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2.1 REACTOR COOLANT SYSTEM PIPING

Learning Objectives:

1. State the purpose of the Reactor Coolant System (RCS.).
2. List and state the purpose of the following RCS penetrations:
   a. Hot leg (T_h, reactor outlet piping)
      1. Pressurizer surge line
      2. Shutdown cooling system suction
   b. Cold leg ($T_{c,}$ reactor inlet piping).
      1. Chemical And Volume Control System (CVCS) letdown connection
      2. Pressurizer spray line
      3. Common penetration for High Pressure Safety Injection (HPSI), Safety Injection Tank (SIT), Low Pressure Safety Injection (LPSI) and Shutdown Cooling (SDC)
      4. CVCS charging connections
3. State the purpose of the following:
   a. Pressurizer
   b. Pressurizer safety valves
   c. Power Operated Relief Valves (PORVs)
   d. Pressurizer spray valves
   e. Pressurizer heaters
   f. Quench tank
   g. Pressurizer auxiliary spray
4. Describe the methods for determining pressurizer relief valve leakage.
5. State the safety-related functions of the following RCS Instrumentation:
   a. T_h Resistance Temperature Detectors (RTDs)
   b. T_c RTDs
   c. Pressurizer pressure
   d. RCS flow
6. Explain the following:
   a. Pressurizer spray driving force
   b. Purpose of pressurizer spray bypass
   c. Low Temperature/Overpressure Protection (LTOP)

2.1.1 RCS Purpose

The purposes of the RCS are:

1. Transfer the heat produced in the reactor to the steam generators.
2. Provide the second barrier to prevent the escape of fission products to the public.

2.1.2 General Description

The RCS may be divided into three subsystems; heat source, heat sink, and the circulatory subsystem. The heat source is the reactor and the steam generators serve as the heat sink. This section will describe the circulatory subsystem.

Hot reactor coolant (Figure 2.1-1) exits the reactor vessel and travels to the steam generator through a 42-inch Inside Diameter (ID) horizontal hot leg (reactor outlet). In the steam generator, the coolant transfers its heat energy to the secondary system and exits the generator via the two cold-leg outlets. The coolant is directed by 30-inch ID piping to the suction of the Reactor Coolant Pumps (RCPs), which force the fluid back into the reactor vessel where the circulation path starts over.

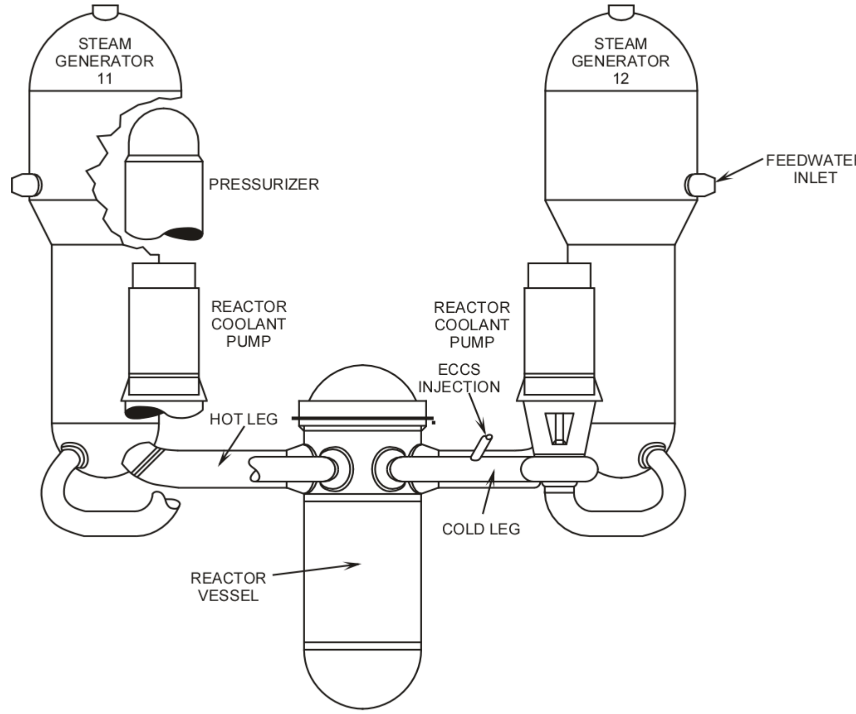

Figure 2.1-1 RCS - Elevation View

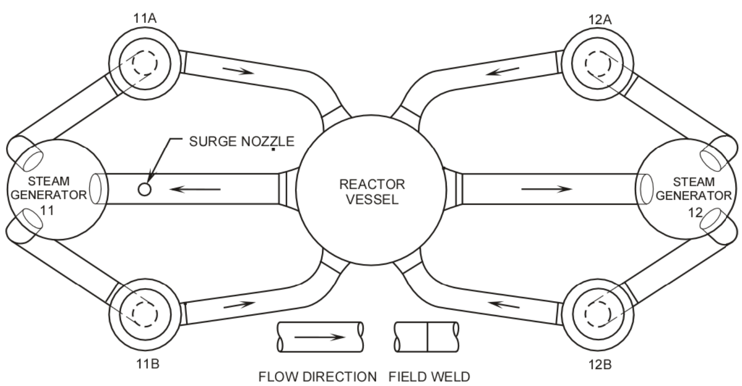

Figure 2.1-2 RCS - Plan View

The section of 30-inch ID piping from the steam generator outlet to the reactor coolant pump suction is a short horizontal run with necessary bends required to mate with the steam generator and reactor coolant pump suction. Coolant is directed from the reactor coolant pump discharge through a short horizontal run of 30-inch ID piping to the reactor vessel. The cold leg consists of that portion of reactor coolant system piping from the steam generator outlet to the reactor vessel inlet. The piping is designed as compactly as possible to minimize the volume of coolant in the reactor coolant system. A small volume of coolant results in a lower containment building pressure in the event of a large break loss of coolant accident. Figure 2.1-2 shows a plan view of the standard Combustion Engineering two-loop, two-steam generator, four-pump reactor coolant system.

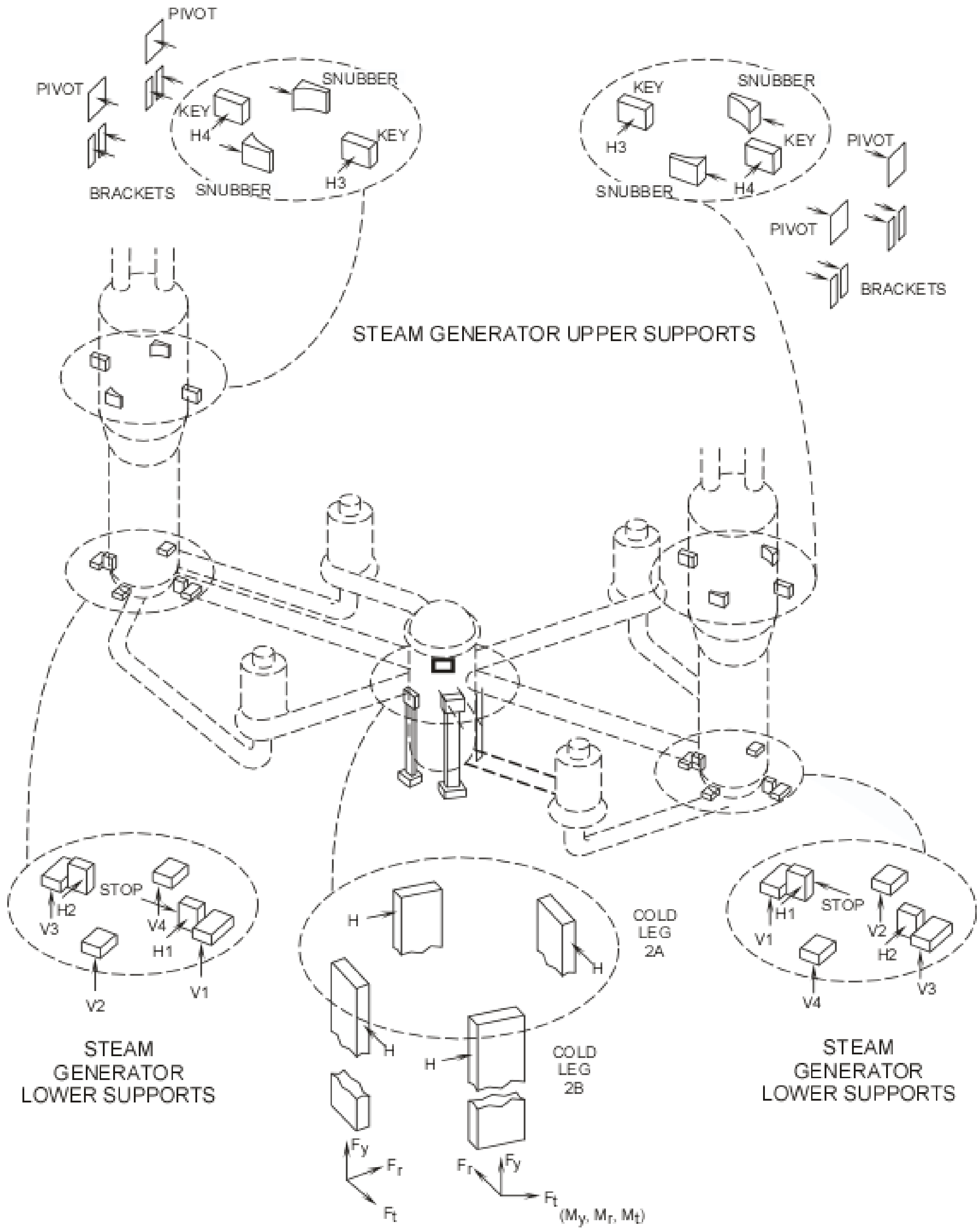

Figure 2.1-3 RCS Supports (Typical)

Figure 2.1-3 illustrates a typical arrangement of reactor coolant system supports.

Since the reactor coolant system also functions as a barrier to the escape of fission products, it must be designed to very stringent requirements. The reactor coolant system piping is constructed of carbon steel, internally clad with stainless steel, with a design pressure of 2500 Pounds per Square Inch Absolute (psia) and a design temperature of 650°F. The circulating reactor coolant is maintained in a subcooled condition by the pressurizer.

2.1.3 RCS Piping Penetrations

2.1.3.1 Hot-Leg Penetrations

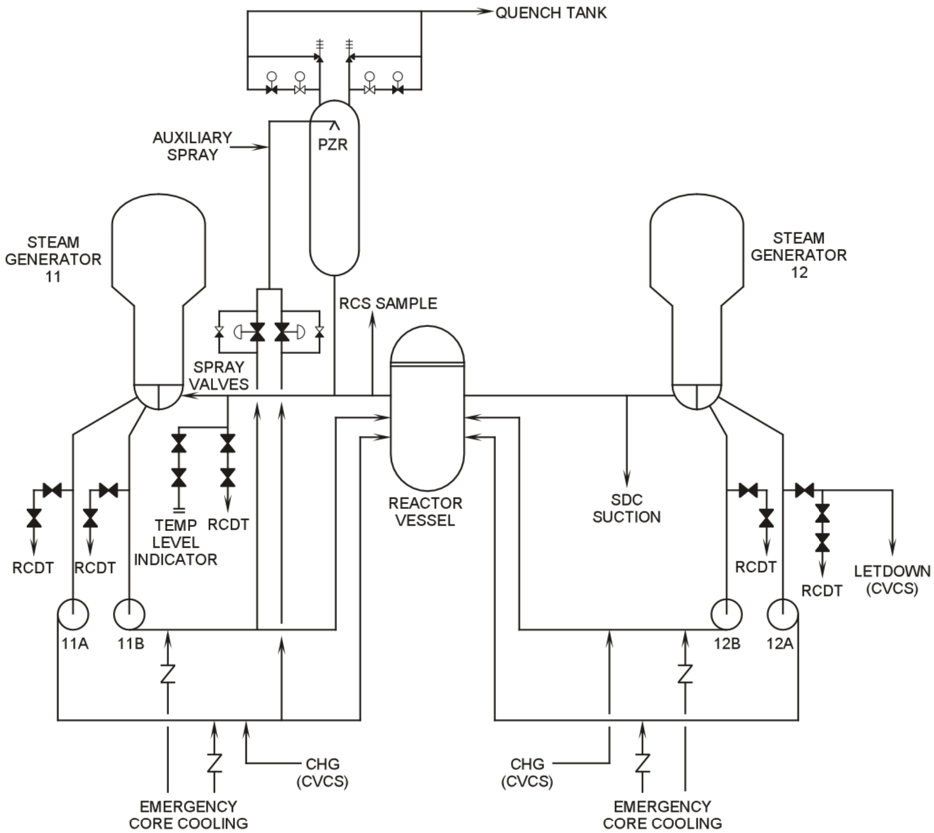

Figure 2.1-4 RCS Flow Diagram

The penetrations into the hot leg are the pressurizer surge line, shutdown cooling suction, reactor coolant system sample connection, and a loop drain to the Reactor Coolant Drain Tank (RCDT).

The 12-inch ID pressurizer surge line penetrates the 11 hot leg and is installed to allow the pressurizer to exert a pressure on the RCS, maintaining the RCS in a subcooled condition. In addition, the surge line allows the pressurizer to accommodate RCS volumetric changes caused by coolant temperature variations.

The 14-inch ID SDC suction penetrates the 12 hot leg and is used to remove decay heat during the latter portions of plant cooldowns and residual heat during cold shutdown operations. Shutdown cooling may be placed in service at 260 psia and 300°F.

The RCS sample line penetrates the 11 hot leg and is a ½-inch ID line used for the routine sampling of the RCS. RCS chemistry is required to be maintained within specific limits in accordance with the plant's technical specifications.

The final penetration into the hot leg is the loop 11 connection to the RCDT which is used for draining down the RCS to its various maintenance levels. A connection for the RCS temporary level indication ties into the same penetration. The temporary level indicator is an unimpressive piece of plastic tubing that has a length greater than the highest point in the RCS. When the RCS is cooled down and depressurized, the level in the tubing equals the level in the system. The temporary level indicator is used to monitor RCS levels during maintenance.

2.1.3.2 Cold-leg Penetrations

The cold-leg penetrations are used to interface with the CVCS, the Emergency Core Cooling Systems (ECCS), the pressurizer, and loop drains. The CVCS interfaces consist of one two-inch ID letdown line and two two-inch ID charging penetrations. The letdown connection taps into the suction piping of 12A RCP and serves as the purification supply to the CVCS. The charging connections return purified coolant from the CVCS to the discharge of 11A and 12B RCPs.

The ECCS interfaces are 12-inch ID pipes that tie into the cold leg on the discharge side of each RCP. This connection serves as a common injection point for HPSI, the SITs, and LPSI. In addition, these connections provide a return path for cooled RCS fluid during SDC operations.

The two three-inch ID pipes located on the discharge of 11A and 11B RCPs supply spray water to the pressurizer. If pressurizer pressure reaches a predetermined set point, the spray valves open allowing cold water to spray into the pressurizer steam bubble. This action lowers the saturation temperature and pressure of the pressurizer.

The last penetrations into the cold-leg piping are the two-inch ID loop drains in the suction line to each RCP (this drain line shares a penetration with the letdown line in loop 12A). These drains are used to drain the RCS to various maintenance levels. The loop drains are routed to the RCDT which, in turn, is pumped to the liquid waste system.

2.1.4 RCS Instrumentation

2.1.4.1 Loop Temperature Instrumentation

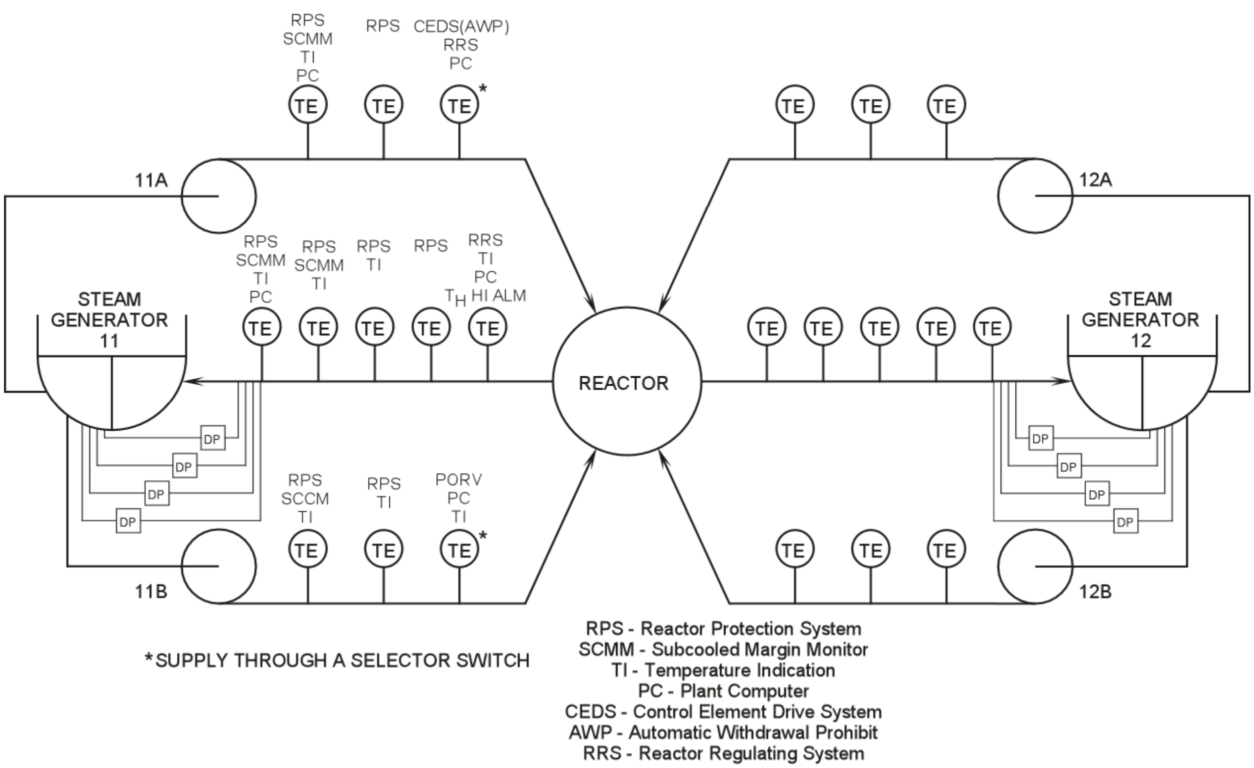

Figure 2.1-5 RCS Instrumentation

RCS loop temperature is sensed with precision, platinum Resistance Temperature Detectors (RTDs). There is a total of 22 well-mounted RTDs, illustrating the CE philosophy of complete separation of control and safety systems.

Each loop hot leg has five RTDs installed. In addition to the outputs for indication, alarm and the Subcooled Margin Monitor (SCMM), four of the RTDs supply wide range (0 - 700°F) safety grade signals to the Reactor Protection System (RPS) for the ΔT power reference calculation used in the Thermal Margin Low Pressure (TMLP) trip circuitry. The fifth RTD supplies a narrow range (515 – 615°F) control grade signal to the reactor regulating system (RRS) for calculation of average loop temperature (T_{avg}) and a high hot-leg temperature alarm in the Main Control Room (MCR).

Each loop cold leg has three RTDs installed. Two of the RTDs supply wide range (0 - 700°F) safety grade signals to the RPS for the ΔT power reference calculation used in the TMLP trip circuitry. The third RTD supplies a control grade signal through a selector switch to two temperature transmitters which supply the temperature signal to the RRS for calculation of T_{avg}, the Control Element Drive System (CEDS) for an Automatic Withdrawal Prohibit (AWP) feature and to the PORV control circuitry for LTOP protection. Upon loss of loop 11A (12A) input, loop 11B (12B) input can be manually selected to ensure a cold-leg signal to the RRS.

2.1.4.2 Loop Flow Instrumentation

Reactor coolant flow is determined by measuring the reactor coolant pressure drop across the steam generators. The pressure drop across each steam generator is sensed by four independent differential pressure detectors which are connected by piping from the hot leg to the cold-leg connection of the steam generator.

The output signal from each flow detector is summed with the signal from the corresponding flow detector in the other loop. The result is four independent channels of reactor coolant flow signal. Each channel provides a signal to individual flow indicators in the MCR and to the Reactor Protection System (RPS) for the loss of flow reactor trip.

2.1.5 Pressurizer

2.1.5.1 Pressurizer Design Information

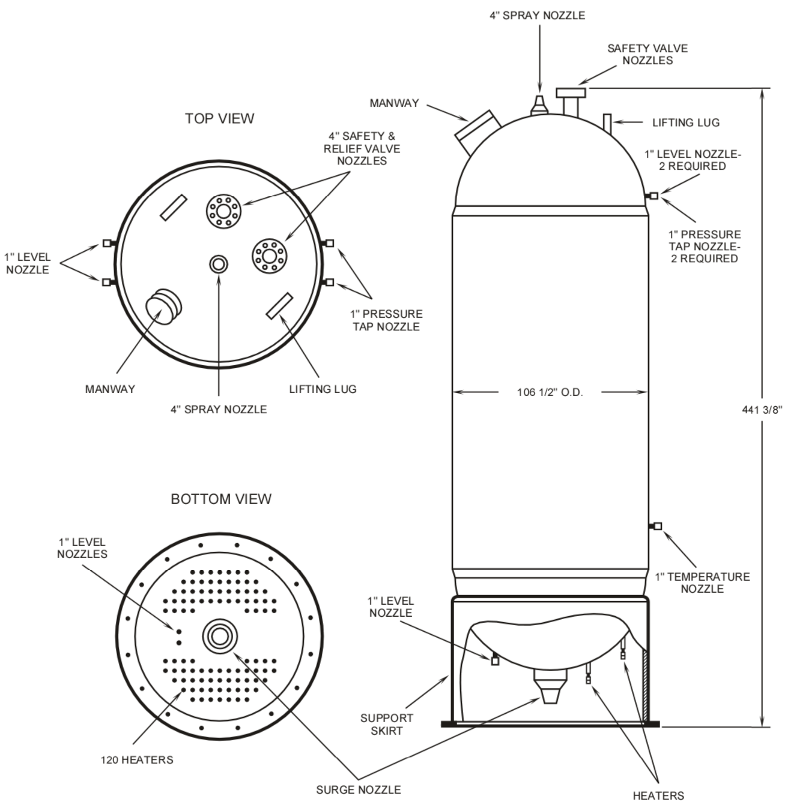

Figure 2.1-6 Pressurizer

As shown in Figure 2.1-6, the pressurizer is a cylindrical carbon steel vessel with rounded top and bottom heads and is clad with stainless steel on its internal surfaces. The pressurizer is supported by a cylindrical skirt welded to the bottom head. It is approximately 37 feet high, with a diameter of approximately nine feet.

The pressurizer is slightly over half full of water during full power operation, with the rest of the volume filled with steam. The principal internal components of the pressurizer are its heaters in the lower section and its spray line in the upper section. Operation of the heaters and the spray maintains the steam and water at saturation temperature conditions corresponding to the desired coolant pressure. Small pressure and volume variations are accommodated by the steam volume which absorbs flow into the pressurizer and by the water volume which allows flow out of the pressurizer.

Pressurizer connections include the surge line, the spray line, safety valve nozzles, level taps, pressure taps, and 120 heater penetrations. Table 2.1-2 summarizes the pressurizer design data.

The pressurizer normal operating water volume of 600 - 800 ft^3 will satisfy the following design requirements:

1. Maintain RCS operating pressure (2250 psia).
2. Compensate for changes in coolant volume during load changes. The total coolant volume changes are kept as small as possible and within the capacities of the CVCS components.
3. Contain sufficient volume to prevent draining the pressurizer and preclude a safety injection actuation as a result of a reactor trip or loss of load event.
4. Limit the water volume to minimize the energy release and resultant containment pressure during a Loss-of-Coolant Accident (LOCA).
5. Prevent uncovering of the heaters by the out surge of water following design load decreases (10% step or 5%/min. ramp).
6. Provide sufficient volume to accept the insurge following a load rejection without the water level reaching the safety valve and power-operated relief valve nozzles.

2.1.5.2 Pressurizer Theory of Operation

In order to understand how the pressurizer performs its function of maintaining RCS pressure, several basic principles must be clearly understood. First, the RCS is a closed hydraulic system, that is, its volume is constant. Second, at normal operating temperatures and pressures, water is about six times as dense as steam. Third, the pressurizer is a two phase saturated system. In a saturated system there is a pressure associated with each temperature. If temperature changes, then pressure must change to a new pressure corresponding to the new temperature. Fourth, assume that water is incompressible. It is not completely incompressible, but it is a good approximation. Finally, the steam will be treated as an ideal gas, which is another good approximation that will not detract from the explanation.

The ideal gas law is:

$$P = \rho R T$$

where: P = pressure,
ρ = density,
R = ideal gas constant, and
T = temperature.

Since the pressurizer is a saturated system, holding the temperature constant will hold the pressure constant. Since it is desired that the RCS be at constant pressure, the pressurizer is operated at constant temperature. Since R and T are constant, then pressure is proportional to density. The RCS is a closed system, therefore, pressure changes in the pressurizer will be transmitted to the entire RCS. In a pressurized water reactor (PWR), it is desirable to operate the loops about 50°F subcooled, that is, about 50°F below saturation temperature. The higher temperature in the pressurizer is maintained by electrical heaters.

If the pressure decreases in the RCS for some reason, the pressure in the pressurizer will now be lower than saturation pressure for the temperature in the pressurizer. Water will boil using stored energy and energy from the heaters. When the water changes to steam, it will expand about six times. The RCS and pressurizer are, however, a fixed volume so the steam will have to increase in density, and the pressure will increase.

Conversely, if RCS pressure increases, pressure will be above saturation pressure, and steam will condense. The steam will contract to about 1/6 of its volume when it condenses to water, leaving more volume for the remaining steam at a decreased density and pressure. The condensation of the steam is aided by spraying in relatively cold water from an RCS cold leg.

It is important to note that the pressurizer acts as a surge volume for the RCS for transients and changes in steady state power. The pressurizer is designed to maintain a relatively constant pressure during all conditions using heaters and/or sprays.

2.1.5.3 Pressurizer Heaters

The pressurizer heaters function to initially form the steam bubble in the pressurizer, increase pressurizer pressure to normal operating pressure (2250 psia), and maintain normal operating pressure. Each of the 120 pressurizer heaters is an immersion type heater rated at 480 Vac and 12.5 kW. The heaters are approximately seven feet long and are vertically mounted through sleeves welded in the bottom head of the pressurizer.

The heaters are separated into two groups for control purposes. The first group is called the proportional group and is installed to compensate for pressurizer heat losses to ambient. This group has 24 heaters that are divided into two 150 kW banks. These heaters are called proportional heaters because their power input is proportional to the deviation of pressurizer pressure from its normal value of 2250 psia. The heaters will receive maximum power at a pressure of 2225 psia and minimum power at 2275 psia.

The backup heaters are the second group of heaters. The 96 backup heaters are divided into four banks of 24 heaters (300 kW per bank). All backup banks are bistable controlled with an on point of 2200 psia and an off point of 2225 psia.

All pressurizer heaters are interlocked with low pressurizer level to prevent damage caused by uncovering the heaters. To assure sufficient pressurizer control for natural circulation flow following a loss of off-site power, the heaters are capable of being powered from the emergency buses.

2.1.5.4 Pressurizer Surge Line

The pressurizer surge line allows the pressurizer to exert its pressure onto the RCS and also allows the pressurizer to serve as a surge volume for the RCS. The surge line originates at the top of the 11 hot leg and connects to the bottom of the pressurizer through the use of a thermal sleeve that minimizes temperature induced stresses. A temperature element is installed in the surge line to alert the operators to a possible loss of spray bypass flow. The bypass flow causes a continuous circulation from the pressurizer to the RCS.

2.1.5.5 Pressurizer Spray

Pressurizer spray originates at the discharge of 11A and/or 11B reactor coolant pumps and functions to decrease pressurizer pressure by condensing a portion of the steam bubble.

The spray valves are controlled by the Pressurizer Pressure Control System (PPCS) and provide a maximum spray line flow rate of 375 gpm. The valves are full open if pressure increases to 2350 psia and close at a value of 2300 psia. Figure 2.1-8 summarizes the various pressurizer pressure setpoints. Since neither the spray valves nor their control system are safety grade, no credit is taken for the termination of Anticipated Operational Occurrences (AOOs) by the spray system in safety analysis.

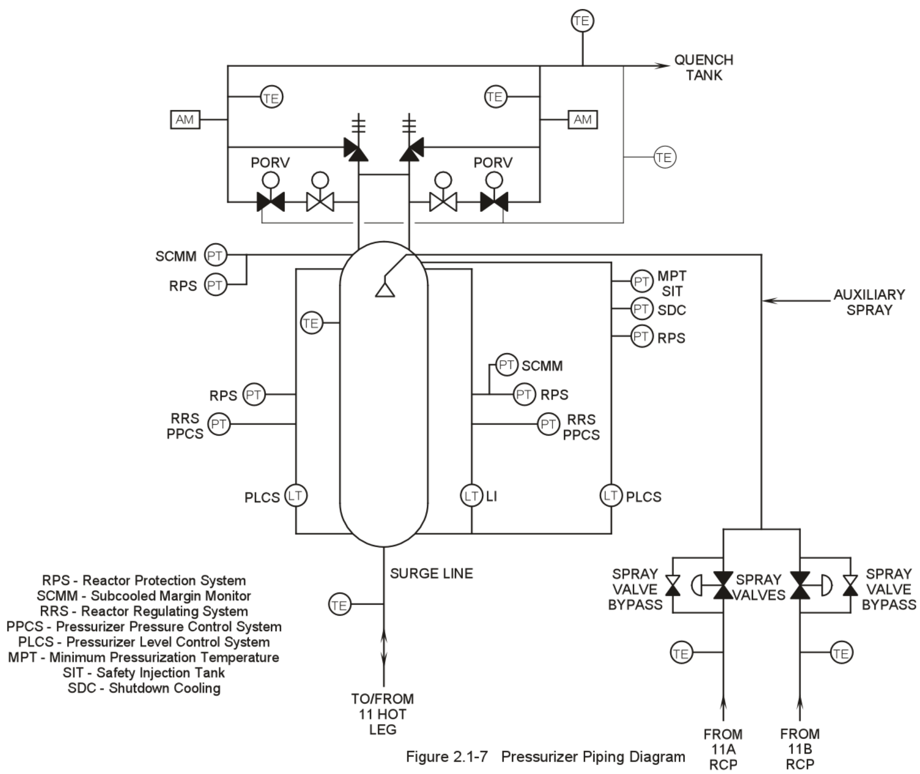

Figure 2.1-7 Pressurizer Piping Diagram

A spray bypass valve parallels each spray valve and is used to maintain a continuous bypass flow of 1.5 gpm through the spray line. This bypass flow maintains the spray lines and spray nozzle close to Tc values which minimizes thermal transients on these components when the spray valves are opened. In addition, the bypass flow helps to maintain the pressurizer and RCS boron concentration at equal values. Maintaining the pressurizer concentration equal to the RCS concentration prevents reactivity changes during pressurizer outsurges. RTDs are installed in each spray line to alert the plant operators to the possibility of insufficient spray bypass flow.

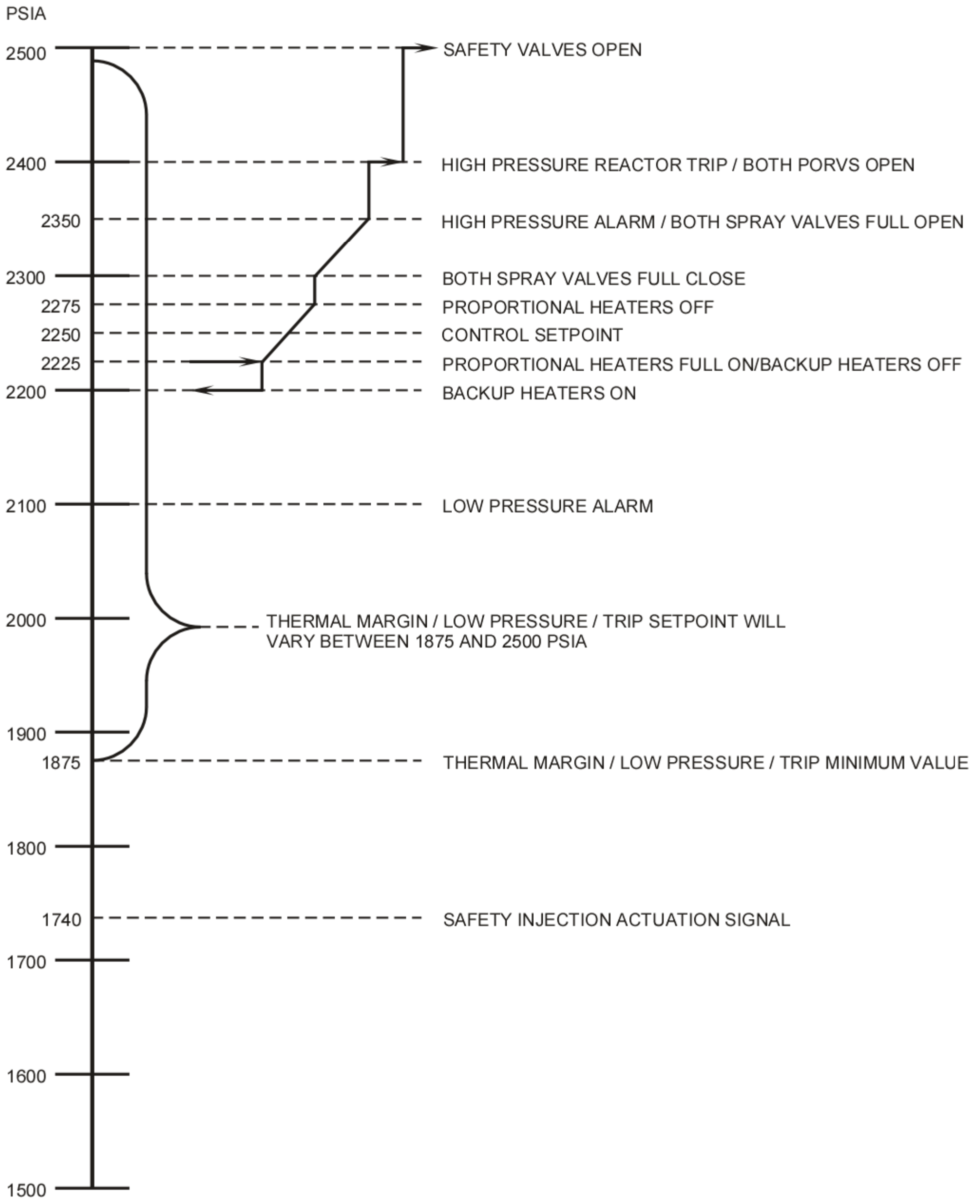

Figure 2.1-8 Pressurizer Pressure Program

In addition to the normal spray valves, the pressurizer is equipped with an auxiliary spray connection that supplies spray water from the CVCS charging pumps. This source of spray would be used during startup/shutdown operations when the RCPs are not in service or to control pressurizer pressure during natural circulation.

2.1.5.6 Pressurizer Overpressure Protection

Control of pressurizer pressure provides overpressure protection for the RCS during normal operations. During transient operation, four pressure relief valves provide added assurance of system overpressure protection. Two of the valves are regular spring-loaded, self-actuated code safety valves and two are Power Operated Relief Valves (PORVs).

The two PORVs are located in two parallel piping loops, connected on the inlet side to the relief valve nozzles on top of the pressurizer and on the outlet side to the piping to the quench tank. Branching off each of the PORV loops, and in parallel with the PORVs, are the lines that contain the code safety valves. All four flowpaths merge into a common pipe that discharges to the quench tank.

The pressure relief system is designed such that if an abnormal incident results in a high pressure of 2400 psia, a reactor trip occurs. The high pressure reactor trip signal opens both of the PORVs. If the pressure continues to increase, one code safety valve

opens at 2500 psia and a second code safety valve opens at 2565 psia. If, for some reason, a reactor trip did not occur at 2400 psia, then the PORVs remain shut and the code safety valves will provide overpressure protection for the RCS.

2.1.5.6.1. Power Operated Relief Valves

The PORVs operate to relieve RCS pressure at a setpoint below the setting of the code safety valves. The PORVs have remotely operated isolation valves to provide a positive shutoff capability should a relief valve become inoperable. The electrical power for both of the PORVs and the isolation valves is capable of being supplied from an emergency power source to ensure the ability to seal this possible RCS leakage path.

The PORVs are solenoid operated valves with a relieving capacity of 153,000 lbm/hr which normally relieves pressure to the quench tank when the high reactor coolant system pressure trip setpoint of 2400 psia is reached. This setting may be lowered to 430 psia to protect the reactor vessel from overpressurization during cold conditions less than 330°F. This low value set is called the Minimum Pressurization Temperature (MPT) or Low Temperature Overpressure Protection (LTOP). The PORV settings may be changed by use of two handswitches located in the MCR.

The RCS must be protected from being pressurized beyond the limit defined by the minimum pressure and temperature (MPT) curves of the Technical Specifications. Heatup and cooldown curves are calculated to prevent non-ductile failure (brittle fracture) of RCS components. Brittle fracture is the sudden, catastrophic failure of a metal component at relatively low temperatures, where the metal exhibits less ductile behavior than at higher temperatures. The most limiting RCS component with respect to brittle fracture is the reactor vessel beltline material, which undergoes progressive neutron radiation embrittlement with operating history.

MPT or LTOP achieves its purpose of protecting the RCS from overpressurization at low,non-ductile temperatures by continuously comparing actual pressurizer pressure and RCS cold leg temperature to two fixed pressure and temperature setpoints. It actuates both the power-operated relief valves (PORVs) when RCS pressure reaches the LTOP low range setpoint applicable for the current RCS temperature.

In the event of an abnormal transient which causes a sustained increase in pressurizer pressure at a rate exceeding the control capacity of the pressurizer spray, a high pressure reactor trip will be reached at 2400 psia. This signal trips the reactor and opens the two PORVs which discharge steam to the quench tank to lower the system pressure.

The PORVs have sufficient capacity to:

1. Handle the maximum steam surge from a continuous control element assembly withdrawal incident starting from low power, without letdown or pressurizer spray operable, or
2. Handle the maximum steam surge from a loss of load incident at full power, with the pressurizer spray operable and a reactor trip on high pressure.

2.1.5.6.2. Code Safety Valves

The two pressurizer safety valves are installed to provide overpressure protection for the RCS. The valves are self-actuating and have setpoints of 2500 psia and 2565 psia. If RCS pressure increases to the safety valve setpoint, the safety valves will open and sequentially relieve the overpressure to the quench tank. The safety valves have capacities of 296,065 lbm/hr and 302,000 lbm/hr respectively. This capacity prevents RCS pressure from exceeding 110% of design pressure (ASME requirement) during AOOs.

The operational occurrence that determined the relieving capacity of the safety valves is a 100% loss of load. The following conservatisms were assumed for the analysis:

1. Loss of load without a reactor trip until the first RPS trip setpoint (pressurizer pressure high) is reached,
2. Initial reactor power is at rated thermal power,
3. No credit was taken for Steam Dump and Bypass Control System (SDBCS) actions,
4. No credit was taken for the operation of the PORVs,
5. The valves reach maximum flow capacity at 103% of design setpoint or less (3% accumulation),
6. The valves reseat at not less than 96% of the setpoint pressure (4% blowdown) and
7. The valves start to relieve within 1% of setpoint pressure (setpoint tolerance).

2.1.5.6.3. PORV and Code Safety Valve Instrumentation

Two different instruments located downstream of the respective relief valves are installed to provide indication of an open or leaking valve.

The temperatures of the PORV and the code safety valve combined discharge lines are monitored by RTDs installed downstream of the respective valves. There is one RTD in each of two lines which monitors the combined discharge of one PORV and one code safety valve. An additional RTD is located in the PORV combined leakoff line. All three RTDs send signals to the plant computer for temperature indication which can be displayed on a CRT in the MCR.

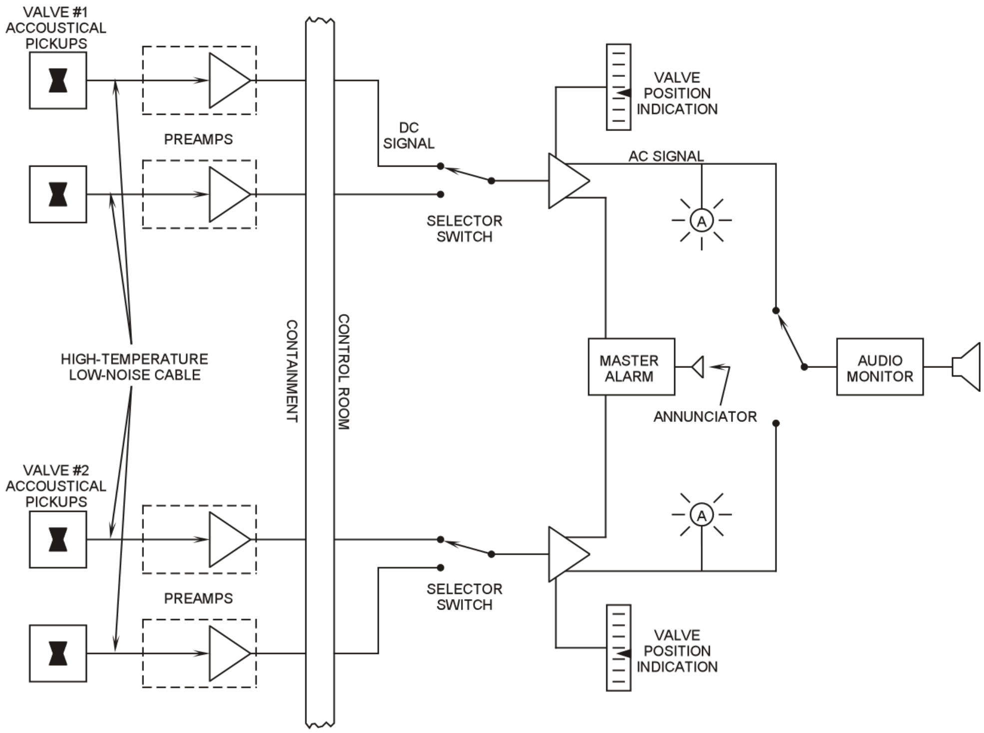

Figure 2.1-9 Acoustical Valve Monitoring

Position indication (required by NUREG-0737, "Clarification of TMI Action Plan Requirements") is provided by an acoustic monitor system (Figure 2.1-9). The system determines if any liquid or steam is flowing past the valves by utilizing an accelerometer to detect vibrations which are induced by flow in the relief valve piping. The accelerometer transmits a signal to an amplifier housed in the Reactor Regulating System (RRS) cabinet. Indication of each valve position is provided by a separate analog indicator on the RRS cabinet and by a digital readout on a main control board. A PORV/safety valves acoustic monitor alarm is also provided when any of the four valve flow indications rises to a predetermined value.

2.1.5.7 Quench Tank

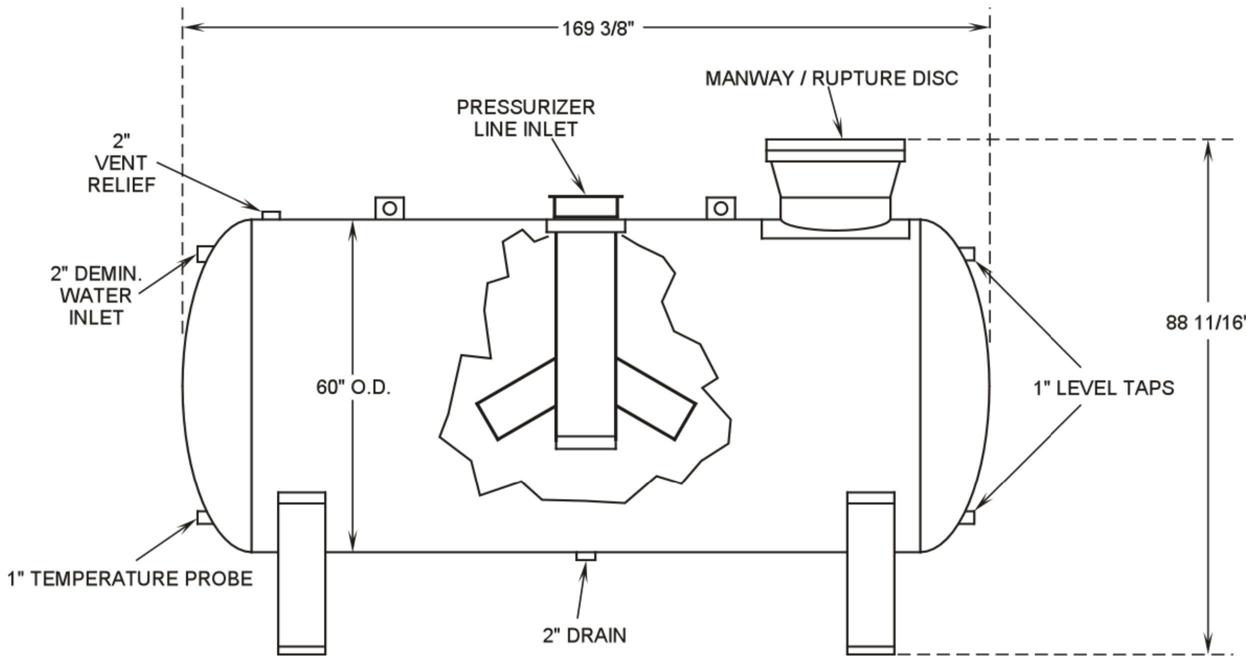

Figure 2.1-10 Quench Tank

The 217 ft^3 capacity quench tank receives and condenses the steam discharged by the four pressurizer relief valves. The steam is discharged beneath the water level in the quench tank preventing release of coolant activity and energy to the containment building. The quench tank is designed to prevent the discharge of the PORVs or the code safety valves from being discharged to the containment building.

During normal operation, a volume of approximately 100 ft^3 of water blanketed by a three psig nitrogen pressure is maintained in the tank. This level (about 24 inches) is sufficient to reduce the necessary tank volume and pressure requirements and to accommodate the code safety valve discharge from two consecutive events: loss of load from 10% power without a concurrent loss of load reactor trip followed by a discharge caused by a continuous Control Element Assembly (CEA) withdrawal accident that occurs as the plant is returned to power. After receiving the discharge, the quench tank pressure will be greater than the tank relief valve setpoint (35 psig) but less than the quench tank rupture disc failure pressure (100 psig). The quench tank is not designed to receive a continuous, uncontrolled safety valve discharge. Table 2.1-3 summarizes the quench tank design data.

The quench tank sets above, and is drained to the Reactor Coolant Drain Tank (RCDT). Other connections into the quench tank are a nitrogen supply and a supply from the demineralized water system. Nitrogen is supplied to the tank to provide an inert atmosphere which precludes the buildup of an explosive hydrogen mixture. The demineralized water supply helps to maintain the proper tank inventory.

2.1.5.8 Pressurizer Level Instrumentation

As shown on Figure 2.1-7, pressurizer level is monitored by three level transmitters. Two of these transmitters are used by the Pressurizer Level Control System (PLCS)

and are calibrated to be accurate when the pressurizer is at normal operating temperature (653°F). The third level indicator is density compensated by pressurizer water space temperature to reflect pressurizer level at all pressurizer temperatures. This indication is used to monitor pressurizer level during shutdowns and startups. Pressurizer level is not a safety-related parameter.

2.1.5.9 Pressurizer Pressure Instrumentation

The pressurizer pressure instrumentation consists of four safety channels, two SCMM channels, two control channels and two low range channels.

Four pressurizer pressure detectors supply signals to four independent pressurizer pressure safety channels. The four channels provide narrow range (1500 - 2500 psia) signals to the RPS and the Engineered Safety Features Actuation System (ESFAS). These signals are used by the RPS to develop the high pressure trip and PORV actuation (2400 psia), the high pressure pre-trip alarm (2350 psia), the TMLP trip (1875 to 2500 psia) and the TMLP pre-trip alarm. The ESFAS uses the input for the lo-lo pressurizer pressure Safety Injection Actuation Signal (SIAS) logic. The four channels also provide signals to individual pressure indicators for each channel in the MCR.

Two pressurizer pressure detectors provide wide range (0 - 4000 psia) signals to two independent SCMM channels which in turn provide indication of subcooling margin and wide range pressure in the MCR.

Two pressurizer pressure detectors supply narrow range signals to two independent pressurizer pressure control channels. Each pressure signal is used for control of the backup heaters, the proportional heaters and the spray valve. A pressurizer pressure high/low alarm annunciated in the MCR is also supplied from the control channels. Additionally, the RRS receives a signal from the control channels; however, this signal is not currently used at Calvert Cliffs.

The remaining two pressurizer pressure detectors supply low range (0-1600 psia) signals for shutdown pressure indication, SIT isolation valve automatic open (300 psia), SDC return valve automatic closure (300 psia) and input to the MPT logic circuitry.

2.1.5.10 Pressurizer Temperature Instrumentation

A single RTD is installed in the steam space of the pressurizer and provides control room indication of pressurizer temperature. Temperature indication is used by the operator to monitor pressurizer steam bubble formation as well as heatup and cooldown rates. There are no controls associated with pressurizer temperature.

2.1.6 RCS Operations

2.1.6.1 Plant Startup

For the purposes of this discussion, the initial conditions of the RCS are as follows:

1. The reactor is shutdown with a shutdown margin of 3% $\Delta K/K$,
2. The shutdown cooling system is in service for RCS temperature control,
3. The RCS is drained to some maintenance level and
4. RCS temperature <200°F, and vented to atmosphere.

With these conditions, the first step in the startup is the filling and venting of the RCS. The RCS can be filled from the CVCS through the charging connections or from the Refueling Water Tank (RWT) via the SDC system.

During the fill process, the pressurizer may begin to be heated using the pressurizer heaters once pressurizer level is higher than approximately 42% to save some time in the bubble formation process. The RCS will continue to be filled until the pressurizer is full and the vent is shut. The pressurizer heatup will be terminated when the pressurizer temperature reaches 300°F. A drain path from the RCS is then established and the pressurizer is drained to approximately 40% level. During the drain down the bubble will form, as indicated by a continuing decrease in level without a consequent decrease in pressure. Normal charging and letdown can then be established and the pressurizer level control system can then be placed in automatic control.

After pressurizer bubble formation is completed, pressure will be increased by continued heat addition from the pressurizer heaters. When the pressure exceeds the RCP Net Positive Suction Head (NPSH) requirements, the RCPs can be started. A pump is run in each loop for 3-5 minutes, and the RCS is vented. The pump run ensures that the air in the top of the steam generator U-tubes is swept out.

After venting operations have been completed, three RCPs are placed in service and the heatup of the RCS is begun. Once the RCPs are running, the SDC system is shutdown and aligned to its emergency lineup. RCS pressure is increased as RCS temperature increases. During the RCS heatup, letdown flow will be increased to compensate for RCS expansion and to maintain pressurizer level.

Before the RCS pressure goes above 300 psia, the SIT outlet valves are opened. When temperature exceeds 500°F, the fourth RCP is started. The final step involves placing the pressurizer pressure controls in automatic at 2250 psia.

2.1.6.2 Plant Shutdown

After the reactor is shutdown, a cooldown and depressurization of the RCS is started. RCS temperature is reduced by stopping one RCP in each loop and dumping steam from the steam generators to the main condenser. Makeup from the CVCS compensates for RCS volume contractions during the cooldown. RCS pressure is reduced by manual control of the pressurizer spray valves. When temperature has been reduced to less than 300°F and pressure is at or less than 260 psia, the SDC system is placed in service. The remaining RCPs are stopped. Further temperature reduction is accomplished by the SDC system while the auxiliary spray is used to lower pressurizer pressure. These systems will be used to achieve the desired pressurizer pressure and RCS temperature.

2.1.7 RCS Low Temperature

To provide overpressure protection for the reactor vessel during cold plant conditions (Tc less than 330°F), the relief setting of the PORVs is changed from a 2400 psia setting (normal operating setting) to a setting of 430 psia. When Tc decreases to 330°F and the RCS pressure is less than 430 psia, MPT enable/normal handswitches are placed in the enable position. The handswitches are located in the MCR and align the MPT logic circuitry to provide alarm and control functions. The alarm functions advise

the operator when to enable or disable the MPT protective functions. An additional alarm will warn the operators when the RCS pressure is greater than or equal to 370 psia and RCS temperature is less than 330°F or a bad quality exists on either the temperature input or pressure inputs to the circuit. The additional alarm will warn operators of improper pressurizer heater operation, faulty charging and letdown operation, improper HPSI pump operation or plant computer failure.

2.1.7.1 Saturation Monitors

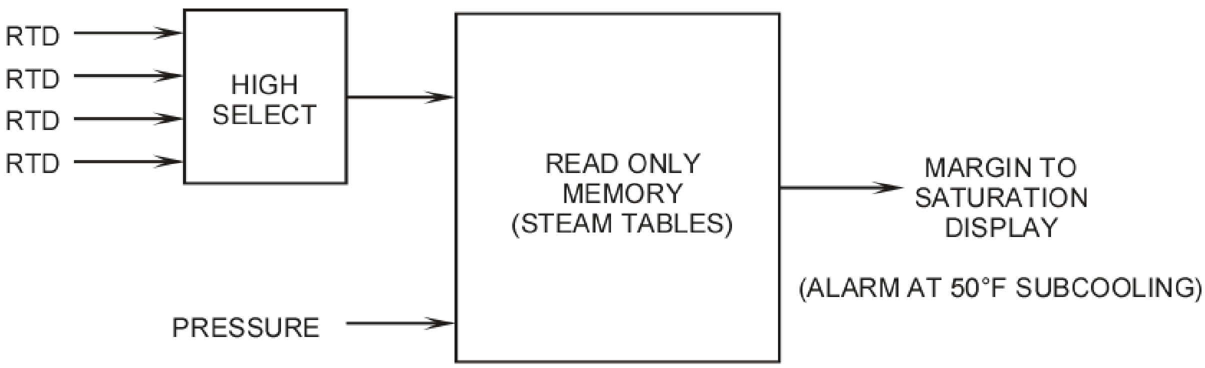

Figure 2.1-11 Saturation Monitor

A typical saturation monitor consists of a microprocessor with the steam tables burned into a read only memory. Reactor coolant system temperatures and pressures are supplied to the processor and are compared with saturation values. If the reactor coolant system temperature is within 50°F of saturation, an alarm is generated. The saturation calculation is conservative, because the temperature inputs are high-selected. The temperature inputs range from 0 - 700°F, with a pressure input range of 0 - 4000 psia is used. Saturation monitors are redundant and powered from vital AC sources.

2.1.8 RCS High Point Vents

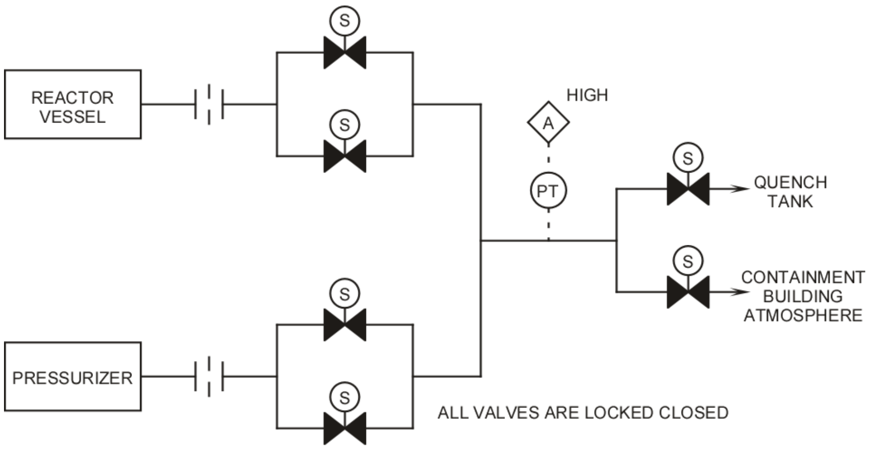

Figure 2.1-12 High Point Vents

The transfer of heat from the core to the steam generators is necessary to prevent core damage in a small break loss of coolant accident because of the low values of emergency core cooling flows. Since the RCPs are powered from non-vital busses, forced circulation is not guaranteed. Therefore, natural circulation is required for core cooling.

Since non-condensable gases from core damage, SIT injection, and RWT injections could block the natural circulation flowpath high point vents have been added to the RCS design.

2.1.9 Reactor Vessel Level Indication

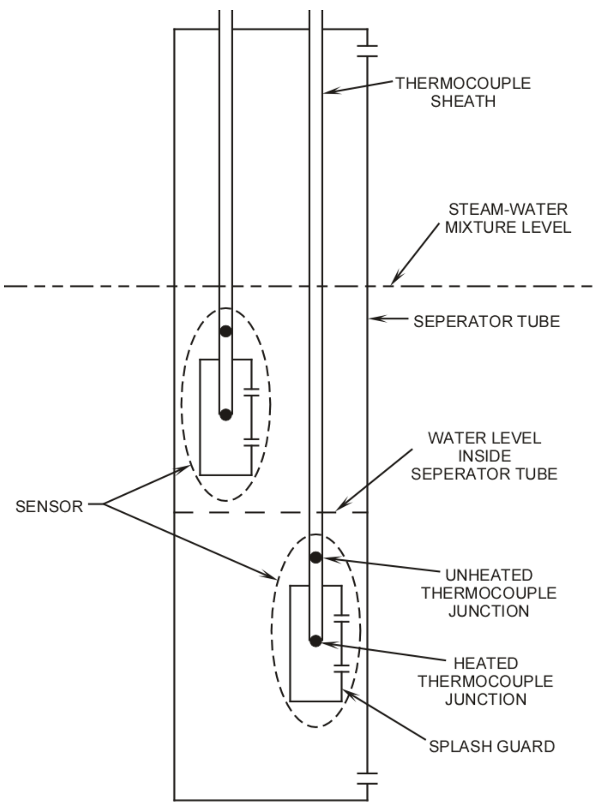

Figure 2.1-13 Reactor Vessel Level Indication

The Combustion Engineering Reactor Vessel Level Indication System (RVLIS) consists of heated junction thermocouples located at eleven different axial positions between the reactor vessel head and the top of the fuel alignment plate.

The basic principle of RVLIS operation is the detection of a ΔT between adjacent heated and unheated thermocouples. Each of the eleven sensors consists of a chromel-alumel thermocouple located near a heater and another chromel-alumel thermocouple positioned away from the heater. As steam replaces liquid in the core, the heat transfer from the heated thermocouple drops. This creates a large ΔT between the heated and unheated thermocouples. The large ΔT is used to indicate a level change. Each of the heated junction thermocouple sensors is shielded to avoid overcooling due to direct water contact during two phase fluid conditions. Vessel level indication is supplied to the safety parameter display system and a digital display in the control room.

2.1.10 PRA Insights

The PORVs are used to limit the primary pressure on transients in order to prevent the safety valves from lifting. The pressurizer PORVs are also used to remove heat from the core by once through core cooling if no other methods of heat removal are available.

The failure of the PORVs are present in several accident sequences which lead to core damage (9% of the core damage frequency). There are two general failure modes for the relief valves.

First, the failure of the PORVs to close when required leads to the need for recirculation cooling of the reactor, and the subsequent failure of the recirculation mode of the Emergency Core Cooling Systems (ECCS) results in core damage.

Second, the failure of the PORVs to open when required for once through reactor core cooling. This failure of heat removal results in core damage. Probable causes of a loss of the PORVs are:

1. Failure to open on demand,
2. Failure of the power supply to the valves,
3. Failure of the block valve to close to isolate a stuck open PORV or
4. Failure of a closed block valve to open when feed and bleed core cooling is necessary.

NUREG 1150 ("Severe Accident Risks: An Assessment For Five U.S. Nuclear Power Plants") studies on importance measures have shown that the PORVs are not a major contributor to risk achievement or risk reduction.

2.1.11 Summary

The RCS consists of the reactor vessel, steam generators, reactor coolant pumps, and interconnecting piping. The RCS is arranged in two heat transport loops with each loop containing one steam generator and two reactor coolant pumps. The RCS has a design pressure of 2500 psia and a design temperature of 650°F and serves as the second barrier to the escape of fission products to the public.

Penetrations into the RCS include thermowells for temperature indications, pressurizer surge and spray connections, CVCS letdown and charging connections, shutdown cooling suction, and emergency core cooling injection connections.

The pressurizer functions to maintain the RCS in a subcooled condition and to provide for temperature induced volume changes. pressurizer pressure is controlled by the use of electrical heaters to increase pressure and pressurizer spray to decrease pressure. Overpressure protection for the RCS is ensured by two code safety valves and two PORVs located on the top of the pressurizer.

RCS temperature along with pressurizer pressure instrumentation is supplied to the RPS for the generation of reactor trips. In addition, low pressure is used to actuate emergency core cooling. Separate RCS RTDs, pressurizer pressure transmitters, and pressurizer level transmitters supply signals to the RRS, PPCS, and the PLCS. RCS flow is determined by measuring the differential pressure across the Steam Generators.

Table 2.1-1 RCS Design Parameters

Design thermal power	2700 Mwt 9.213 x 10^6 BTU/hr
Design Pressure	2500 psia
Design temperature (except pressurizer)	650°F
Number of loops	2
Pipe size, inside diameter reactor outlet reactor inlet surge line, nominal	 42" w/o clad 30" w/o clad 12" w/o clad
Coolant flow rate velocity, hot leg velocity, cold leg	122 x 10^6 lbm/hr 42 ft/sec 37 ft/sec
Cold leg temperature	548°F
Average temperature	572.5°F
Hot leg temperature	599.4°F
Normal operating pressure	2250 psia
System water volume (w/o pressurizer)	9601 ft^3
Pressurizer water volume	800 ft^3
Pressurizer steam volume	700 ft^3
Hydrostatic test pressure of RCS components at 100°F (except RCP)	3125 psia

Table 2.2-2 Pressurizer Design Parameters

Design pressure	2500 psia
Design temperature	700°F
Normal operating pressure	2250 psia
Normal operating temperature	653°F
Internal free volume	1500 ft^3
Design water volume	600 - 800 ft^3
Design steam volume	700 - 900 ft^3
Installed heater capacity	1500 kW
Spray flow, maximum	375 gpm
Spray flow, continuous	1.5 gpm
Nozzles	
Surge line, nominal inside diameter	12"
Safety valves and PORVs, inside diameter	4"
Spray, nominal inside diameter	4"
Heaters, outside diameter	0.875"
Instruments	
Level, nominal diameter	1”
Temperature, nominal diameter	1”
Pressure, nominal diameter	1”
Dimensions	
Overall length, including skirt and spray nozzle	441⅜”
Outside diameter	106½”
Inside diameter	95 9/16”
Cladding thickness, minimum	⅛”
Dry weight, including heaters	206,000 lbs
Flooded weight, including heaters	302,200 lbs

Table 2.1-3 Quench Tank Design Parameters

Design pressure	100 psig
Design temperature	350°F
Normal operating pressure	3 psig
Internal volume	217 ft^3
Normal indicated water level	24"
Blanket gas	Nitrogen
Manway, inside diameter	16"
Nozzles	
Pressurizer discharge, nominal	10"
Demineralized water	2"
Rupture disc	18"
Drain	2"
Temperature instrument	1"
Level instrument	½”
Vent	1½”
Dimensions	
Overall length	144⅜”
Outside diameter	60"

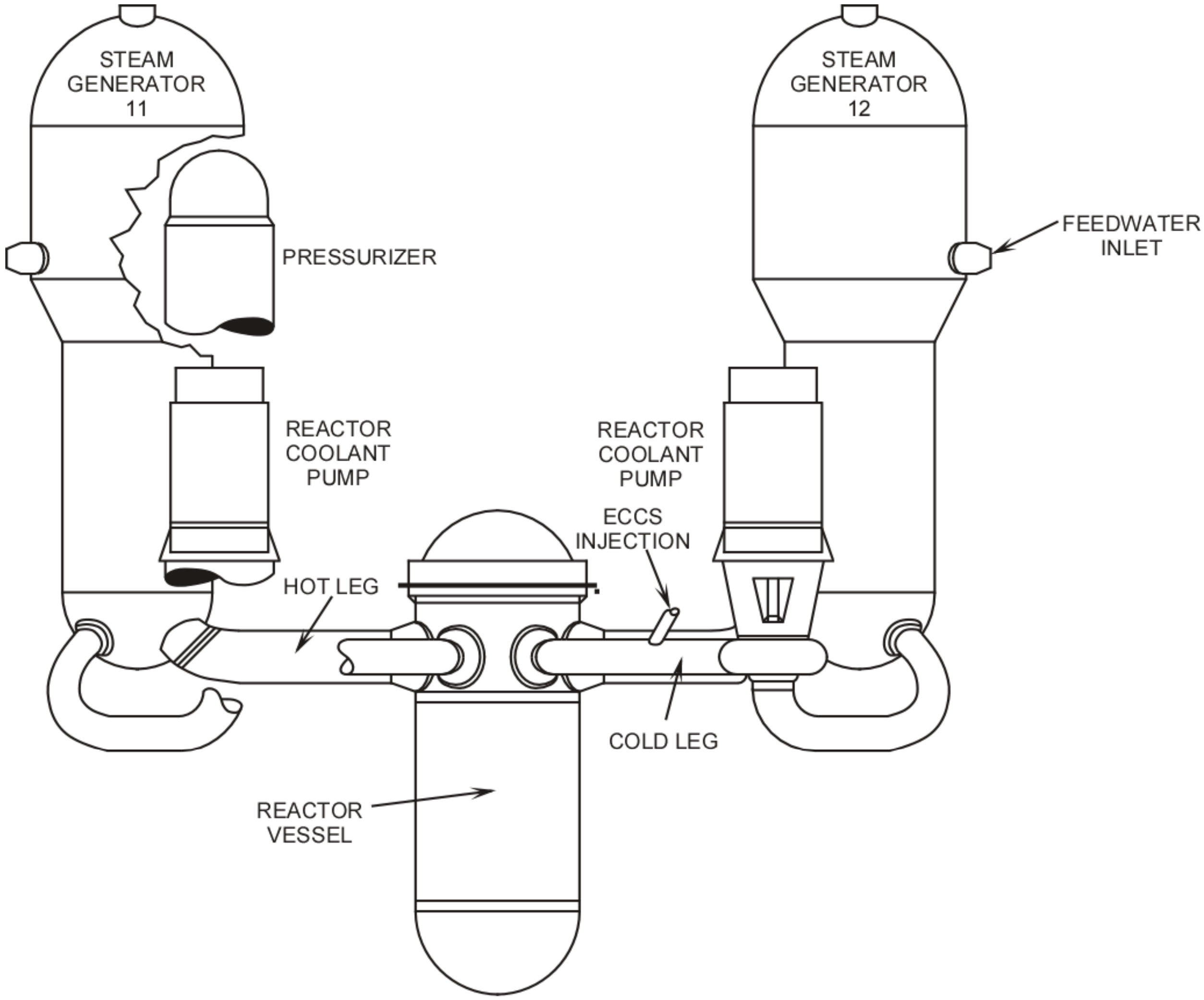

Figure 2.1-1 RCS – Elevation View

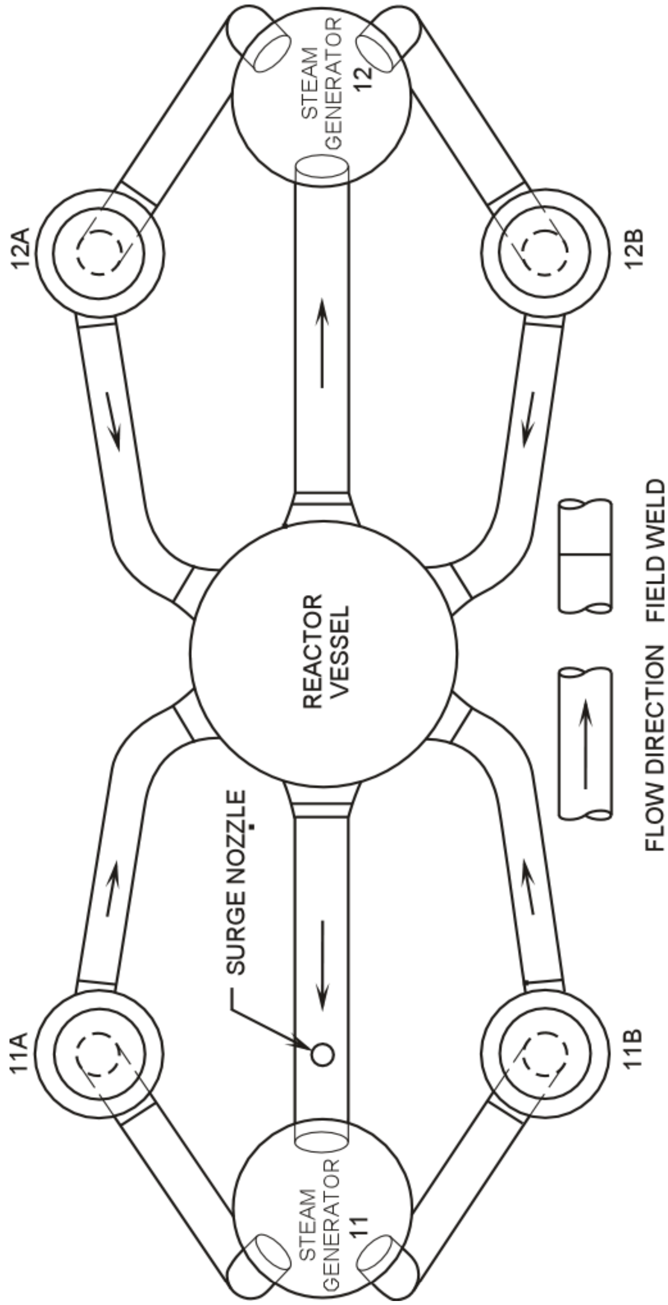

Figure 2.1-2 RCS – Plan View

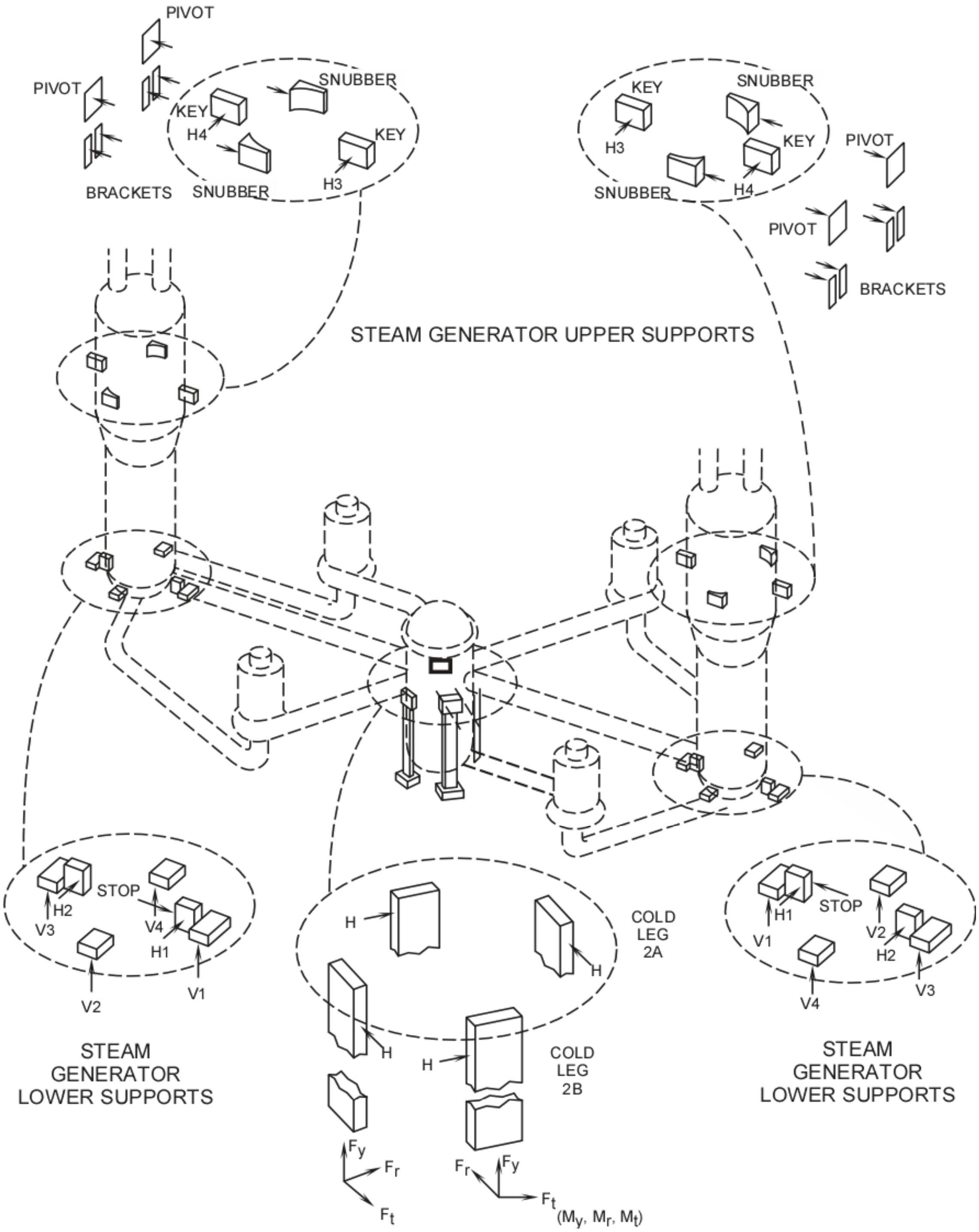

Figure 2.1-3 RCS Supports (Typical)

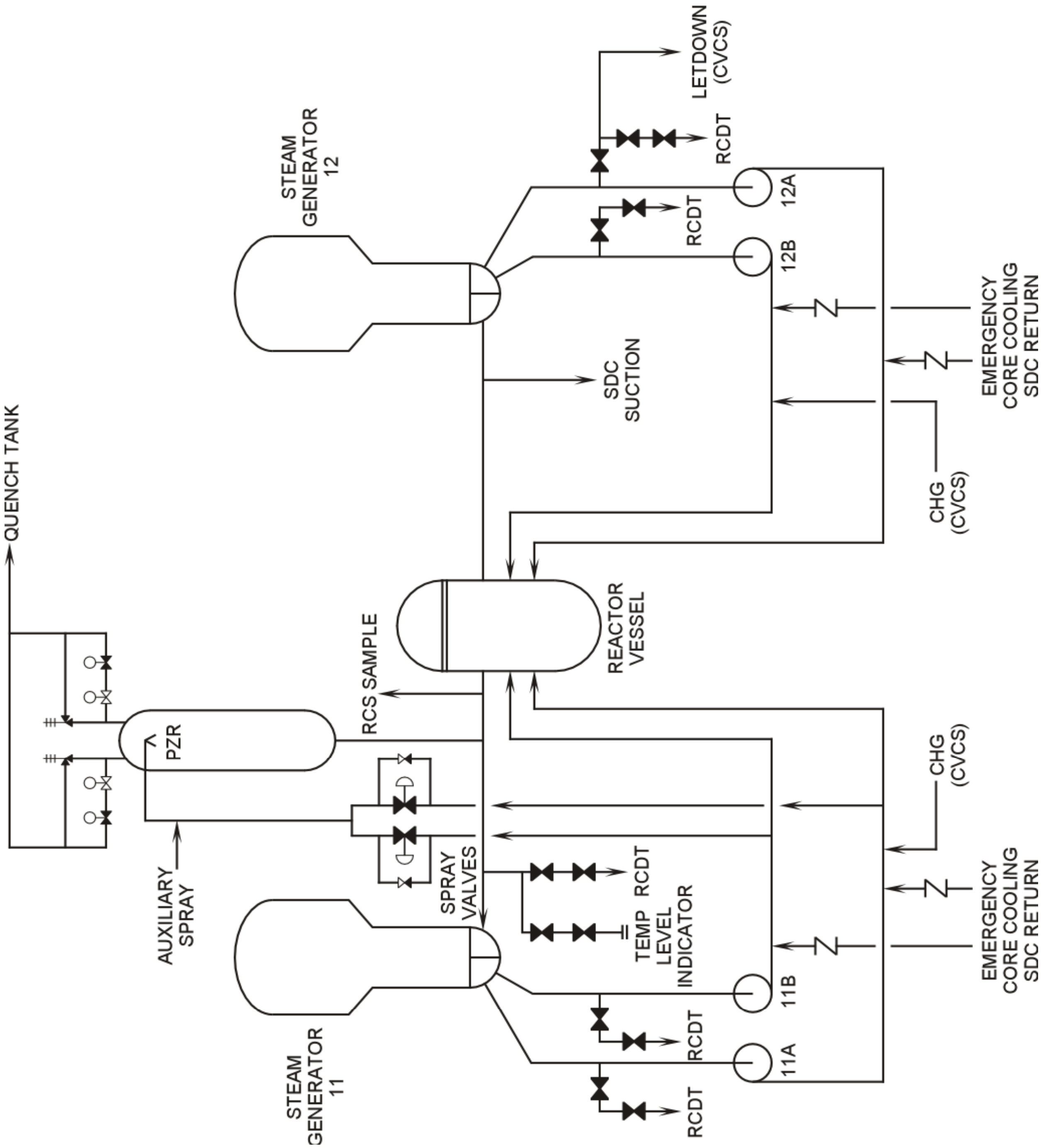

Figure 2.1-4 RCS Flow Diagram

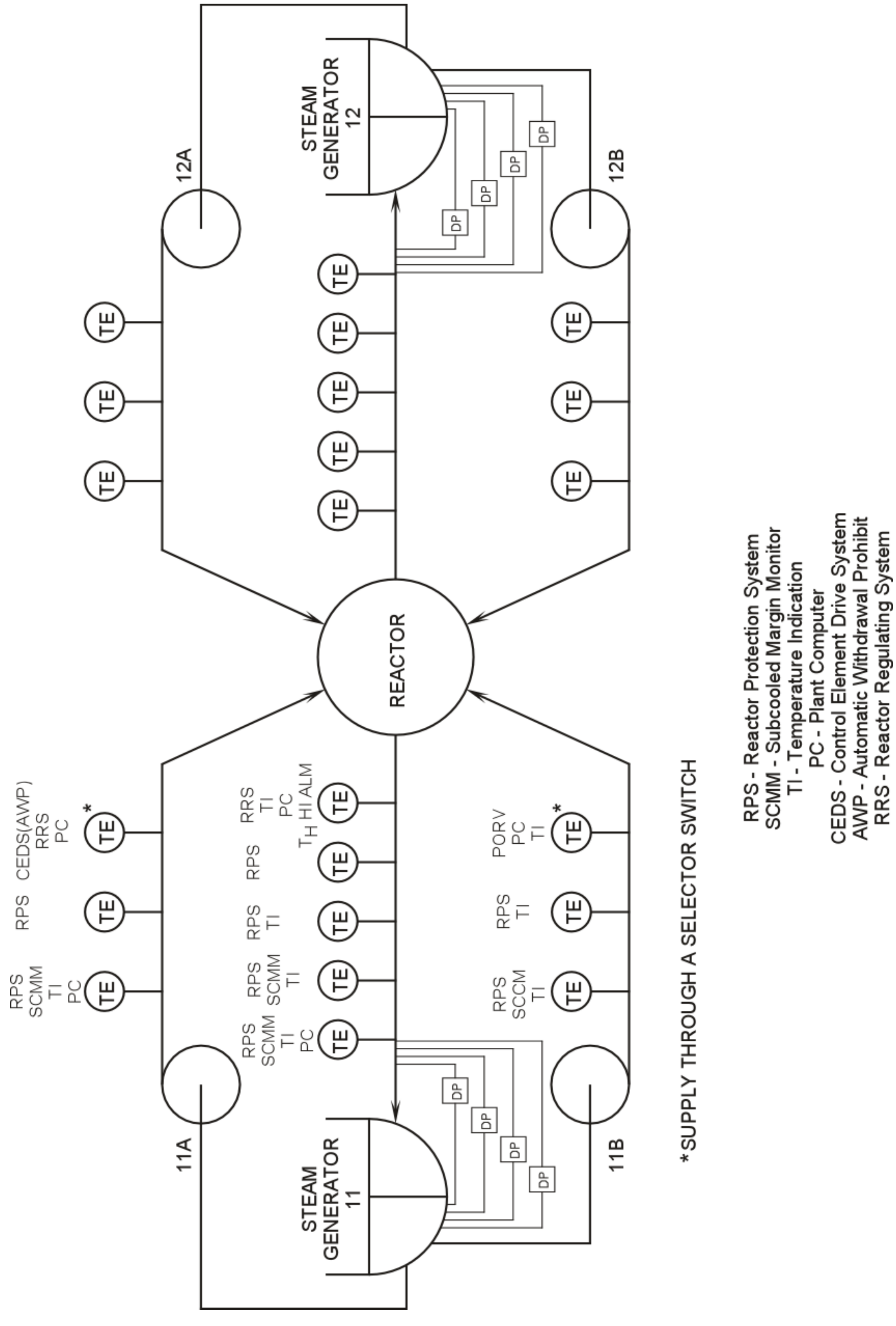

Figure 2.1-5 RCS Instrumentation

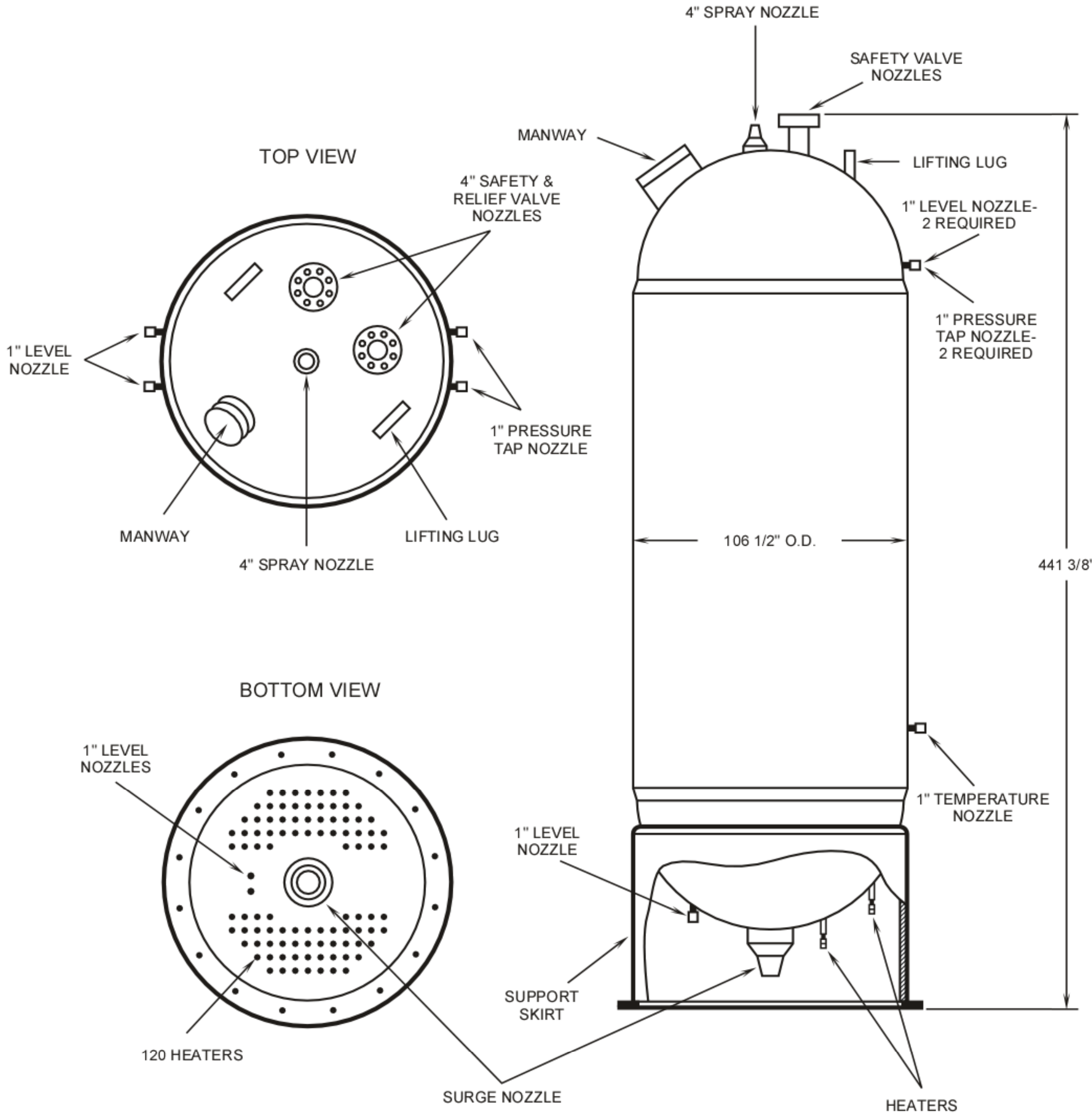

Figure 2.1-6 Pressurizer

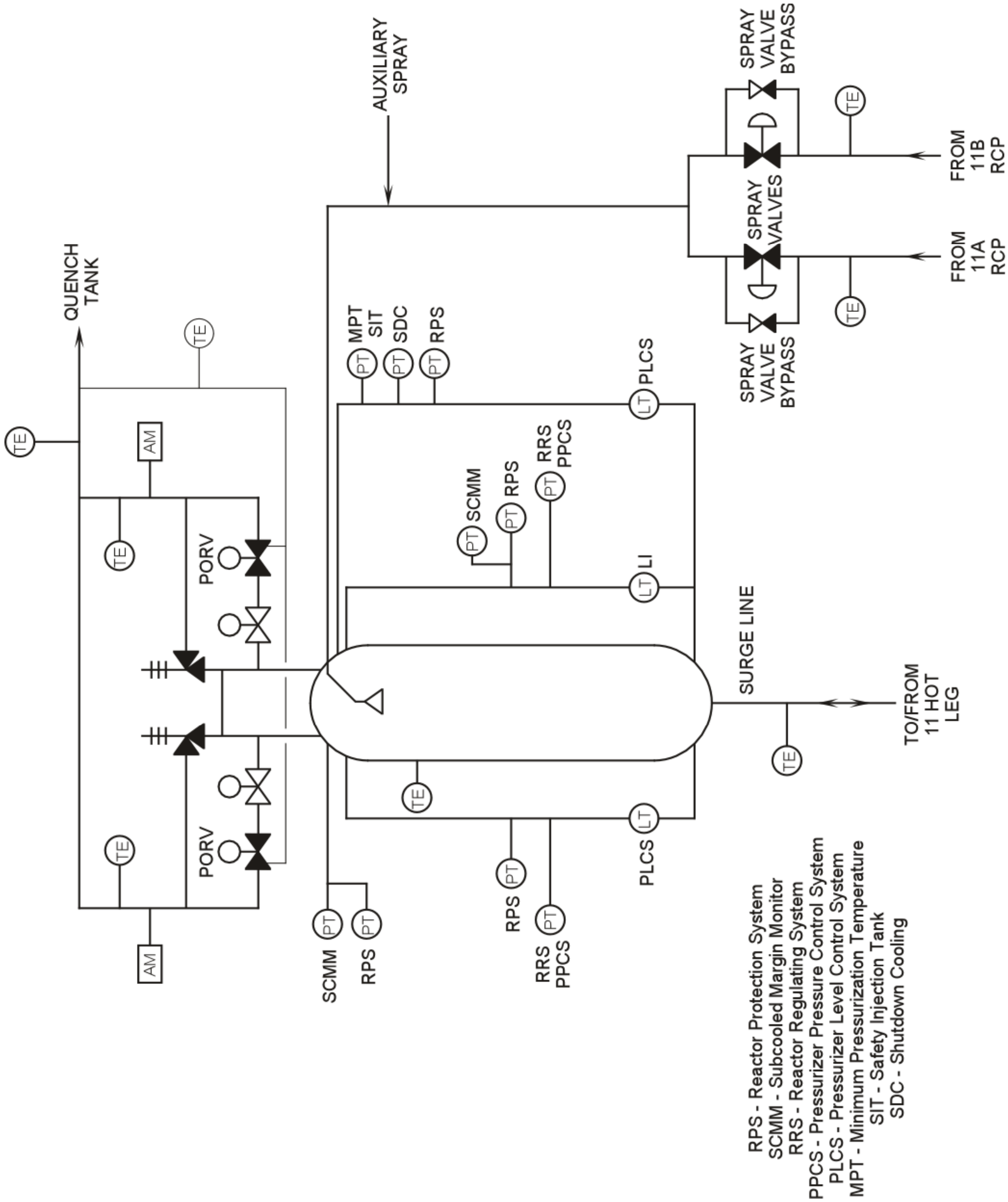

Figure 2.1-7 Pressurizer Piping Diagram

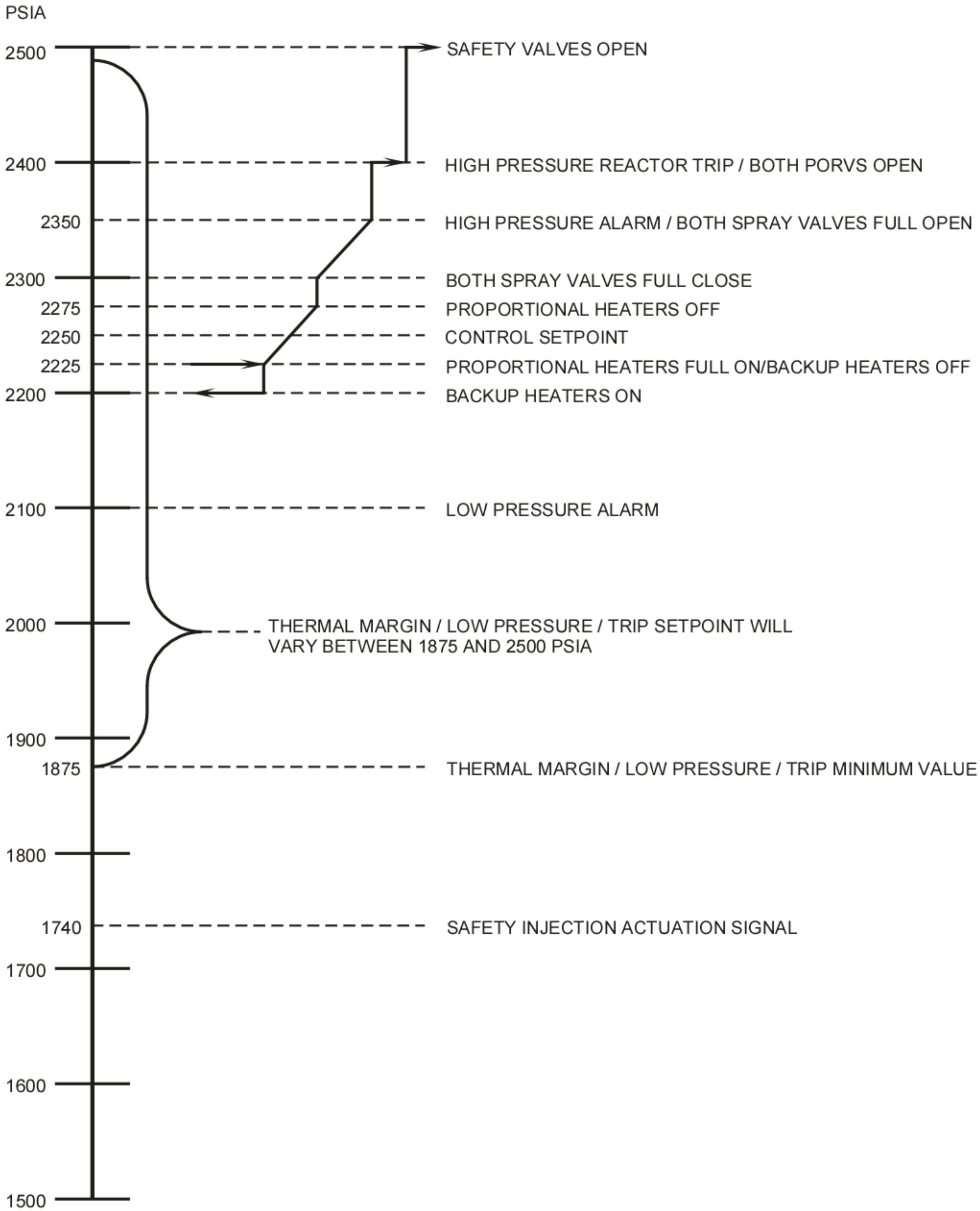

Figure 2.1-8 Pressurizer Pressure Program

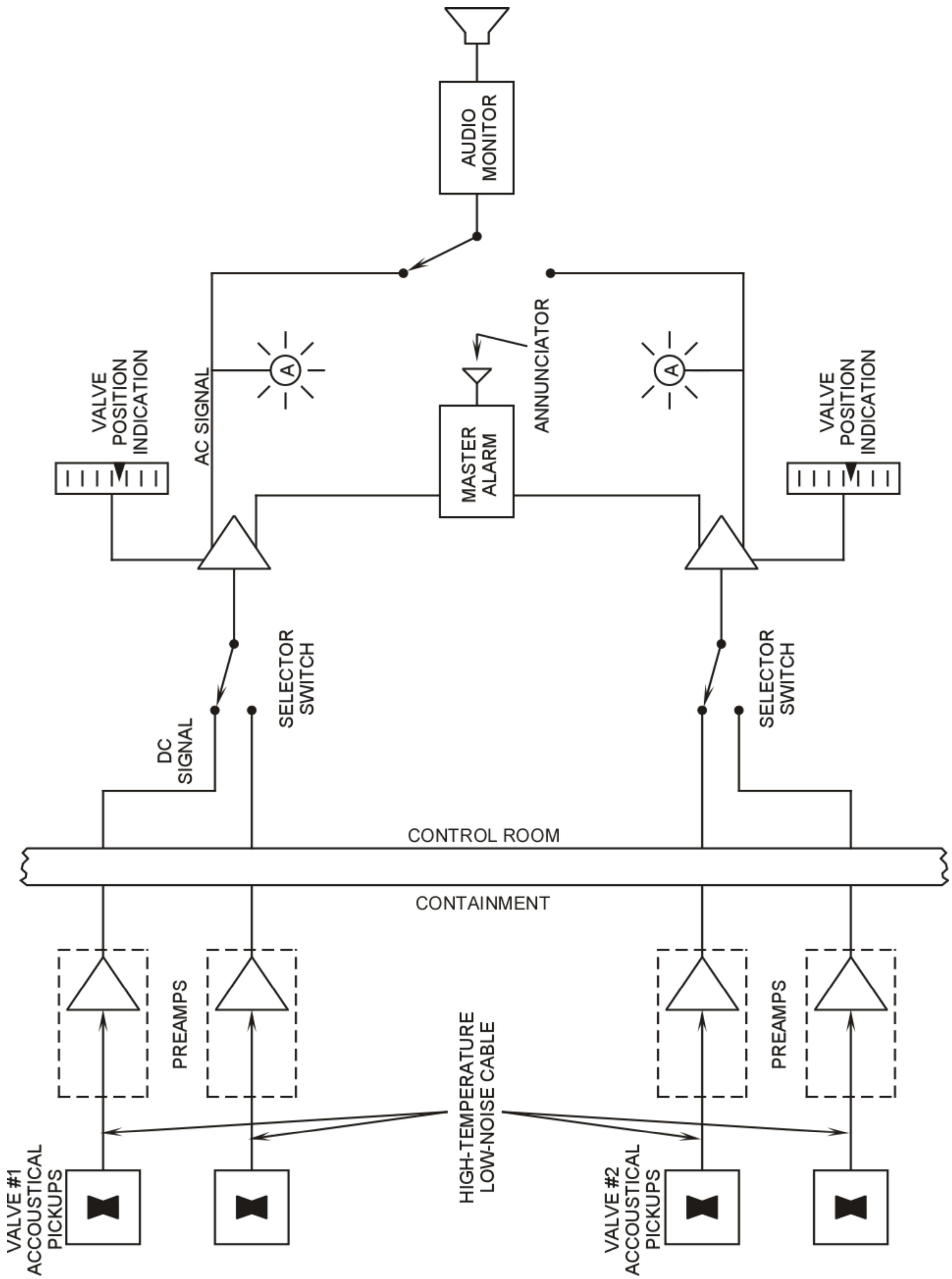

Figure 2.1-9 Acoustical Valve Monitoring

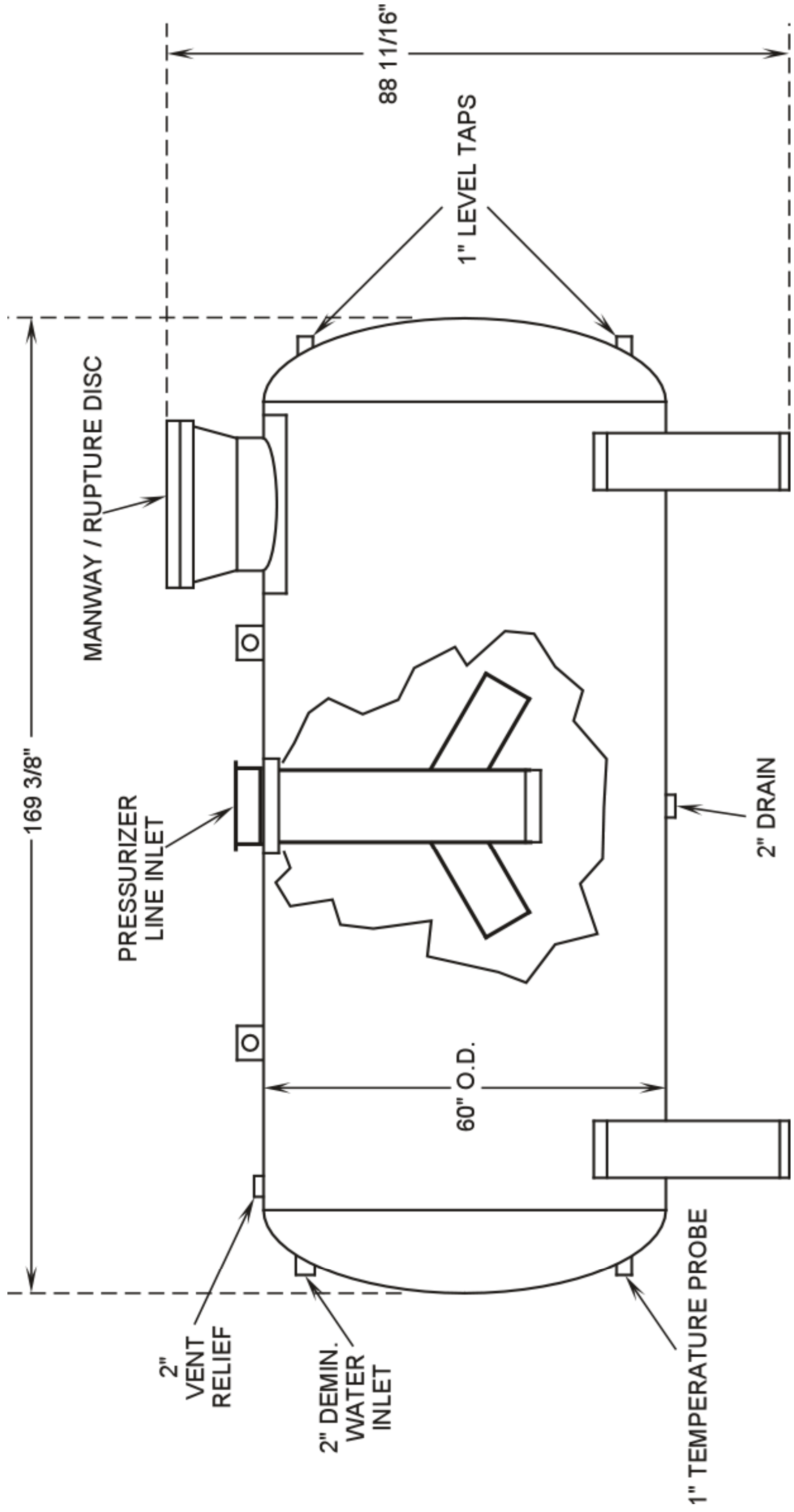

Figure 2.1-10 Quench Tank

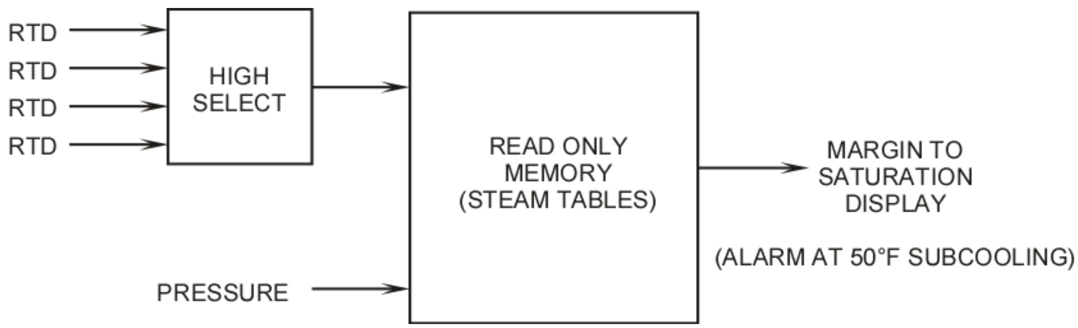

Figure 2.1-11 Saturation Monitor

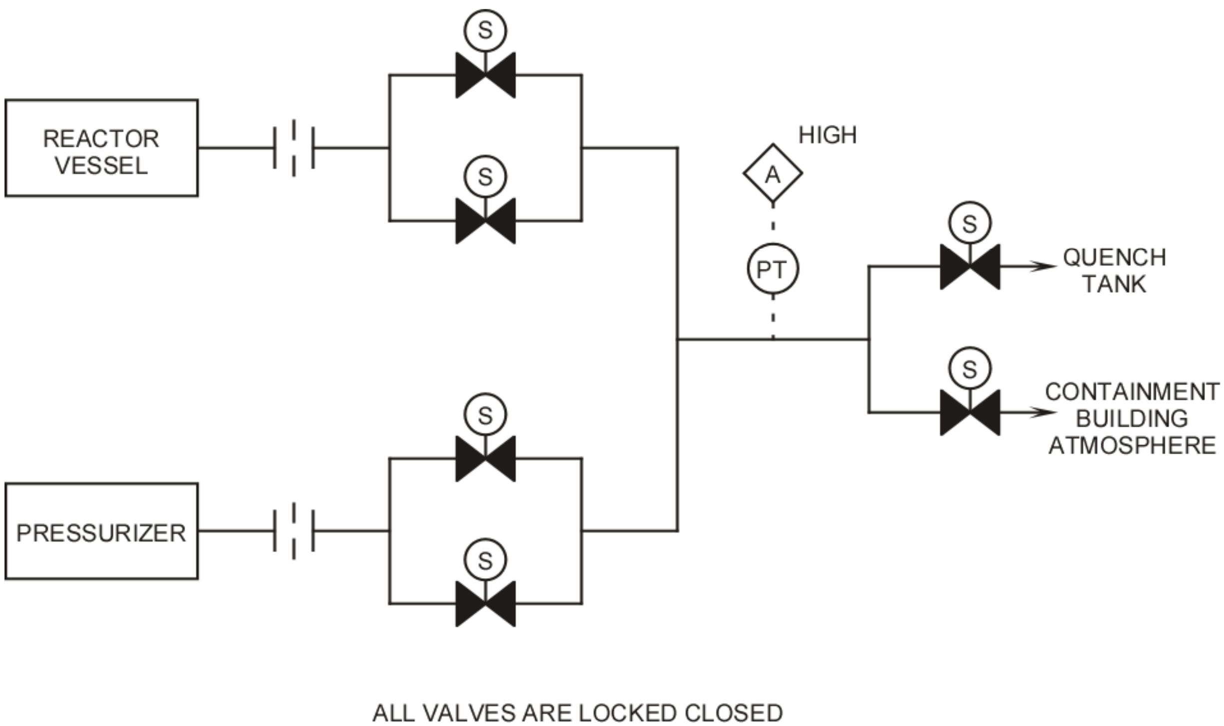

Figure 2.1-12 High Point Vents

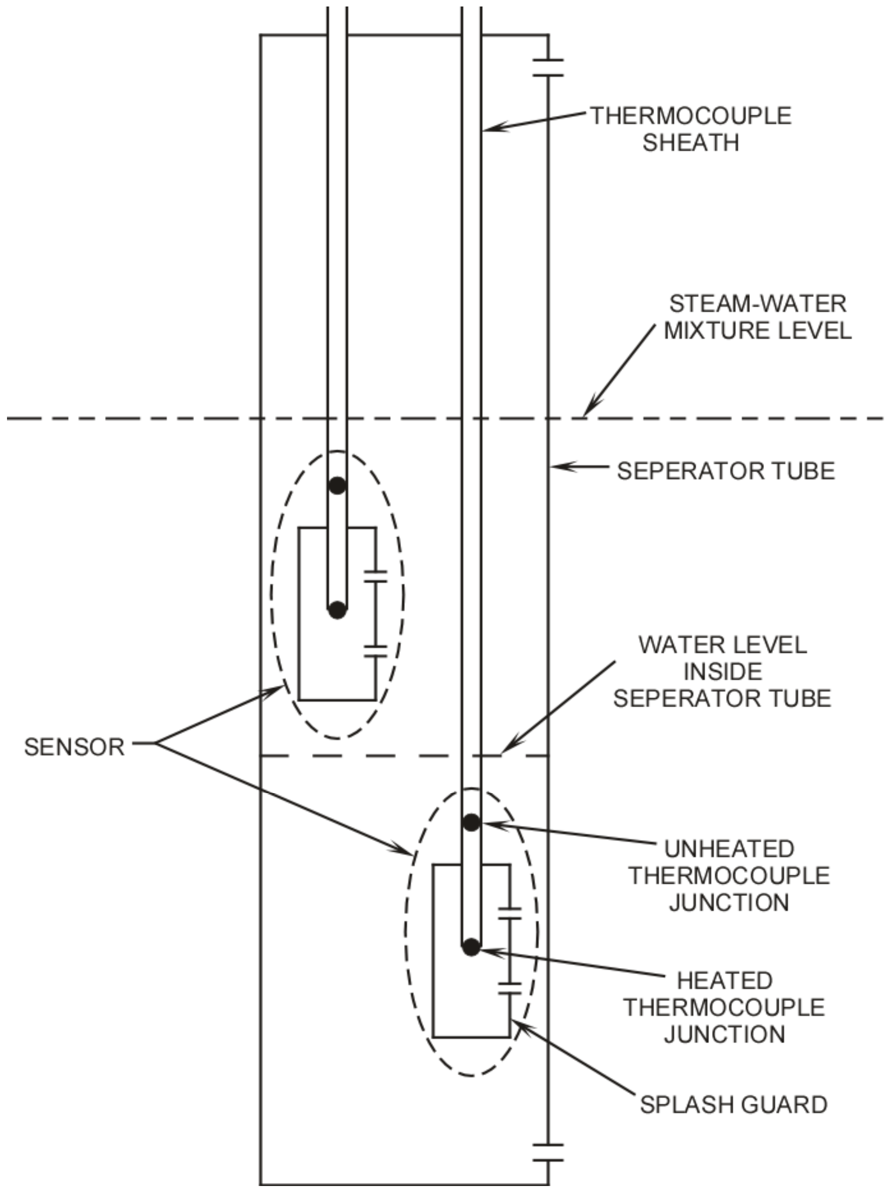

Figure 2.1-13 Reactor Vessel Level Indication