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1 GENERAL PLANT DESCRIPTION

Learning Objectives:

1. Identify the major components included in the primary and secondary cycles.
2. Describe how reactor coolant temperature and secondary system pressure change with load.
3. State the function of engineered safety features.
4. Describe how heat from the primary cycle and primary cycle components is rejected to the environment.

1.1 Introduction

A typical Pressurized Water Reactor (PWR) dual-cycle plant consists of two closed reactor coolant loops connected to the reactor vessel (primary), and a separate power conversion system for the generation of electricity (secondary).

The use of a dual cycle minimizes the quantity of fission products released to the main turbine, condenser, and other secondary plant components and subsequently to the environment. The following paragraphs describe the systems installed in a typical Combustion Engineering designed PWR. The information in this section was obtained from the Calvert Cliffs Final Safety Analysis Report (FSAR). Calvert Cliffs is the model plant for the Technical Training Center simulator and will be used for system descriptions in this manual.

1.2 Plant Site

The site for the Calvert Cliffs nuclear power plant consists of approximately 1,135 acres on the western shore of the Chesapeake Bay, in Calvert County, about 10.5 miles southeast of Prince Frederick, Maryland. The site is characterized by a minimum exclusion radius of 1,150 meters, remoteness from population centers, an abundant supply of cooling water, and favorable conditions of hydrology, geology, seismology and meteorology. The nearest population center is Washington, DC, which is approximately 45 miles to the northwest of the site.

1.3 Plant Layout

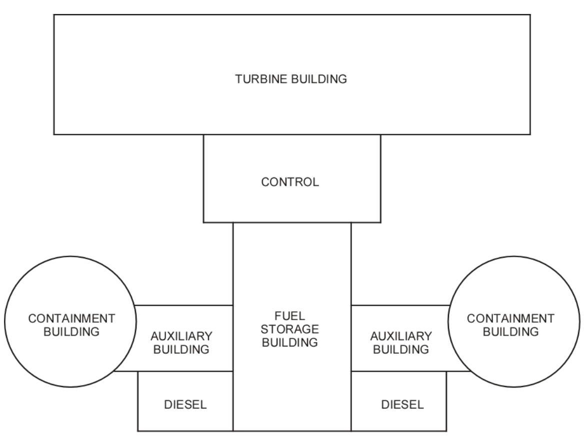

Figure 1-1 Plant Layout

The turbine building at Calvert Cliffs is oriented parallel and adjacent to the shoreline of the Chesapeake Bay with the twin containment structures and auxiliary buildings located on the west, or landward, side of the turbine building. The service building and the intake and discharge structures are on the east, or bay side, of the turbine building (Figure 1-1).

Each containment structure houses a Nuclear Steam Supply System (NSSS), consisting of a reactor, steam generators, Reactor Coolant Pumps (RCPs), a pressurizer, and some

of the reactor auxiliaries which do not normally require access during power operation. Each containment structure is served by a pendant-controlled, circular bridge crane.

The turbine building houses the turbine generators, condensers, feedwater heaters, condensate and feed pumps, turbine auxiliaries, and switchgear assemblies.

The auxiliary building houses the waste treatment facilities, Engineered Safety Feature (ESF) components, heating and ventilating system components, and the Emergency Diesel Generators (EDGs).

1.4 Reactor

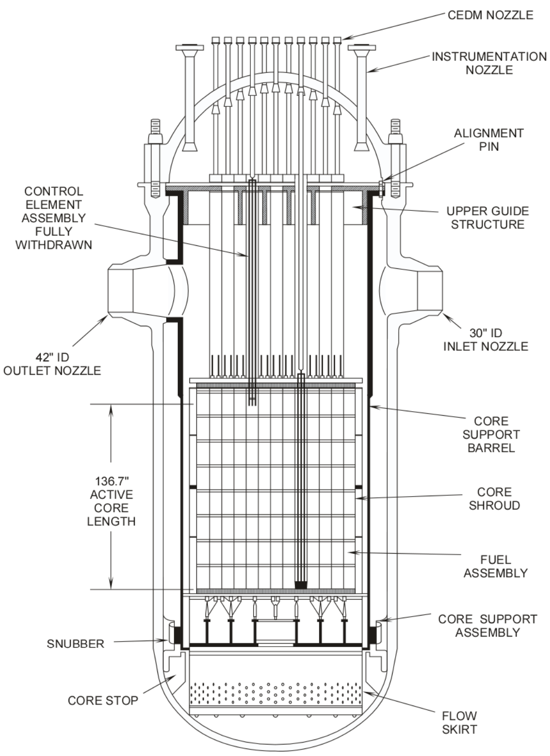

Figure 1-2 Reactor Vessel—Vertical Arrangement

The reactor (Figure 1-2) is a pressurized light water cooled and moderated type fueled by slightly enriched uranium dioxide. The uranium dioxide is in the form of pellets and is contained in zircaloy-4 (Zr-4) tubes fitted with welded end caps. These fuel rods are arranged into fuel assemblies each consisting of 176 fuel rods arranged on a 14 x 14 matrix. Space is left in the fuel rod array to allow for the installation of five guide tubes. These guide tubes provide for the smooth motion of Control Element Assembly (CEA) fingers. The fuel assembly is fitted with end fittings and spacer grids to maintain fuel rod alignment and to provide structural support. The end fittings are also drilled with flow holes to provide for the flow of cooling water past the fuel rods.

The reactor is controlled by a combination of chemical shim and a solid absorber. The solid absorber is boron carbide in the form of pellets contained in Inconel tubes. Five tubes of absorber form a CEA (four tubes in a square matrix plus a central tube). The five tubes are connected together at the tops by a yoke which is, in turn, connected to the Control Element Drive Mechanism (CEDM) extension shaft. Each CEA is aligned with, and is inserted into, a guide tube in the fuel assembly. Chemical shim control is provided by boric acid dissolved in the coolant (water). The concentration of boric acid is maintained and controlled as required by the Chemical and Volume Control System (CVCS).

The reactor core rests on the core support assembly which is supported by the core support barrel. The core support barrel is a right circular cylinder supported from a machined ledge on the inside surface of the vessel flange forging. The core support assembly transmits the entire weight of the core to the core support barrel through a structure made of beams and vertical columns. Surrounding the core is a shroud which serves to limit the coolant which bypasses the core. An upper guide structure, consisting of an upper support structure, CEA shrouds, a fuel alignment plate and a spacer ring, serves to support and align the upper ends of the fuel assemblies, prevents

lifting of the fuel assemblies in the event of a Loss-Of-Coolant Accident (LOCA), and maintains spacing of the CEAs.

1.5 Reactor Coolant System

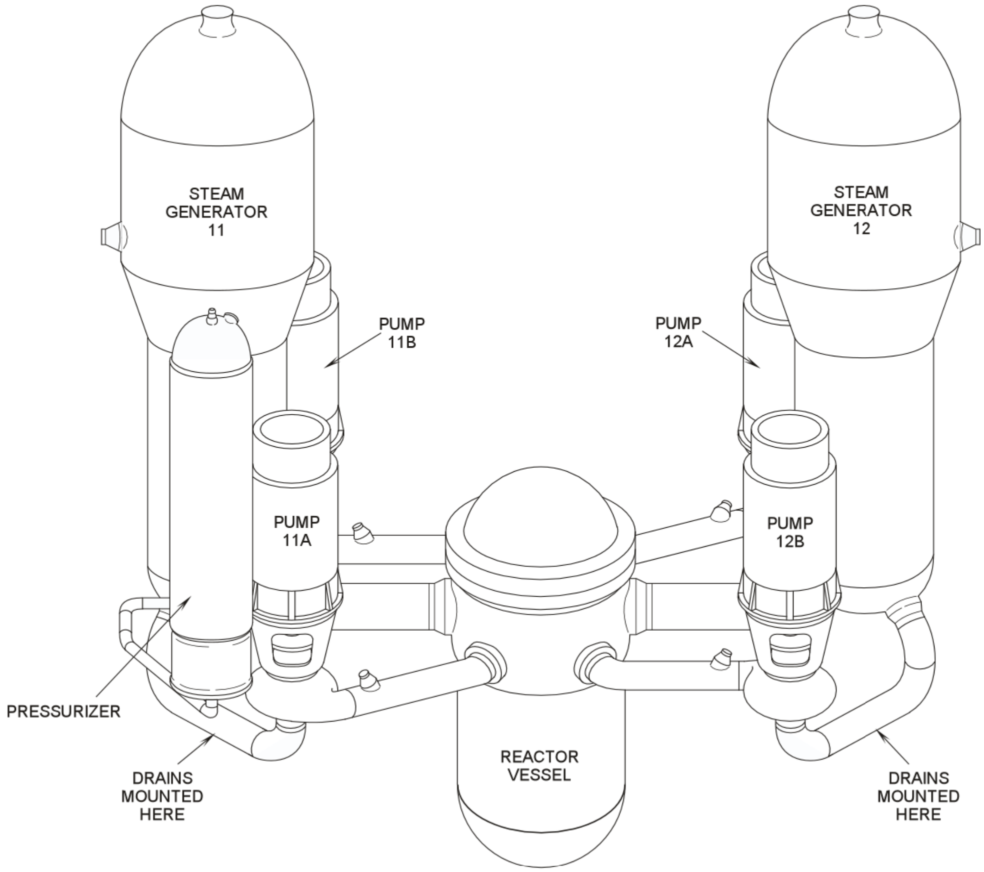

Figure 1-3 Reactor Coolant System

The Reactor Coolant System (RCS) of each unit consists of two closed heat transfer loops (Figure 1-3) in parallel with the reactor vessel. Each loop contains one steam generator and two pumps to circulate coolant. An electrically heated pressurizer is connected to one loop hot leg. The coolant system is designed to operate at a power level of 2,700 MWt to produce steam at a pressure of 850 psia.

The reactor vessel, loop piping, pressurizer, and steam generator plenums are fabricated of low alloy steel, clad internally with stainless steel. The pressurizer surge line and RCPs are fabricated from stainless steel and the steam generator tubes are fabricated from Inconel.

Overpressure protection is provided by power-operated relief valves and spring-loaded safety valves connected to the pressurizer. Safety and relief valve discharge is released under water in the quench tank where the steam discharge is condensed.

The two steam generators are vertical shell and U-tube steam generators each of which produces approximately 6 x 10^6 lbm/hr of steam. Steam is generated in the shell side of the steam generator and flows upward through moisture separators. Steam outlet moisture content is less than 0.20%.

The reactor coolant is circulated by four electric motor-driven, single suction, centrifugal pumps. Each pump motor is equipped with a non-reverse mechanism to prevent reverse rotation of any pump that is not being used during operation with less than four pumps energized.

1.6 Containment

The containment structure uses a pre-stressed concrete design. The structure is in the form of a vertical right cylinder with a dome and a flat base. The interior of the structure is lined with carbon steel plate for leak tightness. Inside the structure, the reactor and other NSSS components are shielded with concrete. An unlined steel ventilation stack is attached to the outside of the containment structure and extends to an elevation about 10 feet above the top of the containment dome. Access to portions of the containment structure during power operation is permissible.

The containment structure, in conjunction with engineered safety features, is designed to withstand the internal pressure and coincident temperature resulting from the energy released in the event of the LOCA associated with 2,700 MWt operations. The design conditions for the structure are an internal pressure of 50 psig, a coincident temperature of 276 °F, and a leak rate of 0.20% by weight of the containment air per day at design temperature and pressure.

1.7 Engineered Safety Features Systems

Separate ESF systems for each unit in conjunction with separate containment systems protect the public and plant personnel from accidental release of radioactive fission products, particularly in the unlikely event of a LOCA. These safety features function to localize, control, mitigate, and terminate such incidents to hold exposure levels below applicable guidelines.

The ESF systems are:

1. The safety injection systems, including High Pressure Safety Injection (HPSI), Low Pressure Safety Injection (LPSI), and the Safety Injection Tanks (SITs);
2. The containment cooling systems, consisting of the containment spray system, and the containment air recirculation and cooling system;
3. The containment penetration room ventilation system;
4. The containment iodine removal system and
5. The auxiliary feedwater system

For each unit, four SITs are provided, each connected to one of the four reactor inlet lines. Each tank has a volume of 2,000 ft^3 containing 1,000 ft^3 of borated water at refueling concentration and 1,000 ft^3 of nitrogen at 200 psig. In the event of a LOCA, the borated water is forced into the RCS by the expansion of the nitrogen. The water from three tanks adequately cools the entire core. In addition, borated water is injected into the same nozzles by two LPSI and two HPSI pumps taking suction from the Refueling Water Tank (RWT). For maximum reliability, the design capacity from the combined operation of one HPSI and one LPSI pump provides adequate injection flow for any LOCA.

Should the Design Basis Event (DBE) occur, at least one HPSI and one LPSI pump will receive power from the emergency power sources, since normal power is lost and one of the EDGs is assumed to fail. Upon depletion of the RWT, the source of water to the HPSI, LPSI, and containment spray pumps, is automatically transferred to the containment sump and the LPSI pumps are shutdown. One HPSI pump has sufficient capacity to cool the core adequately at the start of recirculation. During recirculation,

heat in the recirculating water is removed in the shutdown cooling heat exchangers by the operation of the containment spray system. Further, the suction of the HPSI pumps may be manually aligned so as to inject sub-cooled water from the shutdown cooling heat exchangers directly into the RCS for core cooling.

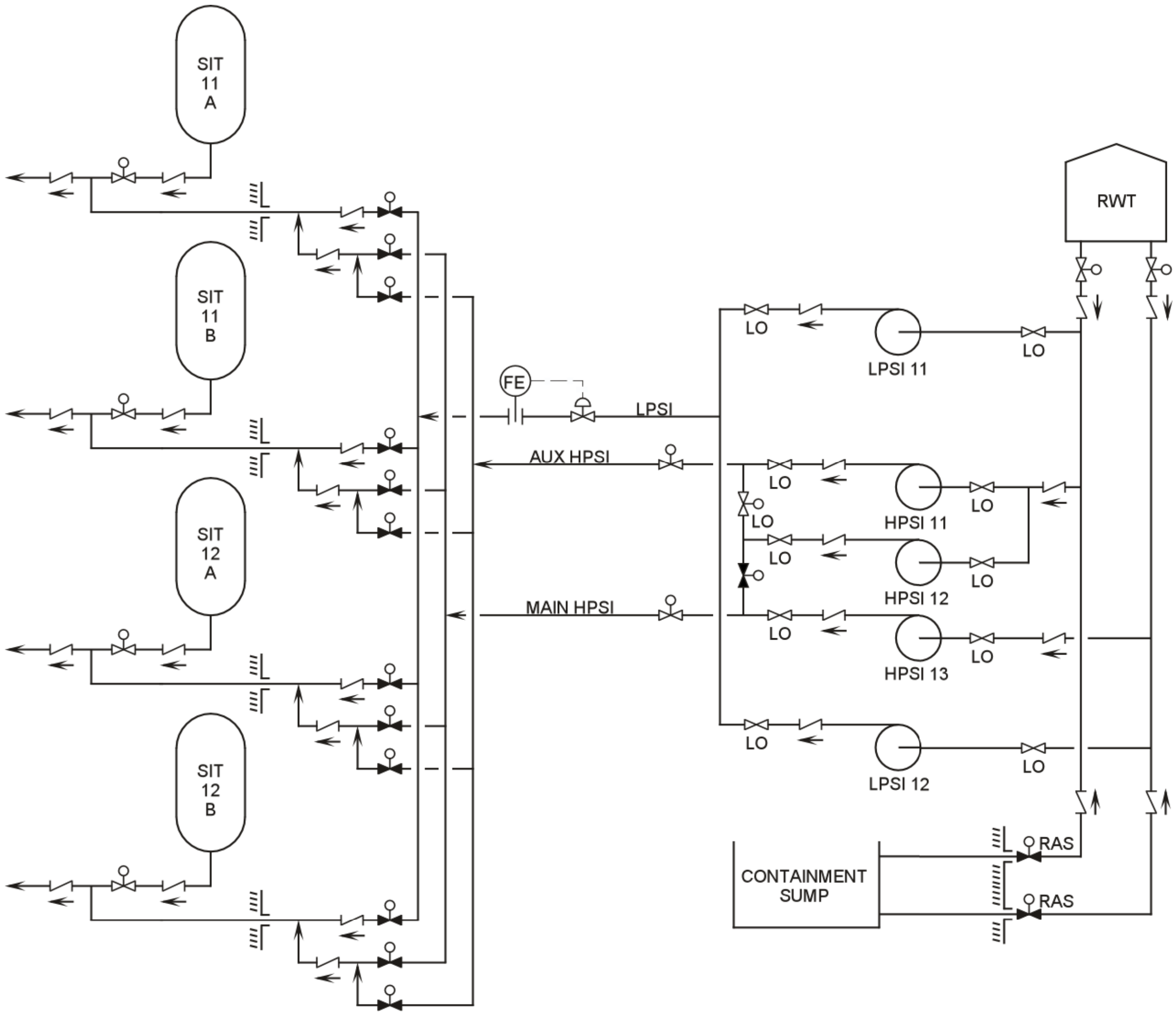

Figure 1-4 Emergency Core Cooling Systems

All LPSI and HPSI pumps are located outside the containment structure to permit access for periodic testing during normal operation. The pumps discharge into separate headers which lead to the containment. Figure 1-4 provides a simplified diagram of the safety injection systems.

The containment spray system supplies cool, borated water which reduces the temperature and pressure of the containment atmosphere. The pumps take suction initially from the RWT.

Long term cooling is based on suction from the containment sump through the recirculation lines. In the recirculation mode of operation, heat is transferred from the recirculating borated water through the shutdown cooling heat exchangers to the component cooling system and ultimately to the Chesapeake Bay water via the component cooling heat exchanger.

The containment air recirculation and cooling system is also designed to provide capability for reducing the temperature and pressure of the containment atmosphere. The cooling coils and fans are sized to provide adequate containment cooling at DBE conditions without assistance from other containment heat removal systems. The heat is transferred to the service water system.

The containment penetration room ventilation system processes the leakage from the containment through the containment penetrations to reduce the radioactivity concentration. The penetration room is maintained at a negative pressure relative to the containment following a LOCA. The penetration room ventilation system is equipped with particulate and charcoal filters to remove radioactivity associated with particulates and iodine before discharging the leakage from the plant.

The containment iodine removal system recirculates containment air through charcoal filters to remove iodine from the containment atmosphere.

An auxiliary feedwater system is installed to provide feedwater to the steam generators in the event of a loss of feedwater or during accidents. The system consists of two turbine-driven pumps and a motor-driven pump that receive water from the condensate storage tank.

The ESF systems are automatically started by the Engineered Safety Features Actuation System (ESFAS). The signals used to actuate engineered safety features are:

1. Pressurizer pressure,
2. Containment building pressure,
3. Containment radiation,
4. Steam generator pressure,
5. Steam generator level,
6. 4160 Vac ESF bus voltage and
7. Refueling water tank (RWT) level.

1.8 Reactor Plant Protection Control and Instrumentation Systems

1.8.1 Reactor Protection

Reactor parameters are maintained within acceptable limits by the inherent self-controlling characteristics of the reactor, by CEA positioning, by boron content of the reactor coolant and by operating procedures. The function of the Reactor Protective System (RPS) is to provide reactor operators with audible and visual alarms when any reactor parameter approaches the preset limits for safe operation. Should pre-selected limits be reached the RPS initiates reactor shutdown to prevent unsafe conditions for plant personnel, equipment and to the general public (Figure 1-5).

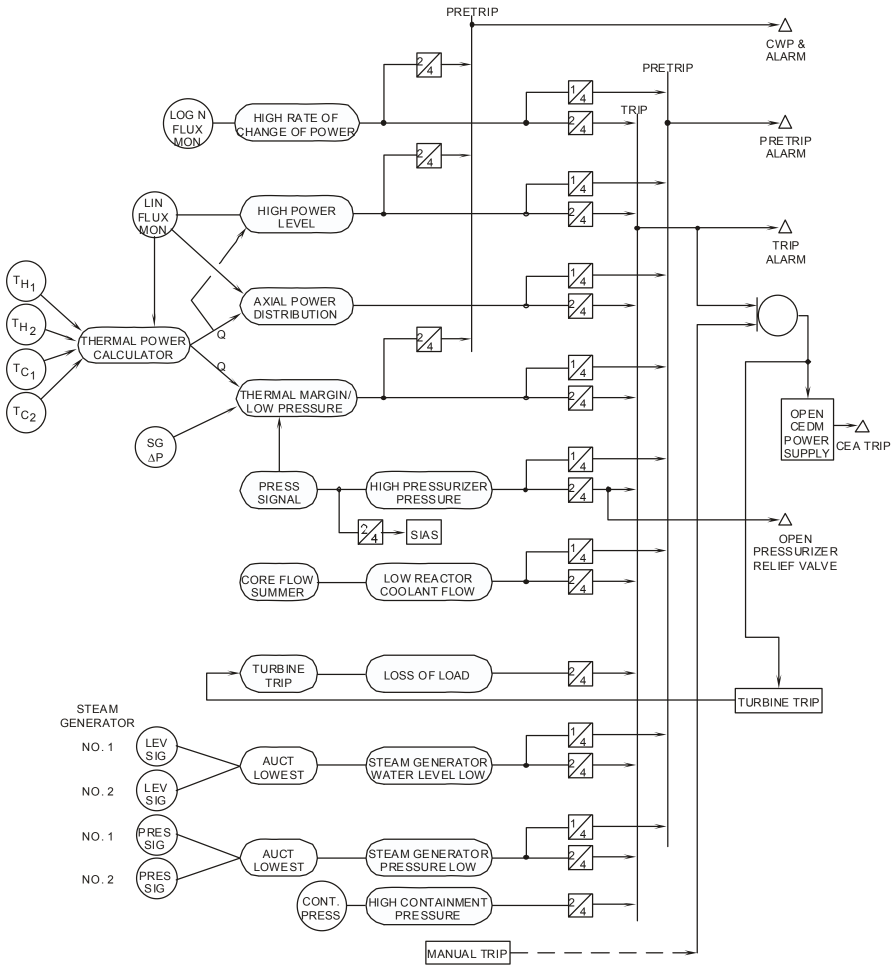

Figure 1-5 RPS Logic

The RPS is divided into four channels, each receiving trip

from separate sensors when the relevant parameter reaches a preset level. If any two of these four channels receives coincident signals, the power supply to the magnetic jack CEDM is interrupted allowing the CEAs to drop into the core and shutdown the reactor. The RPS is completely independent of, and separate from, the reactor control systems.

The following is a list of the reactor trips:

1. Variable Overpower,
2. High startup rate,
3. Low reactor coolant flow,
4. Low steam generator water level,
5. Low steam generator pressure,
6. High pressurizer pressure,
7. Thermal margin low pressure,
8. Loss of load (turbine trip),
9. High containment pressure and
10. Local power density (Axial power distribution)

1.8.2 Reactor Control

The RCS provides for start-up and shutdown of the reactor and for adjustment of the reactor power in response to turbine load demand. The NSSS is capable of following a ramp change from 15 to 100% power at a rate of 5% per minute and at greater rates over smaller load change increments up to a step change of 10%.

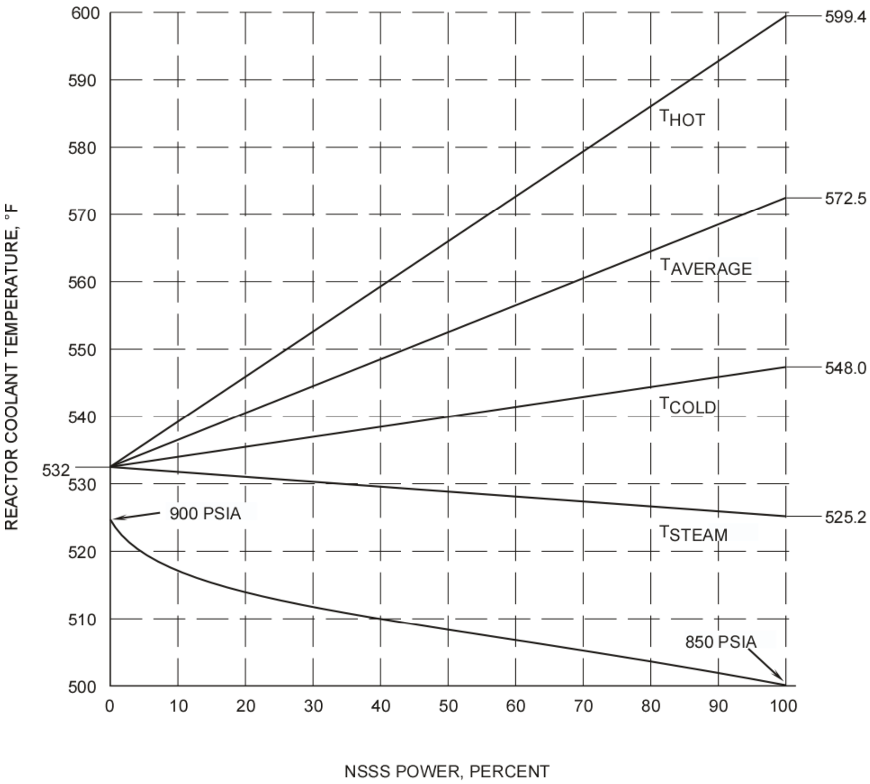

Figure 1-6 RCS Temperature Program

The control may be accomplished by automatic CEA movement in response to a change in reactor coolant temperature, or with manual control capable of overriding the automatic signal at any time. The temperature control program (Figure 1-6) provides a demand temperature which is a function of power. This temperature is compared with the coolant average temperature; if the temperatures are different, The CEAs are adjusted until the difference is within the prescribed control band. Regulation of the reactor coolant temperature in accordance with this program maintains the secondary steam pressure within operating limits and matches reactor power to load demand.

The reactor is controlled by a combination of CEAs and dissolved boric acid in the reactor coolant. Boric acid is used for reactivity changes associated with large but gradual changes in water temperature, xenon effects and fuel burnup. Additions of boric acid also provides an increased shutdown margin during the initial fuel loading and subsequent refueling.

CEA movement provides changes in reactivity for shutdown or power changes. The CEAs are actuated by CEDMs mounted on the reactor vessel head. The CEDMs are designed to permit rapid insertion of the CEAs into the reactor core by gravity. CEA motion can be initiated manually or automatically.

The pressure in the RCS is controlled by regulating the temperature of the coolant in the pressurizer, where steam and water are held in thermal equilibrium. Steam is formed by the pressurizer heaters or condensed by the pressurizer spray to reduce pressure

variations caused by volumetric changes of the reactor coolant due to RCS temperature changes.

1.8.3 Instrumentation

The nuclear instrumentation includes excore and incore neutron flux detectors. Ten channels of excore instrumentation monitor the neutron flux and provides reactor protection and control signals during start-up and power operation.

Four Wide Range Logarithmic channels monitor the neutron flux from the source range to full power. Four Power Range channels monitor the neutron flux range through the full power range. Two additional Power Range Channels monitor the flux through the full power range for reactor control.

The incore monitors consist of self-powered rhodium neutron detectors and thermocouples to provide information on neutron flux distribution and temperature in the core.

The process instrumentation monitoring includes those critical channels which are used for protective action. Additional temperature, pressure, flow and liquid level monitoring is provided, as required, to keep the operating personnel informed of plant conditions, and to provide information from which plant processes can be evaluated and/or regulated. The boron concentration in the reactor coolant water is also monitored and is continuously recorded in the control room.

The plant gaseous and liquid effluents are monitored for radioactivity. Activity levels are displayed and off-normal values are annunciated. Area monitoring stations are provided to measure radioactivity at selected locations in the plant.

1.9 Electrical Systems

The Calvert Cliffs Nuclear Power Plant includes two generating units, the ratings of which are 1,020,000 kVA, 0.9 PF, 25kV, for unit 1 and 1,011,900 kVA, 0.9 PF, 22kV, for unit 2. Each generator delivers power to the 500kV switchyard through two 500,000 kVA main step-up power transformers. Two 500kV transmission lines connect to the switchyard and transmit the plant output to the network.

The plant distribution system utilizes voltage levels of 13.8 kV, 4.1 kV, 480Vac and 120/208 Vac. The system is designed to provide reliable power for normal operation and safe shutdown of the plant. Auxiliary and start-up power will be supplied by two service transformers capable of supplying the total auxiliary load of both units simultaneously. One service transformer is connected to each 500 kV bus in the switchyard.

Four 125 Vdc systems provide continuous and emergency power for control, vital instrumentation, emergency lighting, vital 120 Vac loads, and computers. Both units share a 250 Vdc system which supplies power to the emergency lube oil and seal oil pumps. Separate battery systems are provided for substation control relaying, microwave telemetry, and communications.

The plant has four safety-related Emergency Diesel Generators (EDGs), two dedicated to each unit. Any combination of two of the EDGs (one from each unit) is capable of

supplying sufficient power for the operation of necessary ESF loads during accident conditions on one unit and shutdown loads of the alternate unit concurrent with a loss of offsite power.

1.10 Plant Auxiliary Systems

1.10.1 Chemical and Volume Control System

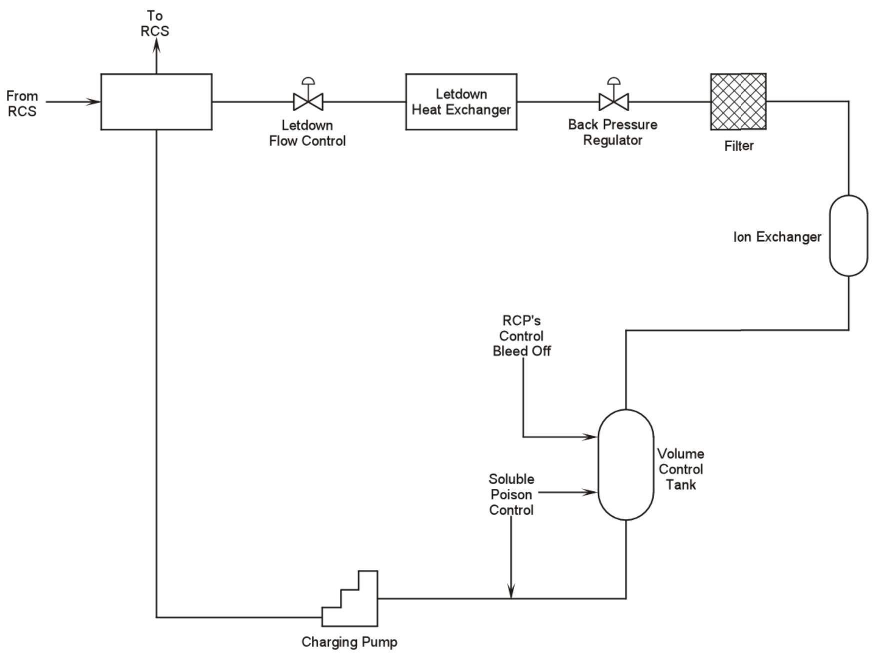

Figure 1-7 Simplified Chemical and Volume Control System

The purity level in the RCS is controlled by continuous purification of a bypass stream of reactor coolant. Water removed from the RCS is cooled in the regenerative heat exchanger. From there the coolant flows to the letdown heat exchanger and then through a filter and ion exchanger where corrosion and fission products are removed. It is then sprayed into the Volume Control Tank (VCT) and returned to the RCS by the charging pumps through the regenerative heat exchanger.

The CVCS (Figure 1-7) automatically controls the rate of coolant removed from the RCS to maintain the pressurizer level within the prescribed control band thereby compensating for changes in volume due to coolant temperature changes. The VCT is sized to accommodate coolant inventory changes resulting from load changes from hot standby to full power. Using the VCT as a surge tank decreases the quantity of liquid and gaseous waste which otherwise would be generated.

Reactor coolant system makeup water is taken from the demineralized water storage system and from the two concentrated boric acid tanks. The boric acid solution in these tanks is maintained at a temperature which prevents crystallization. The makeup water is pumped through the regenerative heat exchanger into the reactor coolant loop by the charging pumps. Boron concentration in the RCS can be reduced by diverting the letdown flow away from the VCT to the reactor coolant waste processing system and using demineralized water for coolant makeup.

1.10.2 Shutdown Cooling System

The Shutdown Cooling System (SDC) is used to reduce the temperature of the reactor coolant at a controlled rate from 300°F to a refueling temperature of approximately 130°F and to maintain the proper reactor coolant temperature during refueling.

The SDC system utilizes the LPSI pumps to circulate the reactor coolant through two shutdown cooling heat exchangers, returning it to the RCS through the LPSI header.

Component Cooling Water (CCW) is used to cool the shutdown cooling heat exchangers.

1.10.3 Component Cooling Water System

The CCW system consists of three pumps, two salt water cooled heat exchangers interconnecting piping, valving and controls. The corrosion-inhibited, demineralized water of this closed system is circulated through the component cooling heat exchanger where it is cooled to a temperature of 95°F by the saltwater cooling system. Typical items cooled by component cooling water are:

1. Shutdown cooling heat exchanger,
2. Letdown heat exchanger,
3. RCP seals and lube oil cooler,
4. HPSI pump seals,
5. LPSI pump seals,
6. Waste gas compressors aftercooler and
7. Waste evaporators.

All items connected to this system and requiring cooling water are fed by parallel flow paths. A head tank floats on the system and absorbs the volumetric changes due to temperature changes.

During normal plant operation, only one of the three pumps and one of the two heat exchangers are required for cooling service.

During normal shutdown, two of the three pumps and both of the heat exchangers are utilized for cooling. For a LOCA, one of the three pumps and both of the heat exchangers can provide the necessary cooling.

1.10.4 Fuel Handling and Storage System

The fuel handling systems provide for the safe handling of fuel assemblies and the disassembly, and storage of the reactor vessel head and internals. These systems include a bridge crane and a refueling machine located inside containment above the refueling pool, the fuel transfer carriage, the tilting machines, the fuel transfer tube, a fuel handling machine in the spent fuel storage room, and various other devices used for handling the reactor vessel head and internals.

The spent fuel pool, located in the auxiliary building, consists of two identical halves. Each half serves one reactor unit. Both new fuel and spent fuel may be stored in the pool. Dry storage for new fuel is provided near the spent fuel pool. A fuel pool service platform is provided for manipulation of the spent fuel.

1.10.5 Cooling Water Systems

The exhaust steam of the main turbine and steam generator feed pump turbines is condensed by circulating water. Six circulating water pumps per unit, having a combined volumetric capacity of 1,200,000 gpm, take suction from and discharge to the Chesapeake Bay through a three shell condenser. The condenser pressure, under rated conditions, is two inches of Hg (~ 1 psia).

A salt water cooling system shares the suction facilities with the circulating water system. Some important loads cooled by this system are the CCW system heat exchangers and the service water heat exchangers.

The service water system supplies a dependable continuous flow of cooling water to various plant components for the transfer of heat to the Chesapeake Bay.

Typical Components that are cooled by service water are:

1. Containment building coolers,
2. Spent fuel pool coolers,
3. Instrument air compressors and
4. Generator cooling.

1.11 Steam and Power Conversion System

The turbine generator for unit 1 is furnished by the General Electric Company. The turbine is an 1,800 rpm tandem compound, six flow exhaust, indoor unit.

Under nominal steam conditions of 850 psig at the stop-valve inlet and with the turbines exhausting to a condenser pressure of 2 inches of Hg absolute, the unit 1 generator produces 883 MW. Turbine output corresponds to a NSSS thermal power level of approximately 2,700 MW.

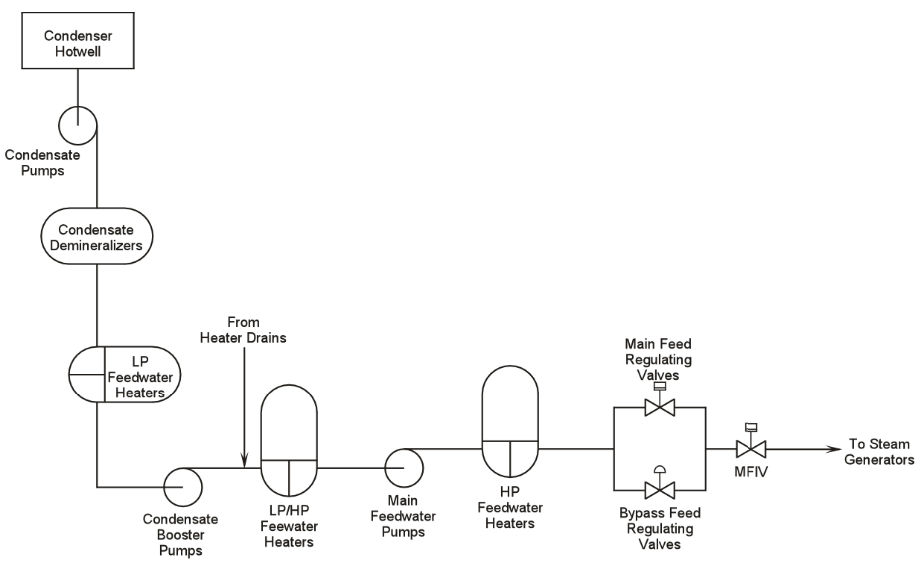

Figure 1-8 Simplified Condensate and Feedwater System

The condensate and feedwater system (Figure 1-8) consists of three condensate pumps, five demineralizers, five low pressure feedwater heaters, three condensate booster pumps, two high pressure feedwater heaters, and two turbine-driven feed pumps.

Normally, the feed pump turbines are driven by reheat steam. At low turbine generator loads, main steam is used to drive the feed pump turbines. All turbines exhaust into their respective unit condenser.

1.12 Waste Processing systems

The waste processing systems provide controlled handling and disposal of liquid, gaseous and solid wastes. Gaseous and liquid waste discharges to the environment are controlled to comply with the limits set by 10 CFR 20.

1.12.1 Liquid Waste System

Reactor coolant from the CVCS and from the reactor coolant drain tanks is processed by the liquid waste system, which is comprised of filters, degasifiers, ion exchangers,

evaporators, receiver tanks, and monitor tanks. The coolant is first purified by the filters, degasifiers, and ion exchangers.

The evaporators are used to concentrate the boric acid. The concentrate is normally returned to the boric acid storage tank, but if the activity is high, or if the solution is chemically unsuitable for reuse, the concentrate is processed in the solid waste processing system and transported to an offsite disposal facility. The distillate from the evaporators is monitored to ensure proper radioactivity limits are not exceeded and then discharged to the circulating water system.

1.12.2 Miscellaneous Waste Processing System

Miscellaneous liquid wastes from the auxiliary building are filtered and stored in the miscellaneous waste receiver tank. The miscellaneous waste ion exchanger is used to purify the miscellaneous waste before it enters the monitor tank. If the radioactivity level of the liquid in the monitor tank is found to be high, the waste can be recycled through the ion exchanger or sent to the liquid waste system.

The liquid in the monitor tank is sampled to ensure proper radioactivity limits are not exceeded prior to discharge to the circulating water system.

1.12.3 Waste Gas System

Waste gases are collected in the vent header and the waste surge tank. One of the two waste gas compressors is used to compress the gas for storage in one of the three waste gas decay tanks. After decay, the gas in the waste gas decay tanks is sampled to ensure proper radioactivity limits are not exceeded, and then is released to the plant vent at a controlled rate.

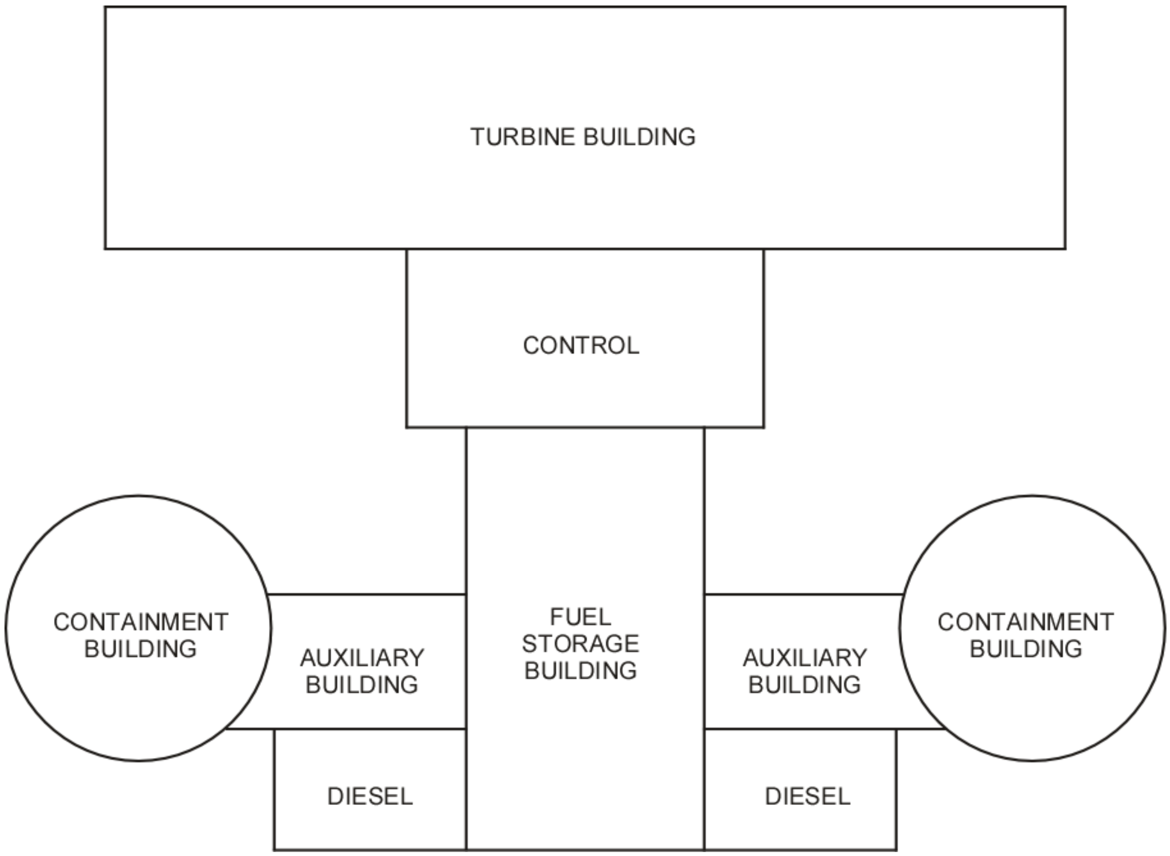

Figure 1-1 Plant Layout

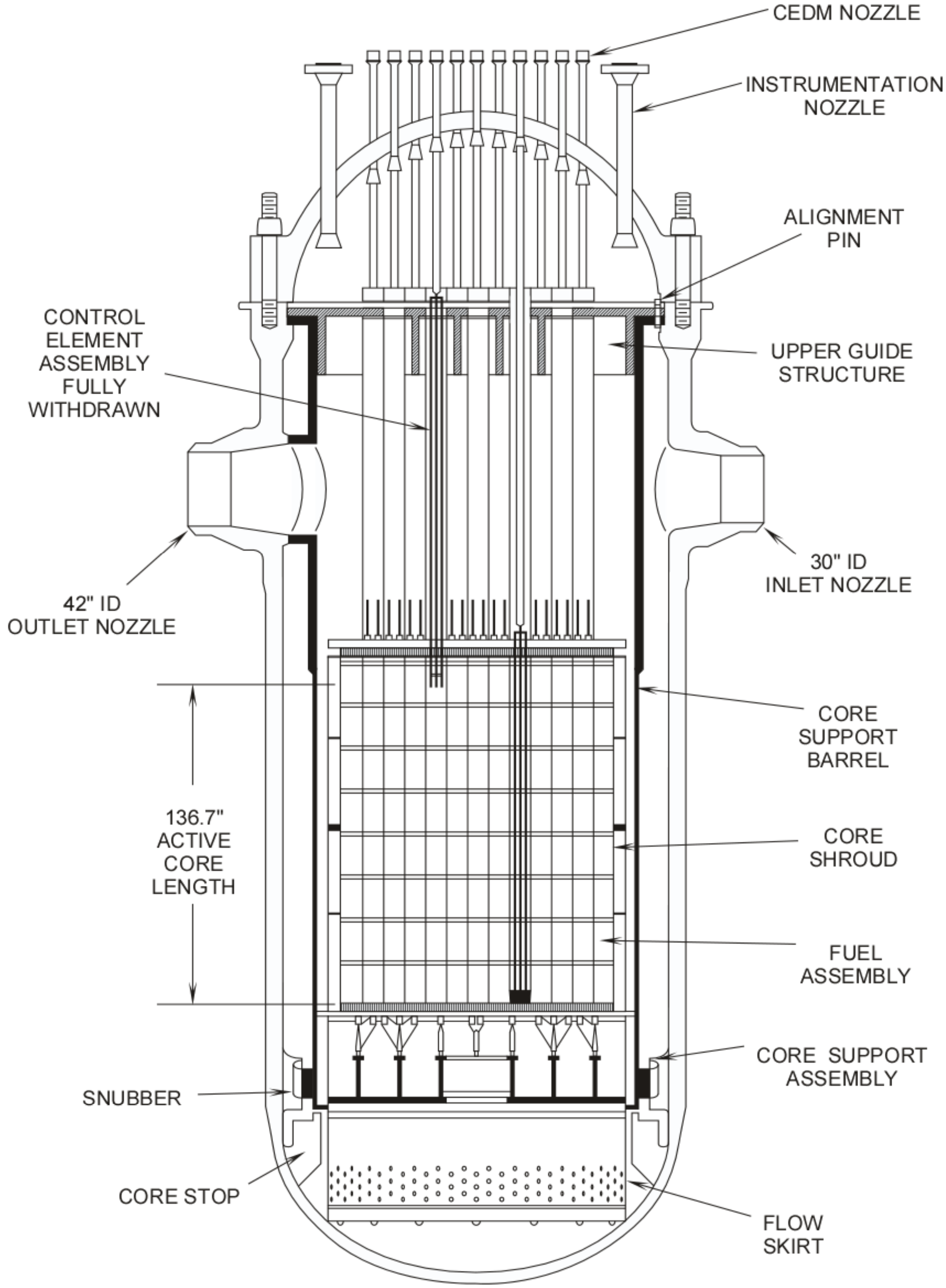

Figure 1-2 Reactor Vessel – Vertical Arrangement

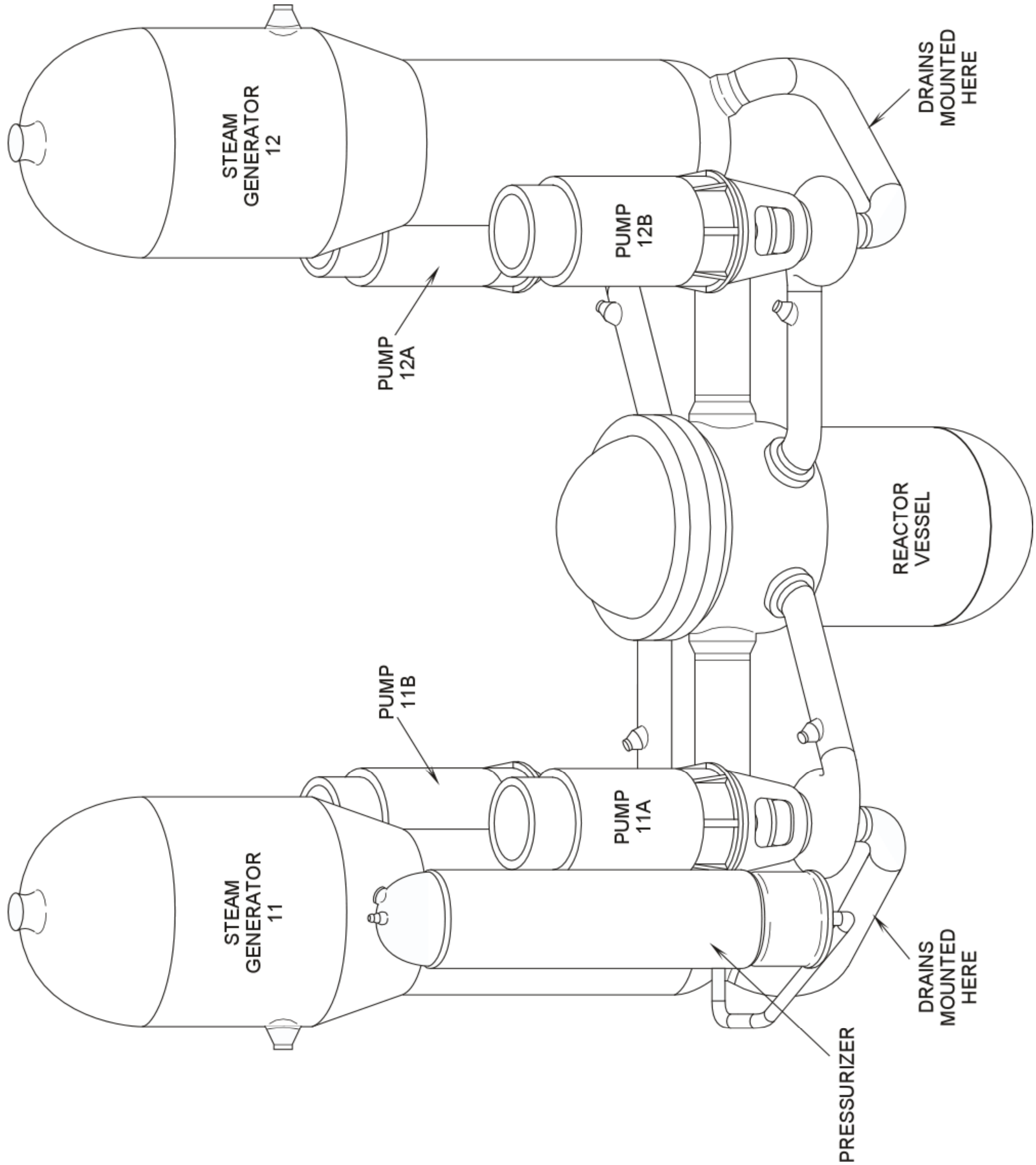

Figure 1-3 Reactor Coolant System

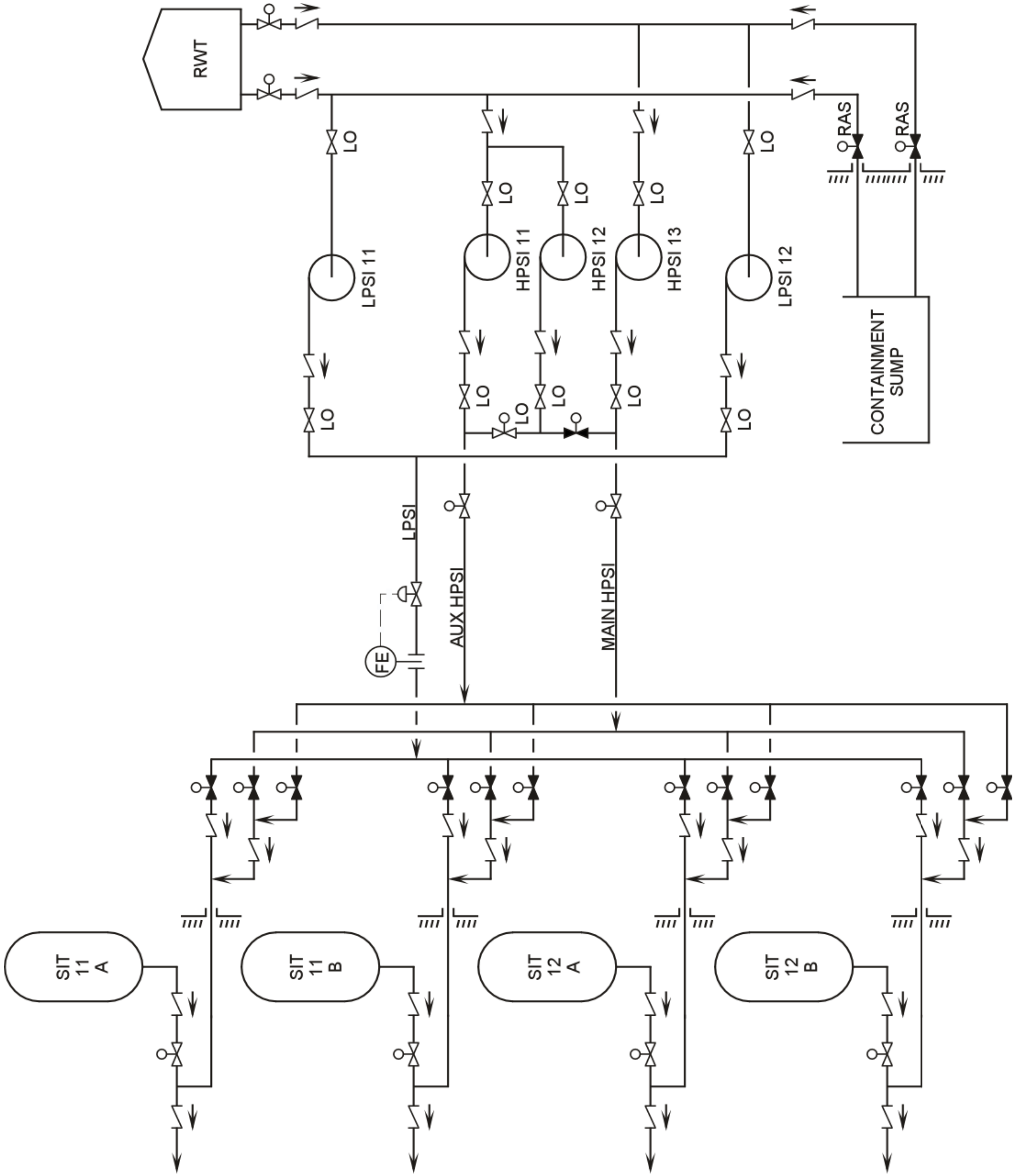

Figure 1-4 Emergency Core Cooling Systems

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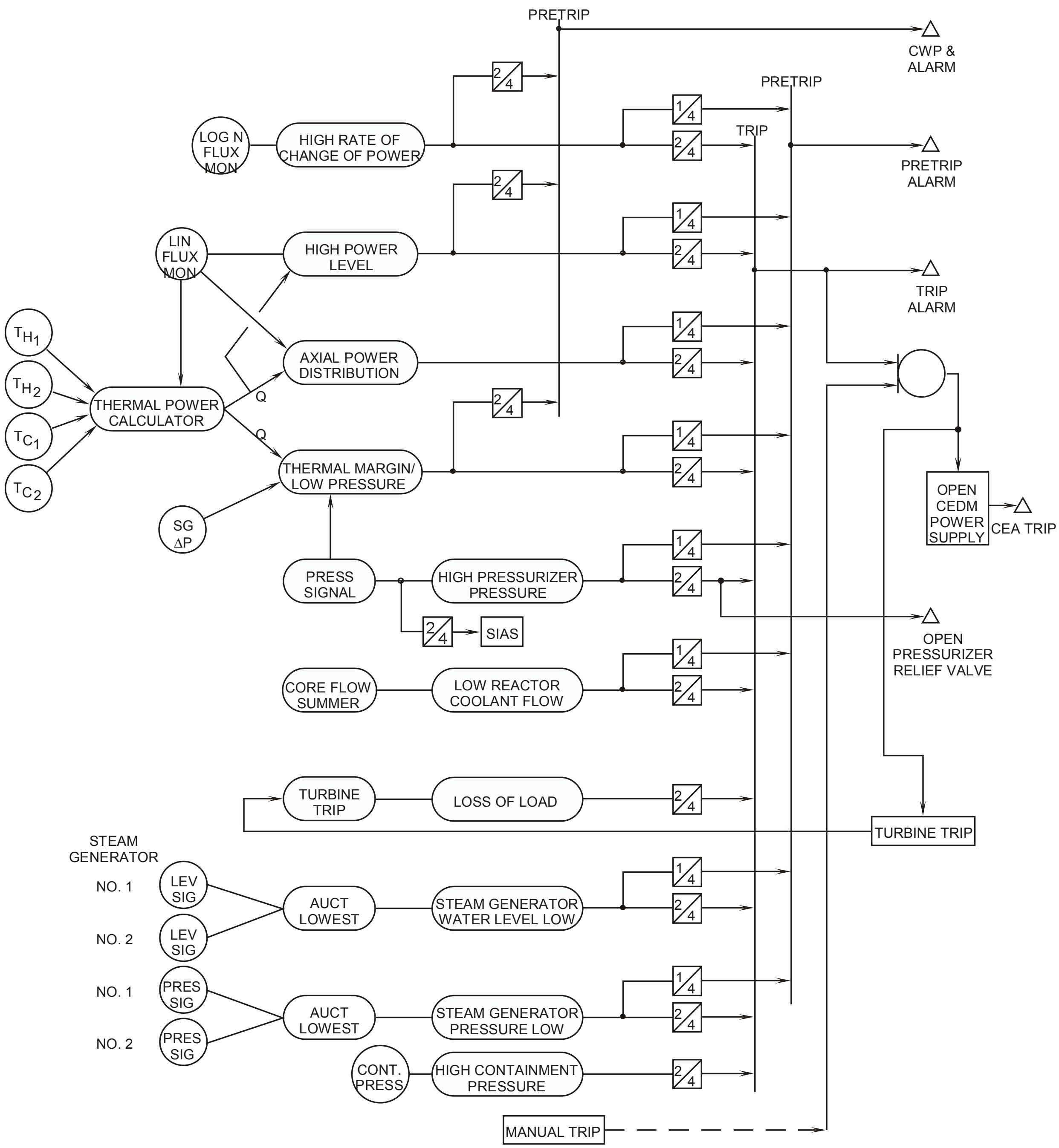

Figure 1-5 RPS Logic

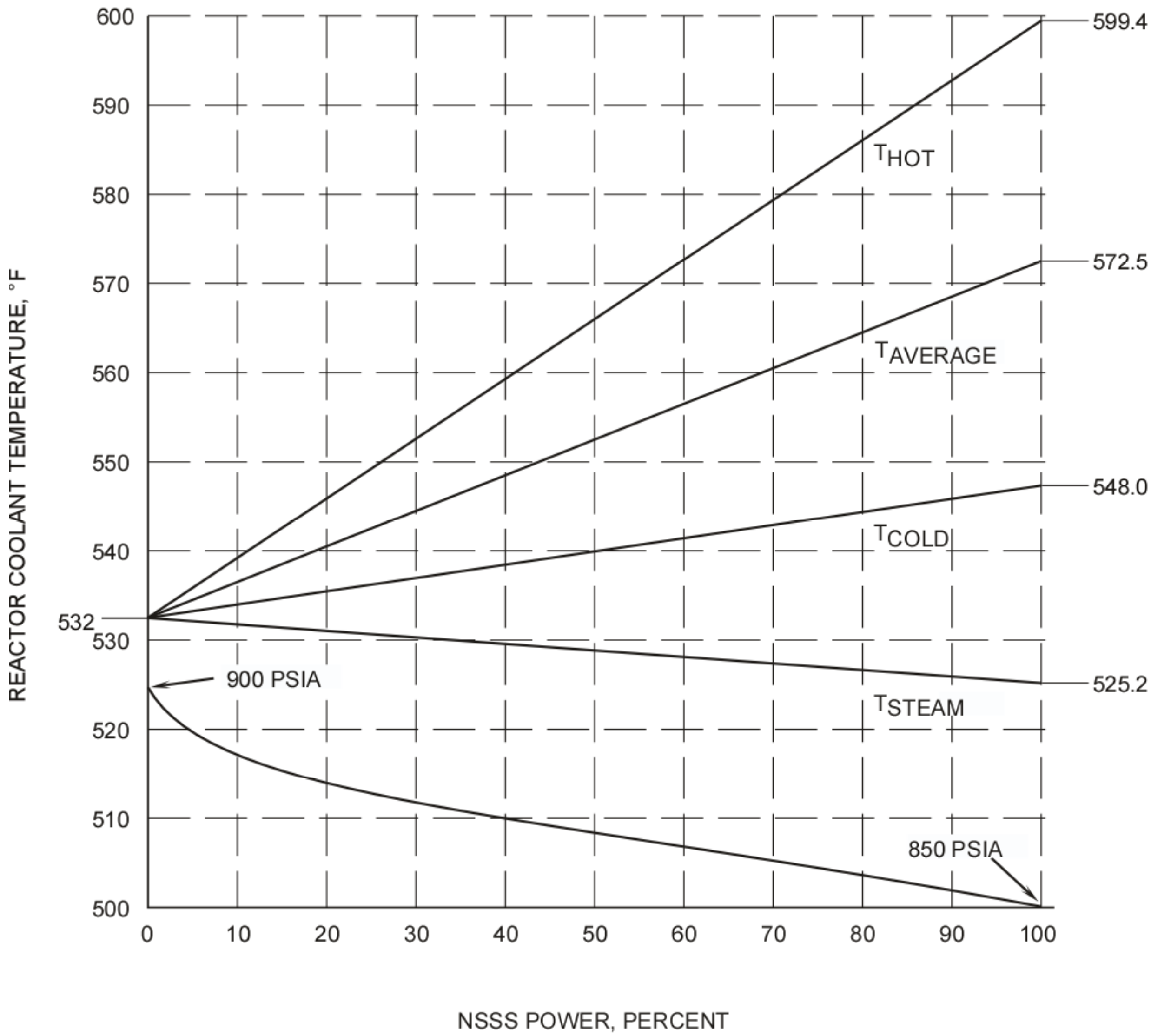

Figure 1-6 RCS Temperature Program

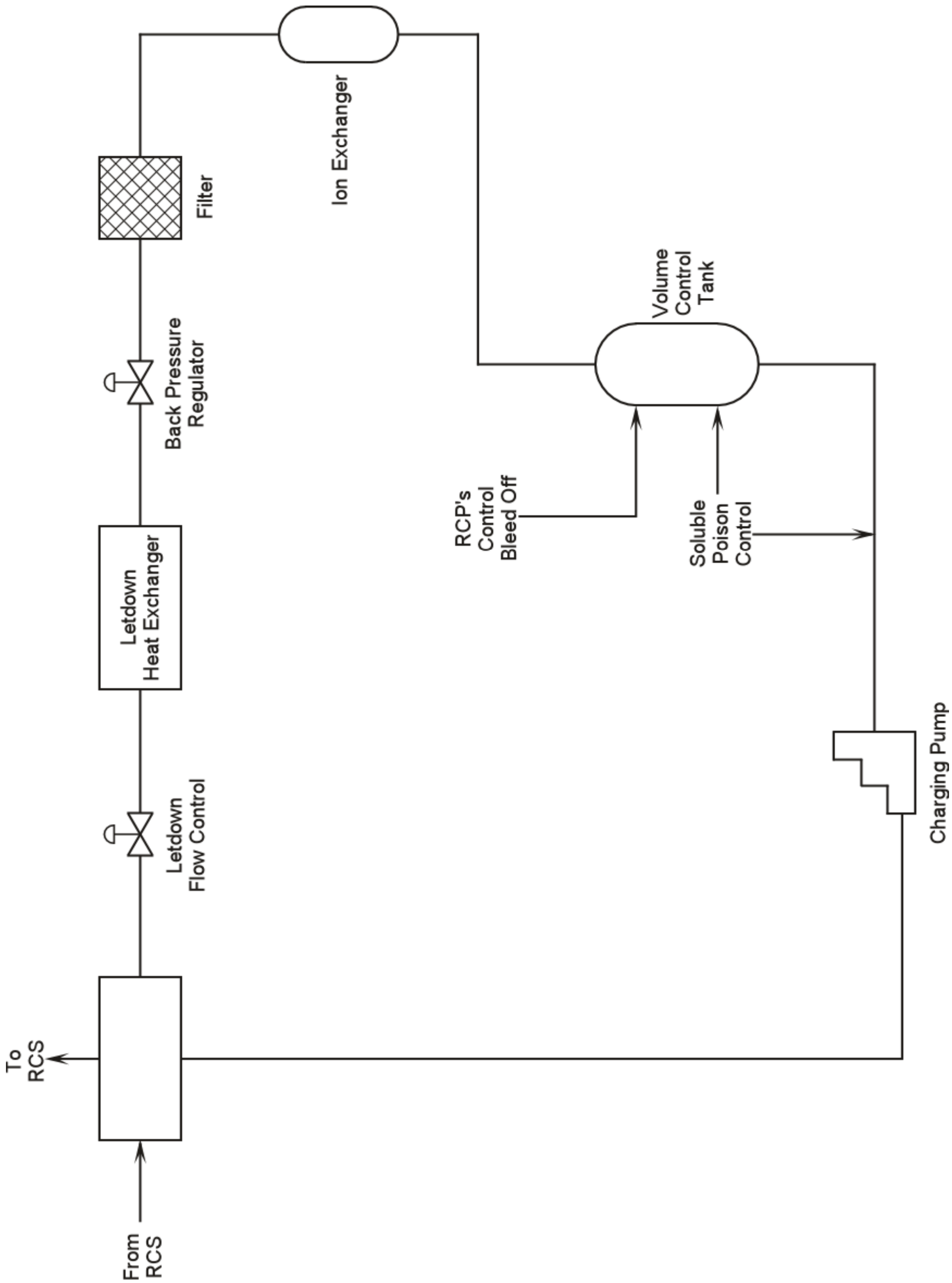

Figure 1-7 Simplified Chemical and Volume Control System

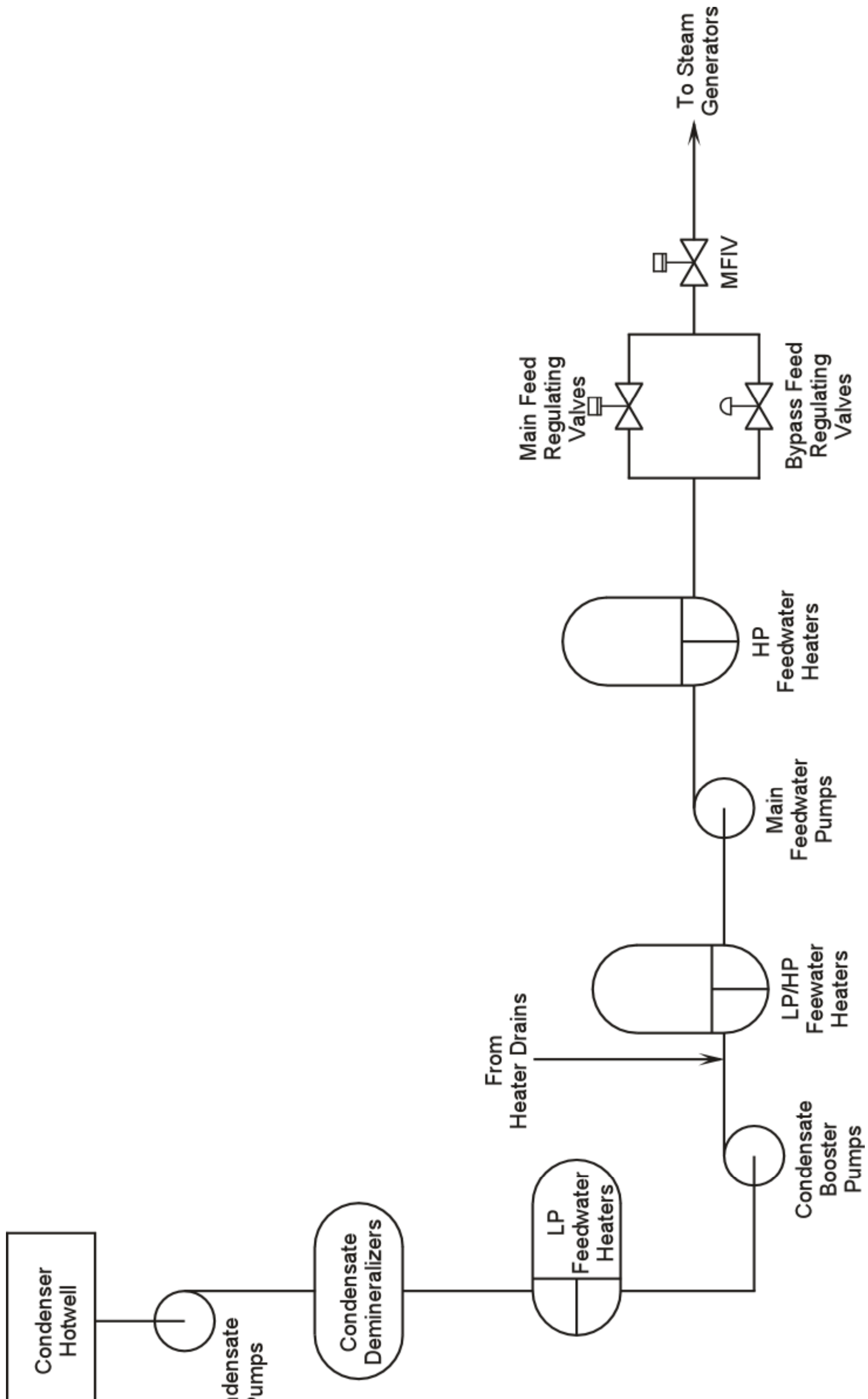

Figure 1-8 Simplified Condensate and Feedwater System