Westinghouse Technology Systems Manual

Section 7.2

Condensate and Feedwater System

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7.2 CONDENSATE AND FEEDWATER SYSTEM

Learning Objectives:

1. List in proper flowpath order and state the purpose of the following condensate and feedwater system components:

   a. Condenser
   b. Condensate (hotwell) pumps
   c. Demineralizers
   d. Low pressure feedwater heaters
   e. Main feed pumps (MFPs)
   f. High pressure feedwater heaters
   g. Feedwater regulating and bypass valves
   h. Feedwater isolation valves (FWIVs)
   i. Steam generators
   j. Startup auxiliary feedwater (AFW) pump
   k. Heater drain system
   l. Condensate storage tank (CST)

2. List the components and connections located in the Seismic Category I portion of the feedwater system piping, and explain the purpose of each.

3. Explain how cascading heater drains increase plant efficiency.

7.2.1 Introduction

The purposes of the condensate and feedwater system are as follows:

1. To transfer water from the main condenser to the steam generators and to preheat it,
2. To collect and distribute heater drains, and
3. To purify secondary water and to maintain secondary chemistry control.

The condensate and feedwater system returns the condensed low pressure turbine exhaust steam from the main condenser to the steam generators. The simplified flow path for this system is shown in Figure 7.2-1. The condensed turbine exhaust steam is collected in the hotwell sections of the main condenser. Each motor-driven condensate (hotwell) pump takes suction on the hotwell and pumps the condensate through the low pressure feedwater heaters. The condensate flow can be directed through the condensate demineralizers. The condensate demineralizers (ion exchangers) remove soluble impurities from the condensate. The low pressure heaters increase the temperature of the condensate before it reaches the suction of the main feedwater pumps.

The turbine-driven feedwater pumps increase the pressure of the condensate, now called feedwater, to a pressure greater than steam generator pressure and direct the feedwater to the steam generators. Before it reaches the steam generators, the feedwater passes through the high pressure feedwater heaters, the feedwater regulating valves, and the feedwater isolation valves. The high pressure heaters provide the final heating of the feedwater, the feedwater regulating valves control the water levels in the steam generators, and the feedwater isolation valves provide the means by which the safety-grade portions of the feedwater system can be isolated from the nonsafety-grade portions during accidents and certain transients. In the steam generators, the feedwater is converted to steam, and the secondary cycle is repeated.

In this section, detailed descriptions of the following topics are provided:

- Condensate system,
- Feedwater system,
- Heater drain system, and
- Secondary chemistry control.

7.2.2 System Description

7.2.2.1 Condensate System

The condensate system preheats, pressurizes, and purifies the condensate collected in the main condenser and transports it to the suctions of the main feedwater pumps. Refer to Figure 7.2-2. The condensate system contains two 70% capacity, motor-driven pumps, the condensate demineralizers, and five stages of low pressure feedwater heating.

The main condenser condenses and collects steam from the low pressure turbine exhaust and/or the steam dump system (Chapter 11.2). The heat sink required to condense the steam is provided by the circulating water system (Chapter 14.3). The circulating water flows through the inside of the condenser tubes, and the exhaust steam is condensed on the outside of the tubes. The condensed steam (condensate) is collected in the three hotwell sections (hotwells A, B, and C) of the main condenser.

The hotwells provide a storage reservoir for the condensate system. This system is shown in detail in Figure 7.2-2. Each of the three condenser hotwells is divided into A train and B train sections. The A and B train sections are interconnected, and the trains are cross-connected at the B condenser hotwell. Each condensate pump takes suction on its associated train of hotwell sections and raises the pressure of the condensate. Downstream of the condensate pumps are connections to the condensate demineralizers.

The condensate demineralizer system consists of eight demineralizers containing filters coated with resin (precoat) as well as systems for removing spent precoat and applying fresh precoat. Refer to Figure 7.2-3. Each demineralizer vessel is a cylindrical tank with a bottom head, 6 ft in diameter and 10.8 ft in overall height. The vessels are made of carbon steel with epoxy phenolic coatings. Each vessel holds 420 nylon filter elements coated with ion exchange resin. The condensate passes through the precoat material first and then through the filters; the condensate is thus purified via ion exchange and filtration. Each vessel can treat 4317 gpm of condensate at 134.5°F and 565 psig.

During normal operation, six vessels contain precoat material consisting of ammonia cation and hydroxide anion resins, while a seventh vessel contains precoat material consisting of hydrogen cation and hydroxide anion resins. The first six vessels are capable of full condensate flow, while the flow through the seventh demineralizer is throttled manually to maintain condensate pH between 9.3 and 9.6. (The eighth demineralizer would be in standby or undergoing replacement of spent precoat.)

The condensate demineralizer system has a flow balancing controller which ensures equal flow through all demineralizers that are maintained in automatic operation. Without flow balancing, the "cleaner" demineralizers would pass more flow than the "dirtier" ones, due to the differential pressures (ΔPs) across the filter elements; eventually all demineralizers would be equally dirty. This condition would necessitate replacement of the precoat in all demineralizers at the same time. As a demineralizer's precoat is exhausted, the conductivity of the vessel contents and the ΔP across the vessel increase. The condensate demineralizer bypass valves will open automatically if the ΔP across any demineralizer exceeds 60 psid.

When demineralizer conditions necessitate precoat replacement, the demineralizer is removed from service. The spent precoat is back washed from the filter elements with water from the CST. The resultant resin-water mixture is drained to the backwash receiver tank for processing. Fresh anion and cation resins are then combined as a slurry and pumped into the demineralizer vessel by the precoat pump.

The demineralizers are not normally in service continuously because morpholine, used to control secondary pH (see Section 7.2.2.4), exhausts demineralizer resin at a high rate. During at-power operation, the demineralizers are placed in service when there are condenser tube leaks or when some contaminant has been introduced into the secondary. Condensate flow through the demineralizers is established on either a single-train or two-train basis by closing either or both of the condensate demineralizer bypass valves. During a startup, condensate (feed) flow is recirculated to the condenser via the demineralizers to establish the appropriate secondary chemistry parameters.

Downstream of the connections to the condensate demineralizer system are five stages of low pressure heaters. Refer to Figure 7.2-2. In each condensate train, the first two stages of heating consist of three parallel paths of two heaters each; the condensate flow then converges and passes through three single-heater stages. The 12 heaters which comprise the first 2 stages of heating are located in the condenser shells. Each train of low pressure heaters can only be isolated at the outlet of the fifth-stage heater. Therefore, in order to repair one heater, all first- through fifth-stage heaters in the associated string must be taken out of service. If a string of heaters is taken out of service, power must be reduced to 70% or less.

All feedwater heaters are U-tube heat exchangers. Refer to Figure 7.2-4. The shells are carbon steel, and the tubes are stainless steel. Steam enters the shell side of each heater, and condensate flows through the U tubes. The steam passes over the tubes and heats the condensate. The condensed steam collects in the drain cooler section of the heat exchanger. The drain cooler is a water-to-water heat exchanger formed within the heater shell by a baffle which envelopes some of the tubes at the condensate (or feedwater) inlet. The condensed heating steam is subcooled there before it drains from the heater. The heater drain system is discussed in Section 7.2.2.3.

The first five stages of feedwater heating increase the condensate temperature from 120°F to 360°F. Heating steam for the first four stages of feedwater heating is supplied by extraction steam from the low pressure turbine. Steam for the first-, second-, third-, and fourth-stage heaters is taken from the eleventh, tenth, eighth, and seventh stages of the low pressure turbines, respectively. Steam for the fifth-stage heaters is taken from the high pressure turbine exhaust. Preheating the condensate (feedwater) results in an efficiency gain of approximately 15% over non-preheating systems.

The discharges of the low pressure heater trains are cross-connected by a 16-in. header. The heater drain pumps also discharge to this header. The combined condensate and heater drain flow provides the suction for the main feed pumps.

7.2.2.2 Feedwater System

The feedwater system preheats and pressurizes the discharge from the condensate system and the heater drain pumps and transports it to the steam generators. The feedwater system extends from the feed pump suction valves to the inlets of the steam generators. Refer to Figure 7.2-5. The feedwater system includes two 70% capacity, variable speed, turbine-driven pumps and two trains of high pressure feedwater heaters.

The MFPs discharge to the high pressure feedwater heaters via cross-connected headers. The high pressure heaters consist of two trains of two heaters each. The high pressure heaters are U-tube heat exchangers constructed of carbon steel shells and stainless steel tubes. The heaters have integral drain coolers and a tube-side (feedwater) design pressure of 1700 psig. The feedwater temperature is raised from 360°F to 397°F in the sixth-stage heaters and to 440°F in the seventh-stage heaters. The extraction steam supplying these heaters is taken from the fourth stage of the high pressure turbine for the sixth-stage heaters and from the second stage of the high pressure turbine for the seventh-stage heaters. One high pressure feedwater heater string can be isolated, provided that plant power is first reduced to 95% or less.

Feedwater from the high pressure heater trains flows into a common 30-in. feed header. This common header contains a pressure transmitter (PT-508) which provides indication on the main control board and an input to the MFP speed control system. The header also contains a recirculation line to the main condenser. This line directs recirculation of feedwater for demineralization, deaeration, and filtration of the feedwater during plant startups. The recirculation line isolation valve is shut during normal at-power operation.

The common feed header splits into four 14-in. feed lines which supply the individual steam generators. Each feed line contains a 14-in. feedwater regulating valve and a 6-in. bypass valve in parallel. Each feedwater regulating valve has an automatic control system which is discussed in detail in Chapter 11.1. The bypass valves are operated manually. Immediately downstream of each feedwater regulating and bypass valve is a feedwater isolation valve (FWIV).

From the first piping restraints upstream of each set of FWIVs to the steam generator feedwater inlet, the feedwater piping is Seismic Category I. Downstream of the feedwater isolation valves, each feed line contains a flow venturi with two flow transmitters. The function of the flow transmitters is discussed in Chapter 11.1. Downstream of each venturi is a check valve. The check valve prevents the loss of steam generator inventory through an upstream feedwater system break. Downstream of the check valve are connections for shutdown chemistry addition and for auxiliary feedwater entry.

7.2.2.3 Heater Drain System

The heater drain system collects condensed steam from the moisture separator reheaters (MSRs) and from the high and low pressure feedwater heaters and returns it to the condensate and feedwater system. Refer to Figures 7.2-6 and 7.2-7.

The drains from the seventh-stage heaters are cascaded or drained to the sixth-stage heaters, which in turn drain to the fifth-stage heaters. The cascading effect ends with the fifth-stage heaters; they drain to the heater drain tanks. Two heater drain pumps transport the collected drains from the heater drain tanks to the condensate system cross-connect header downstream of the low pressure heaters. During full-power operation, the heater drain pumps supply about one third of the total flow at the suctions of the MFPs. Plant power is limited to 90% with only one operating heater drain pump.

The drains from the low pressure heaters are also cascaded. The fourth-stage heaters drain to the third-stage heaters, the third-stage heaters drain to the second-stage heaters, the second-stage heaters drain to the first-stage heaters, and the first-stage heaters drain to the main condenser. The cascading of heater drains improves secondary plant efficiency by allowing the repeated use of relatively hot water for feedwater heating; if each heater were to drain directly to the condenser, a great deal of energy would be lost from the system. Preheating of the feedwater by extraction steam and heater drains means that nearly all of the energy transferred to the feedwater in the steam generators by the reactor coolant system is added as the latent heat of vaporization; comparatively little sensible heating is required to bring the feedwater to saturation.

7.2.2.4 Steam Generator Chemistry Control

During plant operation the control of steam generator chemistry is accomplished by the purification of condensate, by the injection of chemicals into the condensate system to scavenge oxygen and to control pH, and by steam generator blowdown.

Purification of the condensate is performed by the condensate demineralizer system through the ionic exchange process. Ionic impurities (from condenser tube leaks, poor-quality makeup water, etc.) in the condensate system are removed on an as-needed basis by placing the demineralizers in service.

Chemical injection of hydrazine (N_2H_4) for oxygen control and morpholine (C_4H_9NO) for pH control contributes to steam generator chemistry control by minimizing corrosion. Morpholine injection is secured when the condensate demineralizer system is placed in service, and secondary pH is affected by hydrazine addition only (some of the hydrazine decomposes into ammonia [NH_3], a weak base). These chemicals are pumped into a low temperature portion of the condensate system just downstream of the demineralizer system connections (see Figure 7.2-2) to prevent the breakdown of hydrazine. Separate connections for shutdown chemical addition are immediately upstream of the feedwater containment penetrations (see Figure 7.2-5). The volatility of the chemical treatment prevents undesirable chemical concentrations in the steam generators.

Each steam generator acts as a chemical concentrator. The boiling of the feedwater leaves concentrated impurities in the steam generator, which are removed by the steam generator blowdown system. The blowdown system, as shown in Figure 7.2-8, consists of blowdown taps from each steam generator, isolation valves, blowdown flow control valves, a blowdown tank, a heat exchanger, a pump, blowdown ion exchangers and filter, a radiation monitor, and piping for blowdown discharge to the condenser and to the environment.

The function of the steam generator blowdown system is to maintain the steam generator secondary-side water within the chemical specifications prescribed, while treating the blowdown for return to the condenser. Primarily, the steam generator blowdown system will remove impurities that come from sources such as primary-to-secondary leakage, main condenser leakage, and corrosion products.

The blowdown flow rate from each of the four steam generators is individually, manually controlled (100 gpm maximum per steam generator). The blowdown water entering the blowdown tank undergoes a pressure drop across the blowdown flow control valves; some of the water flashes to steam. Most of the steam is condensed by the water in the tank, the rest is directed to the condenser (< 50% power), to feedwater heater 3B (> 50% power), or to the atmosphere (condenser not available). The liquid effluent from the blowdown tank is cooled in the blowdown heat exchanger (service water is the heat sink), purified, and filtered before being discharged to the condenser or to the environment.

7.2.3 Component Descriptions

7.2.3.1 Condensate System Components

Main Condenser

The main condenser is a single-pass, three-shell, multipressure, deaerating, surface condenser. Each shell is located below one of the three low pressure turbines. The condenser tubes are arranged in bundles which cross the condenser shells perpendicular to the longitudinal axis of the main turbine. Refer to Figure 7.2-9.

Each condenser shell is connected to its associated low pressure turbine's outer casing by an expansion bellows, which isolates turbine expansion and vibration from the condenser. The first- and second-stage feedwater heaters are located in the upper portion of each condenser shell just below the entry of turbine exhaust. This area of the condenser shell is called the neck. Each of the low pressure heater trains has first- and second-stage heaters located inside each condenser shell. Each pair of first- and second-stage heaters is installed within a single shell, so that each condenser shell actually contains two heater shells. This arrangement saves floor space, reduces the insulation required for the heaters, and allows shorter piping runs. Below the low pressure heaters are the tube bundles.

The main condenser tubes are constructed of titanium, which is virtually impervious to corrosion. (The condensers at several plants have been retrofitted with titanium tubes for improved corrosion performance.) Each of the approximately 60,000 tubes is 1.25 in. in diameter; tube lengths vary between condenser shells. A different pressure is maintained in each of the three shells. The shells are designed to operate at the following pressures at full power: 3.30 in. Hg for the low pressure (A) shell, 4.00 in. Hg for the intermediate pressure (B) shell, and 5.11 in. Hg for the high pressure (C) shell. The interconnected hotwells below the three shells are maintained at a pressure of 6.73 in. Hg.

Circulating water flows through the three condenser shells in series, entering first the low pressure shell, then the intermediate pressure shell, and finally the high pressure shell. Refer to Figure 7.2-10. The circulating water is heated as it flows through the shells. In order to maintain the heat transfer capability of each condenser shell approximately equal, the heat transfer surface area increases in the direction of circulating water flow. Each shell has the same number of tubes; different heat transfer areas are accomplished with different tube lengths. The tube lengths are 35 ft in the low pressure shell, 45 ft in the intermediate pressure shell, and 55 ft in the high pressure shell. The total heat transfer surface area of the condenser is approximately 900,000 ft^2. The tubes are supported by divider plates spaced along their length. The tubes are welded to tube sheets attached to the inlet and outlet water boxes.

At the center of each tube bundle is a gas collecting space. Noncondensible gases are directed across the relatively cold central tubes and then routed through air off-take piping that penetrates the inlet water boxes. The air off-take pipes of the three shells are connected in parallel. Noncondensible gases are then directed to the suctions of the air ejector assemblies. If gases were not removed, a reduction in vacuum and a loss of turbine efficiency would result.

Gases leaking into the condenser or being stripped from the condensate can blanket the condenser tubes. This would reduce the heat transfer capability of the condenser. The condenser air removal system removes air and noncondensible gases from the condenser shells. During plant startups the three hogging air ejectors draw air from the condenser shells to establish the initial condenser vacuum. During plant operations one or both of the main air ejector assemblies maintain a minimum condenser vacuum of 25 in. Hg. Refer to Figure 7.2-11.

The air ejectors are jet pumps supplied with main steam through a reducing valve. The two 100% capacity, two-stage main air ejector assemblies exhaust to the turbine roof via inter and after condensers and the off-gas system. Conductivity monitors are placed on the inter and after condenser drains to detect condenser tube leaks. A radiation monitor samples gases in the off-gas system prior to their release above the turbine building roof, and gases can be directed through a charcoal adsorber if necessary. The 1200-scfm, single-stage hogging air ejectors exhaust directly to the atmosphere outside the turbine building.

Condensed water in the condenser shells collects below the tube bundles on intermediate bottom plates in the hotwells. Refer to Figure 7.2-12. Condensers A and B have two such plates, which form intermediate and lower hotwell sections, while condenser C has only one. At each intermediate bottom plate, the condensate flows into sumps which contain heatup devices, each of which is a series of perforated plates. The plates break up the condensate into droplets which are heated as they fall through steam. In the lower hotwell section of each condenser, the steam is provided by feed pump turbine exhaust. The feed pump turbine exhaust is piped to the lower hotwell of condenser C first and then to the lower hotwells of the other two condensers via steam crossover piping. Some of the feed pump turbine exhaust steam is directed from the condenser C lower hotwell into the condenser C shell. Similarly, heating steam from the condenser C shell is supplied to the intermediate hotwells of the other two condensers via crossover piping. The steam passages are sized and orificed so that, at design load and circulating water temperature, the appropriate pressures are maintained in the various sections of the condensers.

The lower hotwell of each condenser is divided into train A and train B sections by a longitudinal plate. The train A sections are interconnected, as are the train B sections. The longitudinal plate in the B condenser hotwell has a hole to equalize the levels in the two hotwell sections. Condenser B has separate train A and train B hotwell level control systems, only one of which is in service at any time due to the level balancing in the B condenser hotwell described above. As the other condenser hotwells are connected to the condenser B hotwell, controlling the B hotwell level provides control of the entire condenser hotwell inventory. Inventory control is discussed in more detail in Section 7.2.3.5. The train A and train B condensate pumps take suction on the condenser B train A and train B hotwell sections, respectively.

Condensate (Hotwell) Pumps

Two condensate pumps take suction on condenser B through suction strainers and manual isolation valves. The pumps are eight-stage, vertical, centrifugal pumps driven by 3950-hp motors. The pumps are powered from 12.47-kVac service buses. The thrust and upper guide bearings of the pump motors are oil lubricated; the motor oil coolers are cooled by the bearing cooling water system. Each pump's lower radial bearing is grease lubricated and air cooled. Cooling water for the condensate pump shaft seals is supplied by the condensate transfer pumps. Each condensate pump supplies 11,000 gpm with 1100 ft of head (approximately 477 psi).

The discharge of each pump is provided with a recirculation line to the hotwell of condenser B to protect the pump from overheating. The recirculation valve in each line is controlled as a function of the associated pump's discharge flow. Each valve opens with a discharge flow rate of 3500 gpm and closes with a flow rate of 7000 gpm. The recirculation valves are automatically opened by a feedwater isolation signal.

Operation with the condensate demineralizers bypassed causes an increase in the discharge pressure of the condensate pumps due to the reduced flow resistance. The increased pressure at the discharge of the heater drain pumps decreases the flow from the heater drain tank, resulting in the loss of heater drain tank level control. To avoid this effect, with the demineralizers bypassed the recirculation valve for one condensate pump is manually opened about 50%, thereby reducing condensate pump discharge pressure and increasing heater drain pump flow.

The discharge of each pump is equipped with a motor-operated isolation valve, which is manually operated from the main control board. The isolation valve is closed when the pump is off and opened after the pump is started. Downstream of the discharge isolation valves and the discharge flow elements, the condensate trains are cross-connected by a 24-in. line. The discharge of each pump can be aligned to the condensate demineralizer system. The discharge of condensate pump B also supplies the MFP seal water system and the heater drain pump seals.

7.2.3.2 Feedwater System Components

Main Feedwater Pumps

The MFPs are horizontal, single-stage, centrifugal pumps, each coupled to a nine-stage impulse turbine. Each pump has a dedicated lubricating oil system for its bearings. Each pump has a variable capacity up to 19,800 gpm with a discharge head of 2020 ft. Each pump can support operation up to 70% of main turbine load. An independent speed controller, operated automatically or manually, is provided for each pump. The turbine speed is varied to maintain a programmed ΔP across the feedwater regulating valves. The MFP speed control program is discussed in Chapter 11.1.

Each MFP turbine is supplied with steam from the main steam bypass header during startups and low-load operations and with reheated steam from one MSR during normal operation at higher loads. Steam is supplied via a dual control valve system, with one control valve from each steam supply.

The control valve from the main steam (high pressure) supply does not begin to open until the control valve from the MSR (low pressure) supply is fully open. During low-load and startup conditions, both turbine control valves are open, with the main steam supply controlling MFP speed. At higher load conditions, the MSR supply pressure will be high enough to handle any demands on the MFPs, and the main steam supply control valve for each pump will be fully shut.The MFPs are equipped with protective trips, some of which trip an individual pump and some of which trip both pumps. The following is a list of individual MFP trips:

- Low lubricating oil pressure (5 psig),
- Turbine overspeed (5850 rpm),
- Low turbine exhaust vacuum (20 in. Hg),
- High turbine exhaust temperature (230°F),
- Excessive thrust bearing wear,
- High discharge pressure (1850 psig),
- Suction isolation valve not fully open, and
- Associated condensate pump trip.

Any of the following conditions will cause a trip of both MFPs:

- Engineered safety features actuation signal,
- High steam generator level (69.0%), as sensed by two out of three level detectors on any steam generator, and
- Low suction pressure (195 psig).

Each MFP has a recirculation line to condenser C. The lines ensure minimum flow through the pumps. The minimum flow valves are automatically controlled by suction flow transmitters. Each recirculation valve opens when the flow through its associated pump drops to less than 4000 gpm, and it closes when the flow increases above 9000 gpm. The recirculation valves automatically open with a feedwater isolation signal.

Feedwater Isolation Valves (FWIVs)

Immediately downstream of each feedwater regulating valve and each bypass valve is an FWIV. (An FWIV for each regulating and bypass valve is specific to the Trojan plant design; Westinghouse design plants more typically have one FWIV for each steam generator, i.e., one FWIV for each regulating valve/bypass valve pair.) The valves have hydraulic operators; a nitrogen-charged accumulator supplies the hydraulic fluid for each valve. Each accumulator is capable of one closure and one opening of its associated FWIV before hydraulic pressure is restored. The valves have a maximum closing time of 16 seconds.

The FWIVs are automatically closed by a feedwater isolation signal, which is generated by any of the following:

- High steam generator level (69.0%), as sensed by two out of three level detectors on any steam generator,
- Engineered safety features actuation signal, and
- Reactor trip (P-4) and low T_{avg} (564°F), as sensed in two out of four reactor coolant loops.

Each FWIV can also be manually opened or closed at a control panel in the turbine building. (Controls for the FWIVs are more typically located in the main control room at a Westinghouse design plant.)

7.2.3.3 Startup Auxiliary Feedwater Pump

To avoid wear and tear on the safety-grade auxiliary feedwater (AFW) pumps, a nonsafety-grade startup AFW pump provides feed flow to the steam generators during normal startups and shutdown periods, when main steam and MSR steam are not available. The 1250-hp, motor-driven, eight-stage centrifugal pump supplies 1020 gpm (including 140 gpm of recirculation flow) at a discharge head of 3400 ft (1472 psi). The pump has no automatic start features. It is normally powered from a plant service bus but can be aligned to diesel generator A.

The startup AFW pump takes suction on the condensate storage tank and discharges to the discharge line of either the diesel-driven or turbine-driven AFW pump. Refer to Figure 7.2-13. An isolation valve for each discharge path is provided; one must be shut during operation of the startup AFW pump to ensure separation of the two safety-grade AFW trains. Upstream of the discharge isolation valves is a manually or automatically controlled flow control valve. In automatic, the control system throttles flow to maintain a selected ΔP between the pump discharge and steam generator C. The normal setpoint is 100 psid.

7.2.3.4 Heater Drain System Components

The heater drain system collects the condensate from the feedwater heaters and MSRs and returns it to the condensate and feedwater system. Refer to Figures 7.2-6 and 7.2-7. The system consists of six drain tanks for the two MSRs and associated piping, the feedwater heater shells and associated piping, two heater drain tank pumps, and two heater drain tanks.

Moisture Separator Reheater Drains

Each MSR has three drain tanks: one for the condensate from the first-stage heater tubes (first-stage reheater drain tank), one for the condensate from the second-stage heater tubes (second-stage reheater drain tank), and one for the condensate from the MSR shell (moisture separator drain tank). These drain tanks are located below the MSR shells and function to provide a seal between the high pressure steam in the MSRs and the lower pressure feedwater heater shells or heater drain tanks to which they drain. Each drain tank has a level control system to maintain the water seal.

The second-stage reheater drain tanks receive the condensate from the MSR second-stage reheater tubes. These tanks normally drain to the seventh-stage feedwater heater shells. The drain flow from each tank is automatically controlled to maintain tank level. The level control valve closes automatically on a high level in the associated seventh-stage heater shell, regardless of tank level. A high drain tank level causes its alternate drain valve to open, allowing the tank to drain to one of the heater drain tanks.

The first-stage reheater drain tanks receive the condensate from the MSR first-stage reheater tubes. These tanks normally drain to the sixth-stage feedwater heater shells. The drain flow from each tank is automatically controlled to maintain tank level. The level control valve closes automatically on a high level in the associated sixth-stage heater shell, regardless of tank level. A high drain tank level causes its alternate drain valve to open, allowing the tank to drain to one of the heater drain tanks.

The moisture separator drain tanks receive drains from the MSR shells. This condensate is the moisture removed from the cold reheat steam by the chevron separators in the MSRs. The drain flow into each tank is about 1.5×10^6 lbm/hr at 100% load. These tanks normally drain to the heater drain tanks. The drain flow from each moisture separator drain tank is automatically controlled to maintain tank level. A high moisture separator drain tank level causes its alternate drain valve to open, allowing the tank to drain to condenser A.

Each of the six MSR drain tanks is vented to the source of the drains to remove noncondensible gases.

High Pressure Heater Drains

The seventh-stage heater shells receive heating steam from the second stage of the high pressure turbine and drains from the second-stage reheater drain tanks. These heaters normally drain to the sixth-stage heater shells. The drain flow from each seventh-stage heater is automatically controlled to maintain shell level. The level control valve closes automatically on a high level in the associated sixth-stage heater shell, regardless of the seventh-stage shell level. A high shell level causes the heater's alternate drain valve to open, allowing the heater to drain to a heater drain tank. A very high shell level causes the drain and extraction steam inlets to the heater to isolate.

The sixth-stage heater shells receive heating steam from the fourth stage of the high pressure turbine and drains from the first-stage reheater drain tanks and seventh-stage heaters. These heaters normally drain to the fifth-stage heater shells. The drain flow from each sixth-stage heater is automatically controlled to maintain shell level. The level control valve closes automatically on a high level in the associated fifth-stage heater shell, regardless of the sixth-stage shell level. A high shell level causes the heater's alternate drain valve to open, allowing the heater to drain to a heater drain tank. A very high shell level causes the drain and extraction steam inlets to the heater to isolate.

The fifth-stage heater shells receive heating steam from high pressure turbine exhaust and drains from the sixth-stage heaters. These heaters have no drain coolers and drain directly to the heater drain tanks without level control. A very high fifth-stage shell level causes the drain and extraction steam inlets to the heater to isolate.

Heater Drain Tanks and Pumps

The heater drain tanks are horizontal 13,120-gal tanks. Each tank normally receives drains from its associated fifth-stage heater and moisture separator drain tank. Each tank also receives alternate drains from the associated sixth- and seventh-stage heaters and first- and second-stage reheater drain tanks. Each tank is designed for 220 psig and 400°F. The tanks are cross-connected by a 20-in. line. A dump valve which taps off the cross-connection drains the tanks to condenser A on a high level in either tank.

Each heater drain pump takes suction on one of the heater drain tanks. The pumps are canned-suction, vertical, centrifugal pumps rated at 5950 gpm and 575 psig. The pumps are powered from station service buses. The heater drain pump seals are supplied with cooling water from the condensate pumps.

A heater drain tank level control system maintains levels in the tanks by controlling the heater drain pump discharge valves. If the combined pump discharge flow is less than 2400 gpm, the recirculation lines to the heater drain tanks open to prevent pump overheating. The pumps discharge into a combined header which taps into the condensate cross-connect header just upstream of the MFP suctions.

Low Pressure Heater Drains

The control of inputs to and outputs from the low pressure heaters is similar to that of the high pressure heaters. The fourth-stage heater shells receive heating steam from the seventh stage of the low pressure turbines. These heaters normally drain to the third-stage heater shells. The drain flow from each heater is automatically controlled to maintain shell level. The level control valve closes automatically on a high level in the associated third-stage heater shell, regardless of the fourth-stage shell level. A high shell level causes the heater’s alternate drain valve to open, allowing the heater to drain to condenser C. A very high shell level causes the extraction steam inlet to the heater to isolate.

The third-stage heater shells receive heating steam from the eighth stage of the low pressure turbines and drains from the fourth-stage heaters. Each heater normally drains to the three second-stage heater shells of the same condensate train. The drain flow from each heater is automatically controlled to maintain shell level. The level control valve closes automatically on a high level in any of the associated second-stage heater shells, regardless of the third-stage shell level. A high shell level causes the heater’s alternate drain valve to open, allowing the heater to drain to condenser C. A very high shell level causes the extraction steam and drain inlets to the heater to isolate.

As discussed in the main condenser description, each pair of first-and second-stage heaters is contained within a single shell, with the heaters separated by a longitudinal partition plate. These heaters are located in the necks of the three condenser shells. There are a total of 6 pairs of first- and second-stage heaters (12 heaters total), one from each condensate train in each condenser shell.

Each second-stage heater shell receives heating steam from the tenth stage of one low pressure turbine and about one third of the drains from its associated third-stage heater. Each heater normally drains to the first-stage heater with which it is paired. The drain flow from each heater is automatically controlled to maintain shell level. The level control valve closes automatically on a high level in its associated first-stage heater shell, regardless of the second-stage shell level. A high shell level causes the heater’s alternate drain valve to open, allowing the heater to drain to the condenser shell in which it is situated. A very high shell level causes the drain inlet to the heater to isolate.

Each first-stage heater shell receives heating steam from the eleventh stage of one low pressure turbine and drains from its associated second-stage heater. Each heater normally drains to the condenser shell in which it is situated. The drain flow from each heater is automatically controlled to maintain shell level. A high shell level causes the heater's alternate drain valve to open, which bypasses the normal level control valve. A very high shell level causes the drain inlet to the heater to isolate.

The first- and second-stage heaters do not have isolation valves for the incoming extraction steam. The extraction steam supplies to these heaters are equipped with check valves designed to prevent reverse steam flow from the heaters to the low pressure turbines. A large condensate tube leak could cause inflow to a heater shell in excess of the capacities of the normal level control and alternate drain valves. In such an instance, water could back up into the extraction steam supply piping and leak past the check valve, causing damage to the affected low pressure turbine. When the rate of tube leakage to a heater shell exceeds the drain capacity, the condensate flow to that heater (and thus to the entire condensate train) must be isolated to prevent turbine damage.

7.2.3.5 Condensate Storage Tank (CST)

The CST is the source of makeup water for the condensate and feedwater system and also the primary source of water for the AFW system. The CST is a covered, outdoor storage tank with a capacity of 450,000 gal. Technical Specifications require a minimum stored volume of 239,000 gal, which accounts for 27,700 unusable gal in the bottom of the tank and a 14,400-gal allowance for level instrument error. This volume ensures that there is a sufficient supply for the AFW system to maintain the plant in hot standby for two hours and then to cool down the plant to 350°F in four hours. The CST level transmitters provide indication, high- and low-level alarms, and low-level AFW pump trips.

The in-service condenser hotwell level control system controls the condensate and feedwater system inventory by either rejecting condensate to or gravity draining water from the CST. Figure 7.2-2 shows the components involved in level control. The normal setpoint for the hotwell level of condenser B is 24 in. When the level reaches 28 in., the condensate reject valve downstream of one of the condensate pumps begins to open; the valve is fully open with a hotwell level of 40 in. The makeup valve begins to open when the hotwell level falls to 21 in.; the valve is fully open with a hotwell level of 8 in.

7.2.4 System Operation

During the early stages of a plant startup, the startup AFW pump typically provides feed flow to the steam generators. Decay heat and reactor coolant pump heat are transferred to the feedwater in the steam generators.

As the temperature of the reactor coolant system increases toward the normal operating band, the condensate and feedwater system is readied for service. If necessary, the system is filled and vented. The fill water comes from the CST. The lubricating oil systems for the two MFPs are verified operable and placed in service, in preparation for pump operation. Next, one of the condensate pumps is started, and its associated discharge valve is opened. The MFP recirculation valves are opened, allowing recirculation of condensate through the idle MFPs to the condenser hotwell. Gland steam and seal water to the MFPs will be started at this time.

Once a condensate pump has been placed in service, the condensate and feedwater system is aligned for secondary plant cleanup. The startup recirculation valve is opened, and condensate flow is directed through the condensate demineralizers and throughout the system, up to the common feed header downstream of the high pressure heaters. If the conditions warrant it, the recirculation flow can be limited to smaller portions of the system through the use of the condensate pump or MFP recirculation valves and the closing of appropriate isolation valves. Secondary cleanup is continued until all secondary chemistry parameters are satisfied and within their respective limits. The FWIVs remain closed during the cleanup process.

Once reactor power has reached the point of adding heat, one of the MFPs is started. The operator resets the feedwater isolation signal, closes the startup recirculation valve, and manually rolls the MFP with an individual pump governor control switch. When the maximum output of the governor control switch has been reached and normal operating conditions for the pump have been attained, the individual pump's speed controller is placed in automatic (slaved to the MFP master speed controller). The operator then manually controls the pump's speed with the master speed controller by maintaining a suitable ΔP between the feedwater and steam pressures. The bypass valve FWIVs are opened, and the bypass valves are throttled open while the AFW flow control valves are throttled closed. The steam generator water levels are maintained at the appropriate values at low powers through manual control of the bypass valves and the MFP master speed controller.

When the plant reaches approximately 20% power, the MFP master speed controller is placed in automatic, and steam generator water level control is shifted from the bypass valves to the feedwater regulating valves. The individual water level controllers are placed in automatic. During the remainder of the power ascension, the second condensate pump and MFP are placed in service before power exceeds 70%, the first heater drain pump is placed in service at approximately 30% power, and the second heater drain pump is placed in service before power exceeds 90%.

7.2.5 PRA Insights

The purpose of the plant's power conversion system is to convert the heat removed from the reactor core into electrical energy, which is provided to consumers by that plant's utility. Even though the plant's Technical Specifications contain few provisions which apply to the main feedwater portion of the power conversion system, there are some transients initiated by the loss of feedwater which can lead to core damage. However, the associated sequences typically account for a very small fraction of the total core damage frequency (0.6% for Sequoyah and an insignificant percentage for Zion, Surry, and Trojan). Modifications to the power conversion system would not contribute significantly to risk reduction or risk achievement values.

7.2.6 Summary

The main condenser is a multipressure, three-shell, surface condenser. The condenser receives exhaust steam from the low pressure turbines, steam dumps, and the MFP turbines. Condensate enters the condenser from the condensate pump recirculation lines, the MFP recirculation lines, the low pressure feedwater heater drains, and the CST (hotwell makeup). The condensate pumps transfer the condensate from the main condenser through the demineralizers and low pressure heaters to the suction of the MFPs. The MFPs take suction on the discharge from the condensate pumps and heater drain pumps and transfer feedwater through the high pressure heaters, feedwater regulating valves or bypass valves, and FWIVs to the steam generators. The condensate and feedwater system supplies an automatically controlled flow of high pressure, preheated feedwater to maintain the desired steam generator water levels.

The heater drain system improves plant efficiency by collecting the high temperature drainage from the MSRs and feedwater heaters and by transferring the drains back to the condensate and feedwater system.

During plant operation the control of steam generator chemistry is accomplished by the purification of condensate, by the injection of chemicals into the condensate system to scavenge oxygen and to control pH, and by steam generator blowdown.

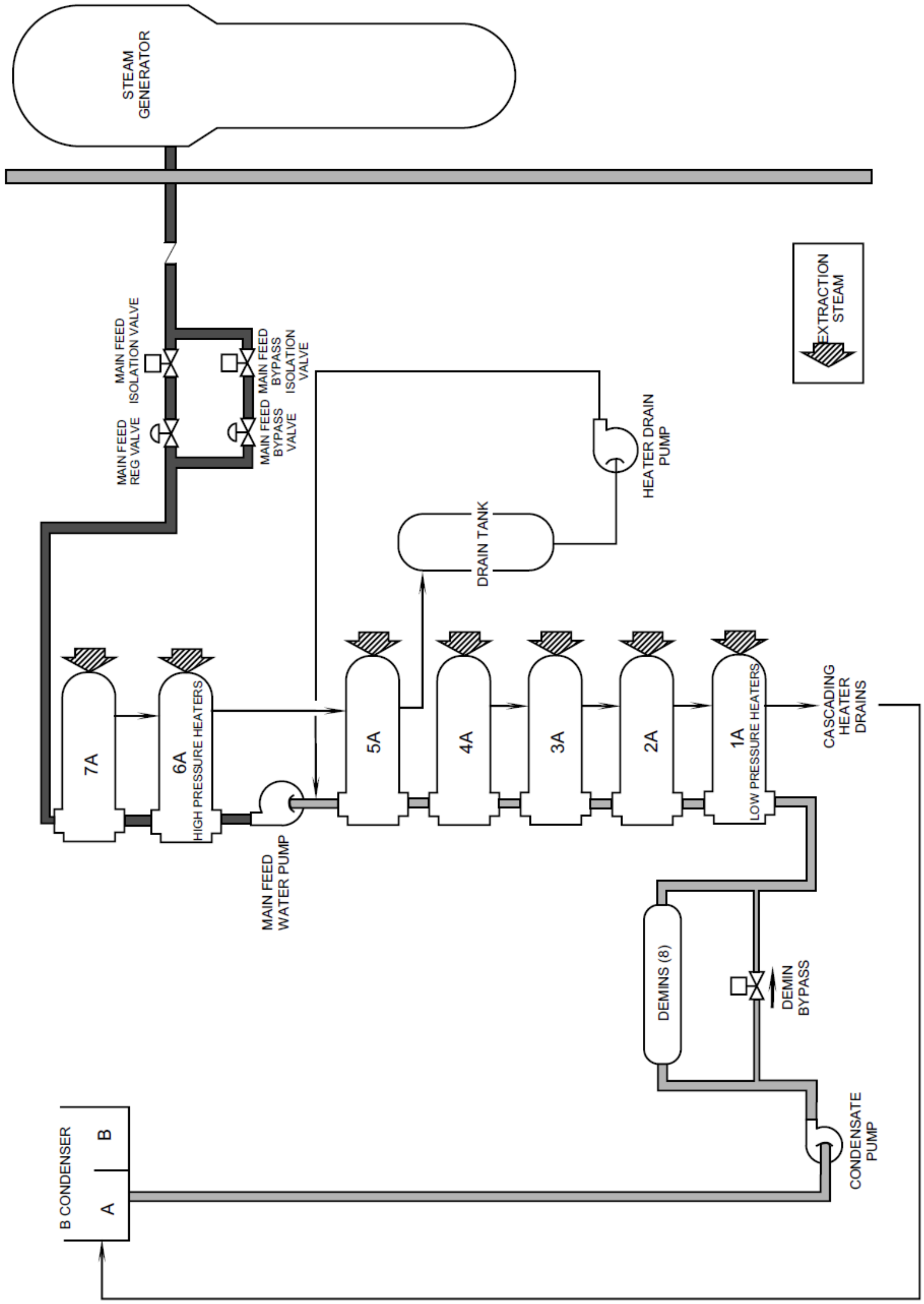


Figure 7.2-1 Simplified Condensate and Feed System

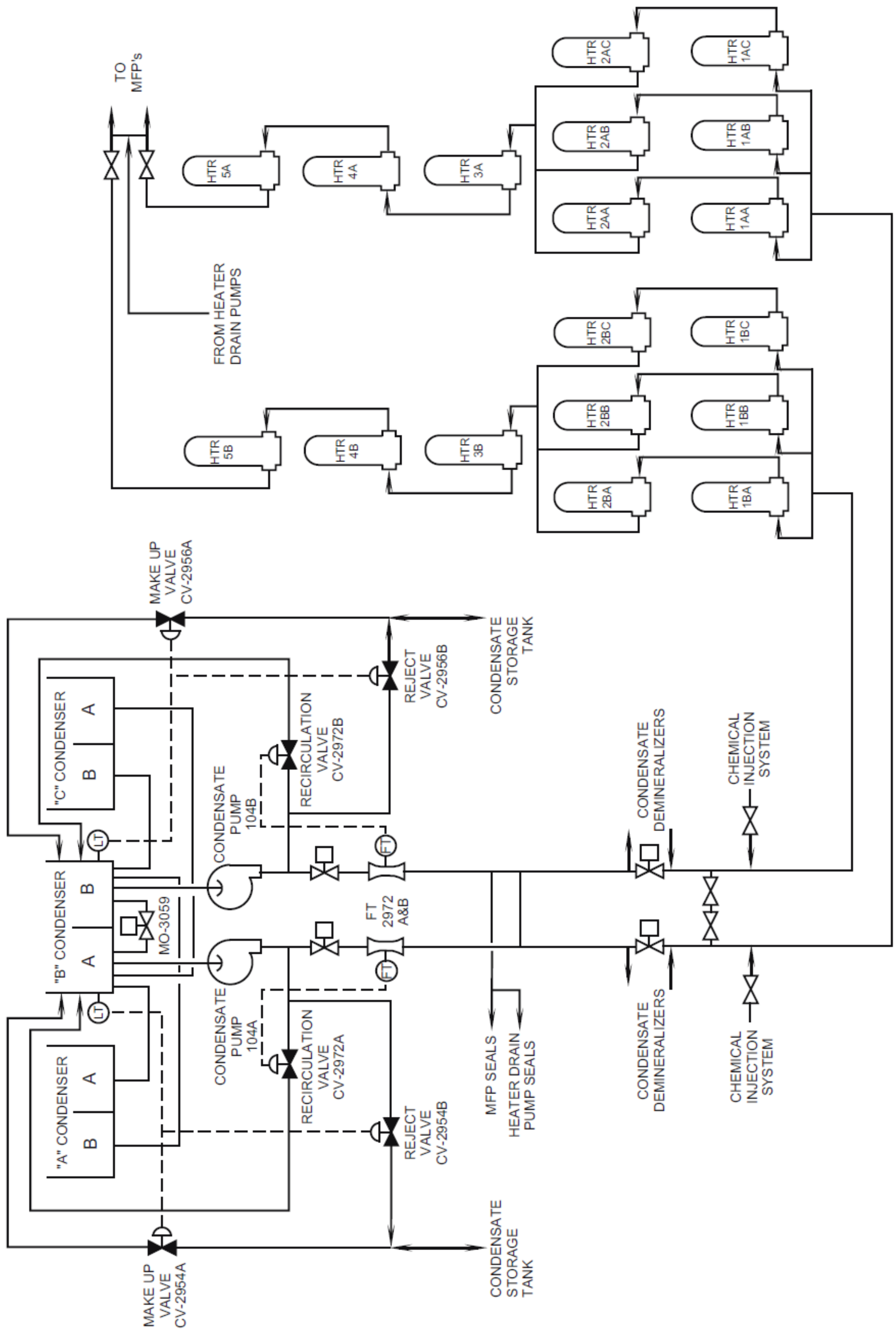


Figure 7.2-2 Condensate System

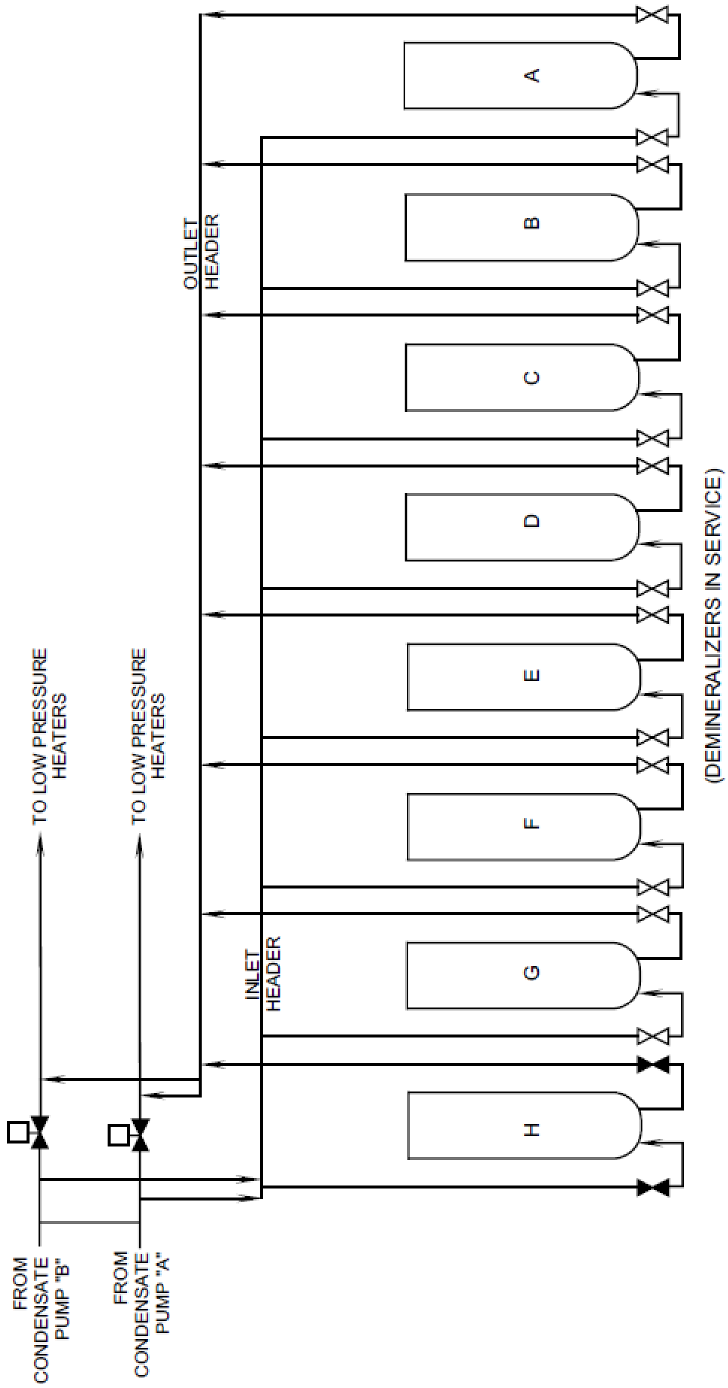


Figure 7.2-3 Condensate Demineralizer System

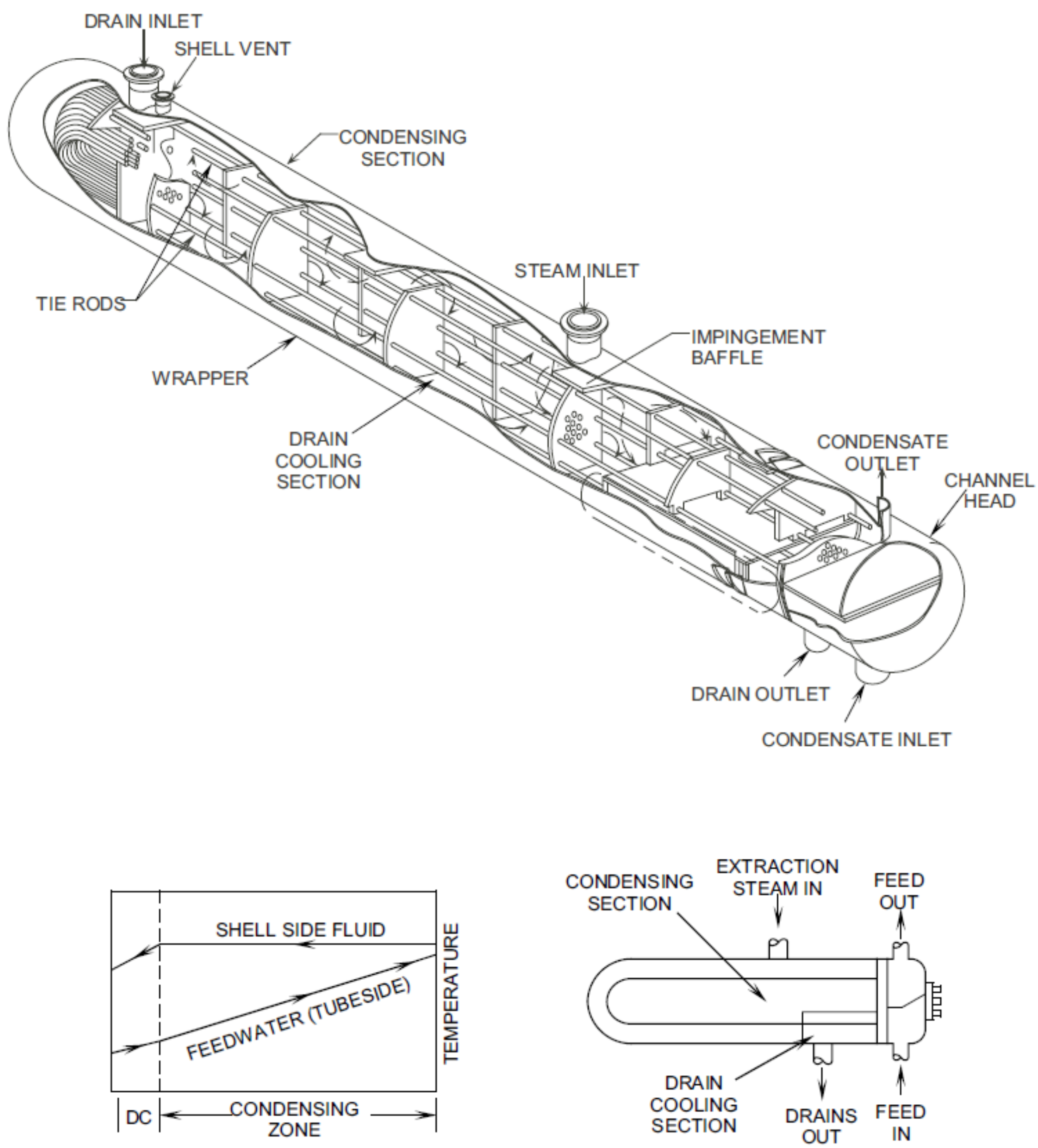


Figure 7.2-4 Feedwater Heater

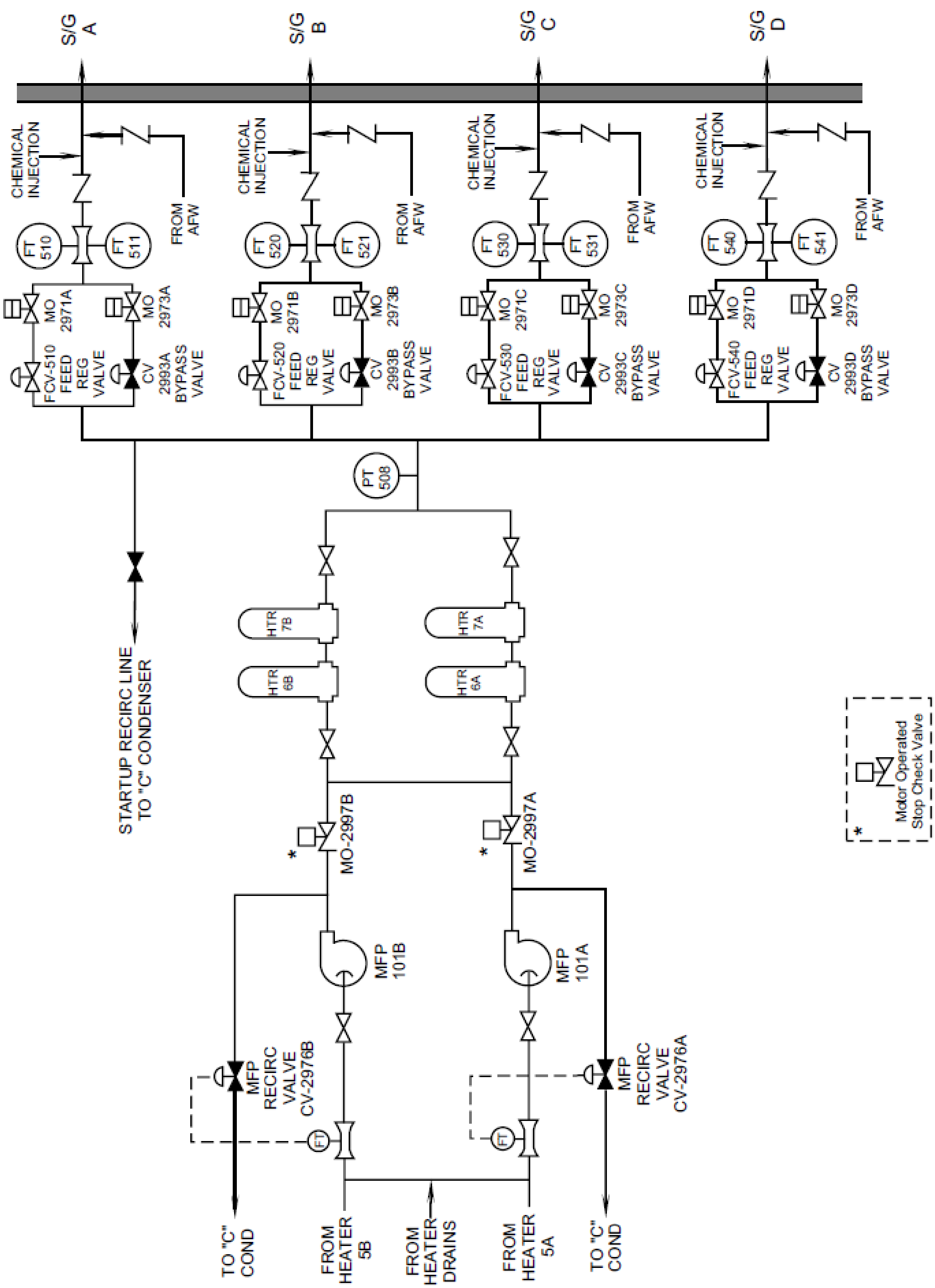
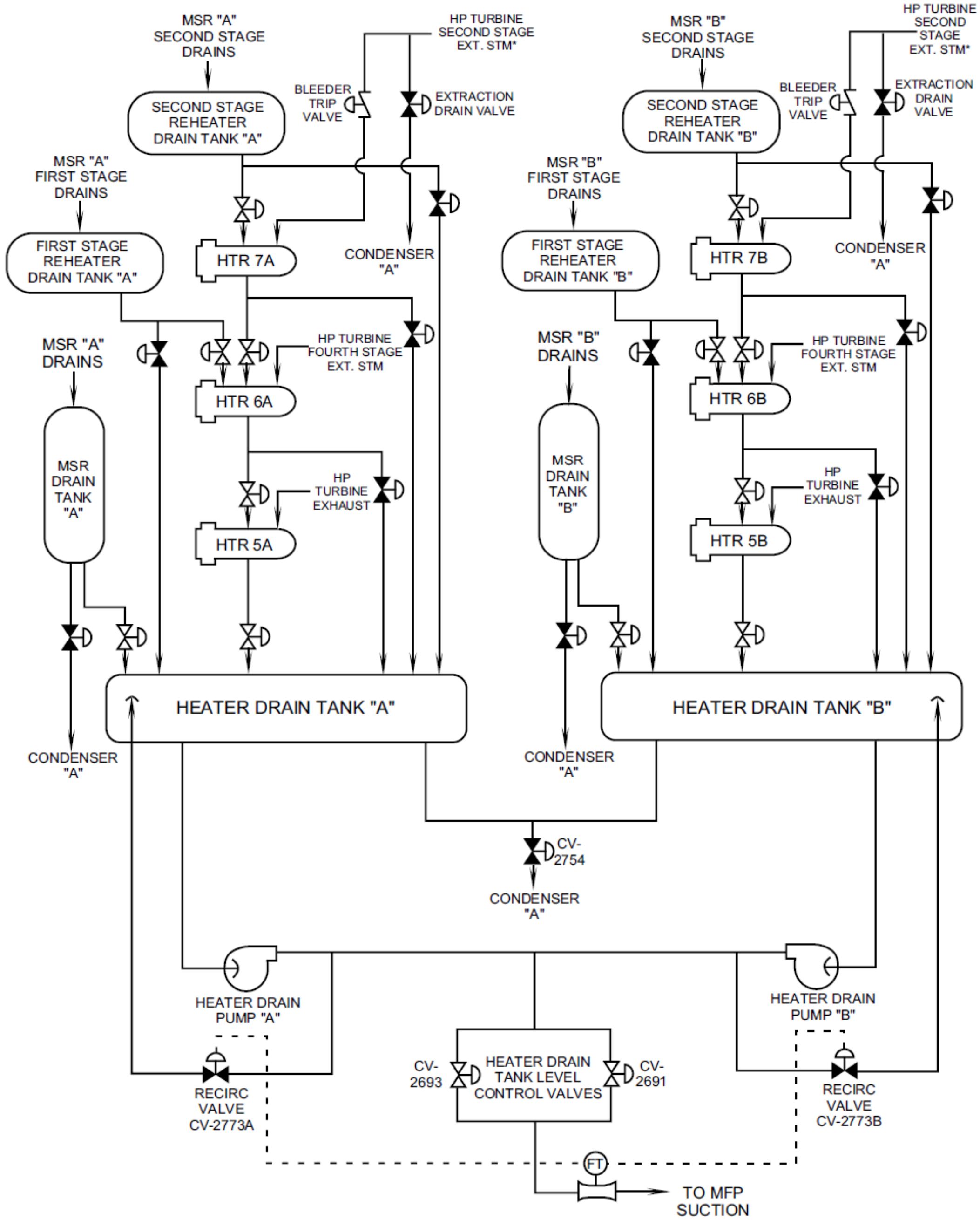


Figure 7.2-5 Feedwater System



*EXTRACTION STEAM SUPPLY AND DRAIN ARRANGEMENT TO EACH HEATER IN THIS FIGURE IS SIMILAR TO THAT SHOWN FOR HEATERS 7A & 7B. THE ARRANGEMENT IS NOT REPEATED FOR SIMPLICITY.

Figure 7.2-6 Moisture Separator / High Pressure Heater Drains

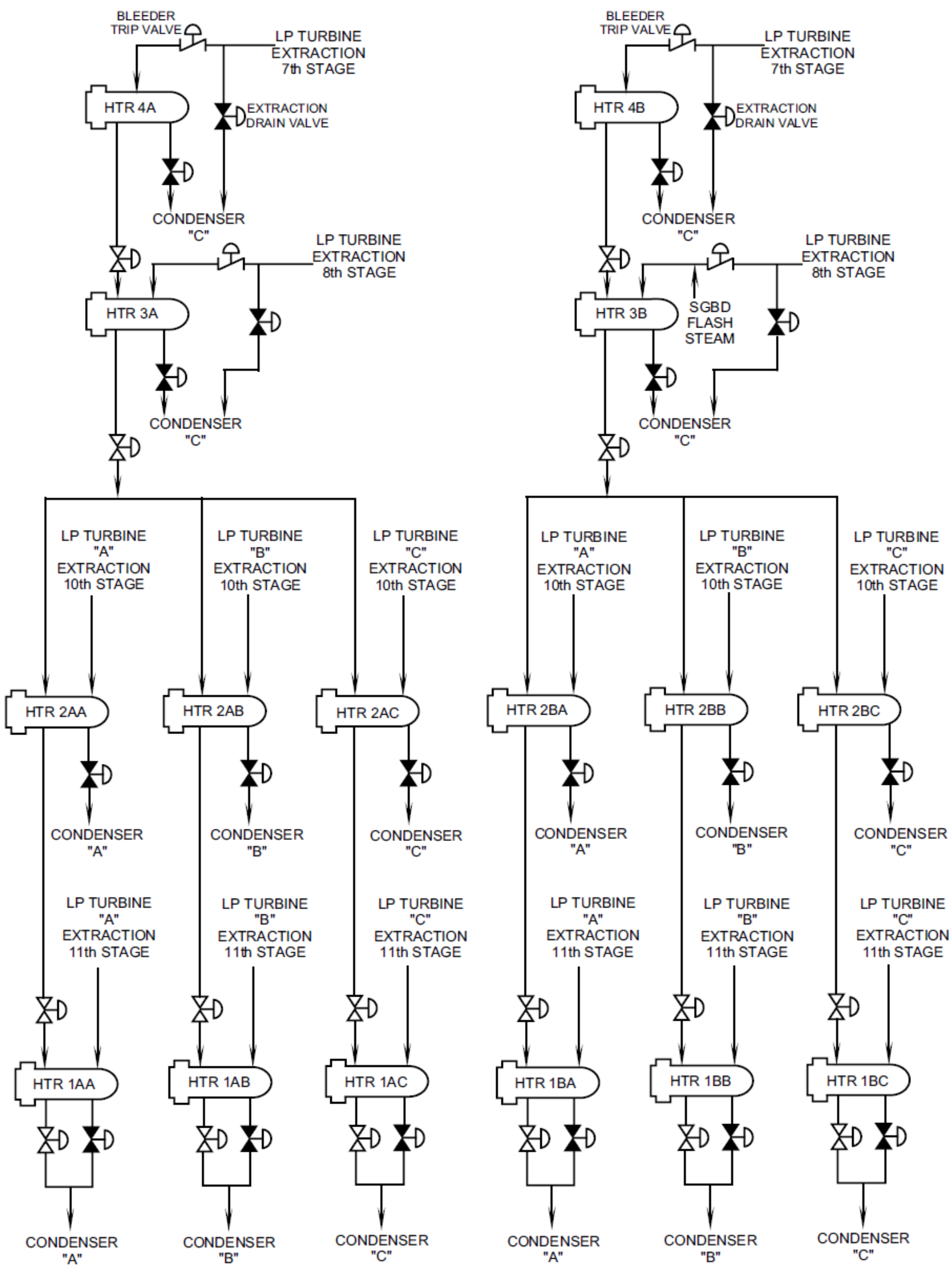


Figure 7.2-7 Low Pressure Heater Drains

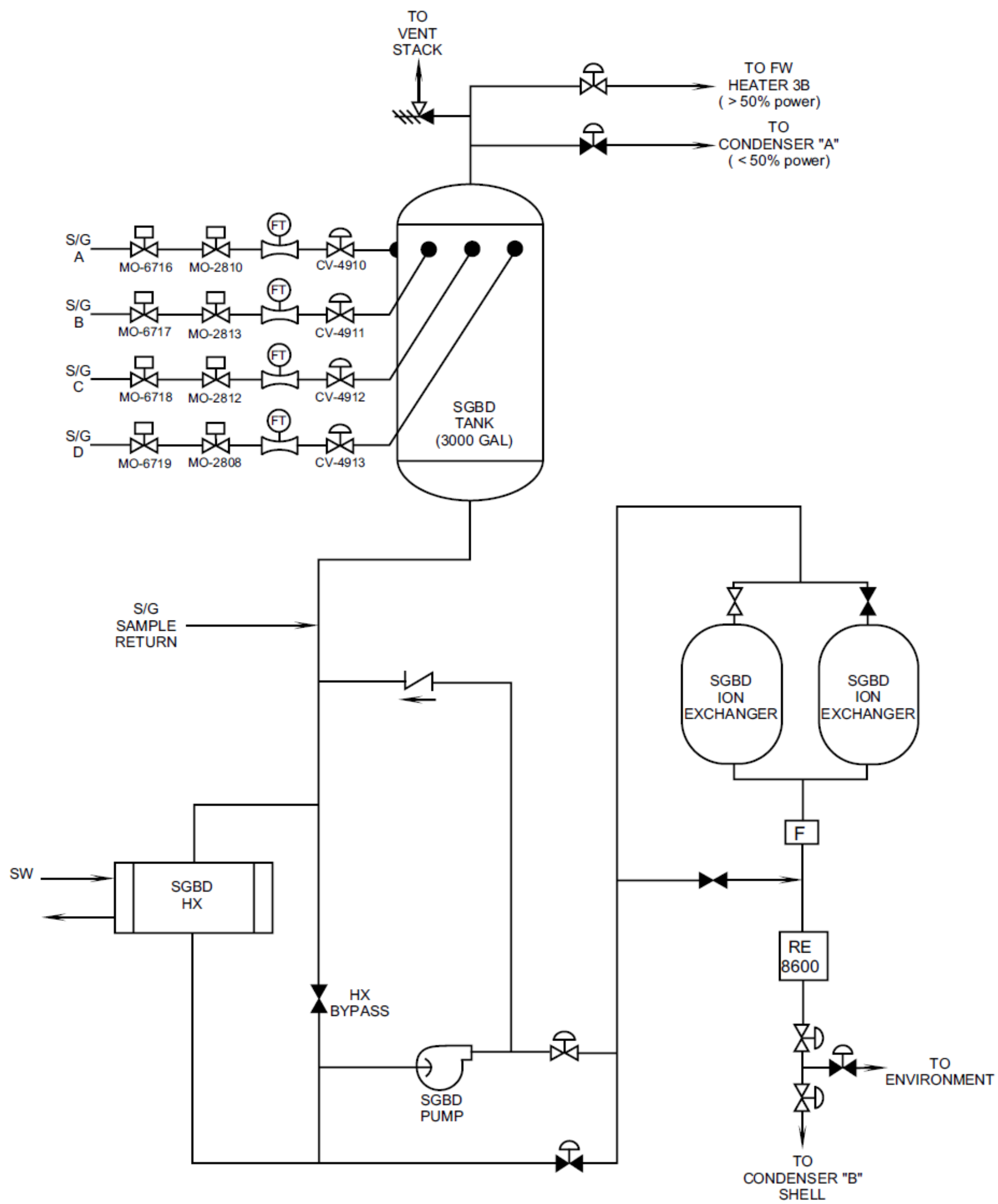


Figure 7.2-8 Steam Generator Blowdown System

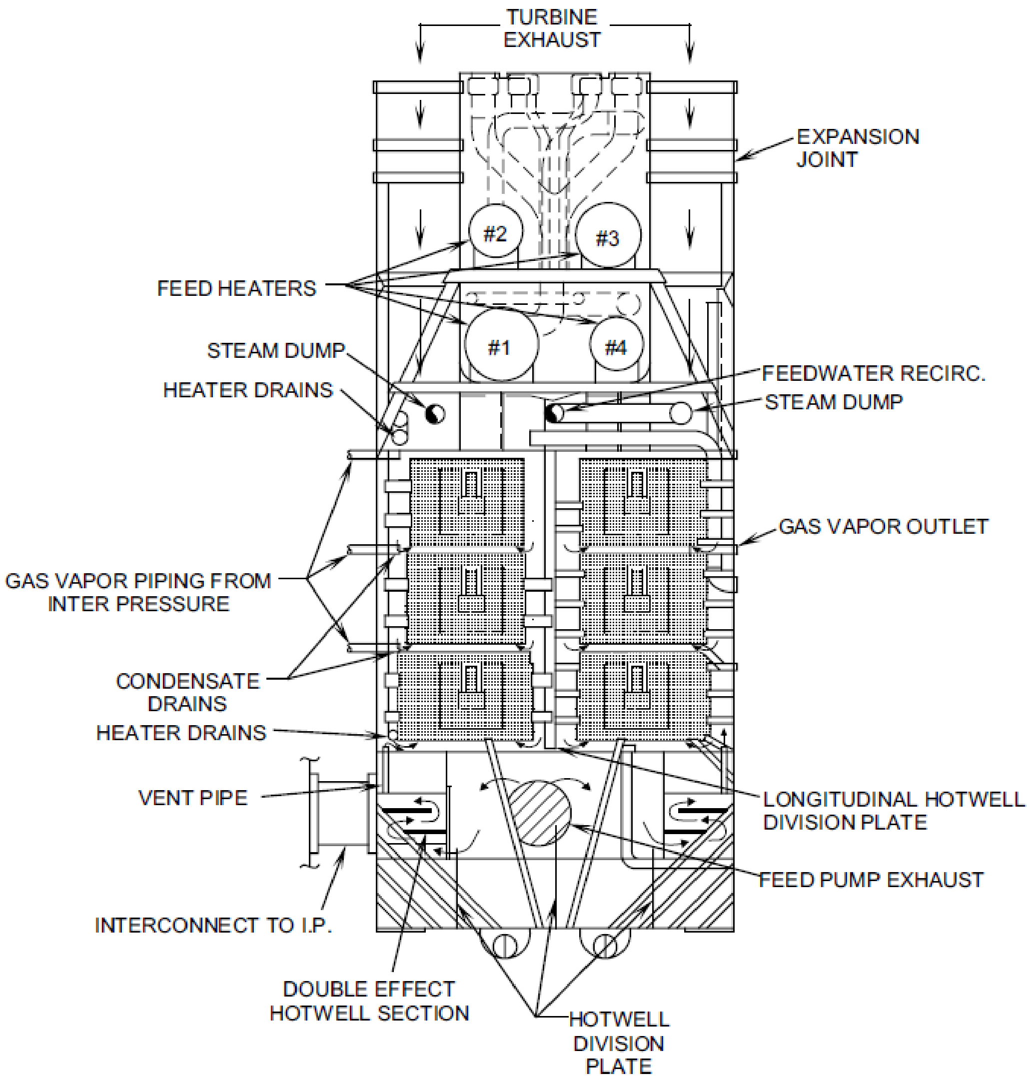


Figure 7.2-9 Condenser

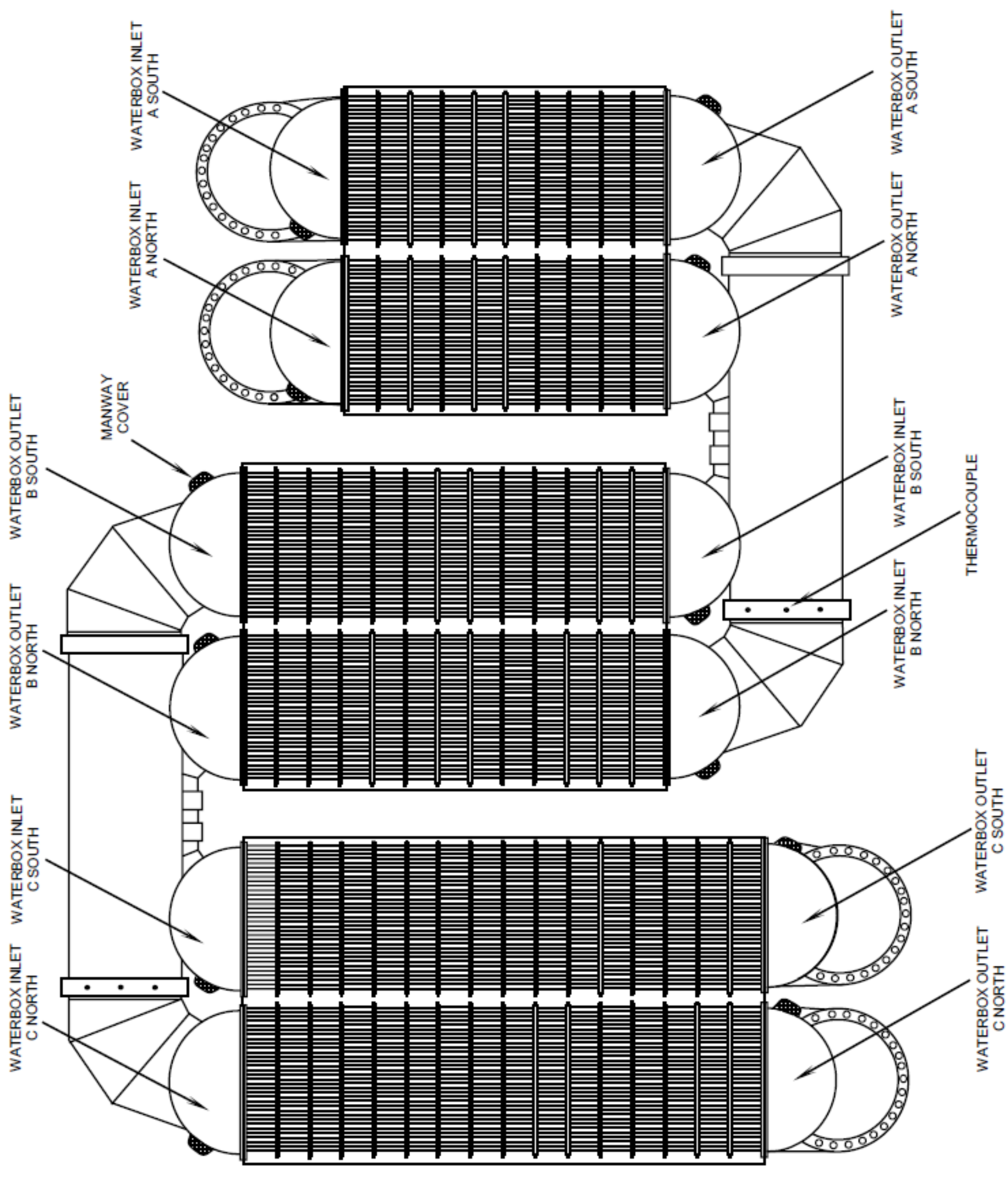


Figure 7.2-10 Circulating Water (Top View)

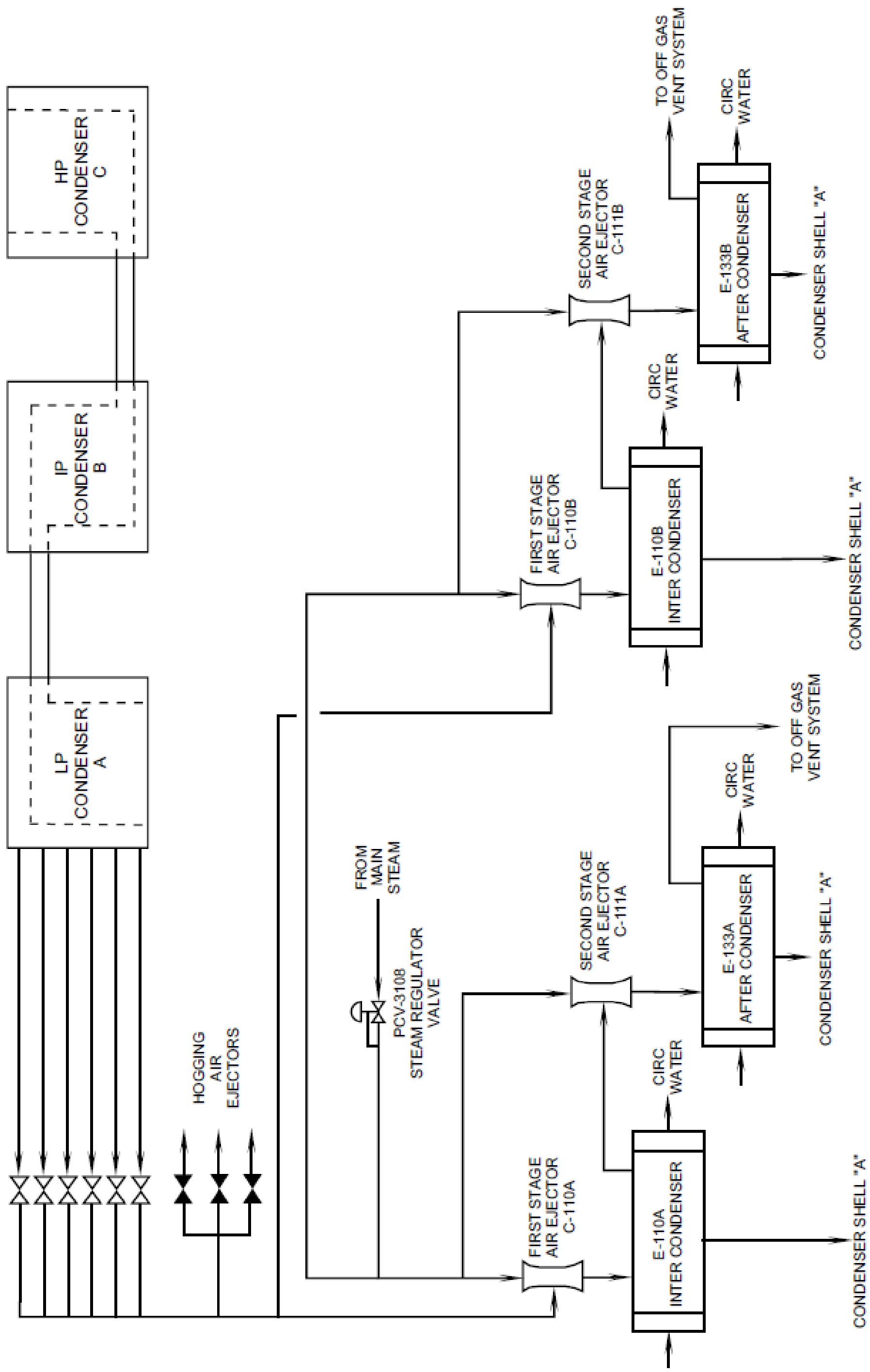


Figure 7.2-11 Main Air Ejector System

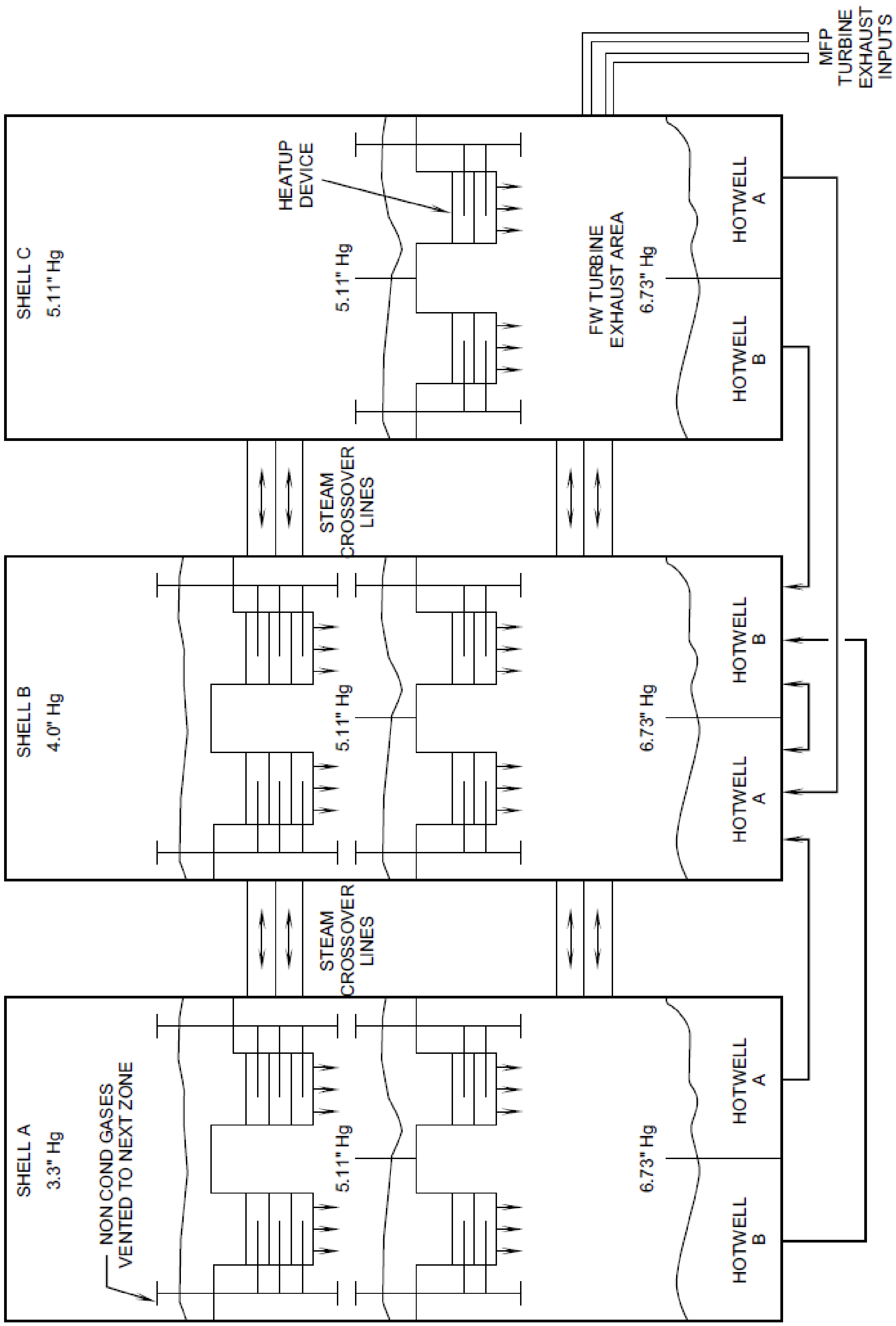


Figure 7.2-12 Condenser Hotwells

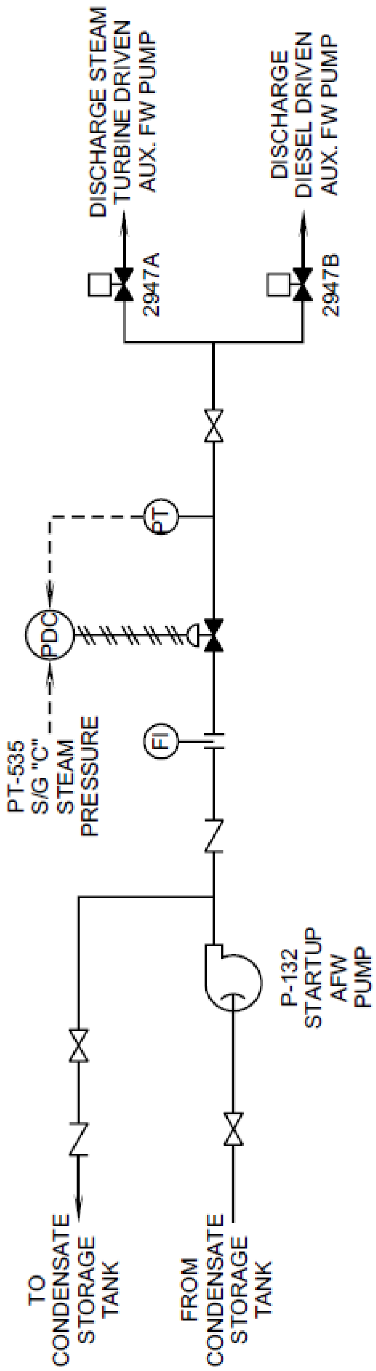


Figure 7.2-13   Startup Auxiliary Feedwater Pump