speed level for automatic loading

$K_{14.23}$ = scale factor for converting grid system voltage to 6900 plant voltage

$K_{14.24}$ = scale factor for converting frequency to grid system voltage

$K_{14.25}$ = scale factor for converting generator voltage to 6900 plant voltage

$K_{14.26}$ = low trip for 230 kV

$K_{14.27}$ = low trip for 22 kV

$K_{14.28}$ = scale factor for converting grid system voltage to 4160 plant voltage

$K_{14.29}$ = scale factor for converting generator voltage to 4160 plant voltage

$K_{14.30}$ = factor for converting kW to amps at 6900 V

$K_{14.31}$ = factor for converting kW to amps at 4160 V

$K_{14.32}$ = factor for converting kW to amps at 230 kV

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15. SIGNALS, PROTECTIVE, AND SAFEGUARDS SYSTEMS

15.1. General

The math models in previous sections provide for basic parameter generation which is the point of origin for signals which in turn are used for interaction with other signals, for display on the consoles, for initiating reactor protective trips, and for safeguards actuation. Therefore additional software is required for the specific functions described below.

15.2. Reactor Protective System

If any of the conditions which are tabulated below occur the reactor shall be tripped by initiating the insertion of all control rods into the core. Rod position as a function of time after trip will be provided.

Initiating variable	Trip condition
n (MW thermal in power range)	$> K_{15.1}$
dn/dt (not active above 10% full power)	$> K_{15.2}$
n	$> K_{15.3}\, w_{RC1}$
n	$> K_{15.4}\, N_{RC}$ and $> K_{15.13}$
n and w_{RC1}	$> K_{15.4}\, N_{RC}$ and $< K_{15.5}\, N_{RC}$
N_{RCA}	0
N_{RCB}	0
P_{P1}	$> K_{15.6}$
P_{P1}	$< K_{15.7}$
T_{P1}	$> K_{15.8}$

15.3. Engineered Safeguards Systems

15.3.1. General

In the event of a reactor casualty selected valves, pumps, coolers, etc. are controlled by ten engineered safeguards (ES) channels. These protective channels may be activated automatically from the program or manually from the control console. The following descriptions and diagram indicate typical ES system and component control. A tabulation is provided to indicate specific features of all components.

15.3.2. Typical ES System Control

The ES system is activated automatically from the program. ES channel activation is controlled by reactor coolant pressure (P_{P1}) and reactor building pressure (P_{RB}). The ES channels are activated in pairs as follows:

Chan I/II if $P_{P1} < 500$ psig or if $P_{RB} > 4$ psig

Chan III/IV if $P_{P1} < 200$ psig or if $P_{RB} > 4$ psig

Chan V/VI if $P_{RB} > 4$ psig

Chan VII/VIII if $P_{RB} > 30$ psig

Chan IX/X if $P_{RB} > 30$ psig

The bypass ES push buttons prevent chan I/II and chan III/IV from being activated due to low coolant pressure. However, the bypass must be initiated before the ES channel has activated due to low coolant pressure.

The ES channels may also be manually activated in pairs from the control console.

When an ES channel is activated the "ES chan—activated" push button lights. The ES channel remains active until the automatic activation signal is removed and the channel is "reset" by depressing the "ES chan—active" push button.

15.3.3. ES Component Control

ES components are controlled by either five or six push buttons and by one or two ES channels. Some ES components also serve as normal system components and have additional controls from some other console. Each ES component operates in three modes: (a) normal, (b) test, and (c) ES.

(a) Normal Control — If the ES channel is not activated the component may be operated manually by depressing the "non ES position" or "ES position" push buttons.

(b) Test Control — If the ES channel is not activated the component may be commanded to the ES position by depressing the "test chan—" push button. If the component is a valve the valve will move toward the ES position when "test chan—" is depressed, but will stop movement when the push button is released. That is, the command is present only when the button is depressed. The test signal is "locked in" for other components.

(c) ES Control — If the ES channel is active the normal control and test control signals are inoperative. The component is automatically commanded to the ES position.

The "reset" and "block" push buttons are inoperable unless the ES channel is activated. If the ES channel is activated depressing the "block" push button removes the ES command from the component and it may be controlled manually. The "reset" push button removes the block signal and restores the ES signal.

When the ES channel active signal is removed (by channel reset signal) the component remains where it is; i.e., it must be manually placed in the non ES position.

If the component has additional control from some other console this control is activated and deactivated the same way as the "non ES position" and "ES position" push buttons. The position lights on each control indicates the position of the component in all modes of operation.

Engineered Safeguards Channel Assignments and Emergency Status Tabulation

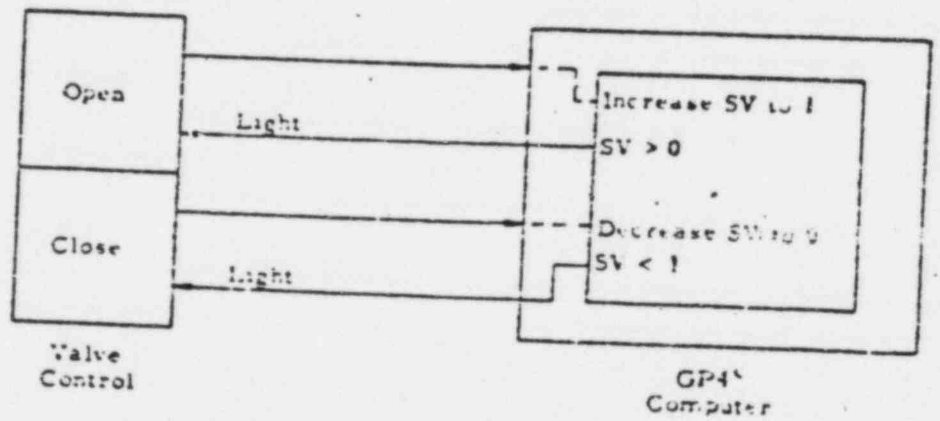
Chan I	Chan II	Chan III	Chan IV	Chan V	Chan VI	Chan VII	Chan VIII	Chan IX	Chan X
SV_{42} - open	SV_{12} - open	SV_{87} - open (3)	SV_{88} - open (1)	RB E. fan A1 - on	RB E. fan B1 - on	RBSP pmp A - on	RBSP pmp B - on	SV_{87} - open (3)	SV_{88} - open (4)
MUP1A - on	SV_{43} - open	DHP1A - on	DHP1B - on	SV_{98} - open	SV_{63} - close (5)			SV_{127} - open	SV_{128} - open
MUP1B - on	MUP1B - on	SV_{50} - open	SV_{51} - open	SV_{97} - open	SV_{100} - open			SV_{12} - open	SV_{91} - open
SV_{18} - open	MUP1C - on			RB E. fan A2 - on	SV_{101} - open				
SV_{76} - open	SV_{58} - open			SV_{102} - open	RB E. fan B2 - on				
SV_{41} - close	SV_{13} - close			SV_{103} - open	SV_{104} - open				
SV_{15} - open	SV_{77} - open			NSRW pmp A - on	SV_{105} - open				
SV_{19} - close	SV_{44} - close			NSW pmp A - on	NSRW pmp B - on				
SV_{46} - close				SV_{31} - open	NSW pmp B - on				
				SV_{65} - close (6)	SV_{33} - open				
				SV_{106} - close	SV_{108} - close				
				SV_{107} - close	SV_{111} - close				
				SV_{109} - close	SV_{118} - close				
				SV_{110} - close	SV[illegible] - close				
				SV_{66} - close	SV_{67} - close				
				SV_{112} - close	SV_{113} - close				
				SV_{114} - close	SV_{115} - close				
				SV_{125} - close	SV_{120} - close				
				SV_{119} - close	SV_{122} - close				
				SV_{121} - close	SV_{124} - close				
				SV_{123} - close	SV_{126} - close				
					SV_{116} - close				

Note Numbers in parentheses, e.g., SV_{87} - open (3), are a cross reference to numbers of other ESS channels.

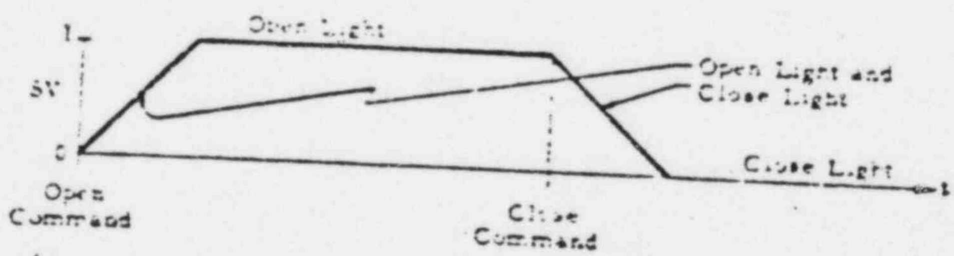
15.4. Valve Control

Throughout the total math model the symbol "S" is used for valves which perform controlling functions and which, therefore, may have an equilibrium position anywhere between closed and open (zero and one). These valves are driven by a controller or controller model.

The symbol "SV" is used for stop valves, block valves, or strictly isolation valves which, except for the Engineered Safeguards System, are "bistable" in nature, i.e., are at equilibrium only in the zero or one state. These valves have their position change initiated by console push buttons or trip signals. Further details are provided by the sketches and descriptions that follow.



Valve position is a linear function of time:



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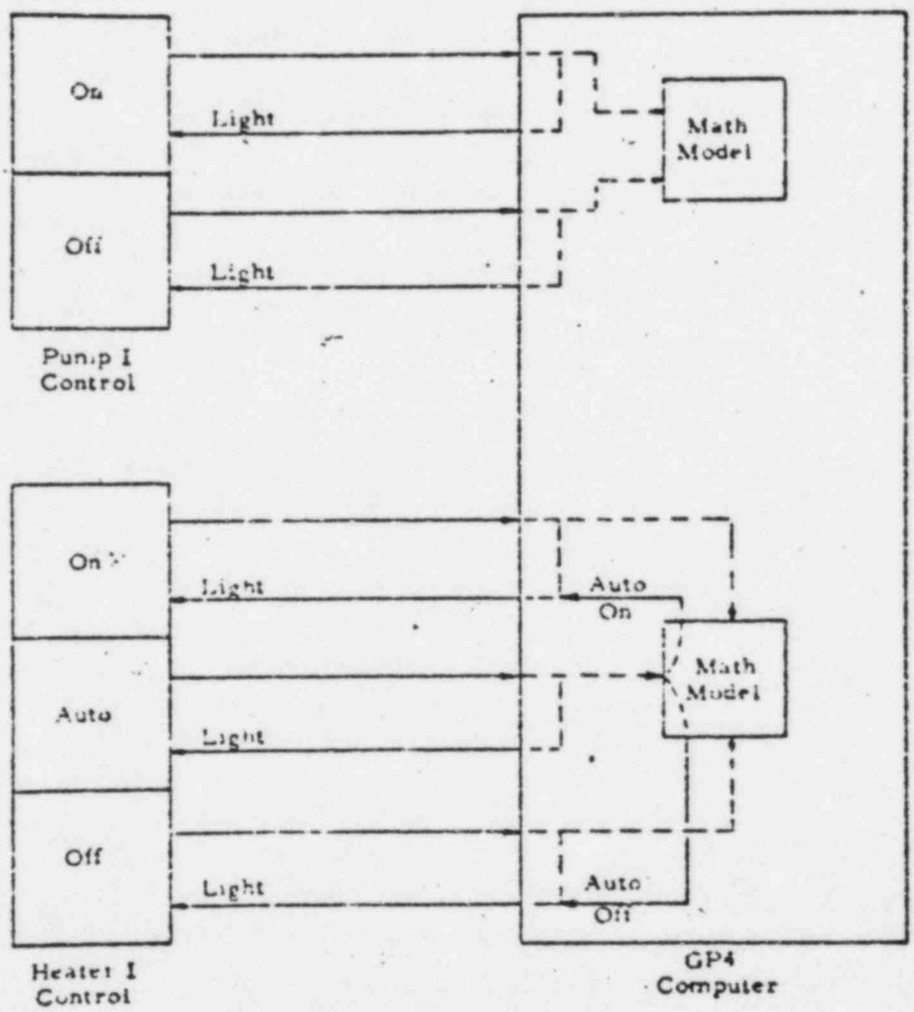
Depressing the "open" or "close" push button initiates valve position change. Depressing the "open" push button causes the position to increase to one. Depressing the "close" push button causes the valve position to decrease to zero.

The "open light" is lit if the position is greater than zero. The "close light" is lit if the position is less than one; i.e., if the valve is neither fully open nor fully closed both lights are lit.

15.5. Pump, Fan, and Heater Control for Non ES Components



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Depressing "on" or "off" push button causes the "on light" or "off light" to light and sends the status of the component to the model. Depressing the "auto" push button causes the "auto light" to light, the model determines the status of the component and lights the "off light" or "on light."

In addition, where an ammeter is associated with a pump, simulation shall be provided for the current, including the in-rush of starting current and the settling out to a steady valve. Functions of current versus time after pump starting will be provided.

15.6. Special Requirements for Reactor Coolant Pumps

In addition to the normal start-stop logic and current simulation, the reactor coolant pumps require simulation for special interlocking features.

These interlocks include, reactor coolant system temperature, reactor power level, status of other coolant pumps, cooling water availability, and the status of auxiliary lubricating oil pumps, four of which are provided for each reactor coolant pump.

The following tabulations summarize the additional simulation requirements:

Summary of Reactor Coolant Pump Start-Run Logic

Identification of external "input" conditions:

1. RC pump switch on
2. RC pump casualty not inserted
3. Auxiliary pumps switch on
4. [illegible] RC pump power available
5. Plant cooling and component cooling systems operating
6. RC pump seal flow available
7. Reactor power level < 15%
8. RC temperature [illegible] F
9. Less than 3 RC pumps already running
10. [illegible] AC power available

Results or output situation	Required external input conditions
Successful RC pump start	1,2,3,4,5,6,7, 8, or 9
RC pump continues running and "on" light is energized	1,2,4
RC pump "off" light energized	Pump start or run conditions not met
DC Hi lift oil pump "on" light energized	3
DC Hi lift oil pump "off" light energized	3 not true
AC auxiliary pumps (4) "on" lights energized	3,10
AC auxiliary pumps (4) "off" lights energized	Either 3 or 10 not true

15.7. Miscellaneous Signal Simulation

The following additional signal simulation shall be provided:

(a) Scaling of signals to meet display requirements.

(b) Logic for signal casualties.

(c) Natural bias for displaying redundant signals.

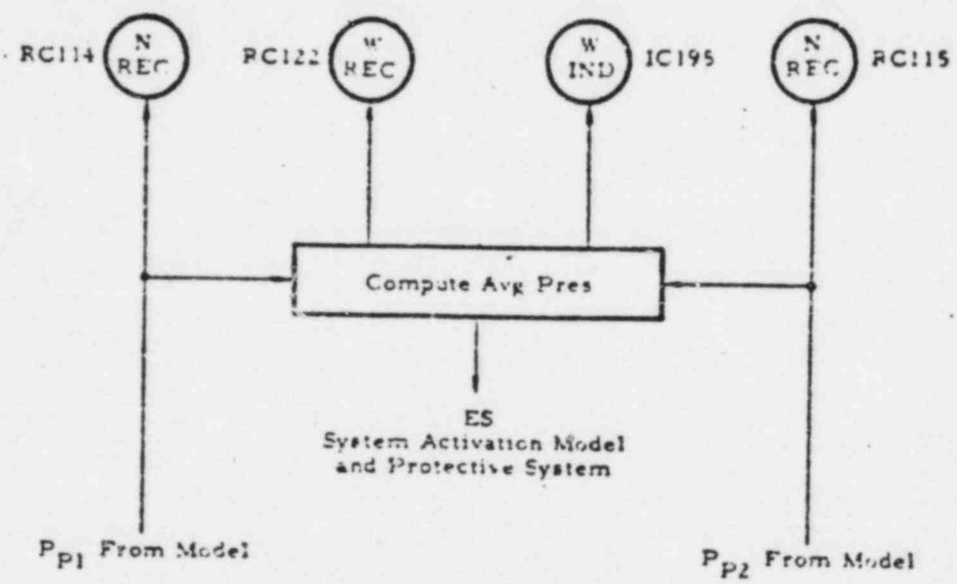
(d) Logic for selection of alternate redundant signal and for lighting confirmation lights.

(e) Simple arithmetic computations such as totaling, averaging, and differencing.

(f) Time lags for temperature sensors.

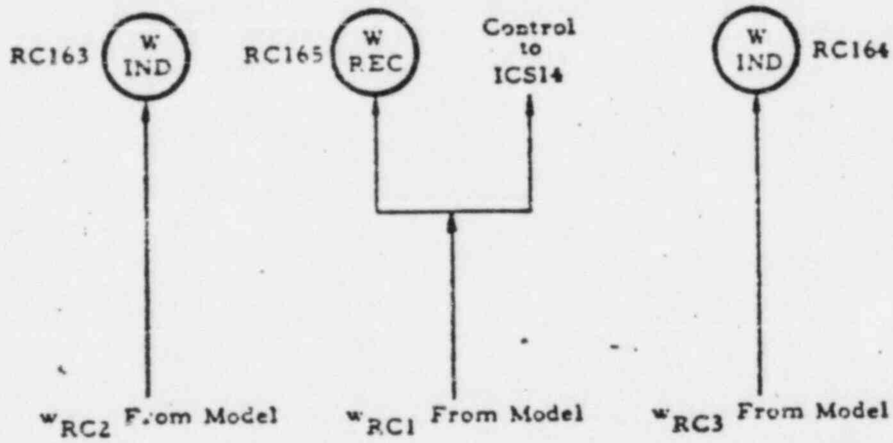
Although these requirements are generally applicable to all signals, they are particularly important for the complex signal systems such as that for reactor coolant system temperature. Diagrams for this and the other more complex systems are provided on the following pages.

Reactor Coolant Pressure



Casualty and Bias Inserted Into These Terms Within Model

Reactor Coolant Flow



Casualty and Bias Inserted Into These Terms Within Model

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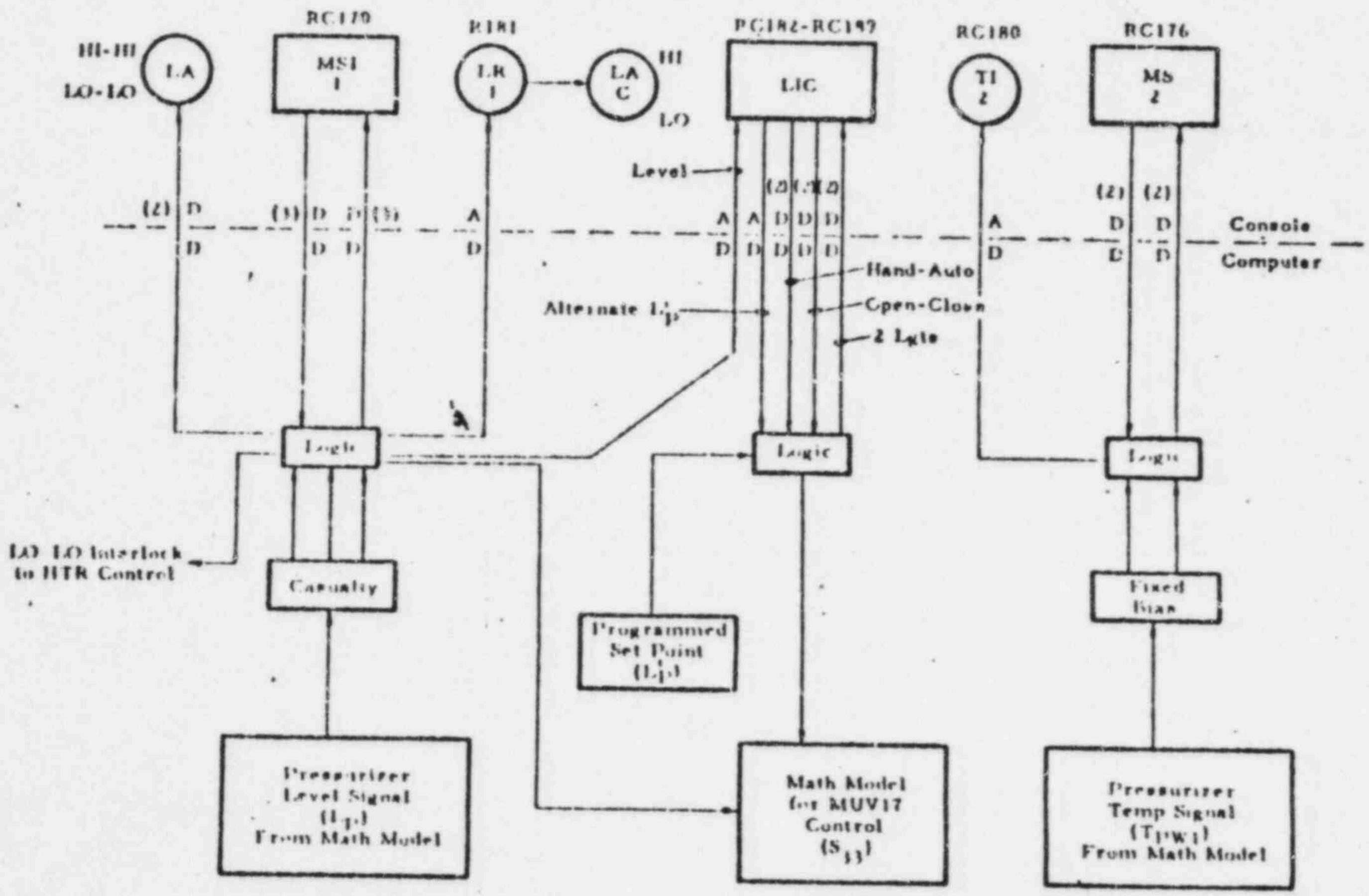
Pressure Level and Temperature Signal Simulation



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Babcock & Wilcox

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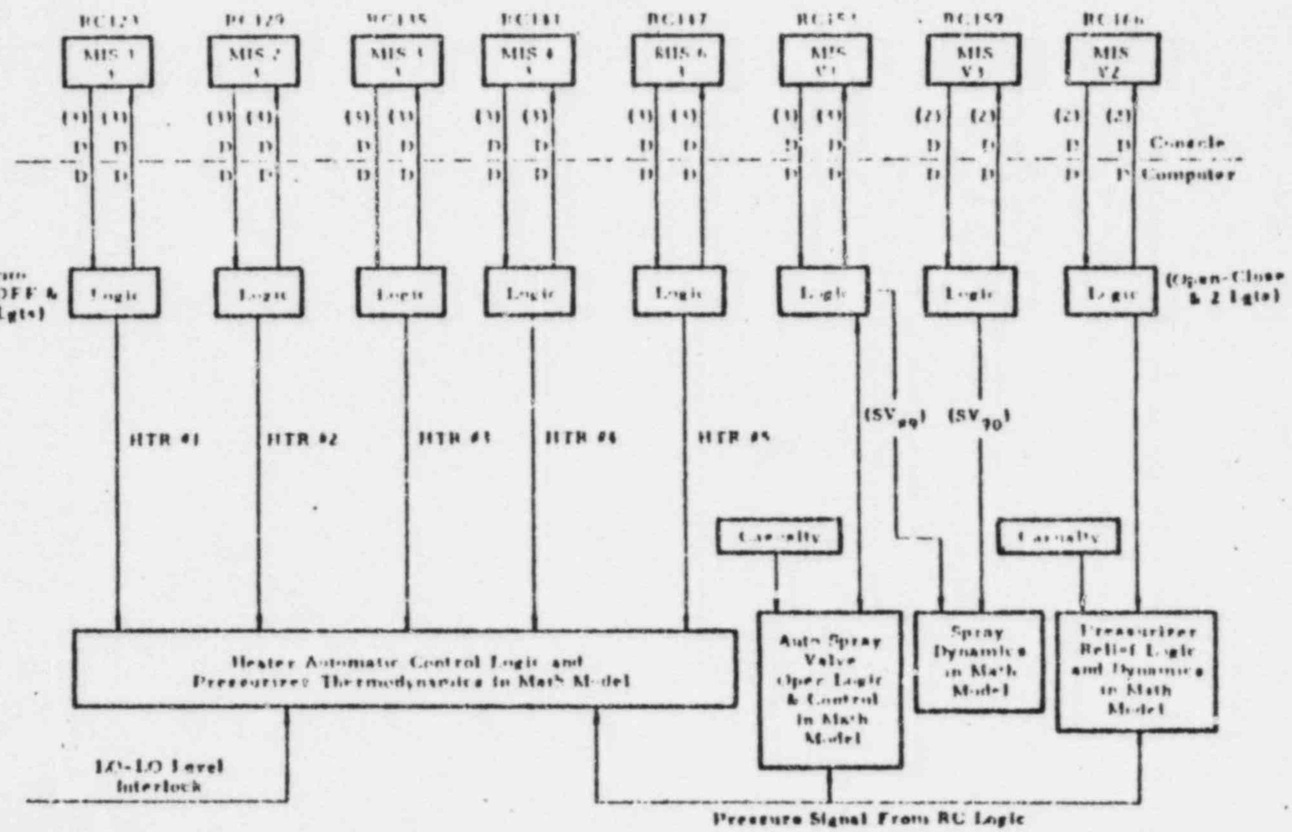
Pressurizer Pressure Control Signal Simulation



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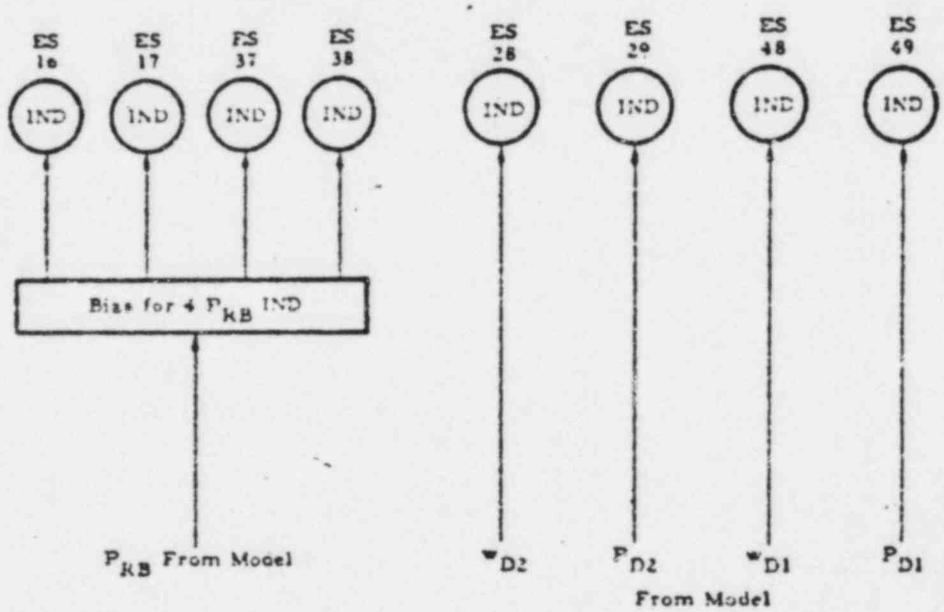
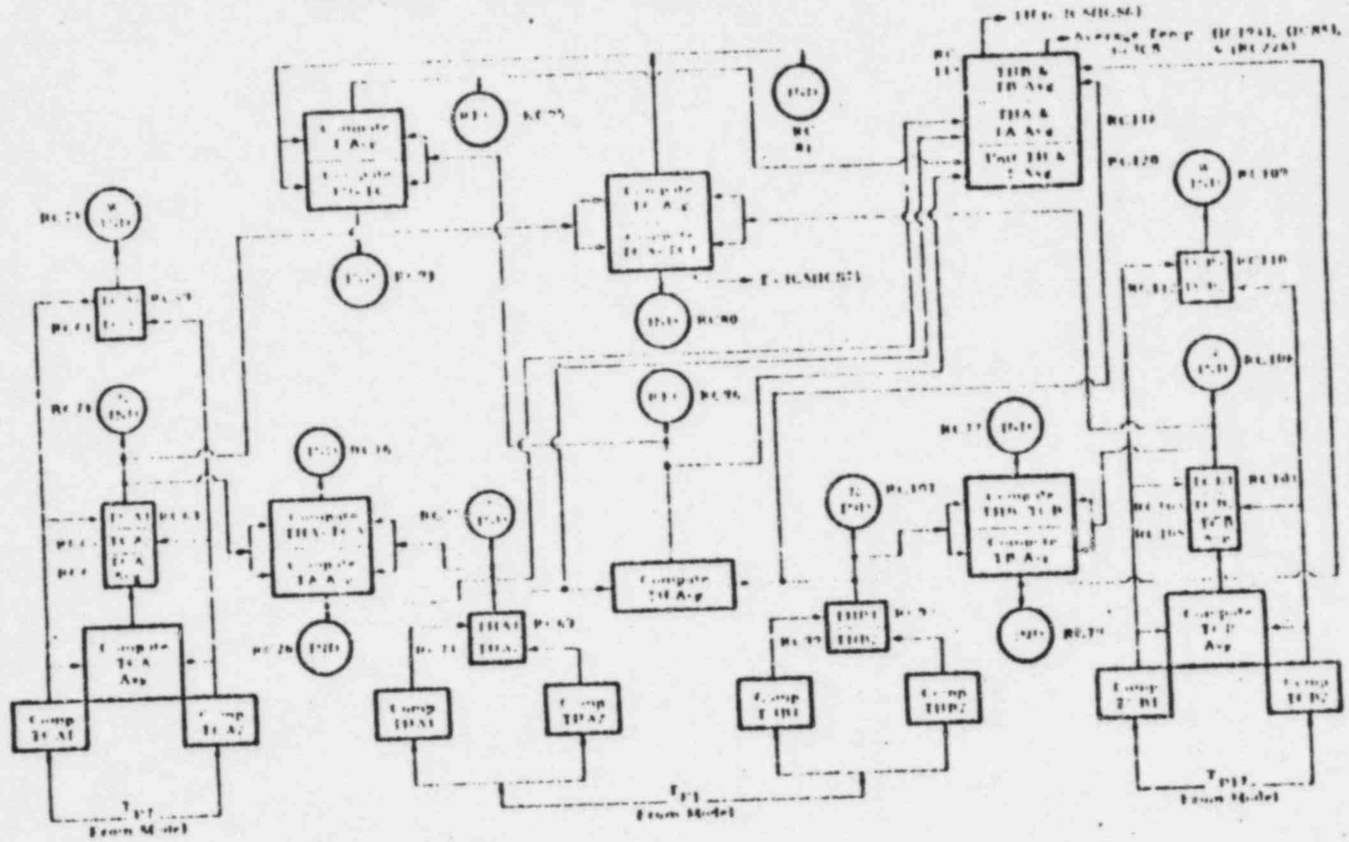
Reactor Building Pressure and Spray



Reactor Coolant System Temperature Signal Simulation



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Constants for Section 15

$K_{15.1}$ = overpower trip point, MW

$K_{15.2}$ = power rate trip point, DPM

$K_{15.3}$ = allowable power to flow ratio, MW/lb per sec

$K_{15.4}$ = allowable equilibrium ratio of power to number of pumps running for 3 pumps

$K_{15.5}$ = trip ratio for two pumps failed, flow (lb/sec) per pumps running

$K_{15.6}$ = overpressure trip point, psig

$K_{15.7}$ = underpressure trip point, psig

$K_{15.8}$ = high temperature trip, F

$K_{15.9}$ = pressure trip point for H. P injection, psig

$K_{15.10}$ = pressure trip point for L. P. injection, psig

$K_{15.11}$ = RB pressure trip point for isolation and RB coolers, psig

$K_{15.12}$ = RB pressure trip point for RB spray and H. P. and L. P. injection, psig

$K_{15.13}$ = power level for immediate trip following loss of one pump, MW ning

ing

W

APPENDIX B

Input/Output Signals

All inputs from the training console, the instructor's console to the computer, and the integrated control system, and all outputs from the computer are tabulated below.

The analog outputs from the computer drive the meters and/or recorders on the consoles. Digital outputs from the computer are generated when the computed variable reaches certain limits or critical values, and may energize position lights, limit lights, or alarms. Digital inputs to the computer originate at console push buttons or switches and provide the logic for valve position, motor status, etc.

Analog I/O signals will be ±10 volts dc. Conversion from analog to digital will require a 12-bit word plus sign and a sampling rate of at least 10 per second.

"Digital light" refers to a lamp which requires a maximum current of 120 milliamps.

"Digital relay" refers to an alarm on a console which consists of a flashing light and an audible alarm. Upon actuation of an acknowledge push button, the audible alarm shall cease and the light shall burn continuously until the parameter returns within the normal range.

The Babcock & Wilcox computer program SIMOR provides detailed tabulation of all input/output signals.

Inputs to Computer	
Digital	1211
Analog	46
Total	1257

Outputs From Computer	
Analog	520
Digital light	1203
Digital alarm	153
Digital-misc	26
Total	1382
Total I/O	3159

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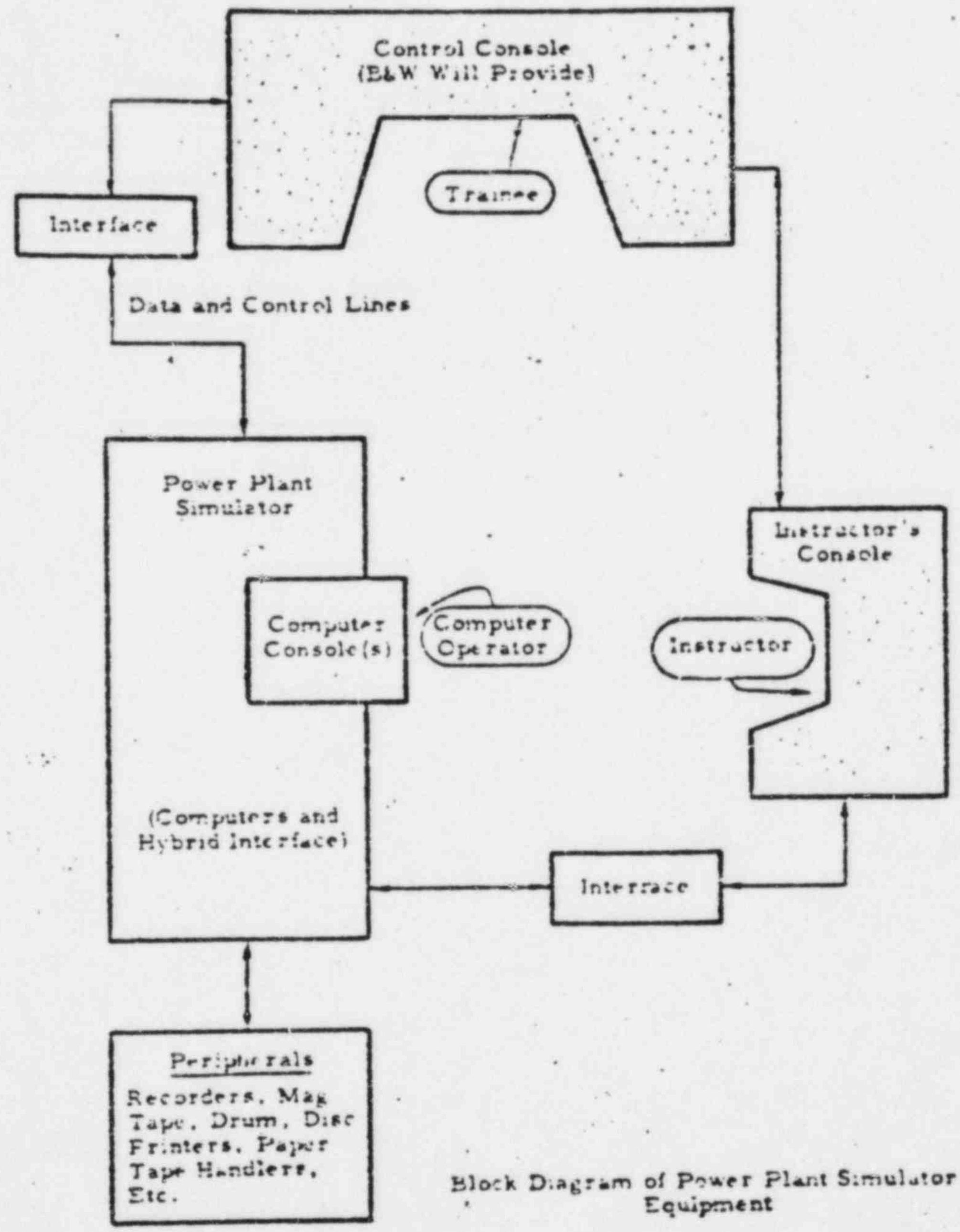
APPENDIX C

Schematic Drawings

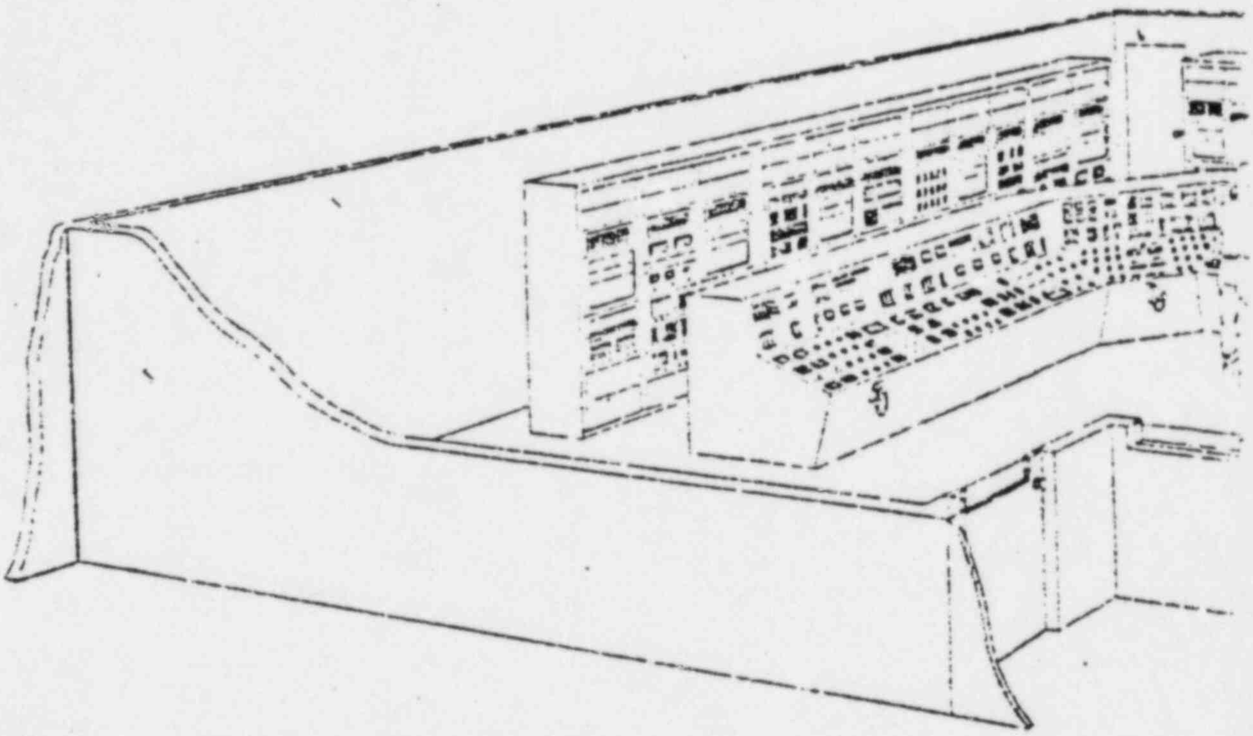


Block Diagram of Power Plant Simulator
Equipment

5-29-68/SS-3-85

Figure C-1

2058 209?



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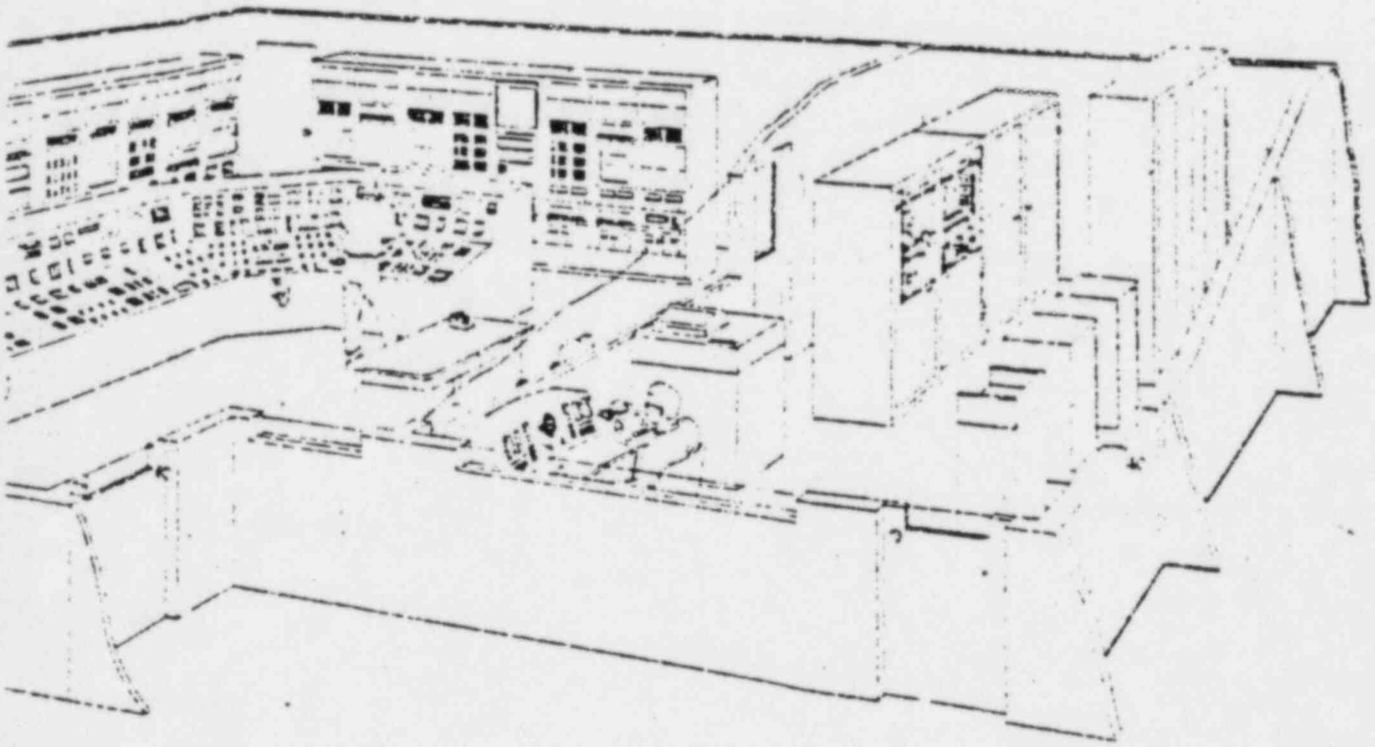
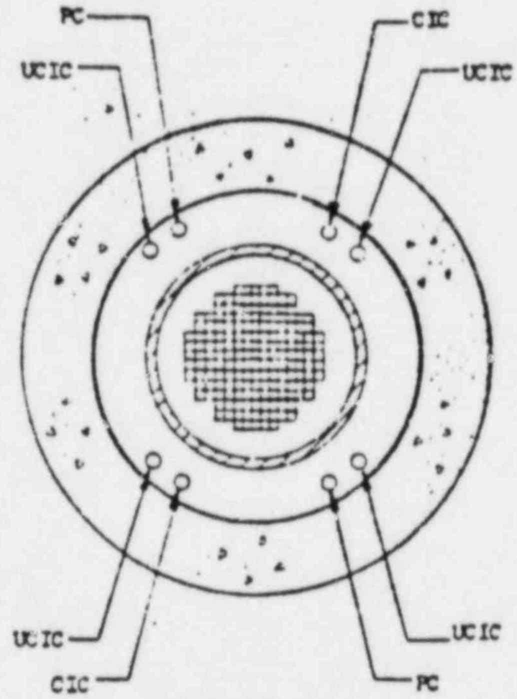
2058 2 0 0 3



Babcock & Wilcox
NUCLEAR POWER STATION SIMULATOR

Figure C-2

2058 200



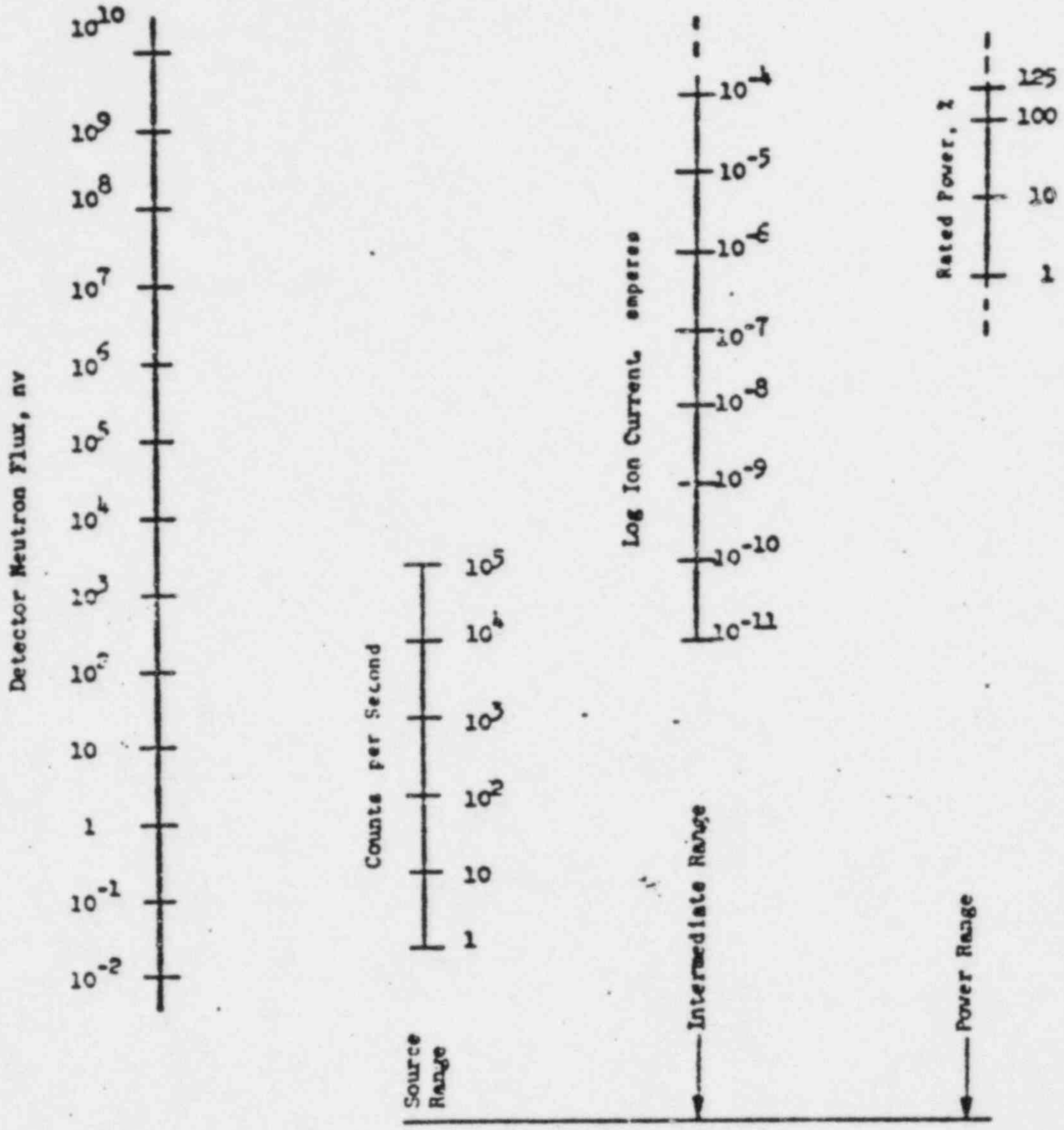
LEGEND

PC - PROPORTIONAL COUNTER - SOURCE RANGE DETECTOR
CIC - COMPENSATED ION CHAMBER - INTERMEDIATE RANGE DETECTOR
UCIC - UNCOMPENSATED ION CHAMBER - POWER RANGE DETECTOR

NUCLEAR INSTRUMENTATION DETECTOR LOCATIONS

6-29-68/SS-3-88

Figure C-3



NUCLEAR INSTRUMENTATION FLUX RANGES

5-29-69/SS-3-88

Figure C-4

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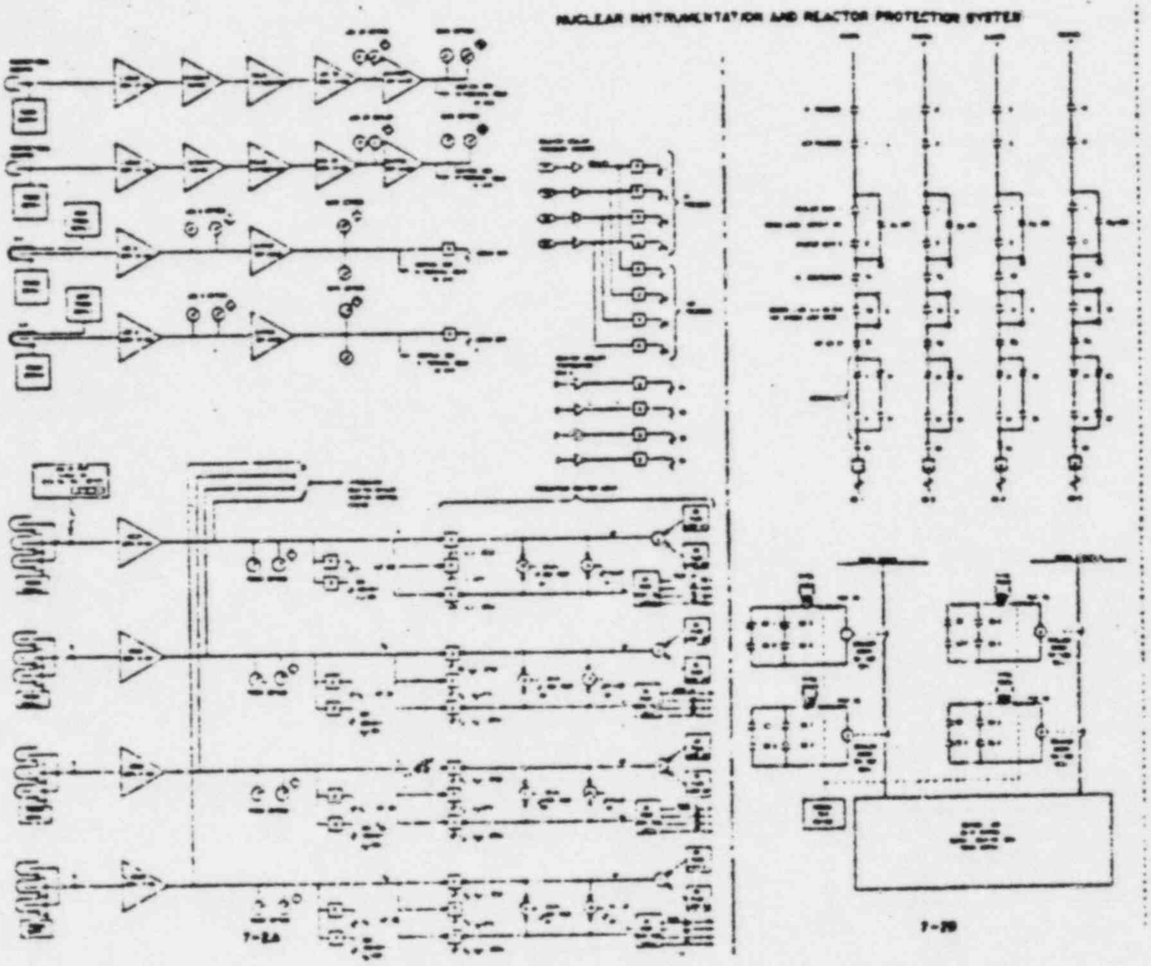
NUCLEAR INSTRUMENTATION AND REACTOR PROTECTION SYSTEM



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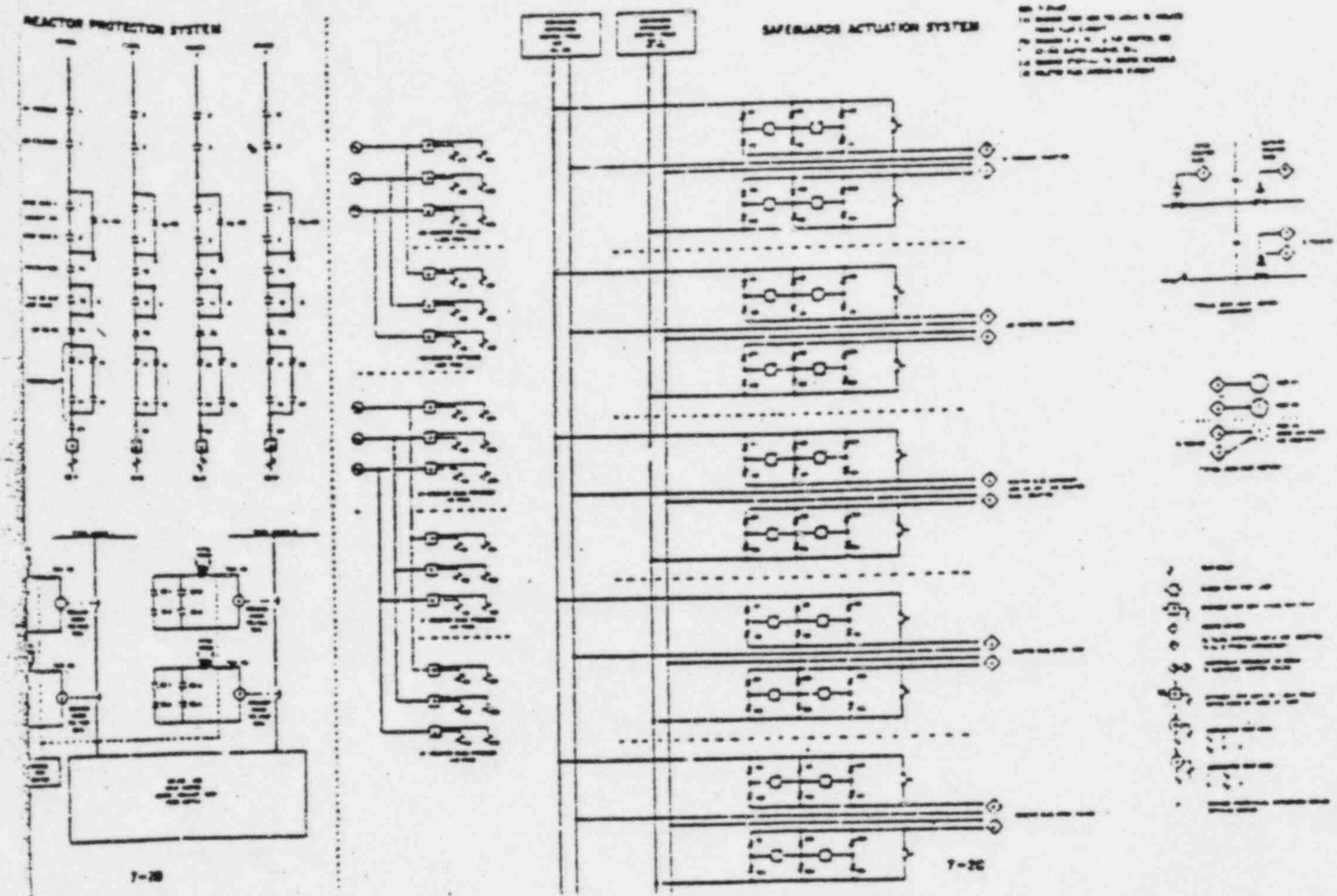

NUCLEAR INSTRUMENTATION & PROTECTION SYSTEMS

Figure C-5

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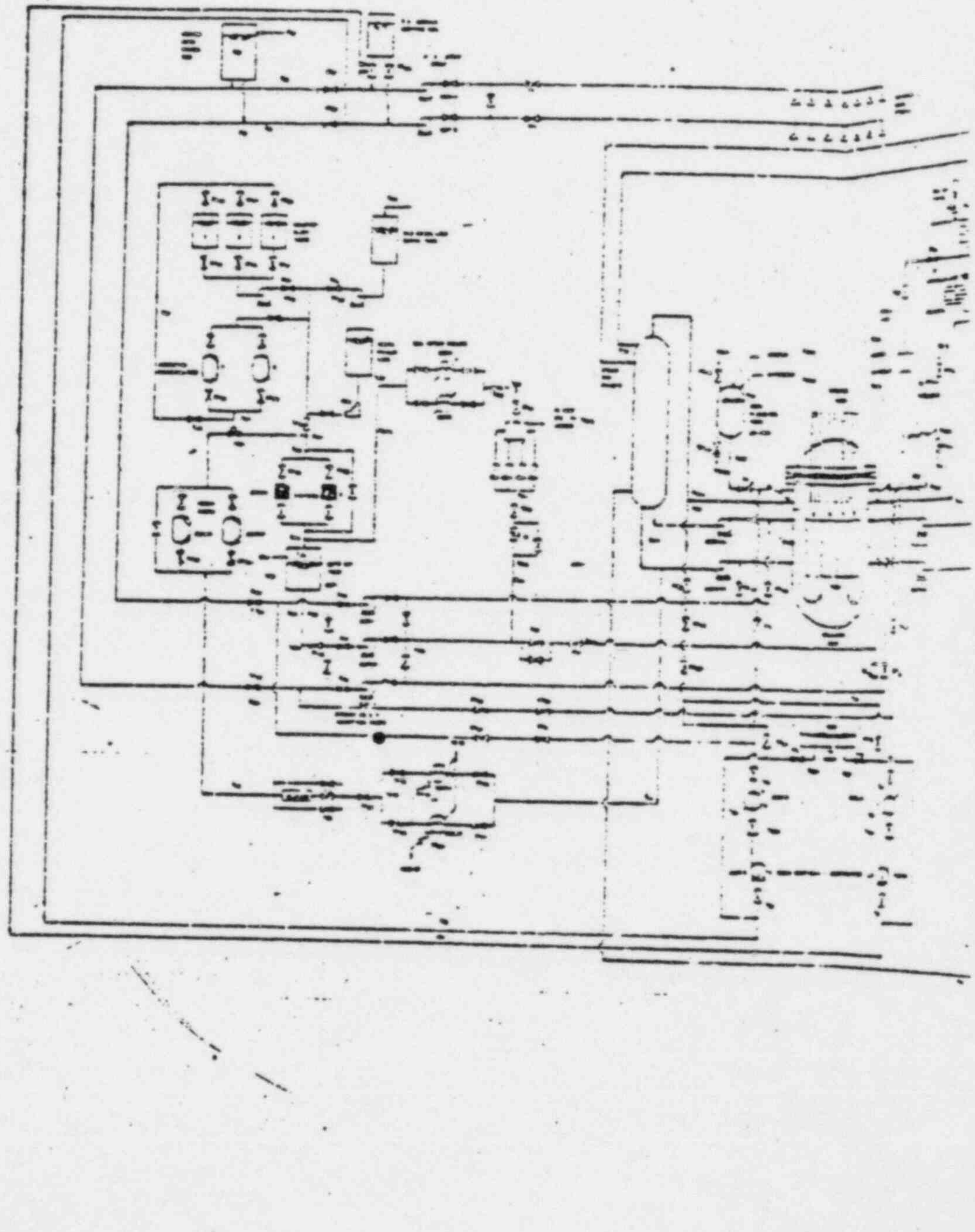

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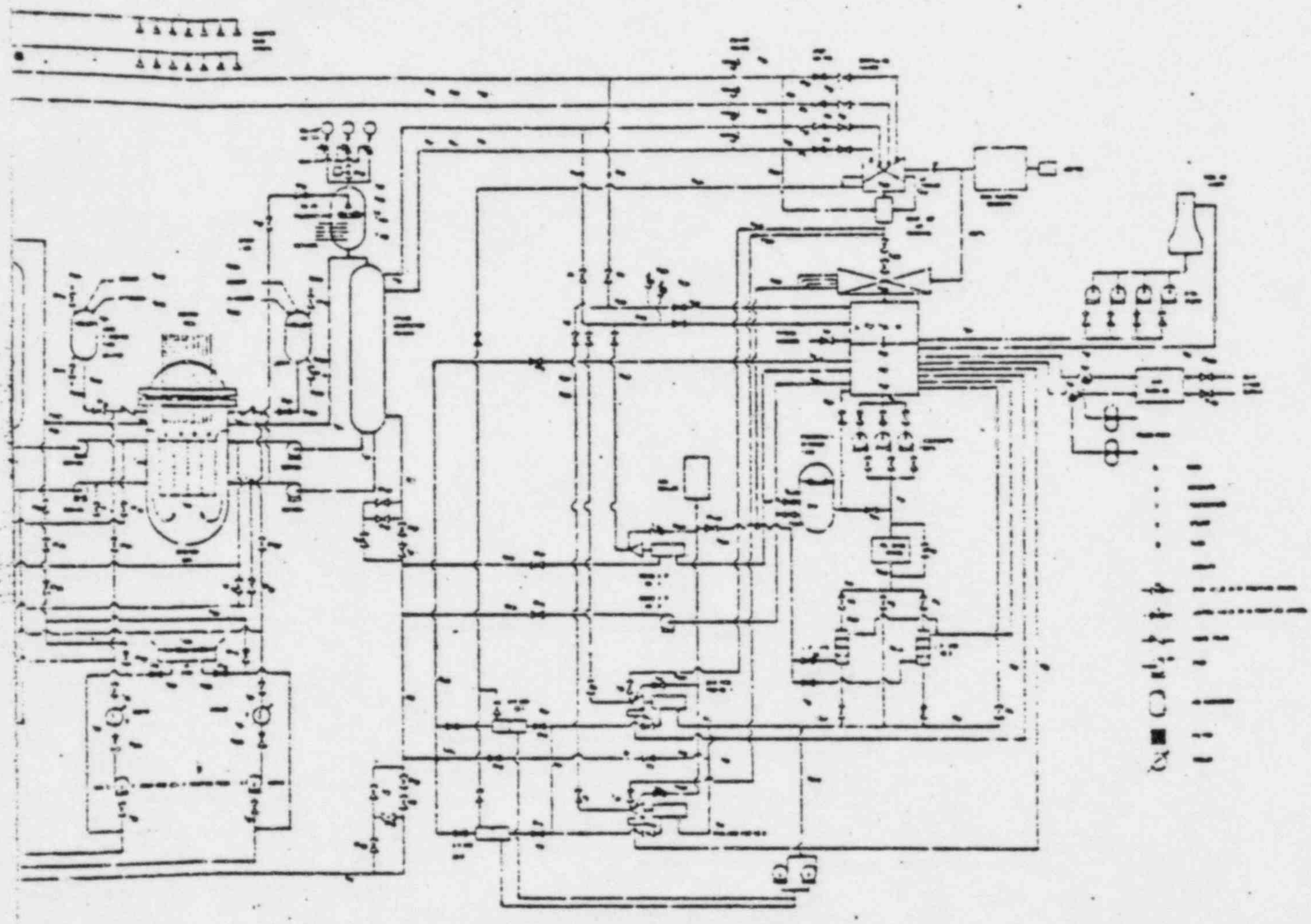

Fluid Systems Diagram for Simulator Specifications

Figure C-6

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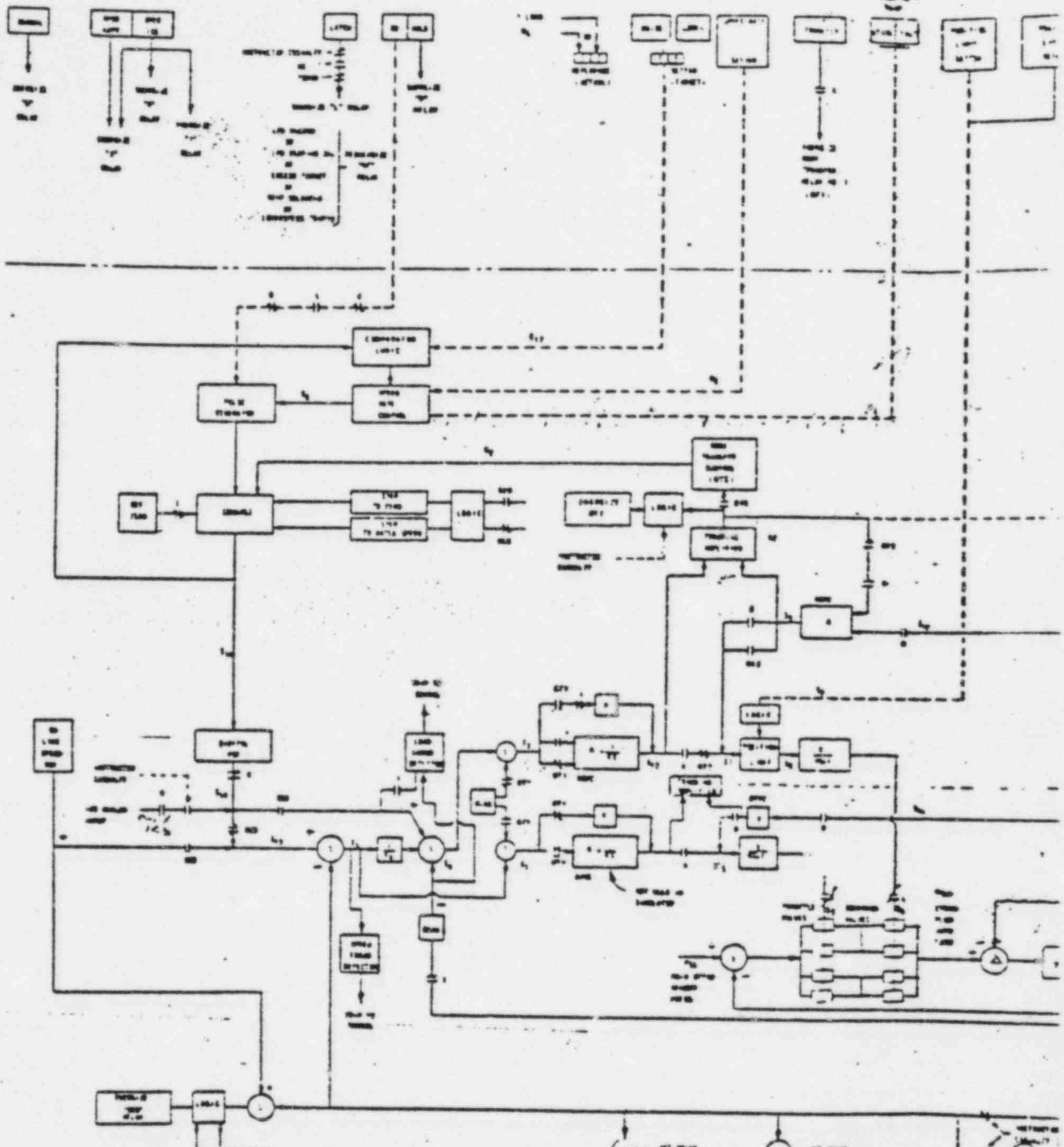

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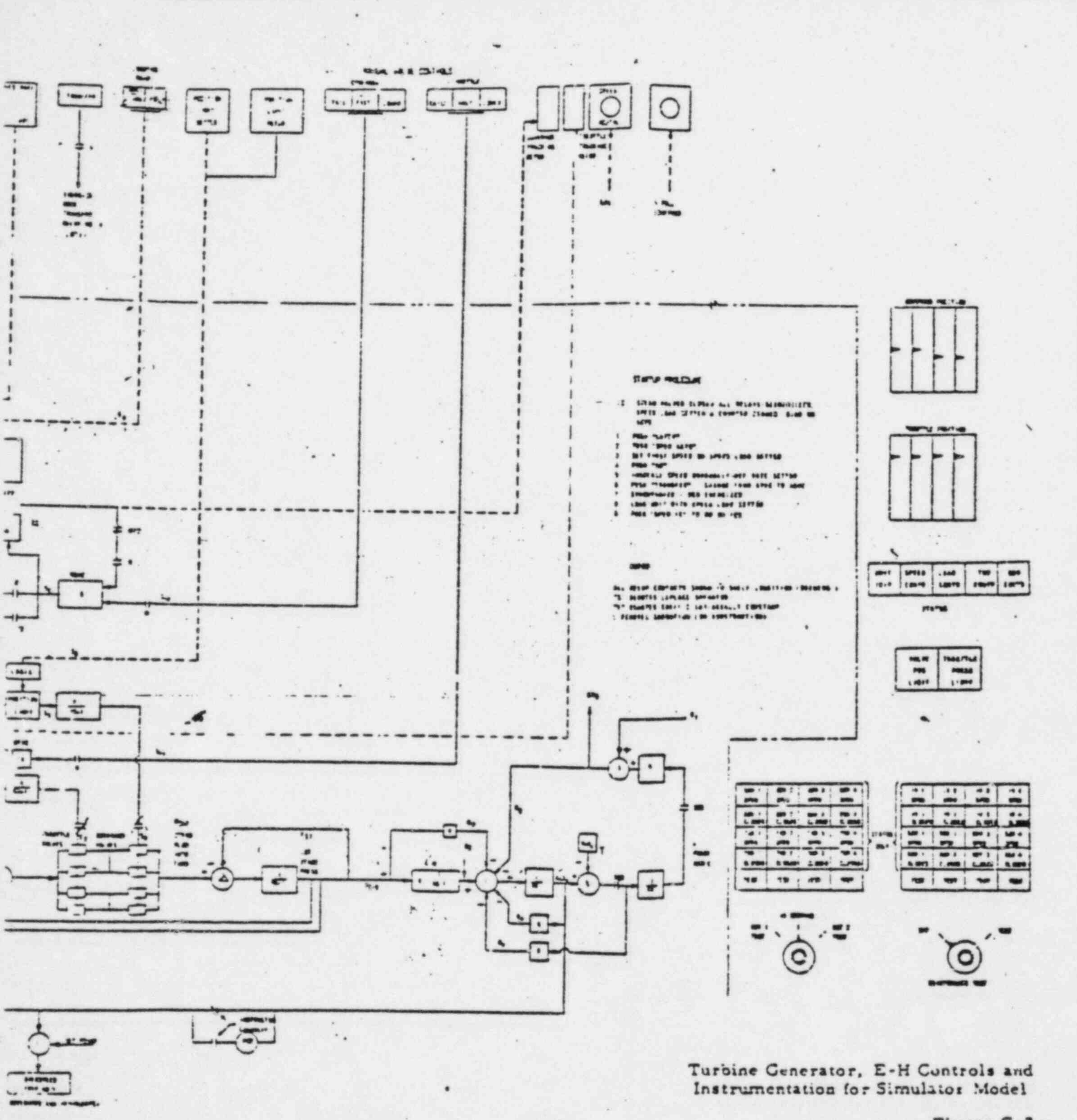

Turbine Generator, E-H Controls and Instrumentation for Simulator Model

Figure C-7

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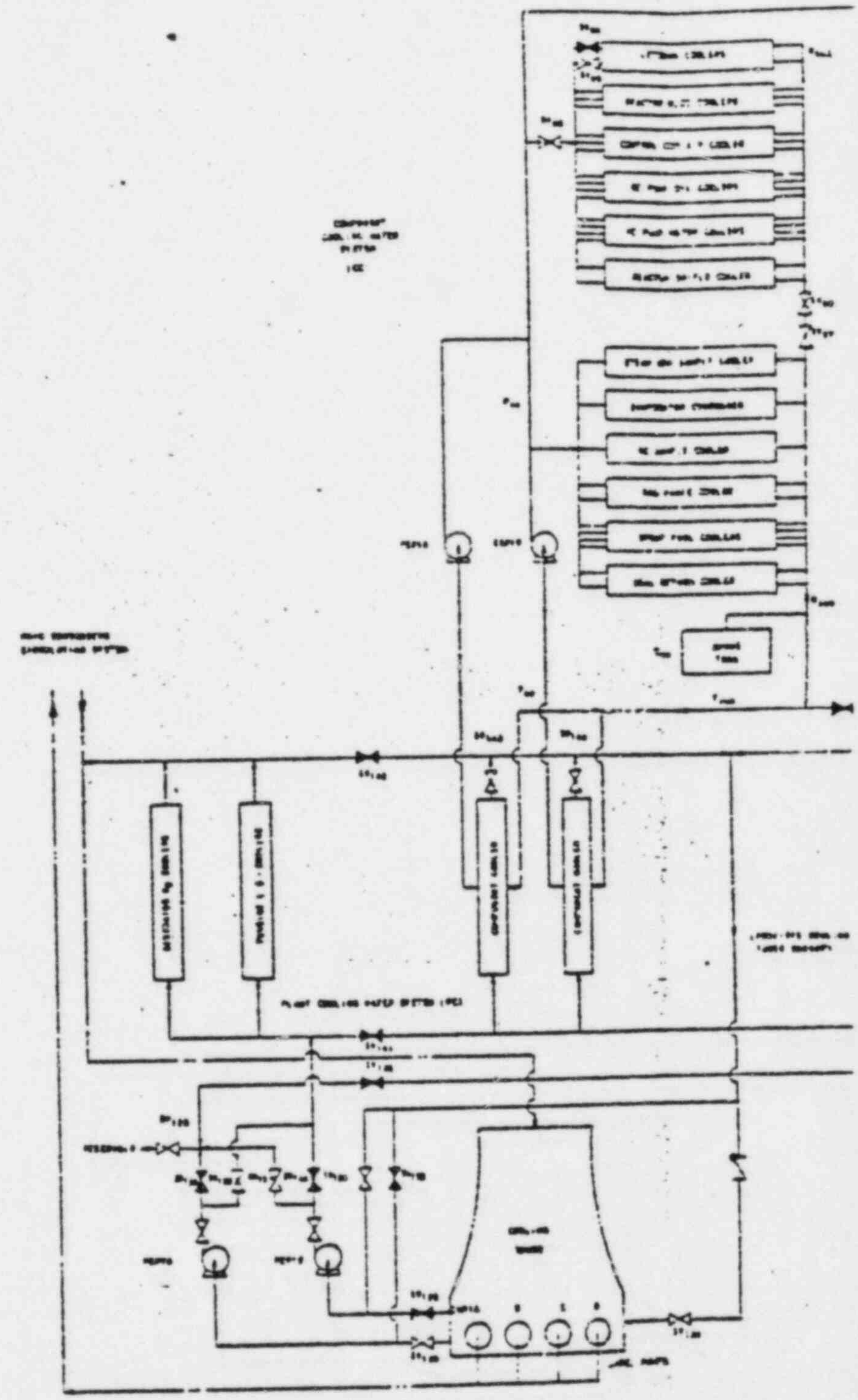

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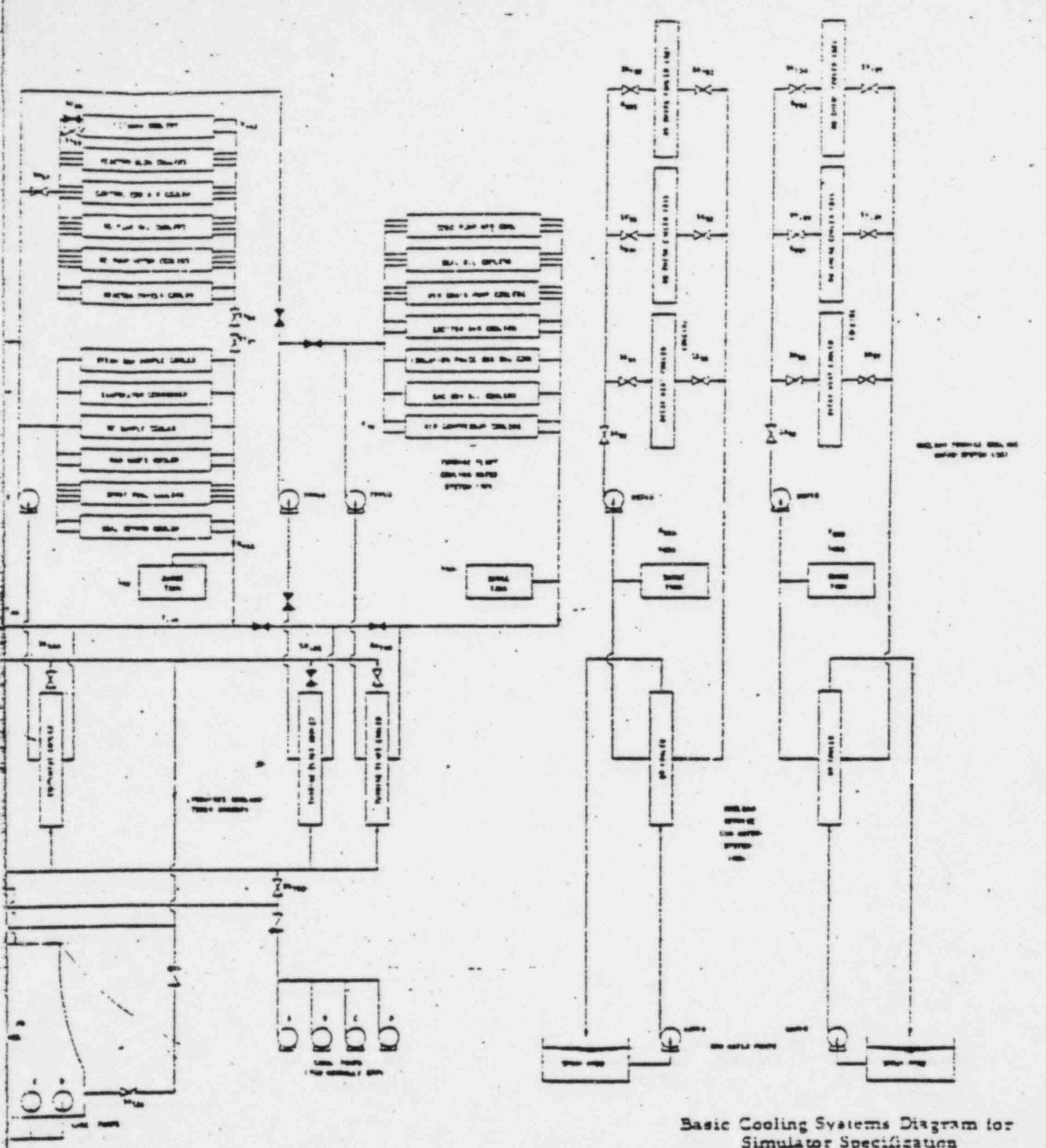
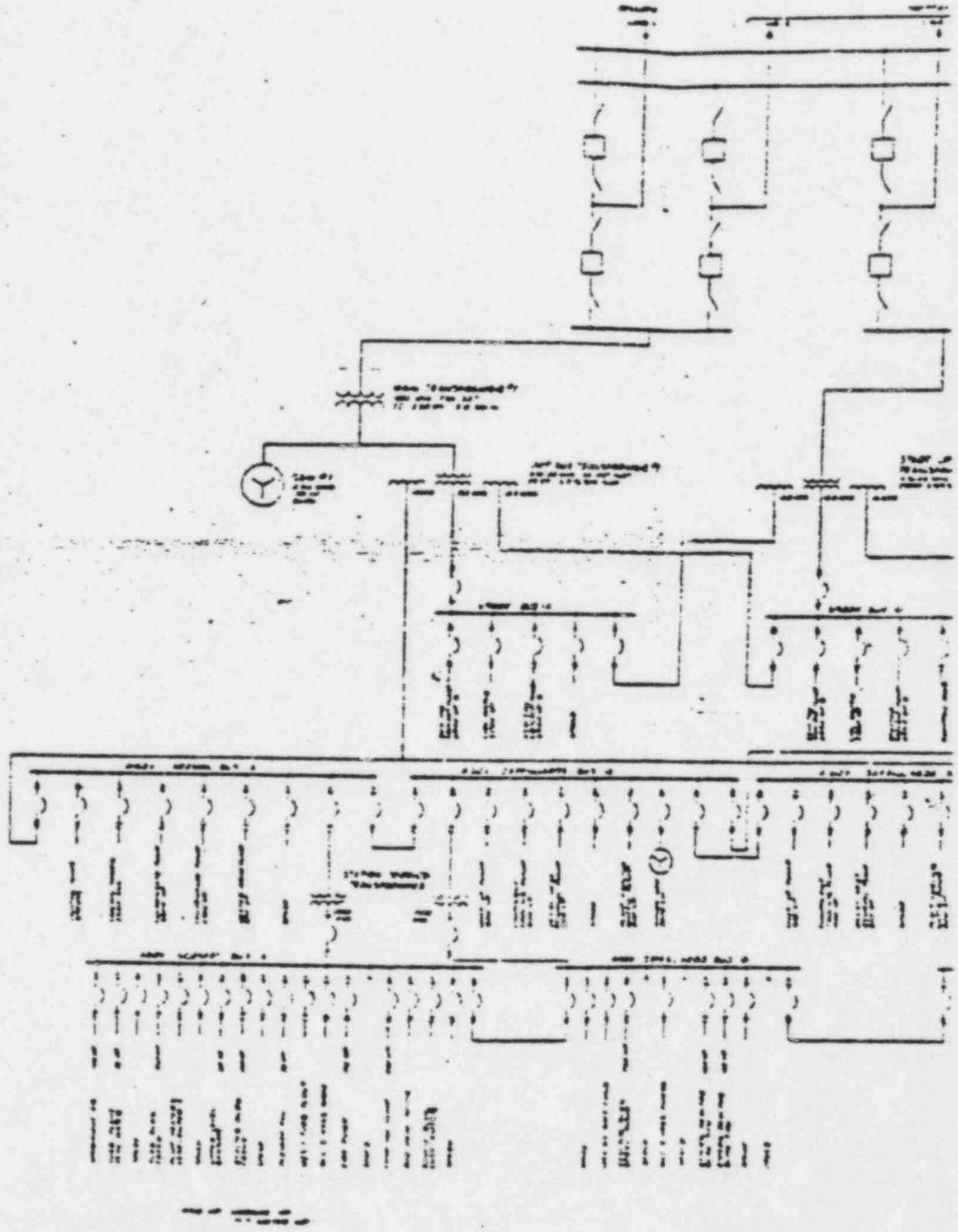


Basic Cooling Systems Diagram for Simulator Specification

Figure C-8



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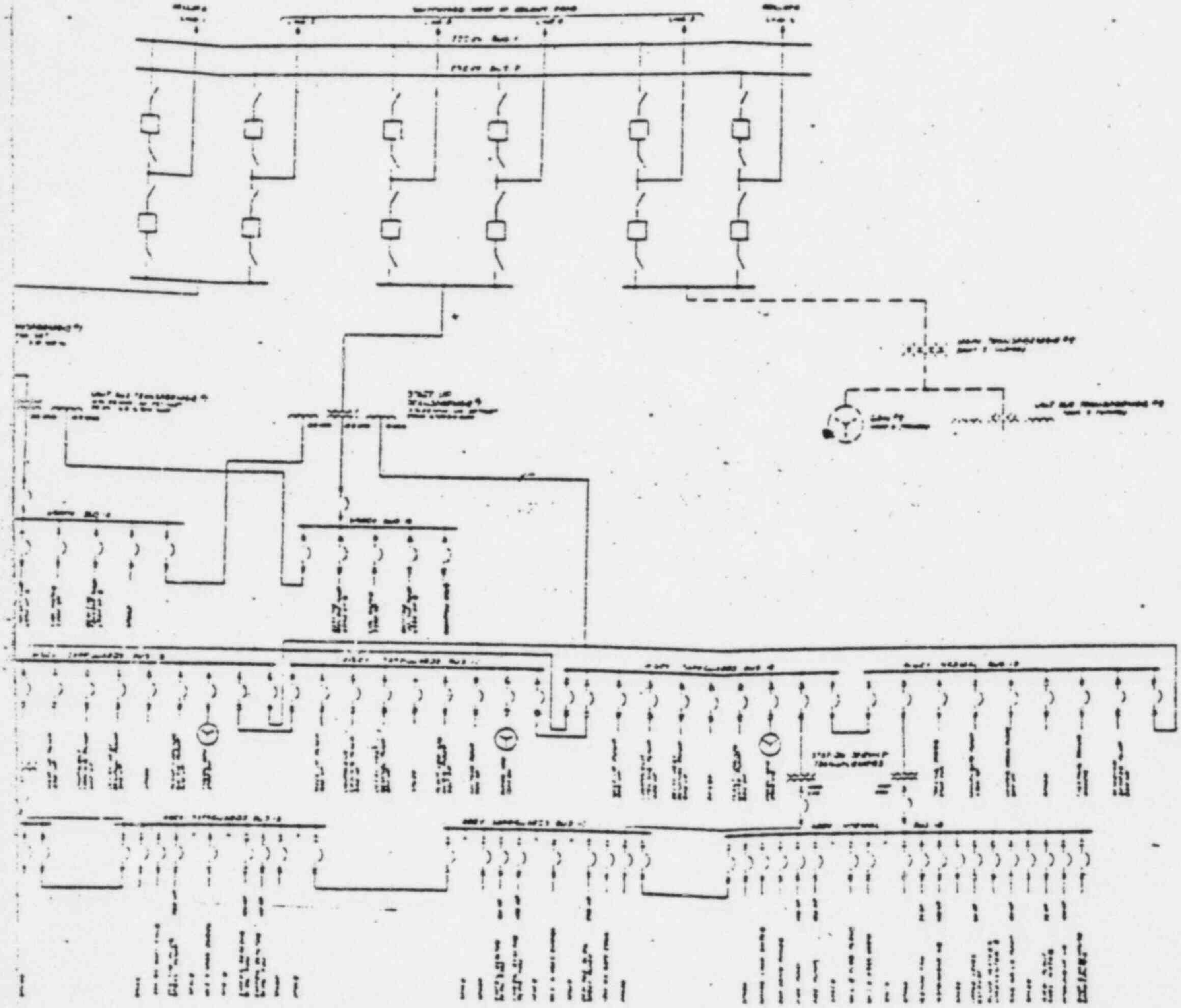

Electrical Power Systems
Single Line Diagram

Figure C-9

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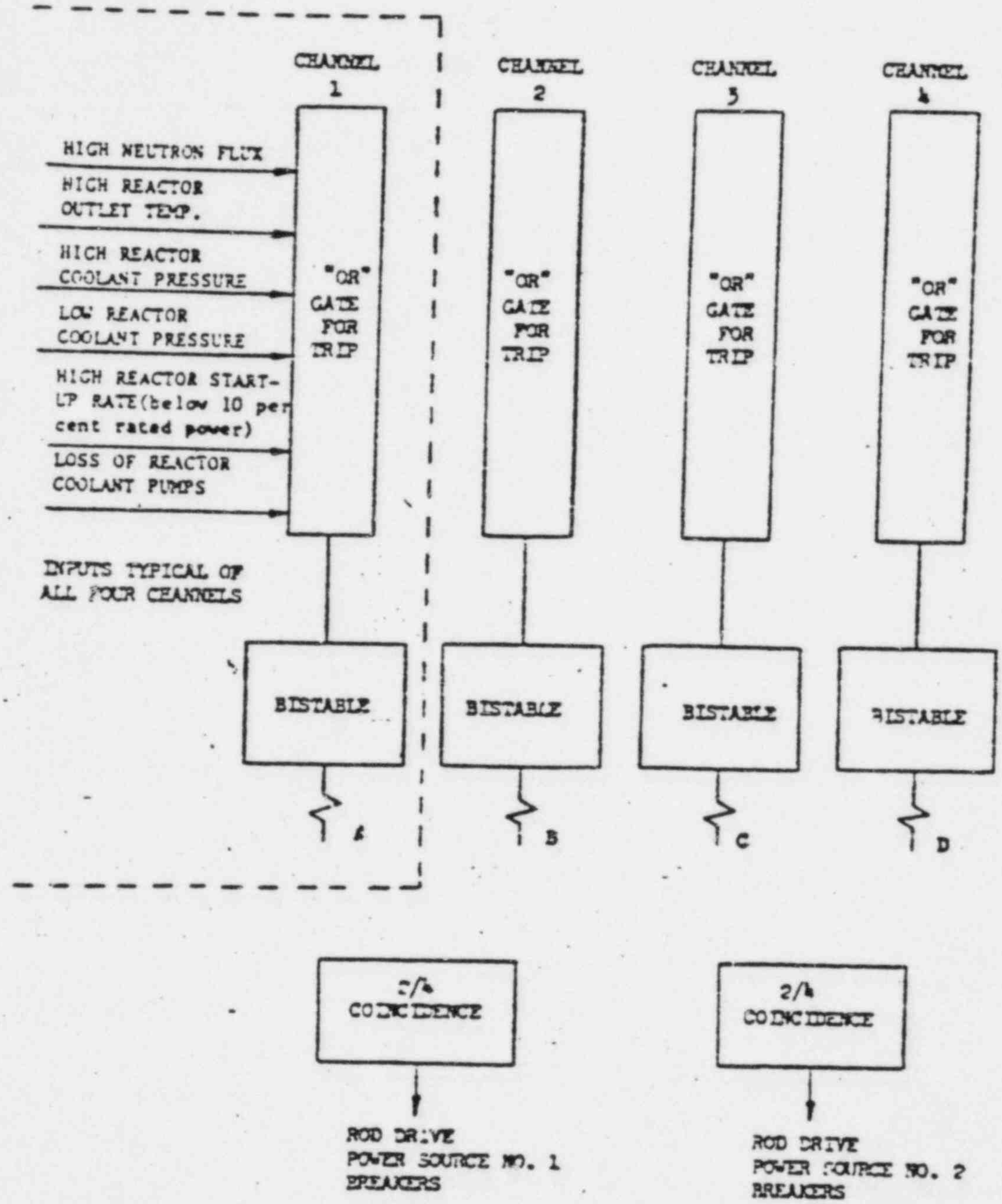
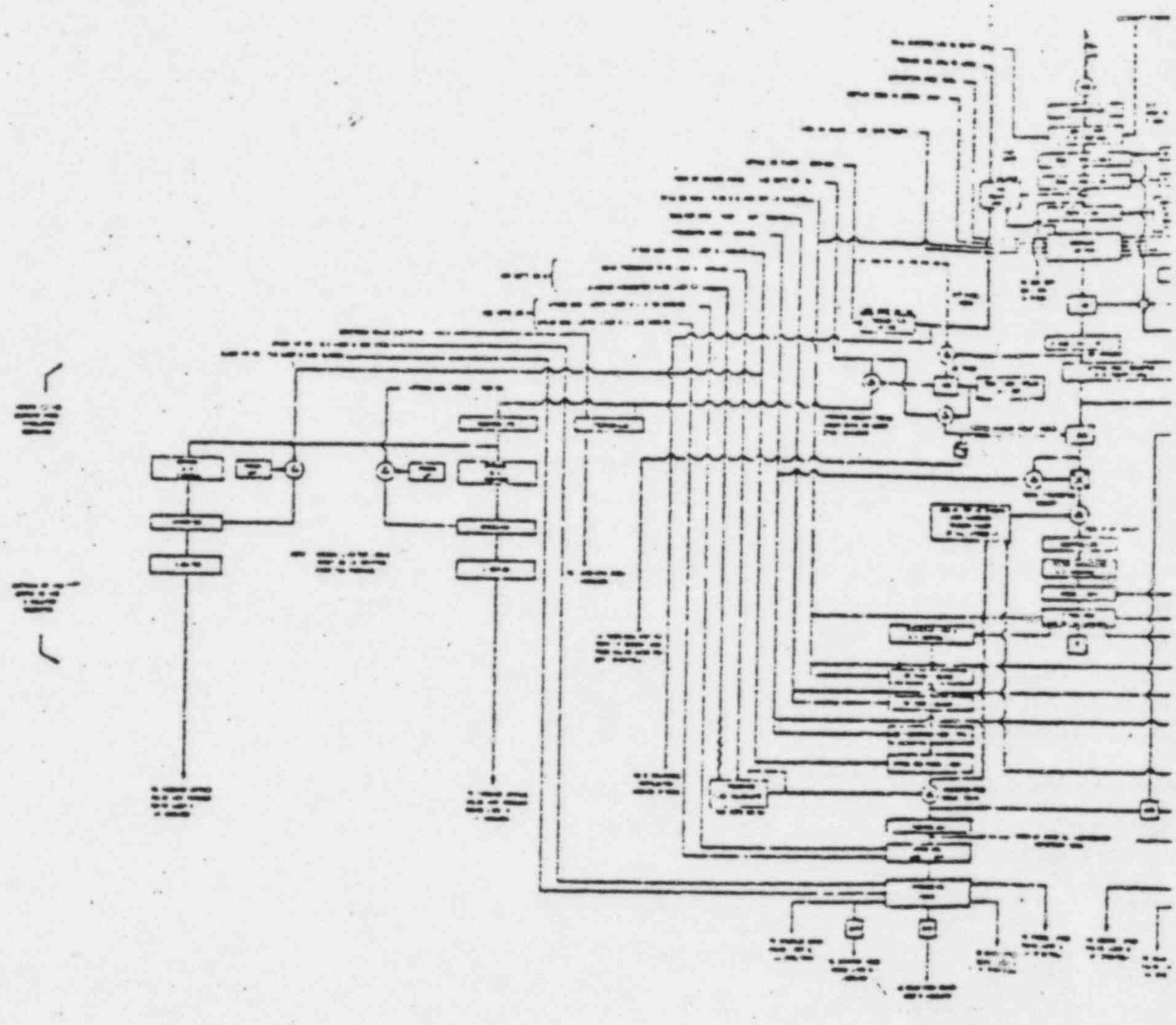


REACTOR PROTECTION SYSTEM BLOCK DIAGRAM

5-29-64/SS-3-88

Figure C-10

2058 001



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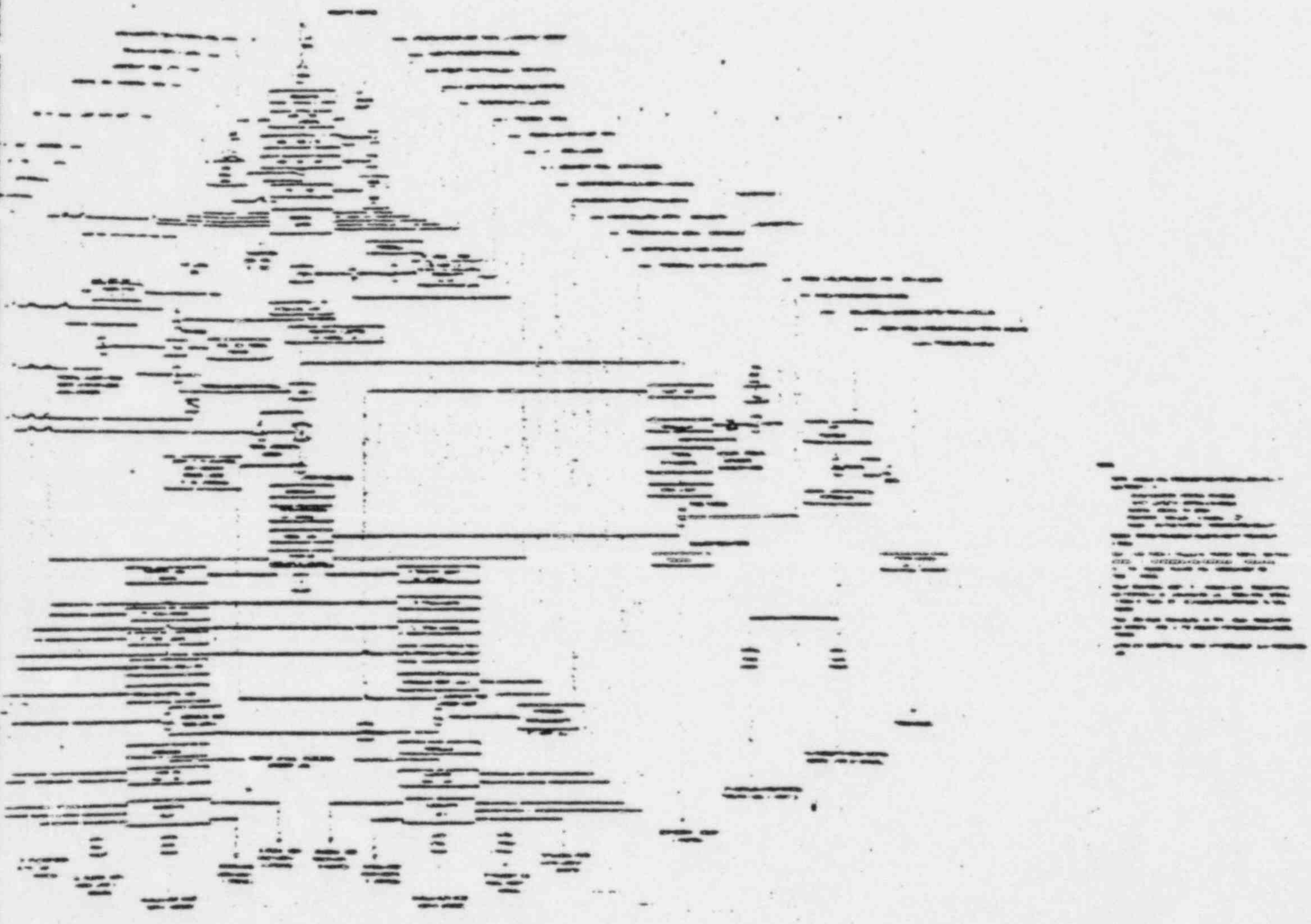

Integrated Control System Diagram

Figure C-11

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APPENDIX D

Excerpts From Link Group Proposal and Correspondence

The Babcock & Wilcox Company
Nuclear Power Station Simulator
Link Group Proposal Summary

Appendix D summarizes commitments made by the Link Group of General Precision Systems, Inc., during the proposal stages of Babcock & Wilcox Specification SS-3-88, with latest edition of May 29, 1968. These statements have been extracted from the Link Proposal 1-AP-832, dated February 5, 1968, and from ensuing letters to a final date of April 16, 1968. In general, the equipment provided is that proposed in the letter of April 16; however, this letter does not have a complete description of the equipment offered to meet the requirements of the subject specification. Following are the items from these papers that are deemed necessary to describe the Link offering adequately.

Pages D-2 through D-9 include a copy of the cover and excerpts from the document. The excerpts are marked in the left margin with the proposal page number from which they were taken. Pages D-11 through D-21 contain copies of pages from the proposal. These pages show their original page numbers. Pages D-22 through D-26 are pages from correspondence with the Link Group, including two sketches.

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1-AP-832
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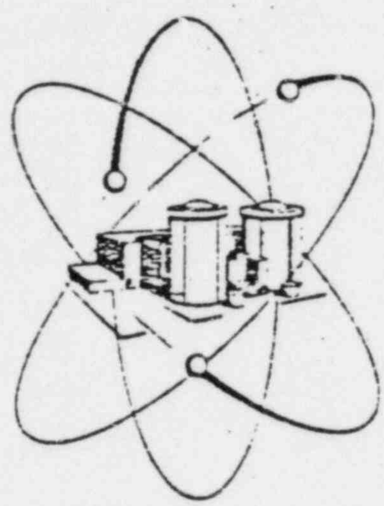


TECHNICAL PROPOSAL FOR

NUCLEAR POWER PLANT SIMULATOR

PREPARED FOR THE

BABCOCK and WILCOX COMPANY
LYNCHBURG, VIRGINIA

FEBRUARY 5, 1968

LINK GROUP OF GENERAL PRECISION SYSTEMS INC.

Page	Text Material
2-1	The Simulator components to be supplied by Link are listed below:

A. Expanded-version Link Model GP-4 computer (not shown)

B. Linkage System (not shown)

C. Instructors Console

The computer and linkage systems should be separate from the simulator area in order not to disturb the integrity of the simulator appearance to the student.

Additionally, Link will utilize as customer furnished equipment one complete set of control panels containing all meters, switches, etc., with appropriate cabinetry and an Integrated Control System less all valves and valve interfacing. Link assumes responsibility for interfacing between specific instrumentation and simulator hardware.

2-9 The Link GP-4 digital computer is a high-speed, large-capacity, general-purpose, solid-state, parallel-process, fixed-point, fractional-binary machine ideally suited to real-time simulation applications. It occupies 2 1/2 standard double-bay cabinets and, together with a GP-4 linkage system, uses approximately 6,000 watts of power. An ASR-33 teletypewriter, a Burroughs Model B122 card reader, two Ampex TM-7 magnetic tape units, and a Potter line printer are provided as peripheral equipment. The teletypewriter and printer are shown in Figure 2-1 in the instructor area, while the tape units and card reader are located in the computer room. Functional integrated silicon microcircuits and solid-state silicon power supplies are used throughout the computer, assuring reliable operation throughout a wide range of ambient temperatures. The GP-4 utilizes a sequential-access drum memory for program storage and a random-access magnetic core memory for data storage. This "split-memory" capability enables the GP-4 to achieve the extremely high speed of operation required for real-time simulation.

2-11 Programs are normally loaded via magnetic tape, using an integral, high-speed loader.

The GP-4 is constructed almost entirely of Motorola emitter-coupled logic (MECL) microcircuits. Where microcircuits are not applicable (less than 5% of circuitry), individual silicon solid-state components are used. Modular construction is used throughout, with individual integrated circuits mounted on printed-circuit cards. The printed-circuit cards plug into standard card bins, which are interconnected by automatic wire-wrapping equipment for maximum reliability. Extremely

Page	Text Material
2-11 (Cont'd)	high packing density has been achieved by Lick through the use of a "functional circuit" (as opposed to the conventional "building block") approach to microcircuit utilization. The entire computer is RFI-shielded.
2-14	The proposed CP-4 digital computer system incorporates the following basic elements.

a. Magnetic drum memory

b. Magnetic core memory 8K

c. Central processor

d. Digital arbitrary function generator (DAFG)

e. Digital data preselector (DDP)

f. Direct memory access (DMA) channel (2)

g. Loader

h. Magnetic tape unit (2)

i. Teletypewriter

j. Card reader

k. Line printer

2-22 Peripheral Equipment

Magnet Tape Units

Two Ampex TM-7 magnetic tape units (MTU's) are provided with the CP-4 computer writes, reads and check digital data in 7-level IBM computer format with bit densities of 200, 556, and 800 bits per inch. The tape drive operates at 45 inches per second and has a start time of 10 milliseconds. The total speed variation is 6% or less of operational speed 10 milliseconds after start command.

Teletype

The ASR-33 teletypewriter provided with the CP-4 is used for low-speed input to and output from the computer. The ASR-33 includes a 10-character-per-second paper tape reader and a 10-character-per-second paper tape punch, as well as a manual keyboard, and can operate in either ASC-II or binary code. The ASR-33 can provide data transfer from the keyboard or paper tape reader to the printer only or to the printer and paper tape punch.

Page	Text Material
2-23	**Card Reader**

The Burroughs Model B122 card reader supplied with the GP-4 computer has a speed of 200 cards per minute and a hopper and stacker capacity of 500 cards. It can be used off-line for direct loading of computer memory via the drum loader. The card reader can also be used on-line via the DMA system for input to various GP-4 software tasks, including input to the DDP and DAPG compilers and input to the utility programs.

Line Printer

The Potter Model HSP3502 line printer or its equivalent will be provided. This device is capable of 10-lines/sec. and can be used for core memory dumps, assemblies, memory traces for debugging, off-line dump of magnetic tapes and other data files. The printer is also the main data log and performance summary output device.

Linkage System

To provide interface between the computer and the rest of the simulator, a real-time input/output (linkage) system will be provided. The linkage system consists of a real-time input/output control system and a number of data conversion systems. The real-time input/output control system (linkage system control) accepts I/O commands from the computer and controls operation of the appropriate data conversion devices through the direct memory access channel. The standard linkage system will contain four basic data conversion systems:

a. Analog-to-digital (A/D) converter

b. Discrete switch input (DSI) system

c. Digital Word Out (DWO) system

d. Digital-to-analog (D/A) converter

Figure 2-6 shows the layout of the linkage and the location of the data conversion systems. A block diagram of the linkage system is illustrated in Figure 2-7.

2-30 **Instructors Console**

The Instructor's Console (Figure 2-8) provides simulator power control and status, operating mode selection and status, system initialization, and malfunction selection and status. The location of the console behind the glass partition (see Figure 2-1) is such that the instructor will have full view of the benchboards, yet not disturb the integrity of the control room floorplan.

Page	Text Material
2-30 (Cont'd)	Mechanical

All control switches and indicators are positioned on a panel mounted at a convenient angle from horizontal. The panel height and angle selected will allow full view of the benchboards. Controls are located within easy reach and view of the instructor. All controls are located on the panel so that the desk portion remains free for papers and documents.

There will be 200 malfunction switches, and 16 mode selection switches provided on the console.

Power control switches will be of the alternate-action push button type. A group of indicators will be located with the power control switches to provide the instructor with the status of simulator subsystems. The indicators will be:

External Power On

Simulator On/Off

Computer Ready

Linkage Ready

These indicators will be derived from the simulator power control unit. These displays indicate that a subsystem is switched to local power control for testing purposes and cannot be energized until return to a ready state by the operating personnel. The purpose is to provide personnel and equipment protection during maintenance periods.

2-32 Electrical Wiring

Control signals to and from the instructor's console are routed through connectors mounted at the base of the console. Access to the cables will be by a removable plate on the back of the console.

The interconnecting signal wiring from switches or indicators and the connector plate will be by single wires routed through a panduct type tray. Terminal blocks will be used to provide a junction between switch or indicator, and cable connector. This will allow easy change if necessary to reroute signals either to computer or directly to instruments for malfunction control. This method also provides that the spares can easily be added to the system.

Controls/Indicators

The controls and indicators will be of the Master Specialties type with removable legend. The arrangement will be such that each switch is a self-latching type, thereby acting as an alternate action switch. A Master Clear, will be provided which will clear all malfunction

Page	Text Material
2-32 (Cont'd)	switches as a group. A "Freeze" control will be provided to freeze the system at any given time for instructional purposes.
	An Intercom is provided for use as a training aid as well as for the convenience of the instructor. Using the intercom, the instructor is able to subject the trainee to realistic internal power plant communication experience, and also instruct the student from the Instructor console. A second intercom channel is provided to allow the instructor two-way communication with the computer room.
3-1	System Operation
	The simulator math models to be supplied under this contract will realistically simulate normal plant operation with parameter input by the instructor to simulate a change in the plant operation. Section 5 of the Babcock and Wilcox specification, entitled "Model Functional Requirements," lists the required simulation parameters and indicates the depth of system mathematical solution. In addition to providing a complete mathematical description and computer programs implementing that description, complete documentation will be provided for the programs.
3-23	Freeze Capability
	Based upon Link's previous training experience with flight simulators, an additional capability will be provided. This additional capability will allow the instructor to "freeze" the progression of all dynamic simulations at any time. During this "freeze" period, the instructor will have time for coaching, correcting, and quizzing the student regarding his performance during the trial period. At the instructor's command, the simulator will resume computation as though zero time had elapsed during the "freeze" interval.
3-24	The freeze is especially desirable when automatic system protection logic action is imminent, or when the student responds to a situation with uncertainty. This freeze-restart capability will allow for objective instructor comment to the student. The freeze capability will also be available for each of the casualty drills provided under Alternate No. 2.
	Link believes that this freeze-restart capability will enhance the value of the simulator as a training device. The student will become better acquainted with hardware reaction and the instructor will be able to provide appropriate comments at any time during the simulation process.

Page	Text Material
3-24 (Cont'd)	Many more training options are being investigated by the Link Group of General Precision Systems Inc. at this time. These training concepts are being developed for advanced flight simulator training applications. Specific items relating to the nuclear reactor simulator which would enhance the training capability of the hardware will be included under separate cover. These capabilities are considered as extensions to the basic training system provided under this contract. The reader will readily see the extension capability of the computer program to the nuclear reactor simulator. These options could be included under this basic contract, or they could be provided as follow-on training work after the basic system has proven its feasibility.
3-26	Diagnostics and Calibrations
	Programs will be provided to perform in both real-time and non real-time, the necessary checks and tests for preventative and corrective maintenance of the computer and its associated peripherals.
3-35	Instructor and Operator Displays and Controls
	In addition to the computer test programs described above, test programs will be provided which will enable the operator to verify all Instructor and Operator Controls and their interface with the computer. The test programs will be divided into two groups as follows:
	a. Displays - The displays will be tested by a series of programs each of which will set all displays and indicators in a predetermined pattern. When the pattern is set, the operator will be asked to verify that all displays and indicators are set to the values specified in the operators guide supplied with the test programs. When it is verified that all displays are correct, the operator informs the computer via the teletype and the computer proceeds to the next test.
3-36	b. Controls - The computer requests that the operator set the controls to a predetermined set of values as specified by the operators guide. When all controls are set, the operator informs the computer via the teletype and the computer senses the control settings. Any variation of control settings from those specified in the operators guide are output to the teletype printer.
4-3	Alternate No. 2
	Options provided to the instructor for monitoring student reaction to pre-programmed casualties will be provided under this alternate. As specified, two functions will be provided as listed below. The two functions relate only to programming effort, since no hardware additions or modifications are anticipated.
	a) Programmed Instructor Drill
	Up to 10 casualty drills can be specified by the instructor

Page	Text Material
4-3 (Cont'd)	

for student operator reaction. Each drill is a time sequence of failures selected at random from the normal list of casualties.

b) This programmed event will consist of the monitoring and logging of a specified group of critical parameters, the calculation of maximum deviation from reference values, deviation counts, maximum duration of deviations, and elapsed time. This program will be under instructor control.

In addition to the above definitions, each instructor-initiated casualty simulation will be logged for event and time.

Programmed Instructor Drill

This program will accept operator initialization inputs for casualty identification. The casualties will be input through magnetic tape, TTY or cards with the following information:

a) Casualty conditions of specific item or state.

b) Sequence of each casualty event.

c) Timing between events and designation of T_o. Designation of T_o will be elapsed time from operator initialization or upon instructor initiation.

The program will sequentially initiate casualties based upon this defined sequence. For each casualty sequence selected, however, critical monitor parameters will be contained within the computer program list of stored values. Figure 4-1 depicts the concept.

Instructor Action	Computer Action
1. Casualty N_1	Casualty Simulation (N_1)
2. " N_2	" " (N_2)
3. " N_4	" " (N_4)
4. "	" "
5. "	" "
6. "	" "
7. "	" "
8. "	" "
9. "	" "
10. " N_k	" " (N_k)
Monitor/Evaluate	Plus Critical Values for (N_1) " " (N_2) " " (N_4) (N_k)

Figure 4-1 Programmed Instructor Drill

For purposes of this proposal, 10 preselected casualties will comprise the condition states; others may be added after checkout and verification, but are not included in the scope of this proposal. Link envisions the inputs and outputs for this routine to be handled as shown in Figure 4-2.

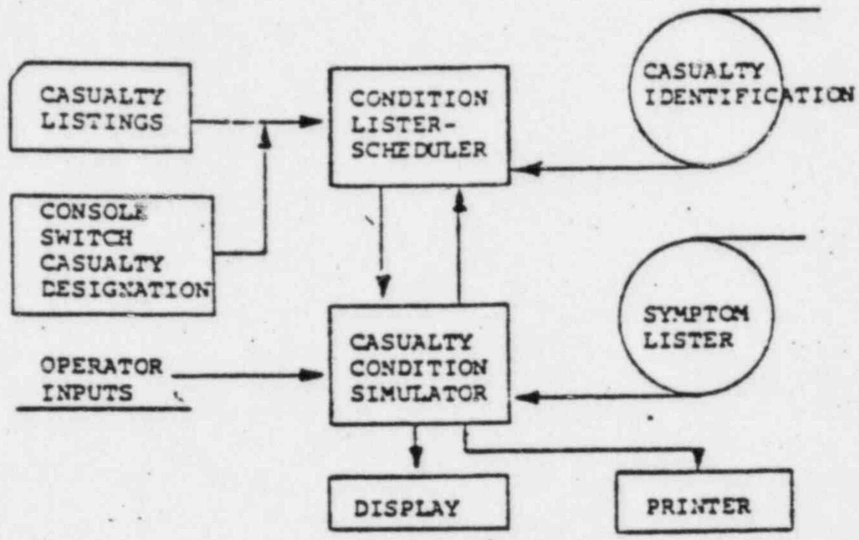


Figure 4-2 Programmed Instructor Drill Model

4.2.2 Student Performance Summary

The remaining program requirement for Alternate No. 2 concerns student reaction to casualty events. This program will provide the basis for an objective evaluation of the student performance by computing or recording specific parameters. Table 4-1 presents these calculation and recording requirements in more detail.

......	For Casualty Event N_x
	1. Monitor and log specific critical parameters 2. Calculate maximum deviation from reference value 3. Record number of deviations 4. Record maximum duration of deviation 5. Record elapsed time of duration

Table 4-1 Student Performance Summary Listing

During student performance runs, a history tape will be maintained of critical item occurance and operator reaction to that occurance. Each major system status will be recorded on a variable time basis (specified by instructor). Also, the sample rate for student reaction recording will be specified by the instructor.

A directory will be maintained showing maximum deviation from a calculated normal value. The normal will be shown together with the out-of-tolerance condition and the deviation. This same directory will also record the number of deviations during a casualty, the maximum duration of a deviation, and the elapsed time for each deviation.

After completion of an exercise, the entire directory can be listed or only those portions dealing with deviations from a norm. For example, only deviations during a particular time period could be listed if desired.

Figure 4-3 illustrates how this program might be structured for compliance with the required task.

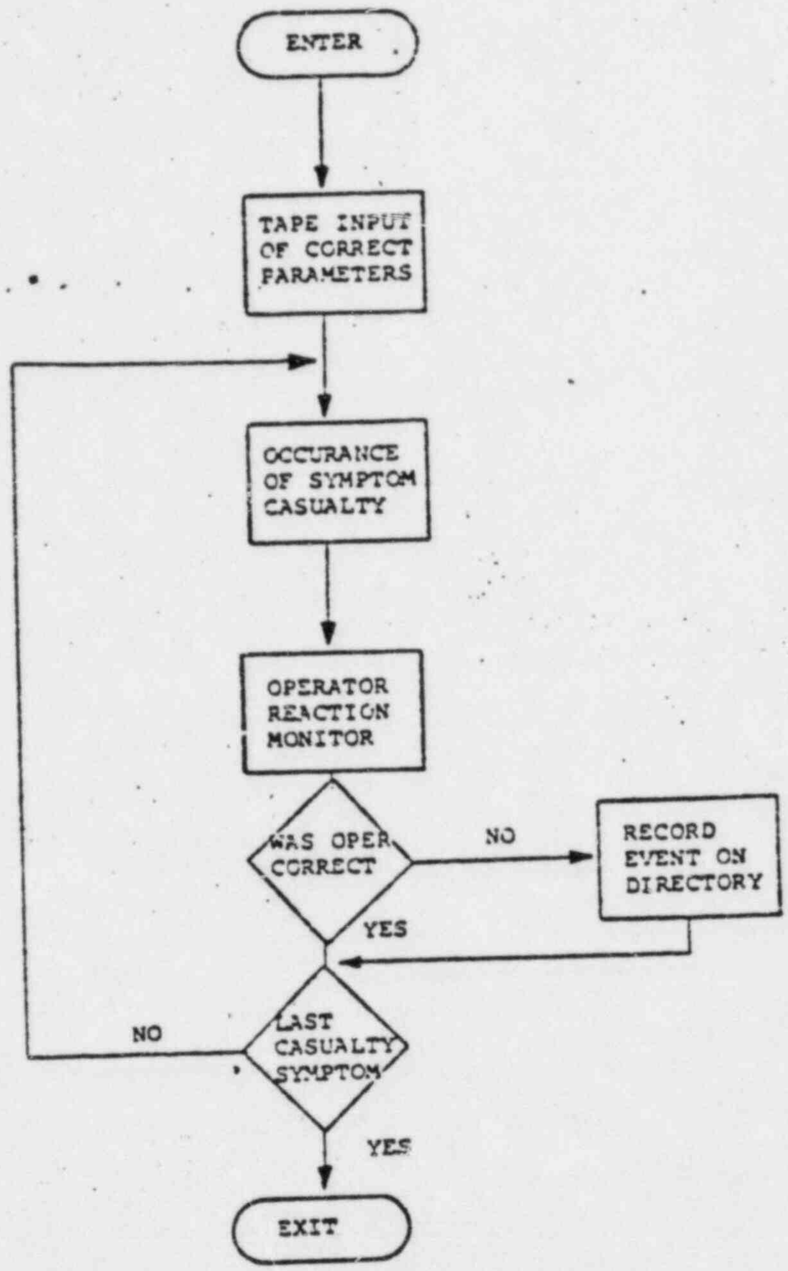


Figure 4-3 Student Performance Summary

6.1.6 Simulator Programming

Link proposes to use the Fortran programs discussed in Section 6.1.4 as the basis for further programming efforts. The Fortran programs will provide documentation that the mathematical model is correct, thereby establishing the basis for the simulation code.

6.1.7 Hardware/Software Integration

Upon completion of GP-4 programming and debugging, all programs will be integrated with the simulation system. These programs will be initialized to drive the various console meters, gauges, and sensors to verify proper interfacing between system components.

6.1.8 System Acceptance Testing

System acceptance testing will demonstrate the operational capability and configuration compliance for the nuclear power plant simulator. During this period, Link will verify that the simulator programs react in a manner adequate for actual power plant operation. The system hardware will be demonstrated, and the computer programs will be verified by actual problem solution. In addition to the above items, operational details of the mathematical model will be verified.

The acceptance testing and subsequent acceptance of the simulator system, as shown on the milestone schedule, will consume approximately one month of actual verification both at Link and at B & W. Link anticipates that the verification and validity testing of the computer program will be minimized since previous acceptance and demonstration of the Fortran programs developed earlier in the model checkout phase proved the mathematical model to be adequate for system function designation. This early demonstration of mathematical compliance with system specifications will also highlight problems with model definition and development early in the program. In this manner, areas of concern to Link and to Babcock & Wilcox will have been identified early enough in the program to allow sufficient resources to be marshalled to resolve the problem.

Link personnel will operate the simulator complex during the acceptance testing phase. Minor equipment modification or repairs will be made at the Babcock & Wilcox facility within the capability of Link on-site personnel. If necessary, maintenance support personnel will be dispatched from the Sunnyvale Link facility. Link anticipates that these minor hardware modifications will be minimal, since the simulator will have been completely checked out prior to shipment to Babcock & Wilcox.

Link does not anticipate any changes will be required in the computer program. This program will have been completely verified before hardware shipment from Sunnyvale. The mathematical model will have been demonstrated to Babcock & Wilcox, and the programs will have been running on the computer prior to shipment. Should minor adjustments be necessary, however, they will be performed by Link on-site personnel at Babcock & Wilcox.

As a normal part of acceptance testing, the computer and peripherals will be demonstrated to insure compliance with input-output and interrupt capabilities. Link will also demonstrate that the programs can be loaded efficiently and that necessary diagnostic programs operate as specified.

2.2 AEC-LICENSING EXERCISES

As opposed to normal training exercises in which the instructor commands and continuously varies the ordering and timing of events, special exercises for AEC-licensing could be used which would be specific, totally objective, "canned" exercises and would consist of pre-defined sets of malfunctions and their associated time-interval/event definitions. They would result in data/event printing according to pre-defined formats (the formats to correspond to the recorded data/event set for given exercises).

The following features could be incorporated for AEC licensing:

1. Standard exercise(s) - to include one or more "canned" sets of malfunctions with their associated time-interval/event descriptions.
2. Real-time recording of specific data/event sets - to correspond with the different exercises.
3. Various formats for printing the recorded data - the print format to correspond with the recorded data/event set.

To initiate one of the AEC-licensing exercises, the instructor would enter the following information into the system through the teletypewriter:

a) Installation identification
b) Instructors name and/or code

c) Operators name and/or code

d) Date, time of day

e) AEC-licensing exercise number
(assuming more than one)

A typical flow chart, Figure 1, is shown which incorporates the AEC licensing exercise.

3.0 SUMMARY AND CONCLUSIONS

Babcock & Wilcox, by virtue of the requirements specified under Alternate No. 2 of the basic specification for the nuclear reactor simulator, demonstrates and recognizes the need for a highly capable and relatively sophisticated automated system for the AEC-licensing of nuclear reactor operators.

In responding to this need, Link believes that the Alternate No. 2 requirements for Programmed Instructor Drill and Student Performance Summaries provides the appropriate base on which the Advanced Training Concepts can be built. Accordingly, the items listed under section 2.0 of this addendum presupposes the acceptance by B&W of Alternate No. 2. Specifically, the Advanced Training Concepts presupposes the acceptance of the following hardware and software design features:

1. Tape No. 1 as the system master tape - contains
   a) Mode initialization tables
   b) Casualty lists
2. Tape No. 2 as the update/history tape - accepts:
   a) System status outputs
   b) Time-oriented system parameter sets
   c) Time-oriented linkage I/O buffers

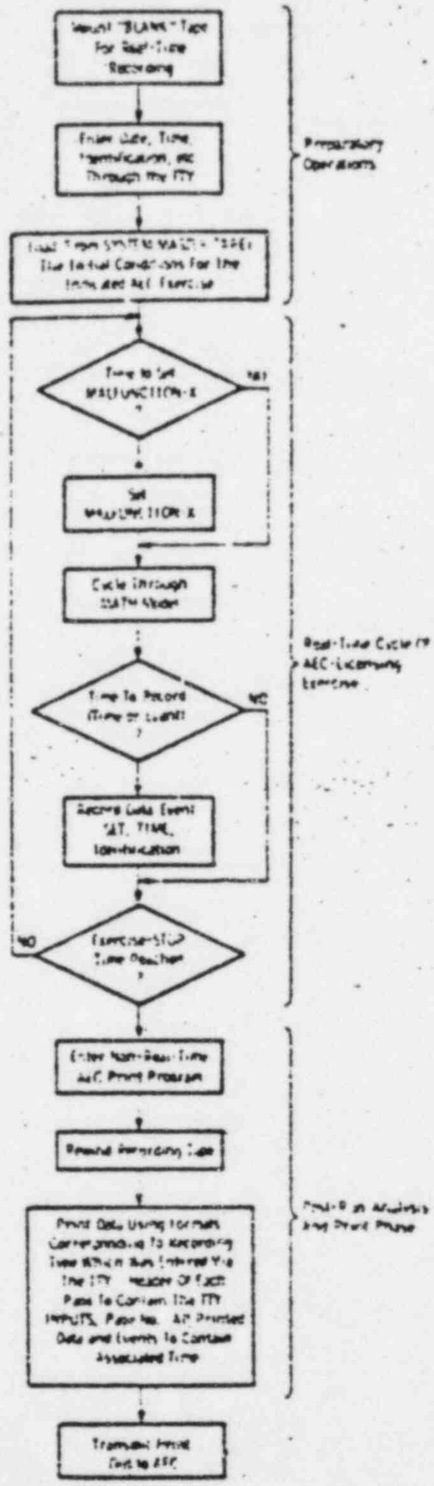


FIGURE 1 AEC LICENSING EXERCISE

3. Problem Freeze - Basic proposal
4. Programmed Instructor Drill - Alternate No. 2
5. Student Performance Summaries - Alternate No. 2

Significant features of computer programs included under the Advanced Training Concepts package are many. They cover a broad range from a "slow motion" of a specified series of events to an ultimate computer-controlled series of verbal directions. As examined in this addendum, licensing considerations and training concepts would be considered in light of their impact on the computer programs which would be supplied with the simulator.

GENERAL PRECISION SYSTEMS INC

LINK GROUP

1077 EAST ARQUES AVE., SUNNYVALE, CALIF. 94086 PHONE 408-732-3800 TWX 910-339-9204
ADVANCED PRODUCTS DIVISION

16 April 1968

The Babcock and Wilcox Company
Boiler Division
P. O. Box 1260
Lynchburg, Virginia

Attention: Mr. R. A. Beal, Section Manager
Purchasing Department

Subject: Nuclear Power Plant Simulator
Price Quotations and Proposed Contract

Reference: (1) B&W/Link Meeting, Lynchburg, 4/2&3/68
(2) B&W Letter dated 4/4/68 from R. A. Beal
(3) B&W Telegram dated 4/10/68 from R. A. Beal

Gentlemen:

The Link Advanced Products Division is pleased to announce that as a result of the successful technical meetings between representatives of our firm and Babcock and Wilcox, we believe that a firm agreement has been established concerning the desired scope of supply for the Nuclear Power Plant Simulator. This belief has been reinforced with the receipt of your latest telegram which specifies in some detail the precise scope of this task which is considered acceptable by B&W.

In accordance with your directions, Link has further reduced its outstanding quotations by removing the cost for the wiring of the nuclear reactor consoles. Our new quote is definitely based on the assumption that the consoles will be supplied wired in accordance with Link's requests.

In a similar vein to provide further savings for B&W, we have changed the project organization to a more streamlined form by utilizing Mr. Robert Perram as both the Project Manager and the Project Hardware Engineer. Mr. Perram will still report to Mr. Bill Gass, the Manager of our Prototype Systems Group. A new functional project organization chart has been enclosed to illustrate the new alignment of personnel. Copies of Mr. Perram's resume are also enclosed.

Also provided as an attachment to this letter is a GP-4 Computer Physical Layout Drawing (SK8450) and Link wishes to re-affirm the fact that the computer configuration offered at this time will include the Direct Memory Access Device Lock. This hardware facilitates the addition of a second linkage and set of nuclear consoles if a second simulator configuration is required in the future.

A second block diagram (SK8453) outlines the complete computer configuration as it is presently proposed. This diagram points out the twenty band configuration GP-4 Computer with band switching circuitry. It is anticipated that only sixteen of these twenty general program bands will be utilized in fulfilling the existing software requirements. The remaining four bands will provide the 25% spare capacity requested by B&W.

Also enumerated on block diagram SK8453 is the drastically increased input output configuration desired by B&W reflecting the new total of 2348 inputs and outputs as compared to the previous total of 1037. This last minute large increase in the computer input output configuration eliminated a significant portion of the total reduction which could have been made available to B&W.

Based upon the above criteria, the Link Group of General Precision Systems Incorporated is now prepared to offer a reduced price for the proposed Nuclear Power Plant Simulator.

COSTS

1. Complete cost for eight spatial region simulation system, including 1 CPU GP-4, peripherals, instructor's console, and necessary software (including Alternate No. 2 requirements)..................................

2. Incremental cost for AEC licensing programs as defined in original proposal..................................

The prices quoted are contingent upon complete review and approval of the B&W revised specification which should be made available to Link within the next two weeks. Link anticipates no problem in this regard and is willing to accept a tentative letter of contract in order to initiate work on this program as soon as possible.

To facilitate this matter, we are further prepared to limit the liability to B&W under a one month temporary agreement to a maximum of   . A specimen letter of intent has been enclosed for your convenience.

Final acceptance of any complete program between Link and B&W must be conditioned upon the acceptance of mutually agreeable terms and conditions as approved by our Contracts Department. We anticipate that a set of terms and conditions fully approved by Link Group, GPSI, will be available for your review within ten days.

We believe that an extremely desirable program has been outlined and agreed upon through the excellent work accomplished by our technical personnel. Link definitely congratulates the staff of B&W for the highly professional manner in which they performed their difficult assignment. Only their continuing cooperation and reasonableness have made it possible to reach this present level of agreement.

We indeed hope that the quotations provided are deemed reasonable and satisfactory for this effort. We look forward to a highly successful venture with B&W and we anxiously await your approval to begin work. For further assistance please do not hesitate to contact Mr. Bruce Wilkerson of our Washington, D.C. office or the undersigned.

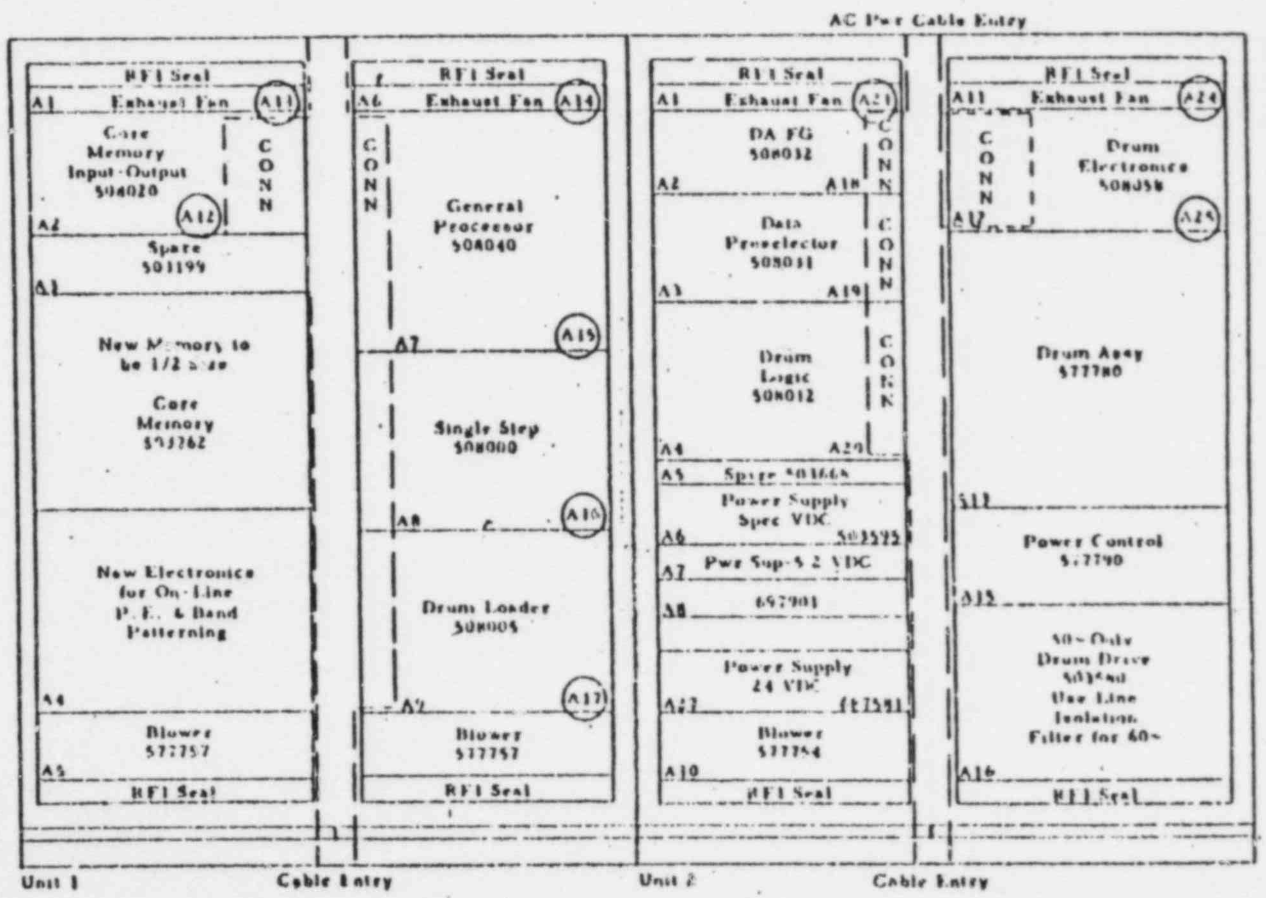
Mr. B. W. Wilkerson
LINK GROUP, GPSI
1030 15th St. N.W.
Suite 1050
Washington, D.C. 20005
202-223-4102

Very truly yours,

Gary J. Dotzler, Manager
Advanced Technology Sales

GJD/ld

Enclosures:
1. Functional Project Organization Chart
2. Mr. R. Perram's Resume
3. SK8450 GP-4 Computer Physical Layout
4. SK8453 Equipment Block Diagram
5. Draft Letter of Intent



GP-4 Computer Physical Layout
(50 Cycle)

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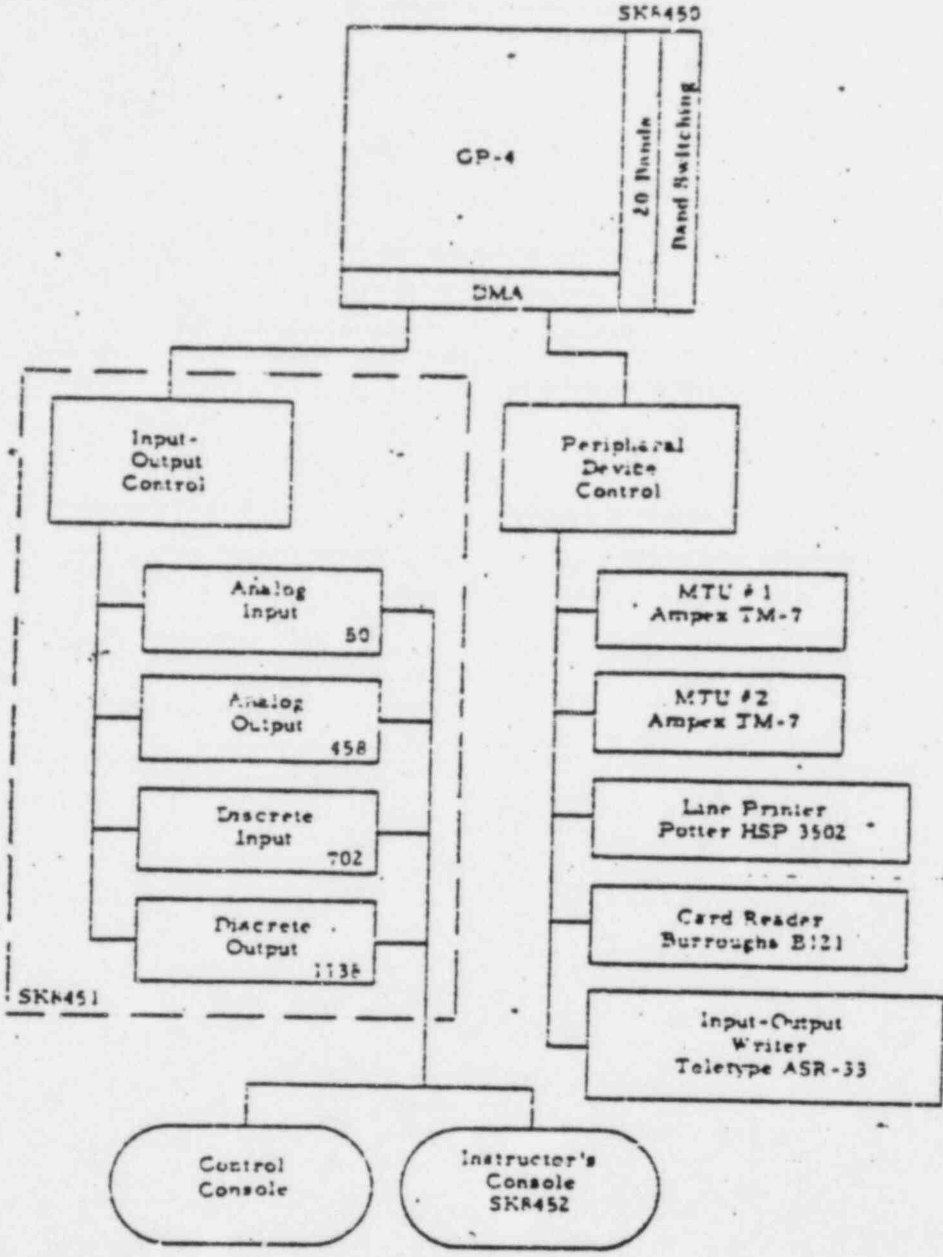

B&W Equipment Block Diagram

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