Westinghouse Technology Systems Manual

Chapter 9

NEUTRON MONITORING SYSTEMS

Section

Westinghouse Technology Systems Manual

Section 9.0

Neutron Monitoring System

9.0 NEUTRON MONITORING SYSTEMS

The neutron monitoring systems monitor the neutron flux level of the reactor core by detecting leakage neutrons from the core and by detecting neutron flux levels from within the core. These neutron monitoring functions are satisfied by two completely independent neutron monitoring systems. The excore nuclear instrumentation system (Section 9.1) monitors leakage neutrons, while the incore nuclear instrumentation system (Section 9.2) monitors the neutron flux level within the core.

The excore system monitors leakage neutrons as a measure of core power and provides control and protection inputs to the reactor control system and the reactor protection system. The incore system is used periodically to monitor relative core power distribution via its movable detector system. Additionally, the incore instrumentation system utilizes thermocouples, located at the outlet of the fuel region, to provide a diverse indication of the relative power distribution for the operator.

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Section 9.1

Excore Neutron Monitoring System

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Learning Objectives:

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2. List the reactor protection system inputs provided by the excore nuclear instrumentation system and the purpose (basis) of each.

3. List the interlocks and permissives provided by the excore nuclear instrumentation system and the purpose (basis) of each.

4. Explain how the excore nuclear instrumentation system is capable of detecting both axial and radial (azimuthal) power distribution.

5. Explain how the power range signal is calibrated to indicate reactor thermal output.

6. Explain why gamma compensation is required only in the source and intermediate ranges.

7. Explain the effects of an improperly compensated intermediate range.

8. Explain why channel test signals are additive to the channel outputs.

9.1.1 Introduction

The purposes of the excore nuclear instrumentation system are to:

1. Provide indication of reactor power from shutdown to full power conditions,

2. Provide inputs to the reactor protection system during startup and power operation,

3. Provide reactor power information to the automatic rod control system, and

4. Provide axial and radial power distribution information during power operations.

The excore nuclear instrumentation system monitors the power level of the reactor by detecting neutron leakage from the reactor core. Leakage neutron flux from the core is monitored for two primary reasons. First, core neutron leakage is directly proportional to the core neutron flux (power level), and second, it is much easier to design and maintain neutron detectors which do not need to operate within the hostile environment of the reactor core.

Three overlapping ranges of excore instrumentation monitor the neutron flux level generated in the core from a few counts per second up to approximately 10^{15} neutrons/cm^2/sec (200 percent of full power). The three different ranges of indication are source, intermediate, and power. Monitoring and protective functions are provided by two independent source range channels, two independent intermediate range channels, and four independent power range channels. The power range instruments also provide an input into the automatic rod control system.

Auxiliary channels provide a source range audio count rate signal or "beeper," for audible indication of changes to the neutron flux rate. In addition, the source and intermediate range startup rates are provided to the reactor operator. This information is used by the reactor operator to determine the approach to criticality and to monitor how rapidly reactor power is changing.

The instrument racks for this system are usually located in the control room area, where they may be visible to the operator. Information generated by this system is displayed on individual channel drawers installed in the excore instrumentation cabinets and on the reactor control section of the main control board. The excore nuclear instrumentation system is considered a safety related system and its components are powered from vital (Class 1E) power supplies.

9.1.2 System Description

9.1.2.1 Excore Nuclear Instrumentation System

Neutron detectors, utilizing solid-state electronic circuitry, are used to monitor the leakage neutron flux from a completely shutdown condition up to 200% of full power. Since the neutron flux covers a wide range (12 decades), three ranges of instrumentation are used to obtain accurate flux level measurements (Figure 9.1-1). The lowest level (source range) covers six decades of neutron flux.

The lowest observed count rate (indicated by the source range) depends upon the strength of the neutron sources in the core and the core multiplication associated with the shutdown reactivity. The next higher range of nuclear instrumentation (intermediate range) spans eight decades. The design of this instrument is chosen to provide overlap between the upper output of the source range channels and the full span of the power range instruments. The highest range of indication (power range) spans approximately two decades. The power range provides a linear display of power and overlaps with the upper portion of the intermediate range channels.

The primary function of the excore nuclear instrumentation system is to protect the reactor core from overpower by monitoring the neutron flux and generating appropriate alarms and reactor trips to shutdown the reactor when required. Each range of instrumentation (source, intermediate, and power) provides overpower reactor trip protection during operation in that range. The overlap of instrument ranges provides reliable protection at all flux levels. During reactor startup as the neutron flux level is increased, and satisfactory instrumentation operation is obtained in a higher range, the overpower protection trip for the lower range may be manually removed by the operator in accordance with administrative procedures. However, automatic reinstatement of the lower range trip settings is provided when reducing power level.

The source, intermediate and power range detectors are placed in instrument wells located within the concrete shield surrounding the reactor vessel (Figure 9.1-2). The instrument well is movable and is positioned by a push-bar located outside the concrete shield wall. If an individual detector requires maintenance or replacement, the instrument well is pulled away from the reactor vessel to a location under an access pipe which is sealed by a water tight cap. After maintenance is complete, the instrument well is pushed back to a position adjacent to the reactor vessel. Failure to return the instrument well to its original position results in an incorrect indication of power due to the change in detector-core geometry.

9.1.2.2 Source Range

The source range instrumentation consists of two independent channels, designated as source range channels N-31 and N-32. Both channels are physically and functionally identical. As shown in Figure 9.1-3, the source range detectors are located 180 degrees apart outside the bottom half of the core. This location provides the maximum sensitivity to low power neutron level increases. The source range circuits monitor and indicate the neutron flux level of the reactor core and the rate by which the neutron flux changes during a reactor shutdown and the initial phase of start-up. The rate of change of the neutron population is indicated as startup rate (SUR). SUR is the number of decades (powers of ten) that the neutron flux (reactor power) is changing per minute and is indicated as decades per minute DPM.

Indication of source range neutron population and its rate of change are provided at the nuclear instrumentation cabinets and at the reactor control panel. The source range indication has a span of 10^0 to 10^6 cps (counts per second) and the source range SUR has a range of -0.5 DPM to +5 DPM.

Each source range channel, Figure 9.1-4, utilizes a preamplifier assembly which amplifies the neutron pulses from the BF_3 proportional counter detector to a workable level (a discussion of the BF_3 proportional counter is provided in section 9.1.4). The circuitry of each channel shapes and integrates the pulses, provides amplification, discriminates against gammas and background noise, produces a logarithmic neutron level signal, and amplifies the log signal prior to its indication.

One of the principal problems in the source range is trying to distinguish the relatively small number of pulses produced by neutrons from the large number of pulses produced by gamma radiation during source range operation. Thus gamma discrimination is of particular interest during shutdown after the reactor core has operated long enough to establish an accumulation of fission products. This condition produces a high gamma field and a low neutron flux around the detector.

The meter face is calibrated to indicate counts-per-second and represents the number of neutron pulses generated per second. This instrument can indicate up to a maximum neutron count rate of 10^6 cps. The count rate signal is also applied to bistable relay assemblies which in turn generate signals for remote protection equipment. The noise-discriminated pulse signal from either source range channel is also applied to an audio count rate drawer assembly and, together with a scaler-timer assembly, converts and amplifies the neutron pulses into an audible tone heard in the control room and in the containment.

Source range channel selection for audio monitoring is accomplished at the front panel of the audio count rate drawer. Integrated pulses are also applied to the comparator and rate drawer assembly where the rate-of-change of neutron flux is computed. The output rate signal is coupled to local and remote SUR meters.

9.1.2.3 Intermediate Range

The intermediate range instruments consist of two independent channels, designated as intermediate range channels N-35 and N-36. Both channels are physically and functionally identical. As shown on Figure 9.1-3, the intermediate range detectors are located 180 degrees apart outside the midpoint of the core. The detectors share the same instrument well as the source range detectors. The midpoint of the core location allows the detectors to monitor the neutron population changes from low power operations to full power. The intermediate range channels monitor the neutron flux of the core and provide signals to the rate circuits to compute its rate-of-change. The intermediate range channels, which cover a span of eight decades, come on scale when the source range channels reach approximately 10^3 counts-per-second. The intermediate instruments monitor neutron flux from this level through full power operation.

As shown in Figure 9.1-4, each intermediate range circuit receives a signal proportional to neutron flux from a compensated ion chamber detector. Gamma compensation is accomplished by the electronic arrangement of the detector. The intermediate range channel, with the exception of the detector, is housed in the intermediate range drawer assembly.

A logarithmic current measuring circuit is used to monitor reactor power over a range of eight decades (10^{-11} to 10^{-3} amperes). Indications of intermediate range neutron flux level and SUR are provided at the nuclear instrumentation cabinets and at the reactor control panel. The neutron flux level signal is also applied to bistable relay assemblies which in turn generate signals for a protective grade permissive and an interlock and a reactor trip on high neutron flux.

9.1.2.4 Power Range Channel

The power range circuits consist of four independent channels, designated as power range channels N-41 through N-44. All four channels are physically and functionally identical. Each power range channel employs an upper and a lower uncompensated ion chamber detector which provide current signals to the power range circuits. As shown on Figure 9.1-3, the power range detectors are located 90 degrees apart. Each location consists of an upper detector and a lower detector, mounted inside the same instrument well. The outputs of both detectors (upper and lower) are combined to produce a channel total power signal. The eight detector outputs (four upper detectors and four lower detectors) are compared to each other to provide power distribution information to the reactor operator.

Within each power range channel, as shown in Figure 9.1-5, the upper detector and lower detector current signals are monitored, summed and amplified, at the summing and level amplifier, to develop a voltage which is directly proportional to reactor power. The summed signal is monitored in percent full power, ranging from zero to 120 percent. The output of each power range channel provides reactor trip signals, alarms and input for control functions. In addition, electronic signals are sent to a channel and a detector current comparator. The channel current comparator assembly uses the output of the four power range channels to verify that the detectors are properly calibrated with respect to each other. The detector current comparator (one comparator for the upper detectors and one for the lower detectors) monitors the four upper or four lower detector outputs to determine if power is being evenly produced throughout the core.

9.1.3 Component Descriptions

9.1.3.1 Source Range Channels

The nuclear instrumentation system is supplied with two independent source range channels as shown in Figure 9.1-4. Boron triflouride proportional counters (N-31 and N-32) provide pulse signals to the source range channels. These detectors are installed on opposite flat portions of the core, near the primary/secondary neutron sources, at an elevation approximating one quarter of the core height. The preamplified detector signal is received by the source range instrumentation conditioning equipment located in separate drawers in separate control room racks.

The detector signal, which is a count rate proportional to the neutron flux leakage, is conditioned for conversion to an analog signal proportional to the logarithm of the neutron flux count rate. The signal received from the counter has a range of 1 to 10^6 pulses per second and is received through a fixed-gain pulse preamplifier.

The preamplifier is located close to the detector to increase the signal-to-noise ratio and also furnishes high voltage coupling to the detector. The preamplifier assembly has internal provisions for generating self-test frequencies of 60 to 10^6 counts per second. These test oscillator circuits are energized by a switch located on the associated source range drawer. The source range channel power supplies furnish low voltage for preamplifier operation and for the drawer-mounted modules.

The preamplifier output is received at the pulse-amplifier/discriminator located in the source range drawer. This module provides amplification and discrimination, both of which are adjustable. Discrimination is provided between neutron flux pulses, and gamma-generated pulses. The discriminator circuit cuts off the low amplitude gamma-induced pulses. The discriminator provides two outputs; one output (isolated) to a scaler-timer unit in the audio-visual channel and the other to a pulse shaper (transistorized) circuit which supplies a constant amplitude pulse to the log integrator module in the source range drawer.

The pulses from the pulse amplifier are supplied to the pulse shaper which shapes it into a square wave. The output waveform is at a constant amplitude at half the frequency of the input frequency. Two input pulses are required to produce an output pulse. The pulse driver receives the standard amplitude pulse from the pulse shaper and provides the drive through impedance matching stages to apply the pulses to a log pulse integrator.

The log pulse integrator assembly receives the square wave pulses from the pulse drive assembly and integrates these pulses to provide a current output proportional to the logarithm of the average pulse rate. The current is then applied to a current summing network and the level amplifier for amplification.

The level amplifier receives the log-level voltage output from the log pulse integrator. The assembly amplifies the voltage to produce an output which is displayed on a meter calibrated logarithmically from 10^0 to 10^6 cps. The output is also applied to bistables, and an isolation amplifier for remote indication.

Reactor trip signals provided by these bistables are transmitted to the protection logic cabinets where the necessary matrices involved in generating reactor trip signals are formed. All logic matrices associated with plant protection or control functions are located in the protection logic or auxiliary relay cabinets, respectively.

During shutdown periods, a high neutron flux in the core actuates a bistable which alerts plant personnel to abnormal reactivity increases. This alarm provides both local visual and audible annunciation (high flux at shutdown), and remote audible annunciation (containment evacuation).

These annunciators ensure that the plant operator is alerted to any unusual or unsafe condition. The bistable alarm function is manually blocked by deliberate operator action during a reactor startup. Blocking is continuously annunciated at the control board during source range operation. The high flux at shutdown alarm setpoint is normally set at approximately one decade above the steady state shutdown flux level.

The high source range flux level reactor trip bistable provides an input into the reactor protection system. Its purpose is to initiate a reactor trip which limits core power to mitigate startup reactivity excursions during power operations in the source range. When the intermediate range indication is on scale, P-6 (the source range block permissive) is energized and the source range reactor trip may be manually blocked by the operator. Once blocked, the high voltage is removed from the source range detectors. Removing the high voltage protects the detector from damage due to the high currents produced by the increased neutron flux levels present at higher reactor power levels. The blocking action is physically accomplished by actuating two momentary-contact switches located on the main control board. While these trips are blocked, the SOURCE RANGE TRIP BLOCKED annunciator is continuously illuminated on the main control board.

If a one decade overlap exists between the top of the source range and the bottom of the intermediate range, the source range block permissive P-6 is generated. The one decade overlap insures that the intermediate range is available and indicating before increasing reactor power above the source range. This permissive, P-6, is generated when one of the two intermediate range instruments exceeds the setpoint of 10^{-10}. After the permissive is made up the reactor operator has approximately 3/5 decade before the source range HIGH FLUX LEVEL REACTOR TRIP (10^5 cps) occurs.

A bistable is used to indicate that the voltage to the detector has failed. A loss of high voltage on either source range channel provides control board annunciation. During a reactor startup when the source range high voltage is intentionally turned off (as mentioned above), the loss of high voltage annunciator is backlit until reactor power exceeds 10% (P-10 Nuclear power above 10%). When P-10 is made up the source range loss of high voltage annunciator is de-energized which prevents the annunciation of a condition which is not abnormal.

Testing of the source range channels is accomplished by switches on the individual source range instrument drawers. An operation selector switch on the source range instrument drawer selects the test signal to be inserted. All test signals are additive to the signal from the detector. Therefore, the resultant channel level will be conservative, equal to the imposed test signal plus the detector signal.

An electrical interlock between the Level Trip Bypass switch and the Operation Selector switch prevents inadvertent actuation of the reactor trip circuits (i.e., the channel cannot be put into the test mode unless the trip is bypassed). The trip bypass is annunciated on the source range drawer and on the main control board.

Each source range channel supplies signals to the following instrumentation.

- Remote count rate meter (NI-31B and NI-32B) The remote meters are driven by isolation amplifiers. The meters are mounted on the main control board and calibrated logarithmically from 1 to 10^6 counts per second.

- Remote recorder (NR-45) - This two-pen recorder is capable of continuously recording any two nuclear instrumentation channels. Each pen receives a signal through a multi position switch which can select any one of the eight nuclear channels.

The Source Range Channel Instrument drawer is shown on Figure 9.1-6. The instrument drawer switches and indications are discussed individually below:

Detector volt meter - monitors the high voltage power supply output to the BF_3 proportional counter.

Neutron Level Meter - Indicates the neutron level output of the BF_3 proportional counter for the source range channel. The meter indication is in counts per second between 10^0 and 10^6, calibrated logarithmically.

Instrument Power On Lamp - Indicates that 118 Volts ac instrument power is applied to drawer instrument power supplies.

Control Power On Lamp - Indicates that 118 Volts ac control power is applied to drawer control signal circuits.

Channel On Test Lamp - Indicates that the drawer OPERATION SELECTOR switch is in a test position.

Loss of Detector Volts Lamp - Indicates that the high voltage supplied to the BF_3 proportional counter is removed, or is low due to a fault in the system. Setpoint is 70% of normal voltage.

Level Trip Lamp - Lights when the neutron count ratel exceeds 10^5 cps.

Level Trip Bypass Lamp - Lights when LEVEL TRIP switch is placed in the BYPASS position to test and calibrate the source range channel circuits.

High Flux at Shutdown Lamp - Indicates when the neutron level exceeds the preset level during reactor shutdown.

Bistable Trip (Spare) Lamp - A spare indication lamp designed manufactured into the cabinet for possible use in the future.

AC Instrument and Control Power Fuses - Provide overcurrent protection for drawer circuitry.

Level Trip Switch - A two position rotary switch which enables test and calibration of the source range channel in conjunction with the OPERATION SELECTOR switch. In the BYPASS position, the LEVEL TRIP BYPASS lamp illuminates, the OPERATION SELECTOR switch is enabled, and a signal is continuously provided to the reactor protection system to prevent a reactor trip during testing (see bistable detail on Figure 9.1-4).

Operation Selector Switch - An eight position switch enabled by the LEVEL TRIP switch permits the generation of test signals for test and calibration of the source range channel. In the 60 CPS, 10^3 CPS, 10^5 CPS or 10^6 CPS positions, a Test Calibrate Module inserts an appropriate counts per second signal to the input of the pulse amplifier. This allows verification of the operating accuracy of the circuits within the source range drawer. In the 60 CPS PREAMP and the 10^6 CPS PREAMP positions one of two test oscillator modules in the preamplifier is energized to generate a known signal for testing the preamplifier and the long run of triaxial cable between the preamplifier and the source range drawer.

Level Adjust Potentiometer - Provides an adjustable test signal for insertion directly into the level amplifier. This enables the adjustment of the trip level of the various bistable circuits within the drawer assembly. The control is effective only when the OPERATION SELECTOR switch is in the LEVEL ADJ position.

9.1.3.2 Intermediate Range Channel

As shown in Figure 9.1-4, two independent, compensated ionization chambers provide extended neutron flux coverage from the upper portion of the source range to approximately 200 percent reactor power. Compensated ionization chambers (N-35 and N-36) serve as neutron sensors for the intermediate range channels and are located in the same instrument wells as the source range detectors (a discussion of the compensated ion chamber is given in section 9.1.4). Each intermediate range channel consists of one compensated ionization chamber which uses high density polyethylene as a moderator and as an insulator. The detectors are positioned at an elevation corresponding to half the core height. Each intermediate range channel is supplied with a positive high voltage and high negative compensating voltage to its respective detector. Compensating voltage is used to cancel out the gamma contribution to the total current signal. Therefore, the signal current delivered to the intermediate range channel circuitry is from neutrons only (Figures 9.1-15 and 9.1-16). Both high voltage supplies are adjustable through controls located inside the channel drawer.

The equipment for each channel, including the high voltage and compensating voltage power supplies, is mounted in separate drawers. The detector signal is received by the intermediate range logarithmic amplifier. This unit produces an analog voltage output signal which is proportional to the logarithm of the input current. This output signal is used for local indication and is sent to the inputs of the various bistables within the intermediate range drawer. Local indication is provided by a meter mounted on the front panel of the drawer. The meter face has a logarithmic scale with a span of 10^{-11} to 10^{-3} amperes. The isolation amplifier is of similar design as that used in the source range. Six separate bistables are used in the intermediate range drawer to perform the following functions:

- Loss of high voltage (Alarm)
- Loss of compensating high voltage (Alarm)
- Permissive P-6 (10^{-10} amps)
- Rod stop C-1 (blocks automatic and manual rod withdrawal at 20% power current equivalent)
- Reactor trip (25% power current equivalent)
- Spare

The intermediate range permissive, P-6, allows the blocking of the source range trip. Bistable outputs from each intermediate range channel are combined in a one-of-two matrix to provide the permissive function and control board status indication of the availability of the permissive. As explained earlier this permissive (P-6) permits the manual blocking of the source range trip and removes the high voltage from the source range detector. One blocking switch is provided for each logic train. The source range trip is automatically reinstated, as required by IEEE 279 1971, if the power level as indicated by both intermediate range channels decreases below the P-6 setpoint.

The source range high voltage and trip functions may also be manually reactivated if required. This is accomplished by operation of two control board-mounted, momentary contact switches. This provision however, is only operable below permissive P-10 (10% reactor power), which is generated by the power range channels. Above P-10, the capability to reinstate the source range is automatically blocked. A one-of-two logic from the intermediate range channels supplies a rod withdrawal rod stop and control board annunciation. Blocking of the rod withdrawal stop is manually performed when nuclear power is above permissive P-10.

The intermediate range reactor trip is provided to limit a reactivity excursion when operating in the intermediate range during a reactor startup. Redundant control board switches are used to block the rod stops and the reactor trip on high current equivalent power. These blocks are manually inserted when the power range instrumentation indicates proper operation through activation of the P-10 permissive. Like the source range instrumentation when power decreases, the intermediate range trip functions are automatically reinstated. High voltage failure monitors provide both local and remote annunciation upon failure of the respective high voltage supplies. A common INTERMEDIATE RANGE LOSS OF DETECTOR VOLTAGE and separate INTERMEDIATE RANGE LOSS OF COMPENSATING VOLTAGE control board annunciators are provided.

Testing of each intermediate range channel is provided by a test-calibrate module which injects a test signal at the input to the log amplifier. The signal is controlled by the OPERATION SELECTOR switch on the front of each intermediate range drawer.

As in source range testing, the OPERATION SELECTOR switch on the intermediate range must be operated in coincidence with a LEVEL TRIP BYPASS switch. An electrical interlock between these switches prevents the interjection of a test signal unless the LEVEL TRIP BYPASS is in operation. Removal of the trip bypass also removes the test signal. The test signals, like the source range test signals, are superimposed upon the detector output signal.

Each intermediate range channel supplies signals to the following instrumentation.

- Remote level meter (NI-35B and NI-36B) - The remote meters are driven by isolation amplifiers. The meters are mounted on the main control board and calibrated logarithmically from 11^{-11} to 10^{-3} amperes.

- Remoter recorder (NR-45) - This is the same 2-pen recorder described for the source range. A level signal from the isolation amplifier is supplied to the recorder.

The intermediate range channel instrument drawer is shown on Figure 9.1-7. The instrument drawer, switches and indications are discussed individually below:

Neutron Level Meter - Indicates the current level output of the compensated ion chamber. Meter indication is in amperes ranging over eight decades between 10^{-11} and 10^{-3}.

Instrument Power On Lamp - Indicates that 118 Volts ac instrument power is applied to drawer instrument power supplies.

Control Power On Lamp - Indicates that 118 Volts ac control power is applied to drawer control signal circuits.

Channel On Test Lamp - Indicates that a test signal has been applied to the drawer through the operation of the OPERATION SELECTOR switch.

Level Trip Bypass Lamp - Lights when LEVEL TRIP switch is placed in the BYPASS position to perform test and calibration functions.

High Level Trip Lamp - Lights when the neutron flux level signal in the intermediate range channel reaches a current equivalent to 25% power.

High Level Rod Stop Lamp - Lights when the neutron flux level in the intermediate range channel reaches a current equivalent to 20% power.

Power Above Permissive P-6 Lamp - Lights when the current level reaches 10^{-10} amps increasing.

Bistable Trip (Spare) Lamp - A spare indication lamp designed manufactured into the cabinet for possible use in the future.

Loss of Detector Voltage Lamp - Indicates a loss of or reduced high voltage supplied to the compensated ion chamber.

Loss of Compensating Voltage Lamp - Indicates a loss of, or a reduced voltage, supplied to the compensating circuit of the compensated ion chambers.

AC instrument and control power fuses - Provide overcurrent protection for drawer circuitry.

Level Trip Switch - Enables test and calibration of the intermediate range channel in conjunction with OPERATION SELECTOR switch and TEST MODE switch. In the BYPASS position the LEVEL TRIP BYPASS indicator lights, the test/calibrate module is energized, and a signal is provided to the reactor protection system to prevent a reactor trip during testing (see bistable detail on Figure 9.1-4). In the bypass position, the IR Rod Stop C-1 is also defeated.

Operation Selector Switch - A ten-position switch which applies test signals from the test calibrate module to the intermediate range channel circuits.

Test Mode Switch - A two-position switch (FIXED/VARIABLE). In the FIXED position, it allows the test/calibrate module to provide a fixed current level selected by the OPERATION SELECTOR switch. In the VARIABLE position a potentiometer is switched into the test calibrate module circuitry to provide current variations about the selected level.

Variable Potentiometer - Varies current output from the test/calibrate module above or below the current level selected by the OPERATION SELECTOR switch. Control is activated only when the TEST MODE switch is in the VARIABLE position.

9.1.3.3 Power Range Channel

As shown in Figures 9.1-3 and 9.1-5, four, dual section, uncompensated ionization chambers (N-41A and N-41B through N-44A and N-44B) are used for power range neutron flux leakage detection. Each channel provides two current signals corresponding to the neutron flux in the upper (A) and lower (B) sections of a core quadrant. Each detector has a total neutron sensitive length of ten feet. A description of an uncompensated ionization chamber is provided in Section 9.1.4.

The four power range channels are energized from separate vital ac instrument power supplies and are housed in separate racks so that a single failure will not cause a loss of protective functions. Each power range channel drawer B converts the vital ac instrument power into a regulated low (±25 volts dc) and a high (+300 to +1500 volts dc) voltage source. The high voltage power supply has a current limiting feature so that for extreme current demands by the detector (such as an over-power condition), the power supply is maintained at a constant current output. This feature maintains an output from the detector (prevents the detector from becoming saturated and its indication failing off-scale low) and assures an output for proper reactor protection actions.

The individual current signals, one from each of the two sections of the detector, are proportional to upper and lower core neutron flux levels. These signals are received at the channel input and pass through separate ammeter shunt assemblies. The meter range switch selects shunt resistors for the meter, but never interrupts the ion chamber signal to the power range channel. The circuit is designed so that a failure of the meter or its associated switch will not interrupt the signal to the power range circuitry. Individual detector currents are displayed on two drawer-mounted meters. Isolation amplifiers in the detector current circuit supply signals to the overpower and overtemperature ΔT protection circuitry in the reactor protection system.

The isolation amplifiers also provide an output for the remote recorders (NR-41, NR-42, NR-43, or NR-44), the remote meters (NI-41C, NI-42C, NI-43C, or NI-44C), the computer, and the axial and radial flux deviation circuitry. The individual detector current signals (top and bottom) are sent to a summing and level amplifier which produces a linear signal proportional to the neutron flux in the core quadrant associated with that channel.

The output signal from the summing and level amplifier (calibrated to a thermal power value as calculated by a secondary heat balance) corresponds to 0 to 120 percent of full power, and is displayed on a power meter on the power range drawer. This same signal is delivered directly to the remainder of the power range circuitry for control, protection, and indication.

The rate circuit associated with each power range channel calculates the rate-of-change of nuclear power and a reactor trip signal is generated on either a high positive or a high negative rate. A high positive rate is indicative of an ejected rod, while a high negative rate indicates one or more dropped full length rods. The rate unit compares actual power with a delayed power signal received through a lag network and amplifies the difference between the two signals. This amplified difference signal is simultaneously delivered to two bistables set to trip when the difference signal exceeds a preset amount. Both of these bistables if actuated, seal in ensuring that the necessary protective action is initiated and carried to completion even though the rate-of-change signal is only momentary.

A switch on the power range drawer (RESET-NORMAL) must be manually operated to remove the seal in function and reset the bistable. This action also removes the trip signal from the RPS trip logic matrix. The rate trips cannot be blocked and are always active. The setpoints are chosen so that normal design transients do not actuate either of the rate trips.

Other bistables which receive the power level signal from the summing and level amplifier are non-seal in and perform the following functions:

- Overpower rod stop C-2 (blocks automatic and manual rod withdrawal)
- Permissive function P-8 (single loop loss of flow permissive)
- Permissive function P-9 (turbine trip - reactor trip permissive)
- Permissive function P-10 (nuclear at power permissive)
- Power range trip, low setpoint (25%).
- Power range, high setpoint (109%).

The overpower rod stop (C-2) is a non-protective function that actuates at 103% nuclear power to stop control rod withdrawal. This action may prevent the high range reactor trip from occurring at 109% nuclear power. Logic for the rod stop is one out-of-four channels (1/4). Individual channel rod stops may be manually defeated to allow testing or continued operation with a failed channel.

The nuclear at power permissive (P-10) employs a 2/4 logic at 10% nuclear power. When this permissive is actuated, the operator is permitted to manually block both the Power Range Low Setpoint Trip (25% power), the Intermediate Range Hi Flux Trip (also at 25%), and the Intermediate Range Rod Stop (20%). The P-10 permissive prevents manual reinitiation of the high voltage power supply to the source range detectors. At high flux levels the source range detectors would be damaged if energized.

The turbine trip - reactor trip permissive (P-9) allows the unit to withstand a turbine trip below 50% power without a direct reactor trip. P-9 requires a 2/4 logic from the power range channels.

The single loop loss of flow permissive (P-8) is provided to allow loss of flow in one reactor coolant system loop (single reactor coolant pump trip) without a direct reactor trip when power is below 39%.

The power range high flux, low setpoint trip (25% increasing) provides startup reactivity excursion protection and can be manually blocked when power is above the nuclear at power permissive P-10.

The power range high flux, high setpoint trip (109%) limits reactor power due to reactivity addition events and limits the maximum power level to a value consistent with that assumed in the accident analysis section of the plant's FSAR. The trip cannot be blocked and remains active at all times to prevent an overpower condition. An additional bistable monitors the high voltage power supply to the detectors. If voltage drops to a preset level, a LOSS OF DETECTOR HIGH VOLTAGE alarm is actuated at the control panel.

A test-calibrate module provides a means of superimposing a test signal onto the detector output. The variable test signal can be directed to either detector A, or B, or to both detectors simultaneously. Since the test signal is additive, a channel in test cannot indicate less than actual detector output. This feature prevents a technician from inadvertently lowering the output of a detector, thereby changing the trip logic from a two-out-of-four to a two-out-of-three coincidence. The test signal is used to raise the output of the summing and level amplifier to check the setpoints of all the bistables associated with each channel and to calibrate the isolation amplifiers in the individual detector current circuitry.

Operation of the rate trip bistables is verified by changing the test signal rapidly (i.e. increasing or decreasing the potentiometers position). During such tests, only one channel at a time is checked. Bypassing the channel in test is not necessary (and physically cannot be done) since a 2/4 trip logic is used in the reactor protection system and the channel in test still responds to reactor power changes.

Each power range channel provides signals to the following:

- Remote recorder (NR-45) - Each power range supplies a 0 to 120 percent of full power signal to the selector switches for the two pen nuclear recorder NR-45. Any two nuclear instrument channels can be monitored continuously during power range operation. Also, any two of the four power range channels can be selected for recording axial flux difference (AFD) on NR-45.
- Remote meters (NI-41B through NI-44B) - These meters (located on the main control board) continuously display the power level signal from each channel on a linear scale calibrated from 0 - 120% of full power.
- Overpower recorder (NR-46 and NR-47) - A pair of two-pen recorders are used to monitor the individual nuclear power indications from the four power ranges. Each recorder provides continuous monitoring of two power range channels and has a full scale deflection time of 0.25 seconds. The recorders are capable of displaying overpower excursions up to 200 percent of full power.
- Ion chamber current recorders (NR-41 through NR-44) - Four two-pen recorders are provided on the control board to record the calibrated upper and lower ion chamber currents. Comparison of the traces provides quadrant power distribution indication.
- Remote delta flux meters (NI-41C through NI-44C) - Four control board mounted meters display the flux difference between the upper and lower ion chambers for each of the power range detectors. The indication is calibrated to conform with the axial offset as determined by incore flux measurements. The scale of this meter is ± 30 percent.

The power range channel instrument drawers are shown in Figures 9.1-8 and 9.1-9. The instrument drawer switches and indications are discussed individually below:

Power Range Drawer A

- Percent full power meter - output of the summing and level amplifier. Meter indication is 0 - 120 percent.
- Control Power Fuses - Protect control power line against current overloads.
- Control Power On Lamp - Indicates 118 Volts

ac control power is applied to drawer assembly control circuits.

- Loss of Detector Voltage Lamp - Indicates a loss of or reduced high voltage supplied to the uncompensated ion chamber.
- Overpower Trip High Range Lamp - Indicates that reactor power has reached the high flux, high setpoint of 109% of full power.
- Overpower Rod Stop Lamp - Indicates that reactor power has reached the overpower rod stop setpoint of 103% (control grade interlock C-2).
- Reactor Trip Low Range Lamp - Indicates that reactor power has reached the high flux, low setpoint of 25%.
- Power Above Permissive P-10 Lamp - Indicates that reactor power has reached 10% allowing operator action to block the intermediate range trip and rod stop, and the power range high flux, low setpoint (25%) trip.
- Power Above Permissive P-8 Lamp - Indicates that reactor power has reached 39% which enables the single loop loss-of-flow trip.
- Positive Rate Trip Lamp - Indicates, that a rapid increase in power has been sensed indicating an ejected control rod. Setpoint is + 5% change in 2 seconds.
- Negative Rate Trip Lamp - Indicates that a rapid decrease in power has been sensed indicating one or more dropped control rods. Setpoint is - 5% change in 2 seconds.
- Rate Mode Switch - A switch that resets the positive and negative rate trip bistables.

Power Range Drawer B

- Detector Current Meter (A) - Indicates the current level output of the upper uncompensated ion chamber section (detector A) of the power range channel. Meter indication is current level ranging between 0 to 5 milliamperes.
- Detector Current Meter (B) - Indicates the current level output of the lower uncompensated section (detector B) of the power range channel. Meter indication is current level ranging between 0 to 5 milliamperes.
- Detector A and B Range Milliamperes Switches - Four-position range switches which select the correct shunt resistor for the detector current meters. The meters display the detector A and B current including test current level. Selectable ranges are 0.1, 0.5, 1 and 5 milliamperes full scale.
- Detector A Test Signal Potentiometer - Varies the test current level to the power range channel circuit through the detector current meter for the detector A source. Current is inserted only when the DETECTOR A or DETECTOR A & B position is selected by the OPERATION SELECTOR switch.
- Detector B Test Signal Potentiometer - Varies the test current level to the power range channel circuit through the DETECTOR CURRENT meter for the detector B source. Current is inserted only when the DETECTOR B or DETECTOR A & B position is selected by the OPERATION SELECTOR switch.
- Operation Selector Switch - A four-position switch which enables the test circuitry of the power range channel. In the DET A or DET B position, the DETECTOR A or B TEST SIGNAL potentiometer output is connected in parallel with the associated detector. In the DET A & B position, both potentiometers are connected simultaneously.
- Gain Potentiometer - Adjusts gain of summing and level amplifier to calibrate the power range channel to the power output as determined by secondary plant heat balance (calorimetric) measurements.
- Instrument Power Fuses - Protect instrument power line against current overloads.
- Instrument Power On Lamp - Indicates 118

Volts ac instrument power is applied to drawer assembly power supplies.

- Channel on Test Lamp - Indicates a test signal position has been selected through the operation of the OPERATION SELECTOR switch.

9.1.3.4 Audio Count Rate

The audio count rate circuit (shown on Figure 9.1-4) provides an audible signal, in the control room and in containment, which is proportional to the neutron flux level in the core when the reactor power is in the source range. The purpose of the system is to alert plant personnel to reactivity changes which might affect shutdown margin and radiation levels inside containment.

The audio count rate channel assembly (Figure 9.1-10) receives pulses from either source range channel. The pulses are transmitted through a selector switch to the scaler-timer chassis. The scaler-timer (Figure 9.1-11) provides binary coded decimal (BCD) signal output in accordance with the counting rate of the input signal.

The resultant digital data is decoded and used to trigger an oscillator, subsequently producing an audible tone burst at a repetition rate proportional to the source range count rate. Switch selection of appropriate BCD output, divides the input count rate by factors of ten, one hundred, one thousand, or ten thousand to maintain a discrete audible signal. A speaker mounted on the drawer assembly and one mounted near the reactor (in containment) provides audible monitoring of reactor power level during shutdown conditions. Therefore, if the count rate increases, the rate at which the audible tone burst occurs also increases. The local and remote speakers receive their signals from separate audio amplifiers. A selector switch on the rear panel of the drawer assembly provides the means of powering the remote speaker from either amplifier in the event of an amplifier failure.

A. Audio Count Rate Circuit

Sources of Signals - The signals come from either source range channels N-31 or N-32.

- Scaler-Timer - The scaler-timer receives signal pulses from the discriminator output of the selected source range channel. The pulses are counted through decimal counters and then read out to the audio count rate channel drawer assembly in the form of BCD logic. The scaler-timer can also be used as a means of accurate counting to obtain plateau values for the source range detectors at low count rates. The scaler-timer also provides accurate measurement of the source range counts for calculating the inverse count rate ratios.
- Audio-Multiplier - A range switch which controls the division of the pulses received from the selected source range channel to obtain a suitable listening rate.
- Speakers - The local speaker at the nuclear instrumentation system rack and a remote speaker near the reactor (in containment) produce audible pulses for monitoring the neutron flux count rate.

B. Audio Count Rate Drawer - Figure 9.1-10

- Audio Power On Lamp - Indicates 118 Volt ac power is applied to the drawer assembly.
- Scaler Power On Lamp - Indicates 118 Volt ac power is applied to the scaler-timer assembly.
- AC Audio Channel Power Fuses - Protect input circuit transformer against primary power current overloads, and isolates audio channel faults from the scaler-timer circuitry.
- AC Timer Scaler Power Fuses - Protect scaler-timer against primary power current overloads.
- Channel Selector Switch - Selects source range channel N31 or source range channel

N32 input signals for the input to the scaler-timer for audio monitoring.

- Volume Potentiometer - Controls the audio level output from the local loudspeaker.
- Audio Multiplier Switch - Selects the division of the audible count rate to produce a discernible rate. Division is accomplished in 4 steps; by 10, 100, 1000, and 10,000.
- Amplifier Selector Switch - Selects an amplifier circuit in the drawer assembly to drive the local and remote loud speakers. In the NORMAL position, amplifier A1 is used for the local speaker and amplifier A2 is used for the remote speaker. In the A1 position, amplifier A1 is used only to drive the remote speaker; in the A2 position, amplifier A2 is used only to drive the remote speaker. In the A1 only and A2 only positions, the local speaker is inactive.

9.1.3.5 Rate Calculating Circuit

The startup rate circuits in the comparator and rate drawer assembly receive signals from each source range channel and each intermediate range channel. The rate unit computes the rate-of-change of neutron flux (startup rate) for each input channel. The rate circuit assemblies within the comparator and rate drawer derive an output proportional to the rate at which the power-level signal is changing; an independent rate output is computed for each channel. Each rate output signal can be selected for display on a common panel meter and is supplied to its dedicated main control board meter.

A. Rate Calculating Circuit - Figure 9.1-4

Source of Signals - The signals for computing startup rate (SUR) come from four sources; NC-31 or NC-32 (source range channels) or NC-35 or NC-36 (intermediate range channels).

- SUR Amplifier - The startup rate amplifiers receive signals from the source range and intermediate range drawers. The startup rate amplifier produces a signal directly proportional to the rate-of-change of the input.
- Indication - There is one local meter for SUR information plus 4 SUR meters on the main control board. The SUR meters read between -0.5 dpm and 5.0 dpm.

B. Comparator and Rate Drawer - Figure 9.1-12

- Startup Rate Meter - Indicates the rate-of-change of neutron level from a selected source or intermediate range channel. Meter indication is in decades per minute (DPM) over a range of -.5 to 5.
- Instrument Power On Lamp - Indicates 118 Volts ac control power is applied to drawer assembly instrumentation.
- Control Power On Lamp - Indicates 118 Volts ac control power is applied to drawer assembly control signal circuits.
- Rate Channel Test Lamp - Lights when RATE TEST switch is placed in the 1 DPM or 5 DPM position to perform test and calibration functions.
- Channel Selector Switch - Selects either source range channel or either intermediate range channel.
- Rate Test Switch - Enables generation of rate test signals for calibration of the source range and intermediate range channel rate amplifiers.

9.1.3.6 Power Range Channel Current Comparator

The comparator circuit compares the power indications from the four power range channels and generates a signal proportional to the percent of full power deviation between channels. The purpose of this alarm is to alert the operator to a possible miscalibration between power range instruments. A bistable is tripped at a deviation level of 2 percent to provide an alarm function.

A. Power Range Circuit - Figure 9.1-5

- Sources of Signals - Four power range level signals are generated by isolation amplifiers in power range channels NC-41 through NC-44.
- Comparator - These power range channel input signals are compared to monitor radial power distribution. If a deviation in indicated output power does occur between any two channels, the comparator develops an output proportional to the amount of deviation, which is then applied to a bistable.
- Bistable - If the deviation between the highest indicating and the lowest indicating power range channel is greater than 2 percent, the bistable is tripped. The comparator also can indicate a power range channel drift or failure. Using the COMPARATOR CHANNEL DEFEAT switch, any single channel output can be eliminated from comparison during a test or the failure of a channel.

B. Comparator and Rate Drawer - Figure 9.1-12

- Channel Deviation Lamp - Lights when the average power level of any two of the four power range channels deviate from each other by 2 percent.
- Comparator Defeat Lamp - Lights when the CHANNEL DEFEAT Switch is placed in one of the four power range positions in order to remove a power range channel from the comparator circuits.
- Comparator Channel Defeat Switch - Removes a power range channel which is faulty or in test so that the three remaining channels may be compared.
- AC Instrument Power Fuses - Protect instrument power line against current overloads.
- AC Control Power Fuses - Protect control power line against current overloads.

9.1.3.7 Power Range Detector Current Comparator

The power range detector current comparator monitors core radial power distribution by comparing the relative power of the 4 quadrants of the upper half of the core and by comparing the relative power of the 4 quadrants of the lower half of the core. The output of each upper detector is compared with the average of the upper detectors. If a ratio of 1.02 is calculated, an alarm DETECTOR FLUX DEVIATION is generated. This ratio is the technical specification limit for quadrant power tilt ratio. An identical calculation is performed for the lower detectors. This circuit provides an alarm function only. The technical specification limits are satisfied by performing a quadrant power tilt ratio calculation manually or through the use of the plant computer.

A. Circuit - Figure 9.1-5

- Calibrated signals from each upper detector and each lower detector of the four power range channels are sent to their respective averaging amplifiers via isolation amplifiers.
- Averaging Amplifier - The averaging circuits combine the inputs to generate an average of the upper detectors and an average of the lower detectors.

Comparator - The comparator circuit performs two functions:

- Compares each of the four calibrated detector inputs with the average, and
- Energizes an annunciator if any input is greater than the average by a ratio of 1.02. This alarm function is automatically defeated when all channels are below 50% of their full power output. This is indicated by a lamp on the drawer and by actuation of the "detector flux deviation" alarm on the main control board.

B. Detector Current Comparator (Upper Portion of Drawer) - Figure 9.1-13

- All (upper) Channels Below 50% of Full Power Lamp.
- Channel Defeat Lamp - Lights when UPPER SECTION defeat switch is placed in any position except the normal. This lamp indicates that one channel is not being compared with the others.
- Upper Section Deviation Lamp - Indicates that a radial power deviation has occurred in the upper half of the core.
- Instrument Power On Lamp - Indicates 118 volts AC power is applied to drawer instrumentation.
- Spare Lamp
- All (lower) Channels Below 50% of Full Power Lamp
- Channel Defeat Lamp - Lights when LOWER SECTION defeat switch is placed in any position except normal. This lamp indicates that one channel is not being compared with the others.
- Lower Section Deviation Lamp - Indicates that a radial power deviation has occurred in the lower half of the core.
- Upper Section Defeat Switch - A five position switch which removes a channel which is faulted or being tested from the upper detector comparator.
- Lower Section Defeat Switch - A five-position switch which removes a channel which is faulted or being tested from the lower detector comparator.
- AC Instrument Power Fuses - Protects drawer assembly power supply circuits.

9.1.3.8 Miscellaneous Control And Indication Drawer

As shown in Figure 9.1-13 the miscellaneous control and indication drawer contains switches to bypass channels from control circuitry during testing or failed channel conditions.

- Rod Stop Bypass - Automatic rod withdrawal is inhibited following an overpower rod stop condition. Positioning either ROD STOP BYPASS switch to the indicated channel bypass position removes the rod stop function for that channel.
- Power Mismatch Bypass - The four power range channel levels are normally transmitted to a high auctioneer circuit in the automatic reactor control programmer for comparison with turbine power for the rod drive system. Bypass switches allow up to two power range channels to be removed from the auctioneering circuit during testing or failed channel operation.

9.1.4 Neutron Detector Operation

Neutrons are uncharged particles and as such cannot cause ionizations directly. Neutrons must interact with matter by means of a nuclear reaction which in turn generates charged particles. The charged particles cause ionization within a gas-filled detector and the ion pairs produce a voltage pulse or some mean level current when collected at the electrodes of the detector. The nuclear reaction which produces these charged particles in the excore detector is as follows:

$$ {}_0^1n + {}_5^{10}B \rightarrow {}_5^{11}B \rightarrow {}_3^7Li + \alpha + energy $$

The charged particles resulting from this reaction are:

$$ \alpha^{++} \text{and} {}_3^7\text{Li}^{+++} $$

These charged particles produce ionizations as they pass through the gas-filled detectors.

9.1.4.1 Source Range Detector

The source range detector, Figure 9.1-14, is a BF_3 gas-filled detector. In this detector, the incident neutron generates the charged particles (Li and α) which are highly ionizing. Due to the voltage at which the detector is operated, additional ionizations called secondary ionizations are caused by the initial ionization. This produces a large pulse for each neutron event. Gamma radiation also produces ionization of the gas in the detector but at a lower amplitude. Gamma induced pulses are, therefore, of a lower amplitude than neutron induced pulses.

9.1.4.2 Intermediate Range Detector

The intermediate range detector (Figure 9.1-15) is a gas-filled, compensated ion chamber. This detector is actually two detectors in one case. One of the chambers is coated with boron enriched with B-10 and is, therefore, sensitive to neutrons and gammas. The second chamber is uncoated and is, sensitive only to gamma radiation. By connecting the two chambers so that their output currents are electrically opposed, the net electrical output from the detector will be an algebraic sum of the two ionization currents, which is equal to the neutron current only. Mathematically it could be written as:

$$(i_n + i_\gamma) = neutron + gamma\ current$$

$$i_\gamma = gamma\ current$$

$$i_{total} = (i_n + i_\gamma) - i_\gamma$$

$$i_{total} = i_n$$

Normally, compensated ion chambers are designed to operate slightly undercompensated (Figure 9.1-16).

9.1.4.3 Power Range Detector

The power range detector, Figure 9.1-17, is an uncompensated ion chamber. The detector consists of a single cylindrical chamber whose operation is identical to that of the boron-lined chamber of the compensated ion chamber. This chamber is sensitive to both gamma and neutrons; however, in the power range of operation the neutron flux level is many times greater than the gamma flux. Also, while operating in the power range, gamma flux is proportional to the reactor power. Therefore, no gamma compensation is required in the power range. The power range instruments are calibrated on the bases of a secondary heat balance to display percent of full thermal power.

The movable incore neutron flux detectors (incore detectors), in conjunction with the plant computer, INCORE Code, present a true representation of the actual neutron flux distribution within the reactor core. Meanwhile, the excore nuclear instruments (excore detectors) rely upon leakage neutrons to determine the flux distribution within the core. Due to the distance and shielding between the reactor core and the excore detectors, these detectors cannot provide a "true" representation of the flux distribution within the core. Since the excore detectors provide reactor protection signals and also provide the reactor operator with continuously monitored indication of power and flux distributions within the core, it is necessary to calibrate the excore detectors.

9.1.5 System Interrelationships

9.1.5.1 Calibration of the Excore Detectors

Each excore power range channel consists of two six-foot detectors (one upper detector and one lower detector). The upper detector, in theory, should monitor and provide an output that is representative of the power in the upper six feet of the core while the lower detector should provide an indication of the power in the lower half of the core. However, in reality this is not the case; neutrons leaking from the core do not necessarily leak from the core at 90 degree angles. Some of the leakage neutrons generated in the lower half of the core will be detected by the upper detector and conversely the lower detector will indicate neutrons that were produced in the upper half of the core. Since the core must be protected from departure from nucleate boiling (DNB) and excessive power generation in both the upper and lower halves of the core, it's essential that the inputs to the protective circuitry reflect the actual conditions in the core.

Providing the correct information to the reactor protection system is accomplished by calibrating the excore detectors to the conditions that exist within the core. This calibration procedure is called the Incore-Excore calibration. The core conditions and a synopsis of this calibration procedure can be found in Chapter 9.2 (Incore Nuclear Instrumentation) section 9.2.4.3.

9.1.6 Summary

The excore nuclear instrumentation system monitors reactor power from shutdown levels in the source range, through the intermediate range and to greater than 100 percent of full power in the power range. This is accomplished by means of thermal neutron flux detectors located in instrument wells in the primary shield adjacent to the reactor vessel. The system provides indication, control and alarm signals for reactor protection and operation. The location of the detectors at discrete axial and radial locations allows detection of core axial and radial power distribution. Power range channels are calibrated to indicate percent rated thermal power by a secondary heat balance (calorimetric). Excore power distribution circuitry is calibrated using information obtained from the movable incore instrumentation.

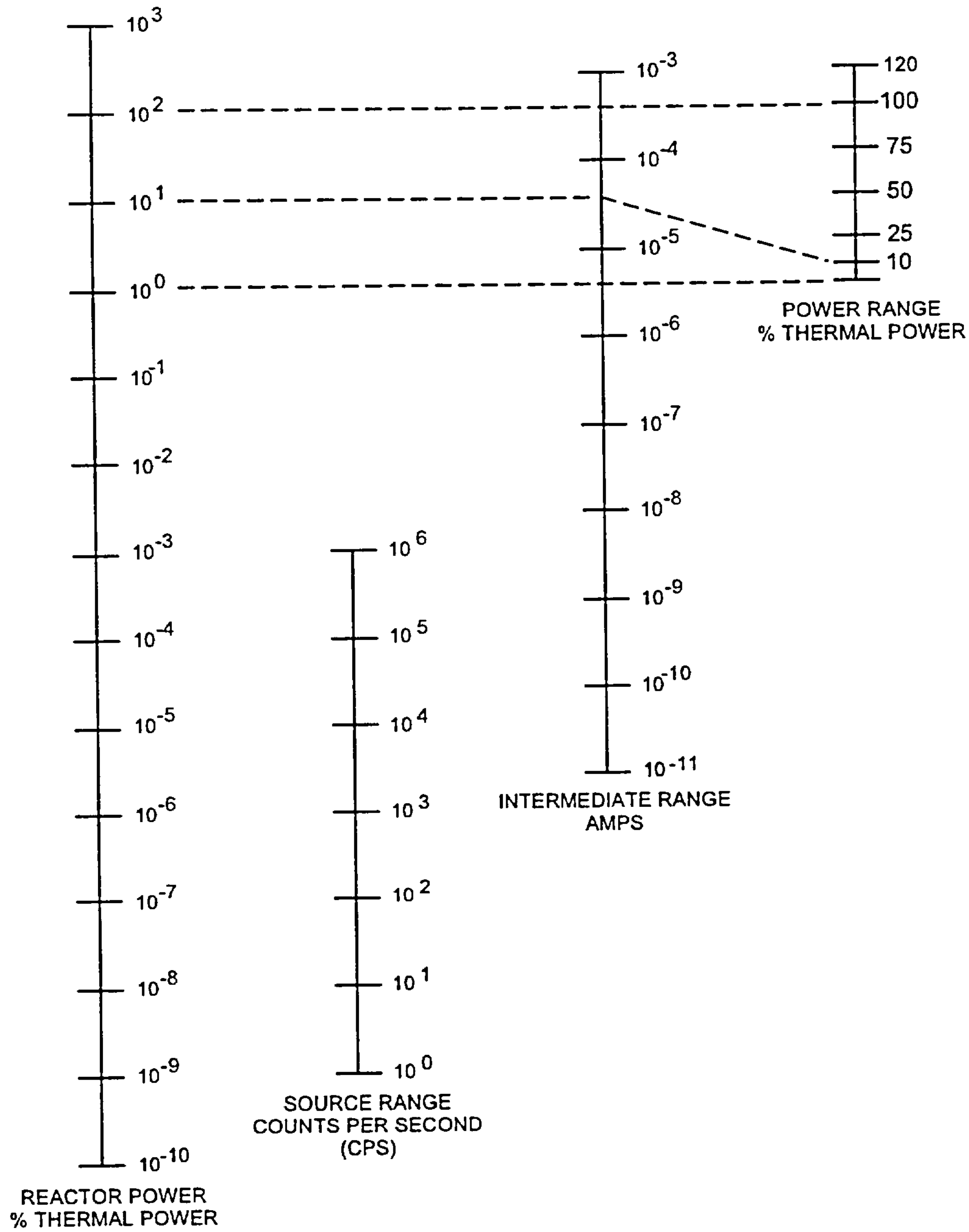


Figure 9.1-1 Neutron Detectors Range of Operation

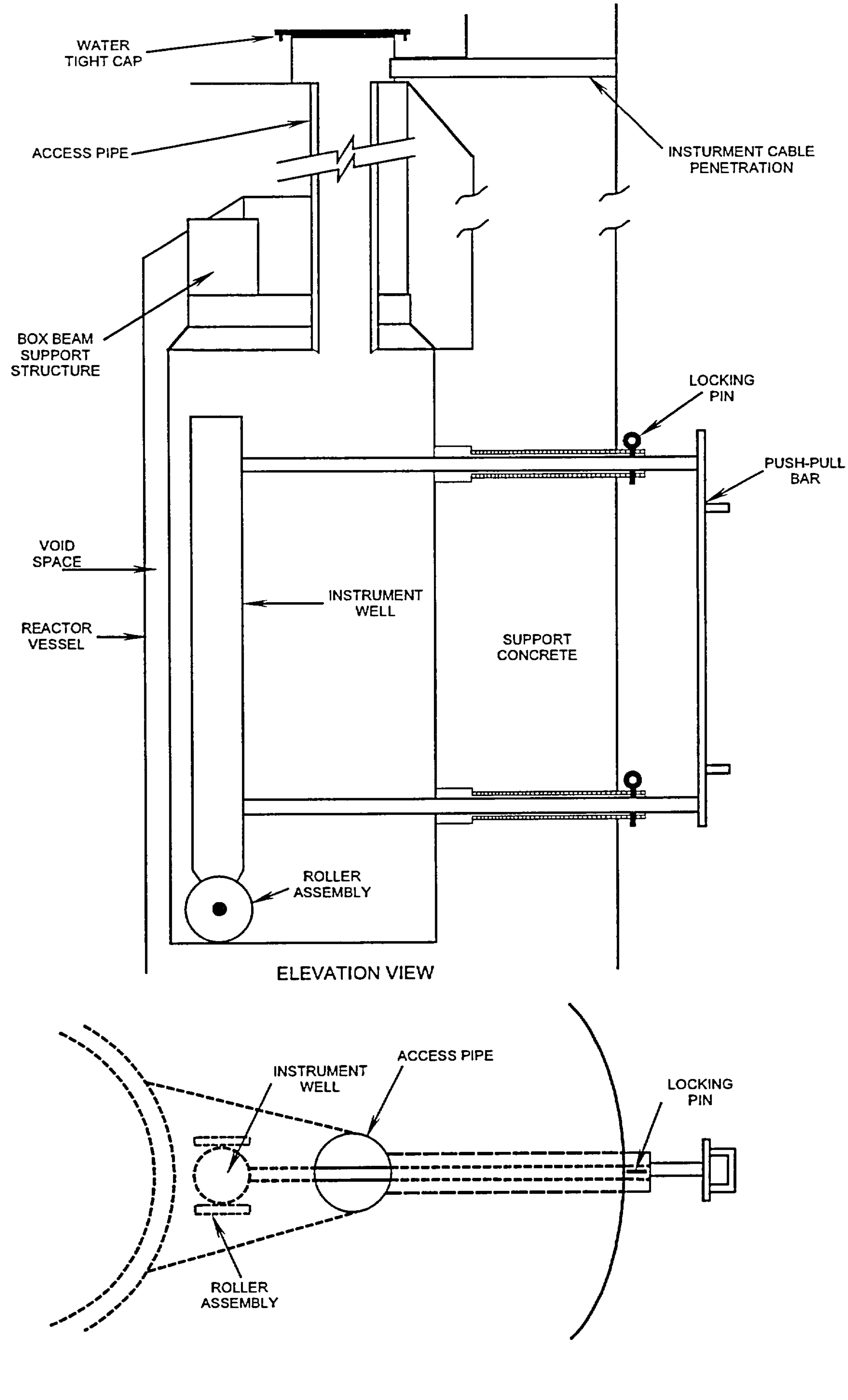
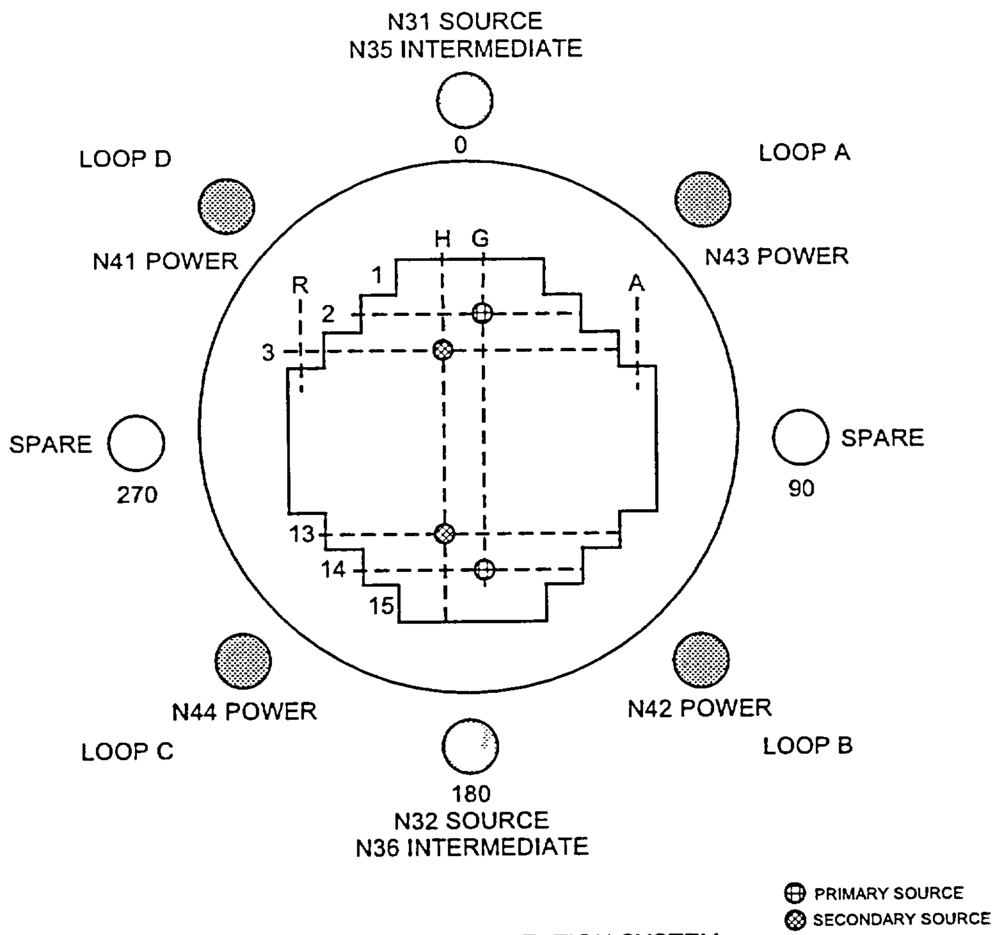
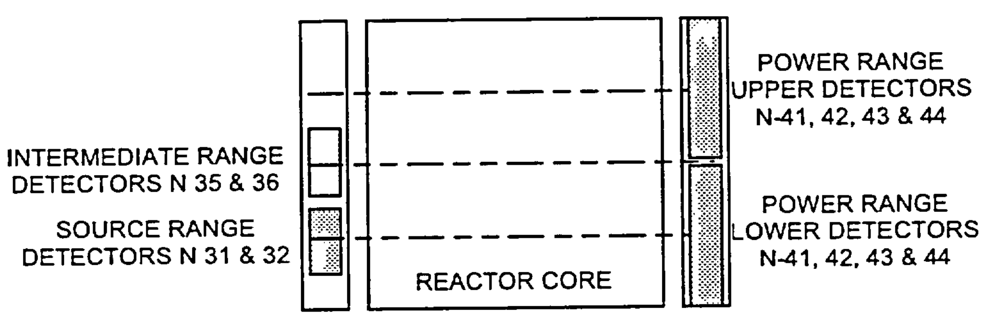


Figure 9.1-2 Detector Instrumentation Wells



NUCLEAR INSTRUMENTATION SYSTEM
DETECTOR POSITIONS



CROSS SECTION

Figure 9.1-3 Nuclear Instrument Detector Locations

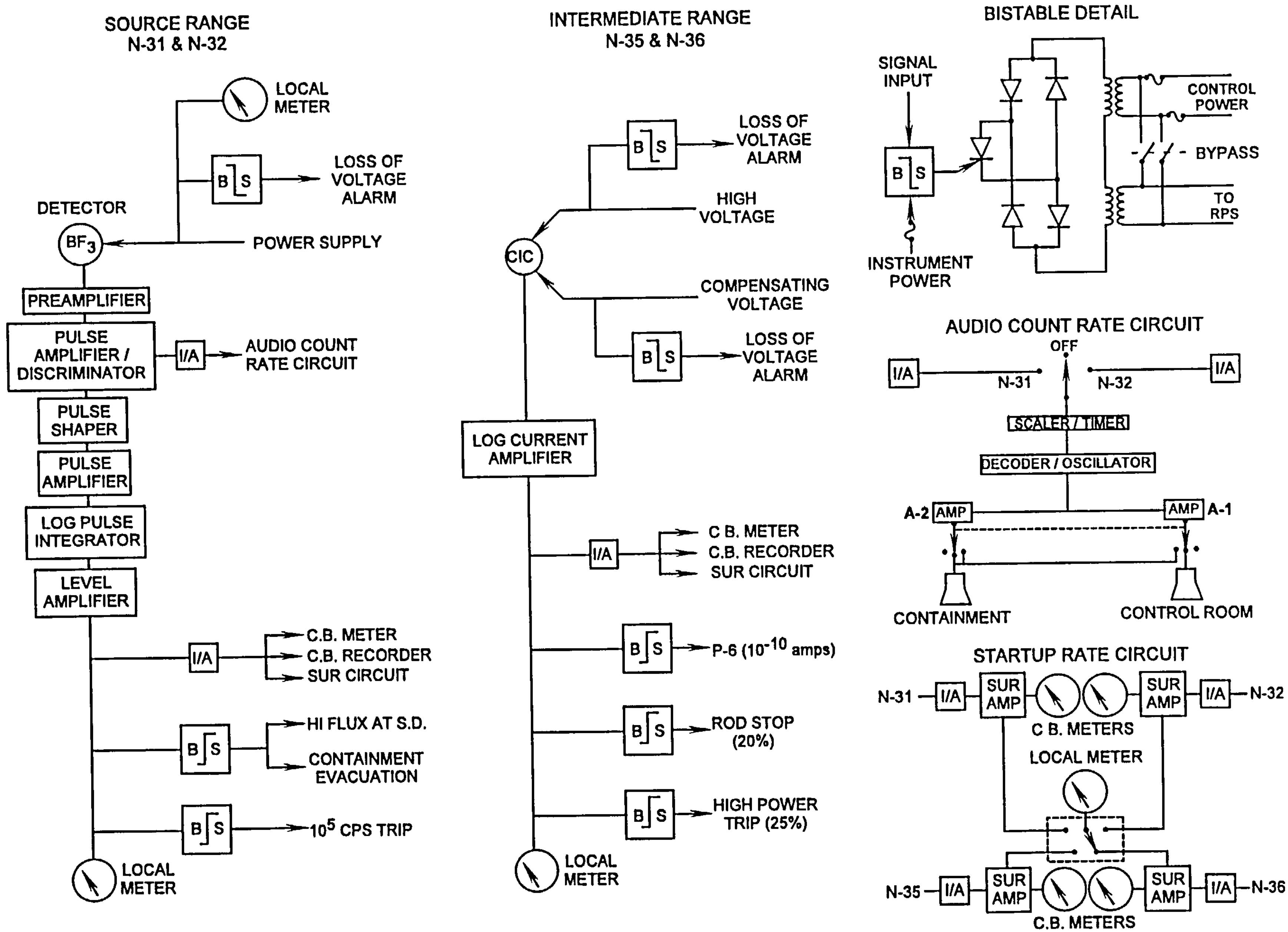


Figure 9.1-4 Source and Intermediate Range Block Diagrams

0600-3

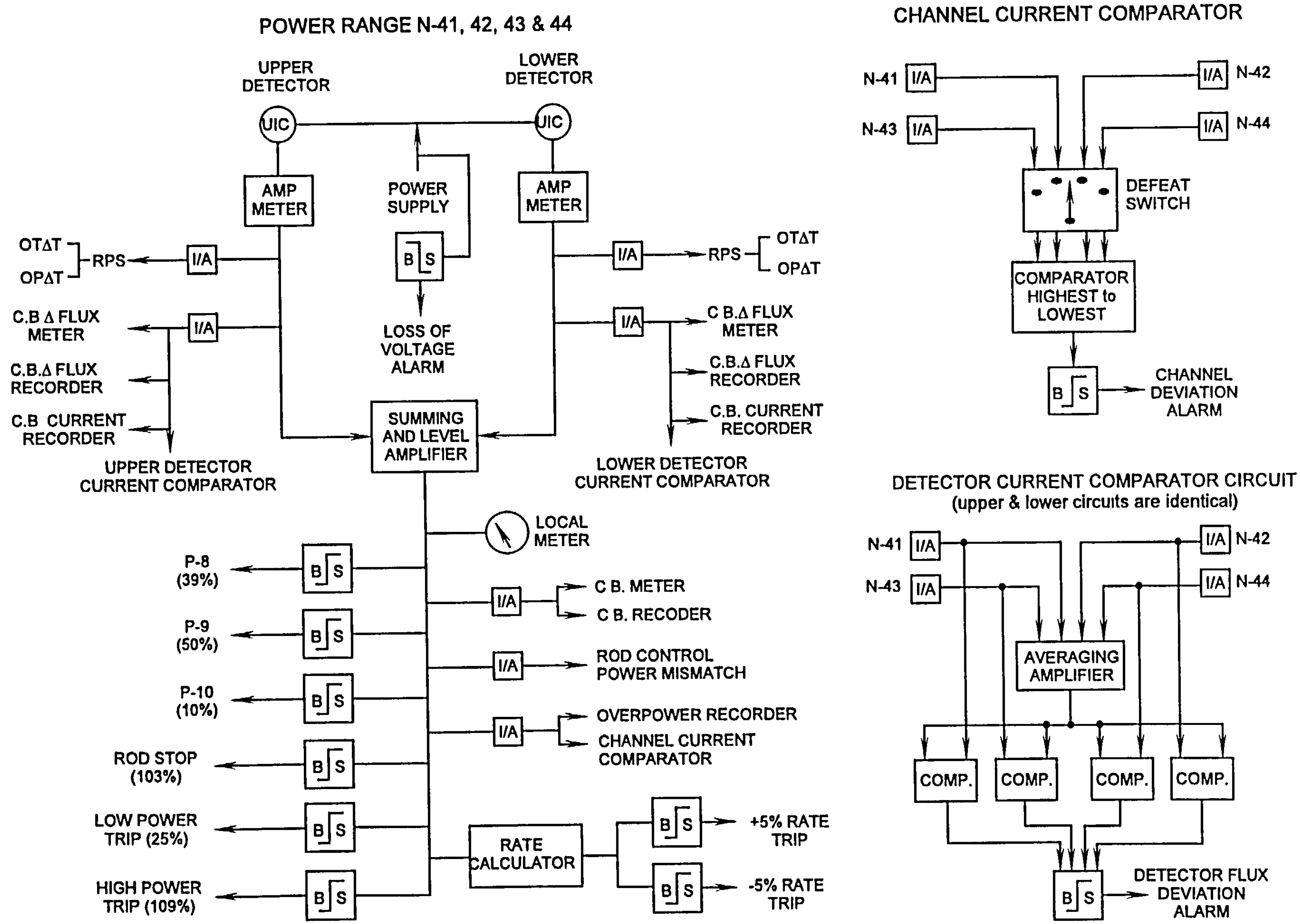


Figure 9.1-5 Power Range Channel Block Diagram

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9.1-5 2-11

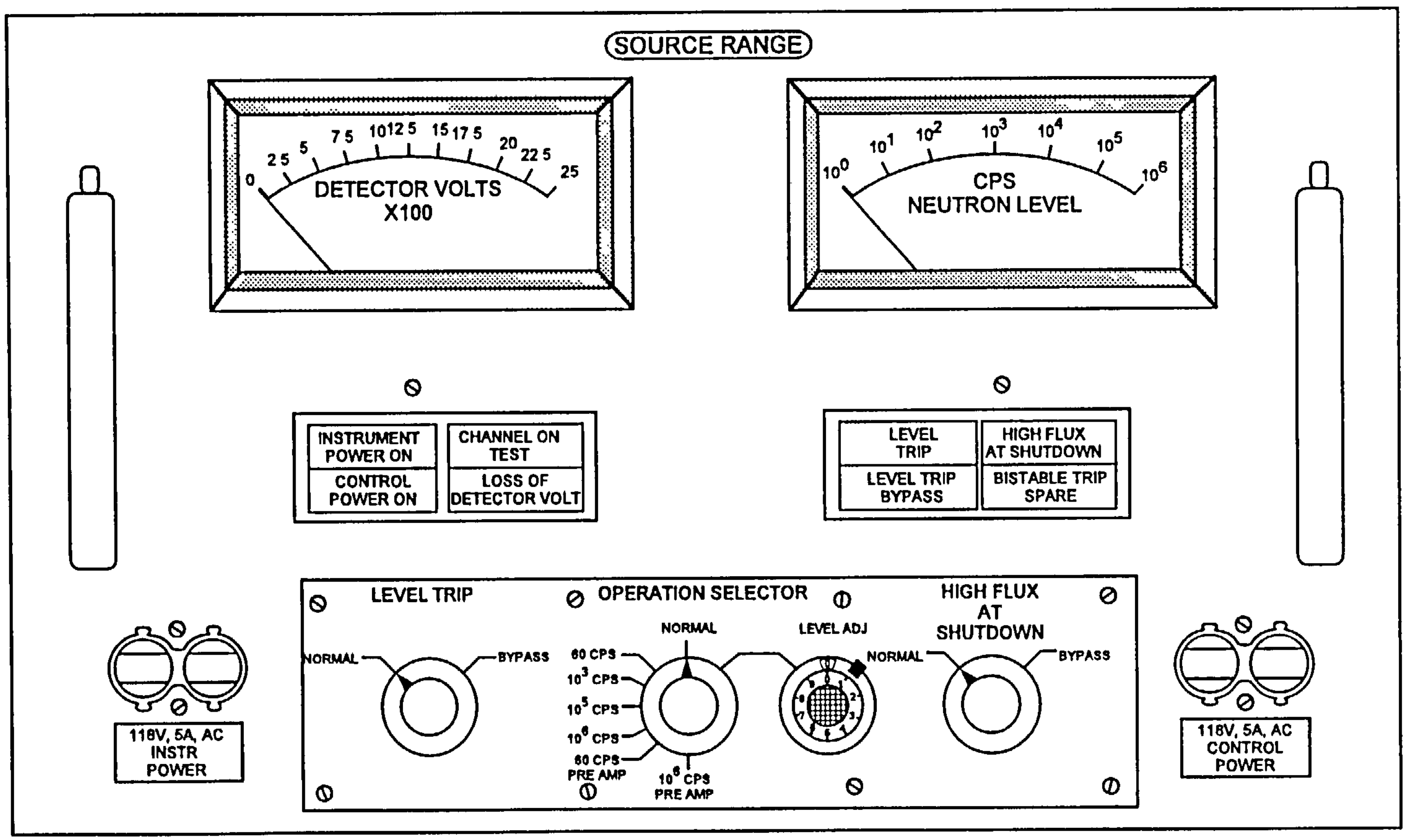

Figure 9.1-6 Source Range Drawer

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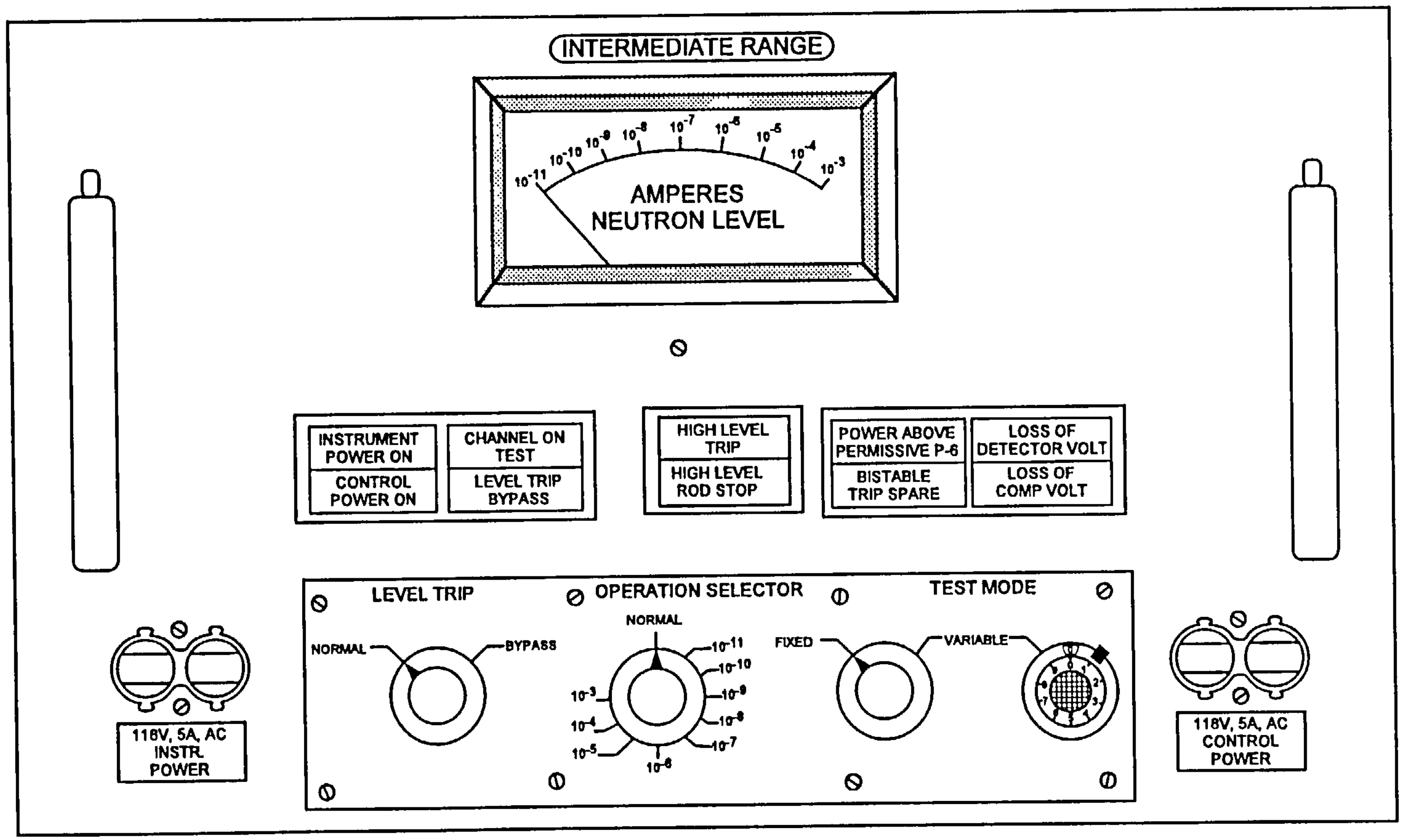

Figure 9.1-7 Intermediate Range Drawer

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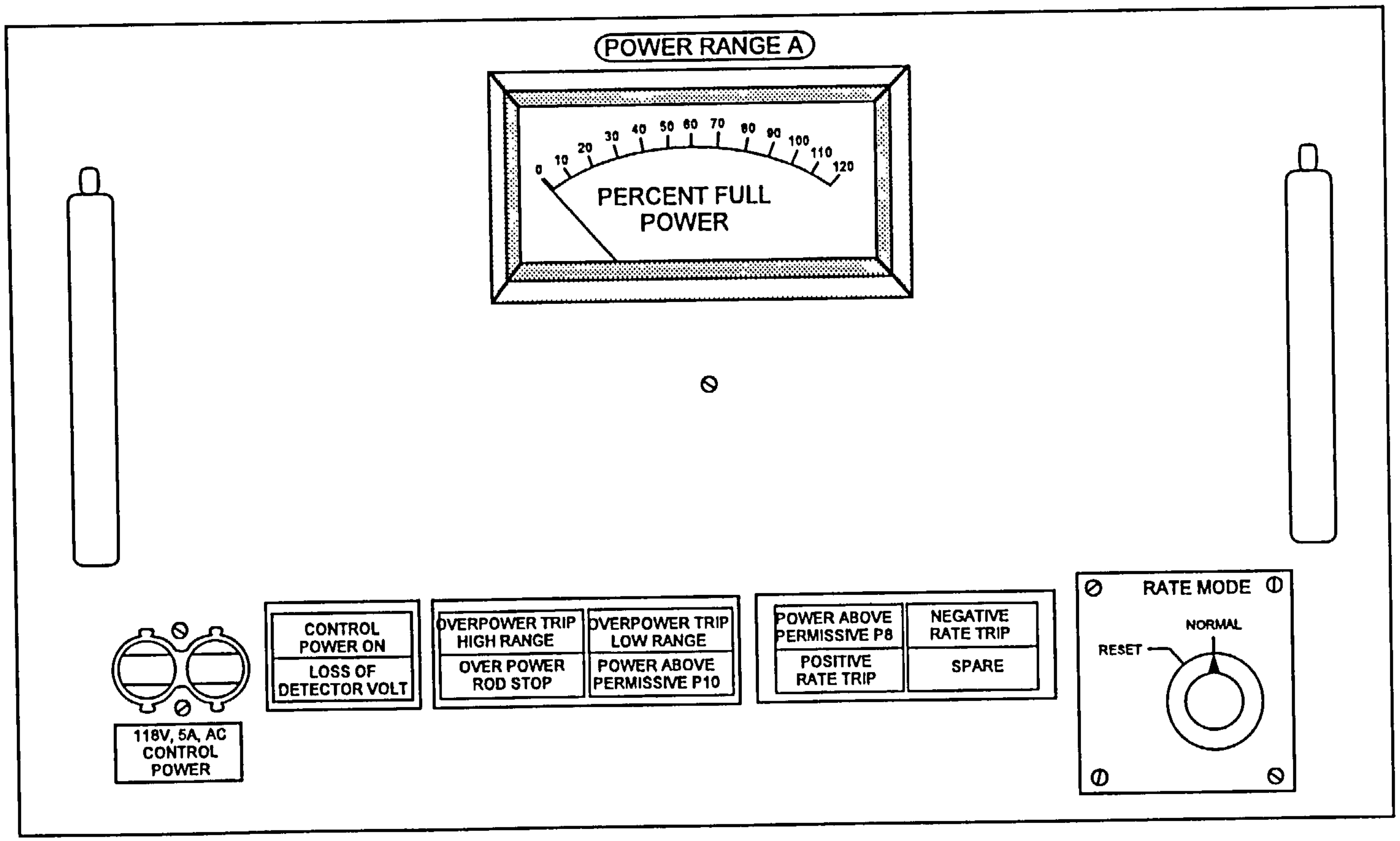

Figure 9.1-8 Power Range Drawer "A"

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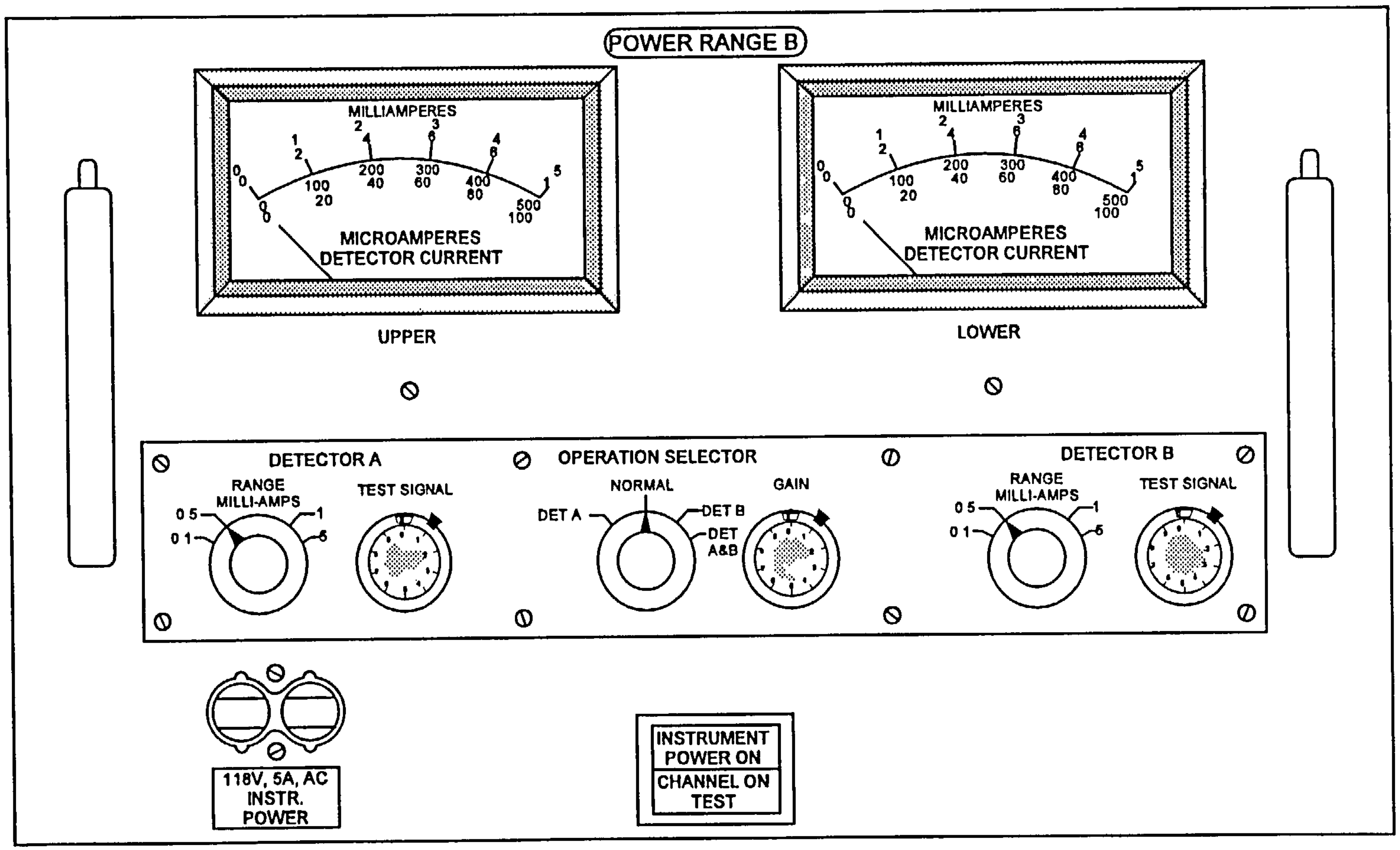

Figure 9.1-9 Power Range Drawer 'B'

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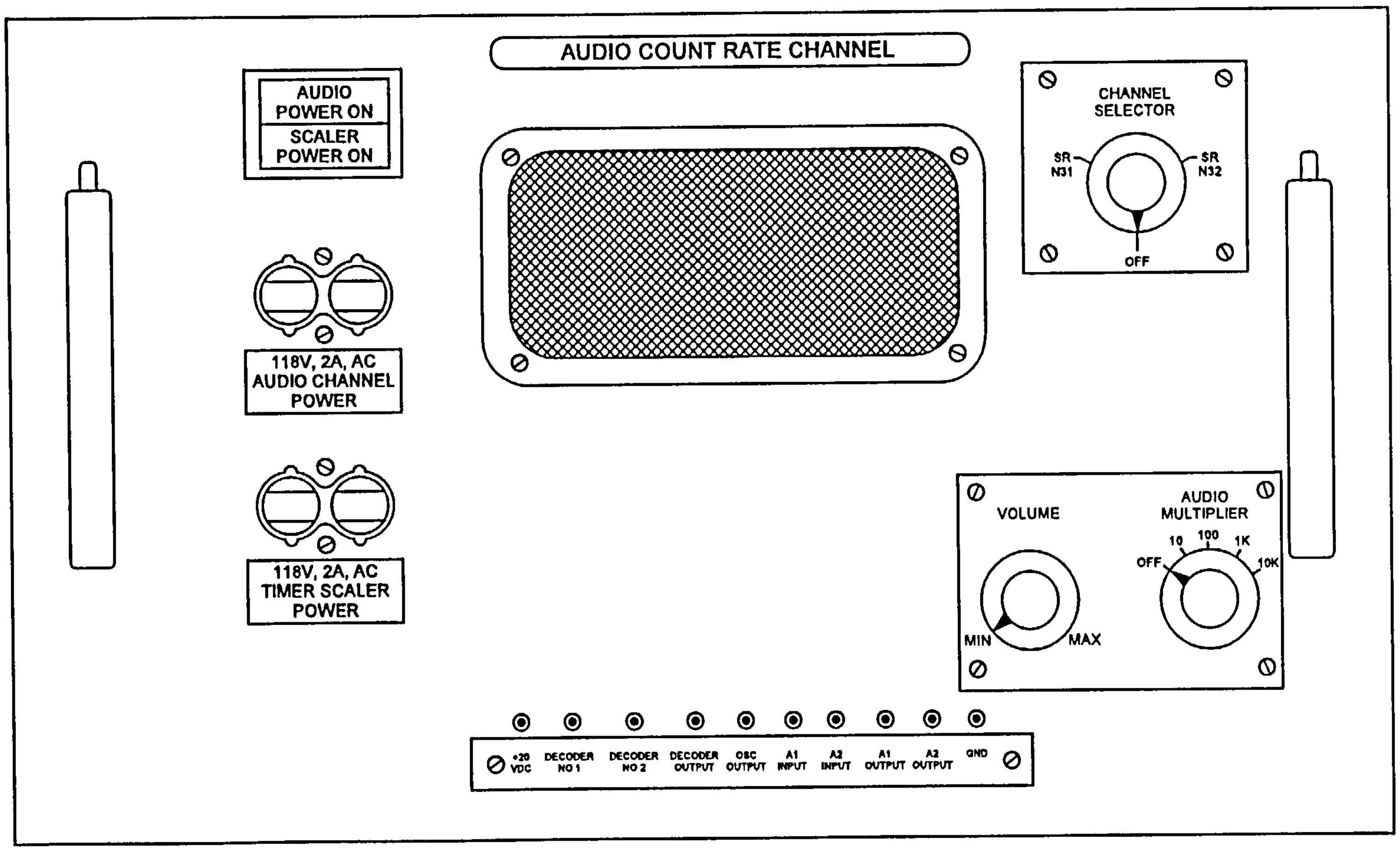

Figure 9.1-10 Audio Count Rate Channel

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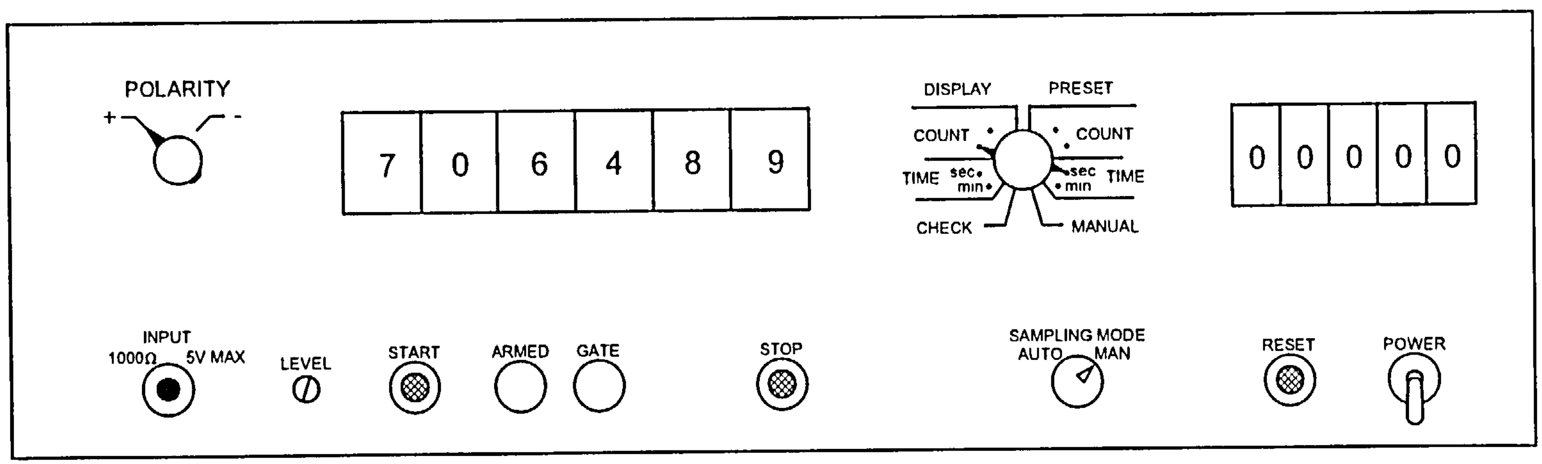

Figure 9.1-11 Scaler Timer Drawer

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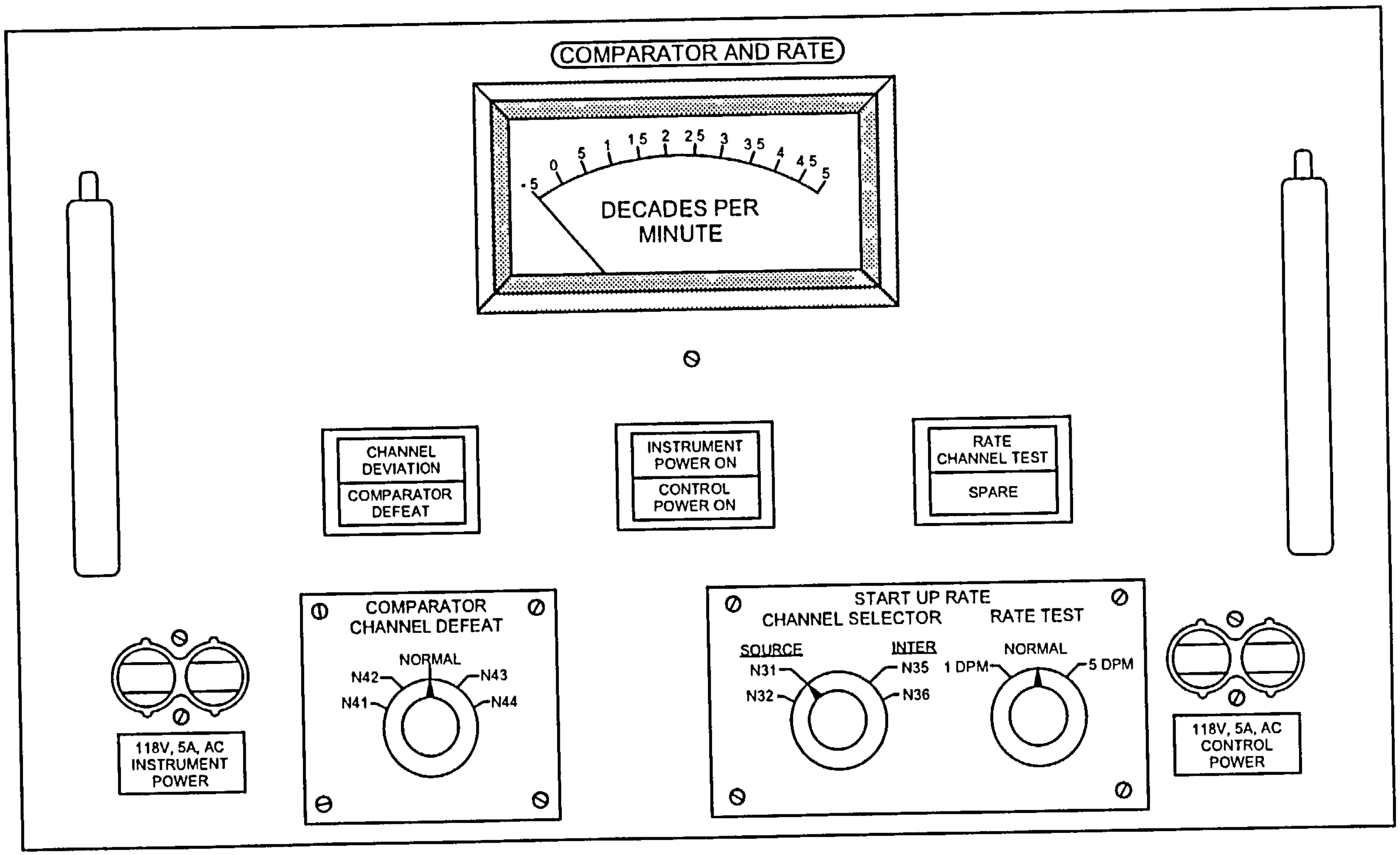

Figure 9.1-12 Comparator and Rate Drawer

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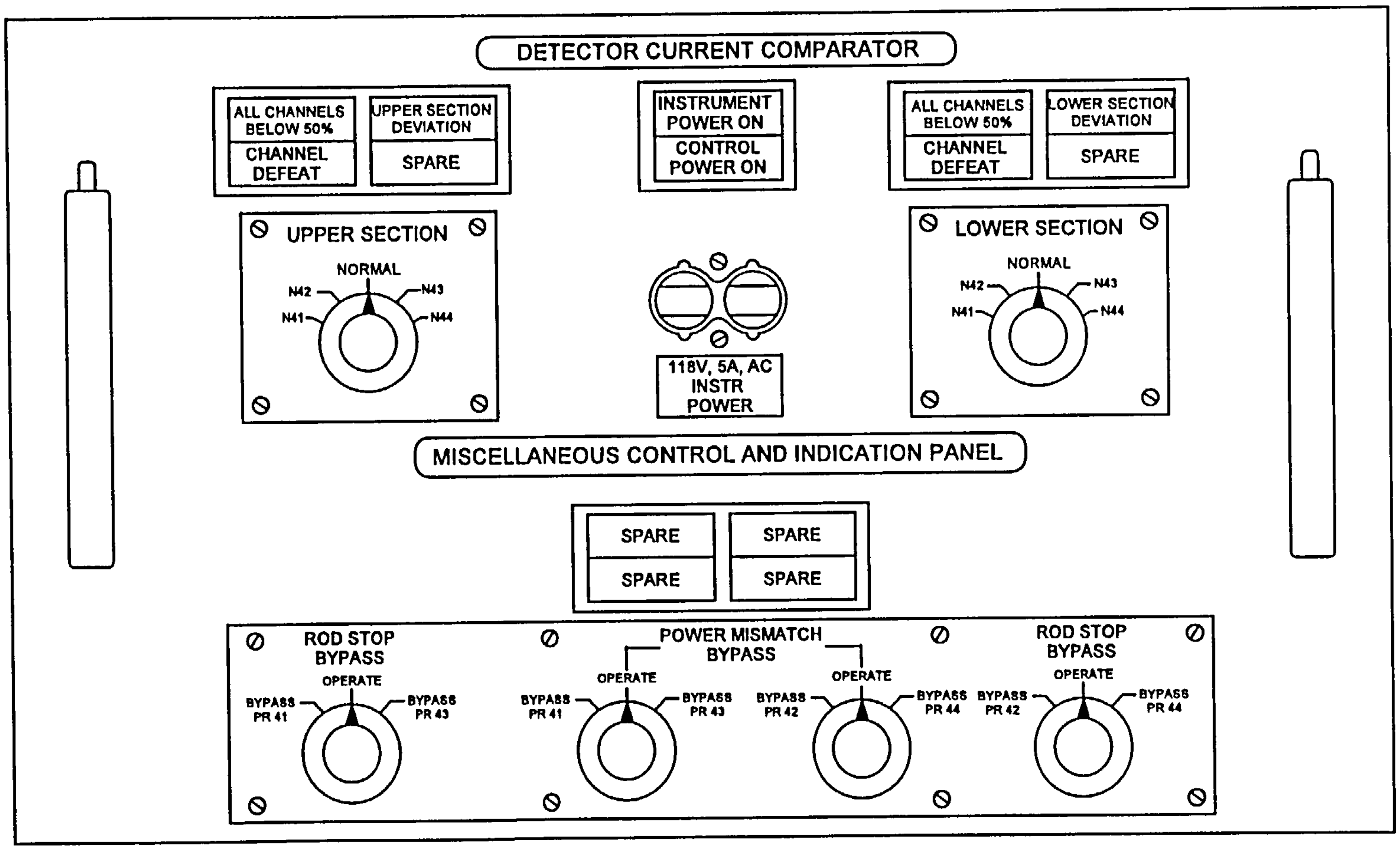

Figure 9.1-13 Detector Current Comparator

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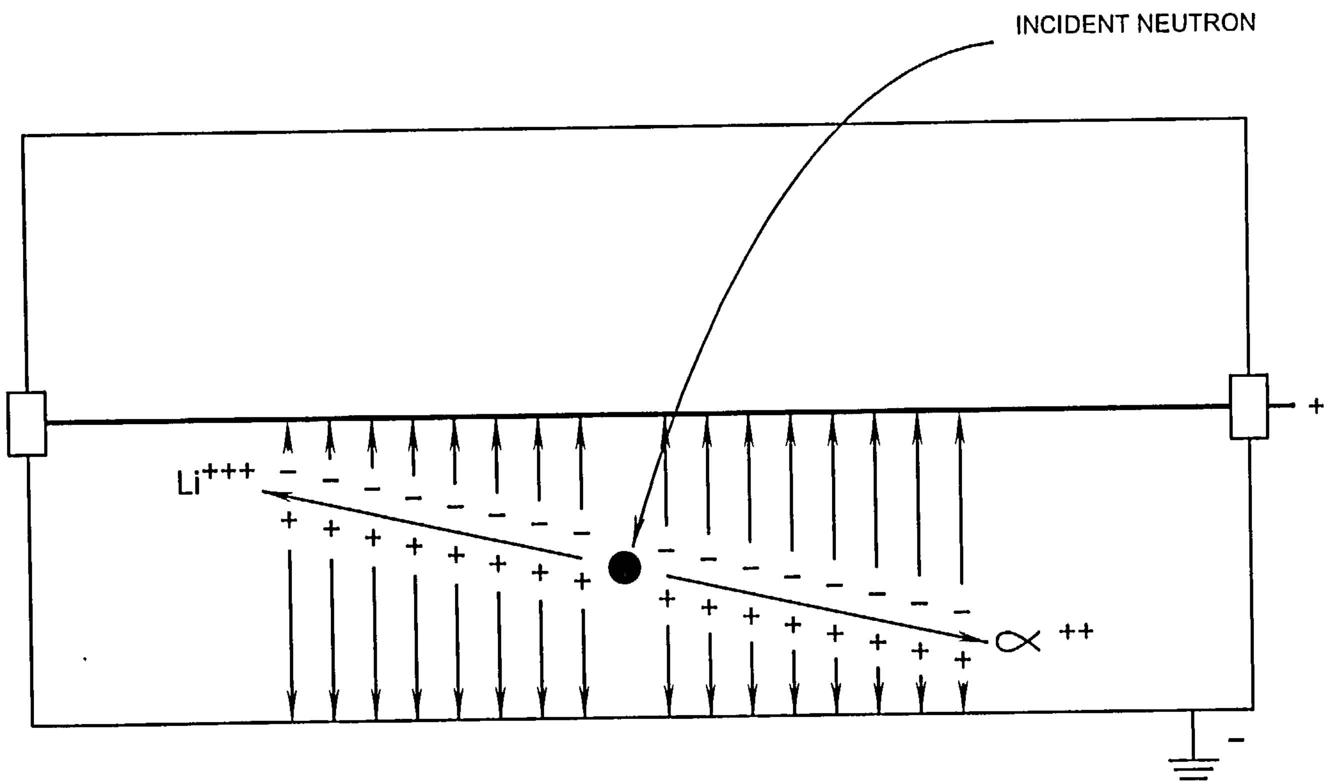

BF_3 DETECTOR

Figure 9.1-14 BF_3 Detector

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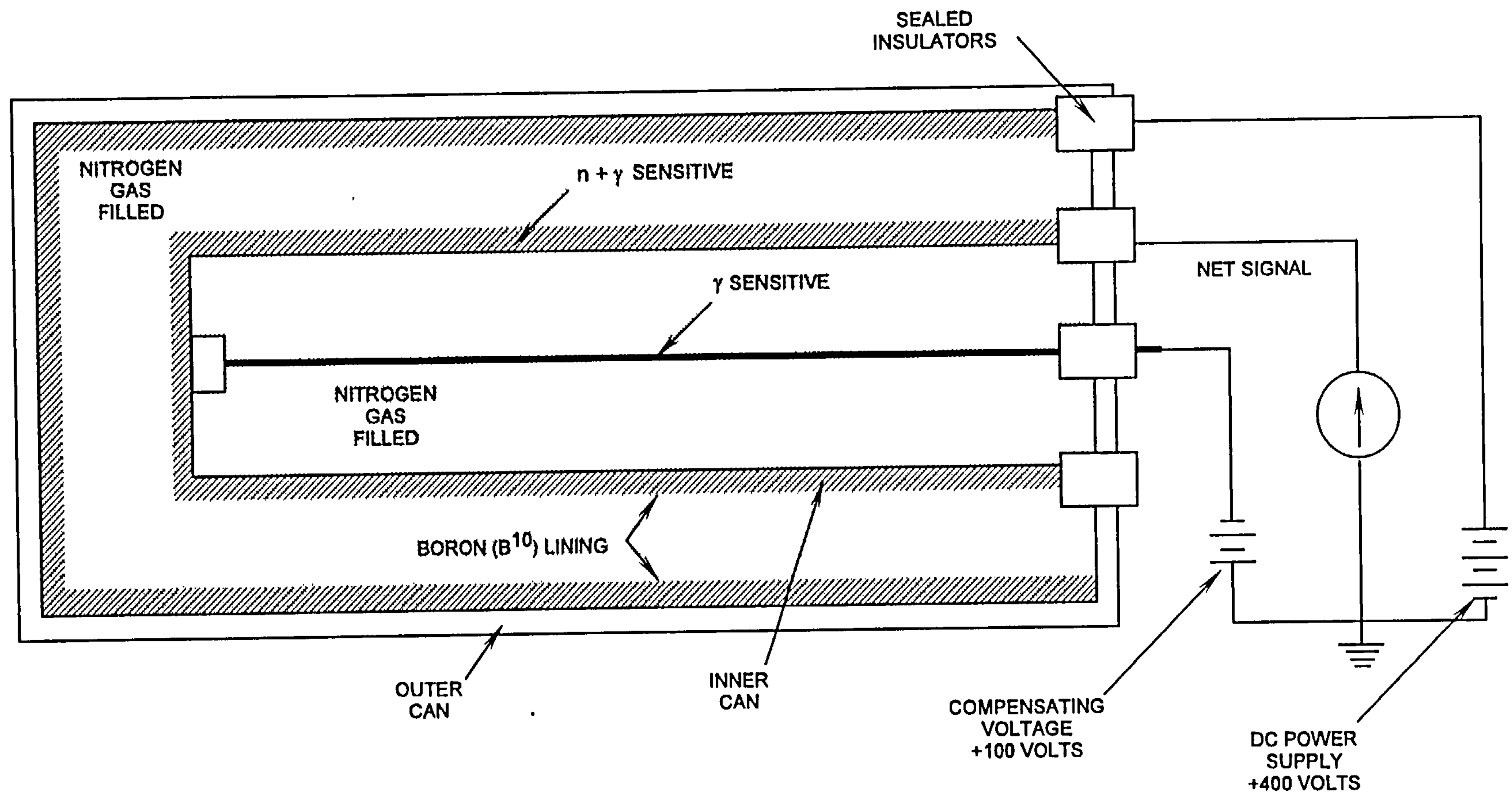
9-3.2 1-3



COMPENSATED ION CHAMBER
(CIC)

Figure 9.1-15 Gamma Compensated Ion Chamber

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9-4 2 1-4

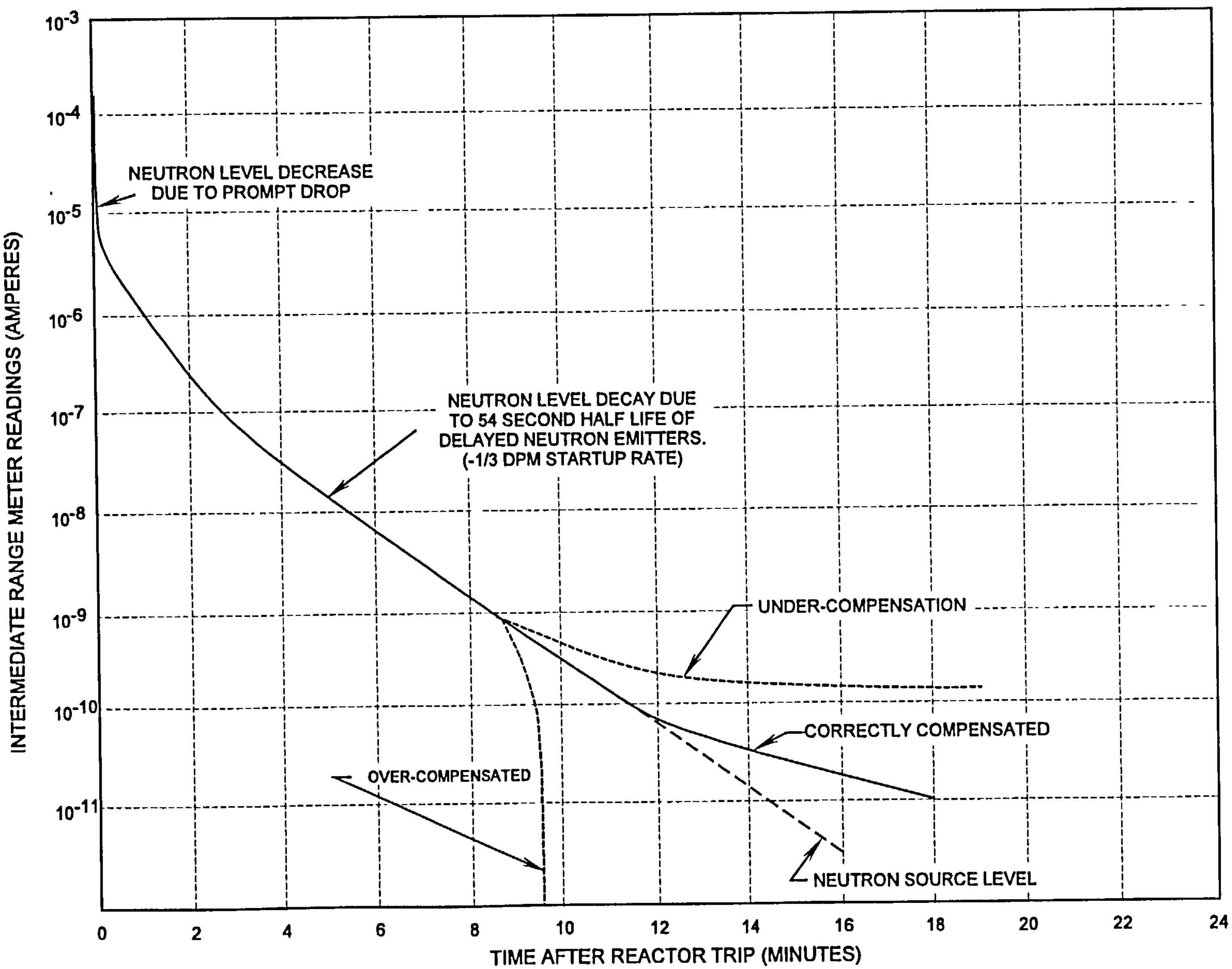

Figure 9 1-16 Gamma Compensated Curve

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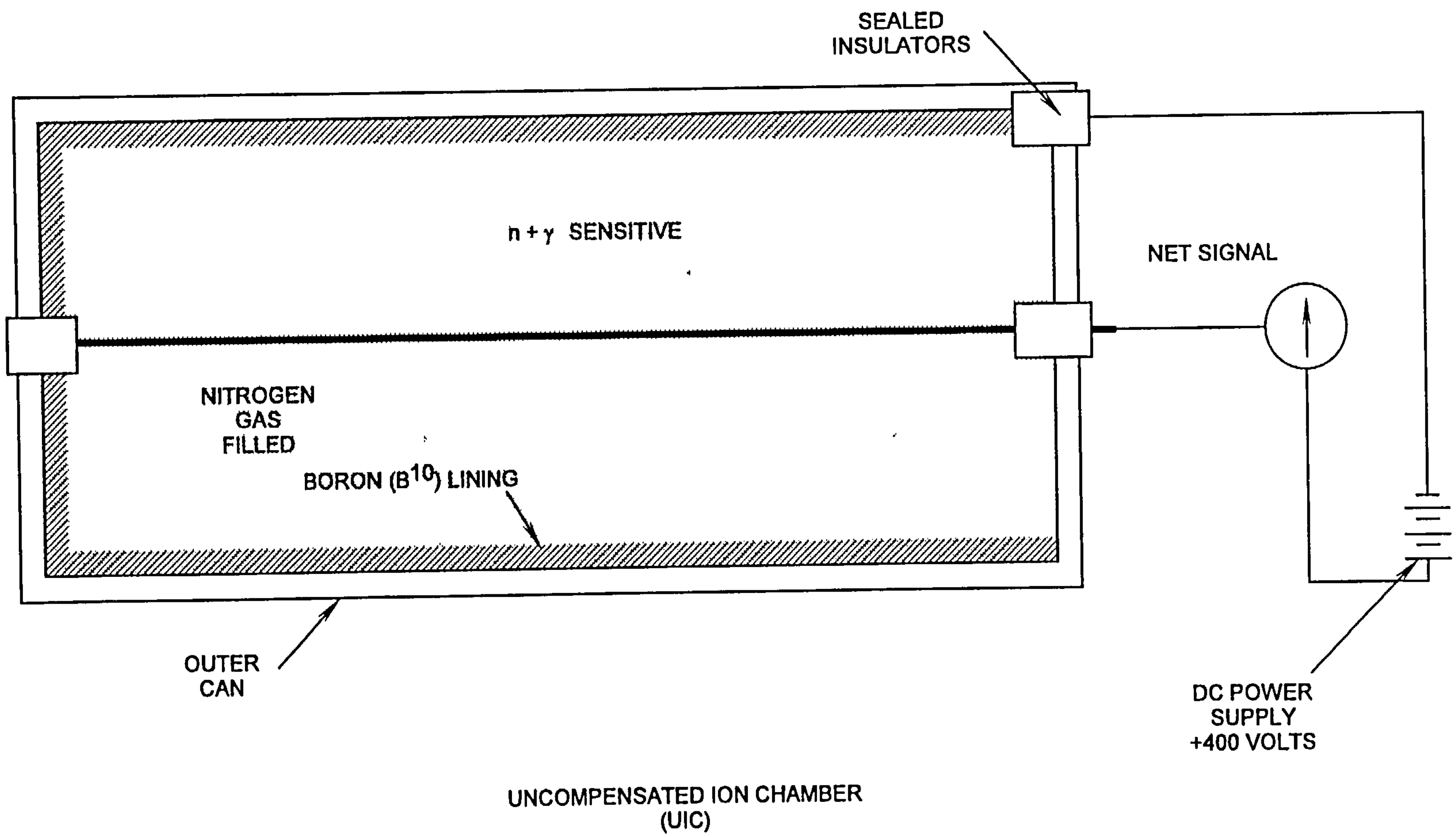

Figure 9.1-17 Uncompensated Ion Chamber

Westinghouse Technology Systems Manual

Section 9.2

<u>Incore Instrumentation System</u>

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9.2 INCORE INSTRUMENTATION SYSTEM

Learning Objectives:

1. State the purposes of the incore instrumentation system.

2. Briefly describe the two types of incore instrumentation and the information available from each.

3. Describe the method used to detect flux thimble leakage.

4. ~~Describe how a full-core flux map can be obtained using a limited number of detectors.~~

5. List four uses of the data obtained from the incore instrumentation.

9.2.1 Introduction

The purposes of the incore instrumentation system are to provide information on neutron flux distribution and fuel assembly outlet temperatures at selected core locations. The incore instrumentation system provides data acquisition only and performs no protective or plant operational control functions. The incore instrumentation system includes the movable incore neutron flux monitoring system and the incore temperature monitoring system. The number of incore temperature monitoring thermocouples and the number of flux thimble paths available within the core for the movable detectors varies depending upon the Westinghouse design, i.e., two, three, or four loop designs. The location and distribution of the incore instrumentation, flux thimbles and thermocouples, within the reactor core of a 4-loop Westinghouse plant is shown in Figure 9.2-1.

The incore neutron monitoring system consists of miniature fission chambers with sufficient sensitivity to permit measurement of localized neutron flux distribution variations within the reactor core. The data obtained from the incore neutron flux monitoring system is used to:

1. Calculate the three-dimensional core power distribution for verification of safety-related predictions,

2. Calculate the hot channel factors for compliance with Technical Specifications,

3. Calibrate the excore power range nuclear instruments for axial flux difference (AFD),

4. Detect and verify core radial and axial asymmetries, and

5. Detect and verify control rod misalignments, such as dropped rods or rodlets, and rods above or below their respective bank position.

The incore temperature monitoring system consists of fixed thermocouples, positioned at the top of the upper core plate. These thermocouples, referred to as core exit thermocouples (CET's), are used to measure fuel assembly coolant outlet temperature. This data is used to:

1. Determine the core radial power distribution,

2. Conduct continuous on-line monitoring of core radial power sharing and incore thermocouple temperatures,

3. Compute the coolant enthalpy rise in the instrumented fuel assemblies,

4. Detect abnormal rod configurations,

5. Confirm indications given by the excore

instrumentation system and the incore neutron monitoring system,

6. Provides an input into the subcooling margin monitors and,

7. Provide the operators with an indication of inadequate core cooling conditions during emergency situations.

9.2.2 System Description

9.2.2.1 Incore Neutron Monitoring System

Movable miniature fission chamber detectors (Figure 9.2-2), using U_3O_8 (uranium oxide) enriched to greater than 90 percent in U-235, provide detailed flux (neutron level) mapping of the reactor core. Each detector is attached to a flexible drive cable that can be driven into selected core locations by the plant operating staff. When not in use the detectors are stored in a shielded concrete vault to minimize radiation exposure to plant personnel.

Figure 9.2-3 shows the basic system for the insertion of the movable miniature fission chamber into the core. Retractable detector thimbles, into which the miniature detectors are driven, are positioned as shown. Since these retractable detector thimbles are sealed at the leading (reactor) end, they are dry inside. The thimbles thus serve as a pressure barrier between the reactor water pressure (design pressure of 2500 psig) and the atmosphere. Mechanical high pressure seals between the retractable thimbles and the conduits are provided at the seal table. During normal plant operation, these retractable thimbles are stationary and fully inserted into selected fuel assemblies. The detector thimbles are retracted from the core before refueling or during core maintenance periods at which time the reactor coolant system is depressurized.

The drive system for the insertion and withdrawal of miniature fission chamber detectors consists of drive units, limit switch assemblies, five-path rotary transfer devices, ten-path rotary transfer devices, and isolation valves. The drive units are mounted permanently on a platform directly above the seal table. The remaining components, between the drive units and the seal table, are mounted on a movable support assembly which is moved aside when the retractable detector thimbles are withdrawn from the core. The drive units push the hollow helical-wrap drive cables, with the miniature fission chamber detectors attached, into the core. The helical-wrap drive cables have small diameter coaxial cables threaded through their hollow centers for transmitting the current signal produced by the miniature fission chamber detector.

The six movable incore detectors, a typical number for a Westinghouse 4-loop designed unit, are designated Detector A through Detector F, as shown on Figure 9.2-4. Additional movable incore detector information may be found in Table 9.2-1. During normal operation, each detector is used to measure the relative neutron flux in the detector thimbles connected to the correspondingly-lettered ten-path rotary transfer device; i.e., detector A is normally selected to a core path provided by the "A" ten-path transfer device. However, by means of the operation selector switch (five-path transfer device), each detector can also be routed through several other paths. Each detector can be sent into each path of the next sequentially-lettered ten-path transfer device to serve as an operational spare detector for those thimbles (i.e., A for B, B for C, C for D, etc.). For detector normalization purposes, each detector can be routed separately into a common calibrate path, thus providing direct correlation of the detectors. Each detector can also be routed into any path of common group "C", or to a shielded area for storage.

TABLE 9.2-1
Movable Detectors Design Parameters

Movable Detectors	
4-loop plants, number	6
3-loop plants, number	5
2-loop plants, number	4
Outside diameter, in	0.199
Length, in.	2.1
Performance Data	
Cable Speed (low), ft/min	12
Cable Speed (high), ft/min.	72
Position Indication, in.	0.5
Flux Thimbles	
4-loop plants, number	58
3-loop plants, number	50
2-loop plants, number	36
Nominal O.D., in.	0 300
Nominal I.D., in.	0.199

The readout and control equipment is mounted in a control console (equipment racks) located in the control room. This equipment provides indication and control to make flux maps of the reactor core either by semi-automatic control or by manual manipulation of the controls. The control console contains separate controls, digital position display and power supplies for each detector.

Common equipment, including core path display panel, one common control panel, special low level readout, and 2-pen recorders, are also included in the console assembly (Figures 9.2-5 and 9.2-6).

9.2.2.2 Incore Temperature Monitoring System

Fixed incore thermocouples, made of chromel-alumel, are provided to monitor the outlet temperature of selected fuel assemblies. Fuel assembly inlet and outlet temperatures are used to determine the heat input, or enthalpy rise (Δh), of the fuel assembly. When the enthalpy of the monitored assemblies at various locations is compared, a radial power distribution map can be generated. The core locations for the CET's for a typical four-loop plant are shown in Figure 9.2-1. Additional thermocouple information is provided in Table 9.2-2.

The thermocouple sensing elements are mounted on and above the upper core plate at the point where the reactor coolant exits the fuel assemblies (Figure 9.2-7). The thermocouple leads are sheathed in stainless steel conduits and are routed from the upper core plate to the upper support plate inside of support columns. The conduits are then routed from above the upper support plate to the reactor head penetrations via thermocouple port columns which exit the reactor vessel head with thirteen thermocouple leads exiting from each of the five thermocouple port columns. A sealing arrangement is provided for each of the thermocouple port column penetrations and is part of the reactor coolant system pressure boundary (Figure 9.2-8).

TABLE 9.2-2
Thermocouple Design Parameters

4-loop plants, number	65
3-loop plants, number	51
2-loop plants, number	39
Outside diameter, in.	0.111
Type	Chromel-Alumel

The thermocouple leads are routed to either of two reference junction boxes. The reference junction box temperature is controlled where the transition is made between the chromel-alumel thermocouple leads and the copper instrument wires. If the temperature at this transition is allowed to vary unacceptable errors would be introduced in the temperature signal.

The core exit thermocouples have the advantage of continuously providing data which is easily converted to power by determining the enthalpy rise in the instrumented fuel assemblies. As opposed to the incore flux detectors, which are operated on an intermittent basis, the CET's provide continuous on-line radial power sharing measurements. However, this instrumentation system has the disadvantage of measurement uncertainties and possible errors due to reactor coolant flow mixing patterns at the detector location. To reduce the uncertainty in the thermocouple measurements and provide an accurate radial power measurement for on-line monitoring, the incore thermocouples are normalized to incore flux detector data during periodic surveillance tests. The CET readings are continuously monitored by the plant computer and may be read individually in the control room.

9.2.3 Component Description

9.2.3.1 Conduits, Guide Thimbles, Isolation Valves and Seal Table

Referring to Figure 9.2-3, stainless steel conduits extend from the bottom of the seal table down through the instrument tunnel and then up to the bottom of the reactor vessel. The conduits are welded, to the bottom of a seal table and to the penetration nozzles on the lower reactor vessel head, to form a leak-tight boundary. Therefore, the conduits, once filled with reactor coolant, become an extension to the reactor coolant system pressure boundary. The conduits guide and protect the guide thimbles between the seal table and the lower reactor vessel head.

The guide thimbles are closed at their leading (reactor) end and open at their trailing (seal table) end. The guide thimbles are dry on the inside and serve as a pressure boundary between the reactor coolant system (2500 psia design pressure) and the atmosphere. The somewhat flexible stainless steel guide thimbles are inserted through the seal table into the conduits. They are pushed from the seal table to the bottom of the reactor vessel head and pass through the penetration nozzles. From here they are inserted through the instrument guide tubes or the instrument guide extensions. Finally the guide thimbles are routed through the lower internals to the fuel assemblies. The guide thimbles remain stationary in the fuel assemblies during reactor operation and are retracted for refueling, maintenance, periodic inservice inspections, and work on the reactor vessel internals. Since the guide thimbles are withdrawn by pulling them upward on the trailing ends, ample room for the 14 feet of withdrawal, must be provided. To accomplish this, the five and ten path rotary transfer devices are configured so they are capable of being moved away from the seal table.

The seal table is a 3/8-inch thick, rectangular (8'6" by 2'6"), stainless steel plate mounted over the instrument tunnel. The seal table has 58 penetrations for guide thimbles and has two drain holes. The seal table guide thimble penetrations are sealed with high pressure swagelok fittings during normal operations and low pressure swagelok fittings during refueling.

A manually operated stainless steel isolation valve is provided at the seal table for each guide thimble. When closed, the isolation valve forms a 2500 psia barrier to prevent steam leakage from the reactor coolant system in the event of rupture of the guide thimble. The isolation valves are not designed to isolate a guide thimble with a detector or a drive cable inserted into the guide thimble. Therefore, prior to closing this isolation valve, the incore detector and its drive cable must be withdrawn to a position above the isolation valve.

9.2.3.2 Drive Unit Assemblies

As shown in Figure 9.2-9, each movable detector has a drive unit assembly. Each drive unit assembly is comprised of the following components:

1. Gear motor and slip clutch - One two-speed reversible synchronous gear-motor is provided. The drive motor is 3-phase, 460 volts, 60 Hz, 3600/600 rpm with a gear reducer and is capable of starting under maximum load. The motor incorporates an integral brake when not in operation. The continuous duty rating of this motor provides sufficient power to push a drive cable and detector through any guide path.

2. Drive box - The drive box is designed to operate with the helical-wrap drive cable. The 5-inch hobbed drive wheel is driven by the gear-motor through a slip clutch. Low speed for the drive cable is 12 ft/min, and high speed is 72 ft/min.

3. Storage reel - The storage equipment consists of a spring-loaded take-up reel with an integral locking device. The reel has sufficient take-up torque to prevent the drive unit from overrunning the reel at maximum speed during a change from low to high speed, or during braking. The storage reel accommodates 175 feet of drive cable and includes slip-ring assemblies which permit lead-out of electrical signals while the reel is rotating.

4. Position transmitter - A position encoder is supplied which is capable of operating control panel indicators reading from 0000.0 to 9999.9 inches. The encoder is driven at a speed proportional to the drive cable speed by means of a gear train from the drive wheel shaft. Signals from the encoder are in binary-coded-decimal form for position readout and controlled through the control console.

5. Withdrawal limit switch (Figure 9.2-6) - A withdrawal limit switch, actuated by the detector, is provided at the inlet of each of the five-path rotary transfer devices. This withdrawal limit switch provides the following functions:

   a. Prevents the operation of both the five- and ten-path transfer devices associated with it when the detector is forward of the limit,

   b. Stops automatic withdrawal when the detector reaches the withdrawal limit, and

   c. Actuates cable position lamps on the drive unit control panel in the control room.

6. Safety Switch - A safety switch located near the outlet of the drive unit prevents any attempt to withdraw the detector back over the wheel.

9.2.3.3 Transfer Device Assemblies and Isolation Valves

1. Five Path Rotary Transfer Device and Limit Switch (Figure 9.2-9).

   a. One five-path rotary transfer device is provided with each drive unit for routing the detector into one of the five possible paths. The 5-path transfer device consists of an S-shaped tube mounted inside a rotating assembly. This assembly is bearing-mounted at each end and can be positioned to any one of the five outlets.

When an electrical signal is applied to change the detector path, the S-shaped tube is moved to the selected outlet path position. Cam-actuated microswitches send signals to the control panel for feedback of path selection.

b. A withdrawal limit switch, actuated by the detector, is provided near the inlet of each five-path transfer device. This switch prevents operation of the five-path rotary transfer device unless the detector and cable is in the withdrawn position. The switch also stops automatic withdrawal when the detector reaches the withdrawal limit switch.

2. Wye Units - Wye unit assemblies are mounted as required to reduce the amount of interconnecting tubing between the five-path and ten-path rotary transfer assemblies. Wye units are also installed between the 5-path transfer devices and the calibration path.

3. Ten-path Rotary Transfer Device - Each ten-path rotary transfer device is capable of routing a movable incore detector into each of ten different selectable flux thimbles. Cam-actuated microswitches send signals to the control console for feedback of path selection. Detector-actuated path indicator switches near the outlets of the ten-path transfer devices send signals to the path display panel in the control console for verification of proper core paths.

9.2.3.4 Interconnecting Tubing Runs

Interconnecting tubing runs are supplied for connecting the drive unit assemblies to the safety and withdrawal limit switches, and for connecting the 5-path transfer devices to its associated Wye units and 10-path transfer devices. Additional tubing runs are supplied for connecting the 5-path transfer devices to the calibration path and to the concrete shielded storage area. Tubing runs also connect the 10-path transfer devices to the isolation valves, and connect the isolation valves to the seal table. The isolation valve to seal table tubing runs are designed for 2500 psia and 650°F.

9.2.3.5 Detector and Drive Cable Assemblies

The dimensions of the incore flux detector, i.e., a fission chamber, are 0.188 inches in diameter and 2.1 inches long. A bullet shaped stainless steel shell (0.199 O.D.) encapsulates the fission chamber. The stainless steel shell is welded to the leading end of a helical-wrap drive cable. Each incore flux detector is designed to have a minimum thermal neutron sensitivity of 1.0×10^{-17} amps/nv (where nv = neutron flux in neutrons / cm^2-sec) and a maximum gamma sensitivity of 3.0×10^{-14} amps/R/hr.

The carbon-steel drive cable is a hollow-core helical wrapped cable which meshes with the hobbed drive wheel within the drive box. Each drive cable has an outside diameter of 0.199-inches, and an inside diameter of 0.065 inches. The flux detector is attached to a coaxial cable, 0.040-inch-diameter, which is threaded back through the hollow drive cable and terminates at the trailing end, with several feet of slack ending in an amphenol connector. The drive cables (when new) are approximately 175 feet long. This length allows one or two subsequent cuts of a 12-14 foot section before the cable becomes too short for use. Such cuts may be required for factory replacement of the flux detectors.

9.2.3.6 Readout and Control Equipment

Readout and control equipment is provided as described on the next page, and shown on Figures 9.2-5 and 9.2-6.

1. Position Indication and Control - One position indication and control panel is provided for each detector. As an example the position indication and controls for the "A" detector are derived from signals sent from the "A" drive unit, and similarly for the other detectors. The binary-coded-decimal (BCD) position signal from each encoder is presented as a nixie tube display of five decimal digits from 0000.0 to 9999.9 inches.

2. Operation Selector Switch - A six-position switch is provided for each detector drive to align the five-path rotary transfer device to the position associated with the selected mode of operation. Indicator lights, adjacent to the switch position, are energized by microswitches. These microswitches actuate when the five-path rotary transfer device has reached the selected position. The operation selector switch positions are discussed below:

   a. OFF - When the operation selector switch is placed in the OFF position, a red light adjacent to the switch is actuated, the detector is prohibited from moving, and the drive motor control relays are prevented from being energized. In addition the five-path rotary transfer device is aligned to its NORMAL position.

   b. NORMAL - When the operation selector switch is placed in the NORMAL position, the five-path rotary transfer device is positioned to its normal ten-path rotary transfer device.

   c. CALIBRATE - When the operation selector switch is placed in the CALIBRATE position, the five-path rotary transfer device is positioned to the wye-units for the calibrate path.

   d. EMERGENCY - When the operation selector switch is placed in the EMERGENCY position, the five-path rotary transfer device is positioned to the next sequentially lettered ten-path rotary transfer device. (Drive A to ten-path rotary device B, Drive B to ten-path rotary device C, etc.)

   e. COMMON GROUP - When the operation selector switch is placed in the COMMON GROUP position, the five-path rotary transfer device is positioned to ten-path rotary transfer device C.

   f. STORAGE - When the operation selector switch is placed in the STORAGE position, the five-path rotary transfer device is positioned to the lead shielded concrete storage area located in the seal table room.

3. Ten-Path Selector Switch - A ten-position individual path selector switch is provided for each group to align the ten-path transfer device with the selected detector thimble within that group. Indicator lights adjacent to the switch positions are energized by microswitches on the associated ten-path rotary transfer device. These microswitches close when the ten-path rotary transfer device has reached the selected position.

   Path selection is always achieved on the path selector switch associated with the ten-path transfer device through which the detector must pass (e.g., if the A detector is to be operated in the EMERGENCY mode, path selection is made on the B path selector switch). Detector-actuated microswitches at the outlet of the ten-path transfer devices energize path-display lights on the control console to indicate that the detector has actually reached that position in the selected path.

4. Common Controls - Common control of all detectors (simultaneous detector operation) or individual detector insertion and plotting are provided. The operating circuits are electrically interlocked to prevent attempted simultaneous insertion of two detectors into the same path under automatic control. The withdrawal limit switch is interlocked with the five-path and ten-path rotary transfer devices to prevent their rotation or realignment unless the associated detector is in the withdrawn position.

5. Position Control - The position readout devices are also used in the control system to provide stop signals to the detector drive unit at a preset distance from the bottom of the core and at the top of the core for each selected path during automatic insertion. The position readout devices also furnish an additional stop signal at the preset distance from the bottom after plotting. A set of ten patchboard matrix selector switches (five top-of-core position pins and five bottom-of-core position pins) for each path is provided to preset the bottom-of-core and top-of-core stop signals for normal operation.

   The stop positions are selected by insertion of pins of the correct lengths into the patchboard matrix to make contact as required. Thumbwheel switches are provided for position control settings in Emergency, Common Group, Storage and Calibrate modes of operation. Top-of-core and bottom-of-core position settings are always established on the position control panel of the detector being run.

   Detector position control is accomplished by comparing the encoder binary-coded-decimal (BCD) information with a decimal number created by the patchboard or thumbwheel switches. Each comparator accepts the associated encoder BCD information and compares it with the decimal number presented by the setpoint limits. To make this comparison, the decimal limit setting is converted into a BCD by the comparator.

6. Drive Motor Control - When any operation selector switch is in an ON position and the automatic-manual switch is in the AUTOMATIC position, pushbuttons (INSERT, SCAN, RECORD, WITHDRAW) will control the drive motors. When the automatic-manual switch is in the MANUAL position, the speed switch controls motor speed and the insert-withdraw toggle switch controls motor direction. The drive selector switch (single/multiple) on the common control panel selects either all drives or any single drive.

7. Detector Power Supplies - One power supply is mounted on each detector readout panel. The power supply provides a "floating" dc voltage output continuously variable to 300 volts.

8. Detector Current Readout - A current readout meter, having a range of 0-50 microamperes, is provided in the return circuit from the detector to the power supply. A range switch is provided to shunt the meter so that full scale can also correspond either to 150 or 500 microamperes, or to 1.5 or 5 milliamperes. A 1000-ohm multi turn potentiometer and precision shunts in series with the meter provide outputs to the recorder and plant computer. The full current output can also be supplied temporarily to an external picoammeter for special low current

measurements.

9. Recorders - Strip-chart recorders are provided for each detector. The chart speed is synchronized with the low speed of the drive motors so that one inch of chart movement corresponds to 10-inch movements of the detectors. Each recorder is started automatically by the associated SCAN or RECORD pushbuttons, or can also be started at any other time by using the manual start switch.

10. Special Low Signal Level Equipment - A picoammeter is provided for making special low level measurements when the detector currents are less than five microamperes. The external connectors at the rear of all detector readout chassis are connected in parallel by coaxial cables to the input of the picoammeter. Input to the picoammeter is individually selected by switches on the detector readout panels. Also, in case the rectifier power supplies are too noisy for very low level signals, a special low-noise battery supply is provided.

9.2.3.7 Gas Purge System

The gas purge system, as shown in Figure 9.2-10, consists of a source of dry CO_2 gas which is introduced into the thimble runs whenever the movable detectors are being withdrawn from the reactor core. In order to do this, the transfer devices are contained in metallic enclosures and the gas is allowed to flow into these enclosures whenever the detectors are being withdrawn.

A pressure regulator and a throttling valve (a Hoke flow gage) are mounted near the 10-path transfer devices. A normally-closed ac solenoid operated off-on valve is located at the outlet of the throttling valve, which is electrically opened whenever a RECORD or WITHDRAW operation is called for on any of the detector drive motors. A stainless-steel tubing run connects the gas source to the enclosures through the valves. (The inlet gas tubing is disconnected when the transfer device's assembly is moved aside during refueling.)

These enclosures are designed to withstand an internal pressure of 1.0 psig without damage. The system is sufficiently leak-tight so that with an internal gas pressure of 0.02-inch of water applied, the total gas leakage rate will not exceed 15.0 cubic feet per hour.

9.2.3.8 Leak Detection System

The leak detection system comprises of; a drain header, a liquid level actuated pressure switch, and a 1/4-inch ac solenoid-operated valve, as shown in Figure 9.2-10. The inlet connection to the drain header is made at the 10-path transfer device enclosure, while the outlet connection is made to the plant drain system.

If water leaks from any of the transfer devices, it enters the leak detection system causing the level to rise. When the pressure switch actuates, it energizes the leak alarm and the 1/4-inch solenoid valve. The alarm is acknowledged by pressing the reset pushbutton which silences the audible alarm and seals in the alarm light. When the water level in the drain header decreases below the level actuating pressure switch setpoint, its contact opens de-energizing the solenoid drain valve and the alarm light. The drain line is disconnected during refueling preparations.

9.2.3.9 Thermocouples

There are sixty-five chromel-alumel thermocouples provided for a four-loop plant. Each thermocouple is 1/8-inch (nominal) diameter, stainless steel sheathed, aluminum oxide insulated, with the trailing end terminated in a male thermocouple connector. Each thermocouple is supplied to the specific length required for its assigned location.

9.2.3.10 Thermocouple Reference Junction Box

Two thermocouple junction boxes are provided to permit transition from chromel-alumel thermocouple extension wiring to copper field wiring. These units provide a controlled 160°F temperature reference for the incore thermocouples. Each reference junction box contains three platinum resistance temperature detectors (RTD). Two of the RTDs from each unit are connected directly to the plant computer for monitoring of reference junction temperature. The third RTD in each unit is an installed spare.

9.2.3.11 Thermocouple Indicator

One indicator is mounted in the flux mapping control console to provide backup readout capability (normal is via the plant computer). This instrument is supplied with a double range measuring circuit which permits measurement within the ranges of 100°F to 400°F or 400°F to 700°F. Selection of a single thermocouple to be indicated is made by nonlocking toggle switches on the front of the indicating panel. The toggle switch must be manually held in position (left or right) to monitor the desired thermocouple. The switch returns to the center position (neutral position) when released. Since the thermocouple input signal to the indicator is in parallel with the plant computer, a contact closure signal is provided to inform the computer when any thermocouple is being monitored by the indicator.

9.2.4 Operation and System Interrelationships

9.2.4.1 Detector Calibration

When using the movable incore detectors, the power supply voltages are set near the predicted centers of the plateau regions. The range switches are set at the expected ranges for on scale readings and the selector switch is in the RECORDER position. The following sequence of operations is typically performed:

- Select one of the detectors and run it into the calibration path by placing its five-path operation selector switch in the CALIBRATE position and using the INSERT and SCAN pushbuttons. During the scan, set the range switch so that the peak output is between one-third and full scale.
- After reaching the top-of-core, use manual control to withdraw the detector downward. Stop at or near the point of highest detector output. Take data of voltage versus meter readings for a saturation curve in 10-Volt steps from 20 to 160 Volts. Plot these readings on linear graph paper or run the strip chart for this plot. Select and set the voltage that will provide operation near the center of the plateau region.
- Repeat this procedure for the remaining detectors and normalize each detector's output voltage to provide consistent readings from detector to detector.

9.2.4.2 Flux-Mapping Procedure

After detector calibrations are performed, full or partial core flux maps are typically made in the following semi-automatic steps:

- Turn one or more operation selector switches to the NORMAL position and observe the green light indication. Select the desired individual paths with the ten-path selector switches. During the flux mapping operation, record the reactor core power level to insure that measurement conditions are stable during the mapping procedure.

- On the common control panel, turn the mode switch to the AUTO position. In this mode, the speed is determined automatically as described below. (An override can be made by turning the mode switch to MANUAL, which causes all manually controlled movements to be at the speed selected by the speed switch.)

- Turn the computer switch to the ON position to log the flux-mapping data in the computer. Select the desired operation on the drive selector switch. The ALL position is normally selected to simultaneously insert all detectors. Note that the operation selector switch of the desired drive(s) unit must be in the NORMAL position to obtain flux mapping data from its respective ten-path transfer device.

- Press the INSERT pushbutton momentarily. The detectors will be driven at high speed to the preselected bottom-of-core position and stopped automatically, as indicated by the position indicator digital displays. When the detectors pass through the path indicator switches, contact-closure signals are fed back to the path display panel.

- Press the SCAN pushbutton momentarily. The detectors will be driven at slow speed to the top-of-core and stopped automatically as indicated by the digital displays. During this scan, the recorder is automatically started and a continuous readout of the flux profile is obtained as a function of core height. This serves as a permanent record of the measurement. At this time, observe the current level and recorder response and make all necessary scale changes and adjustments.

- Press the RECORD pushbutton momentarily. The detectors will be withdrawn at slow speed downward through the core and a contact-closure signal will be supplied to the plant computer to indicate that the readouts should be logged. The associated strip-chart recorder automatically starts and again will provide a flux profile as a function of core height. The detectors stop automatically at the bottom of the core. During the record operation, the flux profile data is transmitted to the plant computer further data reduction and evaluation.

- Press the WITHDRAW pushbutton. The detectors will be withdrawn at high speed back to the withdrawal limit switches as indicated by the digital displays. Repeat the above steps for the other paths to give a full or partial core map, including running all detectors in the calibration path for normalization.

9.2.4.3 Incore-Excore Calibration

The movable incore neutron flux detectors (incore detectors), in conjunction with the plant computer, INCORE Code, present a true representation of the actual neutron flux distribution within the reactor core. Meanwhile, the excore nuclear instruments (excore detectors) rely upon leakage neutrons to determine the flux distribution within the core. Due to the distance and shielding between the reactor core and the excore detectors, these detectors cannot provide a "true" representation of the flux distribution within the core. Since the excore detectors provide reactor protection signals and also provide the reactor operator with continuously monitored indication of power and flux distributions within the core, it is necessary to calibrate the excore detectors.

Recall from Chapter 9.1(Excore Nuclear Instrumentation) the excore power range instruments consist of two six-foot detectors (one upper detector and one lower detector) per power range instrument channel. In theory the upper detector should indicate the power in the upper six feet of the core while the lower detector indicates the power in the lower half of the core. In practice however this is not the case as neutrons leaking from the core do not necessarily leak out of the core at 90 degree angles. Some of the leakage neutrons generated in the lower half of the core will be detected by the upper detector and conversely the lower detector will indicate neutrons that were produced in the upper half of the core. Since the core must be protected from departure from nucleate boiling (DNB) and excessive power generation in both the upper and lower halves of the core, it's essential that the inputs to the protective circuitry be reflective of the actual conditions in the core. This protection is provided by trip signals generated from the Over Temperature Delta Temperature trip circuitry (OTΔT) and the Over Power Delta Temperature trip circuitry (OPΔT) of which both circuits receive axial flux difference (AFD) inputs from the excore power range detectors.

The output of the upper and lower excore detectors are calibrated to the incore detectors at the beginning of each fuel cycle and when the monthly surveillance shows a significant difference between the adjusted excore AFD and the incore AFD. AFD is defined as the flux at the top of the core minus the flux at the bottom of the core divided by the flux at the top of the core plus the flux at the bottom of the core at 100% power. This calibration must demonstrate the linear relationship that should exist between the incore and the excore outputs. Electronically the AFD is expressed in terms of difference in current (ΔI) between the upper and lower excore detectors. The slope of that relationship is used to calibrate the following: the $F_1(\Delta I)$ penalty to the (OTΔT) trip setpoint in the reactor protection system, the $F_2(\Delta I)$ penalty to the (OPΔT) trip setpoint in the reactor protection system, the AFD meters on the control board, the output to the detector current comparators, and the AFD monitor program in the plant computer.

In order to establish the existence of a linear relationship between the incore and excore detector outputs, an adequate number of data points (different flux distributions) must be obtained. This is accomplished by inducing an axial xenon transient which causes an axial flux oscillation. During this induced transient, incore and excore measurements are obtained. These measurements are used to calculate the equation for the line that best fits the data by using linear regression. The incore measurements are taken by performing full core and quarter core flux maps at various times during the xenon transient. Each time an incore AFD is obtained by a flux map, all power range excore detector currents are recorded. The current output from the excore detectors is then plotted against the incore AFD. After the linear relationship between the two detector systems is established, the gains of the excore detector isolation amplifiers are adjusted. Adjusting the gain on the isolation amplifiers only effects, the output signal from its respective amplifier to the reactor protection system, detector current comparators and the various Δ flux meters and recorders. This adjustment has no effect on the raw current transmitted from the excore detector which in addition to supplying the isolation amplifiers also provides an input to the summing and level amplifier. Once made this adjustment is such that when there is an actual 0% incore delta flux, the excore detectors will indicate 0% AFD.

9.2.4.4 Computer

In addition to using the strip chart records, on-line computers are installed to provide gross analyses of current core conditions for use on a complementary basis with other on-line monitoring systems.

9.2.4.5 Incore Data Collection

Signal Inputs - A number of active signals are supplied from the flux mapping system to the on-line computer. Firstly, there are analog signals proportional to flux levels as measured by the movable detectors. Secondly, there are three sets of contact closure signals from each detector position control - one to show selection of detectors, another set to show the group 5-path transfer position, and a third set to show the individual 10-path transfer position. The latter two automatically indicate the flux thimble being measured. Finally, there are three interrupt signals, COMPUTER OFF-ON, SCAN, and RECORD.

SCAN and RECORD Programs - The on-line measurements provide an accurate method of determining a three-dimensional power distribution of the reactor core at periodic intervals in order to evaluate current core performance. The SCAN interrupt is received when the movable detector drive mechanism is energized to drive the selected detectors to the top of the core. However, data collection commences only after the RECORD interrupt is received when the movable detector drive mechanism is energized to withdraw the previously inserted detectors from the top of the core.

The objective of the on-line rapid data collection is to provide a high priority scheme by which all pertinent flux mapping data are collected for later reduction either on an offsite basis or for low priority reduction by the plant computer. Also, on-line priority data reduction provides a gross analysis of current core conditions immediately for use on a comparative basis with other on-line monitoring systems such as incore thermocouples, and excore detectors.

Signal Quality Checks - The program also includes provisions to evaluate the quality of the data as the measurement is taken. Briefly, there are two main quality checks made. For each data point on a pass, three consecutive readings are made (maximum 1/15 second apart). Also, each data point is compared with the preceding and succeeding data points, although relatively large variations are normal at the core grid locations.

Normalization - In order to provide a consistent set of measured relative reaction rates, it is important that all flux mapping data be normalized to one reference condition. Discrepancies which affect measurement results and must be corrected for are:

1. Reactor power drift during the flux mapping period,
2. Dissimilarities between the individual movable detectors,
3. Different readout scale settings, and
4. Leakage current in the detector, normally at low power levels.

During each pass, the total reactor power must be known in order to provide a means of converting each pass to one common reactor power level. This is accomplished by integrating the total output from the excore nuclear power channels during each pass. Changes in subsequent excore readings after the first pass provide correction ratios for subsequent passes.

In order to establish the normalization factors associated with each detector, it is necessary to insert each detector into a common thimble location. Differences between range settings is accounted for by multiplying each detector output by its appropriate range setting. Leakage current correction is made by subtracting from the appropriate detector output.

After the data is collected by the computer, it can be processed to provide a full core flux map. By using the symmetry of the core (attained by fuel and poison loading), the data from the selected core locations can be extrapolated to include all fuel assemblies in the core. This may be accomplished by the plant computer, or a more powerful offsite computer.

Thermocouple Input - Use of the on-line computer is the normal means for recording thermocouple readings. The thermocouple signals originating above the core pass through reference junctions in the plant containment and then to terminal strips in the flux-mapping console. From there, they are paralleled with one set going to the computer and the other to a precision indicator with manual selector switches. The latter are intended for use in case of a malfunction of the computer.

Computations Based on Thermocouples - The information received from the thermocouples complements the movable detector system by providing periodic on-line checks on reactor core conditions. Calibrations of the thermocouples and the thermocouple reference junctions are made from tests at known thermal core and system conditions.

Computations are made periodically of the enthalpy rise at each thermocouple location, relative fuel assembly powers and core radial tilting factors. Printouts are made of alarm messages when any of the relative fuel assembly power values or incore thermocouple-based radial tilting factors exceed established limits. A listing of averaged incore thermocouple readings and fuel assembly power values is made for reference usage. Complete core maps and daily thermocouple history are made when requested by the operator.

9.2.5 Summary

Miniature fission chamber detectors can be remotely positioned in retractable guide thimbles to provide flux mapping of the core. The detector is welded to the leading end of a helical wrap drive cable and to a sheathed coaxial instrumentation cable. The retractable guide thimbles are closed at their leading ends, and serve as the pressure boundary between reactor coolant pressure and atmosphere.

The drive assemblies are motor operated, with a hobbed wheel engaging the helical drive cable, a take-up reel and position encoders. The five-path rotary transfer device is used to select the mode of operation (normal, calibrate, storage, etc.). A five-path rotary transfer device is provided for each detector-drive assembly. A ten-path transfer device is supplied for each detector-drive assembly and is used to route a detector into any one of up to ten preselectable fuel assemblies.

Flux mapping consists of a moving detector scan of each provided core location (Figure 9.2-11). The information obtained is collected by the plant computer, which will either directly analyze the data obtained or record it for analysis by more sophisticated offsite computers.

Thermocouples are provided to give rough approximations of core conditions. They have the advantage of being on-line and are immediately available to the operator. The thermocouples are inserted into guide tubes that penetrate the reactor vessel head and terminate at the flow exits just above the fuel assemblies. Thermocouple readings are monitored by the computer with backup readout at a manual point selection

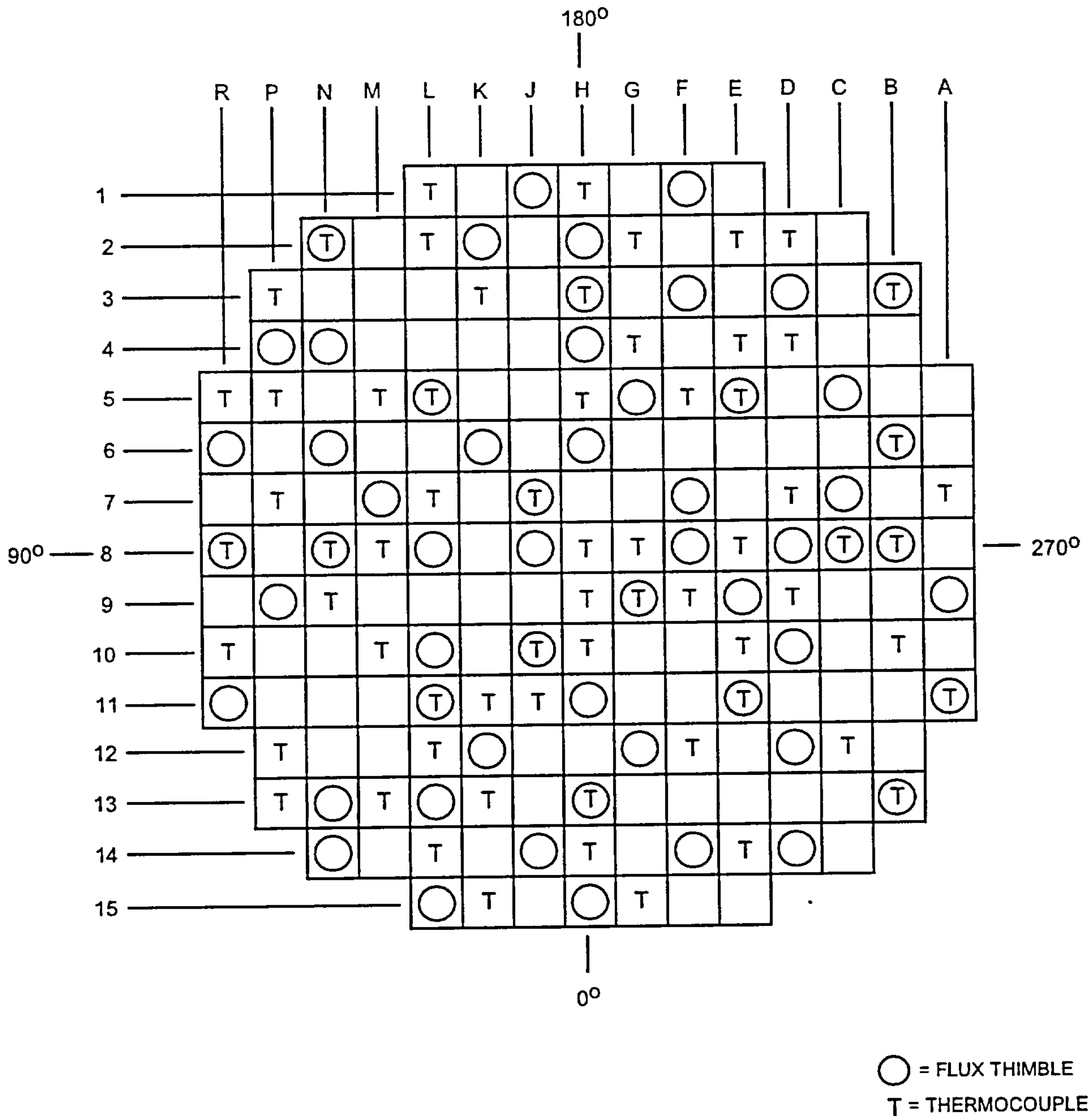

Figure 9.2-1 Thermocouples and Flux Thimble Locations (4 Loop Plant)

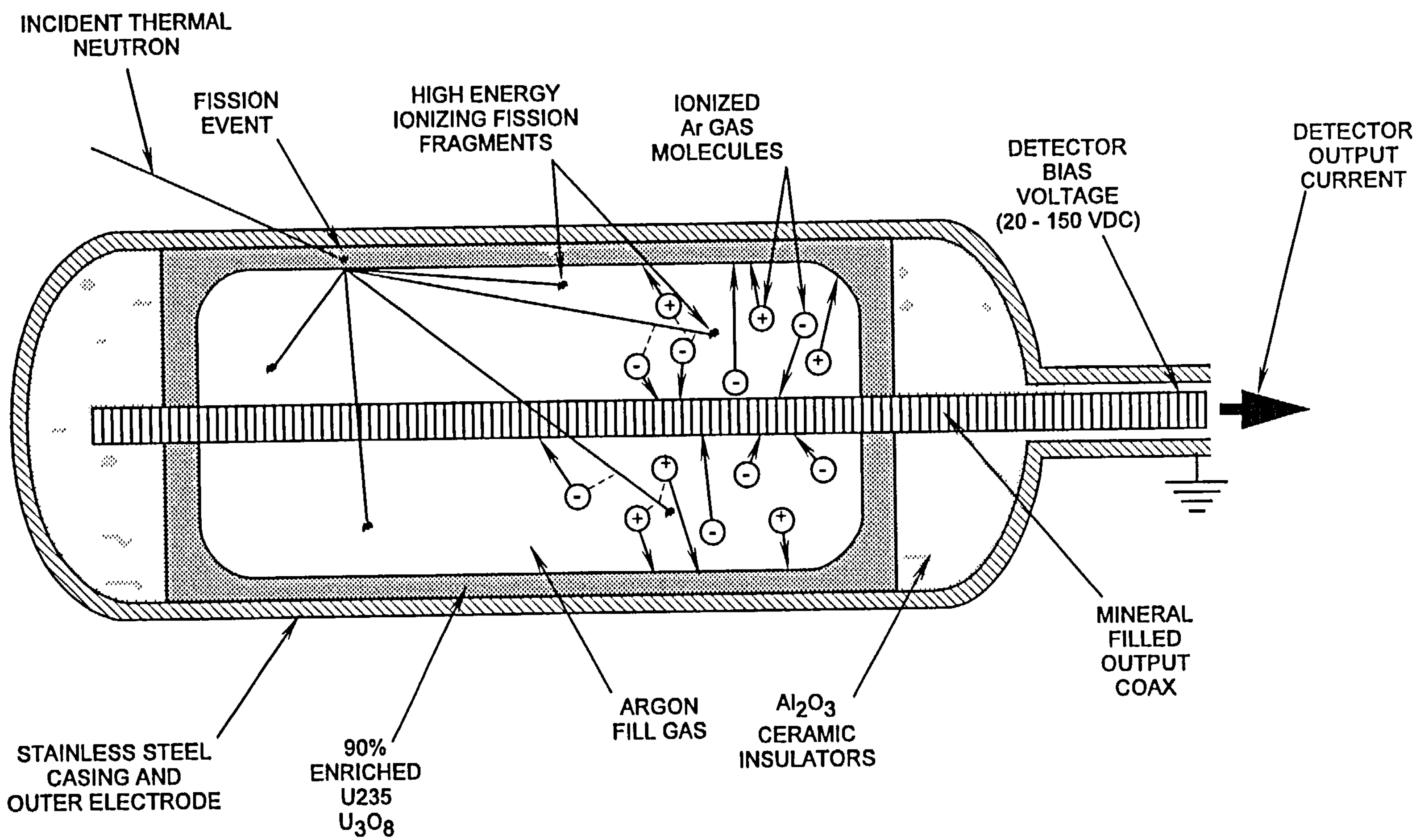

Figure 9.2-2 Incore Fission Chamber

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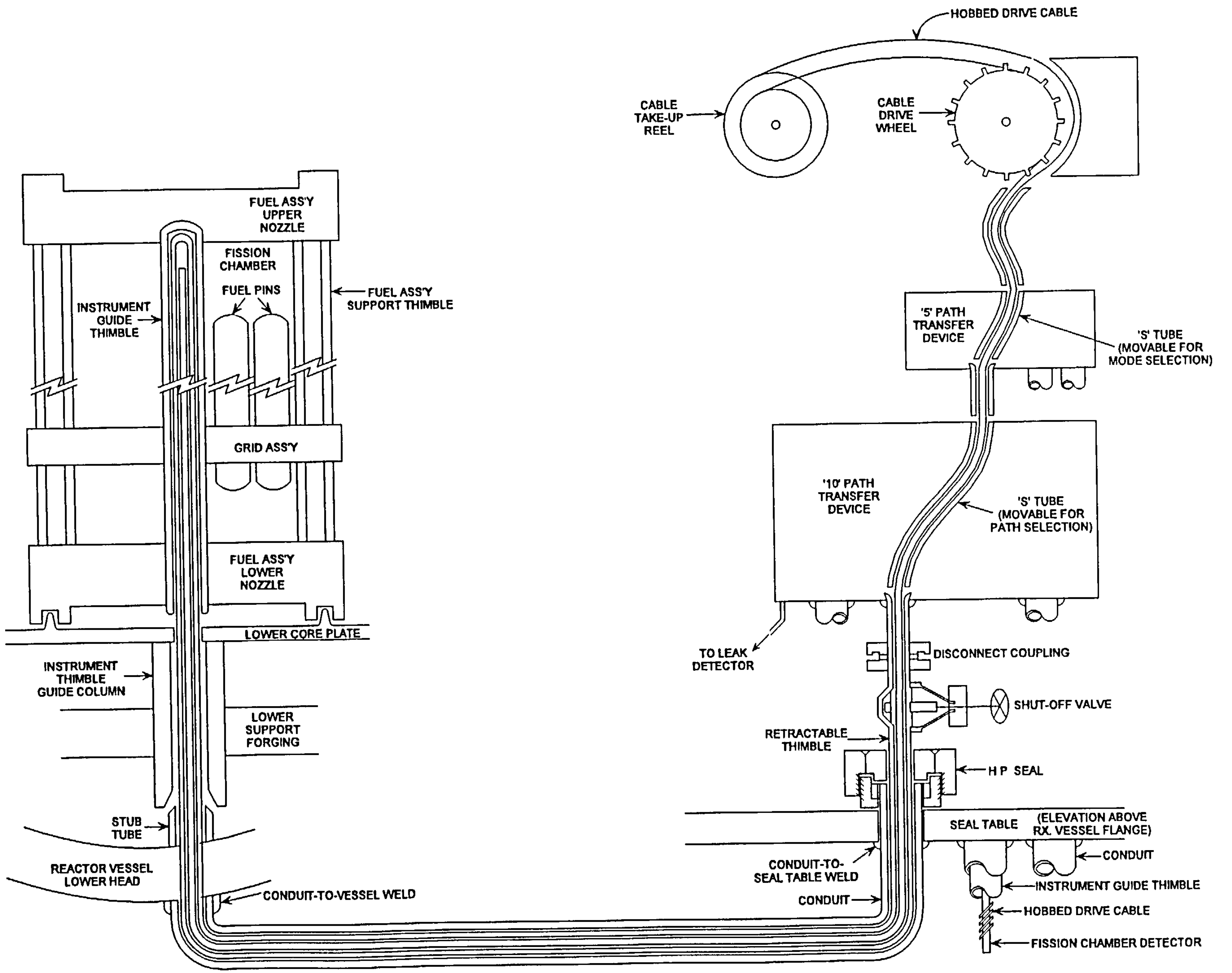

Figure 9.2-3 Movable Detector System

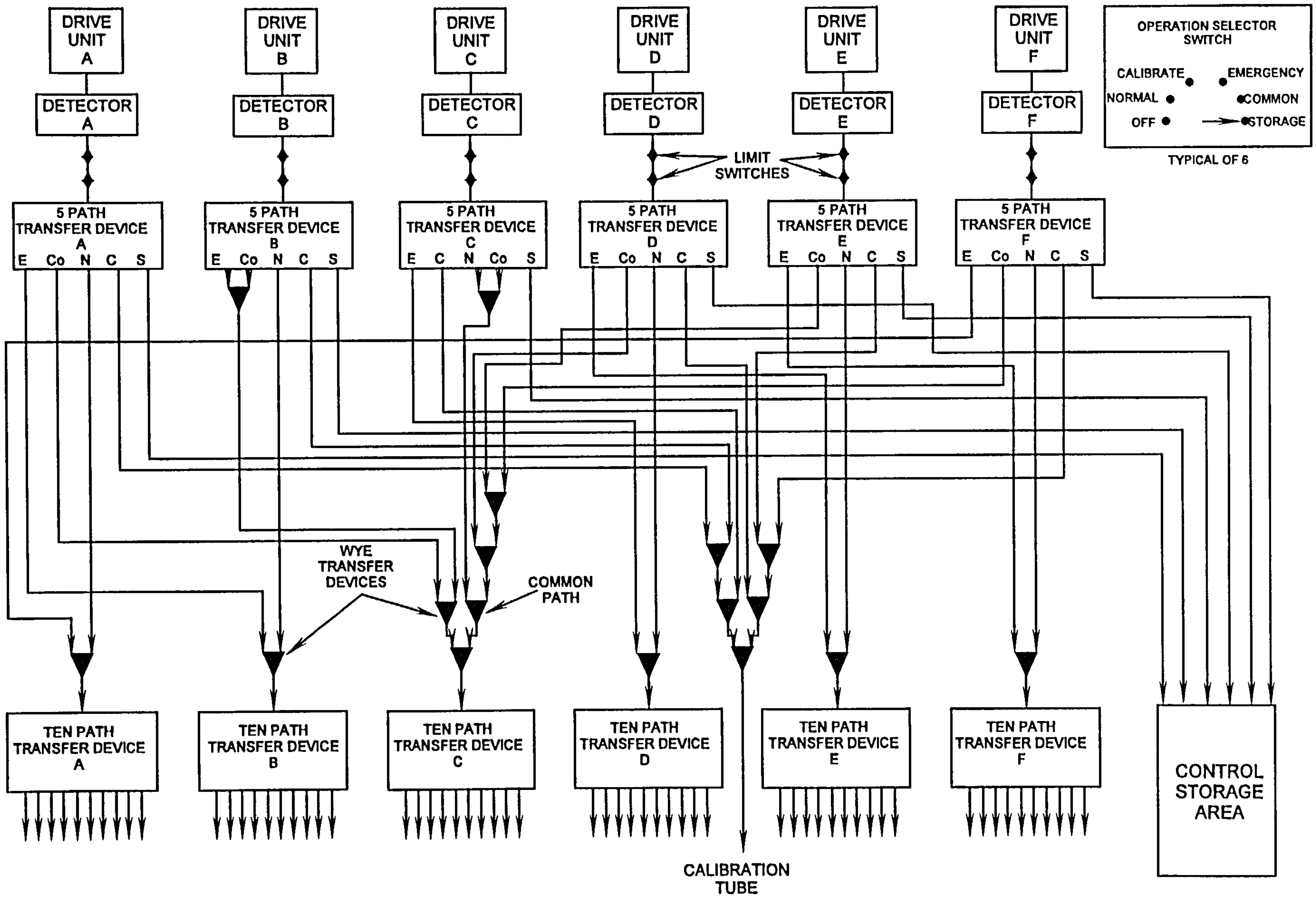

Figure 9.2-4 Incore Nuclear Instrumentation Drive System

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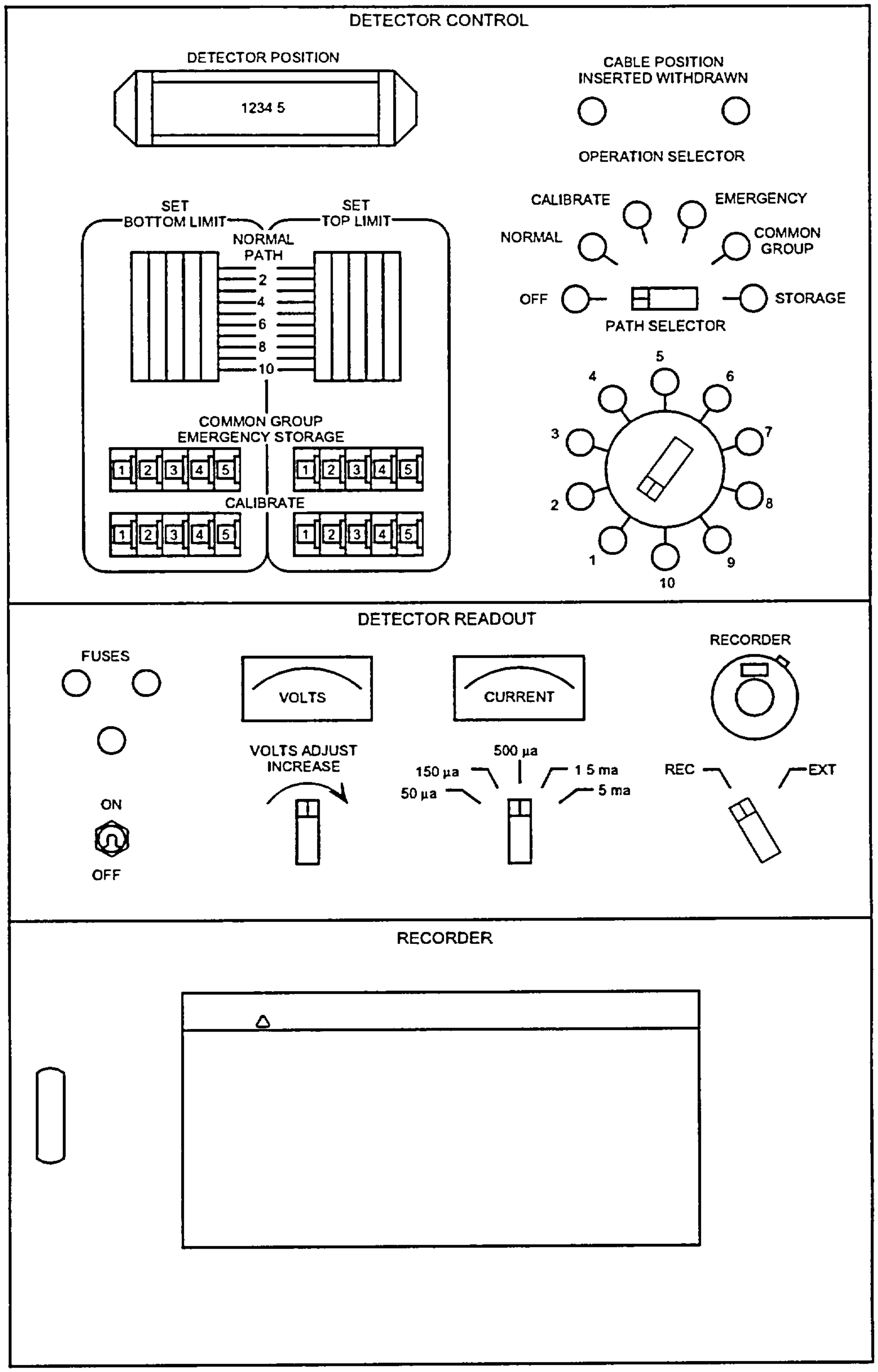

Figure 9.2-5 In-Core Detector Control and Readout

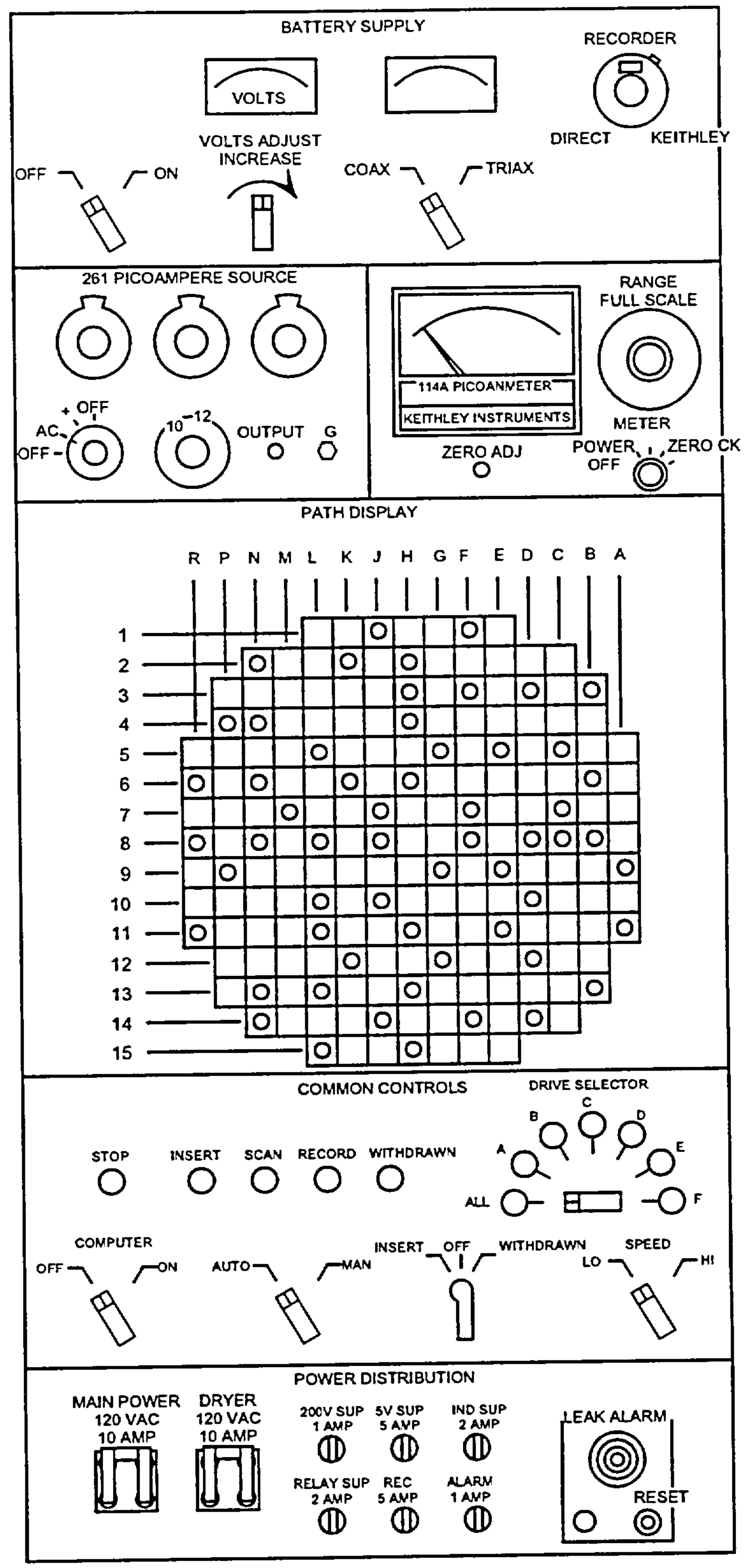

Figure 9.2-6 InCore Common Controls and Display

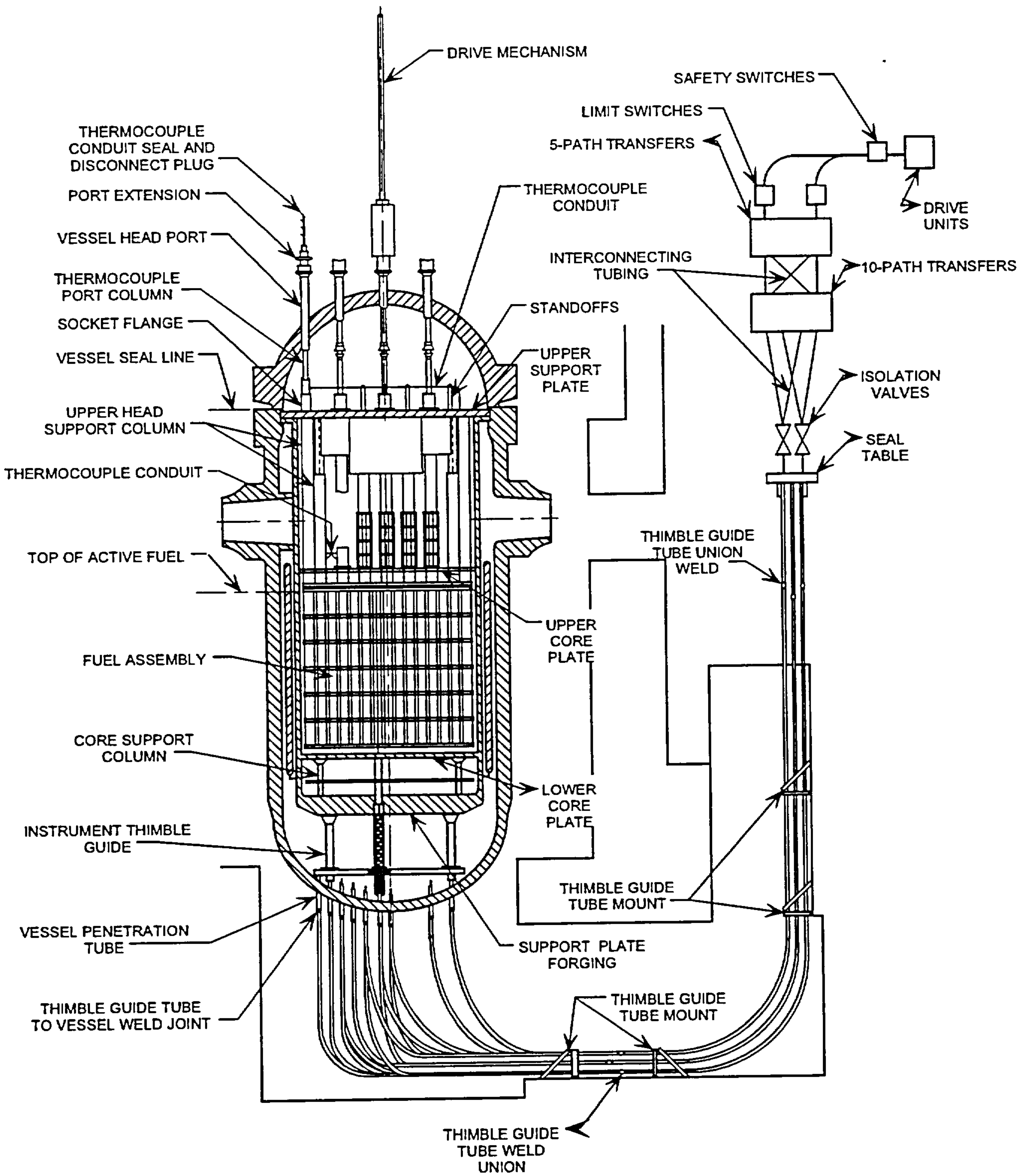

Figure 9.2-7 In-Core Instrumentation

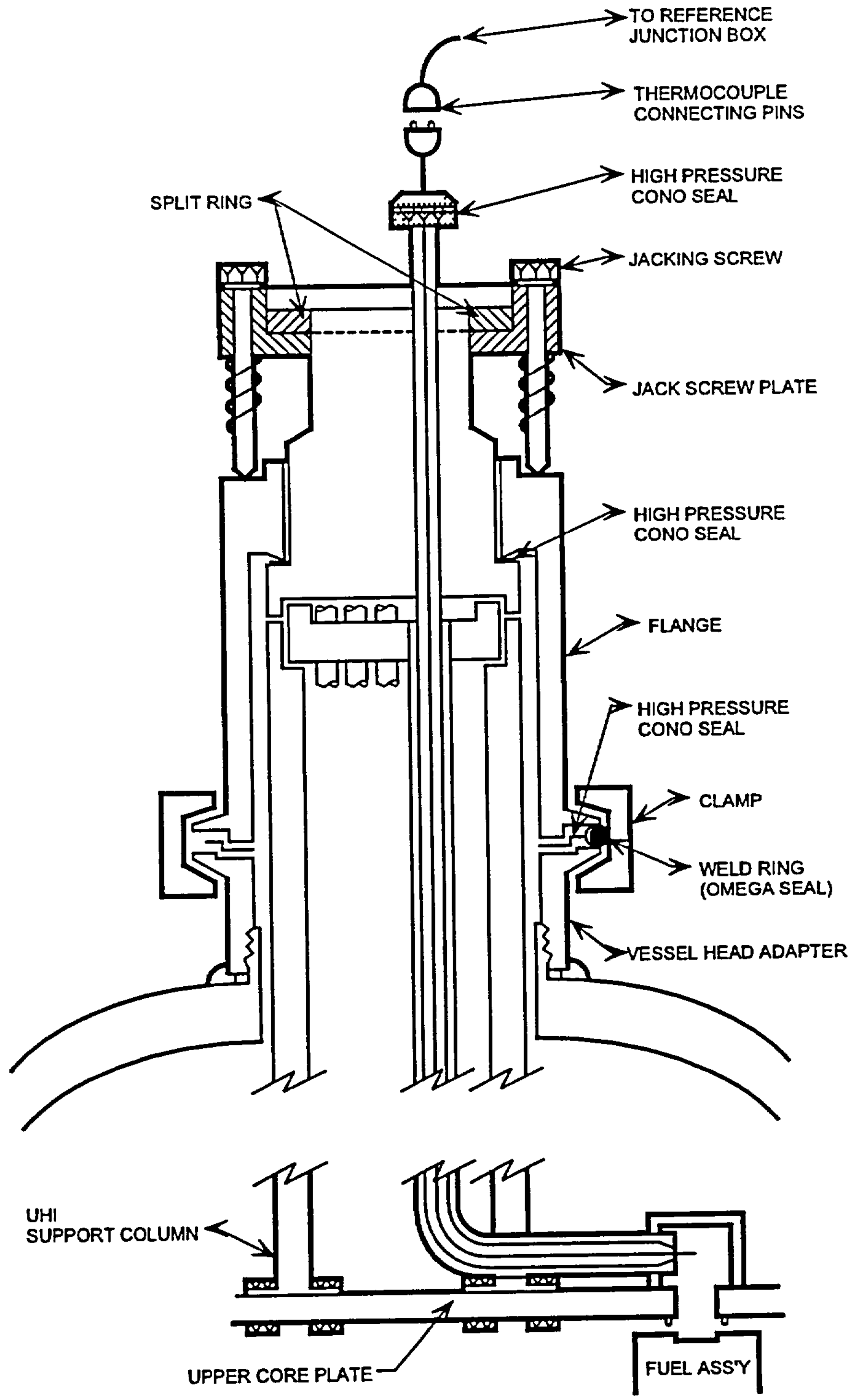

Figure 9.2-8 In-Core Thermocouple Arrangement

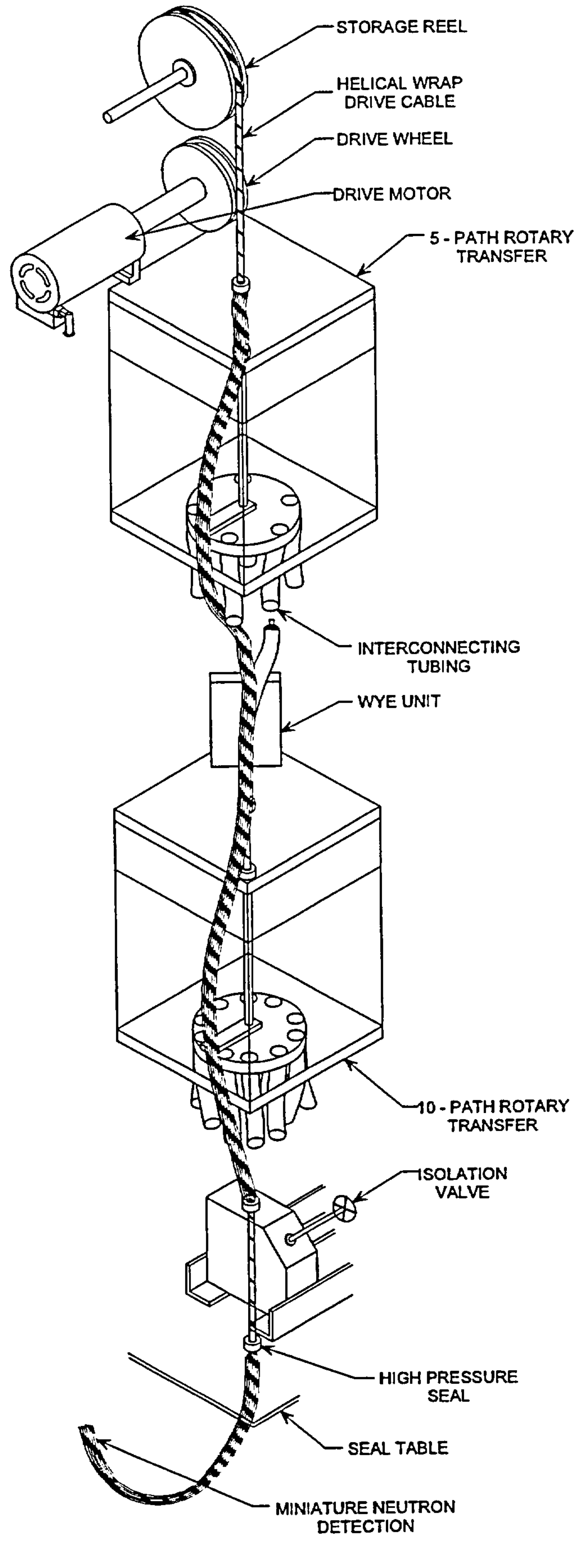

Figure 9.2-9 Drive System for In-Core Instrumentation

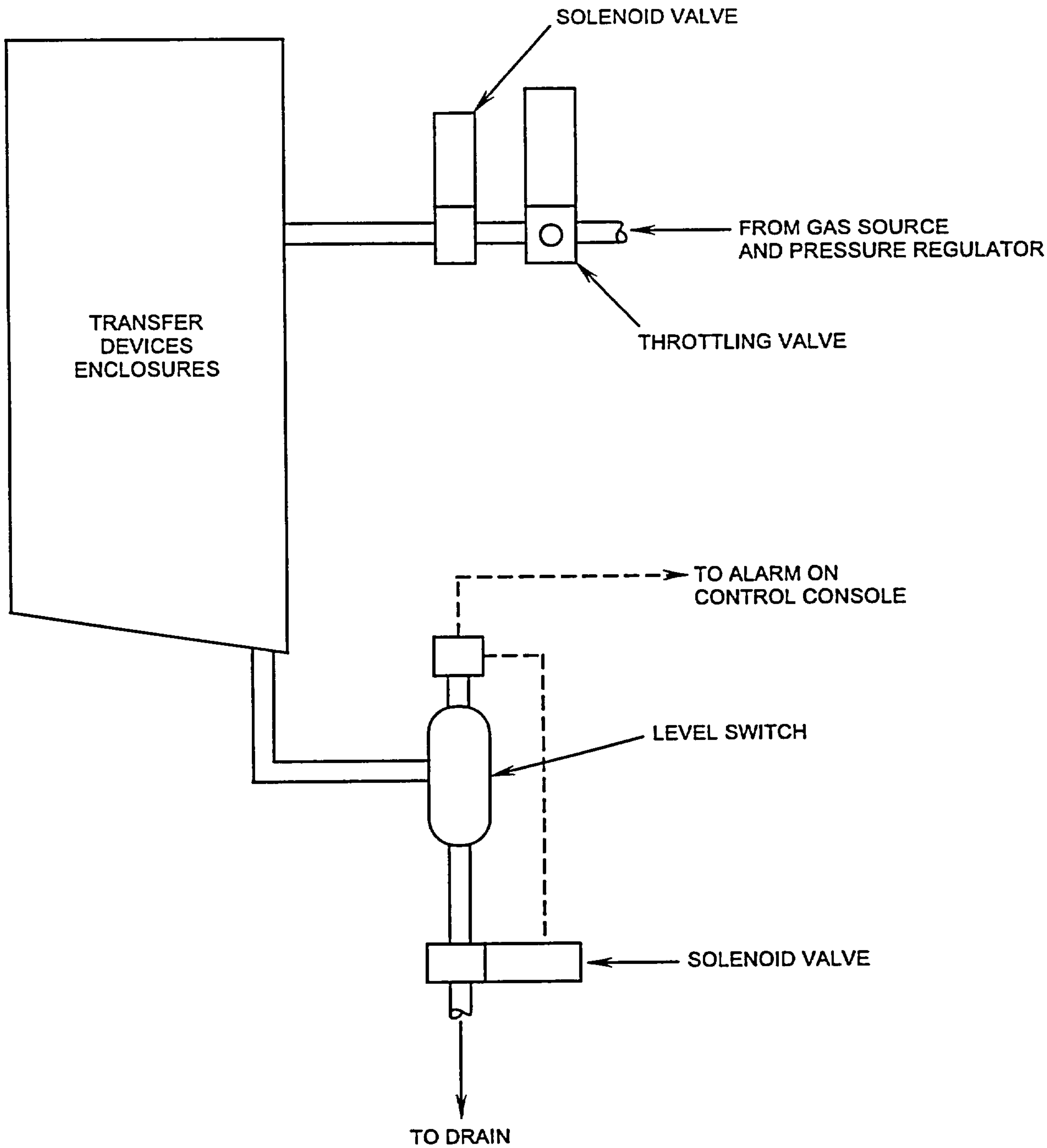

Figure 9.2-10 Gas Purge and Leak Detection System

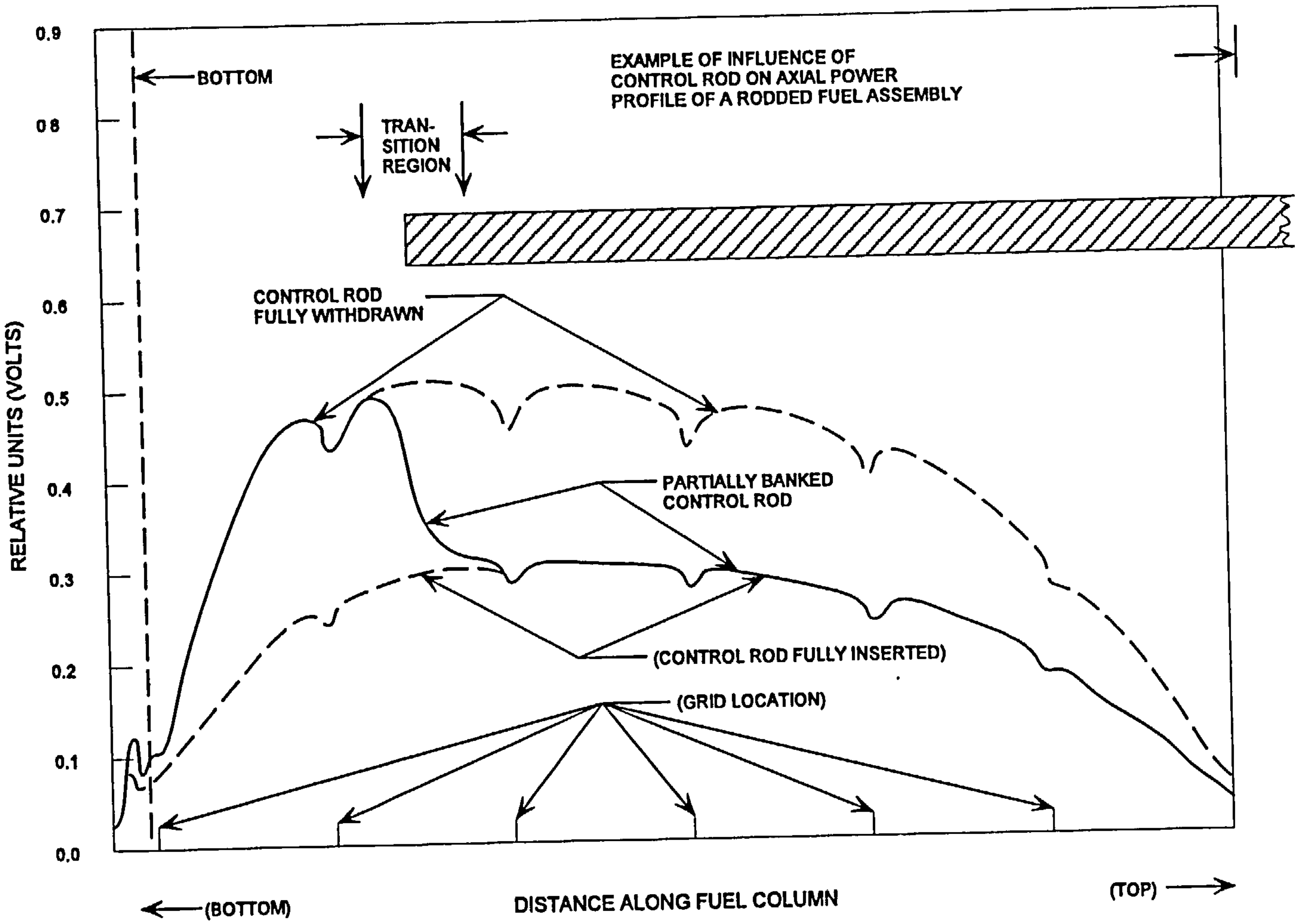

Figure 9.2-11 Flux Profile Curves

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Westinghouse Technology Systems Manual

Chapter 10

PRIMARY SYSTEMS CONTROL AND INSTRUMENTATION

Section

Westinghouse Technology Systems Manual

Section 10.0

Primary Systems Control and Instrumentation

10.0 PRIMARY SYSTEMS CONTROL AND INSTRUMENTATION

Introduction

The purposes of primary instrumentation are as follows:

1. Monitor Reactor Coolant System (RCS) temperature, pressure, and flow and pressurizer level.
2. Provide inputs to the Reactor Protection System (RPS) for reactor trip, engineered safety features actuation, and protective grade interlocks.
3. Provide inputs to various primary and secondary control systems.

Section 10.1 contains descriptions of instruments which measure the following parameters as well as uses for their outputs:

Temperature (10.1.1)
Pressure (10.1.2)
Level (10.1.3)
Flow (10.1.4)
Reactor vessel level (10.1.5) and
RCS Subcooling (10.1.6)

In addition, pressurizer pressure control (section 10.2) and pressurizer level control (section 10.3) will be discussed.

Westinghouse Technology Systems Manual

Section 10.1

Reactor Coolant Instrumentation

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LIST OF FIGURES

10.1 REACTOR COOLANT INSTRUMENTATION

Learning Objectives:

1. Describe how loop average temperature T_{avg} and temperature difference ΔT are derived from the narrow range resistance temperature detector (RTD) outputs and how these signals are used.

2. List the functions of the following temperature monitors:

   a. Reactor Coolant System (RCS) wide range temperature detectors
   b. Pressurizer, surge and spray line detectors
   c. Safety and relief valve discharge line detectors
   d. Pressurizer relief tank (PRT) detectors
   e. Reactor vessel flange leakoff detector

3. Explain how the RCS piping elbow and differential pressure (d/P) cells are used to develop the RCS flow signal.

10.1.1 Temperature

10.1.1.1 Narrow Range Temperature Detectors

The temperature of the reactor coolant is measured by narrow range, fast acting, RTDs. The RTDs are installed in thermowells which are part of the RCS pressure boundary. The output of the narrow range reactor coolant loop temperature is processed to provide the average temperature (T_{avg}) and the difference between the hot leg temperature and the cold leg temperature (ΔT). These processed signals are used for control room indication, inputs to various control systems and finally these signals are used by the reactor Protection System (RPS) to generate protection grade interlocks and reactor trip signals.

Prior to 1987, most Westinghouse pressurized water reactors used a bypass piping arrangement as shown in Figure 10.1-1. This layout is used to monitor the temperature of the fluid in both the hot leg (T_h) and the cold leg (T_c) of the RCS. By using a bypass arrangement, the flow velocity in the bypass piping is much lower than that of the RCS. The lower flow velocity allows direct immersion RTDs to be placed directly into the flow stream without damaging the RTD. Direct immersion RTDs provide a faster time response to temperature changes of the reactor coolant than that of RTDs mounted inside thermowells. However, plant experience demonstrated two major drawbacks to this design:

Lack of Reliability - The bypass piping consists of nearly 280 feet of RCS pressure boundary piping, eight RTD manifolds, approximately 70 valves, and their associated flanges. With the above number of components, various plant shutdowns have been required because of leakage from mechanical joints, valve packing, or because of flow reductions due to valve problems.

Personnel Radiation Exposure - The RTD bypass system is a significant contributor to the man-rem exposure due to the crud traps (low flow/low spots) that exist in this piping configuration. The radiation exposure contribution to the man-rem dose not only comes from performing maintenance on the RTDs, but also adds to the dose received by plant personnel when they were working in the general vicinity of the reactor coolant pumps (RCPs) and the steam generators. It's estimated that the removal of the RTD bypass manifolds and associated piping will save 1500 man-rem per nuclear unit over the next 30 years.

In response to these problems, all existing piping, manifolds, and valves will be cut out and removed from the containment. The direct immersion RTDs will be replaced with fast acting, narrow range RTDs mounted inside the thermowells. The existing penetrations in the hot and cold legs will be used for the narrow range RTD thermowells. The return penetration into the intermediate leg will be capped.

Although the response time of fast acting RTDs located within the thermowells is slower than the response time of direct immersion RTDs, there is no bypass loop transport lag time to account for as with the bypass manifold design. Therefore, the total response time for this arrangement is unchanged, and as such no reanalysis of the accident section of the Final Safety Analysis Report (FSAR) was required.

As shown in the inset of Figure 10.1-1, the narrow range hot leg RTDs use the three flow nozzles from the RTD bypass system. These nozzles extend into the hot leg piping of each loop. The use of this configuration, three nozzles located 120 degrees apart circumferentially, insures that a representative sample of the hot leg water is measured. A thermowell is mounted inside each of these scoops. The scoop is modified so that coolant flows past the scoop and then enters the scoop through small holes on the downstream side, where the coolant comes in contact with the thermowell.

A dual element RTD is inserted into each thermowell. One element provides an electronic signal to a low voltage amplifier. The amplified signal from each of the three hot leg RTDs, in a single loop, are averaged together to generate a single T_h signal (T_h average or T_{have}) for that loop. This averaged signal, along with the T_c signal of that loop are used to generate a loop T_{avg} and a loop ΔT signal.

The cold leg narrow range RTD of each loop, also a dual element fast acting RTD, is inserted into a thermowell directly downstream of the reactor coolant pump. Due to the turbulent flow at the discharge of the RCP only one narrow range RTD is required to provide an accurate indication of temperature.

The second element of each fast acting RTD, at each location, is considered an installed calibrated spare. It is wired directly to the RPS cabinets, but it is not connected to any electronics. In the event of a failure of the first temperature element, the second element is available for use.

The narrow range cold leg RTDs are calibrated to provide an output of 510°F - 630°F, while the narrow range hot leg RTDs are calibrated to provide an output of 530°F - 650°F. Figure 10.1-2 illustrates how both the hot and cold leg RTD temperature signals are used to calculate loop T_{avg} with a range of 530°F to 650°F and a loop ΔT with a range of zero to 120%. These calculated values provide information to the control room operator concerning plant conditions.

Reactor coolant T_{avg} $\{(T_h+T_c)/2\}$ indicates the condition of the coolant in areas such as; the margin to saturation, the heat capacity of the reactor coolant, and the temperature deviation from the programmed temperature setpoint (T_{ref}). The rate of change of T_{avg} and its deviation from T_{ref}, is indicative of an imbalance between primary and secondary power. The average temperature of the coolant is used as an input when determining the margin to departure from nucleate boiling (DNB).

10.1.1.2 Wide Range Temperature Detectors

Hot and cold leg reactor coolant loop temperatures are also measured by wide range RTDs (0-700°F) mounted in thermowells in the reactor coolant piping of each loop. These detectors are used for indication during heatup and cooldown and during natural circulation operations. Both of the wide range RTDs, T_h and T_c, supply an input to the subcooling margin monitor, section 10.1.6. The wide range hot leg RTDs are also used in the RVLIS, section 10.1.5 of this chapter.

10.1.1.3 Pressurizer, Surge Line, and Spray Line Temperature

There are two temperature detectors on the pressurizer (Figure 10.1-3). One measures steam temperature and the other measures the water temperature of the pressurizer. Under normal conditions, the pressurizer is a two-phase system in equilibrium, so water and steam temperatures are equal. When they are not, an abnormal condition is indicated.

The surge line temperature detector provides indication and a low temperature alarm (<517°F). A low temperature alarm indicates that a large insurge of relatively cold water has entered the pressurizer or that ambient heat losses have lowered the temperature to the alarm setpoint. The temperature in the surge line should remain high due to a constant outflow from the pressurizer caused by the constant small spray bypass flow.

The spray bypass flow keeps the spray lines and spray nozzle close to the same temperature. If the spray nozzle is maintained at a temperature near to the temperature of the cold leg coolant temperature, the possibility of a thermal shock to the spray nozzle is minimized.

Each spray line has a temperature detector which provides indication and provides a low temperature alarm (<450°F). A low temperature alarm could indicate a loss of spray bypass flow, or an incorrectly positioned spray bypass throttle valve.

10.1.1.4 Safety and Relief Valve Discharge and Pressurizer Relief Tank Temperature

There is a temperature detector on the discharge of each pressurizer safety valve and a single temperature detector on the common discharge from both power operated relief valves. These temperature detectors provide indication, in the control room, that a safety or a power operated relief valve has opened or is leaking.

A high temperature alarm is actuated when any one of these detectors exceeds 160°F. This alarm alerts the control room operator of a discharge, or seat leakage past one or more of these valves. Since these detectors are located in close proximity to each other; any single valve lifting causes an increase in the output of all the temperature detectors.

There's also a temperature detector on the pressurizer relief tank which provides indication and generates a high temperature alarm (112.5°F). These detectors are shown in Figure 10.1-3. A high temperature in the PRT is an alternate method of alerting the control room operator of possible seat leakage past the pressurizer safety or relief valves.

10.1.1.5 Reactor Vessel Flange Leakoff Temperature

A temperature detector located between the leakoff line isolation valve and the reactor coolant drain tank is provided to alert the reactor operator of a leak from the reactor vessel flange O-ring seal. This alarm provides audible annunciation in the control room and is normally set 20°F above the ambient temperature of the containment.

The reactor vessel flange leak detection system may be isolated from the reactor coolant drain tank by closing (CV-8032) an air-operated valve from the main control board. This valve is designed to fail closed upon loss of containment air. If the reactor vessel flange inner O-ring starts leaking, the outer O-ring may be placed in service by manually realigning two valves located inside the containment.

10.1.2 Pressure

10.1.2.1 Pressurizer Pressure

Four, pressurizer pressure, transmitters provide indication, control and protection grade signals. These signals are used by the control room operator, the pressurizer pressure control system (section 10.2) and the reactor protection system (section 12.1). The pressure in the pressurizer is maintained by the operation of heaters located in the bottom of the pressurizer or by the operation of spray valves. These transmitters are narrow range, with an indication span of 1700 psig-2500 psig.

10.1.2.2 Reactor Coolant Loop and Pressurizer Relief Tank Pressure

Two pressure transmitters (PT-403 & PT-405) are located in the Residual Heat Removal (RHR) System suction line near its penetration into the RCS hot leg (loop 4). These are wide range transmitters (0-3000 psig) and are used for indication during startup and shutdown. They also provide interlocks to permit manual opening (pressure <425 psig) and to automatically close (pressure >600 psig) the two suction valves on the RHR suction line from the RCS. The automatic closure of these valves prevent over pressurizing the RHR system piping.

A pressure transmitter on the pressurizer relief tank provides indication in the main control room as well as a high pressure alarm set at eight psig. A high pressure in this tank may be indicative of a steam discharge into the PRT.

10.1.3 Pressurizer Level

Three pressurizer level transmitters provide indication, control and protection grade signals. These signals are used by the control room operator, the pressurizer level control system (section 10.3) and the reactor protection system (section 12.1). The level in the pressurizer is a direct measure of reactor coolant inventory. These transmitters are calibrated for a normal pressurizer operating temperature of 650°F. A fourth level transmitter is cold calibrated (80°F) and provides level indication during heatup, refueling, and cold shutdown operations.

10.1.4 Reactor Coolant Flow

As shown in Figure 10.1-1, flow in each reactor coolant loop is measured by three d/P transmitters located at the first bend in the intermediate leg of each reactor coolant loop. The square root of the pressure difference between the inside radius and the outside radius of the bend is proportional to flow and provides both indication in the control room and an input into the reactor protection system.

There is one, common high pressure, (HP) tap on the outside bend of the intermediate leg and three, separate low pressure, (LP) taps located on the inside bend of the intermediate leg. The HP tap receives a pressure input from both reactor coolant system pressure and a pressure from the centrifugal force of the coolant flow. The LP tap receives a pressure input from reactor coolant system pressure. Therefore, the difference in pressure between the outside radius and the inside radius of the intermediate leg is dependent upon flow.

If the HP tap fails (becomes clogged, or the instrument line ruptures), all three d/P transmitters would fail low (indicating a loss of flow) and generate a reactor trip signal. If the flow indication arrangement were designed with only one LP tap and it failed, then all three d/P transmitters would fail high, which is in the nonconservative direction, and a reactor trip on low flow in this loop could not occur. Therefore, three LP taps are used to provide redundancy and conservative system response. If one of the three LP taps were to fail, only its corresponding d/P transmitter would be affected (fails high), leaving the remaining two d/P transmitters to provide proper indication of flow and to generate a reactor trip signal if flow is reduced or lost in that loop.

10.1.5 Reactor Vessel Level Indicating System

The Reactor Vessel Level Indicating System (RVLIS) is designed to provide a reliable method of indicating the water level within the reactor vessel under normal or accident conditions. This instrumentation system is installed in the plant as a requirement of NUREG-0737. In addition to providing the operator with the water level in the reactor vessel during normal operations, the RVLIS also provides the operator with the following information during accident conditions, it;

- Indicates the formation of voids in the reactor coolant system during forced circulation
- Detects the approach to inadequate core cooling
- Detects voiding in the reactor vessel head
- Provides guidance to the operator for selecting emergency operating procedures associated with inadequate or degraded core cooling
- Provides an accurate measurement of the reactor vessel water level during natural circulation
- Provides information to the operator when the reactor vessel head vent system is being operated.

As shown in Figure 10.1-4, the RVLIS utilizes two trains of instrumentation, with each train consisting of three d/P transmitters. These transmitters are designed to measure the water level within the reactor vessel or provide information on the relative void content of the fluid surrounding the core during various operating conditions.

Penetrations into the reactor coolant system pressure boundary are made through a spare control rod drive mechanism (CRDM) penetration in the vessel head near its center (low pressure tap) and through an incore instrument conduit at the seal table (high pressure tap). In addition, two penetrations (one per hot leg) are made in the T_h RTD bypass manifold lines of loop 3 and loop 4.

Each sensing line is sealed at both ends with a bellows fluid separator. This separator serves as a hydraulic coupler or hydraulic isolator to transmit the sensed pressure of the d/P transmitter. These bellows, or hydraulic isolators, act as a second isolation valve on the reactor coolant system and functions as a containment isolation valve.

As shown in Figure 10.1-5, different input signals are used by the microprocessors to adjust the density compensation of the measured fluids. After the fluid density has been adjusted for the environmental conditions inside the containment, the microprocessor calculates the level within the reactor vessel.

Each microprocessor, is located on a panel in the control room. The output, from these transmitters, is displayed locally on the microprocessor and a signal corresponding to the level within the reactor vessel is sent to the plant computer. Each of the three d/P transmitters is calibrated to indicate the level in the reactor vessel, the relative void fraction in the reactor coolant or the voiding in the upper head of the reactor vessel. The RVLIS provides no annunciation in the control room. The following is a description of the three d/P transmitters.

One d/P transmitter is calibrated to measure the level in the reactor vessel with the reactor coolant pumps operating (ΔPc). This indication is referred to as the dynamic range and indicates from 0 - 120%. It provides an indication of reactor core and reactor vessel internal pressure drop during forced circulation flow in the reactor coolant system.

The reactor coolant pumps circulate water and steam as an essentially homogeneous mixture. Therefore, if the reactor coolant pumps are operating and if the void fraction in the reactor coolant is greater than zero there will not be a distinct water level in the reactor vessel. However, a comparison of the measured d/P across the reactor vessel with the normal single-phase flow d/P provides an approximate indication of the relative void content or density of the circulating fluid.

Finally, it should be understood that this instrument is not an indication of reactor vessel level during forced circulation but an indication of the relative void fraction of the reactor coolant. In addition, this instrument acts as a backup indication with the reactor coolant pumps turned off, i.e., this instrument is calibrated so that it indicates 40% with the reactor vessel full of water and the reactor coolant pumps turned off. Therefore, during natural circulation, a value of less than 40% would be an indication, to the operator, that the reactor vessel is not completely full.

The second d/P transmitter is calibrated to measure the full range of the reactor vessel with the reactor coolant pumps secured (ΔPb). This indication is referred to as the full range and spans the total height of the reactor vessel (approximately 40 ft). It's calibrated to indicate 100% (instrument range 0-120%) with natural circulation flow in the reactor coolant system.

When all reactor coolant pumps are stopped, if any voids exist in the reactor coolant they separate from the liquid. As a result the liquid collapses toward the bottom of the reactor vessel and the steam voids rise and fill the upper portion of the reactor vessel. This transmitter's output is an indication of the collapsed water level. The actual water level in the reactor vessel may be slightly higher than that indicated, due to the frothy mixture of very small steam bubbles mixed with the coolant in the reactor vessel. In this instance, the RVLIS provides a conservative indication of coolant to provide adequate core cooling.

With the reactor coolant pumps operating the d/P across the reactor vessel is higher than the d/P across the vessel during natural circulation. As a result of the higher d/P this instrument indicates off-scale high during forced circulation and the information provided is invalid.

The third d/P transmitter provides indication of the water level in the reactor vessel head (ΔPa). This indication is referred to as the upper range and spans the total height from the hot leg to the top of the reactor vessel head (approximately 15 ft). This instrument is calibrated to indicate from 60-120% with natural circulation flow in the reactor coolant system. This instrument provides an accurate indication of possible voiding in the upper head region and is used for guidance when operating the reactor vessel head vents. This measurement also provides backup confirmation that the level in the reactor coolant system is above the hot leg nozzles.

If the reactor coolant pumps are operating, the d/P is less than the calibrated span of this instrument during natural circulation. Therefore, like the indication from the full range instrument the output this instrument is invalid whenever there is forced flow through the core.

As previously described, the reactor coolant pumps have a large influence on the output of each of these d/P transmitters. The dynamic head transmitter, ΔPc, is calibrated to indicate 100% with the reactor coolant pumps operating and 40% without any RCPs operating. The full range transmitter, ΔPb, and the reactor vessel head transmitter, ΔPa, are calibrated to indicate 100% with the reactor vessel full of water and without any reactor coolant pumps operating. Therefore, if the reactor coolant pumps are operating, these indicators, ΔPb and ΔPa, will be over ranged high and low respectively. The calibration of these transmitters is accomplished with the RVLIS microprocessor, as shown in Figure 10.1-5.

In addition to reactor coolant pump operation, temperature changes in the reactor coolant or changes in the ambient air temperature inside the containment have an effect on the measured level in the reactor vessel. The RVLIS microprocessor uses the following inputs to compensate for density changes of the measured fluids to ensure that the indicated level is as accurate as possible.

- Wide range T_h,
- Wide range loop pressure and,
- Capillary RTDs.

Temperature measurements of the sensing lines are used to compensate for the density of the fluid. Strap-on RTDs (vertical capillary tube RTDs) are placed on the vertical portion of various sensing lines. The following are examples of some of the areas that these strap-on RTDs may be placed:

- Bottom of the reactor vessel cavity,
- Incore thimble tunnel,
- Hot leg penetration area, and
- Rise above the seal table.

These measurements, along with reactor coolant wide range T_h temperature and reactor coolant system wide range pressure are employed to automatically compensate the d/P transmitter outputs for density changes during normal operations and adverse containment conditions following an accident. The sensed differential pressure is transmitted by the d/P transmitters to the RVLIS microprocessor for processing. The various levels can be read directly off this panel or from a remote display panel located in the control room.

The last input into the RVLIS processor is provided by hydraulic isolator limit switches. These switches provide over-travel alarms (indicative of an abnormally large deflection or failure of an upstream bellows diaphragm) on the microprocessor. This alarm alerts the control room operator that the hydraulic isolators are operating in an undesirable condition. The alarm however, does not mean that the information provided by the RVLIS is invalid.

10.1.6 Subcooling Margin Monitoring

RCS subcooling can either be computed manually using a steam table or automatically by using a computer based algorithm. In either case pressure inputs are supplied by either the RCS wide range pressure indicators or the pressurizer pressure detectors. In most instances a RCS wide range pressure input is used. The temperature inputs used in the computation are RCS wide range T_h, and T_c, and the core exit thermocouples. The temperature input used to determine RCS subcooling is typically the core exit thermocouple temperatures.

The Subcooled Margin Monitor (SMM) is a microprocessor which continually displays the margin to saturation of the reactor coolant. This instrument uses reactor coolant system pressure or temperature as a base for calculating the subcooling margin. Its used as a post accident monitoring instrument in conjunction with the RVLIS and the Core Exit Thermocouples (CETs). It also provides a quick and accurate method to detect the approach to, or the verification of saturated conditions in the reactor coolant.

As shown in Figure 10.1-6, each train of the SMM receives the following process inputs:

- 1 RCS wide range pressure input,
- 2 wide range loop hot leg temperatures,
- 1 wide range loop cold leg temperature,
- 8 core exit thermocouples, and
- 1 cold junction RTD temperature

The reactor coolant system pressure input is provided by RCS wide range pressure instruments PT-403 (train A) and PT-405 (train B). Only one pressure input is sent to either train and there is no designated alternate pressure input.

Wide range T_h inputs from loops two and four are supplied to the train A SMM calculator, while T_h inputs from loops one and three are supplied to the B train. Due to the limit on inputs for the SMM, only one T_c input is provided to each train of the SMM. Reactor coolant system loop one provides the input to train A while loop three provides an input for train B.

The core exit thermocouple inputs into the SMM consist of two groups of eight leads, (two core exit thermocouples per core quadrant). If a thermocouple fails, an alternate input may be substituted with a designated alternate thermocouple at the respective trains' isolator. The selecting of alternate core exit thermocouples may be performed as long as the requirements of Technical Specifications concerning core monitoring are met; i.e., two thermocouples from each core quadrant are available.

To ensure the accuracy of input data from the core exit thermocouples, cold reference junction temperature inputs are provided to the SMM calculator modules. The cold reference junction increases the accuracy of the core exit thermocouple inputs by compensating for signal errors developed by the transition of the thermocouple wiring.

Two analog output channels are provided by each train of SMM. One is used to drive a remote temperature display panel. The other output is sent to the plant computer and the remote shutdown station. In addition, two alarm signals (annunciated in the main control room) are provided from this monitor to alert the control room operator to an impending loss of core subcooling or the actual loss of subcooling. The setpoints for these alarms are as follows:

- 15°F for low margin, and
- 0°F for no margin of subcooling.

During normal operation each SMM displays either TEMP margin or PRESS margin (selectable by the control room operator using a pushbutton on the subcooled monitor display panel). The selected mode is indicated by the backlighting of either the TEMP or PRESS segments of the push button. The displayed value is updated every two seconds. Also located on this panel is a reset switch which functions in the on-line testing mode, or is used to reset any inputs disabled by the operator.

When the pushbutton control switch indicates TEMP, the temperature margin is displayed in °F with a resolution of 0.1°F. The indicated temperature margin is the difference between the measured reactor coolant temperature and the temperature at which the coolant will boil (saturation temperature).

The highest of all the active input temperature values is used to calculate the temperature margin. This is compared to the saturation temperature calculated from the wide range pressure input. The calculated result is then the worst case temperature margin. A negative temperature margin indicates superheated conditions.

When the pushbutton control switch indicates PRESS, the pressure margin is displayed in psi with a resolution of 1 psi. The indicated pressure margin is the difference between the measured reactor coolant pressure and the pressure at which the coolant will boil (the saturation pressure).

In summary, the SMM is particularly useful during accident and post accident conditions when primary coolant temperature and pressure may be rapidly changing. The SMM uses reactor coolant process signals to calculate and provide continuous indication of the margin to saturation of the reactor coolant. The control room operator is provided with a continuous indication of either the pressure or temperature margin to saturation and is able to devote his/her attention to mitigating the consequences of the accident. The possibility of unknowingly changing plant parameters which could lead to uncovering the core is greatly reduced, as the SMM provides an automatic alarm at a preset saturation temperature setpoint.

The RTD inputs (T_h and T_c) are included in the SMM only because they were included in the original SMM design. Should any RTD fail, its input can be disabled in accordance with approved procedures at the affected panel, and the SMM is still operable. The RTD inputs are only "nice to have," but are not required by design. The core exit thermocouples are required inputs. Should a pressure input fail, the affected SMM is inoperable. There is no immediate recovery from this condition short of repairing the pressure input.

Eight core exit thermocouples, two CETs per core quadrant, are required for each SMM. The loss of a CET input not only affects the operability of the affected SMM, but it is also addressed by the Technical Specifications as an issue in and of itself. Therefore, the SMM and the CETs are integrally related in their respective action statements in the Technical Specifications.

Flexibility was considered in the design of the SMM so that a failure of a CET can be overcome. The outputs of all 65 CETs are routed to two process panels, 32 CET outputs in one panel, and 33 CET outputs in the remaining panel. Eight signals in each panel are transmitted to the SMMs. The failure of any single CET input is easily removed from the SMM and an alternate CET is wired in. Note - the CET which is selected as an alternate must be from the same core quadrant as the failed CET.

10.1.7 Summary

Monitoring the reactor coolant system temperature is accomplished with the use of RTDs. These instruments are divided between wide range (0-700°F) and narrow range (510°F to 650°F) RTDs. The wide range instruments provide indication in the control room and supply inputs to the RVLIS and SMM. The narrow range RTDs are electronically combined to form T_{avg} and ΔT signals, which are used to provide indication for the control room operator, and provide inputs to control systems, the reactor protection system.

Protection grade signals from T_{avg} and ΔT are used to generate two reactor trips (OTΔT and OPΔT). In addition the T_{avg} signal is used to generate two protective grade interlocks; Lo T_{avg} and LoLo T_{avg} (Permissive P-12). The protection grade signals are separated from the control grade signals by isolation amplifiers.

The non-safety T_{avg} signal is supplied to the following process systems:

- Rod control,
- Pressurizer level control, and
- Steam dump control.

In addition, T_{avg} and ΔT supply signals to the rod insertion limit comparators which are discussed in section 8.4.

Reactor coolant system wide range pressure (0-3000 psig) is monitored by pressure transmitters located on the residual heat removal suction piping, which is attached to loop four of the reactor coolant system. In addition, the pressurizer and pressurizer relief tank are instrumented so that the reactor operator can monitor the pressure, temperature and level of these tanks. The pressure and level transmitters attached to the pressurizer, as well as their functions, are discussed in Sections 10.2 and 10.3 respectively.

The flow in the reactor coolant system is continuously monitored by loop elbow flow d/P transmitters. The flow in each loop is proportional to the square root of the d/P between the inner and outer radius of the loop elbow. Each reactor coolant loop has three d/P transmitters that provide signals for indication and protection.

The RVLIS is installed to monitor the level within the reactor vessel during normal and abnormal plant conditions. This system incorporates a number of d/P transmitters to indicate the water level in the reactor vessel. The RVLIS is sensitive to either forced flow through the core or natural circulation flow conditions. If an accident were to occur at the plant, the use of this indicating system aids the operator in selecting the proper emergency procedure during various loss of core cooling conditions.

The SMM is installed in the reactor plant to provide indication to the operator as to the status of subcooling (i.e., how close the reactor coolant is to boiling). The inputs to this system are wide range RCS pressure and the core exit thermocouples. The SMM display panel has a selector pushbutton which allows the operator to monitor either the subcooling temperature margin or pressure margin. This indication system, SMM, as with the RVLIS are required by NUREG-0737, and their operability is dictated by the plants Technical Specifications.

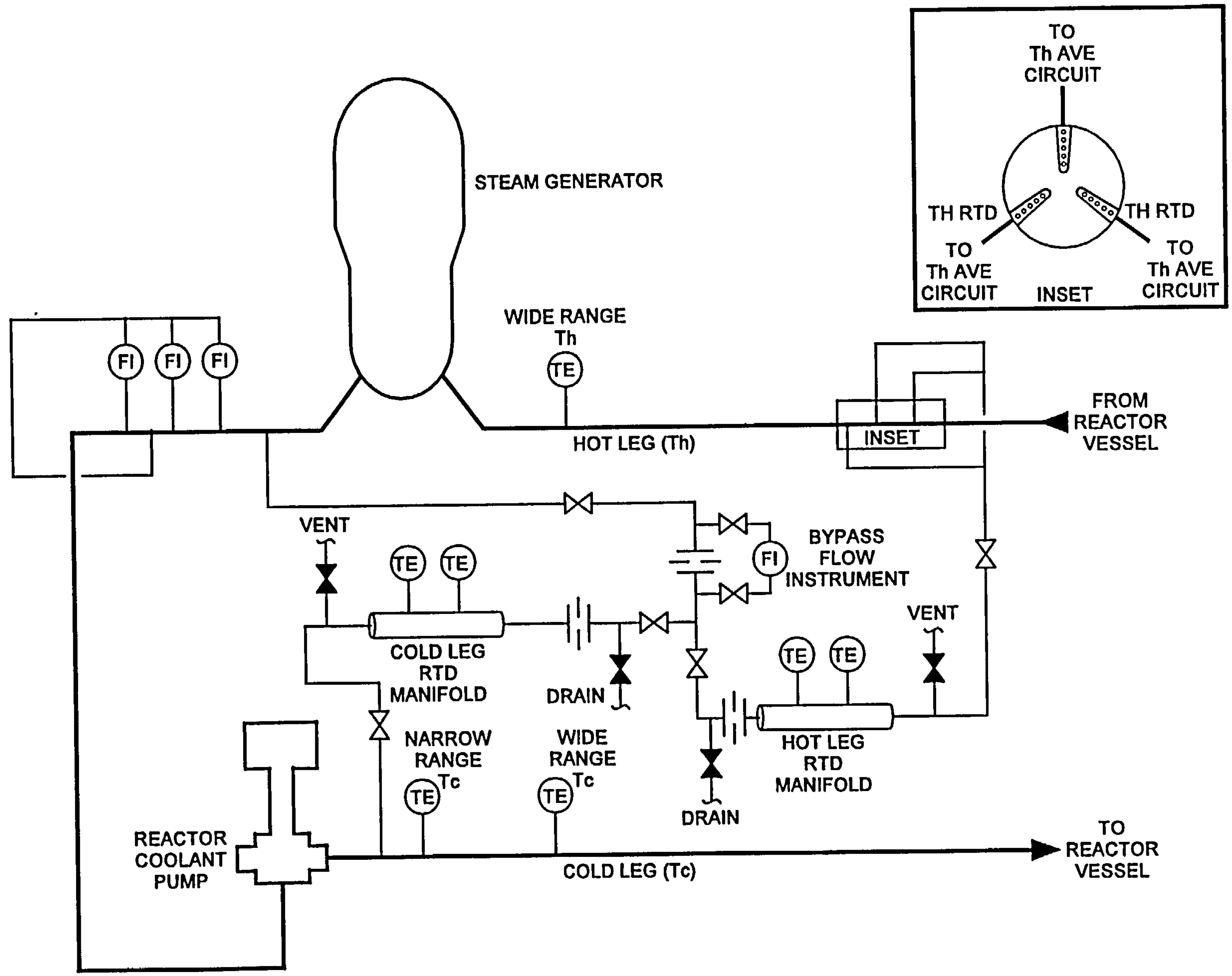

Figure 10.1-1 RCS Loop Instrumentation

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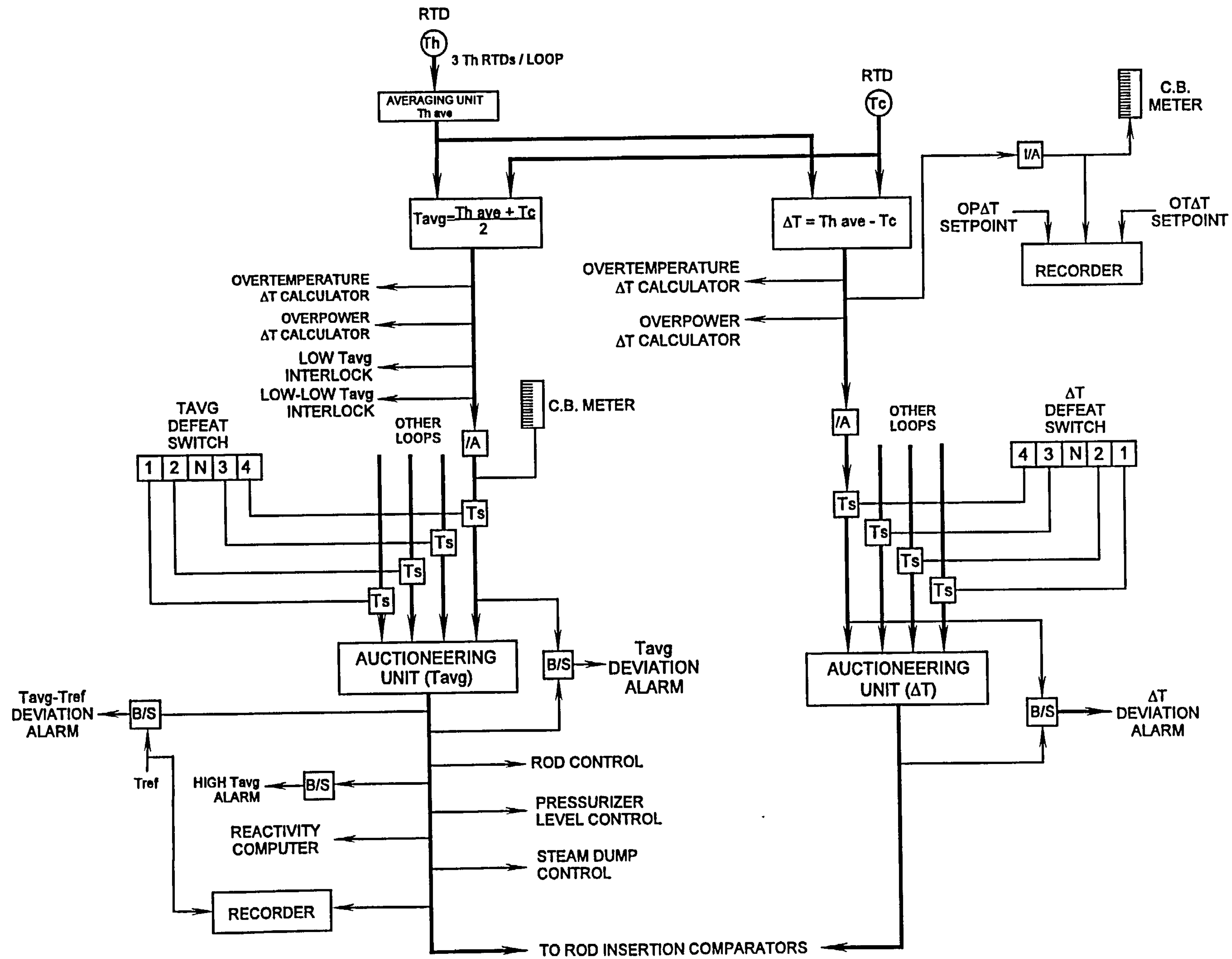

Figure 10.1-2 RCS Temperature Instrumentation

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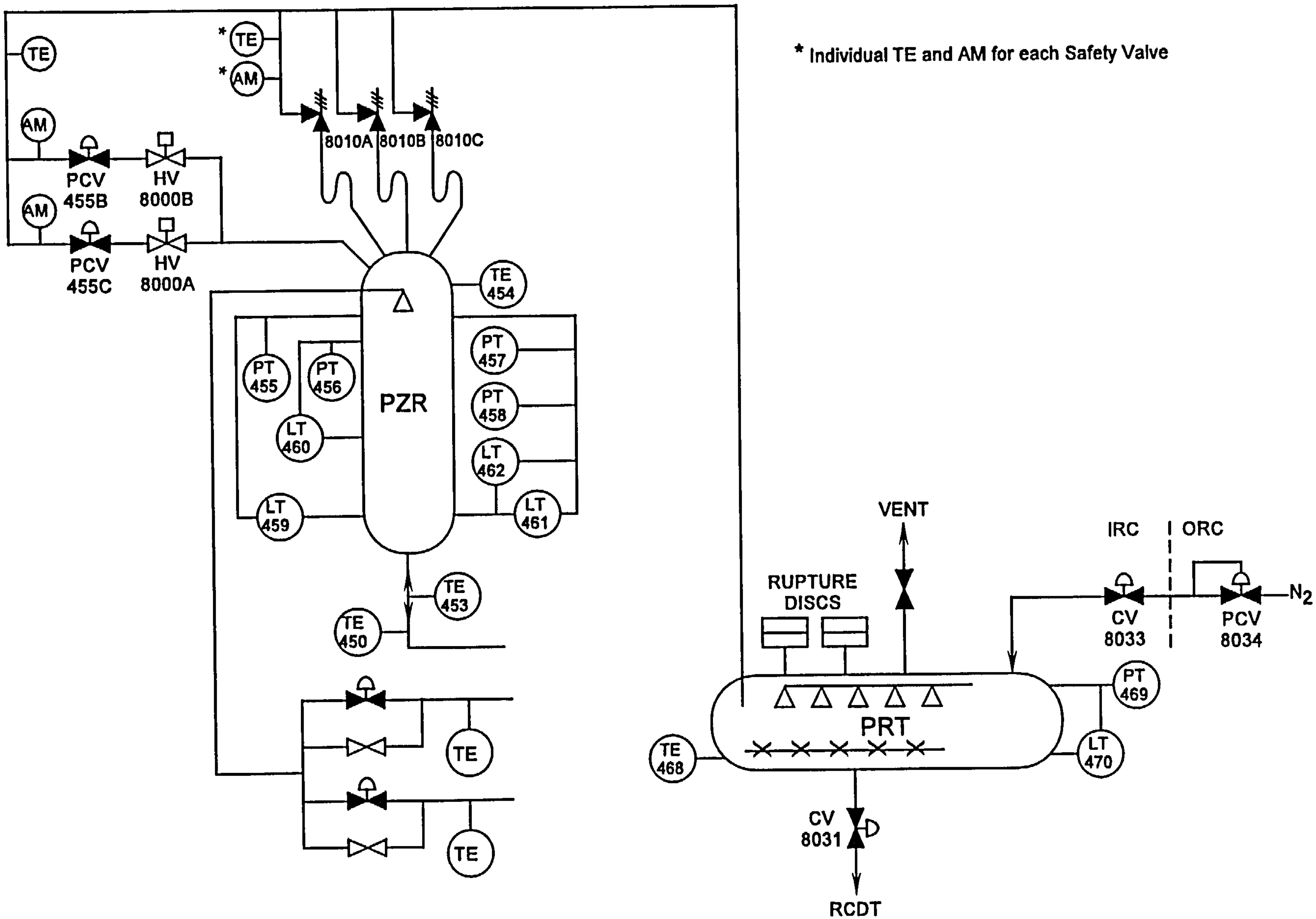

Figure 10.1-3 Pressurizer and Pressurizer Relief Tank

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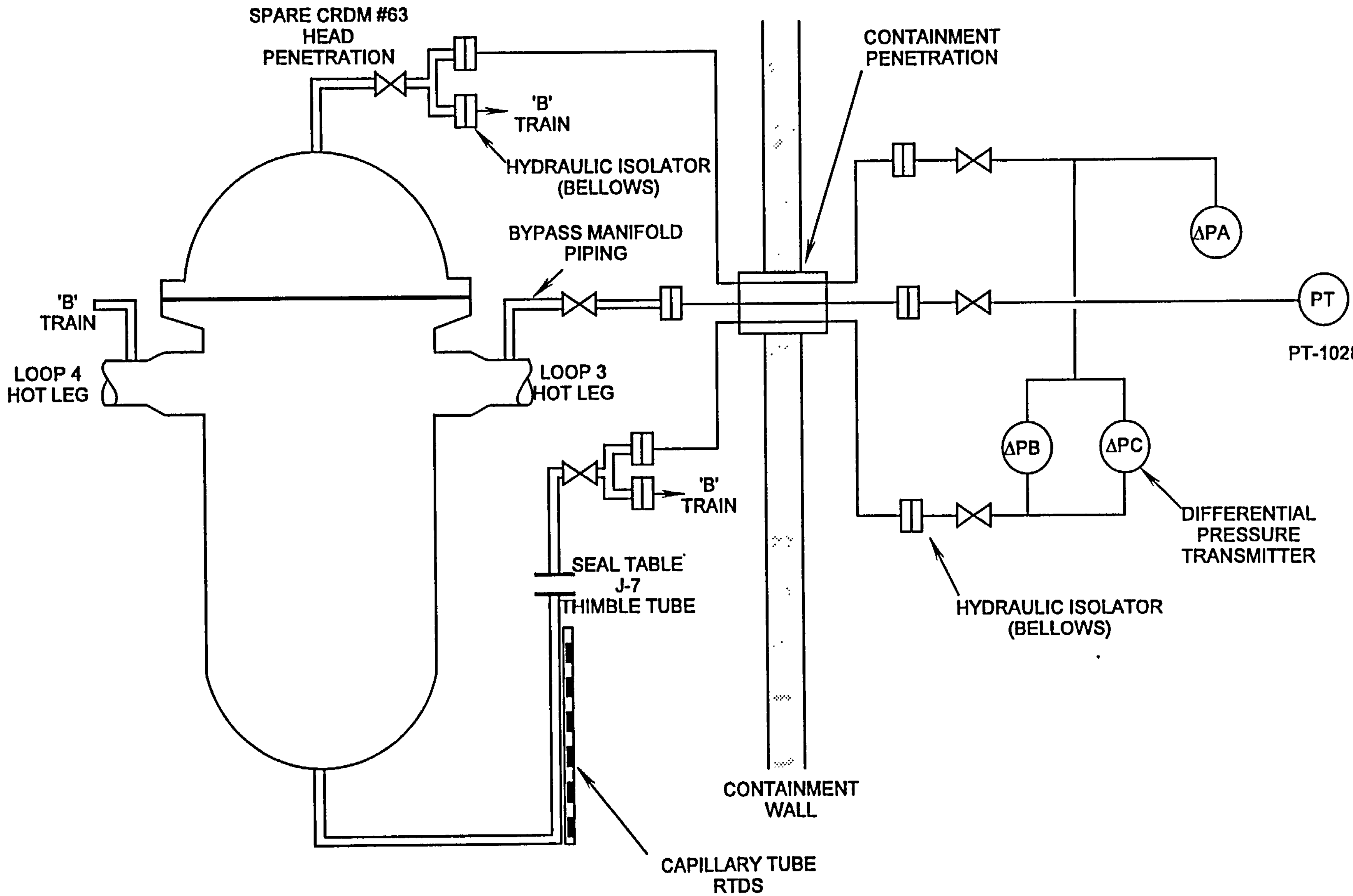

Figure 10.1-4 Reactor Vessel Level Indication System

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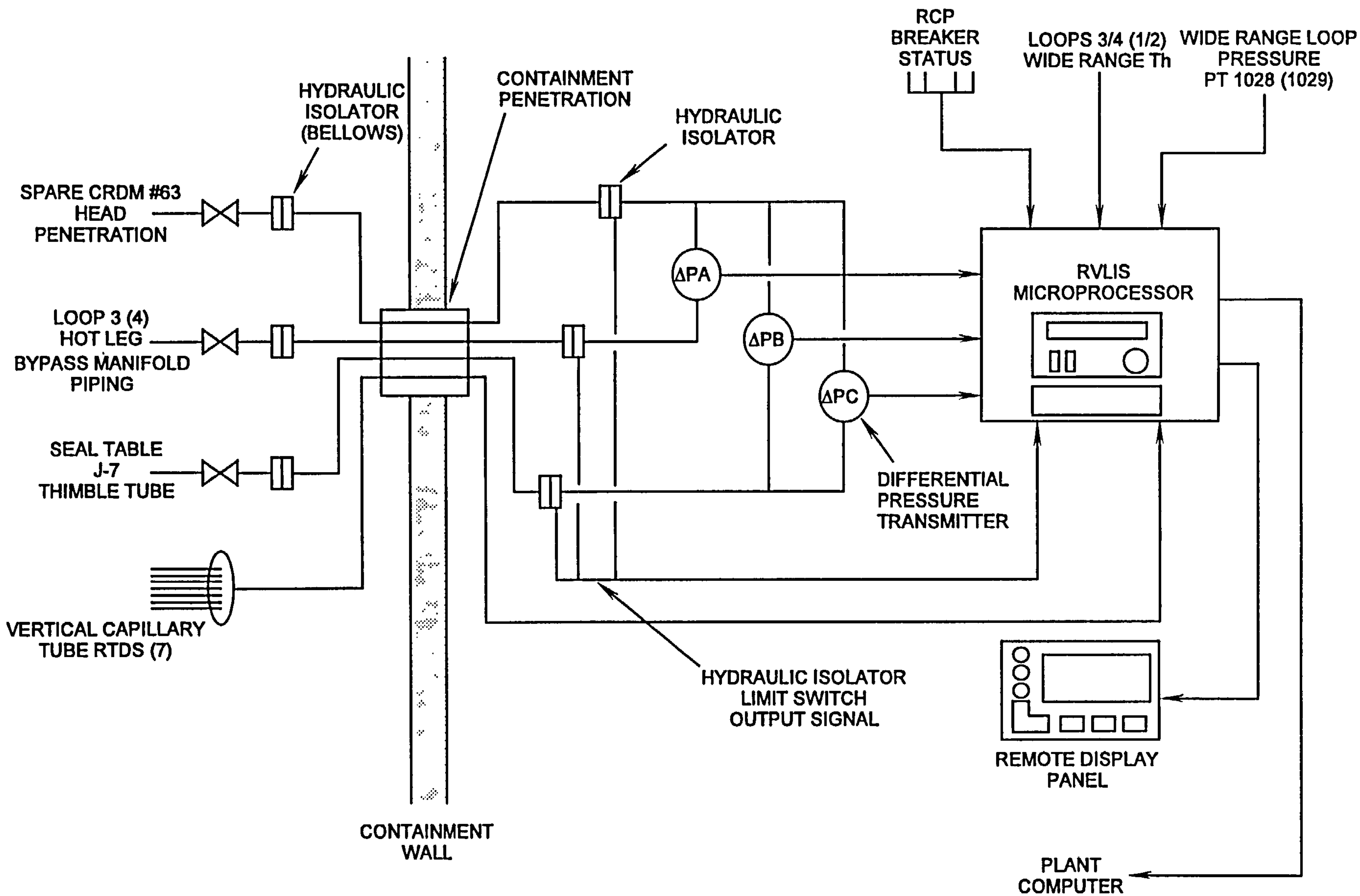

Figure 10.1-5 RVLIS Microprocessor Block Diagram

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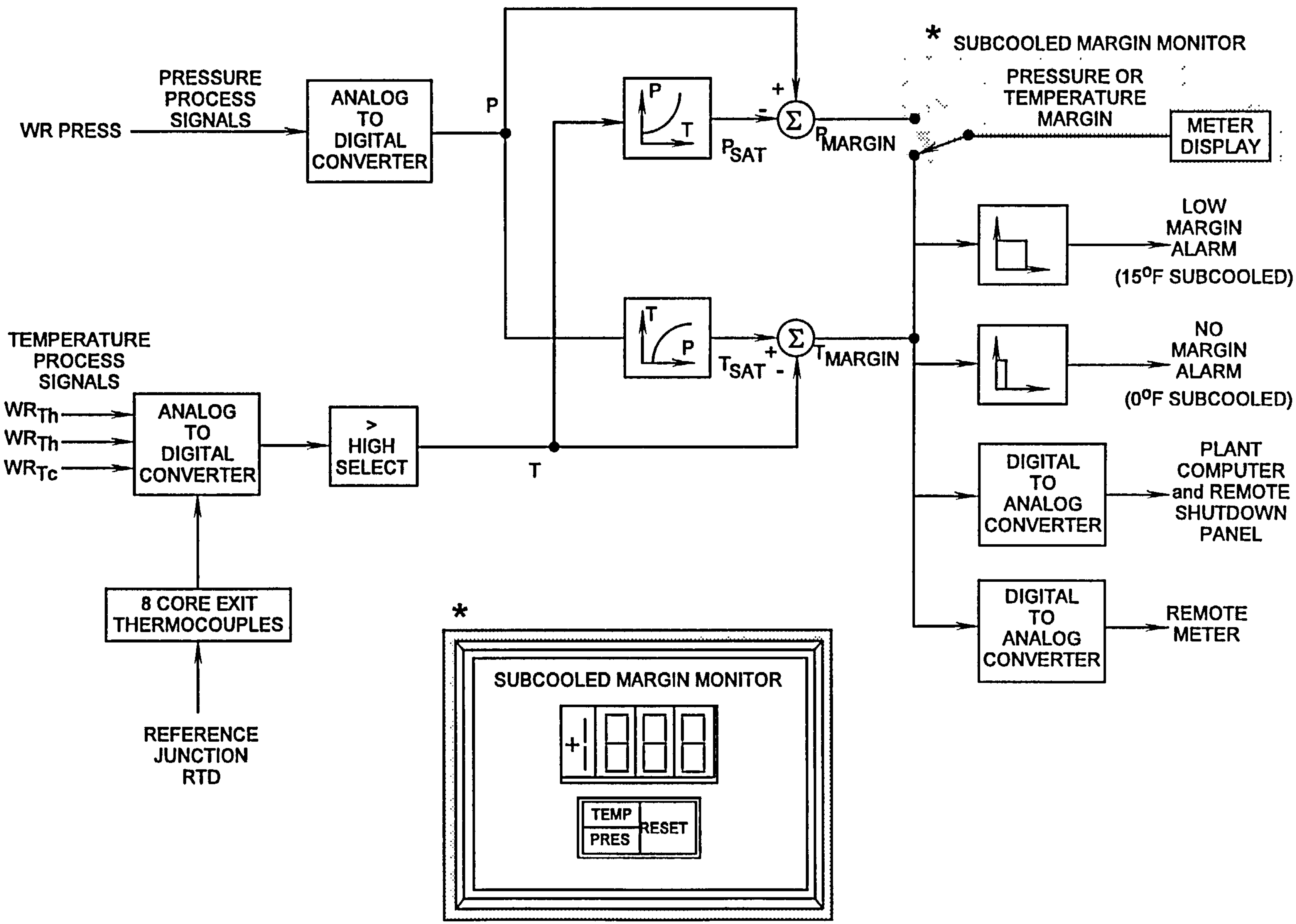

Figure 10.1-6 Subcooled Margin Monitor

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Section 10.2

Pressurizer Pressure Control System

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10.2 PRESSURIZER PRESSURE CONTROL SYSTEM

Learning Objectives:

1. List and describe the purposes (bases) of the protective signals provided by the pressurizer pressure transmitters.

2. List and describe the purposes of the permissives and interlocks provided by the pressurizer pressure transmitters.

3. List in sequence the actions performed by the pressure control system during:

   a. A continuous pressure increase above 2235 psig

   b. A continuous pressure decrease below 2235 psig

4. Explain the effect of changing the pressure control setpoint on both control and protective functions.

5. List the inputs to the cold overpressure protection system and explain the operation of the system.

10.2.1 Introduction

The pressurizer pressure control system maintains the pressure of the reactor coolant system at or near an operator selectable setpoint. The setpoint span is 1700 psig to 2500 psig and is normally set at 2235 psig.

The pressurizer pressure control system controls the operation of electrical heater banks, pressurizer spray valves, and power operated relief valves (PORVs). When these components are actuated at the proper times, under and over pressurization events are minimized. The heaters and spray valves are set to operate at various fixed pressure deviation points from the controller setpoint to control the reactor coolant system (RCS) pressure within a narrow band.

10.2.2 System Description

The pressurizer heaters are divided into four banks consisting of: one bank of proportional heaters (heater bank C) and three banks of backup heaters (heater banks A, B, & D). The proportional heaters are operated by varying their applied voltage, thereby directly and proportionally controlling their heat output over a fixed pressure range of 30 psig. The backup heaters are either energized or de-energized.

The proportional heaters maintain the equilibrium heat balance in the pressurizer during steady state conditions. If the pressure in the reactor coolant system decreases by move than 15 psig from the desired setpoint of 2235 psig, the proportional heaters provide their maximum heat output. If the pressure continues to decrease, and exceeds a value of 25 psig from setpoint, all banks of backup heaters are turned on. The heat provided by the heaters increases the water temperature inside the pressurizer. This results in increased flashing of water into steam, returning the pressure in the RCS to the desired setpoint.

If the pressure in the pressurizer increases above its normal setpoint, all heaters are turned off. If pressure continues to increase, the spray valves are modulated open which allows reactor coolant from the cold legs to flow through the spray nozzle into the pressurizer. The relatively cool water spraying into the steam space of the pressurizer condenses some of the steam, which in turn lowers the pressure.

If the spray valves are not capable of controlling the pressure increase for large overpressure transients; two power operated relief valves, located on the pressurizer, open to aid the spray valves in minimizing the pressure excursion. These relief valves exhaust steam directly to the pressurizer relief tank.

For transients that exceed the capability of the control system, appropriate high and low pressure reactor trips and a low pressure engineered safety features actuation signal are actuated by the reactor protection system (RPS). If the high pressure reactor trip is inoperable or the transient is of such a magnitude that the pressure in the RCS continues to increase, the three code safety valves to relieve steam to the pressurizer relief tank and act as a final means of protecting the integrity of the reactor coolant system pressure boundary.

Figure 10.2-1 shows a diagram of the equipment used to control pressure, while figure 10.2-2 is a functional block diagram for the pressurizer pressure control system. Example setpoints for the system are shown in Figure 10.2-3.

As shown in Figure 10.2-2 one pressurizer pressure channel feeds a PID (proportional + integral + derivative) controller (master pressure controller). The output from the master pressure controller provides an input to the controllers for the proportional heaters and spray valves. The master controller also provides an input to bistables that operate the backup heaters, and an input to the logic for one of the two power operated relief valves.

During steady-state operation, the pressurizer pressure control system operates the proportional heaters to compensate for minor pressure fluctuations. The proportional heaters operate at a low current to compensate for the continuous bypass spray flow (approximately one gpm) and heat losses from the pressurizer to ambient.

As shown in Figure 10.2-3 if the actual pressure in the pressurizer is 25 psig greater than the setpoint, proportional spray is initiated. The spray flow rate is proportionally increased as the pressure error increases until the spray valves are fully open (75 psig above setpoint). A dead band of 10 psig exists between de-energizing the proportional heaters and initiation of proportional spray. This dead band prevents frequent operation of the spray valves during minor system pressure variations.

The purpose of the two power operated relief valves is to maintain reactor coolant system pressure below the high pressurizer pressure reactor trip setpoint during transients that cause pressure in the RCS to increase. In addition, if these valves operate as designed they prevent or minimize the number of times the spring loaded, self actuating code safety valves lift. One power-operated relief valve modulates open with a pressure deviation from the master controller of 100 psig, and the second PORV operates at a predetermined fixed bistable setpoint of 2335 psig.

If the pressure error signal indicates a pressure lower than a predetermined setpoint (-15 psig), the proportional heaters are fully energized. If pressure continues to decrease, and a deviation of -25 psig from setpoint is reached the backup heaters are energized. In addition, a pressurizer low pressure alarm is actuated in the control room. This annunciator alerts the operator that an action requirement associated with the limiting condition of operation for departure from nucleate boiling (DNB) may be in effect as a result of pressurizer low pressure. The backup heater actuation setpoint is low enough to prevent continuous cycling, on and off, of the backup heaters during small pressure fluctuations.

10.2.3 Reactor Protection Signals

Four pressure transmitters are used to generate the required coincidence for the protective functions. In addition, these four channels provide control dependability through a channel selector switch for testing, and in the event of a failed transmitter, a non-faulted detector may be substituted into the control circuitry. The control functions of this system are physically separated from the protective features via isolation amplifiers. The protective functions of these pressure transmitters are discussed below and in detail in Chapter 12.

10.2.3.1 High Pressure Reactor Trip

The high pressure trip is generated when pressure in the pressurizer exceeds to 2385 psig, as sensed by at least two of four transmitters. It provides protection for the reactor coolant pressure boundary. This trip cannot be blocked by the operator.

10.2.3.2 Low Pressure Reactor Trip

The low pressure trip is generated when pressurizer pressure decreases to 1865 psig, as sensed by at least two of four transmitters. The low pressure reactor trip is functional whenever the power of the reactor or the turbine is greater than 10%. This trip is rate sensitive and protects against DNB.

10.2.3.3 Overtemperature ΔT Trip

There are four separate overtemperature ΔT (OTΔT) calculators, one calculator per reactor coolant loop. Each of the four pressurizer pressure transmitters supplies an analog pressure signal to its respective channel's calculator. The pressure input is one of the DNB parameters used in the computation of the OTΔT trip setpoint. The OT ΔT trip provides protection against DNB.

10.2.3.4 Engineered Safety Features Actuation

Three of the four pressurizer pressure transmitters (Channels I, II, & III) are used to generate an engineered safety features (ESF) actuation signal for loss of reactor coolant protection. The signal is generated when at least two of the three pressure transmitters sense a pressure of 1807 psig or less. In later generation designed Westinghouse units, the coincidence of this trip is two out four.

10.2.4 Permissives and Interlocks

10.2.4.1 ESF Actuation Block

The engineered safety features pressurizer safety injection block permissive (P-11) is generated when at least two of three pressure transmitters sense a pressurizer pressure of less than 1915 psig. This permissive allows the operator to manually block the engineered safety features actuation signal and allows the operator to perform a normal plant cooldown and depressurization without actuating the engineered safety features.

In accordance with IEEE Standard 279-1979 if a protective feature is removed from service it must automatically be reinstated if the process requires that protective feature. Therefore, when at least two of the three pressure transmitters sense a pressure of 1915 psig or greater, the P-11 block is automatically removed, and the low pressure ESF signal is reinstated within the logic portion of the reactor protection system.

10.2.4.2 Relief Valve Interlocks and Cold Overpressure Protection

The power operated relief valves attached to the pressurizer are provided with an interlock to prevent an inadvertent operation of these valves if pressurizer pressure is less than 2335 psig. This interlock prevents the failure of either a single pressure transmitter or the failure of the master pressure controller from inadvertently opening a PORV. Accidentally opening of a PORV is in effect a small break loss of coolant accident (SBLOCA) out of the top of the pressurizer, which causes a depressurization of the reactor coolant system. This interlock is built into the system via a second bistable which is actuated from a separate pressure transmitter. The second bistable's setpoint is established at 2335 psig. Using this configuration, as shown in Figure 10.2-2, it takes two channels, sensing a pressure equal to or greater than 2335 psig, in conjunction with the valve operating switch in the AUTO position to open a PORV.

The Standardized Technical Specifications require that the low temperature overpressure protection system (consisting of either two PORVs or an RCS vent) be OPERABLE whenever the RCS cold leg temperature is less than a predetermined value. The normal position of the low temperature overpressure protection switch (one per PORV, as shown in Figure 10.2-2) is the block position. When the pressure, as indicated by the wide range pressure detectors, is ≤ 375 psig, the operator is directed by the plant's operating procedures to place these switches in the unblocked position. This action arms the overpressure protection circuitry, and all that is needed for actuation of the PORVs is for pressure in the reactor coolant system to increase above the cold overpressure bistable setpoints.

If the pressure in the RCS increases to 400 psig, or greater, an alarm is annunciated in the control room alerting the reactor operator of an overpressure condition. If the control room operator takes no corrective action and pressure continues to increase, one PORV (PCV-455A) will open when RCS pressure exceeds 425 psig. If the magnitude of the pressure surge into the RCS is greater than the capacity of a single PORV, the second PORV (PCV-456) will open when the pressure in the RCS exceeds 475 psig. If the PORV's are open, the valves will close in the reverse order of opening as the pressure in the RCS decreases.

The control room operator can override the automatic signal and manually open or close a PORV. Manual control is independent of the pressurizer SI block (P-11) interlock and the cold overpressure protection system, as the manual open signal provides a direct input to the "or" logic used to actuate the PORV.

10.2.5 System Controls

10.2.5.1 Channel Selector Switch

A three-position selector switch mounted on the control board allows the control room operator to select different pressure transmitters for control and relief valve actuation in the event of testing or transmitter failure. This switch allows channel I or III to supply the input to the PID controller, while channels II or IV can supply the input for the actuation circuitry for the PORV not controlled by the PID controller.

10.2.5.2 Pressure Controller

The PID controller, or master pressure controller, provides an output control signal as a result of the comparison of actual pressure to an adjustable pressure reference setpoint in the controller. This setpoint adjustment (1700 psig to

2500 psig) is accessible to the operator via a potentiometer knob on the controller. The controller is normally set at 2235 psig.

10.2.5.3 Relief Valve Controls

Each PORV has a three-position switch located adjacent to each other on the main control board. These switches allow the control room operator to manually open or close the valves, or to place their mode of operation in automatic.

10.2.5.4 Spray Valve Controls

Each spray valve has an automatic/manual controller on the control board. These controllers allow the operator to manually open or close the spray valves, or to place them in the automatic mode of control and allow the master pressure controller to modulate these valves. The amount of modulation is dependent upon the error signal at the output of the master controller. If the pressure in the system increases to 2260 psig (25 psig above setpoint), both spray valves start to modulate open. If the pressure in the system increases to 2310 psig (75 psig above setpoint), both spray valves will be fully open.

10.2.5.5 Heater Controls

The proportional heaters have an on-off switch, mounted on the control board, which places them either in automatic control or de-energizes them. When the proportional heaters are operated in automatic, they receive a proportional current error signal dependent upon the error sensed by the master pressure controller. If the pressure in the system decreases to 2220 psig (15 psig below setpoint), the proportional heaters will be fully on. If the pressure in the system increases to 2250 psig (15 psig above setpoint), the proportional heaters turn off.

Each of the three backup heater groups has an off-on-automatic control switch mounted on the main control board which allows the operator to manually control the heaters or place them in automatic control. If these heaters are in automatic control and the pressure in the system decreases to 2210 psig (25 psig below setpoint), the heaters will be turned fully on. If the pressure in the system increases to 2218 psig (17 psig below setpoint), the backup heaters will be turned off.

In addition, there are local-remote, on-off switches for the backup heater groups, located on the remote shutdown panel in the auxiliary building. These switches allow limited remote control of pressurizer pressure in the event of a control room emergency.

10.2.6 Summary

The pressurizer pressure control system maintains the reactor coolant system pressure at or near a desired adjustable setpoint. This setpoint may be changed by the control room operator and is normally selected to 2235 psig. The pressurizer pressure control system maintains the reactor coolant system at the desired pressure by operating proportional and backup heaters, spray valves, and relief valves. Each component is actuated when the actual pressure in the pressurizer deviates from its setpoint by a specified amount.

The pressure transmitters also provide the reactor protection system with signals to actuate a reactor trip on high pressure for RCS boundary protection or a trip on low pressure to protect the core from departure from nucleate boiling (DNB). In addition if a loss of coolant accident were to occur, the system provides a low pressure signal to actuate the engineered safety features.

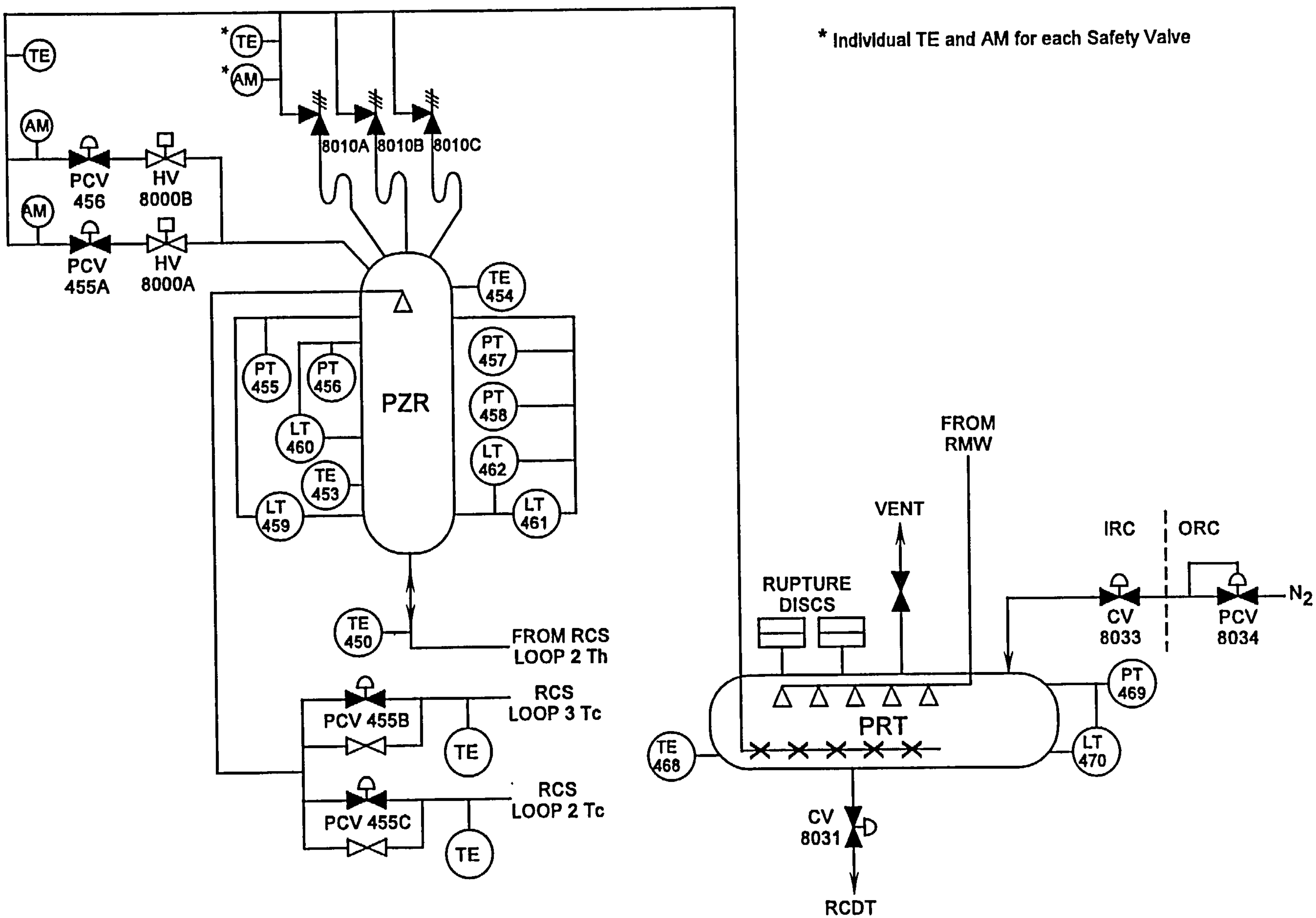

Figure 10.2-1 Pressurizer and Pressurizer Relief Tank

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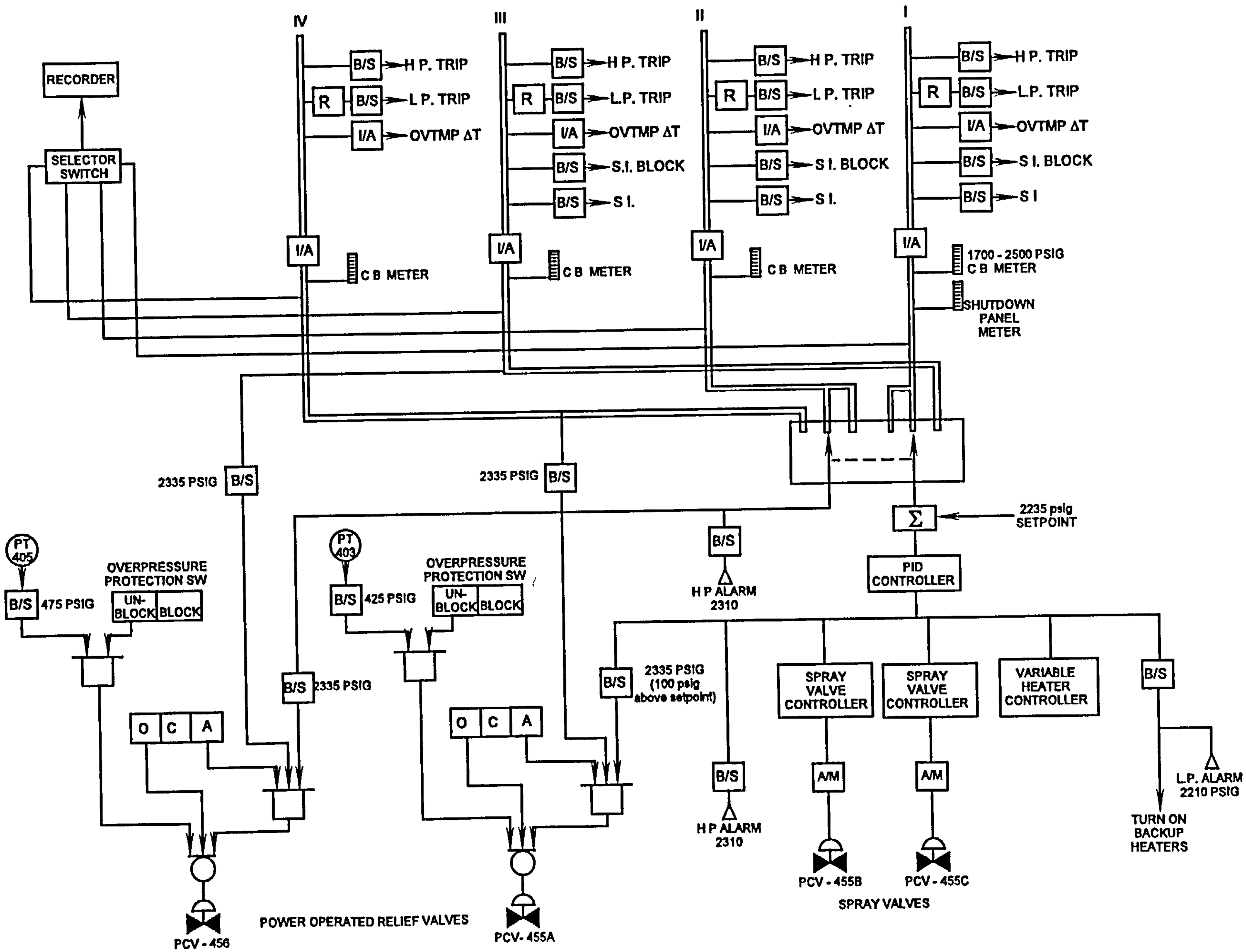

Figure 10.2-2 Pressurizer Pressure Control

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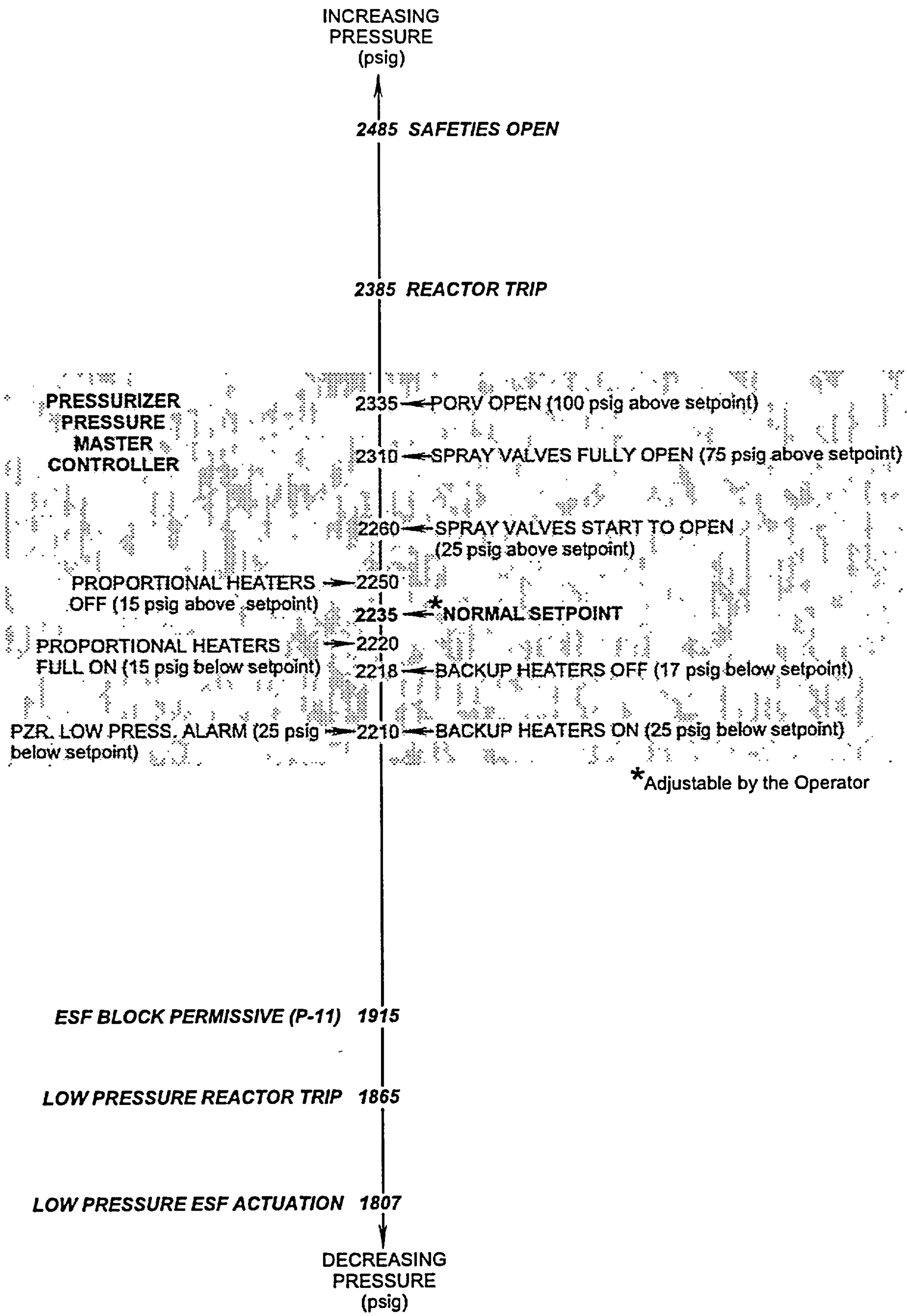

Figure 10.2-3 RCS Pressure Setpoint Diagram

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Section 10.3

Pressurizer Level Control System

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10.3 PRESSURIZER LEVEL CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the pressurizer level control system.

2. List and describe the purposes (bases) of the protective signal provided by pressurizer level instrumentation.

3. Identify the instrumentation signal that is used to generate the pressurizer level program, and explain why level is programmed.

4. Explain how charging flow is controlled in response to pressurizer level error signals during the following:

   a. Centrifugal charging pump operation
   b. Positive displacement charging pump operation.

5. Explain the purposes of the pressurizer low level interlocks.

10.3.1 Introduction

The purposes of the pressurizer level control system are to:

1. Control charging flow to maintain a programmed level in the pressurizer.

2. Provide an input to the reactor protection system for Reactor Coolant System (RCS) boundary protection.

10.3.2 System Description

During steady state operation, an unchanging pressurizer level indicates that a balance exists between the charging flow into the reactor coolant system and the letdown flow from the reactor coolant system into the chemical and volume control system. During transients the level in the pressurizer changes because the reactor coolant expands or contracts as the average temperature of the coolant increases or decreases.

Designing a control system to maintain a constant pressurizer level, as reactor power and reactor coolant temperatures change, is a relatively simple matter. However, a major disadvantage of such a system is that, as the temperature of the reactor coolant increases, the coolant expands. The expansion of coolant is seen as an increase in pressurizer level. When the level in the pressurizer increases above the programmed setpoint, the pressurizer level control system decreases the charging flow.

Recall from the Chemical and Volume Control System (section 4.1) that the amount of letdown flow from the reactor coolant system is constant (75 gpm). Knowing this fact and with the information provided in the previous paragraph, the amount of coolant being letdown is greater than the amount of coolant being returned to the reactor coolant system via the charging pumps. With this imbalance of flow, the level in the volume control tank increases. When the level in the volume control tank reaches a high level, coolant is diverted to the holdup tanks.

Once the water is diverted, it is treated as liquid waste and is processed for reuse. This places a large burden on the liquid radioactive waste processing systems.

On the other hand, a decrease in the temperature of the reactor coolant causes the coolant to contract and places a large demand on the makeup system. To minimize the demands on the liquid waste system and the chemical and volume control system, the level in the pressurizer is programmed to follow the natural expansion or contraction of the reactor coolant as temperature of the coolant increases or decreases.

The pressurizer level control system is shown in Figure 10.3-1, while the functional system parameters are displayed in Figure 10.3-2.

10.3.3 Component Description

10.3.3.1 Level Transmitters

The level in the pressurizer is measured by, comparing the difference in pressure between an external column of water of a known height (reference leg) and a variable unknown height of water inside the pressurizer (variable leg). The differential pressure (d/P) between these two columns of water is converted into a pressurizer level signal.

There are four differential pressure transmitters (d/P cells) mounted on the pressurizer. These d/P cells convert the sensed d/P into an electrical current that corresponds to a level varying from 0 to 100%. These transmitters utilize an external bellows type sealed reference leg with a condensate pot attached at the top of the leg to generate the static pressure head of the reference leg, and the actual water level inside the pressurizer to generate the dynamic or variable leg. Since the density of water varies with temperature, any temperature change of the coolant inside the pressurizer affects its indicated level. Therefore, the pressurizer level instruments are calibrated based upon pressurizer temperature.

Three of the four level transmitters are calibrated for normal operating temperatures and are used for indication, control and protection. The remaining level transmitter is calibrated for cold conditions and is used only for indication while operating at cold shutdown or when establishing a steam bubble in the pressurizer. The cold calibrated transmitter does not provide an input to the pressurizer level circuitry or an input into the reactor protection system.

The output of these level transmitters indicates a level from 0 to 100% inside the pressurizer. A selector switch, located on the main control board, allows the control room operator to select two of the three transmitters used for control. One channel is used for level control, letdown isolation, and pressurizer heater cutoff, while the other channel is used for backup letdown isolation, and heater cutoff. The third channel can be selected to replace either of the two controlling channels during testing or failures. An additional selector switch is provided on the main control board that allows the control operator to select any one of the three transmitters for recording.

10.3.4 System Interrelationships

10.3.4.1 Control Channel

The output of the pressurizer level controller is generated, by comparing the actual pressurizer level to a programmed reference level signal. If an error signal exists, it is transmitted to a PI (proportional plus integral) controller, which controls the chemical and volume control system charging flow. This controller prevents the charging flow from reacting to, small temporary level perturbations while eliminating steady-state level errors. Since the letdown flow is fixed, the inventory balance of the reactor coolant system is maintained by varying the charging flow. This is accomplished by one of two different methods:

1. If the positive displacement charging pump is operating, charging flow is controlled by varying the speed of the positive displacement charging pump.

2. If the centrifugal charging pumps are operating, charging flow is controlled by varying the position of a flow control valve

(FCV-121), located in the common discharge header downstream of the centrifugal charging pumps.

When the plant is operating and the power in the reactor is changed, the average temperature of the reactor coolant system is programmed to change. This change in temperature causes a corresponding change in the level of the pressurizer. To reduce the effect on the charging system, the level in the pressurizer is programmed (shown in Figure 10.3-2), as a function of auctioneered high T_{avg} which corresponds to the natural expansion characteristics of the reactor coolant. However, rapid transients cause an increase or decrease in the level of the pressurizer which requires changes in charging flow. For this reason, both minimum and maximum level limitations are placed on the level program in order to prevent the following:

1. The pressurizer low level setpoint of 25% is selected to prevent the pressurizer from going dry following a reactor trip. In addition, this level; ensures that a step load increase of 10% power will not uncover the heaters.

2. The pressurizer high level setpoint of 61.5% is derived from the natural expansion of the reactor coolant when the coolant is heated up from no load to full power T_{avg} (557°F to 584.7°F), with the assumption that the level in the pressurizer was at 25% when the heatup began.

   This level setpoint (61.5%) is lower than some maximum calculated level value, which ensures that the pressurizer does not go solid following a turbine trip from 100% power without a direct reactor trip, assuming no operator action, and no response by the automatic control systems (rod control and the steam dump system).

   In addition this level 61.5%, is low enough so that the insurge from a step load reduction of 50% will not cause the level in the pressurizer to reach the high level reactor trip setpoint. This assumes the automatic rod control system and the steam dump system respond to the transient properly.

In general, an outsurge of water from the pressurizer results in a system pressure decrease and an insurge of water from the reactor coolant system results in a pressure increase. However, if the insurge is large, it results in a system pressure decrease because the insurge water is cooler than the water in the pressurizer. Therefore, if the level in the pressurizer increases above the program level setpoint by 5%, the control system automatically energizes the backup heaters in an effort to offset the above effect.

This may be observed on a step load decrease (RCS temperature increases due to reactor power being higher than the secondary load), which causes an initial insurge into the pressurizer, and the cooler water entering the pressurizer causes a pressure reduction. This insurge is followed by a larger outsurge as the rod control system brings T_{avg} to program for the lower power level which in turn causes a pressure reduction. Therefore, the 5% deviation above set setpoint serves as an anticipatory signal to limit the pressure reduction in the reactor coolant system upon a load decrease.

The same level signal which is compared to the reference level in the level controller is also sent to a bistable. This bistable provides a low level interlock and is set to actuate at 17% level in the pressurizer. In addition to providing a low level alarm, this interlock isolates the letdown from the chemical and volume control system by closing one letdown isolation valve and all orifice isolation valves, and turns off all pressurizer heaters. Isolating the letdown prevents further lowering of pressurizer level, and the heater cutoff protects the heaters which would be damaged if operated in a steam environment.

10.3.4.2 Redundant Isolation Channel

This channel consists of an actual level signal sent through the channel selector switch and then to two bistables. One of these bistables functions to provide a high level alarm at 70% level. The other bistable closes the second letdown isolation valve, provides a redundant signal to close all orifice isolation valves, and turns off all heaters.

10.3.4.3 Pressurizer High Level Reactor Trip

If two out of the three level transmitters sense a level greater than 92%, a reactor trip signal is generated. This trip is provided to protect the RCS pressure boundary, and trips the reactor before the pressurizer completely fills with water, "goes solid". It also functions as a backup to the high pressurizer pressure reactor trip.

The high level trip setpoint is selected at a value that is low enough so that the discharge of water through the pressurizer safety valves is prevented. This is important because water discharged through these valves does not relieve the overpressure condition as effectively as steam. Steam releases more BTU's of energy per pound mass than water. Also, discharges of water could mechanically damage the pressurizer safety valves.

This trip is an "at power" trip and is only active if either reactor power or turbine power is 10% or greater ("At Power Permissive" P-7). This reactor trip is discussed in detail in Chapter 12.

10.3.5 Summary

The pressurizer level control system maintains the water inventory of the reactor coolant system by varying the charging rate from the chemical and volume control system. In addition, provisions are made to isolate letdown and turn off the pressurizer heaters on a pressurizer low level. This feature minimizes the effects of a loss of coolant and protects the pressurizer heaters.

The system also turns on the pressurizer heaters if the level in the pressurizer is higher than the program level. Turning on the heaters is performed in anticipation of a pressure decrease following a loss of load transient.

A pressurizer high-level reactor trip is provided to prevent operation with a "solid" pressurizer and is incorporated into the reactor protection system for RCS boundary protection.

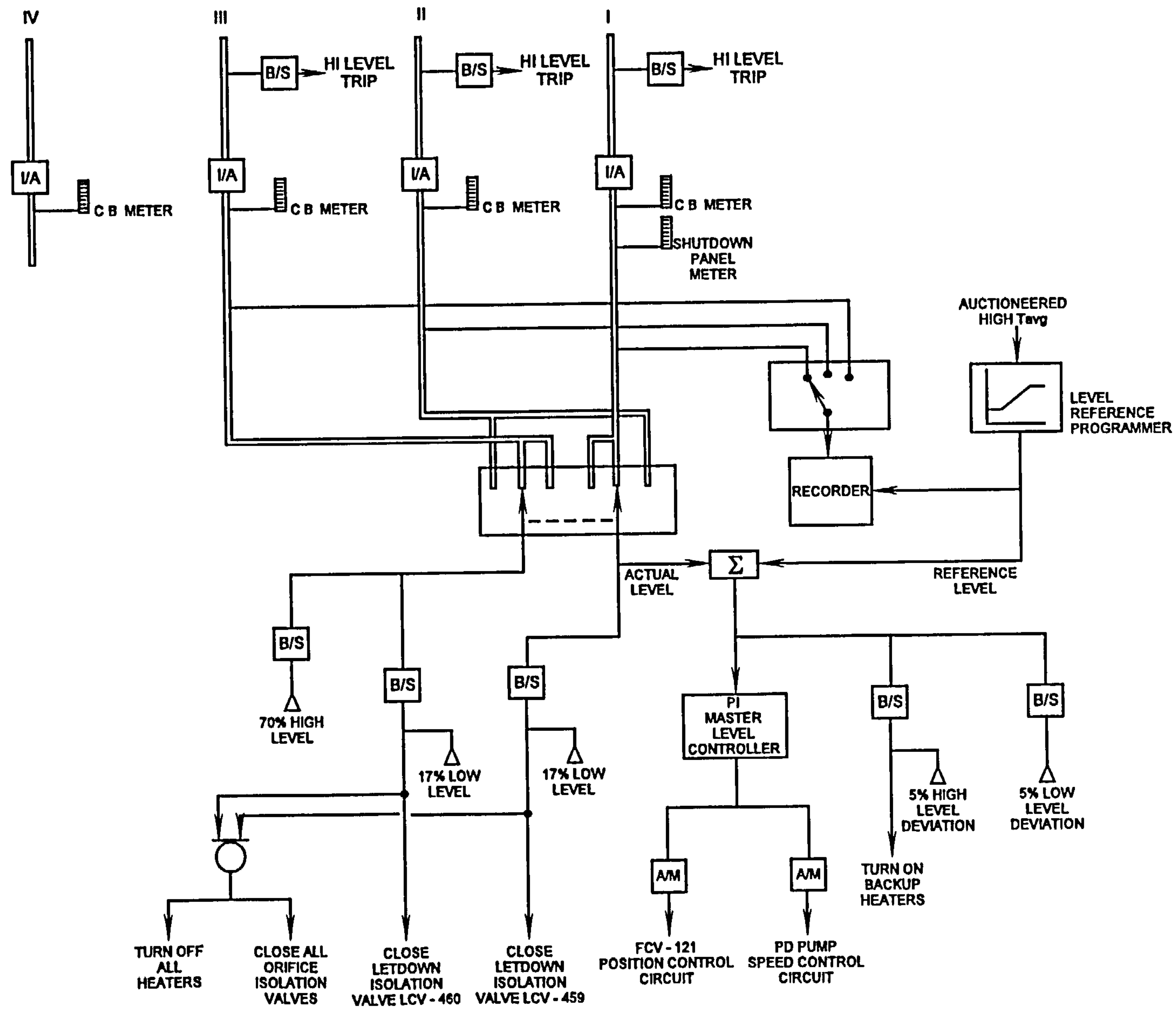

Figure 10.3-1 Pressurizer Level Control

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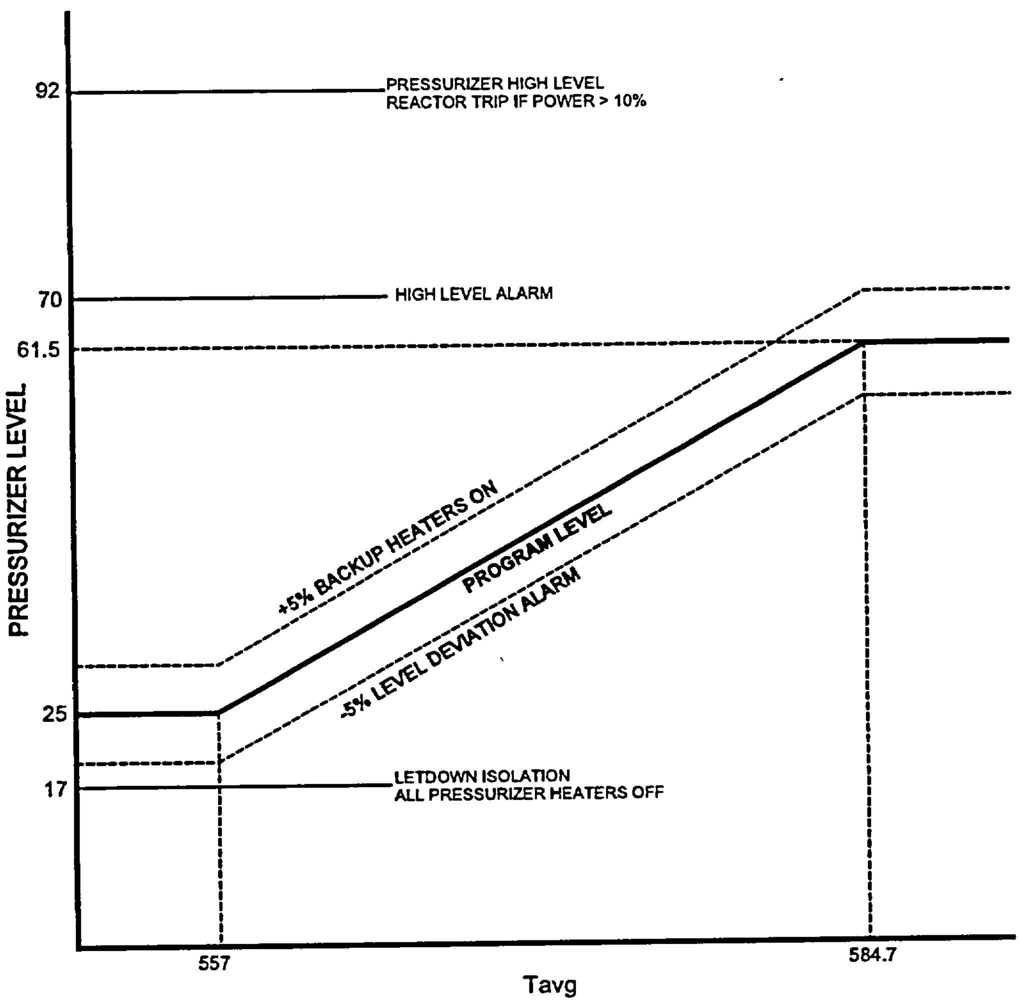

Figure 10.3-2 Pressurizer Level Program

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Chapter 11

SECONDARY SYSTEMS CONTROL AND INSTRUMENTATION

Section

Westinghouse Technology Systems Manual

Section 11.0

Secondary Systems Control and Instrumentation

11.0 SECONDARY CONTROL SYSTEMS

Introduction

The purposes of the secondary control systems are as follows:

1. Control feedwater flow in order to maintain a programmed water level within the steam generators

2. Control the operation of the steam dump valves in order to remove excess energy from the reactor coolant system, as warranted by plant conditions

3. Control the positions of the steam admission valves to the high and low pressure turbines in order to maintain the desired speed and load of the turbine

4. Regulate the steam supply to the second-stage reheater tube bundles of the moisture separator reheaters

The control systems discussed in this portion of the manual include the following:

11.1 Steam Generator Water Level Control System
11.2 Steam Dump Control System
11.3 Westinghouse Electrohydraulic Control System
11.4 Moisture Separator Reheater Control System
11.5 General Electric Electrohydraulic Control System

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Section 11.1

Steam Generator Water Level Control System

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11.1 STEAM GENERATOR WATER LEVEL CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the Steam Generator Water Level Control System.
2. List the Reactor Protection System and turbine trip inputs provided by steam generator instrumentation and state the purpose of each trip.
3. List the inputs used in the feedwater control system. Describe how and why each input is used.
4. List the inputs used in the main feed pump speed control system. Describe how and why each input is used.

11.1.1 Introduction

The purposes of the steam generator water level control system are as follows:

1. To control feedwater flow to maintain the programmed levels in the steam generators.
2. To control the main feed pump speed to maintain the programmed main feed regulating valve differential pressure.

Additionally, the steam generator instrumentation provides inputs into the reactor protection system for loss of heat sink protection and inputs into the turbine trip system for equipment protection.

The steam generator water level control system involves two separate control systems for regulating feedwater flow to the steam generators. The feedwater control system, which controls steam generator level from 20% to 100% power, modulates the positions of the 14-inch main feed regulating valves. This control system is provided with inputs of main steam flow, main feedwater flow, actual level, and reference level (programmed as a function of turbine impulse pressure). Below 20% power, feedwater flow is controlled through manual operation of the 6-inch feed regulating bypass valves.

The main feed pump speed control system is utilized above 20% power to control the speed of the main feed pumps. Appropriate control of feed pump speed maintains each feed regulating valve near the midpoint of its travel. The feed pump speed control system does not directly control the levels of the steam generators. The inputs provided for feed pump speed control are main steam header pressure, main feed header pressure, and a programmed reference differential pressure (ΔP).

The reactor protection system is provided with several inputs from the detectors used in the steam generator water level control system. The inputs are used for the generation of reactor trips and engineered safety features actuations. The reactor protection system also generates feedwater isolation signals, which affect the operation of feedwater system components. Inputs from steam generator instrumentation are also provided to the turbine trip system for turbine protection.

11.1.2 System Description

The steam generator water level control system utilizes the inputs from various detectors to control the feedwater flow to maintain programmed levels in the steam generators. The following sections will provide a detailed discussion of each of the control systems involved.

11.1.2.1 Feedwater Control System

The feedwater control system for one steam generator is shown in Figure 11.1-1. Each steam generator has an identical system. The feedwater control system utilizes the following inputs for controlling the position of the main feed regulating valve:

- One of two pressure-compensated steam flow channels (selectable),
- One of two feedwater flow channels (selectable),
- An actual steam generator level channel (no alternate channel available), and
- A programmed level generated by one of the turbine first-stage pressure channels.

For an accurate measure of the steam flow rate, a pressure-compensated steam flow signal is required. The mass flow rate of the steam is dependent on the density of the steam. Since steam is a compressible fluid, the density is a function of the steam pressure. Feedwater flow does not require density compensation because water is an incompressible fluid. These two flow signals are compared to produce a flow error signal, which is combined with the level error signal as the input to the feed regulating valve controller. The flow signals are also compared to provide steam flow/feed flow mismatch alarms.

The level error signal is derived from the comparison of the actual level signal with the programmed level. The programmed level is generated by turbine first-stage (impulse) pressure. Since impulse pressure is proportional to power, the steam generator levels are effectively programmed with power level.

The programmed level varies linearly from hot zero power (33% narrow-range level indication) to 20% power (44% narrow-range level indication). The programmed level is a constant 44% from 20% power to 100% power. The 33% to 44% ramp in the level program at low powers minimizes the consequences of a steam line break inside the containment. The 44% maximum program level satisfies the following considerations:

- The "shrink" in steam generator water level during a 50% (maximum design) load reduction will not cause a reactor trip on low-low steam generator level,
- The "swell" in steam generator water level during a 10% step load increase will not cause water in the steam generator downcomer to back up into the moisture separators, and
- The peak containment pressure resulting from the blowdown of one steam generator's entire inventory during a steam line break is limited.

The actual level signal is first conditioned by a lag unit to delay the input of level error to level control during the initial stages of a transient. Lagging the actual level signal prevents shrink and swell effects from masking actual steam generator inventory changes and thus allows the flow error to initially control the feed regulating valve position during a transient. The actual level is then subtracted from the programmed level to generate the level error.

The level error is the input signal to a proportional-plus-integral (PI) controller. The proportional section amplifies the error signal. The integral portion adds to the controller's output as long as a level error persists, thereby making level error increasingly dominant. The time constant associated with the integral portion of the controller is two minutes, which allows the flow error to initially control water level and prevents rapid responses to level errors. The integrated level error also prevents an offset in level that could result from calibration errors in steam or feed flow detectors.

The output of the PI level controller is sent to the total error controller, where it is combined with the flow error. The flow error is generated by subtracting feed flow from steam flow. The output of the total error controller (also a PI controller) is used to position the main feed regulating valve. An opening signal to the valve results when either (1) the actual level is less than the programmed level or (2) feed flow is less than steam flow. A closing signal results from one of the converse conditions.

A load change affects steam flow and steam generator level. However, the control action caused by the level change would initially be in the wrong direction. For example, using Figure 11.1-2, during a load increase, steam flow increases, this action by itself produces a corresponding increase in feedwater flow. However, a load increase also causes an increase in steam generator level. This increase in level is called a swell (a temporary effect due to the measurement of level in the downcomer). This increase in level by itself would produce a decrease in feedwater flow (an undesirable effect). To prevent this undesired action the actual level signal is lagged and a large time constant of the PI level controller limits the effect of the swell on the total error controller. Therefore the flow error increases feed flow, which is the desired response. Once the actual level signal passes through the lag unit and any appreciable level error has been integrated for some time, the level error will dominate, and the actual level will be returned to the programmed level.

During a load decrease the opposite of the load increase occurs; in a load decrease case, the actual level in the steam generator level decreases for a short period. This phenomenon is called a shrink. Once again, the control system features allow the flow error to produce the initial desired response of reducing feedwater flow before the level error input returns the actual level in the steam generator to the programmed setpoint.

11.1.2.2 Main Feedwater Pump Speed Control System

Each main feed regulating valve is a throttling valve with linear flow characteristics throughout its travel. However, the best characteristics for flow control result when the valve position is somewhat near the midpoint of valve travel, or from about 25% open to 75% open. To maintain the valve position in this optimal range for all power levels, the speed of the main feed pumps is controlled to overcome the feedwater system dynamic losses (head losses), which vary with the feedwater flow and valve position. As a result, the pressure at the discharge of the pumps varies, and the differential pressure across the feedwater regulating valves changes. Controlling the feed pump speed also reduces regulating valve wear by allowing the valves to be further open with low feedwater flow rates and increases pump efficiency by reducing pump power requirements. The main feed pump speed control system is shown in Figure 11.1-3.

The feed pump speed is controlled by the differential pressure error generated through a comparison of programmed differential pressure and actual differential pressure. The programmed differential pressure is generated by summing the pressure-compensated steam flows from all four steam generators and sending them to a setpoint generator, which has a no-load setpoint as a starting point. The output of the setpoint generator is the programmed differential pressure, which has a range of 45 -195 psid from no load to full power. The programmed differential pressure is then compared to the actual differential pressure. The lag unit on the output of the steam flow summer slows the system response to rapid changes in steam flow. This feature allows the main feed regulating valves, not the feed pumps, to be the primary components controlling steam generator level.

The actual differential pressure is the difference between steam header pressure and feed header pressure. The steam header pressure is sensed in the bypass header of the main steam system. The feed header pressure is measured in the combined header downstream of the high pressure heaters. The programmed differential pressure and the actual differential pressure are compared in a summer to produce the differential pressure error. A positive error (actual differential pressure less than programmed differential pressure) would call for an increase in feed pump speed. This error is sent to the master pump speed (PI) controller, which eliminates steady-state errors and sends an output to the individual feed pump speed controllers.

11.1.3 Instrumentation

11.1.3.1 Level Channels

There are four level detectors for each steam generator (see Figure 11.1-4), three protection-grade narrow-range transmitters and one wide-range transmitter. The span of each narrow-range detector is the top 12 ft of the wide-range span. Each narrow-range detector's upper tap (100% narrow-range level) is located just below an upper manway, and the lower tap (0% narrow-range level) is located 26 in. above the top of the U-tube bundle. Each detector supplies control board indication and level alarms.

The narrow-range detectors generate a reactor trip for loss of heat sink protection when at least two out of the three channels indicate a low-low level (11.5%) in any steam generator. In addition, the low-low level condition starts the auxiliary feedwater pumps. A reactor trip for anticipated loss of heat sink is generated when steam flow exceeds feed flow by 1.51×10^6 lbm/hr in one of the two steam flow/feed flow comparisons developed for a steam generator, coincident with a low level of 25.5% in one of two level channels of that generator. (The narrow-range level channel which provides an input to the feedwater control system does not provide an input to the protection logic for the second reactor trip.)

The narrow-range detectors also generate a turbine trip if two out of the three channels exceed the high-high level setpoint (69%) in any steam generator. This condition also generates a main feedwater isolation signal and trips the main feed pumps. The purpose of this turbine trip is for protection of the turbine blades from excessive moisture carryover.

The fourth level detector for each steam generator is the wide-range channel (not shown in Figure 11.1-1). This instrument provides indication of wide range level and is recorded in the main control room. The location of the lower tap of this detector is one foot above the steam generator tube sheet. The span of the detector is 48 ft. The wide range level detectors are addressed the Westinghouse EOPs and are used by the operator for verification of a loss of heat sink.

11.1.3.2 Turbine First-Stage Pressure

One of the two turbine first-stage (impulse) pressure transmitters is used to generate the reference steam generator level. Since this pressure is proportional to power, steam generator level is effectively programmed as a function of power.

11.1.3.3 Steam Flow Channels

Two steam flow channels for each steam generator can provide an input to the feedwater control system; the operator selects one with a switch on the main control board. Each detector's flow signal is developed from the ΔP sensed across the flow restrictor at the outlet of the steam generator. Because steam is a compressible fluid and its density varies with pressure, the steam flows are pressure compensated to account for density variations. Each steam flow channel is compensated by a separate steam pressure channel.

In addition to providing an input to the feedwater control system, each steam flow detector provides an input to the protection logic for (1) the reactor trip for anticipated loss of heat sink (see Section 11.1.3.1) and (2) the high steam flow engineered safety features actuation and steam line isolation. Each steam flow channel also supplies control board indication and a steam flow/feed flow mismatch alarm.

11.1.3.4 Feedwater Flow Channels

Two feedwater flow channels for each steam generator can provide an input to the feedwater control system; the operator selects one with a switch on the main control board. Each detector's flow signal is developed from the ΔP sensed across the venturi downstream of the feedwater regulating valve.

In addition to providing an input to the feedwater control system, each feed flow detector provides an input to the protection logic for the reactor trip for anticipated loss of heat sink (see Section 11.1.3.1). Each feed flow channel also supplies control board indication and a steam flow/feed flow mismatch alarm.

11.1.3.5 Steam Pressure Channels

Four steam pressure detectors per steam generator are located on the steam line just outside containment and upstream of the main steam isolation valve. One of these detectors is dedicated solely to the control of the steam generator atmospheric relief valve. The other three channels are protection-grade channels. They provide inputs to the protection logic for (1) the high steam line differential pressure engineered safety features actuation and (2) the high steam flow engineered safety features actuation and steam line isolation. Two of the protection-grade channels provide density compensation for separate steam flow channels. All protection-grade steam line pressure channels provide control board indication.

A steam pressure detector on the common bypass header which cross-connects the four main steam lines provides inputs to the feed pump speed control system and to the steam dump control system. This detector provides indication on the control board.

11.1.3.6 Feedwater Pressure Channel

A pressure transmitter on the common feedwater header downstream of the high pressure heaters provides an input to the feed pump speed control system. This detector also provides indication on the control board.

11.1.4 System Interrelationships

Four inputs will override the steam generator water level control system:

1. Manual control by the operator,
2. Reactor trip (P-4) coincident with low T_{avg},
3. Steam generator high level (P-14), and
4. Engineered safety features actuation signal.

Each of the last three conditions listed above generates a feedwater isolation signal, which causes automatic closure of all feed regulating and bypass valves (if open) and main feedwater isolation valves. Each of the last two conditions directly trips the main feed pumps and the main turbine.

11.1.5 Summary

Steam generator water level is controlled through the automatic or manual operation of the main feed regulating valves (at high powers) or through the manual operation of the main feed regulating valve bypass valves (at low powers). In addition, the speed of the main feed pumps is controlled through the maintenance of a programmed differential pressure across the steam generators to maintain efficient operation of the main feed regulating valves. The detectors used in the control systems provide signals for control, protection, and indication.

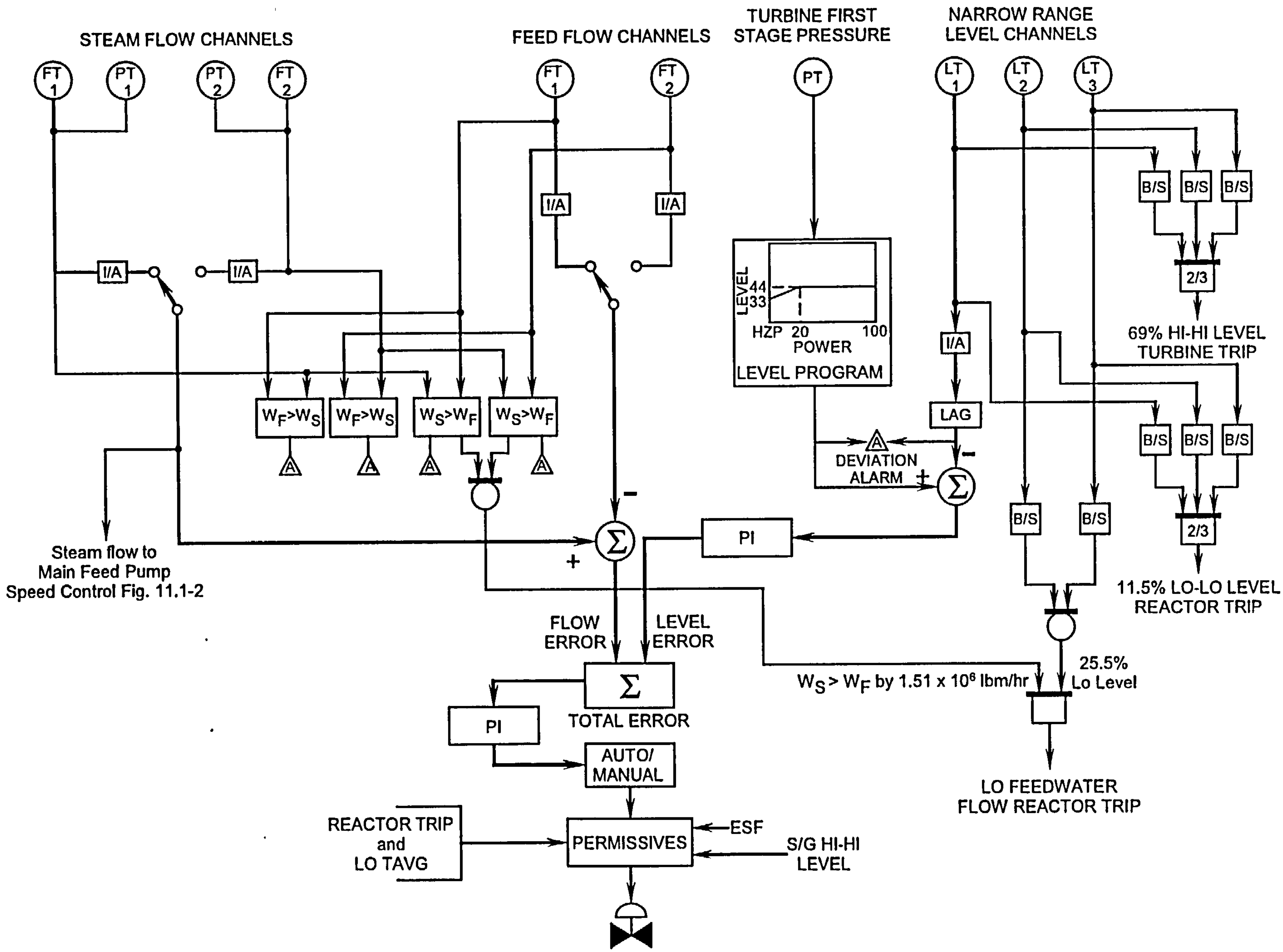

Figure 11.1-1 Feedwater Control System

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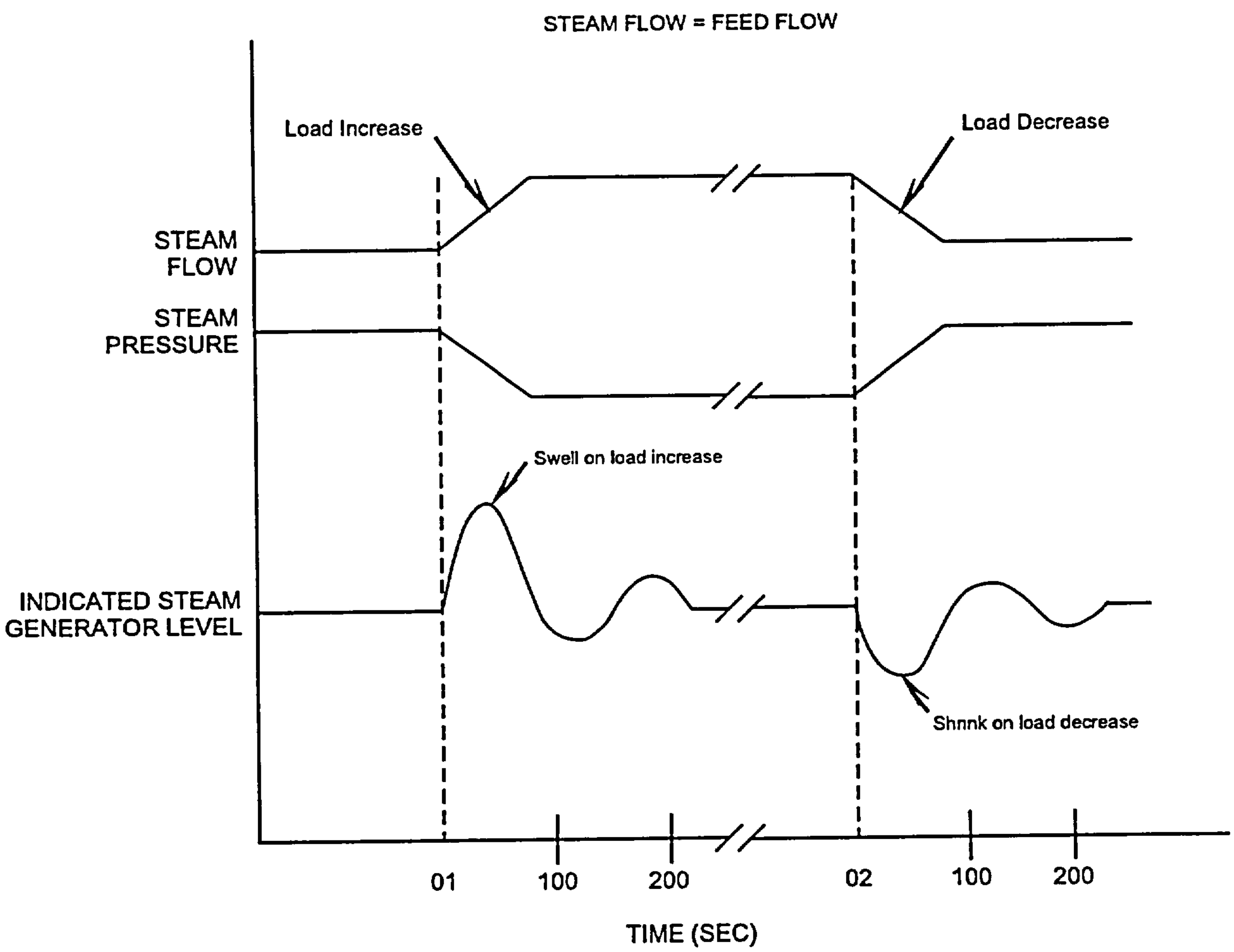


Figure 11.1-2 Steam Generator Shrink and Swell

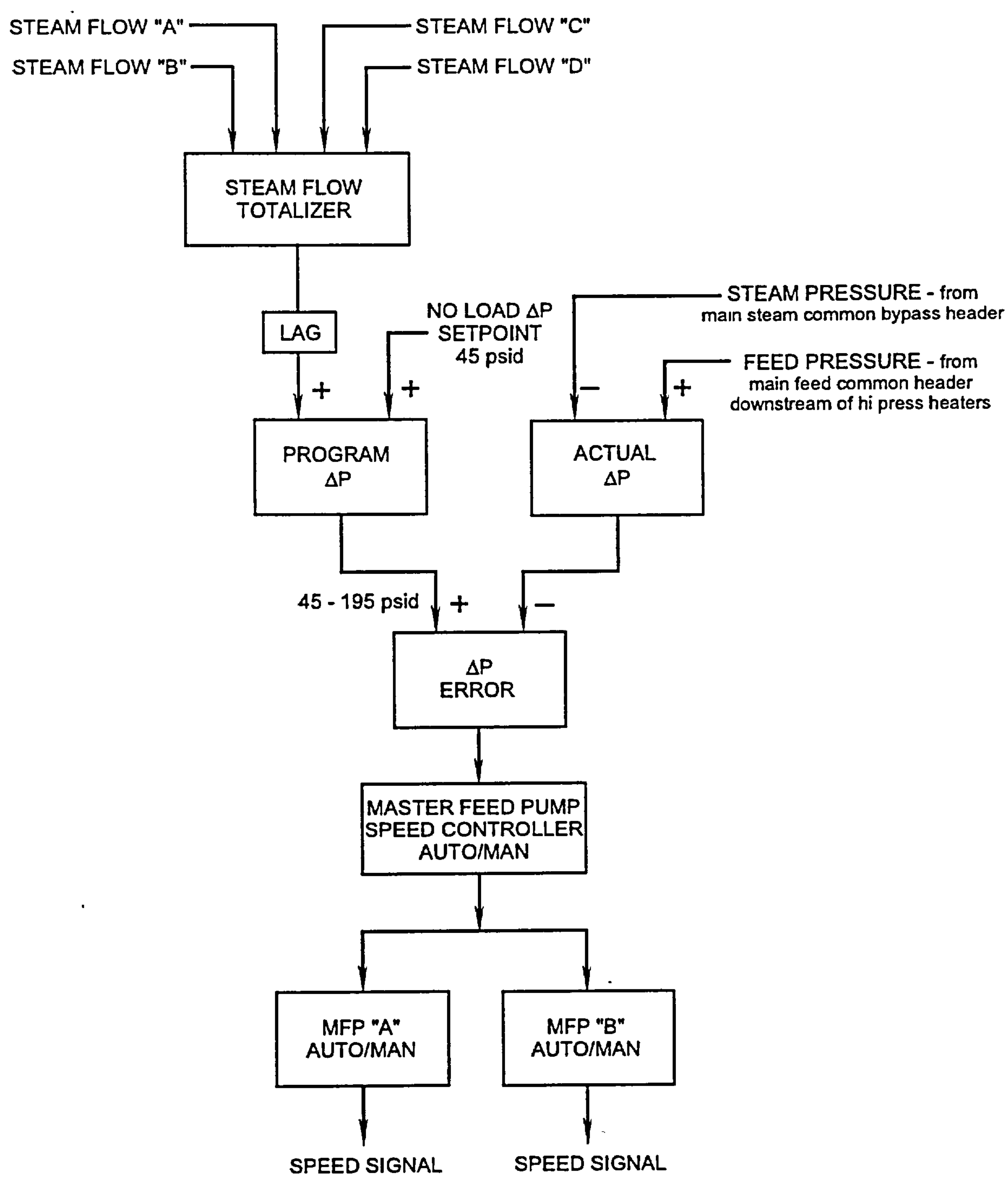
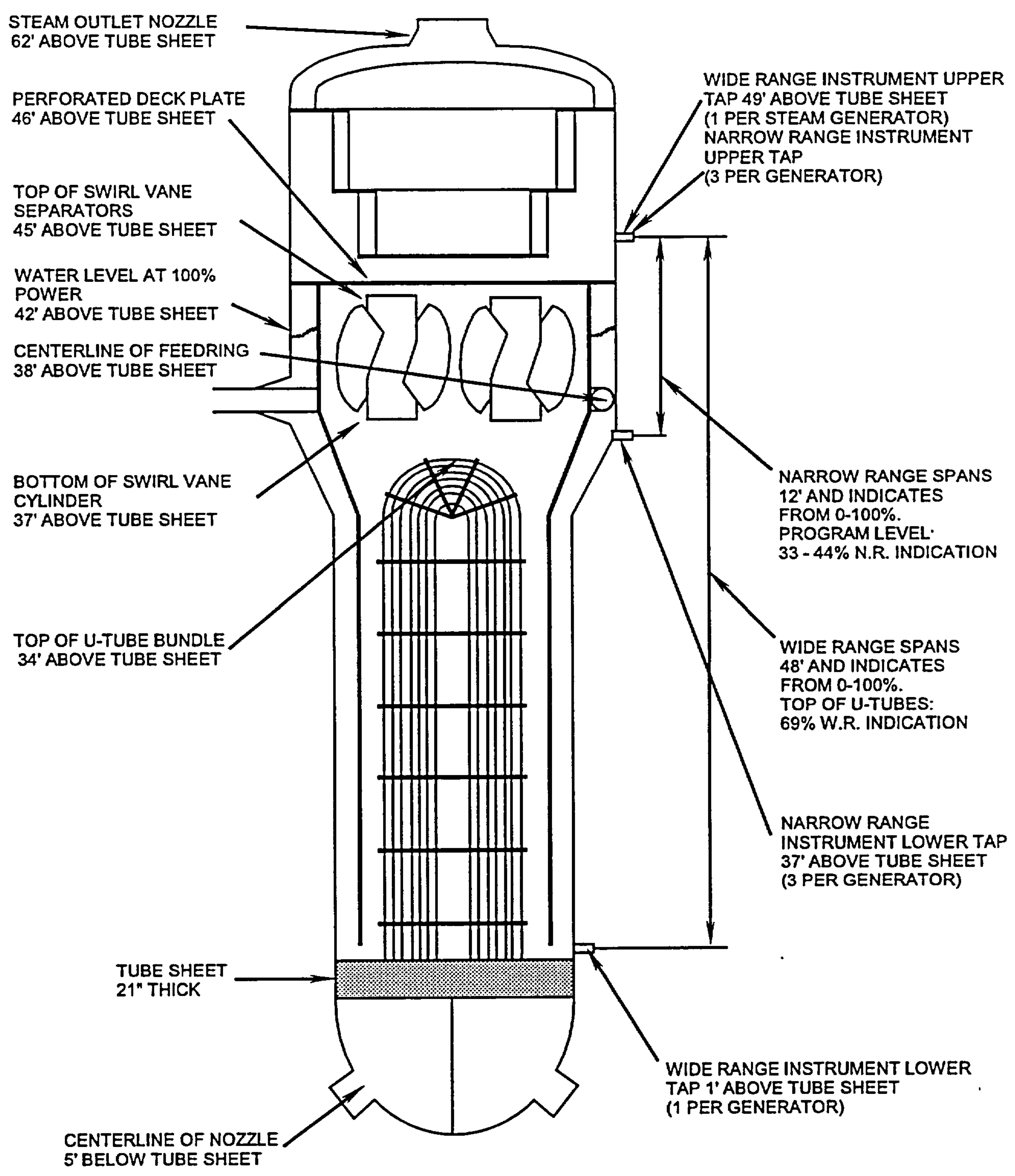


Figure 11.1-3 Main Feedwater Pump Speed Control



NOTE: MEASUREMENTS ROUNDED TO THE NEAREST FOOT

Figure 11.1-4 Steam Generator Level Data

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Section 11.2

Steam Dump Control System

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11.2 STEAM DUMP CONTROL SYSTEM

Learning Objectives:

1. List the purposes of the steam dump system.

2. Briefly describe how each of the purposes is accomplished.

3. Discuss the inputs to the steam dump control system.

4. List and explain the purposes of the steam dump control arming signals and interlocks.

11.2.1 Introduction

The function of the steam dump system is to remove excess energy from the reactor coolant system. The plant's rod control system in the automatic mode is designed to handle a 5%/min ramp or 10% step decrease in power, from steady-state conditions, without a resultant reactor trip or pressurizer relief valve actuation. However, during a turbine load reduction in excess of these design load changes, the automatic rod control system cannot reduce reactor power as fast as the secondary power is decreasing. Under these conditions, a power imbalance results, with reactor power greater than the secondary system load (i.e., more heat is being added to the reactor coolant than that removed by the secondary via the steam generators). This power imbalance causes the temperature of the reactor coolant to increase. The steam dump system is designed to limit this unwanted temperature increase.

Following a reduction in load, the steam dump system limits the temperature rise of the reactor coolant and aids the rod control system in reducing the temperature of the reactor coolant to the programmed T_{avg} for the new turbine load. During operation of the steam dump system, steam from the main steam system bypasses the main turbine and flows directly to the main condenser. The increased steam flow from the steam generators dissipates the excess energy of the reactor coolant until the power in the reactor is reduced to the same value as the secondary load.

The capacity of the steam dump system depends on the individual plant's load rejection capability. In most Westinghouse units the capacity of the steam dump system is 40%.

In a 40% steam dump system, the steam dump valves are designed to pass 40% of the full-power steam flow at some maximum defined steam pressure. This steam dump capacity allows for a 50% turbine load reduction without a reactor trip. The 50% loss of load is accommodated by the steam dump capacity of 40% and by the 10% step change capability of the rod control system. In addition, this dump capacity avoids the lifting of steam generator safety valves following a turbine trip and reactor trip from 100% power.

This chapter discusses the control system for a 40% steam dump system, which consists of 12 steam dump valves and the associated piping between the main steam system and the main condenser. For accident analysis considerations with regard to an accidental overcooling of the reactor coolant due to a small steam break, the opening of any single steam dump valve is designed to pass not more than 895,000 lbm/hr of steam at 1106 psia. The steam dump system is a control-grade system and is not required for the safe shutdown of the reactor.

The modes of operation of the steam dump system and the purposes of each mode are as follows:

1. T_{avg} mode: Enables the nuclear steam supply system to accept a 50% loss of load without incurring a reactor trip.

2. T_{avg} mode: Removes stored energy and decay heat from the reactor coolant following a turbine trip and returns the plant to no-load conditions without actuation of the steam generator safety valves.

3. Steam pressure mode: Controls steam pressure at low- or no-load conditions and provides for a manually controlled cooldown of the reactor coolant system.

4. Steam pressure mode: Provides a constant steam flow during turbine startup and synchronization to facilitate manual feedwater control.

11.2.2 System Description

Figures 11.2-1, -2, and -3 are simplified diagrams of the steam dump control system. They are intended as "building blocks" for the more complete system diagram of Figure 11.2-4.

There are two modes of steam dump control, selectable by the control room operator. One mode is the T_{avg} mode, which includes both the loss of load controller and the turbine trip controller. The other mode of control is the steam pressure mode, which involves the steam pressure controller. The position of the mode selector switch and the plant conditions determine which of the three controllers is in service. These controllers are described in detail in sections 11.2.2.1 and 11.2.2.2.

The 12 steam dump valves are air operated and divided into four different valve groups. Each valve group consists of three valves; each valve within a group discharges to a different condenser shell. The groups are operated sequentially. The first group (which contains the three cooldown valves) modulates to the fully open position before the second group of valves begins to open. After the second group has fully opened, the third group begins to open, and the fourth group begins to open after the third group has fully opened. When the valves close, they do so in the reverse order; that is, the group four valves close fully before the group three valves begin to close, etc.

As shown in Figure 11.2-1, each steam dump valve has a valve positioner which regulates the control air pressure, through two solenoid valves in series, to a diaphragm operator located on the valve. The diaphragm varies the position of the steam dump valve based on the control air pressure developed by its valve positioner. The valve positioner varies the control air pressure in accordance with a variable instrument air signal from its associated current-to-pneumatic (I/P) converter. The I/P converter (one for each steam dump valve) receives an electrical current input from one of three electronic controllers.

In addition to the features already mentioned, the steam dump control system incorporates (1) arming signals, which align the steam dumps for operation during the appropriate plant operating conditions, and (2) interlocks, which prevent or halt operation of the steam dumps when they are not needed or desired. The arming signals are discussed in the next three sections, while the individual interlocks are explained in section 11.2.2.4.

11.2.2.1 Steam Pressure Mode

During a plant startup or cooldown, the steam dump system is operated in the steam pressure mode. As shown in Figure 11.2-1, when the steam dump mode selector switch is placed in the steam pressure position, the relay associated with the mode selector switch energizes and closes two contacts. Closing the contact shown to the right of the steam pressure controller places the steam pressure controller in service, while closing the middle contact in the set of three parallel contacts completes the electrical circuit which "arms" the steam dumps. This arming contact, once closed, allows dc power to be applied to the two solenoid valves in series. The inputs to the steam pressure controller are steam header pressure (measured at the main steam bypass header) and a variable setpoint which is selected by the control room operator. The steam pressure controller is a proportional-plus-integral controller.

The steam pressure mode is selected during hot standby operation, reactor startup, and initial loading of the turbine. The steam dump valves act as a load on the primary system by removing heat from the reactor coolant. As the steam pressure is maintained by the steam dumps at the selected setpoint, the temperature of the reactor coolant is maintained at a value corresponding to the saturation temperature for the setpoint pressure. For example, if the steam pressure setpoint is selected to 1092 psig, the temperature of the reactor coolant will be maintained at approximately 557°F.

At the end of a plant heat-up, the heat added to the reactor coolant by the reactor coolant pumps is transferred to the steam generators and removed by the steam dump system to maintain the reactor coolant at 557°F (no-load T_{avg}). During the subsequent reactor startup and low power operation, withdrawing the control rods causes reactor power to increase, which in turn causes the reactor coolant temperature and the pressure in the steam system to increase. The increasing steam pressure generates an error signal (the actual steam pressure is greater than the setpoint) in the steam pressure controller. This error signal, once converted to control air pressures by the individual valve positioners, modulates open the steam dump valves. The number of open valves and the degree of modulation are determined by the magnitude of the error signal generated by the steam pressure controller. The controller output is directly proportional to the steam pressure error, a steam pressure error of 100 psid results in the full opening of all four valve groups.

When the reactor power is approximately 10-15%, the turbine is placed in service. The steam dump system is still selected to the steam pressure mode, and the dump valves are passing approximately 10-15% of full-power steam flow. During the initial turbine startup, the steam dump system maintains a relatively constant total steam flow in the main steam system. The steam dump valves are open and dumping steam to the main condenser to maintain the desired pressure in the main steam system.

As the turbine governor valves open, steam is admitted to the high pressure turbine, which causes the steam pressure in the main steam header to decrease. This reduces the magnitude of the pressure error generated by the steam pressure controller, and the controller's decreasing output causes the steam dump valves to modulate closed. The net result of this evolution is that the total steam flow remains relatively constant. This process of transferring the main steam flow from the steam dumps to the turbine governor valves continues as the turbine generator is loaded until the steam dump valves are fully closed and the turbine governor valves are passing the entire 10-15% main steam flow.

Since the total steam flow is not affected (i.e., the heat removal from the reactor coolant does not change), the temperature of the reactor coolant does not change significantly, which reduces the need to move control rods. Also, the heat transfer in the steam generators remains unchanged, which allows for a constant feed flow rate to the steam generators, making feedwater control easier for the feed station operator.

After a reactor trip or a controlled reactor shutdown, the steam dump system may be placed in the steam pressure mode of control to perform a plant cooldown. With the steam pressure controller in automatic, the control room operator can lower the steam pressure setpoint to cause the steam dump valves to open, which lowers the steam pressure and T_{avg}. With the controller in manual, the operator inputs a signal to modulate the steam dump valves open to maintain the desired cooldown rate.

11.2.2.2 T_{avg} Mode

During normal power operations, generally greater than 15% of rated thermal power, the steam dump system is placed in the T_{avg} mode. As shown in Figure 11.2-2, there are two controllers in the T_{avg} mode of control. The upper controller, the loss of load controller, is provided with auctioneered high T_{avg} and T_{ref} as inputs. T_{ref} which is generated from turbine impulse pressure, is the desired T_{avg}. The lower controller, the turbine trip controller, is provided with auctioneered high T_{avg} and no-load T_{avg} as inputs. These two controllers differ according to their functions.

(Note: Unless stated otherwise, the relay and contact locations indicated in the following paragraphs of this section refer to their locations in Figure 11.2-2.)

When the control room operator places the steam dump mode selector switch in the T_{avg} position, as shown in Figure 11.2-2, the relay associated with the mode selector switch de-energizes. De-energizing this relay causes the following:

1. The contact directly to the right of the steam pressure controller opens (this contact is shown in Figure 11.2-1 and is not shown in Figure 11.2-2),
2. The second contact to the right of the loss of load controller closes,
3. The second contact to the right of the turbine trip controller closes, and
4. The middle contact in the set of three parallel contacts opens and disarms the steam dumps.

With the turbine trip signal relay de-energized as shown, the contact directly to the right of the loss of load controller is closed, while the contact directly to the right of the turbine trip controller is open. Therefore, if no turbine trip signal is present, the loss of load controller is automatically selected whenever the mode selector switch is placed in the T_{avg} mode of control.

In accordance with this relay/contact arrangement, if a turbine trip occurs, the turbine trip signal relay energizes, causing the contact at the output of the loss of load controller to open and the contact at the output of the turbine trip controller to close. The actuation of this relay also arms the steam dumps by closing the top contact in the set of three parallel contacts. The turbine trip controller is thus automatically selected when a turbine trip signal is present.

The loss of load controller has a 5°F dead band to allow the rod control system to respond to a T_{avg}/ T_{ref} difference first. If a difference greater than 5°F between T_{avg} and T_{ref} exists, then the loss of load is in excess of the designed capability of the rod control system. The steam dump valves begin to open when the T_{avg} / T_{ref} difference exceeds 5°F, provided that the dumps are armed by a loss of load signal (the bottom contact in the set of three parallel contacts is closed). Therefore, on any load reduction that is greater than the design limitations of the rod control system, the steam dumps act as an alternate heat sink (load) until the rod control system returns T_{avg} to within 5°F of T_{ref}.

With a turbine trip, the function of the steam dump system is different. When a turbine trip occurs, the turbine trip controller is automatically placed in service and the steam dumps are armed, as previously described. The steam dump system actuates to remove stored energy and decay heat to return T_{avg} to its no-load value (normally selected to 557°F). There is no dead band associated with the turbine trip controller.

11.2.2.3 Arming Signals

To ensure that the steam dumps operate only during specific plant conditions, arming signals are provided. A control signal opens the steam dump valves only if an arming signal has energized their associated arming solenoid valves. The solenoid valves for each steam dump valve are positioned in series in the air line between the valve positioner and the dump valve. Control power is required to energize the solenoids to port air to the dump valves. The arming signal allows dc power to reach these solenoids by closing a contact in the power supply to the solenoids. There are three arming signals: one for the steam pressure mode of control and two for the T_{avg} mode of control. The arming signals and their relationships with the three steam dump controllers are illustrated in Figure 11.2-3.

When the steam dump mode selector switch is placed in the steam pressure mode of control, the steam dumps are armed. The two T_{avg} mode arming signals are the loss of load signal and the turbine trip signal. The loss of load signal (C-7 interlock) is generated by either of the following: a ramp load decrease at a rate greater than 5%/min, or a step load decrease of greater than 10%. Either of these load reduction indications is sensed from turbine impulse pressure. The turbine trip signal (C-8 interlock) is generated whenever all four turbine stop valves are shut or low pressure is indicated by at least two out of three pressure switches located on the emergency trip system header. (The turbine trip input from the emergency trip system header applies to plants with General Electric turbines and electrohydraulic control [EHC] systems. For plants with Westinghouse turbines and EHC systems, a turbine trip signal is generated when low pressure is indicated by at least two out of three pressure switches located in the auto-stop oil system. See Chapters 11.3 and 11.5.)

If the steam dump system is armed by a loss of load, the system remains armed until the loss of load signal is manually reset by a control room operator. As shown in Figure 11.2-4, this reset is accomplished by placing the mode selector switch to the reset position and then allowing it to spring return to the T_{avg} position. If the steam dump system is armed by a turbine trip, it remains armed until the turbine is latched.

11.2.2.4 Interlocks

As previously mentioned, dc control power must be supplied to the solenoid valves to allow actuation of the steam dumps. An arming signal is required to shut one of three parallel contacts which supply this dc power. In addition, three interlocks must be satisfied to allow operation of the steam dump system. The failure to satisfy any of these interlocks interrupts dc control power, via an open contact, to the series solenoid valves in the air supplies to the dump valves.

The first interlock, the condenser available (C-9) interlock, is provided for condenser protection. As shown in Figure 11.2-4, a sufficient vacuum in the condenser (as sensed by each of two condenser pressure detectors) and at least one operating condenser circulating water pump (for steam condensing) are required to satisfy this interlock and thereby allow the steam dump valves to actuate.

The second interlock (P-12), the low-low T_{avg} interlock, is provided to prevent an inadvertent cooldown of the reactor coolant due to an instrument failure. If T_{avg} is less than 553°F in two of the four reactor coolant loops, the steam dumps will be interlocked off.

To use the steam dumps for a normal cooldown below 553°F, it is necessary to bypass the low-low T_{avg} interlock. As illustrated in Figure 11.2-4, bypassing this interlock allows the operator to use the first group of three steam dump valves, the cooldown valves, to cool down the plant. The other three groups remain shut below the P-12 interlock setpoint. Since this interlock signal is generated in the reactor protection system, there are actually two signals, one from each protection system train. Therefore, there are two bypass interlock switches located on the main control board. Each bypass interlock switch (only one switch is shown in Figure 11.2-4) has three positions: off/reset, on, and bypass interlock. Bypassing the P-12 interlock is accomplished by placing the switch in the bypass interlock position and allowing the switch to spring return to the on position. Placing the switch in the off/reset position disables the dumps by de-energizing the solenoid valves in the air supplies to the steam dump valves.

The third interlock, the low-low steam generator water level interlock, is provided to conserve secondary inventory for steaming the turbine-driven auxiliary feedwater pump following a reactor trip from a high power level. If any of the steam generator levels falls below the low-low level setpoint of 11.5% in two of three channels, dc control power will be interrupted to nine steam dump valves (all except the cooldown valve group). The interlock has a time delay of five minutes to allow for transient conditions.

In summary, all of the following conditions must be satisfied to complete the dc arming circuits for the steam dump solenoid valves:

1. One of the three arming signals discussed in section 11.2.2.3 has been developed,
2. The condenser available interlock logic is satisfied,
3. The reactor coolant temperature is greater than the low-low T_{avg} setpoint, or the operator has bypassed this interlock (three cooldown valves only), and
4. All four steam generator levels exceed the low-low level setpoint (all steam dump valves except the cooldown group).

11.2.2.5 Steam Dump Trip-Open Bistables and Valves

As shown in Figure 11.2-4, in addition to the solenoid valves which are energized by the arming signals, there is a third solenoid valve associated with each steam dump valve. This solenoid valve, located upstream of the arming solenoid valves, is actuated by one of the bistables known as the trip-open or blast-open bistables. These bistables are effective only in the T_{avg} mode of control. When energized, this trip-open solenoid valve directs high pressure air around its associated valve positioner.

Normally, 100-psig air is routed from the service air header through each valve positioner, which regulates the air pressure to its associated steam dump valve. Each valve positioner varies the control air pressure based on a variable instrument air signal from its associated I/P converter. The flow of control air from the valve positioner, now at a reduced pressure, passes into the right-hand port and out the bottom port of the three-way trip-open solenoid valve. (The valve port orientation discussed here corresponds to that shown in Figure 11.2-4.) This control air passes through the two series arming solenoid valves to the diaphragm operator located on the steam dump valve. As the control air pressure from the valve positioner varies, the steam dump valve position will change (i.e., modulate open or closed). However, if the trip-open solenoid is energized, the solenoid valve is repositioned so that the top and bottom ports are open and the right-hand port is closed. With the solenoid valve in this position, 100-psig control air is immediately applied to the valve actuator of the associated steam dump valve. This action allows quick opening of the steam dump valve for large load rejections.

The four trip-open bistables and their associated contacts are shown in Figure 11.2-4 between and to the right of the loss of load and turbine trip controllers. The input to two of the bistables is the temperature error (T_{avg}-T_{ref}) supplied to the loss of load controller, and the input to the other two bistables is the temperature error (T_{avg}- no-load T_{avg}) supplied to the turbine trip controller. When the steam dump mode selector switch is selected to the T_{avg} mode of control (as shown in the figure), the contacts in the circuits from the two upper (loss of load) bistables are closed. If a turbine trip occurs, then the contacts directly to the right of the two upper bistables open, and the contacts directly to the right of the two lower (turbine trip) bistables close. (The locations of the bistables and contacts discussed above refer to their locations in Figure 11.2-4.)

The normal setpoints for these bistables are as follows. For the loss of load bistables, the high bistable setpoint is 10.7°F (T_{avg} - T_{ref}), and the high-high bistable setpoint is 16.4°F. For the turbine trip bistables, the high bistable setpoint is 13.8°F (T_{avg} - no-load T_{avg}), and the high-high bistable setpoint is 27.7°F. The large temperature errors are indicative of the large imbalances between primary and secondary power that would result from large load rejections.

When a high bistable setpoint is exceeded, the trip-open solenoid valves for the first two groups of valves (six valves total) reposition to supply 100-psig air directly to the steam dump valve operators. The steam dump valves then open fully within two to three seconds. When the bistable resets, the solenoid valves are de-energized and repositioned so that the air signals from the valve positioners will modulate the steam dump valves closed. A high-high bistable, if actuated, opens the remaining two groups of three valves (six valves total).

11.2.3 Summary

The steam dump system provides:

- A heat sink for the primary system on a load reduction to prevent a reactor trip,
- A method of returning the plant to no-load conditions following a turbine trip, and
- A method of maintaining and varying reactor coolant temperature during startups and cooldowns.

The control system for the steam dumps accomplishes the first two functions by automatically opening the steam dump valves in response to temperature errors resulting from load rejections (loss of load or turbine trip). The control system accomplishes the third function by controlling steam pressure and thus reactor coolant T_{avg} at a selected setpoint.

The steam dump control system is provided with arming signals and interlocks. The purpose of the arming signals is to ensure that plant conditions requiring steam dump actuation actually exist. The purpose of the interlocks is to provide equipment protection and, in the event of an instrument failure after the steam dumps have been armed, to prevent the reactor coolant system from being overcooled.

In the event of a large loss of load or a turbine trip, trip-open bistables rapidly open the steam dump valves. This action helps limit the increase in T_{avg} for these transients and returns the temperature of the reactor coolant to program faster than if the transients were handled only by the rod control system.

The steam dump system is not a safety-related system; it is supplied with nonvital power, and its operation is not considered by the plant's FSAR for mitigation of any accident. In addition, the operation of the steam dump system is not required for the safe shutdown of the reactor.

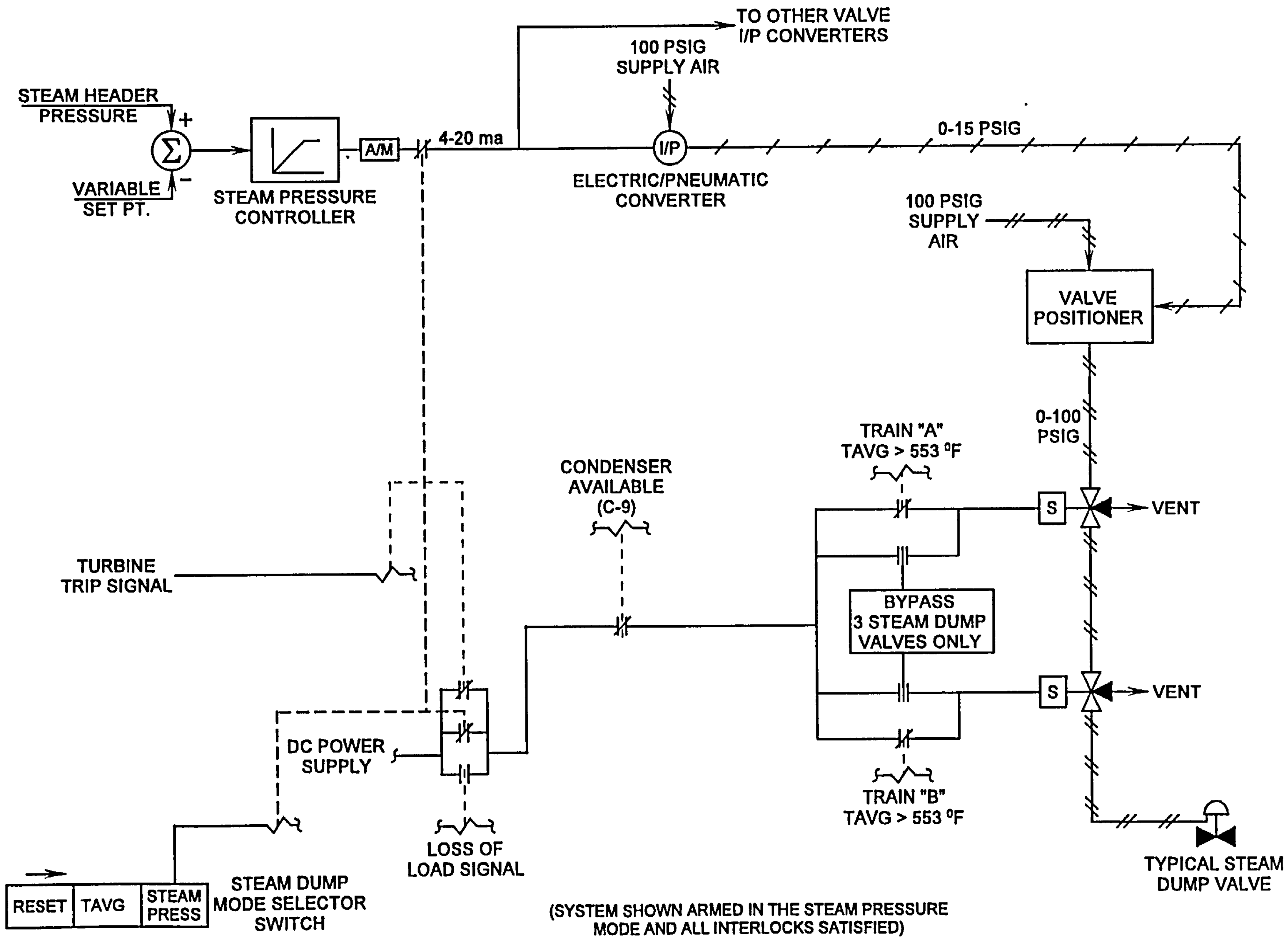

Figure 11.2-1 Steam Pressure Control Mode

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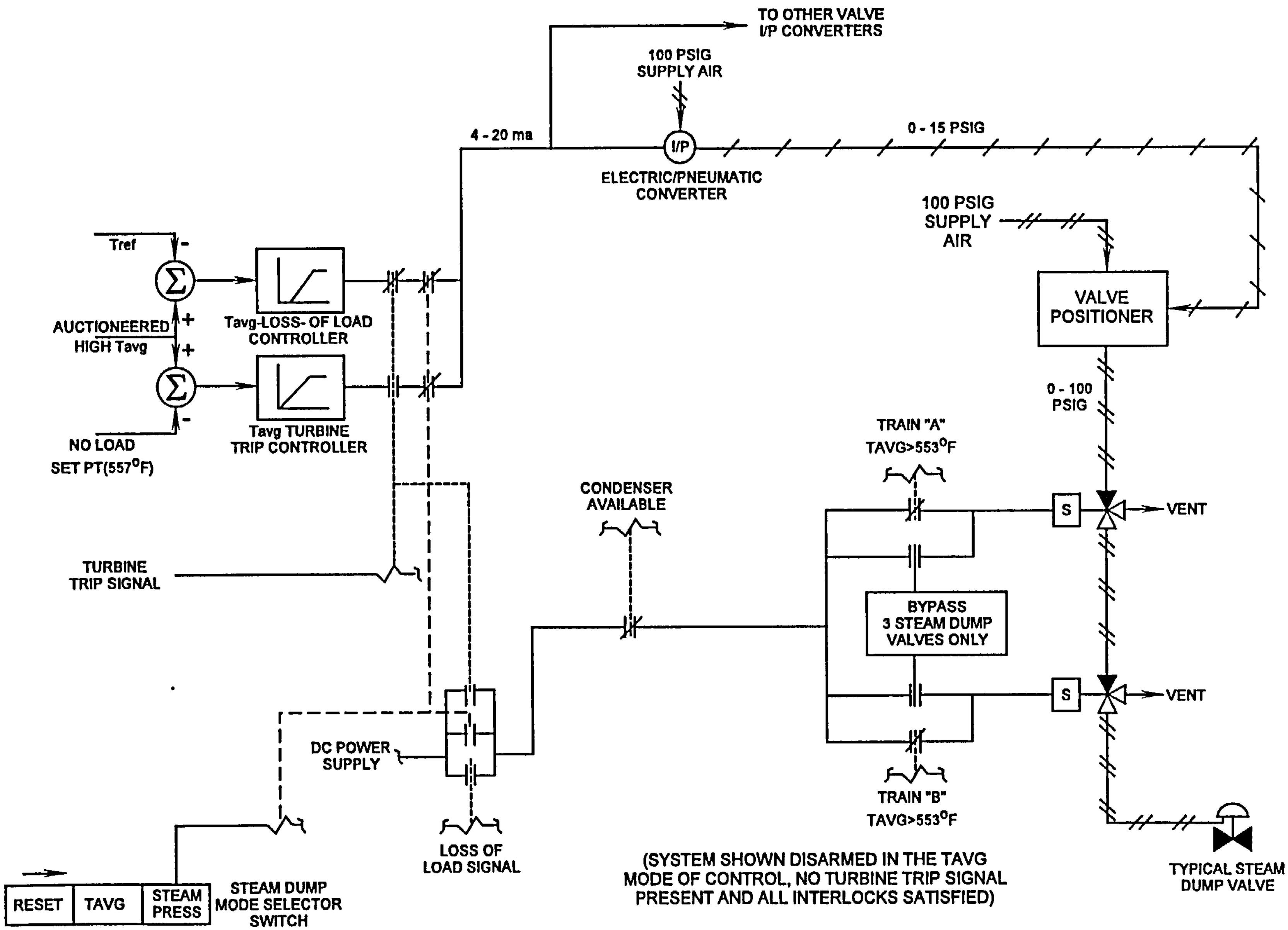

Figure 11.2-2 Tavg Control Mode

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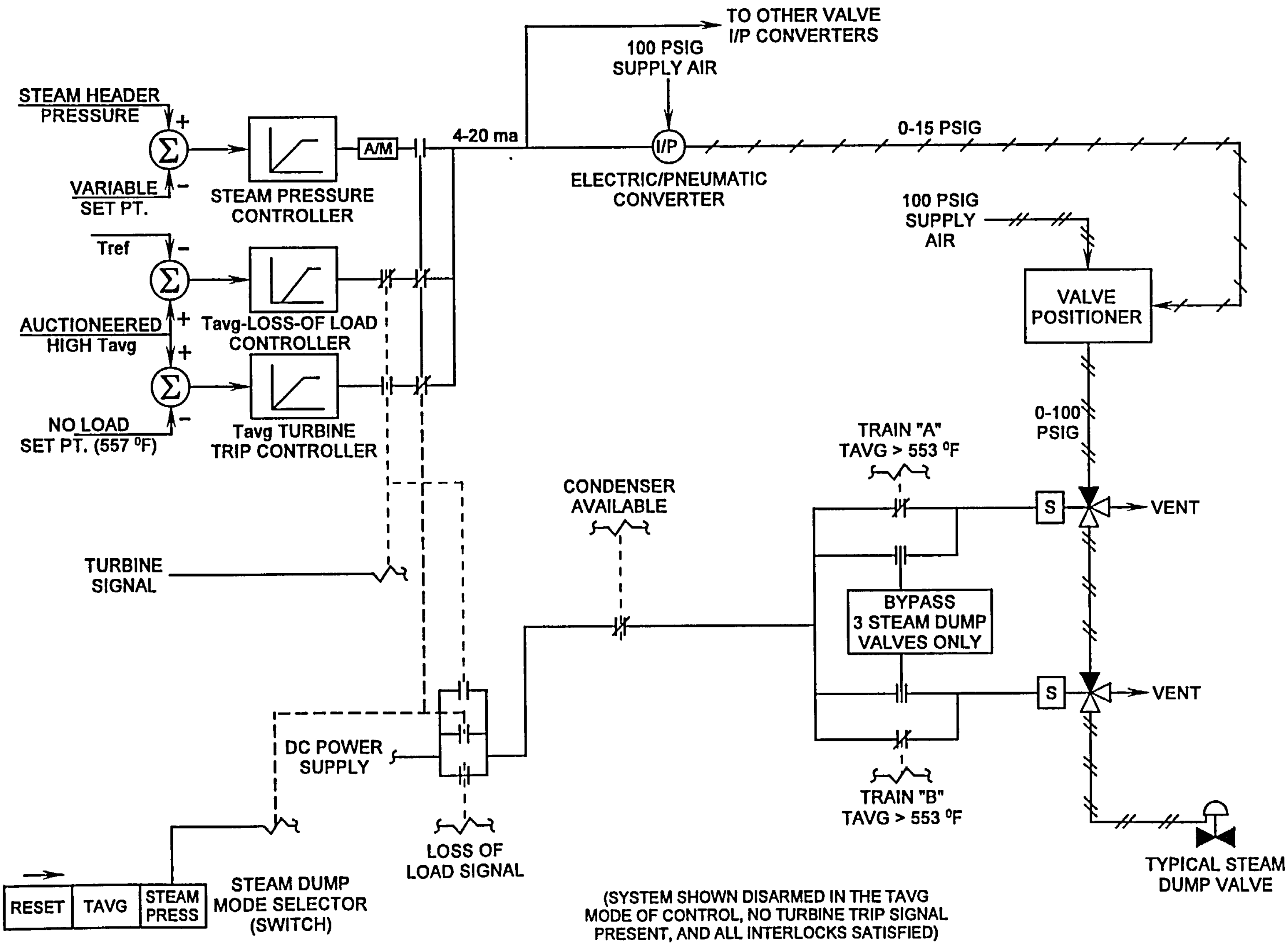

Figure 11.2-3 Steam Dump Control System

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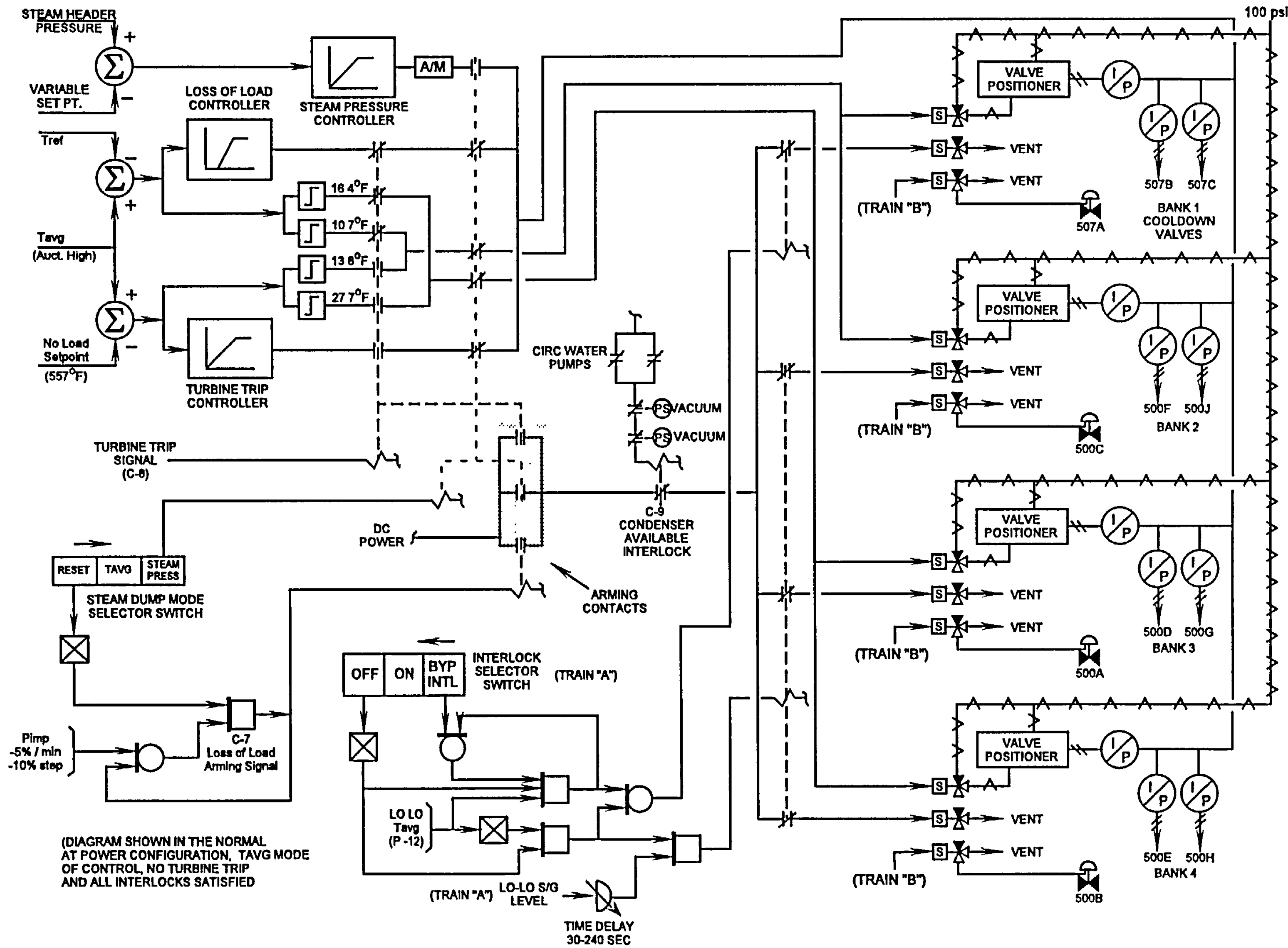

Figure 11.2-4 Steam Dump Control

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Section 11.3

Westinghouse Electrohydraulic Control System

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11.3 WESTINGHOUSE ELECTRO-HYDRAULIC CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the turbine Electrohydraulic Control (EHC) System.

2. Describe the sequence of events which results in a turbine trip when initiated by:

   a. Mechanical input (example: low condenser vacuum)
   b. Electrical input (example: reactor protection signal).

3. Explain what function the following components perform in initiating a turbine trip:

   a. Solenoid trip mechanism
   b. Interface valve
   c. Emergency trip valve.

4. List the input parameters to the control systems used for the following turbine operational modes:

   a. Speed control
   b. Load control.

5. Explain the difference between "impulse in" and "impulse out" during turbine load control operations.

6. Briefly describe the actions initiated by the overspeed protection controller (OPC) for the following conditions:

   a. 103% turbine overspeed
   b. Opening of the generator output breakers at high loads.

7. Explain how the following types of turbine runbacks are accomplished:

   a. Secondary system initiated
   b. Reactor protection system initiated.

8. List the turbine trip indication inputs to the reactor protection system.

11.3.1 Introduction

The purposes of the EHC system are as follows:

1. Control the speed of the turbine-generator from turning gear operation to synchronous speed (60 Hz),

2. Control the load of the generator from synchronization to 100 percent load,

3. Provide rapid shutdown capability (trip) to protect the turbine-generator, and

4. Limit turbine overspeed on partial load rejections.

The EHC system uses high pressure hydraulic fluid to open and position the steam inlet valves to the high and low pressure turbines in response to commands from an electronic controller. An auto-stop oil system interfaces with the high pressure hydraulic system to generate a quick closure of all steam inlet valves if an abnormal condition is sensed by one or more of the turbine protective devices.

11.3.2 System Description

A simplified diagram of the EHC system is shown in Figure 11.3-1. As shown on this figure the EHC system can be divided into three subsystems. The three subsystems are as follows:

1. The electronic controller and the operator's panel are shown on the lower left side of Figure 11.3-1. The controller cabinet receives inputs from; the operators' panel located in the main control room, a speed transducer located on the high pressure turbine rotor, a pressure signal from the impulse chamber of the high pressure turbine, and finally governor valve position (not shown on this figure). The electronic controller sends signals to servo valves for the throttle and control valves.

2. The electrohydraulic (EH) fluid system, a high pressure hydraulic oil system, is shown in the right center of Figure 11.3-1. High pressure hydraulic fluid is supplied to the valve actuators for the throttle, governor, reheat stop, and the interceptor valves. A drain path from the valve actuators returns the hydraulic fluid to the EH fluid sump via an emergency trip device. With the trip device closed, a high pressure is maintained at the valve actuators which keeps the steam supply valves open.

3. The final subsystem is a combination auto-stop and lubricating oil system. It is shown in the bottom right portion of Figure 11.3-1. This system provides lubricating oil to the turbine bearings and acts as a hydraulic fluid in the auto-stop oil system. This hydraulic system keeps the emergency trip device closed during normal operations. Should an unsafe condition exist the auto-stop oil system pressure decreases allowing the emergency trip device to open.

11.3.2.1 EH Fluid System

The valves that admit and control the steam flow to the high and low pressure turbines are opened by high pressure hydraulic fluid acting upon the valves' hydraulic actuators. This high pressure hydraulic fluid is supplied by the EH fluid system, which is shown in Figure 11.3-2. Each steam valve has an actuator (for opening) and a dump valve (for closing). When the EH fluid system is pressurized, the dump valves are kept closed. With the dump valves closed hydraulic fluid pressure is applied to the valve actuator; the force exerted by the EH fluid overcomes the spring force (used to close the steam valve) and opens its associated steam admission valve. When the EH fluid pressure is decreased by opening the interface valve or the emergency trip solenoid, the dump valves open and bleed the hydraulic fluid in the valve actuator to the EH fluid sump. Spring force closes the steam admission valves, blocking steam to the high and low pressure turbines. When all turbine steam valves are closed in this manner, the turbine is said to be tripped.

EH fluid system pressure is maintained by the operation of one of the two positive displacement EH pumps. The idle EH pump is placed in standby. If the pressure in this system drops below 1500 psig, the standby pump automatically starts. The system contains two unloader valves and one relief valve. The unloader valves maintain a desired pressure, while the relief valve prevents the over-pressurization of the system. The unloader valves regulate the hydraulic pressure by unloading (opening) at 2150 psig and closing at 1800 psig, while the relief valve opens at 2350 psig. Accumulators, which are not shown in this figure, are provided to smooth out pressure variations. Orifices are installed in the supply lines to the actuators and the dump valves to prevent repressurizing the system when the interface or the emergency trip valve opens.

The reheat stop valves and the intercept valves supply steam to the low-pressure turbines. These valves are either fully open or fully closed (never modulated). EH fluid is supplied through orifices (O-1 & O-2 as shown on Figure 11.3-2) directly to the valve actuators for these steam valves. The throttle (stop) valves supply steam to the high-pressure turbine through the governor valves. The throttle valves are generally fully open or fully closed. However, they do have a throttling feature, which is used during turbine acceleration from 0 to 1700 rpm. The governor (control) valves supply steam to the high-pressure turbine and are modulated to produce the desired generator output. Because the throttle valves and the governor valves must be capable of modulation, EH fluid is supplied to their respective valve actuators via servo valves. Each servo valve receives a command from the electronic controller, and increases or decreases the hydraulic pressure in its actuator, to either open or close its associated valve.

All turbine steam supply valves are testable to ensure that they close upon a turbine trip signal. The throttle valves and the governor valves are tested one at a time. The test is accomplished by closing and opening the valves individually with their respective servos. The reheat stop valves and the intercept valves have solenoid valves that open the dump valves associated with the valve being tested. The reheat stop valves and intercept valves are tested in pairs; the valves in each steam line from one moisture separator reheater to one low pressure turbine are closed simultaneously and then reopened. Turbine load, hence reactor power, is lowered to about 75% during valve testing so that the generator output can be maintained constant by the control system.

Overspeed Protection Controller (OPC)

The purpose of the OPC is to prevent an overspeed trip of the main turbine. This function is accomplished by securing steam to the turbine for a short period; or securing steam to the turbine until the condition that is generating the potential overspeed condition clears. Three conditions could exist that causes the OPC to actuate.

First, the OPC is provided with a speed signal from a shaft-mounted speed transducer. If 103% of normal speed is sensed, the OPC solenoid valves open. When these valves open, EH trip fluid is dumped into the EH fluid sump. This action closes the governor and intercept valves. A check valve, installed in the EH trip fluid line, prevents dumping EH trip fluid from the throttle and reheat stop valves. When the overspeed condition clears, the solenoid valves close and the governor and intercept valves reopen.

Secondly, if the generator output breakers open when the power is above a preset value, the OPC solenoids energize, as discussed above, closing the governor and intercept valves. This signal resets after a preselected time delay.

Finally, if the difference between the main generator output and the low pressure turbine inlet pressure is greater than a preset value, the test solenoids of the intercept valves are energized to close the intercept valves. The intercept valves reopen when the difference clears. This circuit senses a loss-of-load and shuts these valves to prevent overspeeding the turbine-generator.

Emergency Trip Solenoid Valve

An emergency trip solenoid valve in the EH fluid system provides a backup for the interface valve (see Section 11.3.2.2). Opening of the emergency trip solenoid valve dumps EH fluid from the turbine valve actuators. The emergency trip solenoid valve is opened on any of the following signals:

1. Manual turbine trip (from the control board),
2. Reactor trip signal (train B),
3. High-high level in any steam generator, and
4. Low auto-stop oil pressure.

11.3.2.2 Auto-Stop Oil System

A combined lubricating and auto-stop oil system supplies lubricating oil to the turbine and generator bearings and keeps the interface valve closed during normal operation. Figure 11.3-2 shows this combination system. The EH fluid and auto-stop oil never come into contact with each other. The interface valve is the only component common to both systems, with EH fluid flowing through the valve upon a turbine trip, and auto-stop oil applied to the valve operator to close it against spring force. Low pressure in the auto-stop oil system allows the interface valve to open and trip the turbine.

Oil for the auto-stop system is normally supplied by a shaft-mounted centrifugal pump. When the turbine is not at rated speed, oil is supplied by the seal oil backup pump.

There are five protective trips for the main turbine generated via the auto-stop oil system:

1. Low bearing oil pressure,
2. Thrust bearing excessive movement,
3. Low condenser vacuum,
4. Solenoid (remote) trip, and
5. Mechanical overspeed.

All five trips cause a low pressure in the auto-stop oil system, thereby opening the interface valve. The devices for the first four trips are located on one assembly, the protective trip block, as shown in Figure 11.3-2.

Low Bearing Oil Pressure Trip

Bearing oil is supplied to a spring-loaded diaphragm on the protective trip block. If pressure decreases to five to seven psig, the spring force lowers the diaphragm and raises the dump valve on the opposite end of the protective trip block. This set of events lowers the auto-stop oil pressure, which in turn opens the interface valve and trips the turbine.

Thrust Bearing Trip

This device warns the operator of excessive rotor movement in the axial direction and trips the turbine before such movement is enough to cause serious damage. The device consists of two small nozzles which discharge close to the thrust collar faces. Oil is supplied to the nozzles and through check valves to a spring-loaded diaphragm on the protective trip block. If the rotor moves toward either nozzle, pressure in that line increases. When pressure reaches 35 psig, a pressure switch actuates an alarm. When pressure increases to 75-80 psig, the diaphragm will move up and open the dump valve, causing the interface valve to open and trip the turbine.

Low Condenser Vacuum Trip

This trip also involves a spring-loaded diaphragm on the protective trip block. The diaphragm is subjected to the condenser vacuum. When the vacuum decreases (pressure increases) to 19-22 inches Hg, the diaphragm moves up and opens the dump valve. A vacuum trip latch is provided to permit starting the turbine with a low vacuum; it is engaged when the turbine is latched. The vacuum trip latch automatically disengages when the condenser vacuum reaches 23-25 inches Hg. Even if this latch is engaged it will not prevent a trip if the condenser pressure reaches 2.5-4.5 psig.

Solenoid Trip

This feature allows the initiation of a turbine trip from a remote point through the energizing of a solenoid on the protective trip block, which causes the dump valve to open. Solenoid trips include the following:

1. Manual turbine trip (from the control board),
2. Reactor trip signal (train A),
3. Electrical overspeed (approximately 111%),
4. High-high level in any steam generator,
5. Failure of DC control power to the EHC system,
6. Low lubricating oil level,
7. Low EH fluid level,
8. Low EH fluid pressure,
9. Failure of cooling water to the main generator,
10. High vibration,
11. Loss of both main feedwater pumps,
12. Generator reverse power (with a 30-sec delay), and
13. Trips initiated by main output transformer protective relays.

Mechanical Overspeed Trip

The overspeed trip mechanism consists of an eccentric weight mounted inside a transverse hole in the high-pressure turbine rotor shaft. The weight is held in place by a spring; but because the weight is off-center, it moves outward, away from the center of the rotor, against spring force, when the turbine overspeeds. When the weight moves outward, it strikes a trigger which opens the overspeed trip valve, causing auto-stop oil to drain from the system and the turbine to trip. The setpoint for the mechanical overspeed trip is higher than the trip setpoint of the electric overspeed trip.

The overspeed trip mechanism also seals in any turbine trip developed at the protective trip block. When the dump valve is opened by any of those trips, the auto-stop oil pressure decreases throughout the system. The absence of oil pressure at the overspeed trip valve allows a spring to deflect the overspeed trip trigger, opening the overspeed trip valve, which maintains an open drain path for the auto-stop oil. This feature seals in the trip, even if the initial condition clears and closes the protective trip block dump valve. The control room operator must reset the overspeed trip mechanism either locally or remotely to repressurize the auto-stop oil system.

The overspeed trip mechanism can be tested by injecting oil under the weight to move it into the trigger. To prevent an actual turbine trip during testing, the trip test handle must be manually held to prevent depressurizing the portion of the system containing the interface valve. The trip test handle must be held in the test position until the overspeed trip mechanism is reset and the auto-stop oil pressure is restored. The trips on the protective trip block are also tested while the trip test handle is held in the test position. Each trip tested trips the overspeed trip mechanism.

11.3.2.3 Electronic Control System

The electronic control system calculates deviations between reference signals and turbine speed, valve position, or turbine first-stage pressure (Imp In only). If the turbine is latched (not tripped), it is controlled in one of two operational modes: speed control or load control. Speed control is used to roll the turbine from turning gear speed (about 1-rpm) to synchronous speed (1800-rpm). When the generator output breakers are closed, the EHC system automatically shifts from speed control to load control. In this mode, load control, the EHC system controls the turbine's power output.

Speed Control

Figure 11.3-3 illustrates the speed control circuit, which contains two modes of speed control: throttle valve control and governor valve control. Latching the turbine automatically places the speed control circuit in throttle valve control. When operating in this mode, steam passes through one throttle valve via an internal poppet.

From this poppet steam is directed through all four, fully open, governor valves, into the steam chest of the high-pressure turbine and is called "full arc admission."

Initially, after latching the turbine, the throttle valves and the governor valves are closed. Rolling the turbine for chest warming requires opening the governor valves. To accomplish this, the control room turbine operator depresses the valve position limit increase push button. Increasing the output of the valve position limit, forces the governor valves open due to the 100-rpm open bias input into the low value gate from the PI amplifier. The control room operator continues increasing the setting of the valve position limiter until it indicates 100% and the governor valves are full open. Applying a constant 100-rpm open bias with the integral action of the PI amplifier keeps the governor valves open.

To roll the turbine off its turning gear, warm up the turbine, and increase its speed to 1700-rpm, throttle valve control is used. The control room turbine operator selects a speed and an acceleration rate on the EHC panel (according to the turbine heat-up and loading curves) and depresses the "GO" push-button. The proportion amplifier receives a speed error signal, without the 100-rpm open bias, and sends a proportional output signal to the throttle valve servos (Note: the contact from the 100-rpm open bias is open).

When the turbine attains a speed of 1700-rpm, the control room turbine operator depresses the "TV/GV" transfer push-button to execute the shift-over from throttle valve control to governor valve control. During the shift-over, the "TV/GV" push-button flashes alerting the control room turbine operator that the shift over is in progress. After the shift-over is complete, the "TV/GV" push-button stops flashing. The throttle valves receive a continuous 100-rpm open bias via a PI amplifier, which keeps the throttle valves fully open, and the speed error signal modulates the governor valves to maintain a speed of 1700-rpm. After completing the transfer, the turbine is increased to synchronous speed (1800-rpm) in preparation of paralleling the generator to the grid.

Load Control (Imp Out)

Two modes of automatic load control are incorporated into the design of the EHC system: impulse pressure out of service (Imp Out) and impulse pressure in service (Imp In). Imp Out will be described first.

Referring to Figure 11.3-4, the input signals to this circuitry are two reference signals; speed and load reference, and two measured parameters; turbine speed and turbine impulse pressure. In addition, the governor valve servo circuit receives a feedback signal from governor valve position.

As discussed earlier, speed control was used to warm up the turbine and bring it to synchronous speed. After synchronizing the turbine to the grid, the turbine operator in the control room closes the main generator output breaker. This action automatically shifts the EHC system from speed control to load control. Imp Out is the default mode of operation when the shift-over takes place. The electronic controller sets the reference load at 5%, with a load rate of 1%/min. Increasing the load of the turbine to 5% ensures the generator does not motor.

Besides reference load, the control system is provided with a speed error signal developed by comparing a fixed reference speed (1800-rpm) with the actual turbine speed transmitted from a shaft-mounted speed transducer. Normally the output from this part of the circuit is zero. Supplying a speed error signal to this electronic control system allows the turbine-generator to assist the other generating units to maintain the stability of the offsite electrical system (the grid). If the demand load on the grid is greater than the supplied generating capacity, electrical frequency on the grid decreases. This decrease in frequency generates a speed error signal, which is added to the reference load. The increased demand opens the governor valves increasing the power output from the turbine. The electrical loads from the other turbine-generators tied to the grid are similarly increased. The combined effect should match the total plant power output to the total system power demand, returning and maintaining grid frequency at 60 Hz.

A proportional amplifier receives the combined reference load and speed error signal. A low value gate receives this proportionally amplified signal along with a valve position limit setpoint. The valve position limit is adjusted by the turbine operator to prevent the turbine governor valves form opening beyond a preselected limit; i.e., prevents the secondary load from exceeding a preselected maximum value. As long as the demanded reference signal is less than the valve position limit, the governor valve servo circuit receives the reference load signal. If the load reference demand is greater than the valve position limit setpoint, the low value gate clamps the governor valves at a position demanded by the valve position limiter. If the governor valves are clamped, the reference window continues to increase at the rate input by the turbine operator. This action, reference window display increase, continues until the displayed value in the "Reference" window equals the value in the "Setter" window.

The function generator in each servo circuit [F(X)] accounts for the nonlinear effect of valve position on steam flow and provides a bias to open the governor valves in a sequence if desired. The output of F(X) is compared with the actual valve position provided by a linear variable differential transmitter (LVDT). Any error between the demanded valve position and the actual valve position is amplified and integrated over time to ensure that the valve reaches its demanded position. Only when the valve position feedback equals the demanded position will the proportional-plus-integral (PI) amplifier stop integrating. In the Imp Out mode valve position is the only feedback other than the speed signal.

Finally, if the turbine-generator is operating at 50% power, and the turbine operator is directed to increase power to 100% at 1%/min, the turbine operator, using the reference control increase push-button increases the target load to 100% (displayed in the "Setter" window). The operator also selects 1%/min on the load rate thumb-wheel. To start the load increase the operator depresses the "go" push-button. The system electronically changes the reference load from 50% to 100% at 1%/min. As the reference load increases, as indicated in the "Reference" window, the governor valve servo circuits receive a steadily increasing signal, which results in the governor valves opening farther increasing steam flow to the turbine. The system opens or closes the governor valves to a position that is equivalent to the demanded power level.

Load Control (Imp In)

At 15% to 20% turbine-generator load, the operator may select impulse pressure (Imp In) as a feedback input into the load reference circuitry. Impulse pressure is an indication of actual turbine load. After switching the EHC system to Imp In, the load reference, as shown in Figure 11.3-4, becomes a combination of speed error, reference load and impulse pressure. A proportional-integral (PI) amplifier receives the reference load instead of a proportional-only amplifier. The PI amplifier provides a proportional output dependant upon the magnitude of the input error signal. The integral function increases the proportional gain to ensure that the governor valves open far enough to increase turbine load (as indicated by impulse pressure) to a value that is equal to the desired load.

The electronic control system receives two feedback signals: impulse pressure and valve position. To reach an equilibrium condition, the valve position feedback from each governor valve must be equal to the output of F(X), and the impulse pressure feedback must equal the reference load. There could be some "hunting" of the system while the outputs of the PI amplifiers decrease to zero. Although the design of the function generators linearize the load reference with respect to actual load (a function of governor valve position), linearity can only be achieved in the Imp In mode. Figure 11.3-5 illustrates the difference between the two modes of load control (Imp In vs. Imp Out).

Curve A represents operation with impulse pressure out of service. This curve shows the non-linear relationship between load reference (vertical axis) and generator output (horizontal axis). The non-linearity of this curve is due to the variable steam flow characteristics of the governor valves. This non-linearity is illustrated by the reference loads labeled r' and r" -- where r' is at a lower value than r". As the load reference changes from r' to r", actual generated load remains constant (P2) and is indicated by "c" on Curve A.

Curve B represents operation with impulse pressure in service. With Imp In selected, the control system changes governor valve position(s) until impulse pressure equals the load reference. Since impulse pressure is linear with respect to power, load reference becomes a linear function of power.

These curves also show how the load reference changes as a result of changing modes of operation. Assume that the system is operating in Imp Out, with power at P1 and load reference at R1. The operating point is "a" on curve A. During the shift-over to Imp In, the governor valves do not move. Meanwhile the load reference changes from R1 to R2; i.e. the reference window indication increases to equal the value at P1. The new operating point is "b" on curve B and the reference and setter window indication should be equal. Note the actual load (P1) has not changed, but the load reference has changed. Changing from Imp In to Imp Out results in a similar load reference change.

11.3.3 System Features and Interrelationships

Reactor Protection System

Two different signals from the turbine are sent to the reactor protection system to indicate that the turbine is tripped. One signal is four-out-of-four throttle (stop) valves fully closed, as indicated by the limit switches on the throttle valve stems. The other signal is low auto-stop oil pressure, as indicated by two-out-of-three pressure transmitters located in the auto-stop oil system.

Turbine Runbacks

Turbine runbacks are automatic reductions in turbine load. These runbacks are actuated based upon present plant conditions, if left unattended, could cause a plant trip. The runback signals can be initiated from either the primary or the secondary.

Two turbine runbacks are initiated by the reactor protection system. A runback signal is developed when the ΔT in two out of four reactor coolant loops is within three percent of the OTΔT or OPΔT trip setpoint. These trips are discussed in Chapter 12. If either of these runbacks is in effect, the EHC system reduces load at 200%/min for 1.5 sec (a 5% load change), then holds the load constant for 28.5 sec. If the runback condition has not cleared, the load will be reduced by another 5% in the next 30-sec interval.

The other turbine runbacks are initiated by secondary system conditions. Secondary system runbacks are accomplished via reductions of the governor valve position limit setpoint. Possible conditions that may cause a turbine runback include:

1. a combination of a main feed pump trip and turbine load greater than 80% (the turbine runs back to 75% power),
2. directing heater drains from the heater drain tank to the condenser instead of the suction of the main feed pump (the turbine runs back to 85% power).

11.3.4 Summary

The EHC system is made up of three main subsystems:

1. EH fluid system,
2. Auto-stop oil system, and
3. Electronic control system.

High pressure electrohydraulic fluid opens the steam admission valves to the high and low pressure turbines. Pressure in this system is maintained by, EH control pumps, unloader valves, and an interface valve. The unloader valves maintain the pressure within design values, while the interface valve allows the system to be pressurized.

Auto-stop oil keeps the interface valve closed. If the interface valve is shut the EH fluid high pressure will be maintained at its design value. Opening the interface valve by dumping the auto-stop oil causes a turbine trip.

The electronic control system computes deviations between operator-initiated reference values and turbine speed and load. Deviations are transmitted to servo valves to reposition governor or throttle valves.

The turbine is operated in either speed control or load control. With the system in speed control, the throttle valves control the speed until a preselected speed is achieved and then speed control is shifted to the governor valves.

After the generator output breakers are closed, the system automatically shifts to load control with impulse pressure out of service. When operating in this mode, Imp Out, governor valve position is used as a feedback signal. The operator may select impulse pressure in service after power has exceeded some nominal power level. Once this action has taken place, turbine impulse pressure along with governor valve position are used as feedback signals.

Runbacks are provided to prevent either a reactor trip or a turbine trip. Runbacks may be initiated either from the primary protection system, or from the secondary system. Primary runbacks decrease the turbine load via a decrease in the reference load, while the secondary runbacks decrease the setting of the valve position limiter.

Finally, various protective signals are provided to trip the turbine. Whenever a turbine trip occurs, the overspeed trip device is actuated to seal-in the trip. To prevent a turbine overspeed, an overspeed protection circuit is provided. This circuit momentarily closes the governor and the intercept valves. When the overspeed condition clears, the governor and intercept valves return to their open positions.

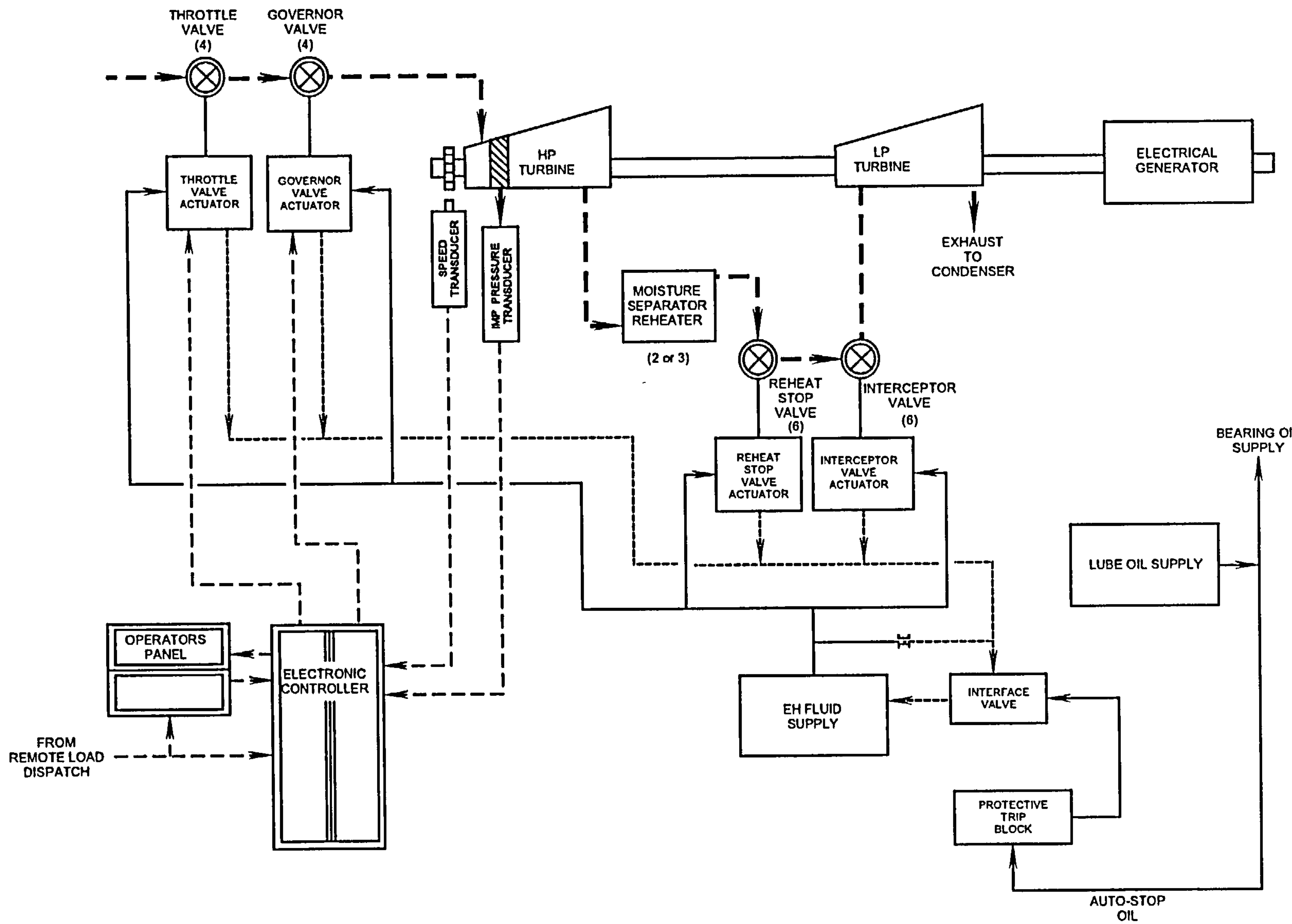

Figure 11.3-1 Simplified EHC System

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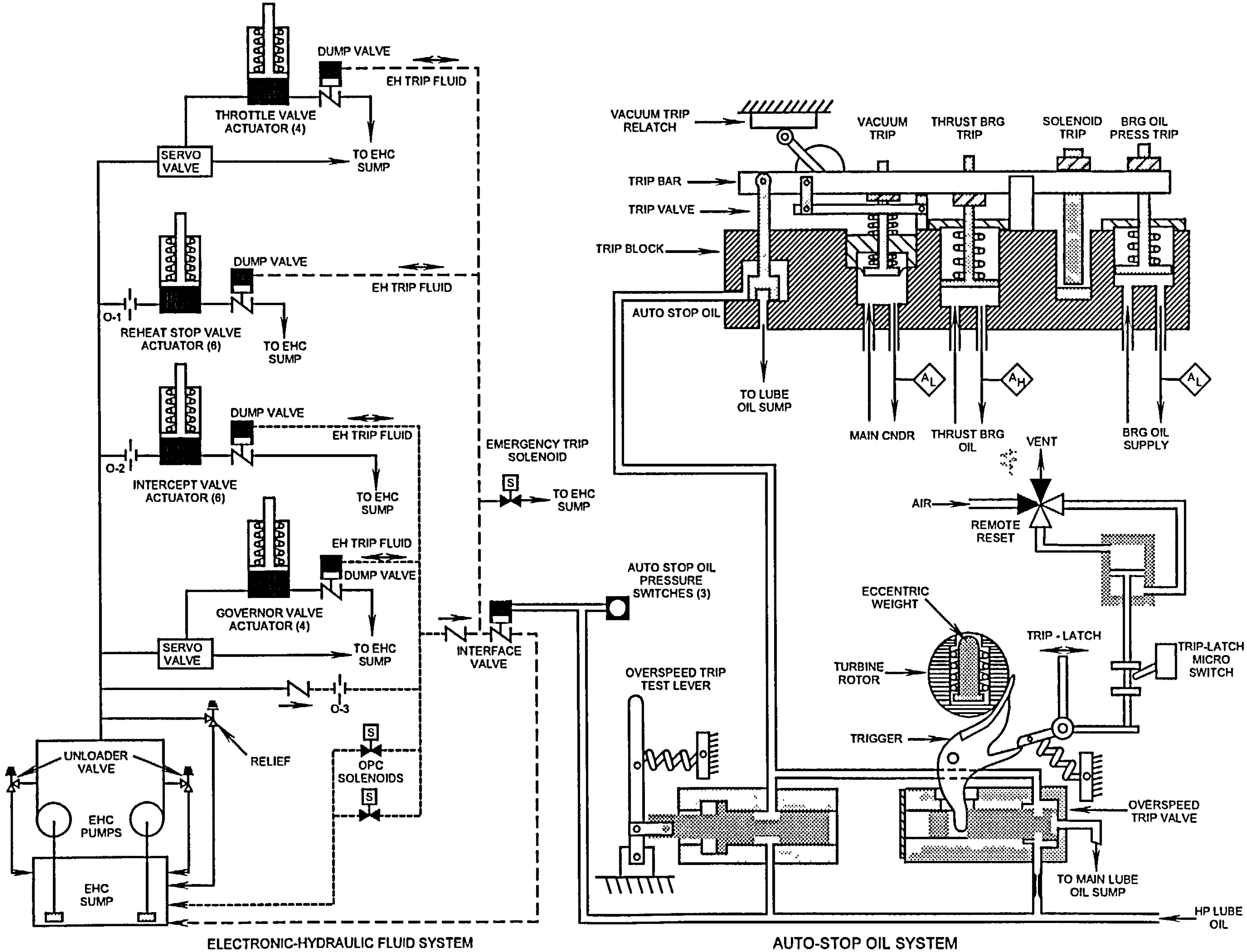

Figure 11.3-2 EH Fluid and Auto - Stop Oil System

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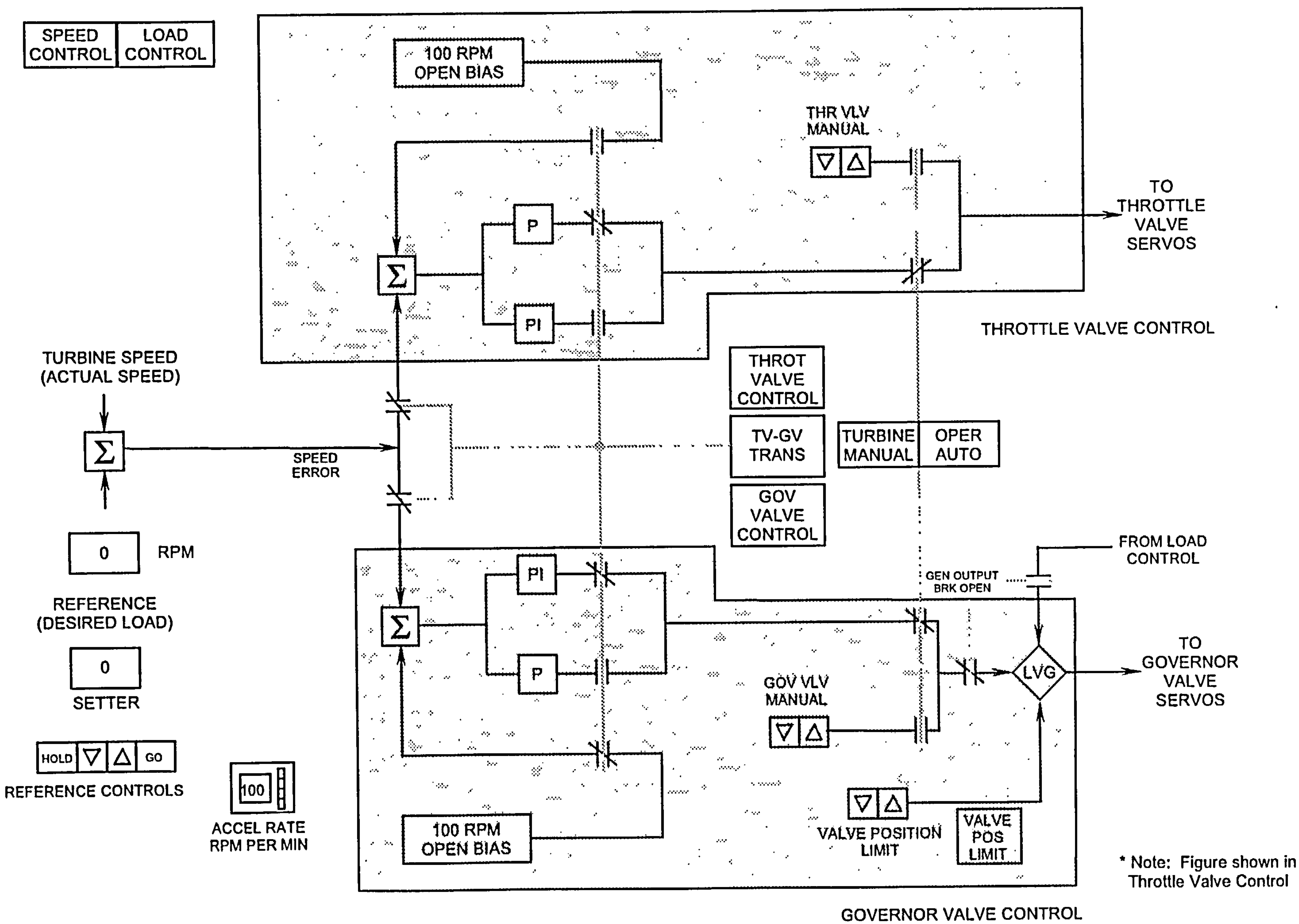

Figure 11.3-3 Speed Control

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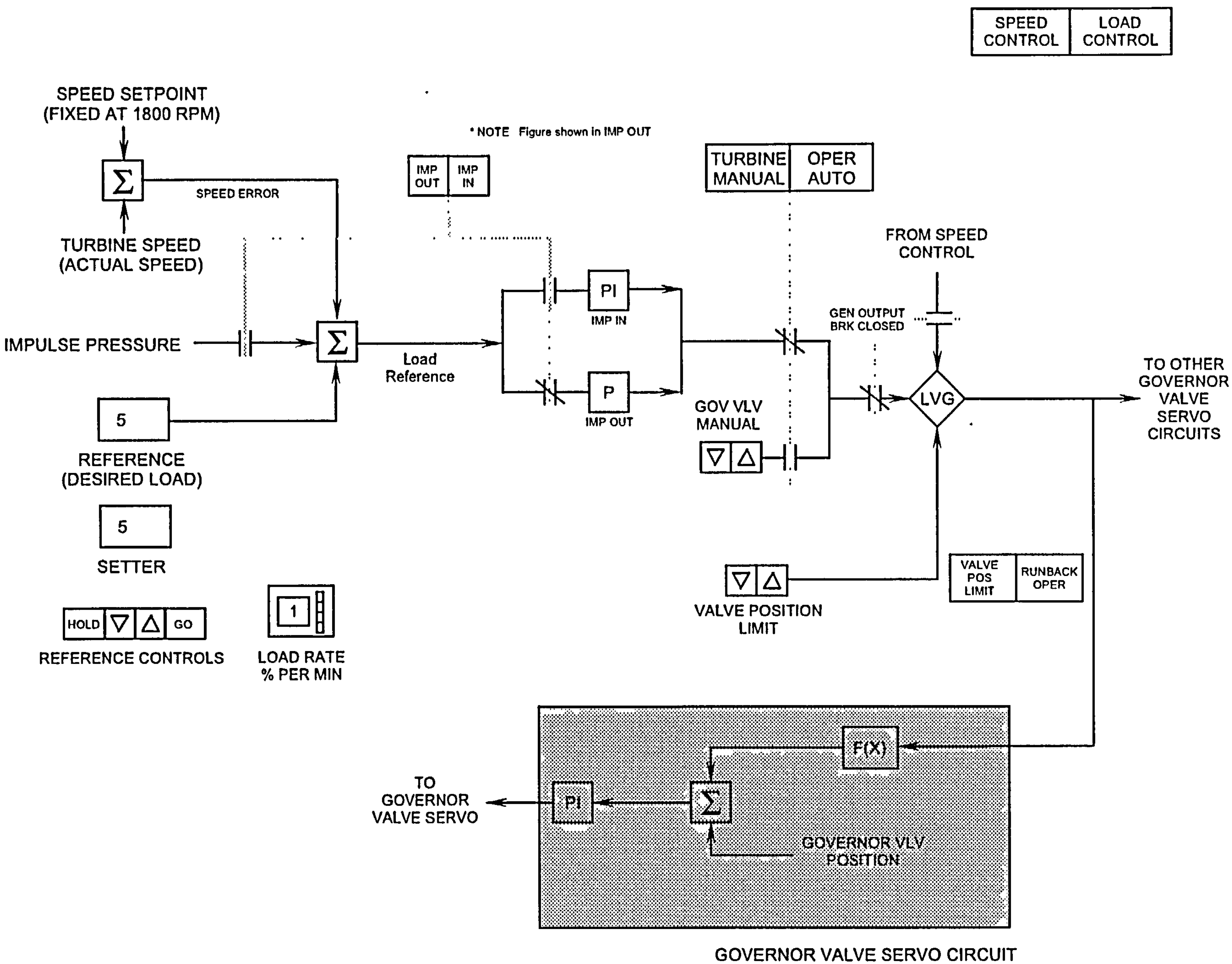

Figure 11.3-4 Load Control

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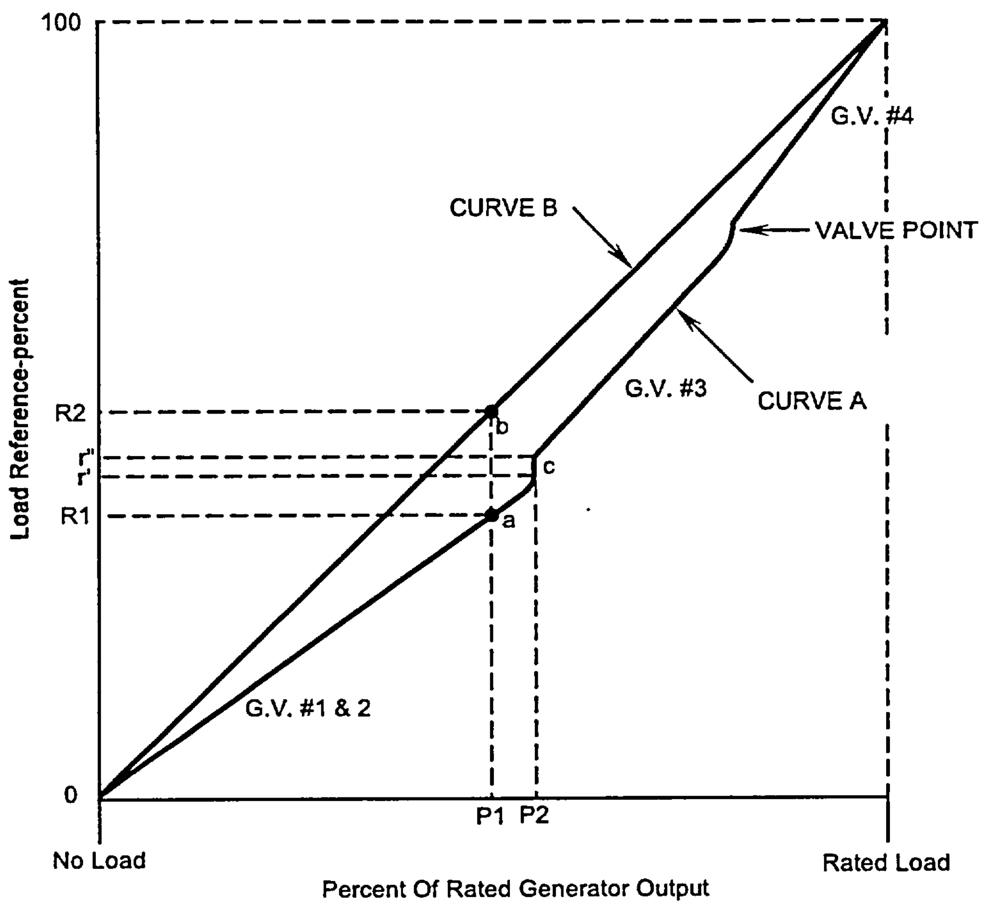

Curve A -- Impulse Chamber Pressure Feedback Out-of-Service (IMP OUT)

Curve B -- Impulse Chamber Pressure Feedback In-Service (IMP IN)

Figure 11.3-5 Impulse Chamber Pressure vs. Load Reference

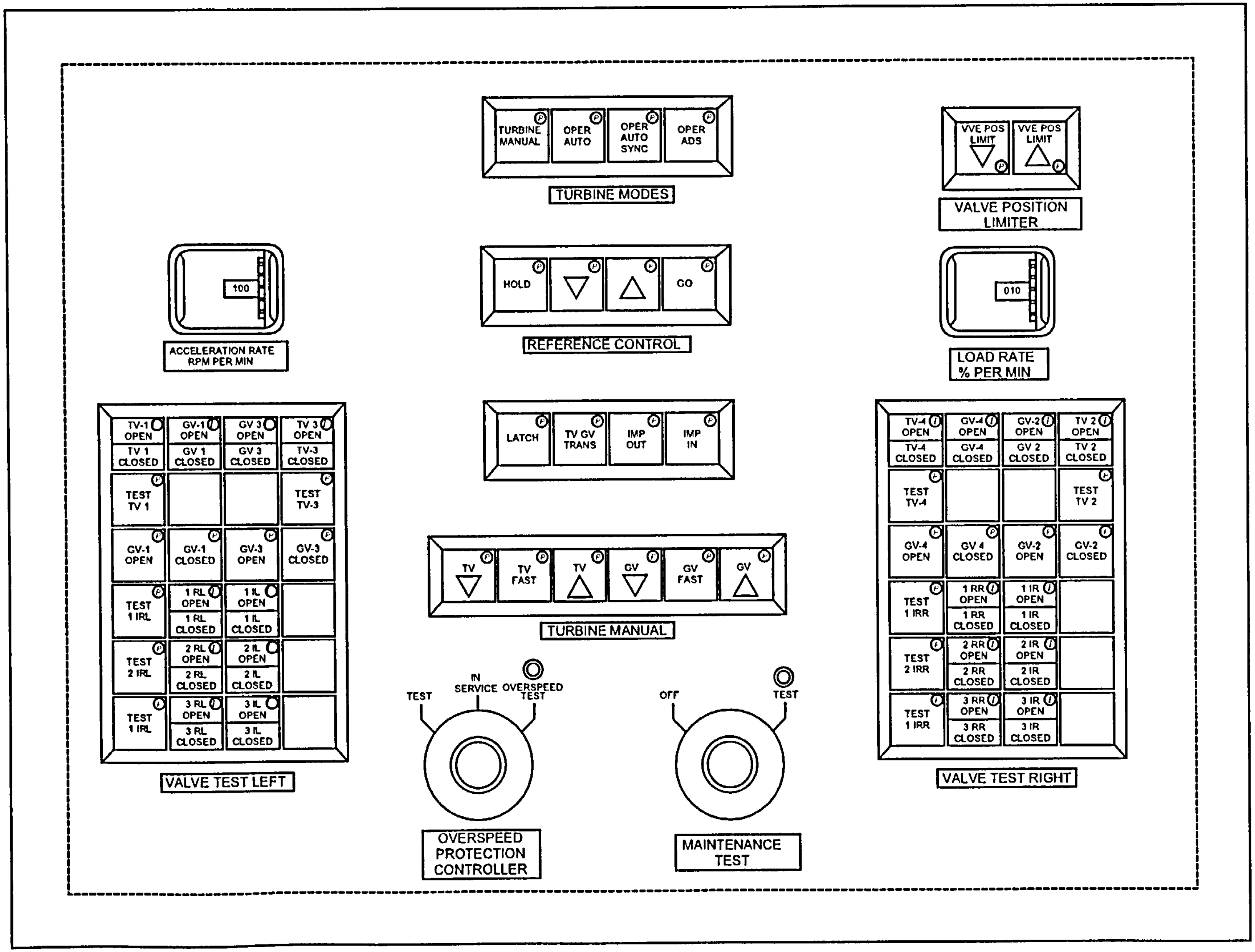

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Figure 11.3-6 EH Control Panel

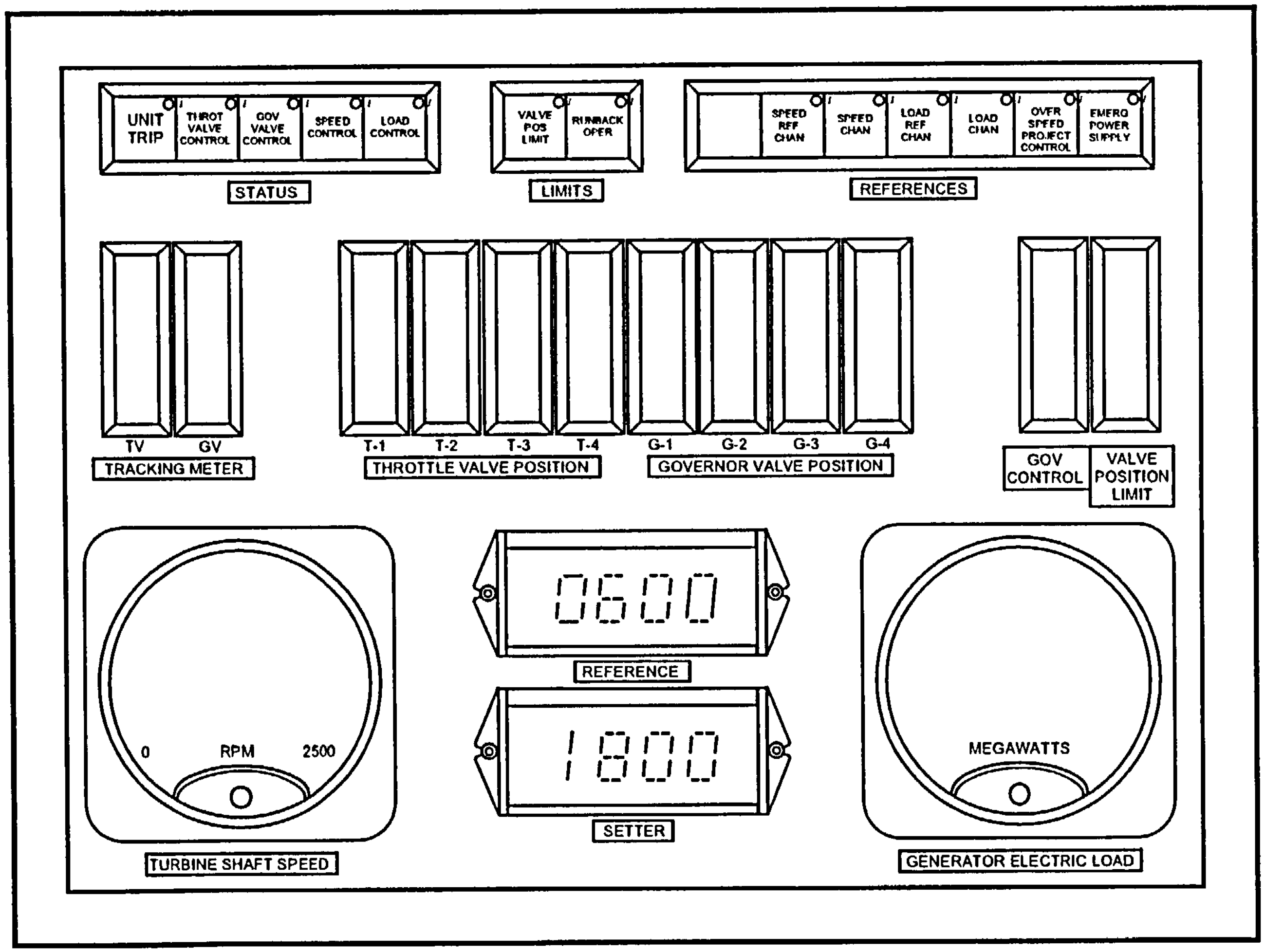

Figure 11.3-7 EH Indicating Panel

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Section 11.4

Moisture Separator Reheater Control

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11.4 MOISTURE SEPARATOR REHEATER CONTROL

11.4.1 Introduction

The moisture separator reheater (MSR) control system; ensures proper heating of the low pressure turbine during cold startups, ensures a minimum differential between the inlet steam and low pressure turbine metal temperatures during hot startups, and provides a smooth decrease in low pressure turbine inlet steam temperature to 400°F after a large load shed from a high power level. These functions are accomplished through the control of the MSR outlet steam temperature.

11.4.2 System Description

After the exhaust steam from the high pressure turbine passes through the moisture separator section of an MSR, the steam enters a two-stage heater section for the addition of superheat. The first-stage heating medium is extraction steam from the high pressure turbine. This steam supply is not regulated. The second-stage heating medium is high pressure steam from the main steam header. This steam supply is regulated by flow control valves to control the temperature of the steam at the outlet of the MSRs.

Figure 11.4-1 shows the operator's panel for the MSR controls. The top of the panel has a row of pushbuttons. Below that is a row of valve status lights for the flow control valves that regulate the main steam flow to the second-stage heater bundles of the MSRs. At the bottom of the panel are three meters, one meter for each low pressure turbine. Each meter indicates the steam inlet temperature supplied to its associated turbine. A status light illuminates when a preset temperature limit has been exceeded and a knob located in the lower right of the panel is provided for manual control.

The POWER ON pushbutton turns the controller on and off. During the performance of a cold startup, the RAMP pushbutton is pushed at 35% of rated power. After this the ramp pushbutton is depressed the flow control valves are opened over a one-hour period. This provides a uniform temperature increase. For a hot startup, the HOT START pushbutton is pushed; the valves are opened quickly, and maintain a low pressure turbine inlet temperature of 400°F to prevent cooling of the low pressure turbine inlet. The 400°F pushbutton is also used during extended low power operations to prevent overheating of the low pressure turbine exhaust sections. MANUAL transfers control to the knob at the bottom of the panel. RESET clears the controller.

After a large load reduction to 10% power or below, the MSR control system automatically positions the second-stage heating flow control valves to maintain a steam temperature of 400°F at the low pressure turbine inlet.

11.4.3 Summary

The inlet temperature to the low pressure turbines is controlled by regulating the flow of high pressure heating steam to the second-stage heater bundles of the MSRs. Steam flow is controlled by flow control valves. The control system will ramp open the valves automatically or maintain a low pressure turbine inlet temperature of 400°F. The valves can also be controlled manually.

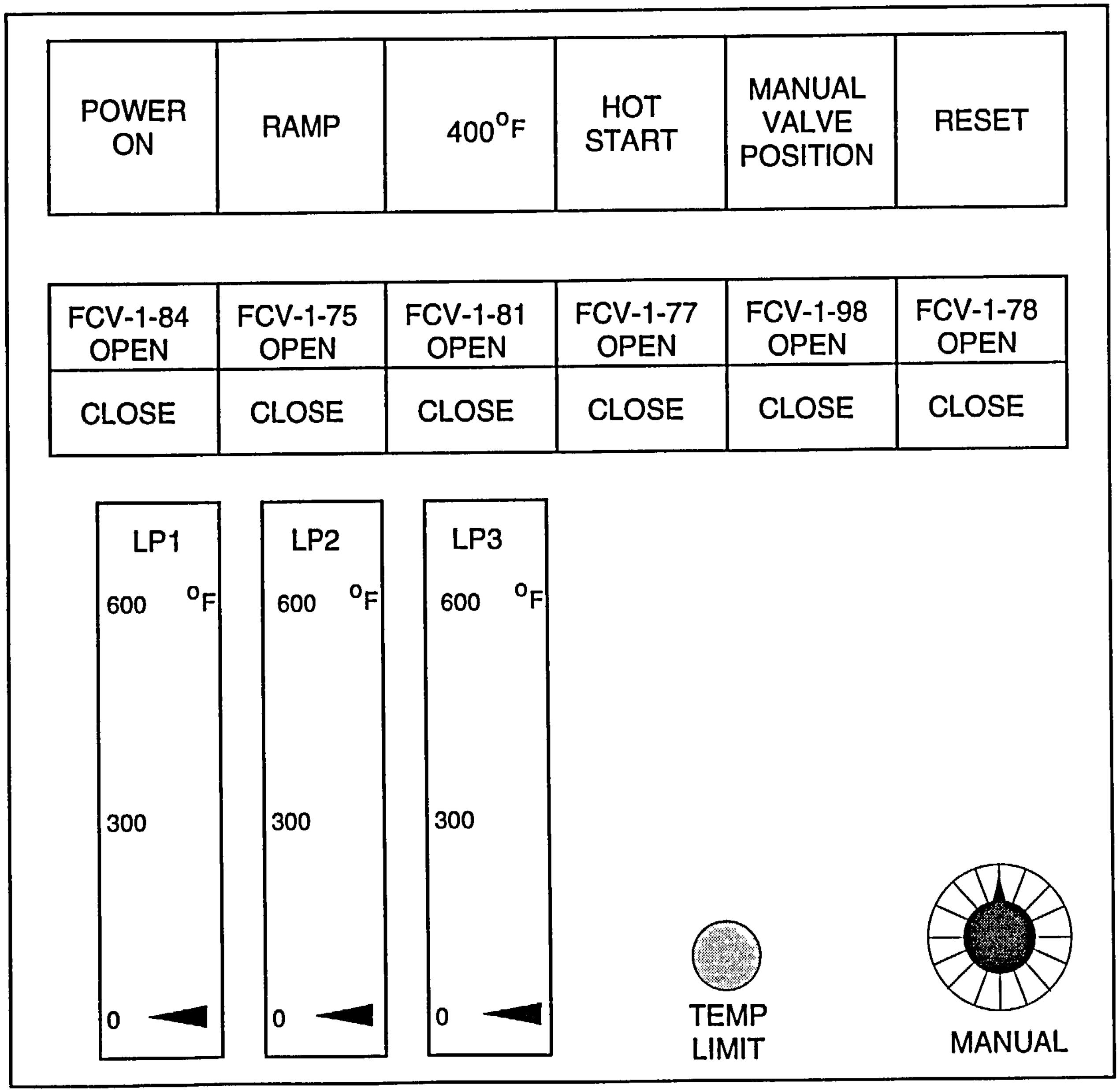

Figure 11.4-1 Reheater Control Panel

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Section 11.5

<u>General Electro Hydraulic Control System</u>

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11.5 GENERAL ELECTRIC ELECTRO-HYDRAULIC CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the turbine electrohydraulic control (EHC) system.
2. Describe the sequence of events that results when a turbine trip is initiated mechanically or electrically.
3. Explain the functions of the following emergency trip system components:
   a. Mechanical trip valve
   b. Lockout valve
   c. Master trip solenoid valve
   d. Relay trip valve
   e. Extraction relay dump valve.
4. Describe the generation of turbine valve positioning signals in the following components of the electrical control system:
   a. Speed control unit
   b. Load control unit
   c. Flow control unit.

11.5.1 Introduction

The purposes of the EHC system are as follows:

1. To govern the warming of the turbine steam chest and high pressure turbine shell,
2. To control the speed of the turbine-generator from turning gear operation to synchronous speed (60 Hz),
3. To control the load of the turbine-generator during normal and abnormal operations, and
4. To provide a rapid shutdown capability (trip) for the protection of the turbine-generator.

The EHC system uses high pressure hydraulic fluid to open and position the steam inlet valves to the high and low pressure turbines in response to commands from an electrical controller. High pressure hydraulic fluid is also supplied to the emergency trip system, which maintains shut the disk dump valves incorporated within the steam inlet valve operators. When the hydraulic pressure in the emergency trip system is relieved, the disk dump valves open, allowing springs to close all steam inlet valves and thereby trip the turbine. A simplified diagram of the EHC system is shown in Figure 11.5-1.

11.5.2 System Description

The EHC system can be divided into three subsystems:

1. The EHC fluid system (high pressure hydraulic fluid),
2. The emergency trip system, and
3. The electrical control system.

11.5.2.1 EHC Fluid System

The valves that admit and control the steam to the high and low pressure turbines are opened by high pressure hydraulic fluid acting on the valves' actuators or operators, which are mechanically linked to the valve stems. This high pressure fluid is supplied by the EHC fluid system, as shown in Figure 11.5-2. Each valve has an operator and a disk dump valve. The application of EHC fluid pressure to the piston in a steam inlet valve's operator overcomes the force exerted by the operator's spring assembly and opens the valve. When a valve operator's disk dump valve opens, EHC fluid is dumped to the EHC fluid reservoir, allowing the spring force to rapidly close the valve. Each disk dump valve is normally maintained in the closed position by the hydraulic fluid pressure applied by the emergency trip system. The means by which emergency trip system pressure is removed are discussed in section 11.5.2.2. When all disk dump valves have opened and the valve operator springs have closed all steam inlet valves to the high and low pressure turbines, the turbine is said to be tripped.

EHC fluid at 1600 psig is supplied to the turbine valve operators by an operating EHC pump, which takes a suction on the EHC fluid reservoir. The second (standby) EHC pump starts if the EHC fluid pressure falls to 1300 psig. The system contains relief valves for overpressure protection, nitrogen-charged accumulators for dampening system pressure variations, and strainers and filters for the removal of contaminants. EHC fluid from the turbine valve operators and from the emergency trip system is returned to the EHC fluid reservoir via two EHC fluid coolers, which are cooled by the bearing cooling water system. The EHC fluid is a synthetic, fire-retardant phosphate ester.

EHC fluid is supplied through servo valves to the operators for the control valves and the #2 stop valve of the high pressure turbine and for three of the six intercept valves of the low pressure turbines. Within a servo valve, commands from the electrical control system result in the movement of an internal spool, which ports more or less EHC fluid to the associated turbine valve operator and thereby causes the turbine valve to open or close further. Once the turbine valve has attained the desired new position, the internal spool returns to its neutral position, which bottles up the EHC fluid between the servo valve and the valve operator in a "hydraulic lock" and maintains the valve position. The turbine valve operators equipped with servo valves are thus capable of modulation.

The remaining turbine valves (high pressure turbine stop valves #1, #3, and #4; three of the six intercept valves; and all six of the intermediate stop valves) are either completely open or completely shut, not modulated. The operator for each of these valves is supplied with EHC fluid through a solenoid-operated valve. With the solenoid de-energized, an internal spool is positioned to admit EHC fluid to the associated valve operator; with the solenoid energized, the spool is positioned to bleed fluid from the operator. Information concerning the positioning of turbine valves during operation is provided in section 11.5.2.3.

11.5.2.2 Emergency Trip System

The EHC pumps supply high pressure EHC fluid to the emergency trip system as well as the turbine valve operators. The emergency trip system, shown in Figure 11.5-3, supplies EHC fluid to the disk dump valves associated with all 20 turbine valves, the relay trip valve, and the extraction relay dump valve (the disk dump valves associated with the control valves and intercept valves are supplied via the relay trip valve). All of the valves listed above are supplied through the mechanical trip valve, the lockout valve, and the master trip solenoid valve. Turbine trip signals act through these latter three valves to dump EHC fluid from the turbine valve operators.

The mechanical trip valve, as its name implies, provides a means of mechanically tripping the turbine. Under normal operating conditions (i.e., a trip condition is not present), the valve aligns the emergency trip system fluid to the lockout valve. In the tripped position, the valve blocks the incoming supply of emergency trip system fluid and opens a drain to the EHC fluid reservoir, allowing emergency trip system fluid to drain from the lockout valve and all downstream components. The mechanical trip valve's incoming and outgoing paths for hydraulic fluid are controlled by the position of an internal spool, which in turn is controlled through mechanical linkages by the overspeed trip device, the manual trip lever, and the mechanical trip solenoid.

The overspeed trip device is an unbalanced ring attached to the turbine shaft; the ring is maintained concentric with the shaft at normal turbine speeds by spring force. At 110% of rated turbine speed (1980 rpm), the ring moves to an eccentric position and strikes the trip finger, which through mechanical linkages places the mechanical trip valve in the tripped position. The overspeed trip device can be tested at normal operating speeds by admitting main turbine lubricating oil inside the ring and thereby causing it to assume its eccentric position (the lockout valve must first be placed in the locked out position; see below).

Pulling the manual trip lever, located on the turbine front standard, to the trip position results in a mechanical linkage striking the overspeed trip finger. From that point, the development of a mechanical trip is identical to that caused by an overspeed condition. Energizing the mechanical trip solenoid causes the same linkage to strike the overspeed trip finger and also results in a mechanical trip. The mechanical trip solenoid is energized when the turbine trip pushbutton in the control room is depressed or when any electrical trip signal is present. The mechanical trip solenoid thus serves as a redundant tripping device to the master trip solenoid valve.

The lockout valve is a three-way solenoid valve located on the turbine front standard. It does not process turbine trips but allows testing of the overspeed trip device (described above) without tripping the turbine. Under normal conditions (i.e., an overspeed trip test is not being conducted), the valve aligns the emergency trip system fluid from the mechanical trip valve to the master trip solenoid valve. In the locked out position, the valve blocks the fluid supply from the mechanical trip valve and aligns a separate emergency trip system fluid supply to the master trip solenoid valve. The lockout valve's alignment is controlled by the position of an internal spool, which is controlled by the lockout solenoid. Energizing the lockout solenoid places the valve in the locked out position.

To conduct a test of the mechanical overspeed trip device, the lockout solenoid is energized. Placing the lockout valve in the locked out position satisfies an interlock which permits the operator to supply lubricating oil to the overspeed trip device. When the overspeed trip is developed, the mechanical trip valve will realign to drain emergency trip system fluid to the EHC fluid reservoir, but the lockout valve will maintain a supply of emergency trip system fluid to the master trip solenoid valve and all downstream components. Pulling the manual trip lever or energizing the mechanical trip solenoid opens an interlock switch through mechanical linkages; the switch in turn de-energizes the lockout solenoid and places the lockout valve in its normal position. Thus, the lockout valve remains in the locked out position only for a mechanical overspeed trip (testing-induced or actual) and allows normal functioning of the emergency trip system for all other turbine trips.

The last of the three valves in the emergency trip system supply line is the master trip solenoid valve. Under normal operating conditions, the valve aligns the emergency trip system fluid from the lockout valve to the downstream emergency trip system components (disk dump valves, relay trip valve, and extraction relay dump valve). In the tripped position, the valve blocks the fluid supply from the lockout valve and opens a drain to the EHC fluid reservoir, allowing fluid to drain from all downstream components. The master trip solenoid valve's alignment is controlled by the position of an internal spool, which in turn is controlled by two solenoids. De-energizing both solenoids places the valve in the tripped position. The valve maintains the fluid supply to the downstream components if either solenoid remains energized; this feature allows either solenoid to be tested (i.e., de-energized) during turbine operation.

When a turbine trip setpoint is reached, a contact or contacts close in the power supply to the master trip bus. The master trip bus then energizes the master trip relays, which open contacts in the power supply to the solenoids of the master trip solenoid valve. De-energizing the solenoids of the master trip solenoid valve causes the valve to assume its tripped position and thereby dump hydraulic fluid from the emergency trip system, causing a turbine trip. The following conditions will cause the master trip bus to be energized:

1. Excessive thrust bearing wear and low bearing oil pressure
2. Low EHC fluid pressure
3. High moisture separator reheater (MSR) water level
4. High turbine shaft vibration
5. Loss of stator cooling water
6. Low shaft-driven lubricating oil pump discharge pressure
7. Loss of EHC system power
8. Loss of turbine speed signal feedback
9. High turbine exhaust hood temperature
10. Loss of condenser vacuum
11. Backup overspeed (111.5% of rated speed, as sensed by a speed transducer)
12. Generator trip
13. Reactor trip
14. Engineered safety features actuation
15. High steam generator water level
16. Low generator output frequency
17. Satisfaction of ATWS (anticipated transient without scram) mitigation system actuation circuitry (AMSAC) logic.

Any of the above conditions redundantly initiates a turbine trip through the mechanical trip solenoid and the mechanical trip valve. When the master trip bus is energized, the master trip relays also close contacts in the power supply to the mechanical trip solenoid. As explained above, energizing this solenoid causes the mechanical trip valve to assume its tripped position.

Downstream of the master trip solenoid valve in the emergency trip system are the disk dump valves for the high pressure turbine stop valves and for the intermediate stop valves, the relay trip valve, and the extraction relay dump valve. Under normal operating conditions, the relay trip valve aligns a separate hydraulic fluid supply (not from the main emergency trip system header) to the disk dump valves for the control valves and for the intercept valves. Emergency trip system fluid pressure is applied to the relay trip valve's internal spool to maintain the valve in its normal position. When the fluid pressure is removed from the spool, the new (tripped) valve alignment blocks the incoming fluid supply and opens a drain to the EHC fluid reservoir, allowing fluid to drain from the downstream disk dump valves.

The extraction relay dump valve serves a purpose similar to that of the relay trip valve. Under normal operating conditions, the extraction relay dump valve aligns the incoming air supply to the operators for the extraction steam bleeder trip valves and for the extraction drain valves. This alignment keeps the bleeder trip valves open (supplying extraction steam to the feedwater heaters) and the extraction drain valves closed (isolating the extraction steam drain lines to the main condenser). Emergency trip system fluid pressure is applied to the relay dump valve's piston to maintain the valve in its normal position. When the fluid pressure is removed from the piston, the new (tripped) valve alignment blocks the incoming air supply and opens an exhaust port which vents the operators of the extraction steam system valves. The loss of air pressure closes the bleeder trip valves and opens the extraction drain valves. Closing the bleeder trip valves prevents the reverse flow of steam from the feedwater heaters to the turbine and possible turbine overspeeding (a great deal of energy remains stored in the extraction steam system immediately following a turbine trip). Opening the extraction drain valves allows the extraction steam to exhaust to the main condenser.

Five pressure switches, physically located on the turbine front standard, are connected to the emergency trip system header downstream of the master trip solenoid valve. The pressure in the header will drop rapidly when either the mechanical trip valve or the master trip solenoid valve dumps hydraulic fluid in response to a turbine trip condition. These pressure switches, set to close at 800 psig, thus indicate whether the turbine has tripped.

Three of the pressure switches supply the reactor protection system logic. A reactor trip is initiated when at least two of these switches are closed with plant power greater than the P-7 permissive setpoint (10%). The remaining two pressure switches provide turbine trip inputs to the turbine electrical control system. When closed, the pressure switches (1) lock in the CLOSE VALVES turbine speed reference and SLOW acceleration setpoint (in this chapter, capitalized terms refer to indications, pushbuttons, and switches on the turbine control panel), and (2) close contacts which apply large closing inputs to the control valve and intercept valve positioning circuits (see section 11.5.2.3 for a detailed discussion of the electrical control system). These last two pressure switches also serve to lock in a turbine trip by closing contacts in series with the master trip reset pushbutton in the power supply to the master trip bus.

To summarize the action of the emergency trip system, consider the following sequence of events initiated by high turbine shaft vibration:

1. The initiating condition closes contacts in the power supply to the master trip bus, thereby energizing the master trip relays.

2. The energized master trip relays close contacts in the power supply to the mechanical trip solenoid and open contacts in the power supply to both solenoids of the master trip solenoid valve.

3. The mechanical trip valve and the master trip solenoid valve assume their tripped positions, opening drain ports which dumps hydraulic fluid from the emergency trip system.

4. With the decreasing emergency trip system header pressure:

   a. The disk dump valves for the high pressure turbine stop valves and for the intermediate stop valves are no longer held in the closed position. EHC fluid is dumped from the turbine valves' operators, allowing springs to close the valves.

   b. The relay trip valve assumes its tripped position, opening a drain port which dumps hydraulic fluid from the disk dump valves for the high pressure turbine control valves and for the intercept valves. The disk dump valves open. EHC fluid is dumped from the turbine valves' operators, allowing springs to close the valves.

   c. The extraction relay dump valve assumes its tripped position, opening an exhaust port which vents air from the operators for the bleeder trip valves and for the extraction drain valves. The bleeder trip valves close, and the extraction drain valves open.

d. The pressure switches connected to the emergency trip system header close when the header pressure decreases to 800 psig. They provide turbine trip inputs to the reactor protection system and to the turbine electrical control system.

11.5.2.3 Electrical Control System

The major components of the turbine electrical control system are the speed control unit, the load control unit, and the flow control unit. These units are illustrated in Figure 11.5-4. The speed control unit controls turbine speed in response to operator commands or maintains the normal rated speed of the turbine-generator. In the load control unit, electrical signals are generated to position the turbine steam valves to maintain the desired load. The flow control unit receives the valve positioning signals, accounts for the steam flow control characteristics of the valves, and positions the valves accordingly. The flow control unit supplies valve positioning signals only to the servo valves associated with the control valves and with intercept valves #1, #2, and #3. The turbine chest and shell warming circuits supply positioning signals to the servo valve associated with stop valve #2. The remaining turbine valves are not modulated. They are either completely open or completely shut in accordance with the turbine operating status and the positions of limit switches associated with the modulated valves.

Speed Control Unit

In the speed control unit, the actual turbine speed is compared to the reference speed, and the actual turbine acceleration is compared to the acceleration setpoint. Either the speed error or the integrated acceleration error is chosen as the unit output and supplied to the load control unit. Normally, the speed error dominates the circuit, but when the reference speed is changed, the integrated acceleration error dominates until the turbine nears the new reference speed. During steady-state operation, the turbine speed is maintained constant at rated speed, and the output of the speed control unit is zero. Refer to Figure 11.5-5.

Turbine speed signals from two speed transducers are provided to separate circuits for redundancy and reliability. In each circuit, the actual speed signal is subtracted from the reference speed to produce a speed error. In addition, each speed signal is provided to a differentiator, which converts the speed signal into an acceleration signal. In each circuit of the speed control unit, the acceleration signal is subtracted from the acceleration setpoint to produce an acceleration error; the error is then integrated. The integrated acceleration error and speed error of each circuit are provided to a low value gate, which selects the signal of lowest value. The outputs of the low value gates of both circuits are provided to another low value gate, which again selects the lowest signal and provides it as the speed control unit output to the load control unit.

The reference speed is selected by the operator at the turbine control panel. The available setpoints are CLOSE VALVES, 100 RPM, 800 RPM, 1500 RPM, 1800 RPM, and OVERSPEED TEST. The normal turbine speed is 1800 rpm; the other discrete speed setpoints can be selected as intermediate stopping points when the turbine is being accelerated to synchronous speed. The CLOSE VALVES reference can be selected to stop a turbine startup in lieu of a manual turbine trip. The OVERSPEED TEST reference is used to develop actual overspeed conditions during overspeed trip testing. The CLOSE VALVES reference is automatically selected when the turbine trips.

The available acceleration setpoints are SLOW (60 rpm/min), MEDIUM (90 rpm/min), and FAST (180 rpm/min). The selected setpoint is governed by the turbine first-stage shell temperature during a turbine acceleration to synchronous speed if shell warming has not been performed first (the higher the temperature, the greater the allowable acceleration). The SLOW reference is automatically selected when the turbine trips.

The relative effects of the speed and integrated acceleration errors are illustrated in Figure 11.5-6 for a turbine speed increase. When the new speed reference is first selected, the speed error is large. The relatively smaller integrated acceleration error dominates initially as the turbine speed increases. Once the turbine has accelerated to the acceleration setpoint, the integrated acceleration error stops increasing and remains constant (at a lower value than the speed error) during much of the remaining speed increase. As the turbine speed approaches the reference speed, the speed error decreases until it becomes smaller than the integrated acceleration error. The speed error is then selected by the low value gates. Hence, the integrated acceleration error ensures that the turbine accelerates at the selected rate during a speed change, and the small or negligible speed error ensures that the steady-state turbine speed matches the selected reference speed.

Load Control Unit

The output of the speed control unit is supplied to the control valve and intercept valve amplifiers in the load control unit, shown in the center portion of Figure 11.5-4. This signal is first conditioned by the control valve and intercept valve regulation circuits. The regulation circuits ensure that the affected valves are modulated closed in response to turbine overspeed conditions.

In the control valve regulation circuit, any incoming speed error from the speed control unit is multiplied by an adjustable gain and then supplied to the control valve amplifier (summer), where it is added to the load reference signal. The gain is adjusted in the EHC control cabinets and usually selected such that the degree of valve regulation is 5%. What this term denotes is that an overspeed condition of 5% greater than normal rated speed (1890 rpm) is required to cause the control valves to close fully from an initial fully open position when the turbine reference load is 100%. In other words, a 5% speed error (actual greater than reference) is multiplied by a gain of 20 (divided by 0.05 or 5%) in the control valve regulation circuit and supplied as a -100% input to the control valve amplifier, where it completely negates a 100% load reference signal and results in a 0% (close completely) signal to the control valves. Note that with a load reference of 100%, the control valves will receive partial-close signals for degrees of overspeed less than 5%, and that lesser degrees of overspeed are required to close the control valves fully for reference loads of less than 100%.

In the intercept valve regulation circuit, the incoming speed error is similarly multiplied by an adjustable gain, except that the selected degree of valve regulation is typically 2% (i.e., a gain of 50). However, the intercept valves do not fully close with a 2% overspeed condition (and a reference load of 100%) because of the "C.V. Reg./I.V. Reg." conditioning applied to the load reference signal. The load reference signal is multiplied by a gain equivalent to the ratio of the control valve and intercept valve regulations (in this case, 5% divided by 2%, or 2.5) and supplied as an additional positive signal to the intercept valve amplifier. A 100% load reference signal is thus supplied as a 250% input to the intercept valve amplifier, where it is added to the always present 100% opening bias (the intercept valves are fully open during turbine operation except for overspeed conditions). To completely overcome this 350% valve opening input to the intercept valve amplifier (i.e., to fully close the intercept valves), a -350% input from the intercept valve regulation circuit, or a 7% overspeed condition (1926 rpm), is required. Also, with these values for intercept valve regulation and load reference conditioning and with a 100% reference load, any overspeed condition between 5% and 7% above rated speed causes partial closing of the intercept valves.

The conditioned load reference signal supplied to the intercept valve amplifier ensures that the amount of overspeed that causes the control valves to close completely also causes the intercept valves to begin to close. The higher turbine speed required to close the intercept valves enables them to continue blowing down the MSR steam inventory after the control valves have closed. Figure 11.5-7 illustrates the relationship between control valve and intercept valve regulation for overspeed conditions with reference loads of 50% and 100%.

In addition to the regulated speed control unit output, the load reference signal is supplied to the control valve amplifier. The operator varies the load reference signal to control the turbine-generator load once the generator output breakers have been closed. This signal is developed by the bi-directional load reference drive motor, which drives a differential transformer. The output of the transformer is provided via the load reference amplifier. Refer to Figure 11.5-8.

Normally, the load reference drive motor is operated by the INCREASE and DECREASE pushbuttons on the turbine control panel. Depressing one of these pushbuttons changes the reference load at a rate of 133%/min, which is reflected on the LOAD SET meter. For an increasing reference load, the rate of change of the reference signal is limited by the load reference amplifier in accordance with the loading rate selected by the operator. The available rates are 0.5%/MIN, 1%/MIN, 3%/MIN, and 5%/MIN. There is no rate-limiting capability for a decreasing reference load.

The load reference drive motor can also be operated by the following inputs:

1. Line speed matcher
2. Runbacks
    a. Overpower ΔT (OPΔT)
    b. Overtemperature ΔT (OTΔT)
    c. Loss of stator cooling water
3. Power-to-load unbalance circuit.

The line speed matcher can both increase and decrease the reference load, while the other inputs can only decrease it.

The line speed matcher is used to automatically match the turbine speed with the grid frequency during the synchronization process. The line speed matcher is removed from the load reference circuit whenever the generator output breakers are closed.

The turbine runback signals reduce the reference load in response to abnormal conditions. An OPΔT or OTΔT runback signal is generated whenever the reactor coolant loop ΔT is within three percent of the respective reactor trip setpoint (see Chapter 12.2). Either of these runback signals is applied to the load reference drive motor in an on/off cycle such that the reference load is decreased at the rate of 133%/min for 2.3 sec and then held constant for the next 27.7 sec. This cycle imposes an overall 10.2%/min runback rate. The runback initiated by the loss of stator cooling water (indicated by low stator cooling water flow, low pressure, or high outlet temperature) is provided in a one-sec-on, five-sec-off cycle, for an overall runback rate of 22%/min. For any runback, the on/off cycle repeats as long as the runback condition persists and ends when the condition has cleared. The loss-of-stator-cooling-water runback is effective for loads greater than 23%.

The last input to the load reference circuit, the power-to-load unbalance circuit, is designed to prevent an overspeed condition in response to a sudden load rejection by immediately closing the control valves and by rapidly reducing the load reference signal. The power-to-load unbalance setpoint is a mismatch of 40% between turbine power (measured in terms of high pressure turbine exhaust pressure) and generator load (measured in terms of generator output current). When the unbalance condition is sensed, the reference load is driven toward zero, and the output of the load reference circuit is removed from the control valve and intercept valve amplifiers. Outside the load reference circuit, the power-to-load unbalance circuit energizes solenoid-operated valves (not shown in any figure in this chapter) which dump the hydraulic fluid from the control valve disk dump valves, causing the control valves to shut. When the unbalance condition clears, the control valves reopen, the load reference circuit output is restored, and the new reference load corresponds to the endpoint of the reference load decrease which occurred while the unbalance condition was in effect.

The last input to the control valve amplifier is first-stage pressure feedback. This input is provided only during control valve testing; it compensates for the closure of one control valve by providing an additional opening signal to the other three. The first-stage pressure feedback circuit provides a signal proportional to the difference between the desired load and turbine power (as derived from first-stage pressure in the high pressure turbine). As the first-stage pressure drops in response to the closure of the tested control valve, the feedback circuit provides an additional opening signal to the other three control valves in order to maintain the desired load. (Note: At some plants the first-stage pressure feedback circuit provides true load feedback in the load control unit.)

The output of the control valve amplifier is supplied to a low value gate. The other potential input to the gate is a minimum signal supplied from the emergency trip system header pressure switches. This input provides a large closing signal to the control valves when the turbine trips. This closing signal is a backup to the mechanical tripping of the valves initiated by the emergency trip system.

The output of the low value gate proceeds to the throttle pressure compensator. Throttle pressure compensation is necessary because of the inherent decrease in steam pressure that accompanies an increasing steaming rate from a U-tube steam generator. The compensator corrects for the variation of throttle pressure with load to maintain a nearly linear relationship between steam flow and turbine load demand. The compensator multiplies the input signal by a gain equal to the ratio between the throttle pressure at rated load and actual throttle pressure (measured from the steam chest between the stop and control valves). The output of the throttle pressure compensator is supplied to another low value gate. The other inputs to the gate are the initial pressure limiter and the load limit circuit.

The initial pressure limiter compares the actual throttle pressure (measured by a different instrument from the one that supplies the throttle pressure compensator) to an adjustable setpoint. The operator selects the setpoint with a potentiometer on the turbine control panel. The range of the potentiometer is 0 to 100% of rated throttle pressure; it is normally adjusted to 90%. If the throttle pressure decreases below the setpoint, the pressure limiter circuit becomes limiting (is selected by the low value gate) and begins to close the control valves. The control valves close completely if the throttle pressure drops to 10% below the setpoint. The limiter protects the turbine against an excessive decrease in inlet steam pressure (and potential moisture carryover) when the steam generation rate of the steam generators falls below the turbine steam demand.

The load limit input to the low value gate is supplied by a potentiometer on the turbine control panel. The potentiometer setting, acting through the low value gate, acts as a clamp on valve opening; that is, the valves cannot respond to an opening signal larger than that called for by the potentiometer. Adjusting the load limit potentiometer allows the operator to prevent inadvertent load increases above some limit associated with equipment operation. For instance, if the plant is limited to 60% power with one operating main feed pump, a load limit setting of 60% prevents load increases above this value. In addition, at some plants setback signals are generated through the load limit circuit. A turbine setback automatically inserts a control valve opening limit into the load limit circuit in response to the loss of some necessary power conversion system component, such as a main feed pump or circulating water pump. If the reference load demand exceeds the limit when the setback condition arises, the low value gate accepts the setback input, and an immediate reduction in control valve position results.

To summarize, the last low value gate in the control valve load control circuitry is supplied with a reference load input from the control valve amplifier (via the throttle pressure compensator) and with inputs from the initial pressure limiter and the load limit circuit. The reference load is selected unless some limit is imposed by the other two inputs. The output of the low value gate is supplied to the control valve positioning units in the flow control unit.

The intercept valve amplifier receives the following inputs: the regulated output of the speed control unit (described previously in this section), the modified output of the load reference circuit (also described previously), and a 100% opening bias. During normal operation the opening bias provides a fully open signal to the intercept valves. The intercept valve amplifier would provide a less-than-full-open demand only during an overspeed event of sufficient severity. The output of the intercept valve amplifier is supplied to a low value gate. The other potential input to the gate is a minimum signal supplied from the emergency trip system header pressure switches. This input provides a large closing signal to the intercept valves when the turbine trips. This closing signal is a backup to the mechanical tripping of the valves initiated by the emergency trip system. The output of the low value gate is supplied to the valve positioning units for intercept valves #1, #2, and #3 in the flow control unit. These are the intercept valves capable of modulation; the other three intercept valves are slaved to the modulated valves.

Flow Control Unit

The flow control unit receives the valve positioning signals for the control valves and for three of the intercept valves from the load control unit and positions the valves accordingly. The flow control unit contains seven valve positioning units, one for each of the modulated turbine valves. A typical valve positioning unit is illustrated in Figure 11.5-9.

The output from the load control unit (control valve or intercept valve position demand) is supplied to a summing amplifier, along with the actual valve position from the feedback circuit. For a control valve, a sequencing bias would also be applied to the summing amplifier if the control valves do not open and close in concert. The output from the summing amplifier is supplied via a servo amplifier to the servo valve, which controls the position of the associated turbine valve.

When a new valve position is demanded by the load control unit, the servo amplifier at first receives a large (in magnitude) signal from the summing amplifier due to the large error between demanded and actual valve position, and then a gradually decreasing (in magnitude) signal as the actual position approaches the demanded position. When the valve has attained the desired new position, zero current is applied to the servo valve, the servo valve's internal spool is again in the neutral position, and the hydraulic lock applied to the valve operator maintains the valve position until the next new position demand is received.

Actual valve position is relayed to the feedback circuit by a linear variable differential transformer mounted on the valve. The transformer's output is varied by a stroke transducer which follows the motion of the valve's operating piston. A diode function generator compensates the actual valve signal in the feedback circuit to account for the nonlinear relationship between valve position and steam flow. What has been termed a "valve positioning signal" in this section might be better described as a "steam flow demand signal"; the function generator ensures that the valve is positioned such that the demanded steam flow is obtained.

Chest and Shell Warming

Prior to rolling the turbine, the steam valve chests (the chambers between the stop and control valves) and the high pressure turbine shell must be heated slowly to minimize the development of thermal stresses. In addition, shell warming minimizes differential expansion between the turbine rotor and the high pressure turbine casing. A slow heatup capability for these turbine regions is provided by the internal bypass valve of stop valve #2 (see Chapter 7.4) and its associated control circuit. Refer to Figure 11.5-10.

To initiate chest warming, the turbine must be reset and the CLOSE VALVES reference speed must be selected. The operator depresses the CHEST WARM pushbutton and adjusts the position of the #2 stop valve internal bypass by manipulating a potentiometer on the turbine control panel. The potentiometer output and valve position feedback signal are supplied as inputs to a summing amplifier; the amplifier's output is supplied to the #2 stop valve's servo valve. This positioning circuit is similar to the control valve and intercept valve positioning units described above. A maximum limit is incorporated in the positioning circuit to ensure that the main disk of the #2 stop valve is not lifted.

The operator adjusts the potentiometer to obtain the desired warming rate in accordance with the steam chest temperature limits. The steam chests associated with all stop and control valve pairs are warmed through the steam chest cross-connections. The steam chest warming process also equalizes the pressures across the stop valve main disks in preparation for subsequent opening.

Turbine shell warming is conducted in a similar fashion. (Note: At some plants, a separate shell warming procedure is not implemented, and the turbine shell is warmed as the turbine is accelerated to synchronous speed.) To initiate shell warming, the operator depresses the SHELL WARM pushbutton and again manipulates the potentiometer to obtain the desired heating rate. The initiation of shell warming automatically opens the control valves and closes the intermediate stop valves. Heating steam is admitted to the high pressure turbine shell via the #2 stop valve internal bypass and the open control valves. The steam condenses within the shell and exits the turbine via the shell drains.

Positioning of Unmodulated Turbine Valves

The unmodulated turbine valves are operated in accordance with the turbine operating status or the positions of limit switches associated with the modulated valves.

The #2 stop valve receives a full-open signal whenever a reference speed other than CLOSE VALVES is selected. The #1, #3, and #4 stop valves receive full-open signals when the #2 stop valve open limit switch opens; they receive full-close signals when the limit switch closes (indicating that the #2 stop valve is not fully open). The limit switch is operated by a rod mechanically linked to the #2 stop valve's operator piston. Hence, the other three stop valves are slaved to the #2 stop valve.

The #1, #2, and #3 intercept valves also receive a full-open signal whenever a reference speed other than CLOSE VALVES is selected. Each of the #4, #5, and #6 intercept valves is slaved to one of the modulated intercept valves. The slaved valves open or close in accordance with the positions of limit switches associated with the modulated valves. When a modulated valve is opened and reaches the full-open position, the associated slaved valve opens. When a modulated valve reaches the 50% open position as it closes, the associated slaved valve closes.

All intermediate stop valves open when the master trip reset pushbutton is depressed. They are open for all turbine operations except for shell warming.

11.5.3 System Operation

The following paragraphs describe the warming, acceleration, and loading of the turbine in terms of operator actions at the turbine control panel. Refer to Figures 11.5-11 and 11.5-12 for the locations of panel indications and pushbuttons.

Prior to a turbine startup, the operator verifies the following EHC system indications at the turbine control panel:

- The turbine is tripped, as indicated by the illuminated mechanical trip TRIPPED light and emergency trip system TRIPPED light.
- The SLOW starting rate and CLOSE VALVES speed set pushbuttons are backlit.
- The chest/shell warming OFF pushbutton is backlit and the chest/shell warming potentiometer is set at zero.
- The load set megawatt meter is set at zero and the load limit set potentiometer is set at 10%. The LOAD LIMIT LIMITING light is extinguished.
- The initial pressure limit ON pushbutton is backlit and the limiting pressure potentiometer is set at 90%.
- The throttle pressure indicator is displaying main steam pressure.
- All servo valve current indications are negative.

To initiate the turbine startup, the operator depresses and holds the RESET pushbutton. The mechanical trip RESETTING light is illuminated until the mechanical trip valve is reset, at which time the RESETTING and TRIPPED lights extinguish and the RESET light illuminates. When the master trip solenoid valve resets, the emergency trip system TRIPPED light extinguishes and the RESET light illuminates. Now that the turbine has been reset, the intermediate stop valves open fully.

Next, the chest warming controls are used to warm the turbine steam chests. The operator depresses the CHEST WARM pushbutton and uses the chest/shell warming potentiometer to admit steam to the chests via the #2 stop valve bypass. When the chest metal temperature is within 50°F of main steam temperature, chest warming is terminated by closing the #2 stop valve bypass with the potentiometer.

Following chest warming, the turbine is rolled to synchronous speed (assume that shell warming is conducted in conjunction with turbine acceleration). The operator selects the 100 RPM speed set. The #2 stop valve opens fully, after which the remaining three stop valves open fully. Also, the modulated intercept valves open fully, after which the slaved intercept valves open fully. The speed control unit controls the turbine acceleration in accordance with the starting rate (SLOW, MEDIUM, or FAST) selected by the operator. As the turbine accelerates, the SPEED INCREASING light is illuminated. When the turbine speed reaches 100 rpm, the SPEED INCREASING light extinguishes, and the AT SET SPEED light illuminates.

At 100 rpm, proper turbine operation and control are verified. The operator then selects the 1800 RPM speed set and accelerates the turbine to synchronous speed. With the SLOW starting rate selected, the turbine takes about 30 min to reach 1800 rpm. At 1800 rpm, the AT SET SPEED light is again illuminated. If an abnormal condition develops during the turbine speed increase, the CLOSE VALVES speed set may be selected to interrupt steam admission to the turbine. If turbine control is erratic, or if excessive rotor/casing differential expansion or vibration develops, the operator trips the turbine by depressing the TRIP pushbutton.

With a turbine speed of 1800 rpm, the generator is ready for synchronization with the electrical grid. (At this point, the reactor will have been made critical, and reactor power will have been increased to 10-15%. The steam dump system is in operation.) The load selector INCREASE and DECREASE pushbuttons or the line speed matcher are used to match generator and grid frequencies. Once the generator output breakers are closed, the operator immediately increases the load setpoint with the INCREASE pushbutton to a value high enough to clear any potential generator motoring alarms.

During the power ascension, load setpoints and loading rates are selected in accordance with applicable turbine temperature limits, the status of other plant equipment, and load dispatcher instructions.

11.5.4 Summary

The EHC system is made up of three main subsystems:

1. The EHC fluid system,
2. The emergency trip system, and
3. The electrical control system.

The EHC fluid system supplies high pressure hydraulic fluid to the operators of the steam inlet valves of the high and low pressure turbines. The emergency trip system provides the means by which the hydraulic fluid is dumped from the valve operators, allowing springs in the operator assemblies to rapidly close the valves. The electrical control system provides signals for turbine valve positioning to control the turbine-generator's speed and loading in accordance with operator commands.

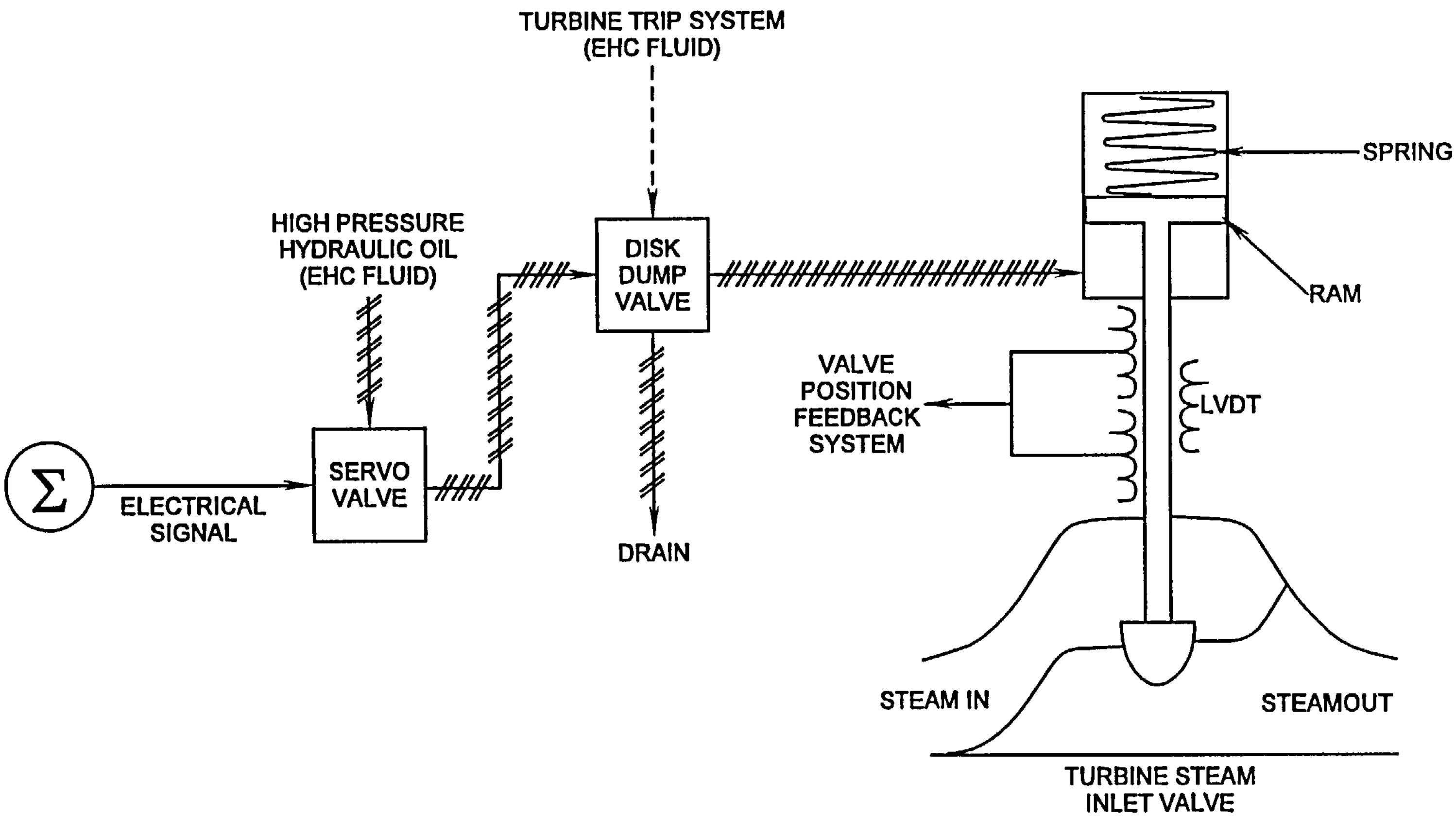

FIGURE 11.5-1 Simplified EHC System

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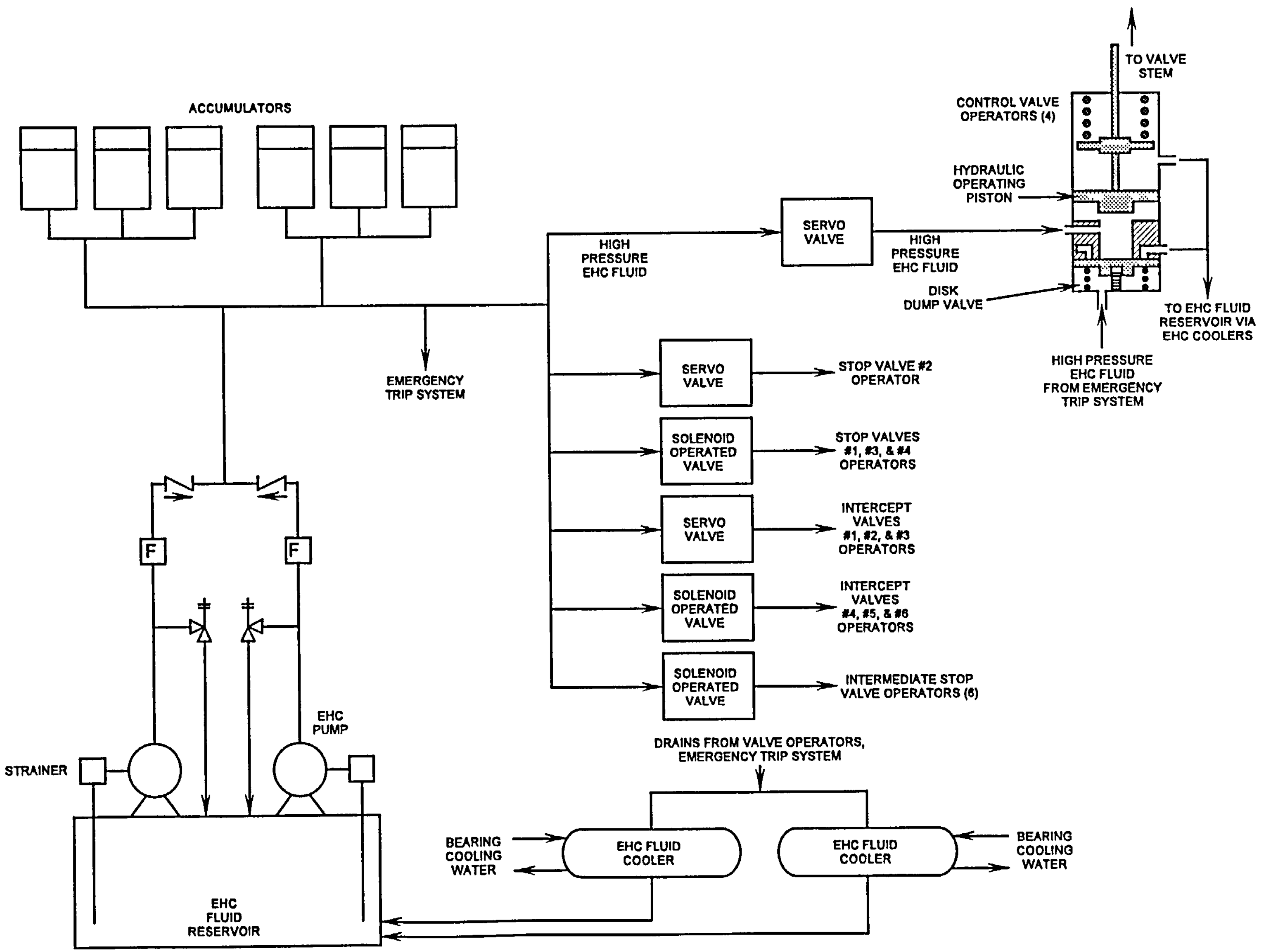

Figure 11.5-2 EHC Fluid System

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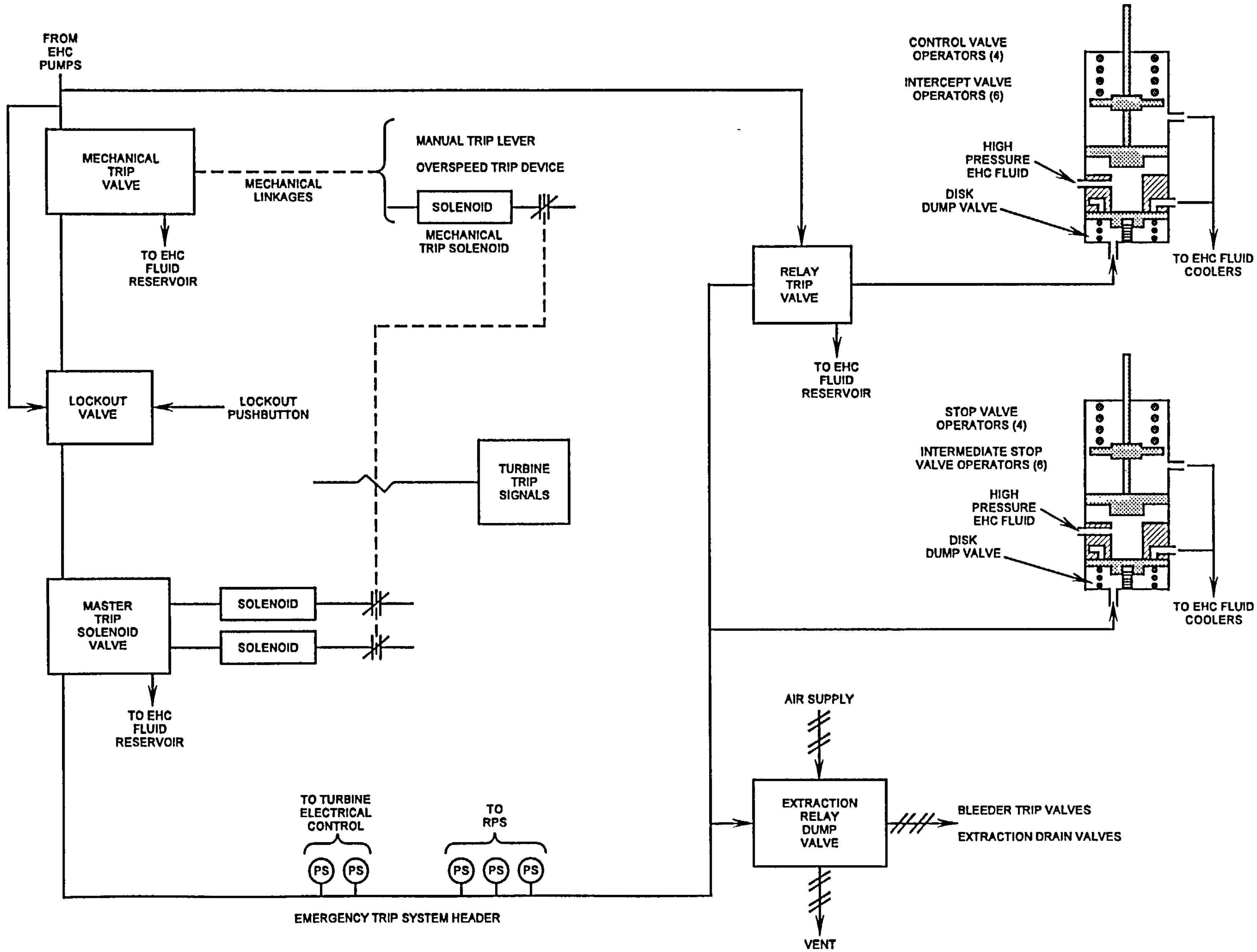

Figure 11.5-3 Emergency Trip System

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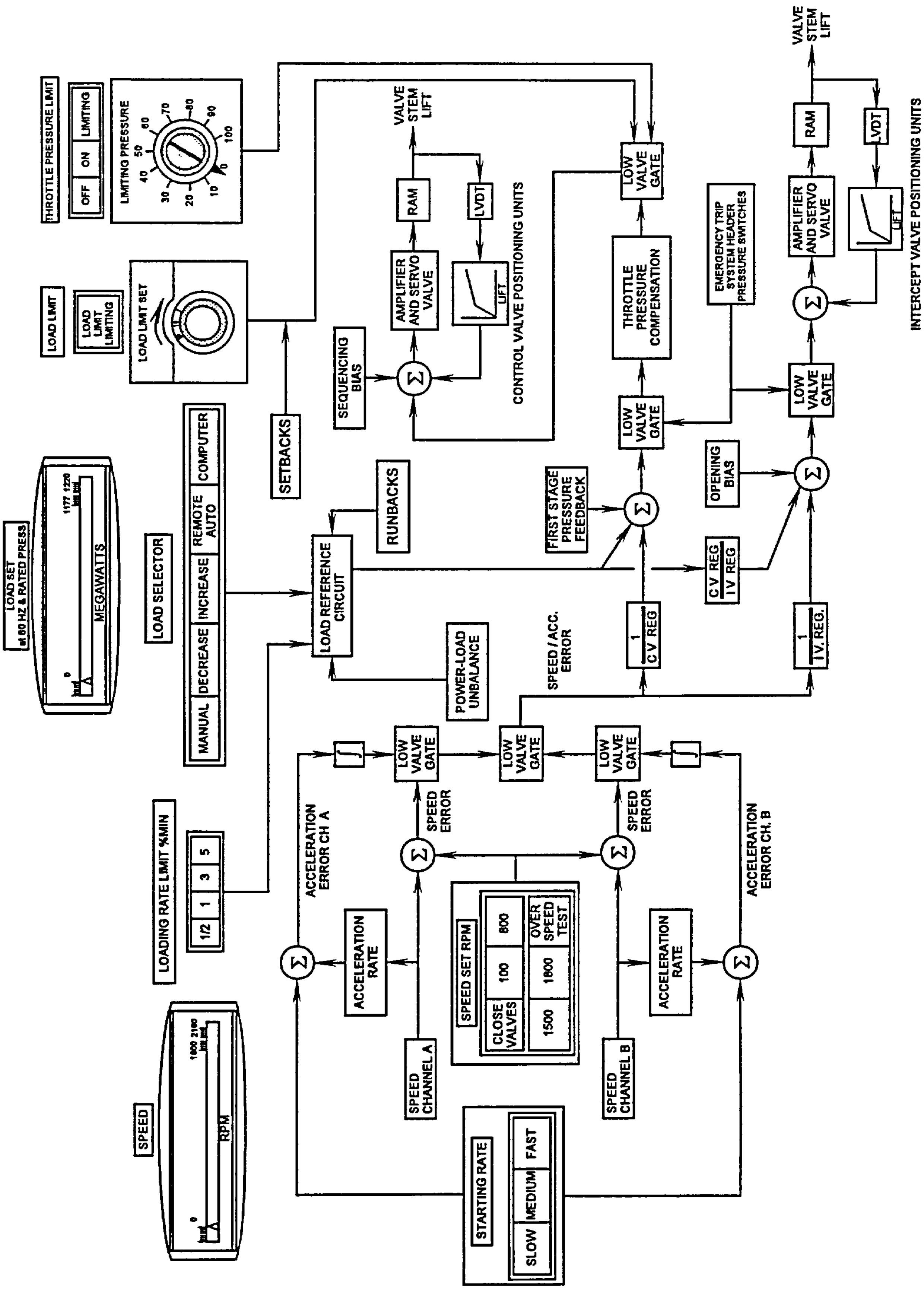

FIGURE 11.5-4 Turbine Electrical Control System

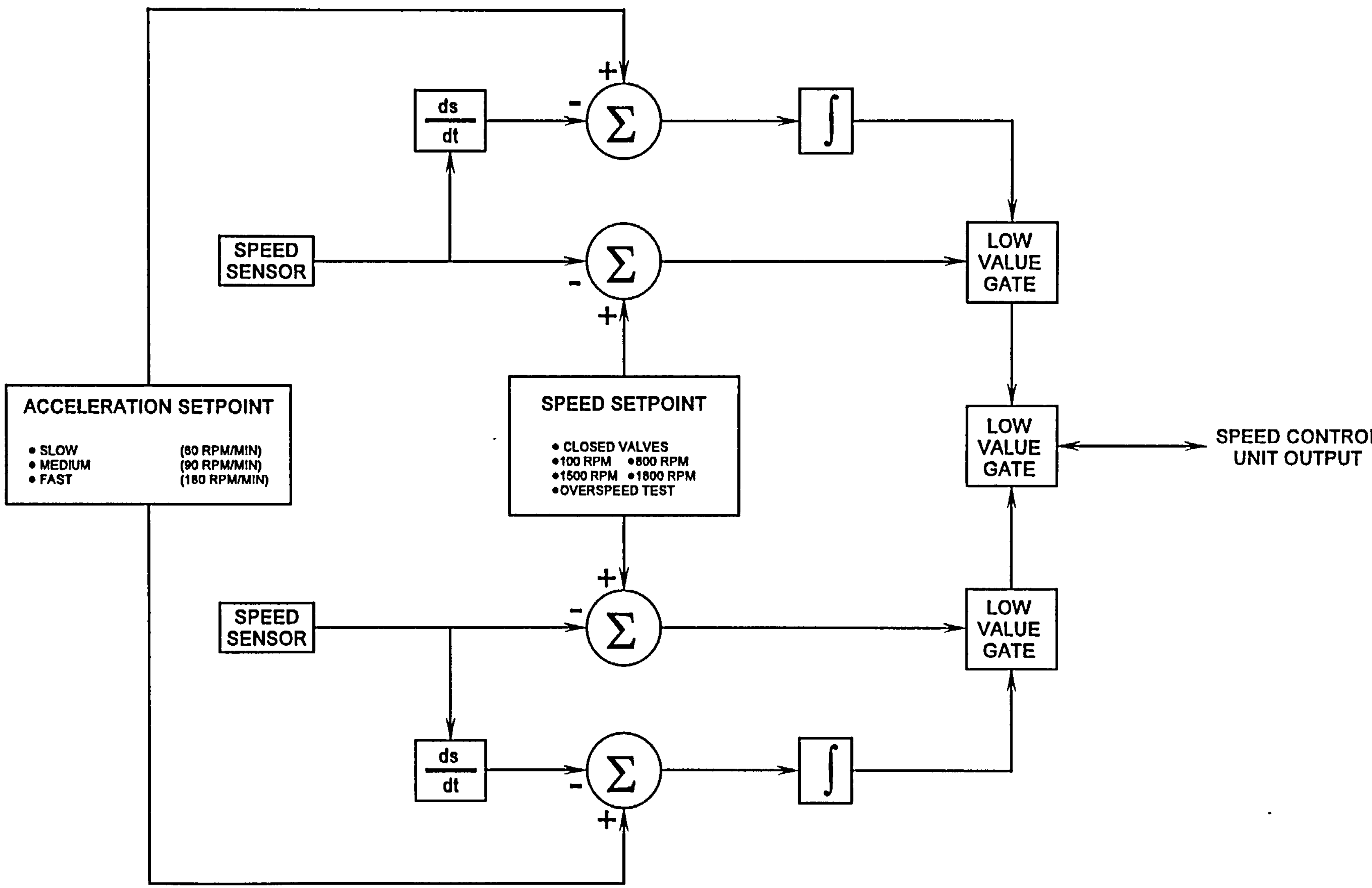

Figure 11.5-5 Speed Control Unit

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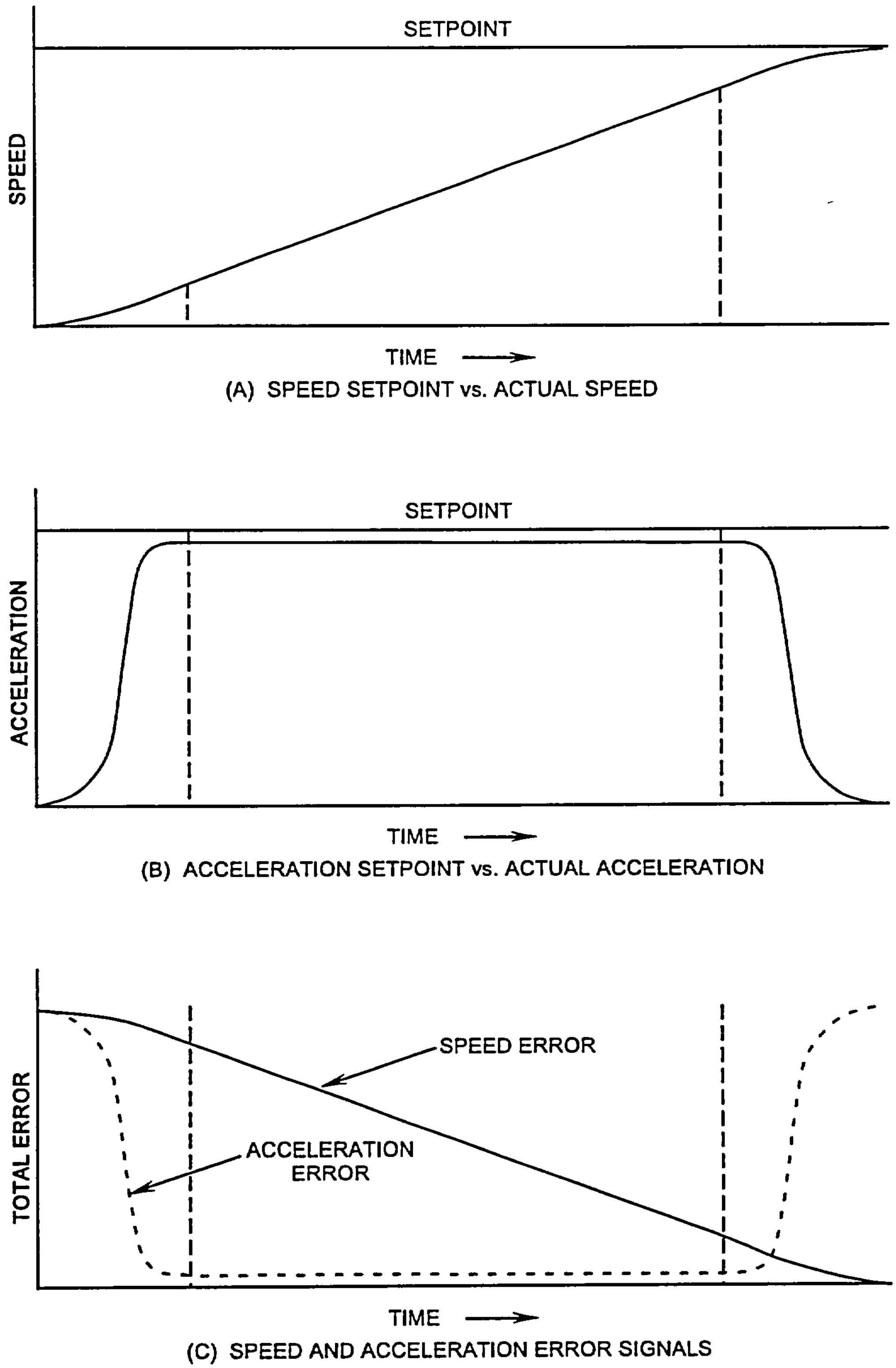

Figure 11.5-6 Speed Control Operating Characteristics

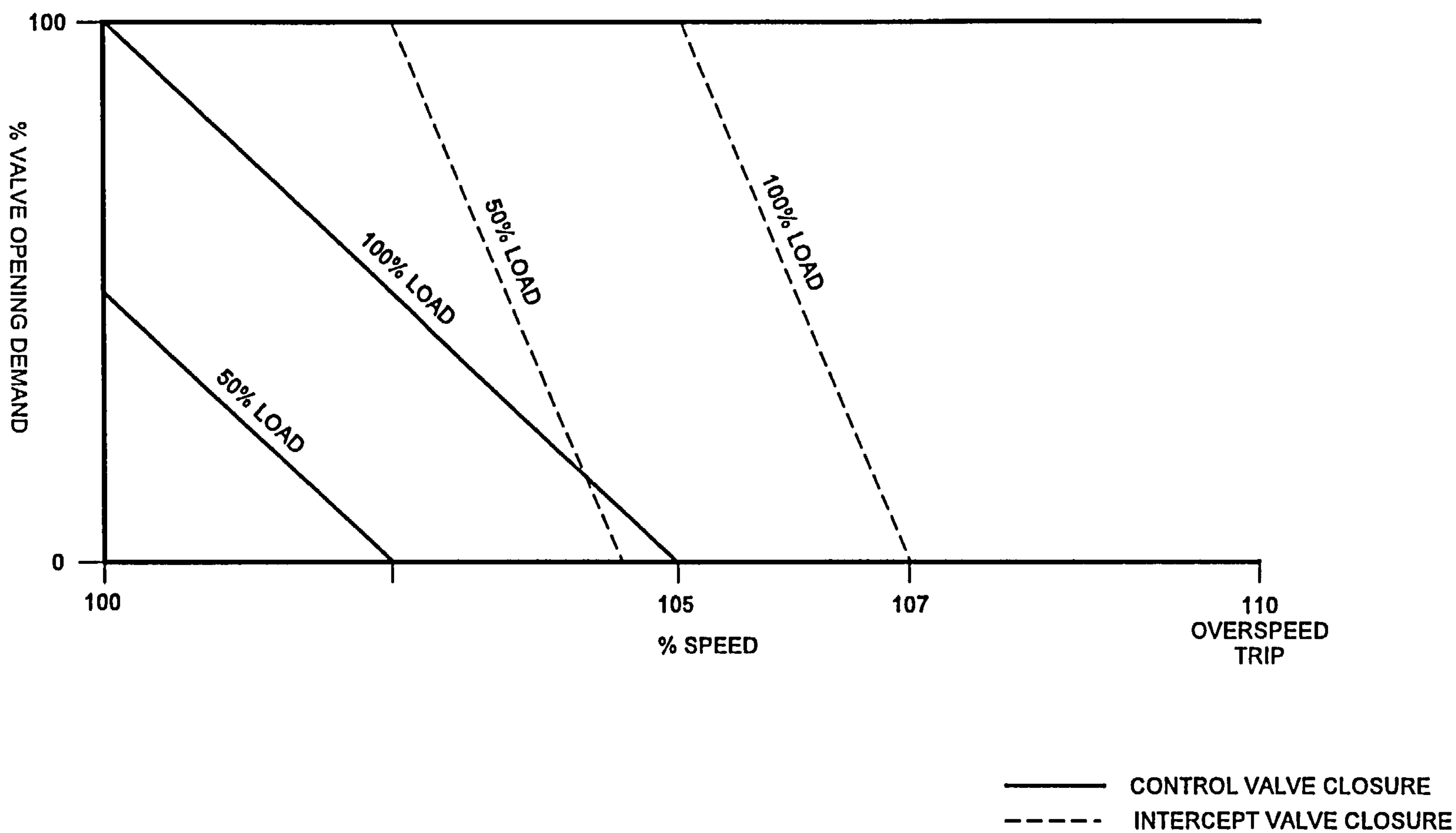

Figure 11.5-7 Control and Intercept Valve Regulation

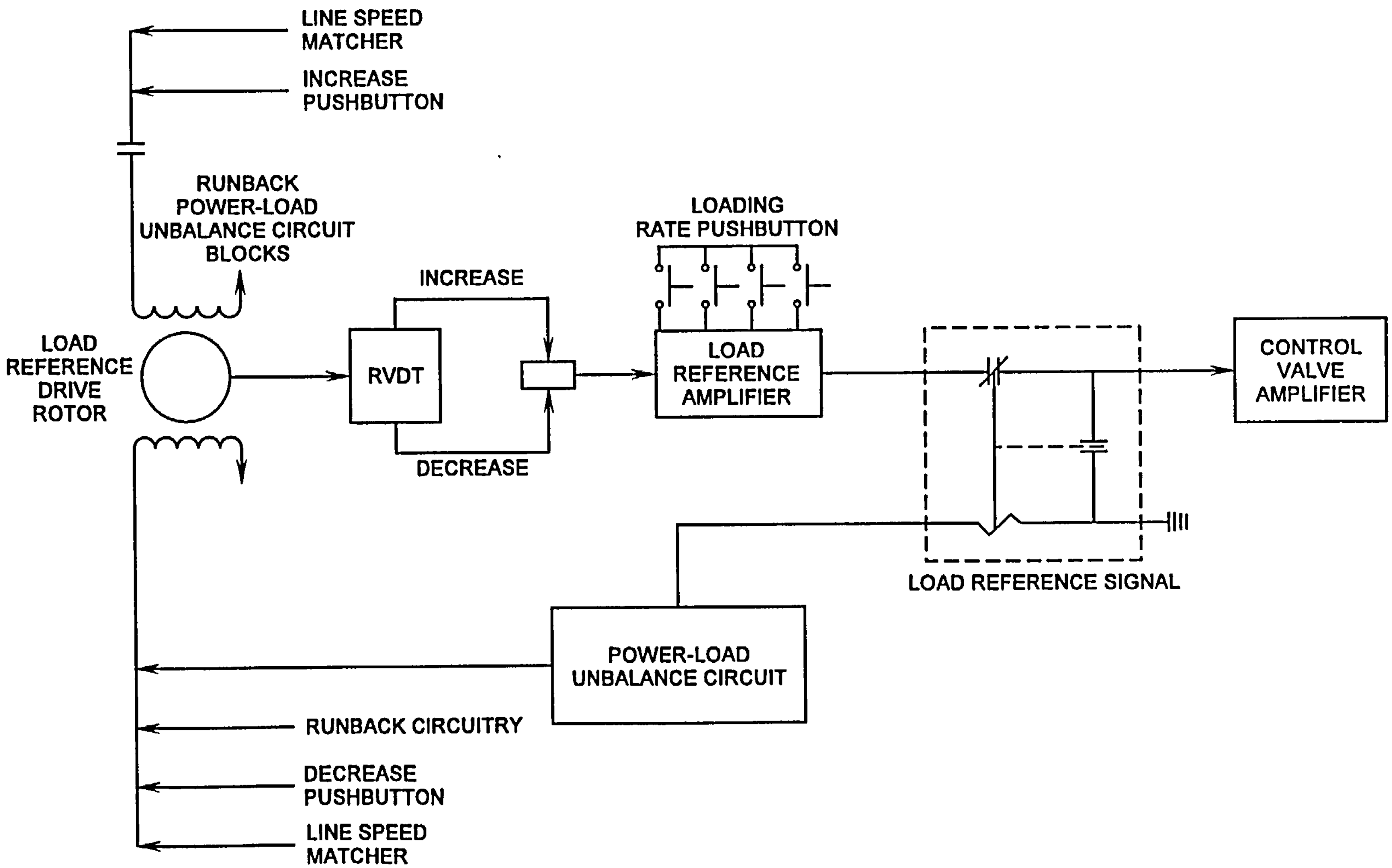

Figure 11.5-8 Load Reference Signal Generation

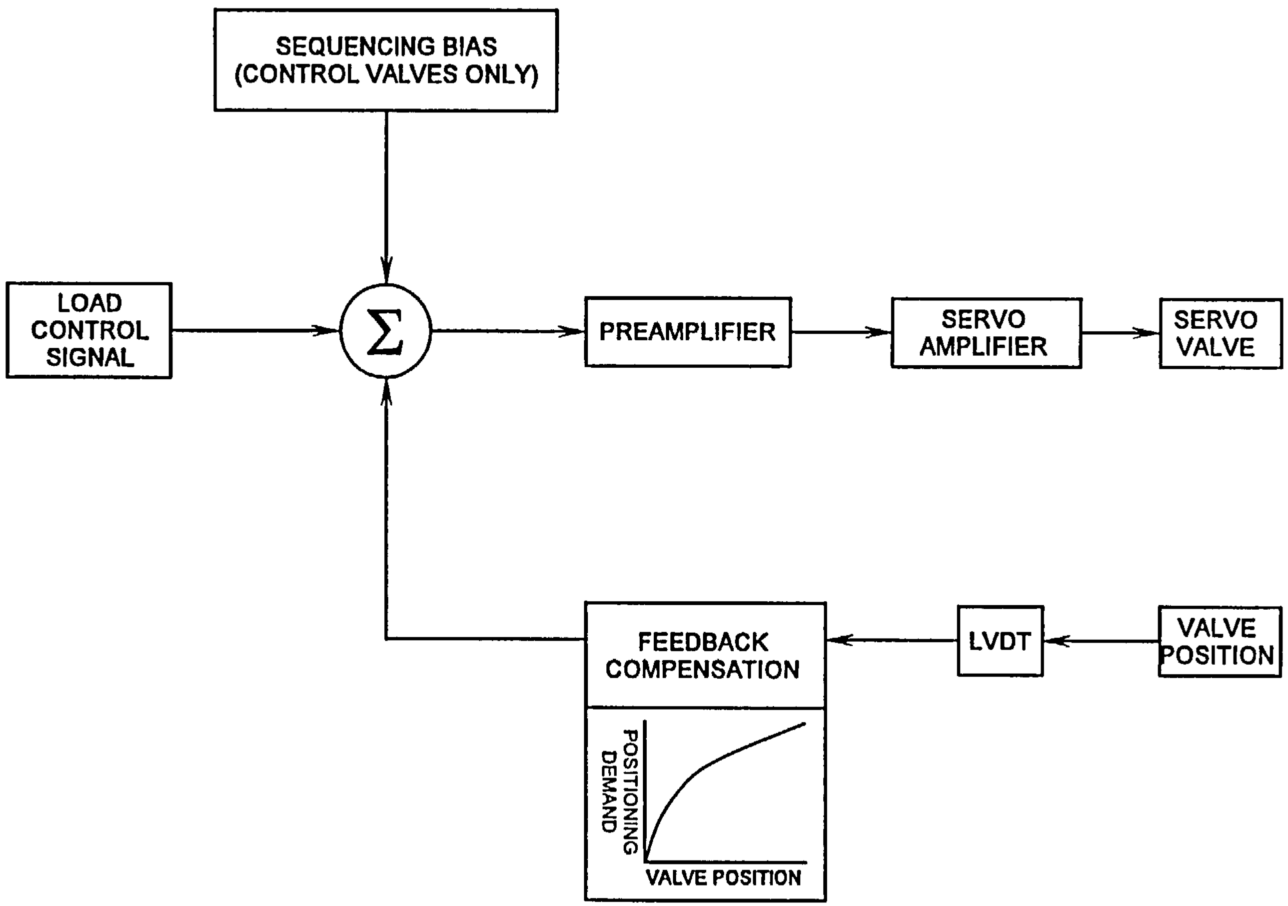

Figure 11.5-9 Typical Valve Positioning Unit

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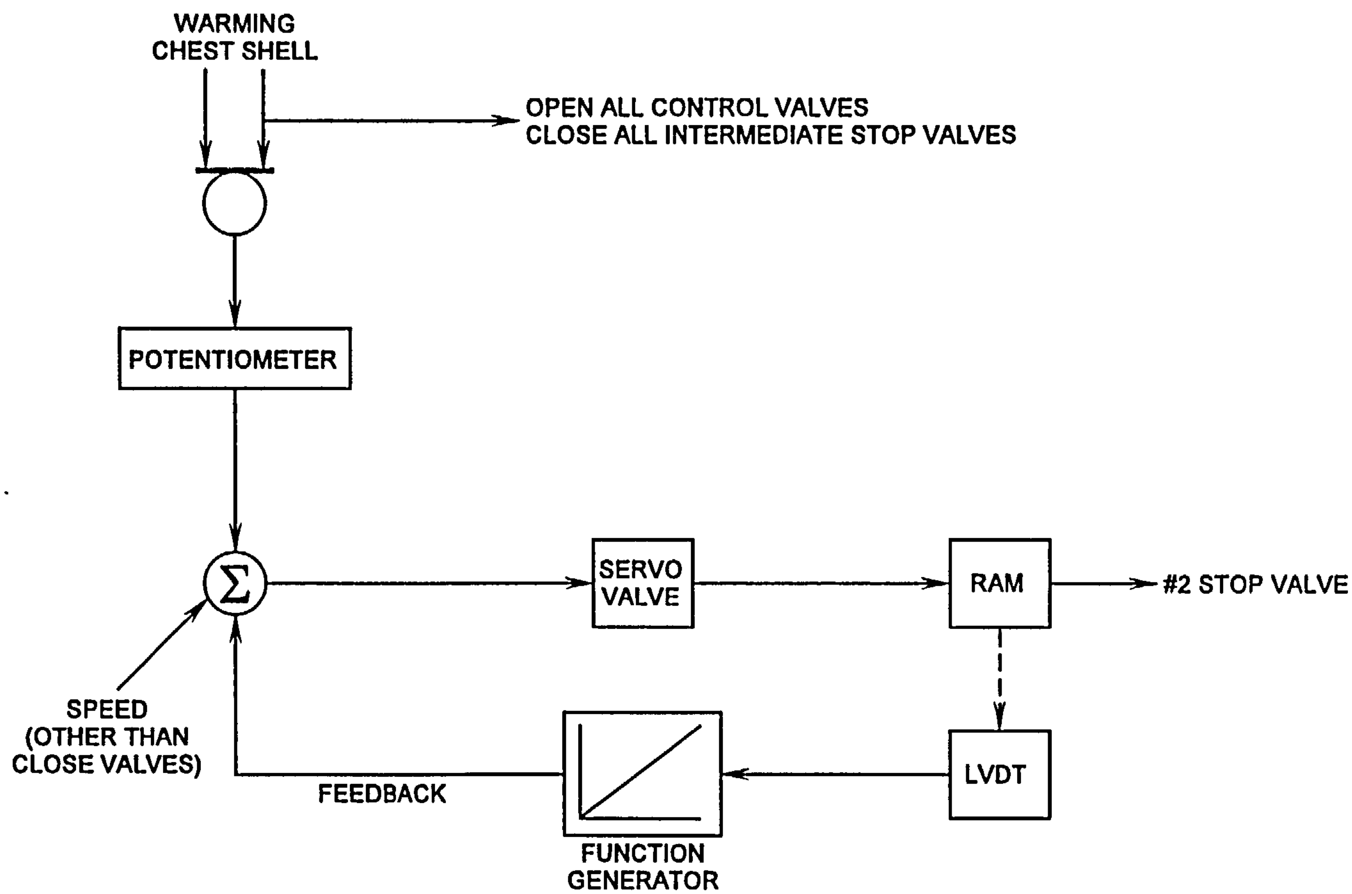

Figure 11.5-10 Chest / Shell Warming

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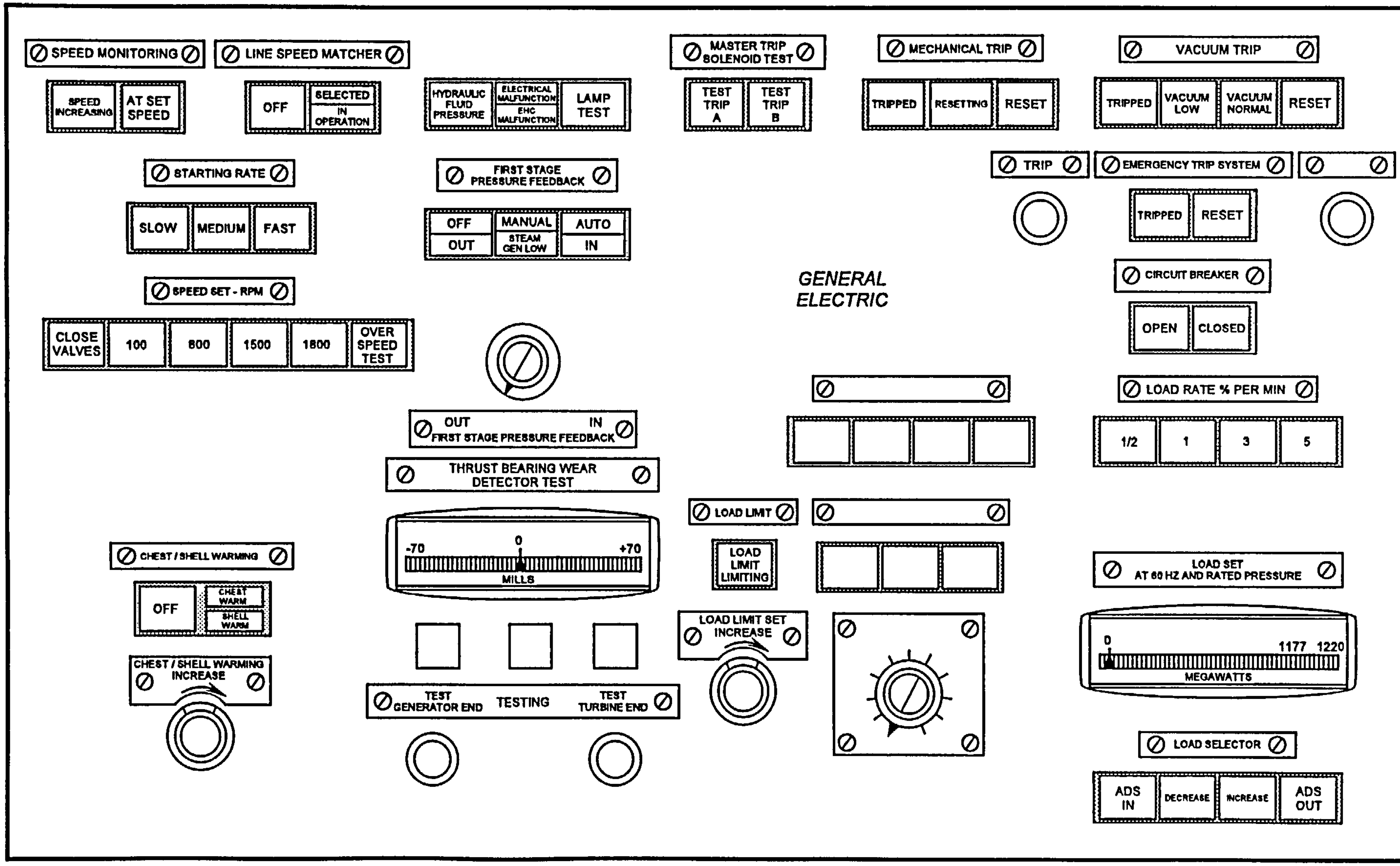

Figure 11.5-11 Turbine Control Panel

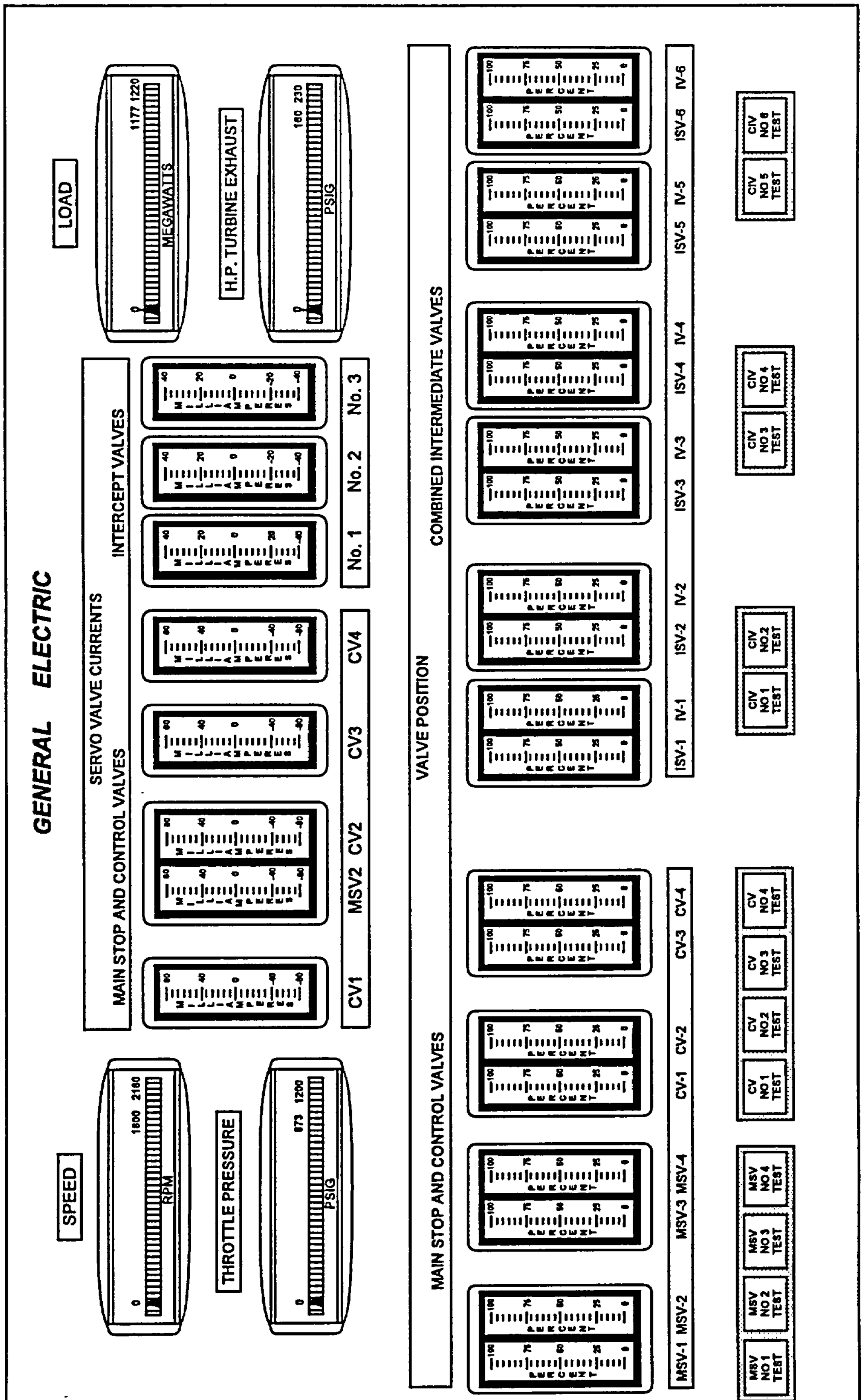

FIGURE 11.5-12 Turbine Instrument Panel