1.0 PWR SYSTEMS OVERVIEW

1.1 INTRODUCTION

The reference pressurized water reactor (PWR) generating system is a dual cycle plant based on the Westinghouse nuclear steam supply System. It consists of a reactor vessel and up to four closed coolant loops connected in parallel (primary cycle) and a separate power conversion system (secondary cycle). The use of a dual cycle design minimizes the quantities of radioactive materials released to the power conversion system components and the subsequent release of radioactive materials to the atmosphere. The composite flow diagram shown in Figure 1.1-1 illustrates the dual cycle design of a PWR.

There are two major systems utilized to convert the heat generated in the fuel into electrical power for industrial and residential use. The primary system transfers the heat from the fuel to the steam generator, where the secondary system begins. The steam formed in the steam generator is transferred by the secondary system to the main turbine generator, where it is converted into electricity. After passing through the low pressure turbine, the steam is routed to the main condenser. Cool water, passing through the tubes in the condenser, removes excess heat from the steam, which allows the steam to condense. The water is then pumped back to the steam generator for reuse.

In order for the primary and secondary systems to perform their functions, there are approximately 100 support systems. In addition, for emergencies, there are dedicated systems to mitigate the consequences of accidents.

1.2 REACTOR COOLANT SYSTEM

The primary system (also called the reactor coolant system) consists of the reactor vessel, steam generators, reactor coolant pumps, a pressurizer, and connecting piping (Figure 1.2-1).

A reactor coolant loop is a reactor coolant pump, a steam generator, and the piping that connects these components to the reactor vessel. The primary function of the reactor coolant system is to transfer the heat from the fuel to the steam generators. A second function is to contain any fission products if they were to escape the fuel. One of the loops is connected to an electrically heated pressurizer for system pressure control.

Reactor coolant (water) is pumped through the reactor core to remove the heat generated by nuclear fission. The heated water exits the reactor vessel and passes via the loop piping to the steam generator. Inside the steam generator, the reactor coolant is circulated through tubes and gives up some of its heat to the feedwater (secondary system). The steam generator tubes are the barrier between the primary and secondary cycles.

The reactor coolant then exits the steam generator and is directed to the suction of the reactor coolant pump. The reactor coolant pump returns the coolant to the reactor vessel to complete the primary cycle.

1.3 SECONDARY CYCLE (POWER CONVERSION SYSTEM)

The reactor coolant flows from the reactor to the steam generator. Inside the steam generator, the hot reactor coolant flows inside the many tubes. The secondary coolant, or feedwater, flows over the tubes, where it picks up heat from the primary coolant. When the feedwater absorbs sufficient heat, it starts to boil and form steam. At this point, the steam generators used by the three pressurized water reactor vendors are slightly different in their design and operation.

For all of the steam generator designs, the steam is piped to the main turbine and the coolant is routed to the suction of the reactor coolant pumps.

In the reference PWR, the power conversion system begins in the shell side of the four steam generators, where the feedwater picks up heat and is boiled as it contacts U-tubes containing hot reactor coolant.

The saturated steam produced in the shell side of the steam generators exits through the steam lines and steam line isolation valves and is directed to the high pressure section of the main turbine. After passing through the high pressure turbine, the now low energy, moisture laden steam is routed to a moisture separator/reheater, where excess moisture is removed and the steam is heated to a new internal energy level.

The dry, reheated steam then passes through low pressure turbines, then exits to the main condenser. The high and low pressure turbines are mounted on a common shaft which drives the main generator.

The generator produces the electrical power which is supplied to the utility's distribution network or "grid."

Inside the condenser, the exhaust steam is condensed (cooled and depressurized) by passing over tubes containing water from the condenser circulating water system. The condensed steam (or condensate) is collected in the condenser's hotwell. The condensate is then pumped from the condenser by condensate pumps.

The condensate pumps discharge through condensate demineralizers, which remove impurities from the fluid. These demineralizers can become a source of radioactive waste should primary to secondary leakage occur in the steam generators.

The condensate flow then passes through several strings of low pressure feedwater heaters. Here the condensate temperature is raised utilizing the energy of steam extracted from the main turbine. The condensate exits the low pressure feedwater heaters and then enters the high pressure main feedwater pumps.

The feedwater pumps (which are driven by steam turbines) increase the pressure of the water so that the fluid (now called feedwater) can re-enter the steam generators.

On the way back to the steam generators, more feedwater heating is accomplished in the high pressure feedwater heaters. Feedwater then passes through the flow-controlling feedwater regulating valves, re-enters containment, and finally enters the steam generators.

Once inside the steam generators, the feedwater is raised to its saturation temperature and converted into high energy steam as it passes around the U-tubes heated by primary cycle fluid. The secondary fluid cycle thus continues.

1.4 CONTAINMENT BUILDING

The reactor coolant system is located inside the containment building (Figure 1.4-1). PWR containments are designed to withstand the pressures and temperatures that would accompany a loss of coolant accident (LOCA). Should a break occur in the primary system, the containment retains radioactive fission products, except for that loss postulated by leakage to the environment. The containment normally acts as a barrier to any inadvertent release of airborne radioactive particulates or fission gases. Releases to the atmosphere are usually limited to controlled purges.

1.5 SUPPORT SYSTEMS

The chemical and volume control system (CVCS) is a major support system for the reactor coolant system (Figure 1.5-1). Some of the functions of this system are to:

- Purify the reactor coolant system using filters and demineralizers,
- Add and remove boron as necessary, and
- Maintain the level of the pressurizer at the desired setpoint.

A small amount of water (about 75 gallons per minute) is continuously routed through the CVCS (called letdown). This provides continuous cleanup of the reactor coolant system, which maintains the purity of the reactor coolant and helps to minimize the amount of radioactive material in the coolant.

During normal operations, the mechanical filters and demineralizers that make up the CVCS have the highest concentration of radioactivity in the radwaste system. The demineralizers are typically changed out only once per fuel cycle when they are depleted. Typically they are of low volume (30 cubic feet or resin or less per demineralizer bed). The mechanical filters are changed out more frequently (several times per fuel cycle) and typically are changed based on radiation level and not differential pressure.

The reactor coolant pumps (RCPs) have seals that prevent the leakage of primary coolant to the containment atmosphere. CVCS provides the cool, clean water that keeps the seals cool and provides lubrication for the seals.

There is also a path to route the letdown flow to the radioactive waste system for processing and/or disposal.

The CVCS maintains the purity of the reactor coolant system by means of demineralizer beds that continuously purifies a small letdown stream from the RCS. This purified water is charged back into the RCS at a controlled rate to maintain the proper volume of water in the system. The CVCS interacts with the liquid, solid, and gaseous radwaste systems.

Ventilation is provided to condition air, cool equipment, and maintain suitable environmental conditions throughout the plant (Section 1.7).

The component cooling water system (CCW) provides a cooling medium to various components such as the CVCS letdown heat exchanger and the residual heat removal system heat exchanger. It is a closed loop system and is cooled in turn by the service water system, which receives its water from the river, lake, or ocean near which the plant is located. It can become contaminated by leakage of water from the systems that it cools (Section 1.8).

1.6 PLANT LAYOUT

The entire reactor coolant system, including the steam generators, is located in a containment building that isolates the radioactive reactor coolant system from the environment in the event of a leak. The containment building is designed to contain the pressure produced by a complete rupture of a reactor coolant system pipe.

Safety related and potentially radioactive auxiliary systems are located in the Seismic Category I auxiliary building, which is normally located between the turbine building and the containment. Ventilation from this building is passed through high efficiency particulate filters and/or charcoal filters to minimize releases of radioactive material to the environment. A fuel storage building (sometimes part of the auxiliary building) is provided for handling and storage of new and spent reactor fuel. The fuel storage building is also a Seismic Category I building.

The control building (also sometimes part of the auxiliary building) is a Seismic Category I structure, housing the main control room, the cable spreading room, auxiliary instrument room, plant computer, and battery rooms. The turbine building contains most of the secondary cycle equipment and secondary support systems. The main turbine and auxiliaries, moisture-separator reheaters, feedwater heaters, main condenser, condensate and feedwater pumps, etc., are all located in the turbine building. The turbine building is not a Seismic Category I structure.

1.7 BUILDING VENTILATION SYSTEMS

The major building ventilation systems are:

- Containment building ventilation,
- Auxiliary building ventilation, and
- Turbine building ventilation.

Each of these systems consists of several subsystems. This course discusses only the containment and auxiliary building ventilation systems, because the turbine building is rarely a source of radioactive emissions to the environment.

Since ventilation system designs are site-specific, this discussion is intended to provide an overview of the general characteristics of PWR building ventilation systems. The specific features and details are not necessarily applicable to all plants.

1.7.1 Containment Ventilation Systems

During normal operations, the functions of the containment ventilation system are to:

- Provide filtered, heated (if required) air to the reactor containment,
- Limit the containment temperature (i.e., 120°F maximum and 65°F minimum),
- Enable cleanup of the containment atmosphere prior to personnel access at power,
- Maintain containment building pressure within design specifications, and
- Reduce the concentration of gaseous and particulate radioactivity for continuous access during normal reactor shutdown.

The containment ventilation system is shown in Figure 1.7-1.

1.7.2 Containment Purge System

The containment purge system is designed to reduce airborne particulates in the containment atmosphere and ensure safe, continuous access to the containment within three hours after a planned or unplanned reactor shutdown.

The containment purge system provides filtered, pre-heated outside air to the reactor containment. The purge exhaust is routed through high efficiency particulate air (HEPA) filters before discharge to the ventilation stacks.

1.7.3 Auxiliary Building Ventilation System

The auxiliary building ventilation system serves all plant areas of the auxiliary and fuel handling buildings and encompasses areas such as the radwaste building. It features the handling of both intake and exhaust air and is designed to maintain pressure in potentially contaminated areas to minimize the spread of contamination or unintentional release.

This system incorporates individual cooler units to provide supplementary cooling to specific safeguard equipment cubicles.

1.7.4 Ventilation Exhaust Components

The auxiliary building ventilation exhaust consists of:

- Exhaust fans,
- Charcoal booster fans,
- Fuel handling exhaust filters,
- Cubicle exhaust filters,
- Main exhaust filters,
- Charcoal filters,
- Cubicle cooling units, and
- Cooling coils.

The fuel handling building exhaust filters are composed of banks of pre-filters and HEPA filters installed in series. Each pre-filter bank contains a couple of dozen individual filter elements. Each filter element has a rated efficiency of 85%. Each filter bank also contains a HEPA filter, which has a rated efficiency of 99.97% for particulates with a size as small as 0.3 microns.

The HEPA filters are arranged in three separate banks. The main bank of filters returns air from general areas in the auxiliary building, and usually consists of six filter modules. The second bank of filters exhausts from the auxiliary building equipment cubicles. It usually consists of three filter modules. The third bank of filters exhausts from the fuel handling building. It consists of two filter modules. One filter module in each bank is normally on standby.

There are usually two banks of charcoal filters. The charcoal subsystem includes four booster fans. Three of the four are sufficient to maintain required flow through the charcoal beds.

During refueling, the filter units are used to process exhaust from the fuel handling building. They also process air from contaminated equipment cubicles when high radioactivity is detected in these ventilation flow streams. The cooling coils are housed in a common cabinet, with redundant fans on each cubicle unit cooler. The fans start automatically when required.

The radwaste building exhaust filters consist of banks of pre-filters, HEPA and charcoal filters rated at about 4,000 cfm. The pre-filter bank contains several (about 4) individual filter elements with nominal efficiencies of 35%. The companion HEPA filters have a nominal efficiency of 99.97%. The charcoal filter bank contains about 6 individual filter elements.

Filters are normally changed when a significant pressure drop (5 inches of water) occurs across the HEPA filters or the radiation levels reach pre-established limits.

Typically, the auxiliary building exhaust has three fans per unit, of which two are in operation. The auxiliary building ventilation stacks are sometimes compartmentalized to independently handle the exhaust from different systems. The compartmentalized design maintains the design discharge velocity for any of the exhaust systems regardless of operation of the other systems.

1.8 COOLING WATER SYSTEMS

This section provides an overview of the following cooling water systems:

- Condensate and feedwater systems,
- Auxiliary feedwater system,
- Component cooling water system,
- Service water system,
- Circulating water system, and
- Spent fuel pool cooling system.

Again, these systems vary from station to station. In particular, the circulating water system may be supplemented with a cooling tower or other such system that modifies its function and design substantially.

1.8.1 Condensate and Feedwater System

The functions of the condensate and feedwater systems (Figure 1.8-1) are to:

- Return the condensed steam from the main condenser and the drains from the feedwater heaters to the steam generators,
- Automatically maintain the steam generator water levels during normal and transient conditions,
- Provide a means of reheating the water to increase efficiency,
- Provide a means for injecting chemicals for secondary system chemistry control, and
- Provide volume and mass to accommodate design load changes without a unit trip.

Sufficient feedwater storage capacity is maintained within the condensate-feed systems for mass fluid transfers arising from contraction and expansion during load changes.

Chemical control of the steam generators is maintained by injecting volatile chemicals in the hotwell pump discharge portion of this system. Hydrazine is used for oxygen scavenging and ammonia provides pH control. The motive force is provided by variable speed metering pumps, which are automatically controlled by on-line chemical sampling system feedback signals.

1.8.2 Component Cooling Water System

The component cooling water system (CCW) is a closed-cycle system designed to remove heat from heat exchangers, pumps, and the waste disposal systems. Component cooling water flows through these units in parallel flow circuits, picks up heat from the various components, and is then cooled in the component cooling water heat exchangers by the service water system. The component cooling loop serves as an intermediate system between the RCS and the service water system. This double barrier arrangement reduces the probability of leakage of high-pressure, potentially radioactive coolant to the service water system.

The CCW system provides cooling for:

- Residual heat removal heat exchangers,
- Reactor coolant pump motor bearings and thermal barriers,
- Letdown heat exchangers,
- Excess letdown heat exchangers,
- Seal water heat exchangers,
- Spent fuel pit heat exchangers,
- Sample heat exchangers,
- Reactor vessel support cooling,
- Residual heat removal pumps,
- Safety injection pumps,
- Charging pumps, and
- Waste gas compressors.

1.8.3 Spent Fuel Pool Cooling System

The spent fuel pool cooling system (Figure 1.8-2) is designed to remove heat generated by the stored spent fuel elements from the spent fuel pool. It also clarifies and purifies the water in the spent fuel pool, transfer canal, and refueling water storage tanks. The system design enables total unloading of a reactor vessel for maintenance or inspection. It incorporates redundant active components. System piping is arranged so that failure of any pipeline does not drain the spent fuel pool below the top of the stored fuel elements.

The clarity and purity of the spent fuel pool water is maintained by passing about 100 gpm of each loop's flow through a filter and demineralizer. Skimmers are provided to prevent dust and debris from accumulating on the surface of the water.

The refueling water purification pump and filter can be used separately or in conjunction with the spent fuel pool demineralizer to regain refueling canal water clarity after a crud burst. This changeover capability is necessary to prevent loss of time during refueling due to poor visibility. The system is also used to maintain water quality in the refueling water storage tank.

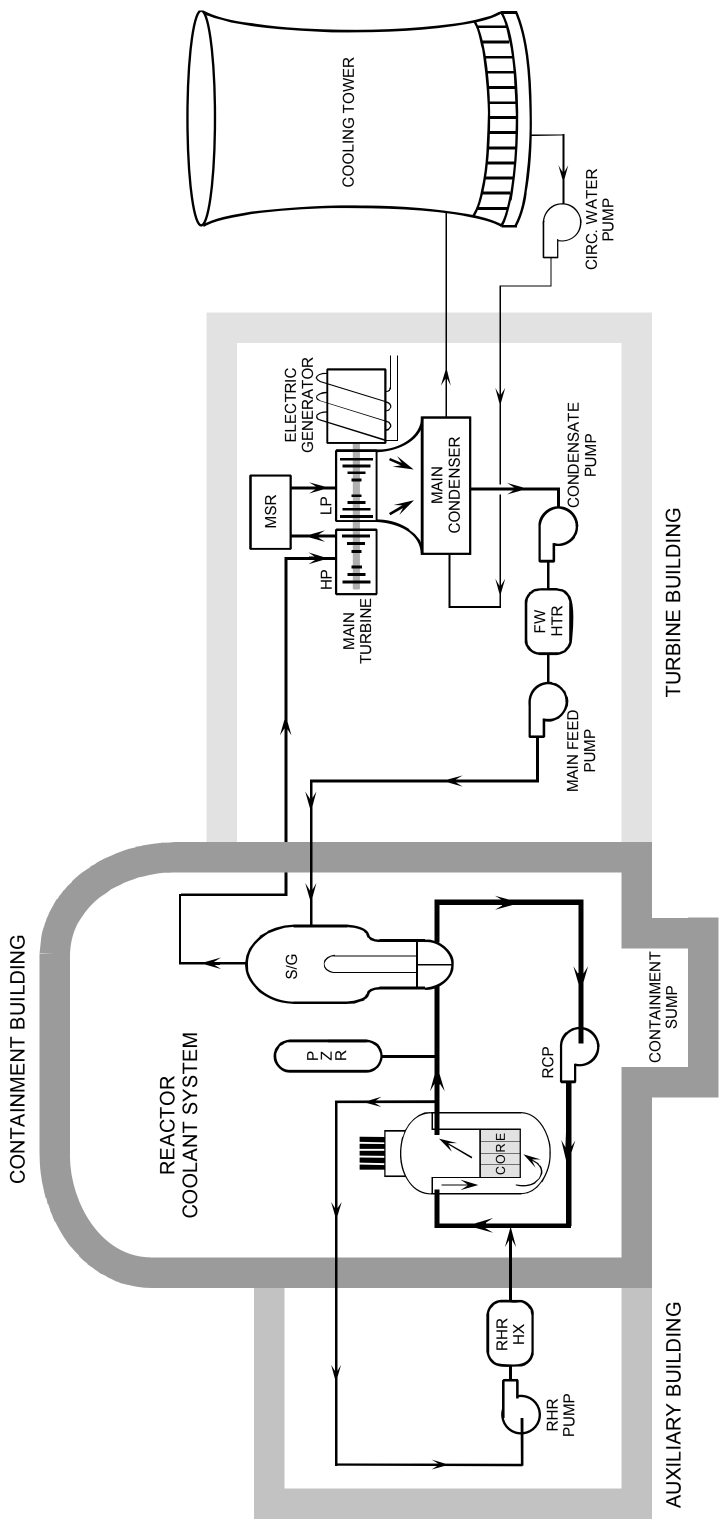

Figure 1.1-1 Pressurized Water Reactor

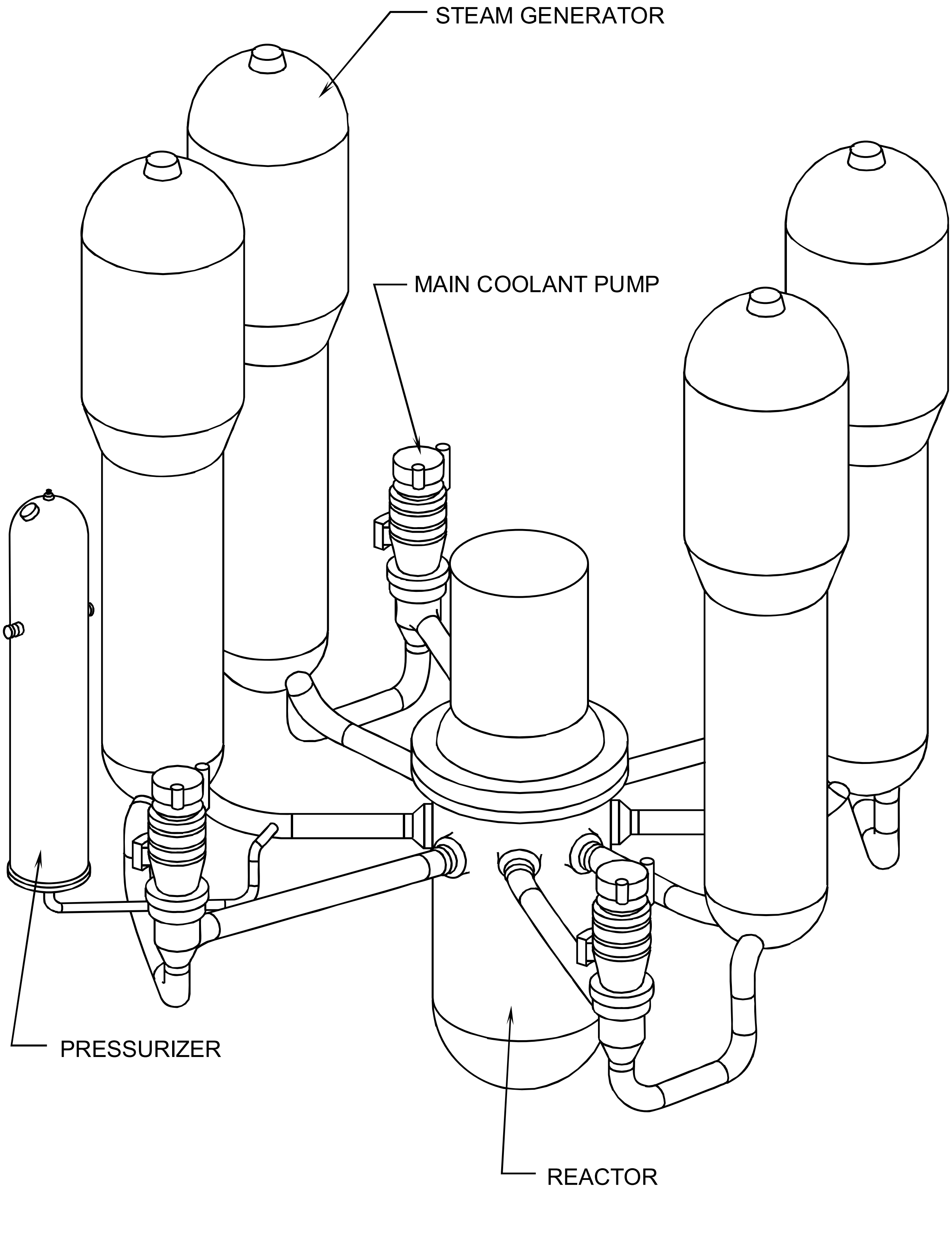

Figure 1.2-1 PWR Primary System

LEGEND:

1. CONTAINMENT
2. FUEL BUILDING
3. REFUELING CAVITY
4. FUEL TRANSFER CANAL
5. OPERATING DECK
6. CONTAINMENT POLAR CRANE
7. REACTOR VESSEL HEAD ASSEMBLY (ON STORAGE STAND)
8. UPPER INTERNALS STRUCTURE (ON STORAGE STAND)
9. LOWER INTERNALS STORAGE STAND
10. REACTOR VESSEL
11. REACTOR CORE
12. REFUELING MACHINE
13. ROD CLUSTER CONTROL CHANGING FIXTURE
14. FUEL TRANSFER TUBE
15. FUEL HANDLING MACHINE AND HOIST
16. FUEL STORAGE TANKS
17. SPENT FUEL CASK LOADING AREA

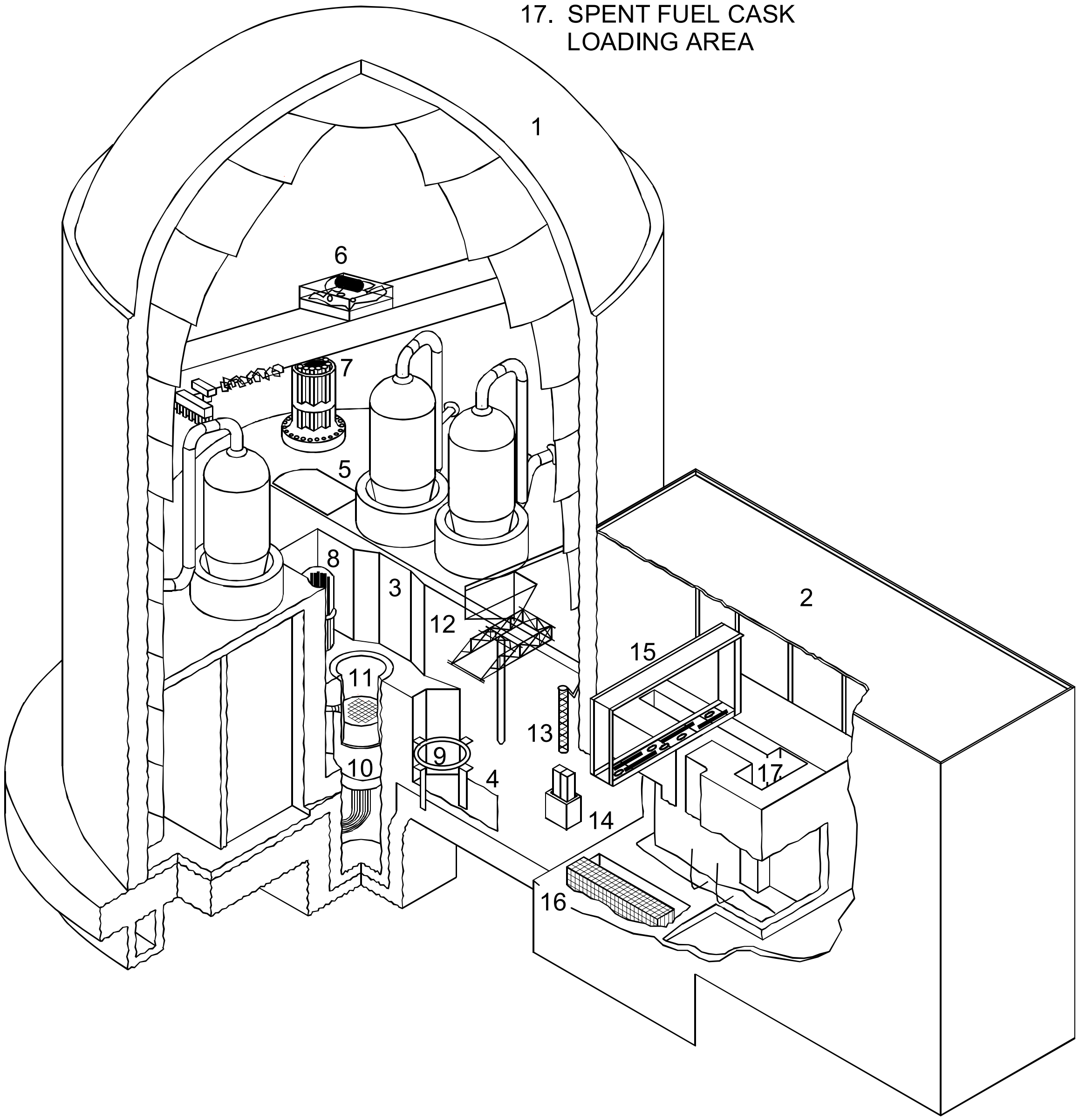

Figure 1.4-1 PWR Containment

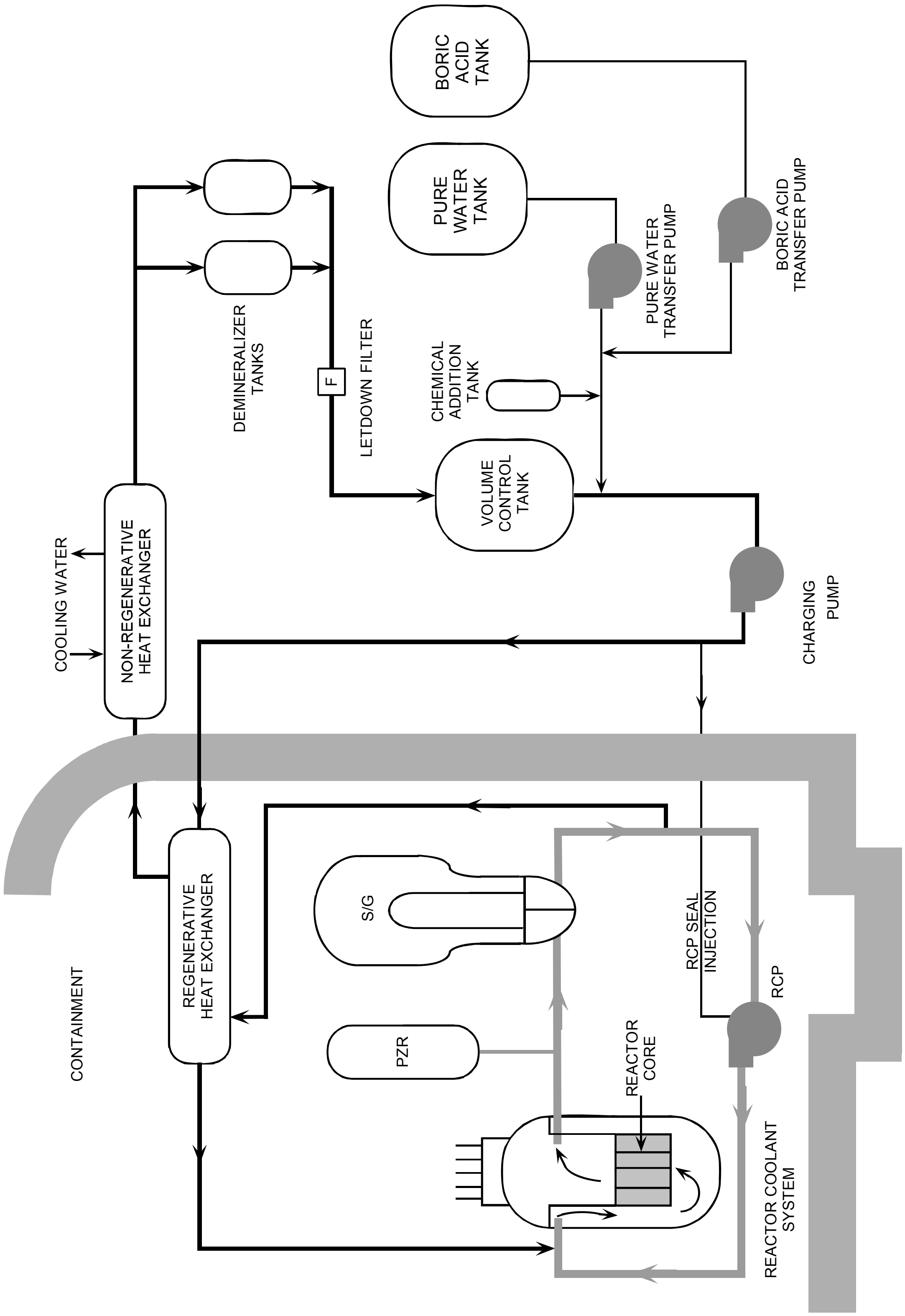

Figure 1.5-1 Chemical and Volume Control System

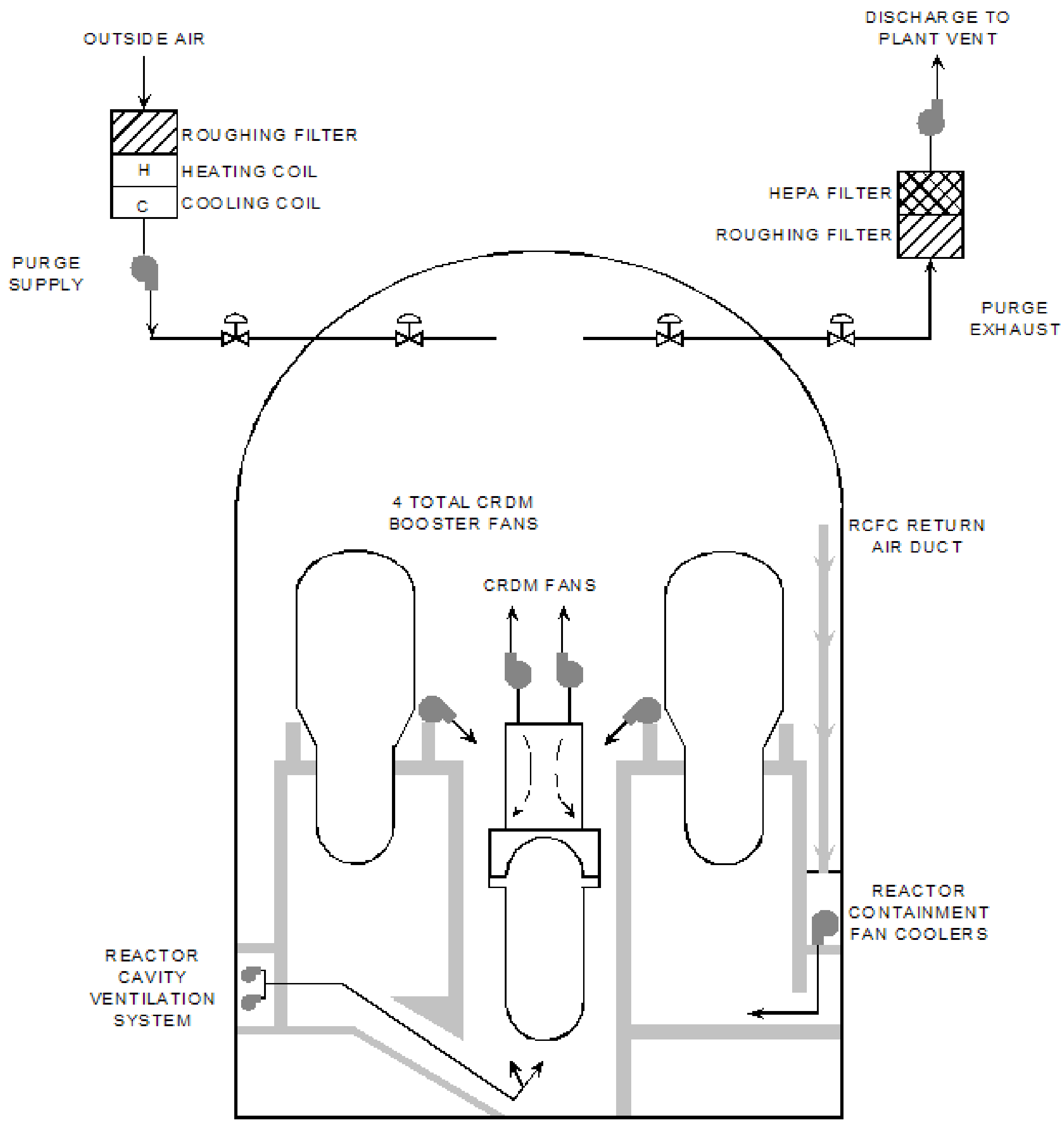

Figure 1.7-1 PWR Containment Ventilation System

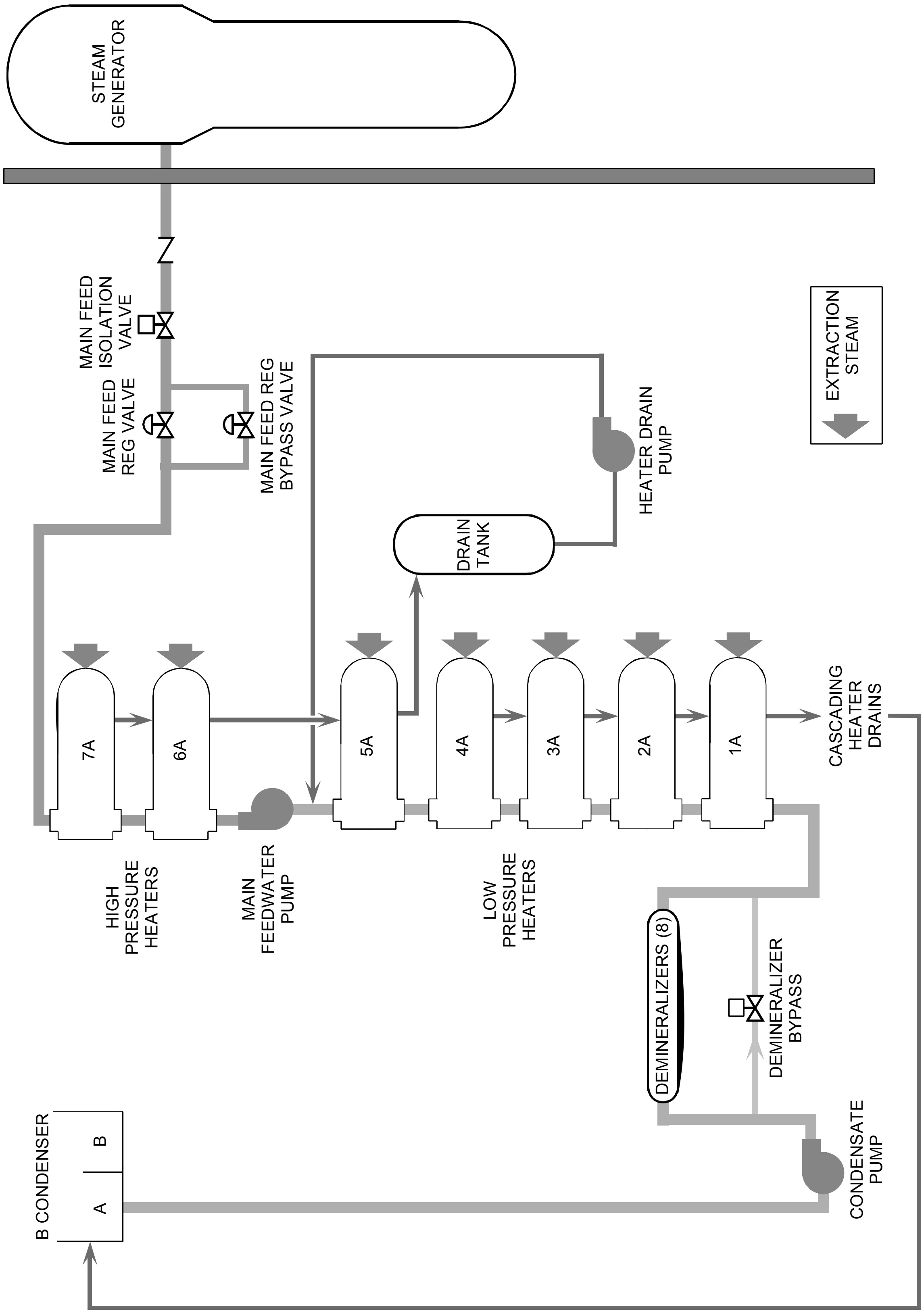

Figure 1.8-1 PWR Condensate and Feedwater System

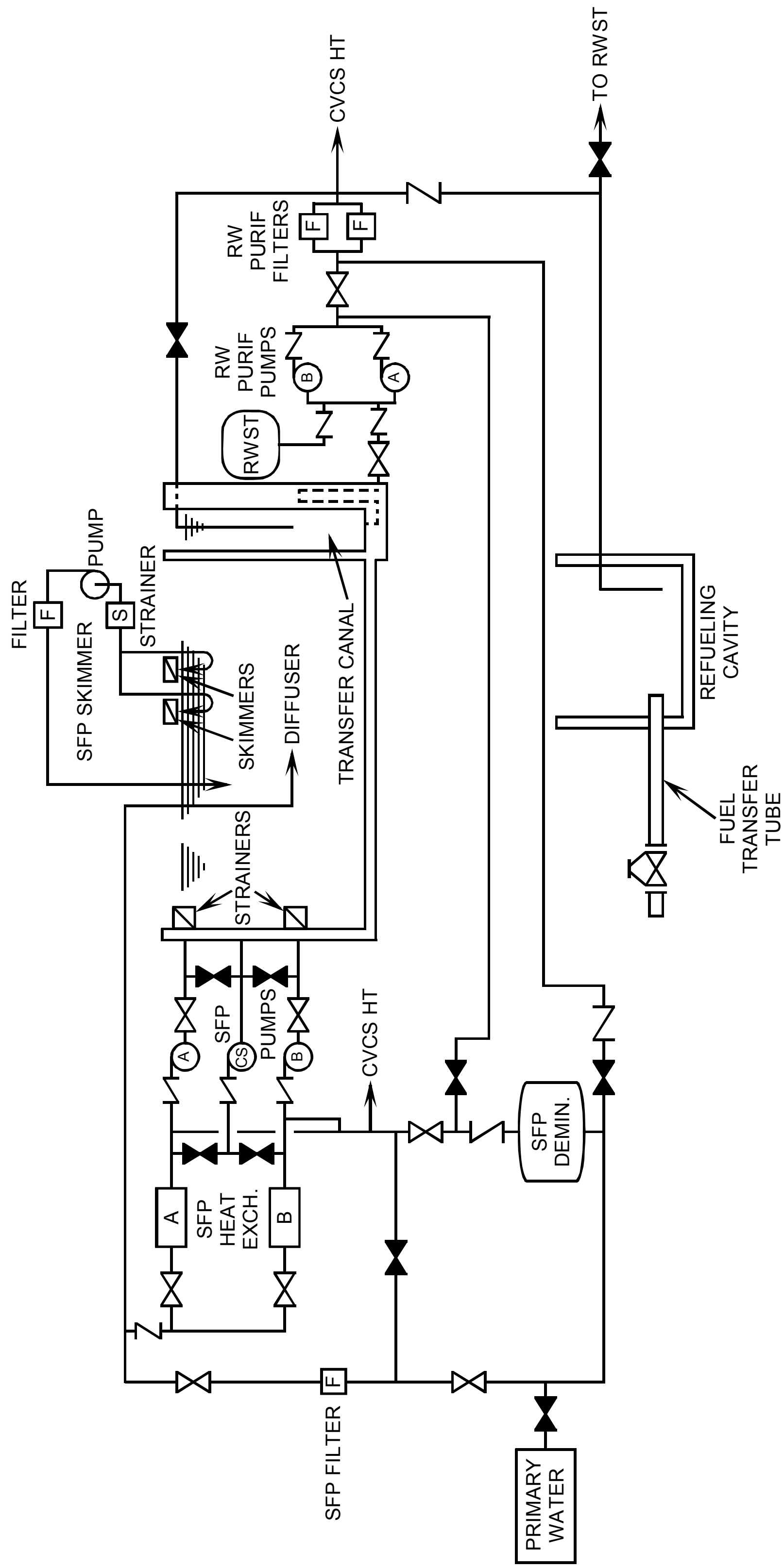

Figure 1.8-2 PWR Spent Fuel Pool Cooling System